WIRELESS TECHNOLOGY EVOLUTION TOWARDS 5G:

3GPP RELEASE 13 TO RELEASE 15 AND BEYOND

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1 INTRODUCTION

The mobile wireless industry has made momentous progress over the last several years as for the first-time LTE has brought together the entire mobile industry, evolving deployments to a single technology, enabling an ecosystem larger than ever before. Already almost a quarter of all global mobile subscribers are using Long Term Evolution (LTE) and it's expected that by 2021 this will increase to more than half. While LTE deployments continue to expand, and grow across the world, certain regions such as Korea, Japan, China and the U.S. have nearly reached or exceeded 90 percent penetration of LTE. This has led to focus in the mobile industry towards 5th Generation (5G) mobile technology, standards development, demos and trials. There continues to be growing demands for higher throughputs and more data capacity, particularly for video, to provide better broadband services. But this is just one of the drivers for 5G. In addition, 5G is targeted to address new vertical markets including massive machine type communications (mMTC), ultra-reliable low latency communication and a broad range of Internet of Things (IoT) applications in general.

Given the continued focus on LTE deployment and the parallel industry effort to define 5G, 3rd Generation Partnership Project (3GPP) has been actively working both tracks. The 3GPP Release-13 (Rel-13) specifications were completed in March-June of 2016, and focused on further enhancements to LTE and the Evolved Packet Core (EPC) in areas such as active antennas, Multiple-Input Multiple-Output (MIMO), Self-Organizing Networks (SON also called Self-Optimizing Networks), Carrier Aggregation (CA) & Dual Connectivity (DC), LTE in unlicensed spectrum (Licensed Assisted Access or LAA), interworking/aggregation between WLAN and LTE (LTE-WLAN Aggregation or LWA and LTE-WLAN IP aggregation or LWIP), Machine Type Communications (MTC), Narrow Band IoT (NB-IoT), Proximity Services (ProSe) and Device-to-Device (D2D) Communication and Public Safety. The rich feature content for LTE in Rel-13 demonstrates the strong demand for continued enhancements to not only improve throughput/capacity with LTE, but also to extend the application of LTE, such LTE use in unlicensed spectrum and LTE solutions for new verticals/IoT. And the evolution of LTE does not stop with Rel-13 as there are also many significant LTE features already being worked on as part of Rel-14 including further MIMO enhancements, CA enhancements, enhanced LAA (eLAA), enhanced LWA (eLWA), Voice over LTE (VoLTE) enhancements and enhancements to Proximity Services / Device to Device (ProSe/D2D).

With LTE now on its 7th release of specifications and approaching a decade since its initial specification in Rel-8, the industry is now focusing on defining the 5th Generation mobile wireless technology and architecture. As in the past, the International Telecommunication Union (ITU) is providing guidance, requirements and recommendations that are setting the stage for this next generation of mobile wireless technologies. Just like the ITU defined International Mobile Telecommunications-2000 (IMT-2000) to drive towards Third Generation (3G), and IMT-Advanced to drive towards Fourth Generation (4G), the ITU now is defining IMT-2020 to drive towards 5G specification. As the name implies the IMT-2020 process is targeted to define requirements, accept technology proposals, evaluate the proposals and certify those that meet the IMT-2020 requirements, all by the 2020 timeframe. This however, requires that 3GPP start now on discussing technologies and system architectures that will be needed to meet the IMT-2020 requirements. 3GPP has done just that by defining a two phased 5G work program starting with study items in Rel-14 followed by two releases of normative specs spanning Rel-15 and Rel-16 with the goal being that Rel-16 includes everything needed to meet IMT-2020 requirements and that it will be completed in time for submission to the IMT-2020 process for certification.

The 5G work in 3GPP on Rel-14 study items is well underway and focused on both new Radio Access Network (RAN) technologies and new System Architecture (SA) aspects. The studies on new RAN technologies for 5G are called New Radio (NR) in the 3GPP RAN working groups and are focused on

defining a new radio access flexible enough to support a much wider range of frequency bands from <6 GHz to millimeter wave (mmWave) bands as high as 100 Gigahertz (GHz). Given this wide range of carrier frequencies that must be supported, it is expected that Orthogonal Frequency Division Multiplexing (OFDM) will be the basis for the 5G NR air interface. All new, state-of-the-art frame structures, coding, modulation, MIMO, beamforming, etc. technologies are being investigated as part of the 5G NR study item. Given this is the first 3GPP technology targeted at providing optimized performance in the mmWave bands, much of the focus in 3GPP 5G NR is on channel modeling and radio access features designed to address the quasi-optic nature of mmWave communications. In parallel, the System Architecture (SA) groups in 3GPP have been busy studying the Services and Markets Technology Enablers (the SMARTER study) that will drive the next generation system architecture, which has led to design principles, requirements and target deployment scenarios for the 5G network architecture. This has led to the identification of many key issues that need to be addressed as part of defining the 5G network architecture such as the support for Network Slicing, Quality of Service (QoS), Mobility and Session Management, Policy, Security and more.

This paper provides a detailed status of all the work in 3GPP on the abovementioned LTE enhancements and studies towards definition of the radio access and system architecture for 5G. Section 2 begins with a global look at the trends and drivers for continued evolution of LTE and definition and specification of a new 5G technology. Section 3 provides details of the enhancements provided in 3GPP Rel-13, which primarily focuses on RAN and network level enhancement for LTE and the EPC but also includes some enhancements for HSPA+. Section 4 then discussion the IMT-2020 role and process towards driving the definition of 5G, and discussed the work program that 3GPP has put in place to study and define the RAN and SA technologies that will be needed to support the IMT-2020 requirements. Section 5 completes the paper with a look at the work to date on Rel-14, covering the studies on 5G NR, the SMARTER studies, the principles, requirements and key issues identified in the 5G system architecture studies and the study and work items for continued LTE enhancement. The 3GPP timeline is shown in Figure 1.1.

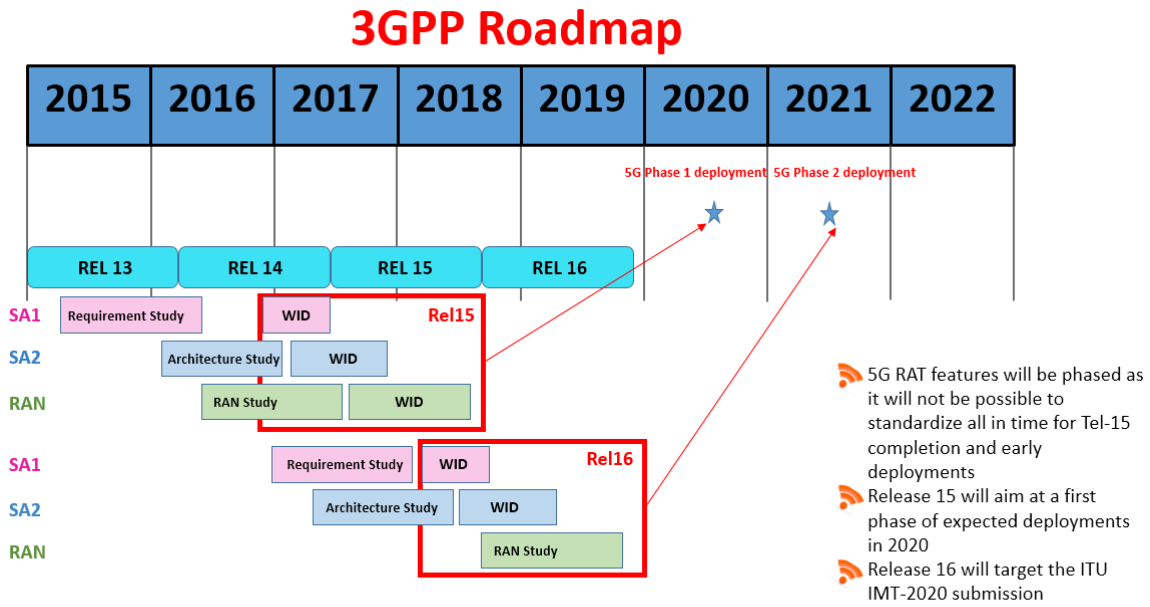

Figure 1.1. 3GPP RAN Progress on "5G".[1]

[1] 3GPP Timeline. March 2016.

2 GLOBAL MARKET TRENDS, MILESTONES AND STANDARDIZATION

By the end of 2015, more than a third of the 7.4 billion people worldwide had access to a Fourth-Generation Long Term Evolution (4G LTE) network, providing them with high-speed services and applications including mobile internet. As LTE deployments continue to accelerate across the globe, it is anticipated that by the end of 2016, LTE coverage will reach about 2.17 billion people.

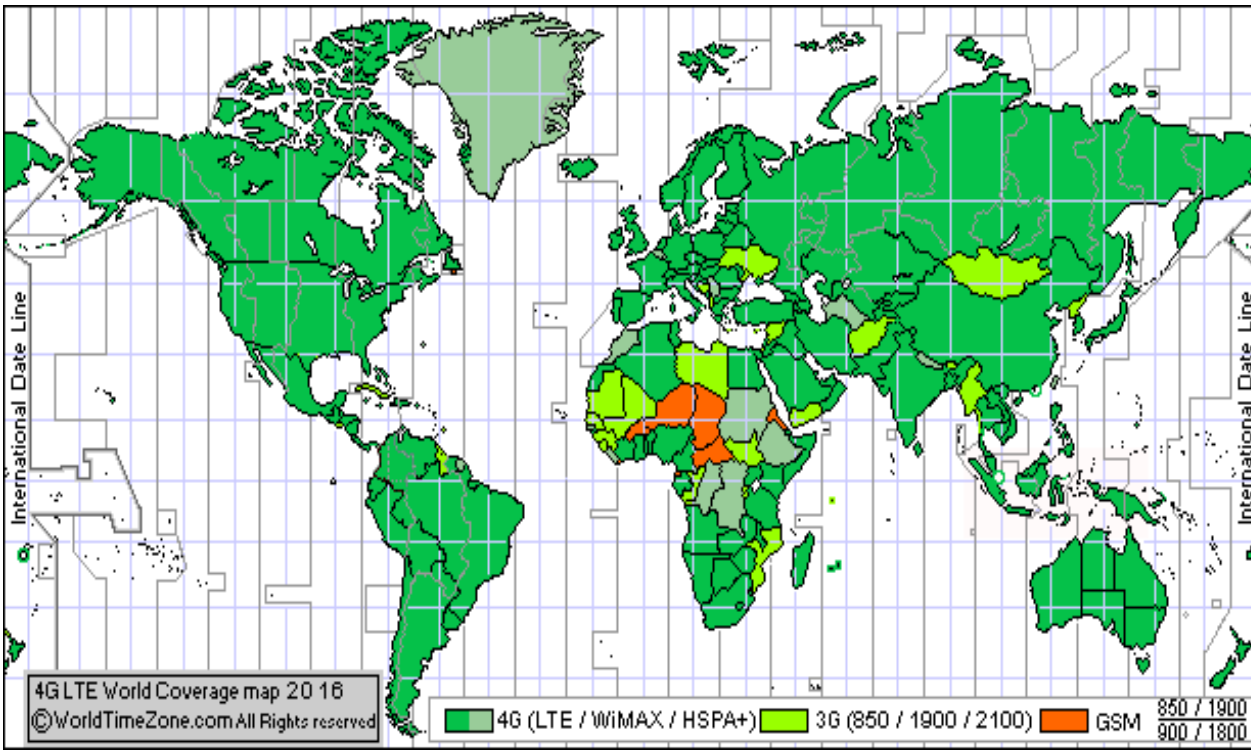

Figure 2.1. 4G LTE World Coverage Map - LTE, WiMAX, HSPA+, 3G, GSM.[2]

In addition to the expansion of LTE networks, which number well in excess of 500 worldwide[3], the number of LTE connections is also growing rapidly, more than doubling from 200 million at the end of 2013 to more than half a billion (500 million) at the end of 2014.[4] That number more than doubled again to 1.1 billion at year end 2015 representing 15 percent of all global mobile connections and is forecast to reach 1.7 billion at the end of 2016 for 24 percent of total connections.[5] It has been forecasted by many industry analysts that LTE's global momentum will continue between now and 2020. Figures 2.2 and 2.3 show the growth of LTE connections and the forecast for LTE's continued growth through 2021.

[2] WorldTimeZone.com, October 2016
[3] *LTE, LTE-Advanced & 5G Ecosystem: 2016 – 2030 – Infrastructure, Devices, Operator Services, Verticals, Strategies & Forecasts*, SNS Research. September 2016.
[4] *WCIS*, Ovum. December 2015.
[5] *WCIS*, Ovum. October 2016.

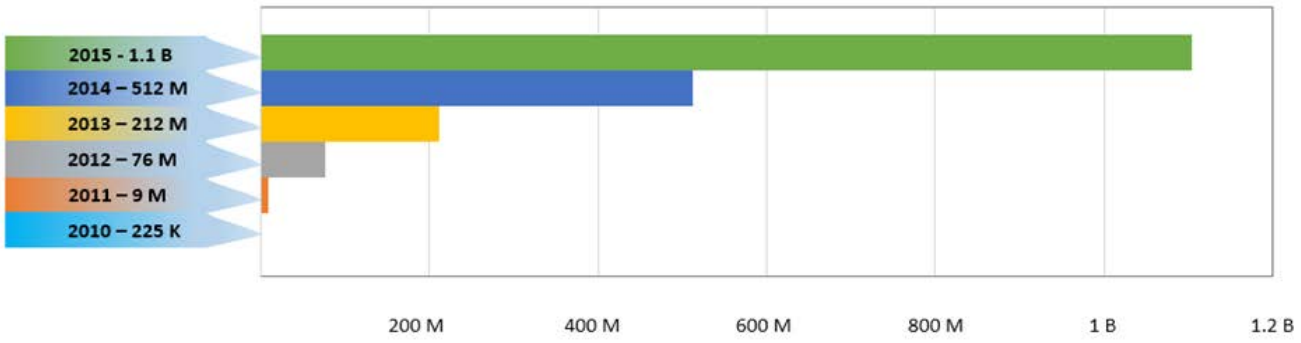

Figure 2.2. LTE Connections 2010-2015.[6]

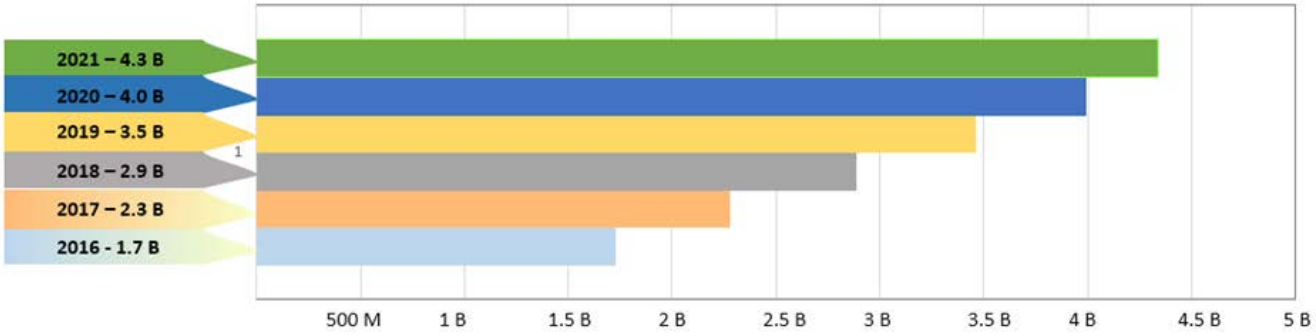

Figure 2-3: LTE Forecast 2016-2021.[7]

By 2021, LTE is expected to account for nearly 52 percent of global connections.[8] In addition, LTE networks are expected to cover 55 percent of the global population by this point.[9]

While GSM represented 49 percent of the global market in 2015, this will decline to 11 percent worldwide in five years. HSPA will nearly double and LTE will more than triple. The shift from 2G is evident; some service providers (e.g., AT&T) have announced sunsetting their 2G networks by 2017 to allow their customers advanced notice to properly plan in areas such as Machine-to-Machine (M2M) communications and other connected devices. The need for service providers to sunset their networks weighs heavily on their available spectrum assets, reframing their spectrum and getting the best efficiencies by using more advanced 4G technology in those limited spectral resources.

[6] *WCIS,* Ovum, October 2016.
[7] *Ibid.*
[8] *Ibid.*
[9] *Ibid.*

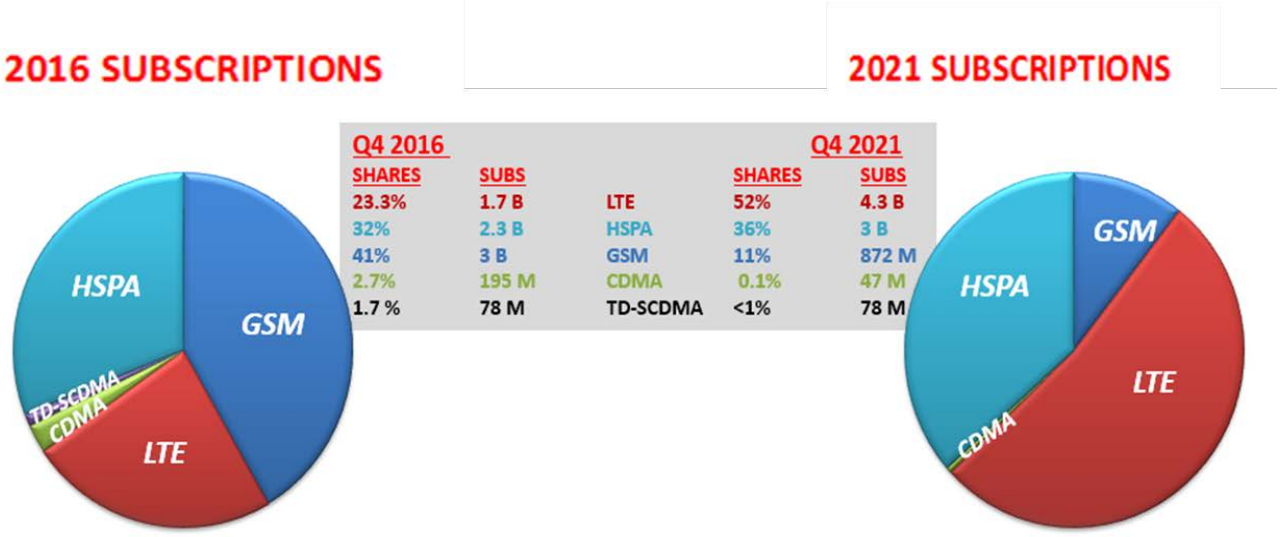

Figure 2.4. Global Mobile Technology Shares and Subscribers 4Q 2016 – Forecast 4Q 2021.[10]

About 46 percent of the global population, 3.4 billion of the world's 7.3 billion people, had internet connections in 2015.[11] Growth in internet access was driven by developing countries to reach 3 billion mobile internet users by 2015,[12] with two-thirds of those users living in the developing countries.[13]

Data traffic from wireless and mobile devices, including both Wi-Fi and cellular connections, will account for two-thirds of total IP traffic by 2020. In 2015, wired devices accounted for the majority of IP traffic at 52 percent.[14] Global IP traffic is expected to increase nearly threefold from 2015 to 2020 at a compound annual growth rate (CAGR) of 22 percent; monthly IP traffic will reach 25 GB by 2020, up from 10 GB per capita in 2015.[15] Additionally, smartphone traffic will exceed PC traffic by 2020.[16]

The number of mobile data subscriptions is increasing rapidly along with a continuous increase in the average data volume per subscription, driving growth in data traffic. Global mobile data traffic grew by 69 percent in 2014 and reached 2.5 exabytes per month at the end of 2014, up from 1.5 exabytes at the end of 2013.[17]

Following are some key observations according to the *Cisco VNI Mobile 2016* report:

- Mobile data traffic will increase eightfold between 2015 and 2020 with a CAGR of 53 percent
- Global mobile data traffic was 5 percent of total IP traffic in 2015 and will increase to 16 percent by 2010
- Globally, the average mobile network connection speed in 2015 was 2.0 Mbps; the average speed will more than double and will be 6.5 Mbps by 2020

[10] *WCIS,* Ovum, April 2015.
[11] www.internetlivestats.com/internet-users. October 2016.
[12] *Global Internet Report 2015*, internetsociety.org.
[13] *Measuring the Information Society Report 2014 launch*. ITU, November 2014.
[14] *VNI,* Cisco. Sept 2016.
[15] *Ibid.*
[16] *Ibid.*
[17] *Ibid.*

Ericsson Mobility Report June 2016 revealed that:

- In 1Q 2016, there were 7.4 billion mobile subscriptions, 3.7 billion mobile broadband subscriptions and 3.4 billion smartphone subscriptions
- Subscriptions associated with smartphones continue to increase; during 3Q 2016, the number of smartphone subscriptions will surpass those for basic phones. In 1Q 2016, smartphones accounted for close to 80 percent of all mobile phones sold
- By 2021 there will be: 9 billion mobile subscriptions, 7.7 billion mobile broadband subscriptions and 6.3 billion smartphone subscriptions
- Global mobile broadband subscriptions will account for 85 percent of all subscriptions by 2021. Mobile broadband will complement fixed broadband in some segments, and will be the dominant mode of access in others[18]

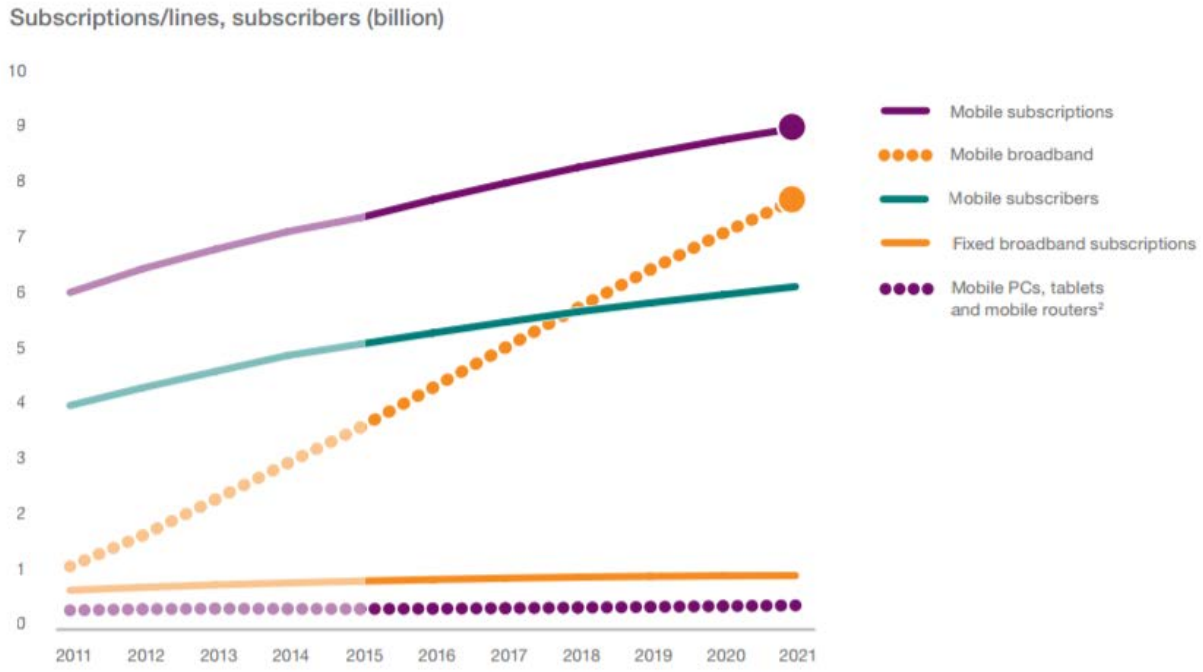

Figure 2.5. Growth of Subscriptions/Lines and Subscribers.[19]

North America's rapid migration to LTE and its leadership role for several years has led to the highest LTE share of subscriptions for this technology in the world—268 million subscriptions and a market share at 2Q 2016 that reached 60 percent.[20] Market share represents the percentage of mobile wireless connections that are LTE technology versus all other mobile technologies. Other leading regions of the world posted market shares of 34 percent in Oceania, Eastern and Southeastern Asia and 30 percent in Western Europe. Growth in Latin America and the Caribbean was also impressive; the region added 55 million new LTE connections in 2Q 2016 achieving a 12 percent share of market—tripling the LTE market share year-over-year from 2Q 2015.

[18]The number of fixed broadband users is at least three times the number of fixed broadband connections, due to multiple usage in households, enterprises and public access spots. This is the opposite of the mobile phone situation, where subscription numbers exceed user numbers.
[19] Fixed Wireless Access (FWA) subscription not included *Source:* Ericsson, June 2016.
[20] *WCIS*, Ovum. September 2016.

By 2020, LTE will represent nearly 400 million connections or 93 percent of the North American region's mobile subscriptions, not including Machine-to-Machine (M2M) connections.[21]

In another outstanding milestone, the penetration rate of LTE connections to the population of 364 million in North America reached 74 percent. This data compares to Western Europe at 39 percent penetration and Oceania, Eastern and Southeastern Asia with 35 percent penetration.

The strong growth in mobile broadband subscriptions in the Latin America region will be driven by economic development and consumer demand. With heavy investment in LTE, Latin America has seen a substantial increase in LTE deployments which numbered 85 commercial networks in 44 countries in September 2016, and subscribers which totaled 82 million at 2Q 2016 having added 55 million LTE connections year-over-year. This may be largely attributed to the spectrum auctions that have occurred throughout the region allowing service providers the ability to offer LTE services to their customers beginning primarily in the densely populated urban cities. LTE is forecast to reach 109 million connections at the end of 2016 (forecast does not include M2M) and a 16 percent share of market. By 2019, LTE will be the dominant technology in the Latin America region with about 46 percent market share and HSPA/WCDMA is expected to have a higher percentage of the market at 39 percent than GSM/EDGE-only subscriptions at 15 percent.[22]

Global uptake of LTE continues aggressively. With more than 500 LTE commercial networks deployed[23] the number of LTE connections stood at 1.4 billion at the end of the 2Q 2016 out of the total of 7.5 billion total cellular connections worldwide. There were 684 million new LTE connections year-over-year for a growth rate of 89 percent.[24] LTE connections are forecast to reach close to four billion by the end of 2020, when the market share worldwide for LTE will reach 50 percent.[25]

LTE innovations with LTE-Advanced and LTE-Advanced Pro are ongoing. It is significant to note that by September 2016, there were more than 150 LTE-Advanced commercial deployments worldwide. The earliest LTE-Advanced feature deployed by operators is Carrier Aggregation (CA) and more than 150 operators have deployed CA.[26] By 2020, over 50 percent of all LTE subscribers will be supported by LTE-Advanced networks.[27] In November 2016, LTE-Advanced network deployments totaled 166 worldwide of 537 LTE deployments of which 457 LTE deployments are of FDD-only mode.[28]

In this section, the global market trends of wireless data are demonstrated by examples of the uptake of mobile broadband applications for consumers and the enterprise, analysts' predictions for their growth, as well as the introduction of a greater variety of wireless data devices such as smartphones, tablets and M2M or connected devices. In addition, the 3GPP technology commercial milestones achieved by numerous leading operators and manufacturers worldwide on the new standards in Release 99 through Release 15 are outlined.

[21] *WCIS*, Ovum. September 2016.
[22] *Ibid.*
[23] *LTE, LTE-Advanced & 5G Ecosystem: 2016 – 2030 – Infrastructure, Devices, Operator Services, Verticals, Strategies & Forecasts, SNS Research*. September 2016.
[24] *WCIS,* Ovum, *September 2016.*
[25] *Ibid.*
[26] *LTE, LTE-Advanced & 5G Ecosystem: 2016 – 2030 – Infrastructure, Devices, Operator Services, Verticals, Strategies & Forecasts,* SNS Research. September 2016.
[27] *Ibid.*
[28] *Ericsson Mobility Report*, November 2016.

2.1 MOBILE DATA GROWTH FORECASTS AND TRENDS

Mobile data traffic continues its rapid growth, driven mainly by video and social networking. According to Cisco, overall data traffic is expected to grow eightfold between 2015 and 2020. Monthly data traffic will grow at a CAGR of 53 percent from 2015 to 2020, reaching 30.6 exabytes per month by 2020.[29] Three-fourths (75 percent) of the world's mobile data traffic will be video by 2020.[30]

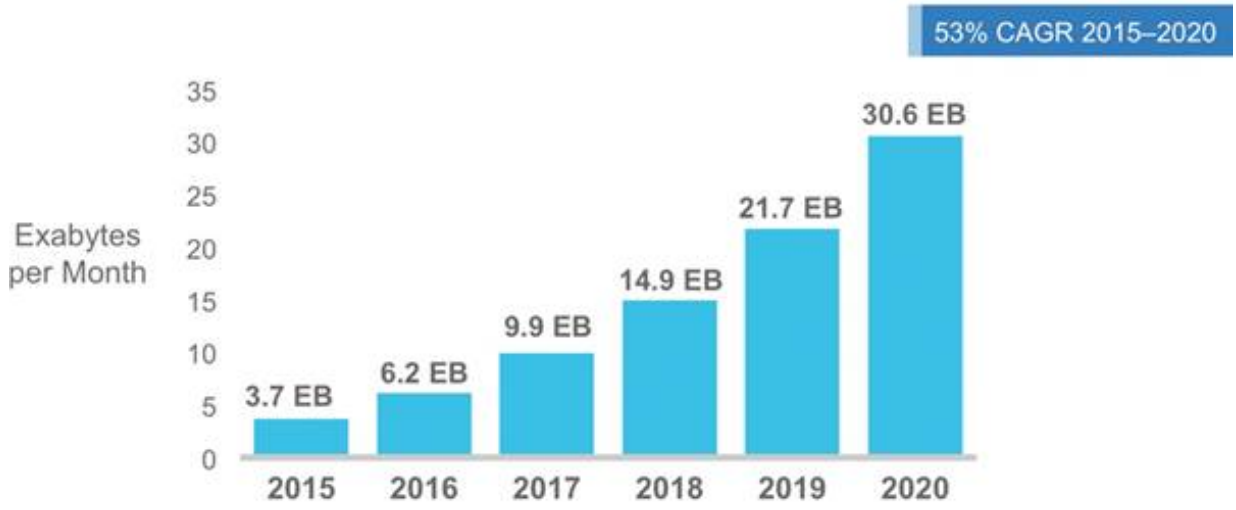

Figure 2.6. Global Mobile Data Traffic 2015 to 2020[31]

Cisco reported on the impact of smartphones on data traffic[32]:

- Globally, smart devices represented 36 percent of the total 7.9 billion mobile devices and connections in 2015; smart devices, however, accounted for 89 percent of the mobile data traffic ("smart devices" refers to mobile connections that have advanced multimedia/computing capabilities with a minimum of 3G connectivity)
- In 2015, on an average, a smart device generated 14 times more traffic than a non-smart device
- Average smartphone usage grew 43 percent in 2015; the average amount of traffic per smartphone in 2015 was 929 MB per month, up from 648 MB per month in 2014
- Smartphones (including phablets) represented only 43 percent of total global handsets in use in 2015, but represented 97 percent of total global handset traffic
- In 2015, the typical smartphone generated 41 times more mobile data traffic (929 MB per month) than the typical basic-feature cell phone (which generated only 23 MB per month of mobile data traffic)

In their *Mobility Report 2016, Ericsson* cites similar data for mobile data traffic[33]:

- About 90% of mobile data traffic will be from smartphones by the end of 2021

[29] Cisco VNI: *Global Mobile Data Traffic Forecast Update 2015-2020*. February 2016.
[30] *Ibid.*
[31] *Ibid.*
[32] *Ibid.*
[33] *Ericsson Mobility Report*. June 2016.

- North America is the region in the world with the highest monthly data usage per active smartphone subscription. This trend will continue; in 2021, monthly smartphone data usage per active subscription in North America (22 GB) will be 1.2 times that of Western Europe (18 GB) and 3 times that of Asia Pacific (7 GB)
- North America and Western Europe currently have a larger share of total traffic volume than their subscription numbers imply. This is due to high penetration of high-end user devices and well built-out WCDMA and LTE networks with affordable packages of large data volumes. This leads to higher data usage per subscription

2.2 WIRELESS DATA REVENUE

Total mobile revenues reached more than US$1 trillion in 2015, an increase of 1.8 percent over 2014. However, this represents a significant slowdown over growth rates of the last five to ten years. Limited opportunities in subscriber growth in developing markets, coupled with increased competition and a challenging macro-economic climate in developing markets are presenting a trend toward relatively modest growth, at an annual average of just under 2 percent to 2020.[34]

Mobile operators in markets across the world are showing signs that they can monetize the strong growth in data traffic. This is at a key time when revenues from more traditional services are being compromised and operators have significant network investments. By bundling video and audio streaming applications and other services, operators are seeing benefits with 4G networks and LTE devices.[35]

Global mobile data revenue accounted for nearly half of total mobile revenue in 2015. That's expected to rise further in 2016 and out to 2020 per Pyramid Research.[36] Mobile network operators are searching for new ways to monetize their investments in mobile broadband infrastructure by differentiating their offerings and engaging users both more broadly and deeply, per Pyramid, by developing attractive service, media and messaging platforms that enable customers to consume content and conduct transactions easily and within a budget. Thus, a growing number of operators are focusing on convergence of multiple products and services into a variety of bundled services packages and by partnering with value-added IP-based communications and content providers.[37]

2.3 MOBILE BROADBAND DEVICES AND M2M

In 2014, the number of mobile connected devices exceeded the world's population. Device growth continues; according to Ericsson, by 2020, 90 percent of the world's population over six years old will own a mobile phone. Each year several new devices in different form factors and increased capabilities and intelligence are introduced into the market. In 2016, for example, phablets were a considerable market entrant and tracking of shipments was initiated by some analysts and OEMs.

More than half a billion mobile devices and connections were added in 2015 bringing the total number of connections to 7.9 billion. By 2020, there will be 8.2 billion handheld (or personal mobile-ready) devices and 3.2 billion M2M connections. Regionally, North America and Western Europe are going to have the

[34] *The Mobile Economy 2016.* GSMA Mobile Intelligence.
[35] *Ibid.*
[36] *Report: Mobile Data Revenue Nearly Half of Total Mobile Revenue… and Growing*, Telecompetitor. Andrew Burger. 31 August 2016.
[37] *Ibid.*

fastest growth in mobile devices and connections with 22 percent and 14 percent CAGR from 2015 to 2020 respectively.[38]

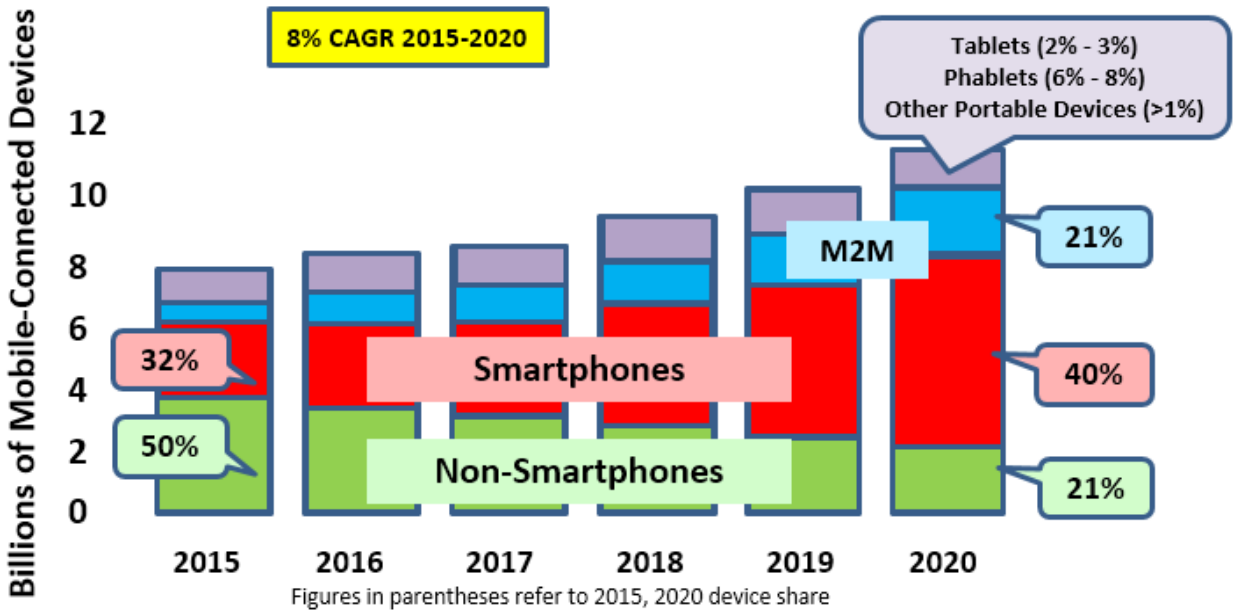

Figure 2.7. Global Mobile Device Growth by Type.[39]

Of particular note, is the rapid decline in the share of non-smartphones from 50 percent in 2015 to 21 percent by 2020. The most notable growth is going to occur in M2M connections. Subscriptions associated with smartphones will continue to increase. During 3Q 2016 the number of smartphone subscriptions surpassed those for basic phones. In 1Q 2016, smartphones accounted for close to 80 percent of all mobile phones sold.[40]

The spread of mobile broadband networks, the emergence of new mobile device categories and the expansion of mobile service propositions are continuing to establish the "Internet of Things" (IoT). Within the next decade, billions of new devices will be connected to mobile networks, providing consumers and businesses with an array of applications, services and experiences. This will usher in the 'Connected Future' and the emergence of 'smart cities' in which users are always connected, anywhere and at any time.

There will be around 400 million IoT devices with cellular connections at the end of 2016 and that number is projected to reach 1.5 billion in 2022. It is expected that 70 percent of the wide-area IoT devices will use cellular technology in 2022.[41] This growth is due to increased industry focus and 3GPP standardization of cellular IoT technologies which is further explained in this white paper.

Mobile phones continue to be the largest category of connected devices, but by 2018 they are expected to be surpassed by IoT, which includes connected cars, machines, utility meters, wearables and other

[38] Cisco VNI: *Global Mobile Data Traffic Forecast Update*, 2015-2020. February 2016.
[39] *Ibid.*
[40] *Ericsson Mobility Report*. June 2016.
[41] *Ibid.*

consumer electronics. IoT devices are expected to increase at a compounded annual growth rate (CAGR) of 21 percent from 2016 to 2022, driven by new use cases.[42]

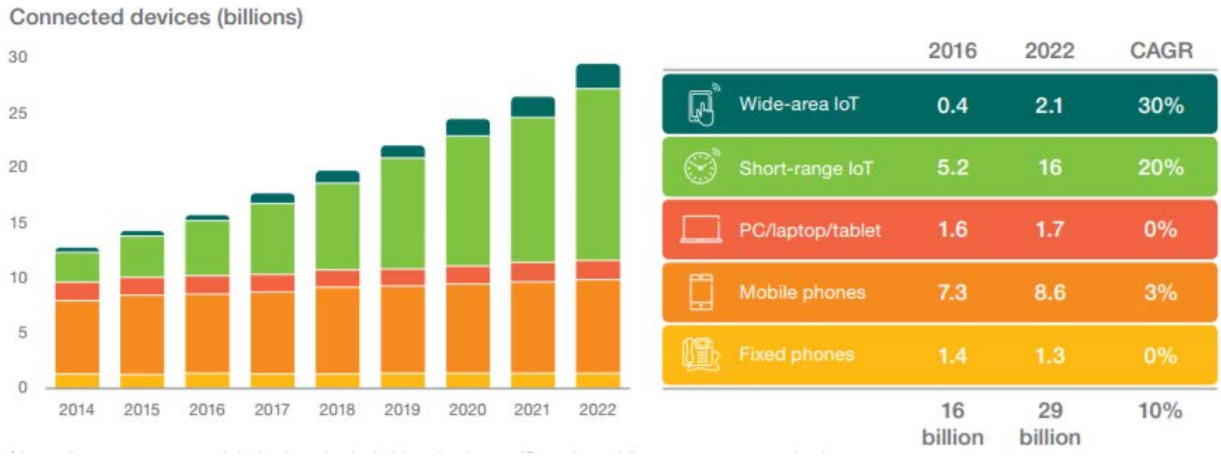

Figure 2.8. IoT Growth 2014-2021.[43]

Within IoT, two major market segments with different requirements are emerging: massive and critical applications.

Massive IoT connections are characterized by high connection volumes, low cost, requirements on low energy consumption and small data traffic volumes. Examples include smart buildings, transport logistics, fleet management, smart meters and agriculture. Many things will be connected through capillary networks. This will leverage the ubiquity, security and management of cellular networks. As of June 2016, around 70 percent of cellular IoT modules were GSM-only[44]. Network mechanisms are being implemented, resulting in extended network coverage for low-rate applications. Additional functionality will allow existing networks to support different device categories, and enable prioritization of devices accessing the network. Network system improvements, such as sleep mode, will support battery lifetimes beyond 10 years for remote cellular devices.

Critical IoT connections are characterized by requirements for ultra-reliability and availability, with very low latency. Examples include traffic safety, autonomous cars, industrial applications, remote manufacturing and healthcare, including remote surgery. Today, LTE's share of cellular IoT device penetration is around five percent. Declining modem costs will make LTE-connected devices increasingly viable, enabling new, very low latency applications. This will be achieved by reducing complexity and limiting modems to IoT application capabilities. Evolved functionality in existing LTE networks, as well as 5G capabilities, is expected to extend the range of addressable applications for critical IoT deployments.

The average data usage per device is on the rise, and so is the total number of connected devices each person owns. Wearables are one category that is sweeping the cellular device market. CCS Insight studied the future of wearable technology and forecasts that 411 million smart wearable devices worth $34 billion will be sold in 2020. The analyst firm claims the industry will reach $14 billion in 2016 with wrist-based

[42] Ericsson Mobility Report. November 2016.
[43] *Ibid*
[44] *Ibid.*

devices - such as smartwatches and fitness trackers - continuing to dominate. Its forecast states half of all wearable technology sales over the next year will be from smartwatches.[45]

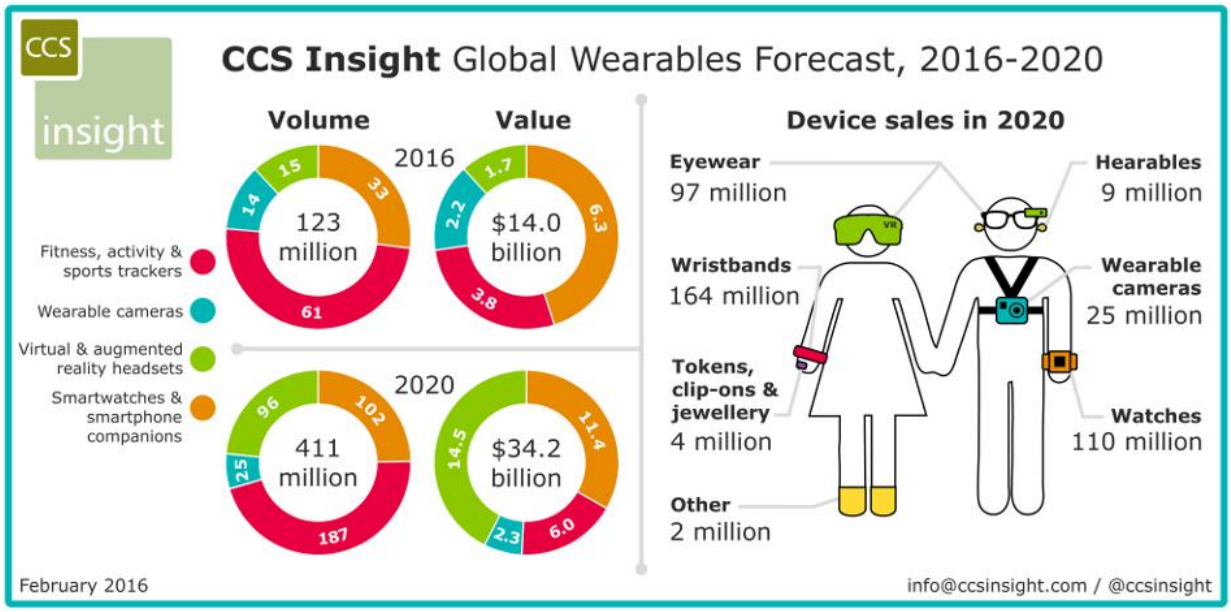

Figure 2.9. Global Wearables Forecast.

The popularity of smart home devices and services are on the rise as Parks Associates reports that 10 percent of all U.S. households have at least one smart home device and 38 percent of U.S. broadband households are likely to buy a smart home device in 2016.[46] Gartner forecasts that number to skyrocket to 500 smart home devices per household by 2022.[47] Such devices can control lighting systems, garage door openers, network security cameras and programmable thermostats.[48] On a global scale, Strategy Analytics predicts that the smart home market will reach $100 billion by 2019, which represents 224 million households worldwide.[49]

Numerous industry analysts are expecting gains to continue well into the future with M2M and the IoT. In 2014 to 2015, companies used a wide range of technologies to connect their M2M solutions, including fixed-line (63 percent), cellular (60 percent) and Wi-Fi (56 percent), according to a Vodafone study.[50] LTE makes new kinds of applications practical and cost-effective across industries, including video-based security, in-vehicle information services, assisted living, m-health solutions, and much more.

Research shows that at the current rate of trajectory, global cellular M2M connections will reach close to one billion by 2020, growing at 25 percent per year (CAGR) over the period of 2015 to 2020. However, there is a forecast scenario hypothesis that could emerge, if a number of the current growth inhibitors are addressed by both the industry players and governments, which could potentially lead to a faster growth rate of greater than 40 percent per annum. The best-case upside forecast scenario results in the realization of a potential 2 billion cellular M2M connections globally by 2020.[51]

[45] *Wearable Tech Market to be Worth $34 Billion by 2020*, Forbes. 17 February 2016.
[46] *38% of U.S. broadband households very likely to buy smart home device in 2016*, Parks Associates. 2 August 2016.
[47] *Gartner Says a Typical Family Home Could Contain More Than 500 Smart Devices by 2022,* Gartner. September 2014.
[48] *Smart Home Ecosystem: IoT and Consumers, Parks Associates*. January 2015.
[49] *The smart home promise vs. reality,* RCR Wireless. March 2015.
[50] *2015 Predictions: M2M, IoT set for strong growth in 2015,* Andrew Morawski, Vodafone. January 2015.
[51] Cellular M2M Forecasts, GSMA Intelligence. February 2015.

2.4 MOBILE BROADBAND SERVICES AND APPLICATIONS

Mobile video traffic is forecast to grow by around 50 percent annually through 2022, when it should account for nearly three-quarters of all mobile data traffic[52] While social networking is forecast to grow by 39 percent annually over the coming six years, its relative share of traffic will decline from 15 percent in 2016 to around 10 percent in 2022, as a result of the stronger growth in the video category. The rest of the application categories have annual growth rates ranging from 19 to 34 percent, so they are shrinking in proportion to the whole. The trend is accentuated by the growing use of embedded video in social media and web pages, which is considered video traffic in this context.[53]

From Ericsson's Mobility Report are the following market results:

- Average values from measurements in a selected number of commercial High Speed Packet Access (HSPA) and LTE networks in Asia, Europe and the Americas show that regardless of device type, video is the largest contributor to traffic volumes (42–58 percent). However, there is a large variation between networks.
- YouTube still dominates video traffic in most mobile networks and accounts for between 40–70 percent of total video traffic for almost all measured networks, regardless of terminal type.
- In markets where Netflix has launched services, its share of video traffic can reach 10–20 percent of total mobile video traffic.

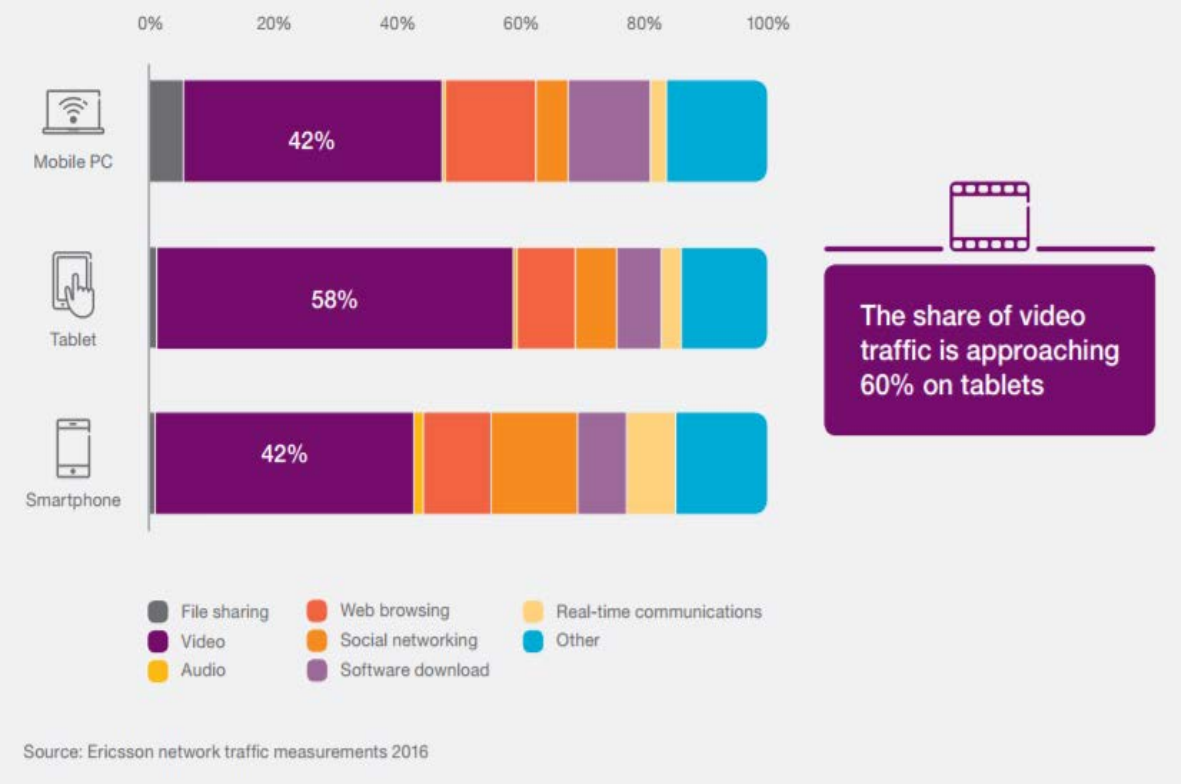

Figure 2.10. Mobile Traffic Volumes by Application Category and Device Type.[54]

[52] *Ericsson Mobility Report*, November 2016.
[53] *Ibid.*
[54] *Ibid.*

- For smartphones, social networking is the second largest traffic volume contributor, with an average share of 20 percent in measured networks.
- File sharing is more prominent on mobile PCs than on other devices, but overall is decreasing, constituting around 5 percent of traffic. The very small part of file sharing that is associated with smartphones and tablets comes predominantly from tethering traffic.
- The share of traditional web browsing traffic shows a decreasing trend on all three types of devices.

As previously covered in this section, data traffic is expected to continue growing significantly. The introduction of laptops, tablets and high-end mobile handsets onto mobile networks are key drivers of traffic, since they offer content and applications not supported by the previous generations of mobile devices.

2.5 MOBILE BROADBAND DEPLOYMENTS AND SPECTRUM

LTE has seen the most aggressive deployment of any mobile technology in history. From the first launch of LTE by TeliaSonera in Sweden and Norway in 2009, the technology deployments have grown consistently. In Figure 2.11, the deployments of LTE are shown with 494 live LTE networks worldwide in 157 countries and another 200+ operators[55] that have announced intentions to deploy LTE in the future.

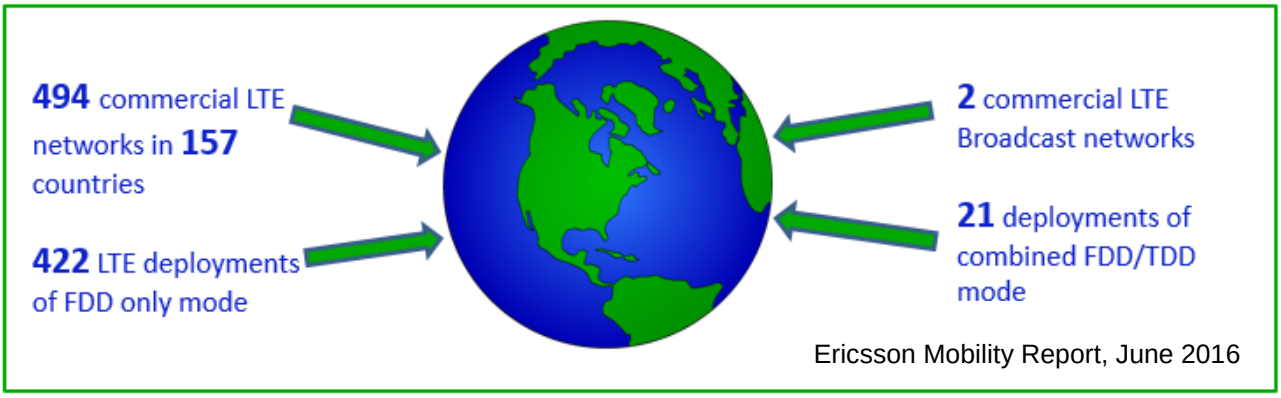

Figure 2.11. LTE Deployments – May 2016.

North America continues to lead in LTE progress; market share for LTE is at 62 percent of all mobile connections as of September 2016, with a big drop down to the next regional market of Oceania, Eastern and Southeastern Asia at 38 percent with Western Europe at 32 percent.

The reasons for LTE's success include the careful development of the 3GPP standards. The challenge has been the allocation by governments of premium internationally harmonized licensed spectrum. In fact, the ITU studied the spectral requirements for the growing demand of wireless data and confirmed that there is a gross deficit in current allocations in many countries.

4G adoption is closely correlated to coverage, which in turn is dependent on the timing, type and amount of spectrum assigned to operators for 4G services.

[55] *Ericsson and GSA*. May 2016.

There is an impending spectrum crisis as pressure on spectrum resources increases, almost forcing operators to invest in the most efficient technologies. LTE typically is being deployed using the Digital Dividend bands (700/800 MHz), re-farmed spectrum in existing 2G/3G bands (notably 1800 MHz) or the International Mobile Telecommunications (IMT) - extension bands (2500/2600 MHz). Three-quarters of 4G deployments to date are running on one of these three bands, suggesting that progress is being made on 4G spectrum harmonization.

In the U.S., LTE typically uses the 700 MHz (primarily band 13 or band 17) or AWS (1.7/2.1 GHz) bands. New digital dividend spectrum is being allocated in Europe, Asia and elsewhere, enabling extended geographical coverage and improved in-building performance. Commercial LTE services are running on several networks using 800 MHz (band 20), often targeting rural broadband needs and improved indoor coverage. The capacity band in most regions is 2.6 GHz. There is high interest in reframing 2G spectrum for LTE, especially 1800 MHz, and in a few cases, 900 MHz. Most regulators adopt a technology neutral approach. Initial LTE Frequency Division Duplex (FDD) deployments in Japan use 800/850 MHz, 1.5 GHz, 1.7 GHz and 2.1 GHz (operator dependent). New 700 MHz (APT700) spectrum has been allocated and is ready for future use. 1800 MHz may be the most widely used band for LTE deployments globally.

Of growing significance is the deployment of LTE Time Division Duplex (TDD) which does not use paired licensed bands such as LTE FDD. As of May 2016, there were 72 commercial LTE TDD networks of which 21 are both LTE TDD and LTE FDD (Figure 2.11). Frequency bands for TDD and FDD mode networks are shown in Appendix A. The table in Appendix A shows the numerous bands in which LTE has been deployed worldwide.

In its *Report ITU-R M. 2290*, the International Telecommunication Union (ITU) outlines the need for a minimum amount of spectrum for the year 2020 depending on the market development status (referring to two Radio Access Techniques Groups, RATG1 and RATG2). For the sake of simplicity, the markets are categorized as either lower user density setting or higher user density setting.

Table 2.1. Predicted Spectrum Requirements for RATG 1 and RATG 2 in 2020.[56]

Market Setting	Spectrum Requirement for RATG 1	Spectrum Requirement for RATG 2	Total Spectrum Requirement
Higher user density setting	540 (MHz)	1420 (MHz)	1960 (MHz)
Lower user density setting	440 (MHz)	900 (MHz)	1340 (MHz)

The target spectrum requirements represent the total amount of spectrum in a given country market. An example of a country that would fall into the category of a higher market setting would be the U.S., and its need for additional spectrum is evident. New services, applications, devices and continued increases in the usage of smartphones, tablets and connected machines are only amplifying the need for additional spectrum.

[56] *Report ITU-R M. 2290.* International Telecommunications Union, December 2013.

2.6 MILESTONES FROM RELEASE 99 TO RELEASE 15: UMTS/EVOLVED HSPA (HSPA+) AND LTE/EPC/LTE-ADVANCED

This section summarizes the commercial progress of the 3GPP standards beginning with Rel-99 through Rel-15 and includes several important milestones in the industry. It is historical in nature, building to the success of LTE as the next generation global mobile industry standard, the ongoing commercialization of LTE-Advanced and LTE-Advanced Pro and initial development and trials of 5G technology.

Leading manufacturers and service providers worldwide support the 3GPP evolution. To illustrate the rapid progress and growth of UMTS through LTE and beyond, participating 5G Americas member companies have each provided detailed descriptions of recent accomplishments on Rel-99 through Rel-15 which are included in Appendix B of this white paper.

2.6.1 HSPA AND HSPA+ PROGRESS TIMELINE

The 3GPP Rel-99 UMTS specifications were initially standardized in early to mid-1999 and published by 3GPP in March 2000, establishing the evolutionary path for GSM, General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE) technologies. Rel-99 enabled more spectrally efficient and better performing voice and data services through the introduction of a 5 MHz UMTS carrier.

Rel-4, completed in March 2001, introduced call and bearer separation in the Core Network. Rel-5 introduced significant enhancements to UMTS, including High Speed Downlink Packet Access (HSDPA), IP Multimedia Subsystem (IMS) and Internet Protocol (IP) Universal Terrestrial Radio Access Network (UTRAN) and was published in March 2002.[57] Rel-6, completed in March 2005, introduced further enhancements to UMTS High Speed Uplink Packet Access (HSUPA) such as Enhanced Dedicated Channel (E-DCH), Multimedia Broadcast/Multicast Services (MBMS) and Advanced Receivers.[58]

Uplink speeds for HSUPA increased from peak 2 Mbps initially, up to 5.8 Mbps using 2 milliseconds (ms) Transmission Time Interval (TTI). HSUPA eliminates bottlenecks in uplink capacity, increases data throughput and reduces latency resulting in an improved user experience for applications such as gaming, Voice over Internet Protocol (VoIP), etc.

HSPA Rel-6 mobile broadband equipment supports peak theoretical throughput rates up to 14 Mbps downlink and up to 5.8 Mbps uplink, capabilities that are typically added to existing networks using a simple software-only upgrade, which can be downloaded remotely to the UMTS Radio Network Controller (RNC) and NodeB.

Most leading operators moved forward with deployment of Rel-7 HSPA+. Nearly all vendors had existing NodeB modules that were already HSPA+ capable and the activation was done on a software-only basis.

For HSPA, Rel-9 introduced support for uplink dual-cell, as well as the capability to enable downlink dual-cell deployments across non-contiguous frequency bands. Also added in Rel-9 was the support of simultaneous Multi-Input Multi-Output (MIMO) and Dual Carrier-High Speed Packet Access (DC-HSPA) operation, as well as enhancements to the transmit diversity modes to improve performance with non-MIMO capable devices.

[57] *3GPP Rel-5 and Beyond - The Evolution of UMTS.* 3G Americas, November 2004.
[58] *The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond.* 3G Americas, December 2005.

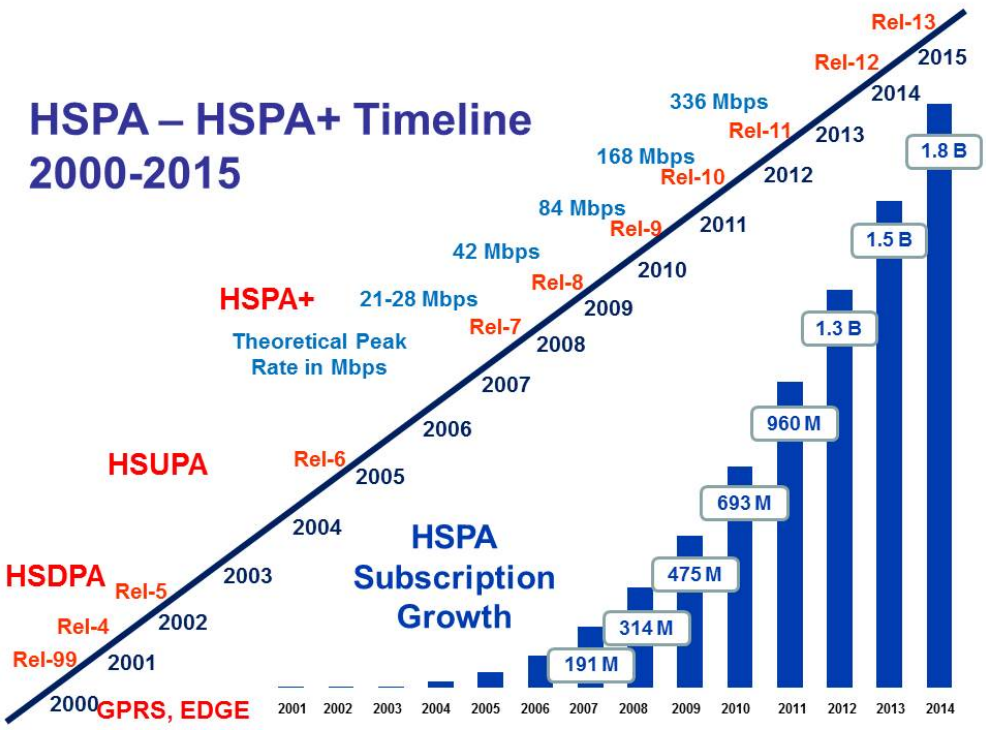

Figure 2.12. HSPA – HSPA+ Timeline 2000-2015.

The first commercial deployment of UMTS networks began with the launch of Freedom of Mobile Multimedia Access (FOMA) by NTT DoCoMo in 2001, with 2003 as the year when Rel-99 UMTS networks were more widely commercialized. The number of commercially deployed UMTS systems grew rapidly, as substantiated by more than 370 commercial UMTS networks as of year-end 2010.

In November 2003, HSDPA was first demonstrated on a commercially available UMTS base station in Swindon, UK. It was first commercially launched on a wide-scale basis by Cingular Wireless (now AT&T) in December 2005 with notebook modem cards, followed closely thereafter by Manx Telecom and Telekom Austria. In June 2006, "Bitė Lietuva" of Lithuania became the first operator to launch HSDPA at 3.6 Mbps, which at the time was a record speed. As of December 2013, there were more than 543 commercial HSPA networks in 199 countries. Nearly all UMTS deployments were upgraded to HSPA and the point of differentiation passed; references to HSPA are all-inclusive of UMTS.

Initial network deployments of HSDPA were launched with PC data cards in 2005. HSDPA handsets were made commercially available in 2Q 2006 with HSDPA handhelds first launched in South Korea in May 2006 and later in North America by Cingular (now AT&T) in July 2006. In addition to offering data downloads at up to 1.8 Mbps, the initial handsets offered such applications as satellite-transmitted Digital Multimedia Broadcasting (DMB) TV programs, with two to three megapixel cameras, Bluetooth, radios and stereo speakers for a variety of multimedia and messaging capabilities.

Mobilkom Austria completed the first live High Speed Uplink Packet Access (HSUPA) demonstration in Europe in November 2006. One month later, the first HSUPA mobile data connection on a commercial network (of 3 Italia) was established. In 2007, Mobilkom Austria launched the world's first commercial HSUPA and 7.2 Mbps HSDPA network in February, followed by commercial 7.2 USB modems in April and 7.2 data cards in May. There were numerous announcements of commercial network upgrades to Rel-6 HSUPA throughout 2H 2007 and by December 2008, there were 60 commercial networks and 101

operators who had announced plans to deploy HSUPA.[59] AT&T was the first U.S. operator to deploy enhanced upload speeds through HSUPA in its HSPA networks in 2007 with average user upload speeds between 500 kbps and 1.2 Mbps and average user download speeds ranging up to 1.7 Mbps.

HSPA base stations supported most IMT frequency bands including the 1.7/2.1 GHz AWS band and the 700 MHz band in the U.S. and Canada. A top vendor provided LTE-capable multi-standard base stations as early as 2001, offering many options to operators, including a smooth transition to new technology while minimizing Operating Expenses (OPEX) and reducing environmental impact.

Over the course of 2006 to 2007, there was significant progress on Rel-7 standards which were finalized in mid-2007. Rel-7 features were commercially introduced as HSPA+ and trials began as early as 3Q 2007, including several planned commercial announcements made in the 2007 to 2008 timeframe. The world's first data call using HSPA+ was completed in July 2008, achieving a data transfer rate of more than 20 Mbps in a 5 MHz channel. The industry's first HSPA+ Rel-7 chipset was launched in early 2009 which set the state for the first commercial launch of HSPA+ by Telstra. In February 2009, Telstra in Australia became the first operator in the world to launch Rel-7 HSPA+ using the 850 MHz band and a data card, and one month later in Austria, Mobilkom launched in the 2100 MHz band; both operators initially provided peak theoretical downlink speeds of 21 Mbps. Rogers was the first mobile operator in the Americas to commercially launch HSPA+ at 21 Mbps in July 2009, more than doubling the speeds of its HSPA network. By the end of 2009, there were 38 commercial launches of HSPA+ in 24 countries including Rogers, Telus and Bell Canada, as well as T-Mobile USA in North America. By the end of 2010, the number of commercial launches of HSPA+ had risen to 103 worldwide in 54 countries. That number stood at 354 commercial HSPA+ networks (21 Mbps or higher peak theoretical speeds) in 153 countries in December 2013.

Hence, the advantages of HSPA+ included its cost-efficient scaling of the network for rapidly growing data traffic volumes, the ability to work with all HSPA devices and an improved end-user experience by reducing latency. The percentage of HSPA operators who had commercially launched HSPA+ was at 65 percent by December 2013.

In Rel-11, HSPA+ introduced new capabilities including eight-carrier downlink operation, downlink 4-branch MIMO to double maximum theoretical downlink rates to 336 Mbps, downlink multi-flow transmission, uplink dual-antenna beamforming, uplink MIMO with 64-Quadrature Amplitude Modulation (64QAM), several CELL_FACH (Forward Access Channel) state enhancements (for smartphone type traffic) and non-contiguous HSDPA carrier aggregation.

As Release 11 (Rel-11) standards were being finalized in early 2013, work began on 3GPP Rel-12. The primary goal of Rel-12 is to provide mobile operators with new options for increasing capacity, extending battery life, reducing energy consumption at the network level, maximizing cost efficiency, supporting diverse applications and traffic types, enhancing backhaul and providing customers with a richer, faster and more reliable experience. Rel-12 also enhanced UMTS/HSPA+, e.g., in the following areas: UMTS Heterogeneous Networks, SIB/Broadcast optimization, EUL enhancements, HNB optimization, DCH enhancements, MTC and WLAN offload as well as interworking between HSPA, Wi-Fi and LTE. Rel-12 was complete with a functional freeze date of March 2015.

For HSPA+, the main Release 13 items are enhancements for reducing control channel overhead and support for dual band Uplink (UL) Carrier Aggregation with the completion of Rel-13 standards in March 2016.

[59] **"**Global Deployment Status HSPA-LTE" in Appendix B of *4G Mobile Broadband Evolution: Release 10, Release 11 and Beyond - HSPA+, SAE/LTE and LTE-Advanced*. 4G Americas, September 2012.

2.6.2 LTE AND LTE-ADVANCED PROGRESS TIMELINE

LTE has become a phenomenal success. More than half a billion LTE connections were counted by the end of 2014, and it is expected that almost 700 operators will deploy LTE technology in almost 200 countries worldwide in the future. By April 2015, it was estimated that the number of announced commercial LTE devices was approaching 3,000.[60] The LTE ecosystem is thriving due to the historical development of the standards, explained below, with highlights of some key commercial milestones.

After 3GPP approved specifications for Rel-8 standards in January 2008, work continued throughout the year, and in March 2009, the completed final standards on HSPA+, LTE and Evolved Packet Core/System Architecture Evolution (EPC/SAE) enhancements were published.

Rel-8 saw the introduction of the Evolved Packet System (EPS) consisting of a new flat-IP core network called the Evolved Packet Core (EPC) coupled with a new air interface based on Orthogonal Frequency Division Multiplexing (OFDM), called Long Term Evolution (LTE) or Evolved UTRAN (E-UTRAN). The EPS architecture was designed to not only provide a smooth evolution from the 2G/3G packet architectures consisting of NodeBs, RNCs, Serving GPRS Support Nodes (SGSNs) and Gateway GPRS Support Nodes (GGSNs), but also provide support for non-3GPP accesses (e.g., Wi-Fi), improved policy control and charging, a wider range of QoS capabilities, advanced security/authentication mechanisms and flexible roaming.

In Rel-8, LTE defined new physical layer specifications consisting of an Orthogonal Frequency Division Multiplexing Access (OFDMA) based downlink and Synchronization Channel-Frequency Division Multiple Access (SC-FDMA)[61] based uplink that supports carrier bandwidths from 1.4 MHz up to 20 MHz. Rel-8 defined options for both FDD and TDD LTE carriers. Rel-8 also defined a suite of MIMO capabilities supporting open and closed loop techniques, Spatial Multiplexing (SM), Multi-User MIMO (MU-MIMO) schemes and Beamforming (BF). Because OFDMA and Synchronization Channel-Frequency Division Multiple Access (SC-FDMA) are narrowband based technologies, LTE supports various forms of interference avoidance or coordination techniques called Inter-Cell Interference Coordination (ICIC).

Rel-8 has provided several other enhancements related to common Internet Protocol Multimedia Subsystem (IMS), Multimedia Priority Service (MPS), support for packet cable access and service brokering, Voice Call Continuity (VCC) enhancements, IMS Centralized Services (ICS), Service Continuity (SC) voice call continuity between LTE-HSPA VoIP and CS domain (called Single Radio VCC or SRVCC) and User Interface Control Channel enhancements. Voice over LTE (or VoLTE) with Single Radio Voice Call Continuity (SRVCC) to improve voice coverage by handing over the voice session from LTE to 2/3G CS domain was standardized in Rel-8. However, VoLTE was slower to gain commercial traction than the timing of standards may have indicated and is expected to accelerate in 2016. Globally, there were 200 million subscriptions with VoLTE at year end 2016 and this is expected to rise to 3.3 billion by the end of 2022.[62] In North America, it is forecast that by 2022, 90 percent of all LTE subscriptions will use VoLTE compared to 60 percent worldwide.[63] Roaming and interconnect with VoLTE began in North America markets in 2016.

[60] "*Evolution to LTE Report*." GSA. April 2015.

[61] SC-FDMA was chosen for the uplink instead of OFDMA in order to reduce peak-to-average power ratios in device amplifiers, thus improving battery life.

[62] *Ericsson Mobility Report*, November 2016.

[63] Ibid.

VoLTE platform enables HD voice, enhanced HD voice, video communication IP messaging content sharing within calls, multi-device, Wi-Fi calling and more

Live 2X2 LTE solutions in 20 MHz for Rel-8 were demonstrated in 2008. Among the new exciting applications demonstrated on LTE networks at various bands, including the new 1.7/2.1 GHz AWS band, were: HD video blogging, HD video-on-demand and video streaming, multi-user video collaboration, video surveillance, online gaming and even Code Division Multiple Access (CDMA)-to-LTE handover displaying the migration possible from CDMA and EV-DO to LTE.

One of key elements of the LTE/SAE network was the new enhanced base station, or Evolved NodeB (eNodeB), per 3GPP Rel-8 standards. This enhanced Base Transceiver Station (BTS) provided the LTE interface and performed radio resource management for the evolved access system. The eNodeB base stations offered a zero footprint LTE solution, addressing the full scope of wireless carriers' deployment needs and providing an advanced LTE Radio Access Network (RAN) solution to meet size and deployment cost criteria. The flexible eNodeB LTE base stations supported FDD or TDD and were available in a range of frequencies from 700 MHz to 2.6 GHz with bandwidths from 1.4 MHz to 20 MHz. The first Rel-8 compliant LTE eNodeB ready for large-scale commercial deployment was launched in July 2009 and was capable of supporting a peak theoretical rate of up to 150 Mbps on the downlink.

In Rel-9, features and capabilities were added as enhancements of the initial Rel-8 LTE technology, specifically:

- The support of emergency services, location services and emergency warning broadcast services. These features are critical for introducing VoIP over LTE because they are required for VoLTE to meet e911 requirements
- Enhancements (particularly for idle mode camping) to the Circuit Switched Fall Back (CSFB) feature that was introduced in Rel-8
- MBMS to enable broadcast capabilities over LTE
- Self-Organizing Network (SON) enhancements to optimize handover performance, improve load balancing capabilities (within LTE and between LTE and 2G/3G), optimize Random Access Channel (RACH) performance and improve energy savings

Other enhancements included the support of dual layer beamforming to improve peak rates when in beamforming mode, the support of vocoder rate adaptation based on cell loading, architecture enhancements in support of Home NodeB/eNodeB (i.e., femtocells), IMS enhancements to IMS Centralized Services and IMS Service Continuity, Universal Subscriber Identity Module (USIM) enhancements for M2M, femtocells and Near Field Communications (NFC).

As operators evolved their networks toward LTE and EPS architecture and considered software solutions, they built upon the capabilities of their proven Home Location Register (HLR) to incorporate carrier-grade Remote Authentication Dial In User Service for Authentication, Authorization, and Accounting (RADIUS AAA) for packet-switched traffic, Diameter-based AAA and Home Subscriber Server (HSS) support for the IMS core. Inclusive functional suites took full advantage of the communications and media software solutions to ensure data-level coherence and behavioral consistency of the overall mobility management solution across all access domains and technology generations. Linked with pan-generational mobility and data management products that were able to service multiple fixed and mobile access domains, operators leveraged the Communication and Media Solutions (CMS) Policy Controller to assure QoS and provide a

fine degree of control for service offerings consistent with the Open Mobile Alliance (OMA) and 3GPP Rel-8 specifications.

Management of network traffic was the major challenge for operators. Solutions were offered for agile intelligent mobile networks, like web optimizers that supported Rel-8 and beyond networks by using compression, caching and transcoding techniques to increase data transfer rates while decreasing the amount of traffic flowing over the network. Web and media optimizing are intelligent, content-aware solutions that work to automatically trigger optimization when the network reaches pre-determined thresholds. Media optimization addressed the growing richness of mobile internet video content.

The first live demonstrations of the future-proof solutions that formed an integral building block for the EPC or SAE occurred at the Mobile World Congress (MWC) and Cellular Telecommunication Industry Association (CTIA) Wireless in 2007, including support for an integrated Voice Call Continuity (VCC) solution for GSM-Wireless Local Area Network (WLAN) handover. In November 2007, LTE test calls were completed between infrastructure vendors and device vendors using mobile prototypes representing the first multivendor over-the-air LTE interoperability testing initiatives. Field trials in realistic urban deployment scenarios were created for LTE as early as December 2007. With a 2X2 MIMO antenna system, the trials reached peak data rates of up to 173 Mbps and more than 100 Mbps over distances of several hundred meters. Trials demonstrated that future LTE networks could run on existing base station sites.

Many lab and field trials for LTE were conducted in 2008. By the end of 2009, more than 100 operators had indicated their intentions to trial or deploy LTE, and that number grew to more than 350 operators by September of 2012. TeliaSonera launched the first commercial LTE networks in Oslo, Norway and Stockholm, Sweden in December 2009. In August 2012, the milestone of 100 commercial LTE networks, including 9 Time Division LTE (TD-LTE) networks, was achieved and by August 2013, commercial LTE networks topped 200. By October 2016, there were 537 commercial LTE networks in 170 countries including 80 LTE TDD systems in 47 countries, 28 of which were combined LTE-TDD and LTE-FDD networks.[64]

SON was standardized within 3GPP Release 8 and subsequent specifications. The first technology making use of SON features was LTE, but the technology was retro-fitted to older radio access technologies such as UMTS. The LTE specification inherently supports SON features like Automatic Neighbor Relation (ANR) detection, which is the 3GPP LTE Rel-8 flagship feature. In October 2009, T-Mobile completed testing on the world's first LTE SON in Innsbruck, Austria. Also in October, a manufacturer announced a revolutionary base station commissioning process called "SON Plug and Play". An early adopter of SON, AT&T employed SON solutions on its network, optimizing its UMTS RAN. In 2012, AT&T and other leading service providers expanded this SON solution to support their LTE mobile internet products with numerous additional deployments throughout 2013.

[64] GSAcom.com, October 2016.

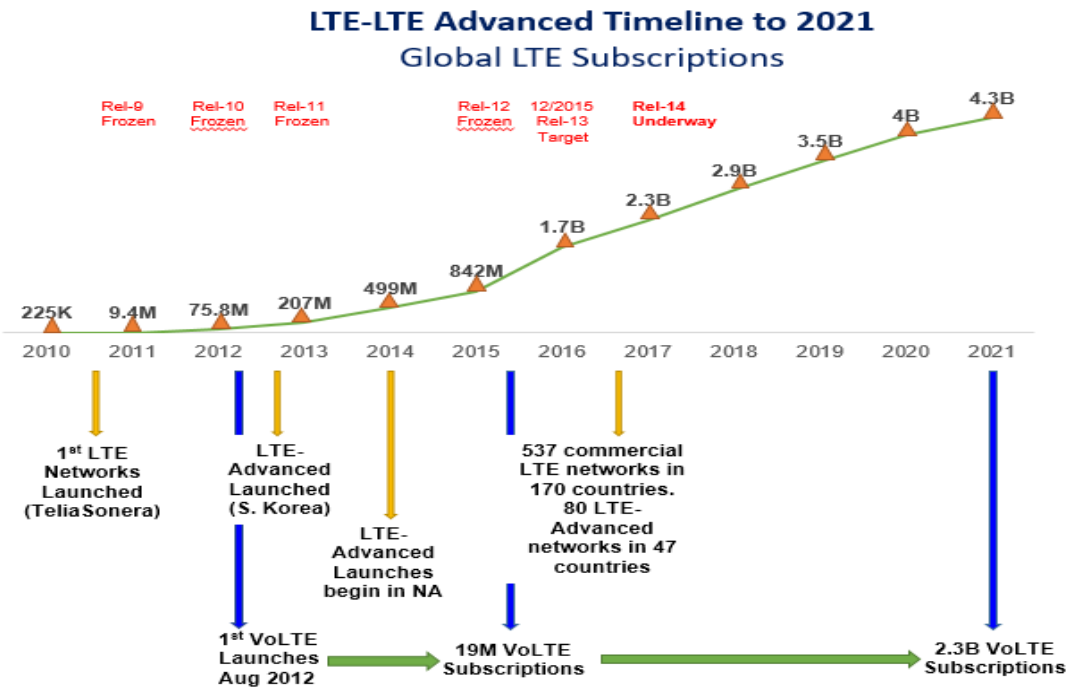

Figure 2.13. LTE and LTE-Advanced Timeline 2010-2021.[65]

Evolved Packet Core (EPC) is the IP-based core network defined by 3GPP in Rel-8 for use by LTE and other access technologies. The goal of EPC is to provide simplified all-IP core network architecture to efficiently give access to various services such as the ones provided in IMS. EPC consists essentially of a Mobility Management Entity (MME), a Serving Gateway (SGW) that interfaces with the E-UTRAN and a Public Data Network Gateway (P-GW) that interfaces to external packet data networks. EPC for LTE networks were announced by numerous vendors beginning in February 2009, allowing operators to modernize their core data networks to support a wide variety of access types using a common core network. EPC solutions typically include backhaul, network management solutions, video solutions that monetize LTE investment and a complete portfolio of professional services.

Telstra, Australia was first to go live in September 2011 with a combined GSM, UMTS-HSPA, LTE core and triple-access SGSN-MME pool based on a leading vendor's portfolio, thereby leading in the commercialization of the EPC.

3GPP LTE Rel-10 and beyond, also known as LTE-Advanced, is intended to meet the diverse requirements of advanced applications that will become common in the wireless marketplace in the foreseeable future. It will also dramatically lower the Capital Expenses (CAPEX) and OPEX of future broadband wireless networks. Moreover, LTE-Advanced provides for backward compatibility with LTE and will meet or exceed all IMT-Advanced requirements. 3GPP Release 10 was functionally frozen (Stage 3 ratified) in March 2011.

Detailed information of these LTE Rel-10 enhancements is available in the 4G Americas' October 2012 white paper, *4G Mobile Broadband Evolution*, in Section 5.

[65] 5G Americas and Ovum, April 2015. GSAcom.com, October 2016.

While 3GPP Rel-9 focused on enhancements to HSPA+ and LTE, Rel-10 focused on the next generation of LTE for ITU's IMT-Advanced requirements and both were developed nearly simultaneously by 3GPP standards working groups. Several milestones were achieved by vendors in both Rel-9 and Rel-10.

Vendors anticipated that the steps in progress for HSPA+ would lead up to 168 Mbps peak theoretical downlink throughput speeds and more than 20 Mbps uplink speeds in Rel-10. At Mobile World Congress 2010, the world's first HSPA+ data call with a peak throughput of 112 Mbps was demonstrated by a leading vendor.

Vendors progressed beyond LTE with the next generation of technologies in Rel-10 for IMT-Advanced, called LTE-Advanced, demonstrating that the evolution of LTE is future-proof. In October 2009, 3GPP submitted LTE-Advanced to the ITU as a proposed candidate IMT-Advanced technology. The final ratification by the ITU of LTE-Advanced (Rel-10) as 4G IMT-Advanced occurred in November 2010 and for which specifications became available in 2011.

As early as December 2008, researchers conducted the world's first demonstration of Rel-10 LTE-Advanced technology, breaking new ground with mobile broadband communications beyond LTE. A leading infrastructure company's researchers successfully demonstrated Relaying technology proposed for LTE-Advanced in Germany. The demonstration illustrated how advances to Relaying technology could further improve the quality and coverage consistency of a network at the cell edge where users were furthest from the mobile broadband base station. Relaying technology, which can also be integrated in normal base station platforms, is cost-efficient and easy to deploy as it does not require additional backhaul. The demonstration of LTE-Advanced indicated how operators could plan their LTE network investments knowing that the already best-in-class LTE radio performance, including cell edge data rates, could be further improved and that the technological development path for the next stage of LTE is secure and future-proof.

Some of the other developments for LTE and LTE-Advanced as early as 2013 included: world's first Single RAN WiMAX/LTE commercial network (Mobily in Saudi Arabia); world's first inter-band LTE-Advanced Carrier Aggregation (10 MHz @ 800 MHz and 20 MHz @ 2.6 GHz) conducted by Vodaphone with peak Downlink (DL) rates over 225 Mbps; and the world's first LTE-Advanced Carrier Aggregation (CA) (20 MHz @ 2.6 GHz and 20 MHz @ 2.6 GHz, 4x4 MIMO) based on LTE TDD with peak DL rates over 520 Mbps by a leading vendor.

LTE-Advanced progress was made by numerous operators in 2013, including some progress in commercial networks, such as SK Telecom's, and others in field tests, such as Turkcell's which reported peak speeds of 900 Mbps and approaching 1 Gbps, which is the official definition of '4G'. However, commercial LTE-Advanced deployments are typically implementing just a small subset of the large menu of options included in 3GPP Rel-10 and Rel-11 standards. The early focus was heavily on CA, with Enhanced Inter-Cell Interference Coordination (eICIC) (for HetNets) and advanced MIMO which were also popular early choices for operators. While LTE-Advanced will remain a small part of the commercial 4G landscape for a couple of years, confined to the most advanced and/or capacity-challenged Mobile Network Operators (MNOs), these efforts are certainly moving the technology forward at a faster rate than was seen in previous generations.

Telstra of Australia pushed the limits in terms of wireless speeds in deploying carrier aggregation across its 900 MHz and 1.8 GHz bands and was the first CA deployment to use the combination of frequencies (both re-farmed from 2G). Vendors remain strongly committed to enabling carrier aggregation solutions on both FDD and TDD bands, including 3CA and 4CA band combinations, TDD-FDD carrier aggregation and Enhanced International Mobile Telecommunications Advanced (eIMTA).

Smart of the Philippines also tested LTE-Advanced and achieved downlink speeds of 209 Mbps in the lab. Other LTE operators, including LG U+ and KT, as well as SK Telecom (Korea), EE (UK) and Saudi Telecom Company (Saudi Arabia) also used LTE-Advanced carrier aggregation. SK Telecom took a leadership role as the first carrier to claim a commercial 'LTE-Advanced' service and reaped rewards from its early investments by the 1Q 2013 when they achieved 300,000 subscribers a month after launch, having doubled their 4G speeds to a peak of 150 Mbps with carrier aggregation. By February 2014, there were five LTE-Advanced commercial networks and that grew to 80 LTE launched in 47 countries by October 2016.[66] There are more than 150 LTE-Advanced commercial networks as of the 3Q 2016 according to numerous sources.

AT&T's mobility network was LTE-Advanced Release 10 ready for upgrade via software patches as of 3Q 2013, and AT&T began to deploy it in certain markets in 2014 starting with Chicago in March using carrier aggregation in 700 MHz and AWS spectrum. By year-end 2014, New York, San Francisco and Dallas all had active LTE-Advanced service and those deployments are expanding through 2015. To take advantage of the LTE-Advanced features requires one of about 20 LTE-Advanced compliant devices that were offered by the carrier in January 2015. As the network deployment of LTE-A continues, and more devices are seeded into the VoLTE market, the faster speeds of enhanced networks will be more apparent. AT&T planned to implement a variety of LTE-Advanced features on portions of their network over several years to take full advantage of its rich functionality. The features include carrier aggregation, high-order MIMO and self-optimizing networks, to name a few.

Sprint first announced the deployment of LTE-Advanced capabilities in Chicago in March 2014, then elsewhere initially in 18 markets, with plans to install hundreds of new Spark-capable cell sites in Chicago as part of a $45 million investment in the area between now and the end of 2016. Advanced capabilities such as 8T8R (8 Transmitters 8 Receivers), multi-layer MIMO and multiple-channel carrier aggregation will gave Sprint the potential to increase the peak speeds a customer will experience to 100 Mbps and beyond. The first carrier aggregation in Chicago was two-channel carrier aggregation in Sprint's 2.5 GHz spectrum (melding together two 20 MHz channels for faster speeds) but by the end of 2015, Sprint fully tested three-channel carrier aggregation with deployments following shortly thereafter and deployed multi-antenna techniques like MIMO for higher capacity. In February 2015, Sprint offered LTE-Advanced in 48 markets with tri-band carrier aggregation in bands 25, 26 and 41.

T-Mobile had deployed Wideband LTE, which increases bandwidth and capacity on its LTE network in 121 markets at end of 2014. Wideband LTE refers to carrier bandwidth of 15+15 MHz or greater in a particular market. These wider carrier bandwidths (of which 20+20MHz is the LTE maximum, after which Carrier Aggregation is needed) are basic LTE features sine Release 8. T-Mobile also led the industry with new technology advancements like 4X4 MIMO in 2016, which is based on 4 layer MIMO with TM 3/4 and is considered a development in Release 10.

The introduction of VoLTE gained traction with 21 percent of operators investing in deployments as of April 2015.[67] As of year-end 2013, VoLTE was deployed in South Korea by SK Telecom, LG U+ and KT Corp; MetroPCS in the U.S. offered VoLTE service in 2013 on select devices. By year-end 2014, AT&T, T-Mobile and Verizon Wireless all had implemented VoLTE with HD voice service; AT&T and T-Mobile followed on with Wi-Fi Calling, Advanced Messaging (RCS) and Video Calling. T-Mobile first launched in Seattle in May 2014, and within two months covered their entire LTE network for the first nationwide VoLTE service. Sprint was deploying VoLTE by 1Q 2015. As of April 2015, 16 commercial VoLTE-enabled HD voice services

[66] GSAcom.com, October 2016
[67] *Evolution to LTE Report*, GSA. April 2015.

were launched in 7 countries, and the proportion of 21 percent of carriers investing in VoLTE translated to 71 in total across 36 countries.[68]

From Ericsson's Mobility Report 2016:

- At the end of 2015 there were more than 100 million VoLTE subscriptions. The uptake is expected to accelerate in the coming years, with 2.3 billion subscriptions projected by 2021 – equal to more than 50 percent of all LTE subscriptions globally. In the U.S., Canada, Japan and South Korea, uptake is projected to be even faster, with around 80 percent of LTE subscriptions using VoLTE by 2021.

- Measurements indicate that there are already networks where around 70 percent of all LTE voice calls are provisioned using VoLTE, instead of utilizing 2G/3G circuit switched voice.

- Many barriers to VoLTE adoption, such as adapting charging and IT systems, having adequate LTE coverage and interoperability between vendors' implementations, are now being resolved. In addition, the penetration of VoLTE-capable smartphones is increasing rapidly.

- In April 2016 there were more than 340 VoLTE-enabled smartphone models, supporting different regions and frequencies.

The VoLTE platform enables services such as HD voice, video communication and IP messaging, as well as new service innovations. Operators that deploy the technology are able to offer high-quality IP-based communications services across LTE, Wi-Fi, and fixed access technologies, as well as 5G when it becomes available.

LTE Broadcast uses evolved Multimedia Broadcast Multicast Service (eMBMS) to allow the same content to be sent to a large number of subscribers at the same time, resulting in a more efficient use of network resources than each user requesting the same content, then having the content unicast to each user. AT&T disclosed plans in September 2013 to use the 700 MHz Lower D and E Block licenses it acquired in 2011 from Qualcomm for an LTE Broadcast service.[69] AT&T's focus was almost "all about architecting networks to deliver video" and that was where AT&T invested much of its capital over the next three years. The company developed a 'broadcast capability' to remove video traffic from its wide area network and first trialed LTE Broadcast in 2014. In January 2015, AT&T demonstrated LTE Broadcast (also called LTE Multicast) at the AT&T stadium at a collegiate national championship. In the trial, AT&T along with four vendors and content-provider ESPN, delivered two channels of streaming video and one channel of data to 40 LTE Broadcast-enabled devices. AT&T used 5 MHz of its LTE spectrum to deliver both video and data streams with speeds about 1 Mbps. Verizon has also trialed LTE Multicast and its entire network is enabled for the technology as they have deployed the necessary software throughout their cell sites. At the end of 1Q 2015, AT&T was working to determine the various business models and use cases for the technology with the expectation that the software upgrades for LTE Broadcast are not difficult to implement.

While Rel-10 was the mainstay, LTE-Advanced was further refined in 3GPP Rel-11. Rel-11 features were frozen in September 2012 with the core network protocols stable in December 2012 and radio access protocols stable in March 2013, though parts of the RAN may not have been completed until June 2013.

For LTE, Rel-11 provides enhancements to Rel-10 technologies such as CA, MBMS, SON and Coordinated Multi-Point Transition and Reception (CoMP) for coordinated scheduling and/or beamforming and better

[68] *Ibid.*

[69] *AT&T to Use Lower 700 MHz D and E Block Spectrum for LTE Broadcast*, Phil Goldstein, *FierceWireless*. September 2013.

cell edge performance, Enhanced Physical Downlink Control Channel (EPDCCH) and Further Enhanced Inter-Cell Interference Coordination (FeICIC) for devices with interference cancellation. These LTE-Advanced features were being tested and introduced in 2015.

Rel-11 also looks beyond phones and beyond the 3GPP technologies by addressing Machine Type Communications/Machine-to-Machine (MTC/M2M), IMS and Wi-Fi integration, plus enhanced support for femtocells (Home NodeB and Home e-Node B).

New spectrum developments are in consideration; there exists up to 500 MHz of unlicensed spectrum around the world in the 5 GHz band used for various applications and services, primarily Wi-Fi. By leveraging the performance characteristics of LTE, the industry plans to take advantage of this spectrum to address the 1000X data challenge. In some world regions, LTE for Unlicensed Spectrum (LTE-U) could be deployed as a pre-standard solution and offer meaningful coverage and capacity gains (2x to 4x, depending on the assumptions) over what is possible with Wi-Fi.[70] In other regions of the world, certain regulatory requirements exist which necessitate some important changes to the LTE standard in order to leverage the unlicensed spectrum. These changes, referred to as LAA (Licensed Assisted Access) were incorporated into Rel-13 of the LTE standard, completed in March 2016. T-Mobile committed to bringing LAA trials to life in 2015 and the technology to customers in the near future. LTE-U will apply technology features that are comparable to what Wi-Fi uses today to ensure how multiple Wi-Fi Access Points, Wi-Fi devices, and other wireless applications, like radar, can use the unlicensed spectrum in a harmonious manner and without interference. LTE-U will be used primarily, if not entirely, in conjunction with small cells. Leading vendors are developing LTE-U.

Small cells play a pivotal role in bringing a huge amount of data capacity, where it is needed the most, by bringing the network closer to the users—indoors outdoors, homes, offices, enterprises, shopping malls and lamp posts. Small cells are available in 3G, 4G, and Wi-Fi and in all the different forms such as user-installed small cells and operator-installed picos and metros. For such dense small cell networks, the key is to make sure interference is managed, mobility is robust and a reliable and consistent user experience is delivered. Though small cells have been commercially available for many years, they are now seeing momentum in the development of the hyper dense network. Operators worldwide are now using small cells, including nearly 30,000 deployed in rural and remote applications.[71] The number of small cells shipped as of year-end 2015 was 13.3 million.[72] Techniques developed by a leading vendor allows multiple users to share the same frequencies, effectively multiplying system capacity through a Cloud-RAN small cell system that delivers superior LTE performance for enterprise and public areas at lower deployment costs. Equipment consists of a baseband controller and multiple radio points that form a single 'super cell' – eliminating handovers and interference across large areas. Another vendor's design also optimizes performance while accelerating deployments. Encompassing RF delivery, equipment housing and concealment, the small cell antennas improve performance of the RF air link, expedite construction and enable faster zoning approvals, thereby decreasing OpEx and CapEx and improving time to revenue.

LTE-WLAN Interworking, to bolster cellular traffic offload capabilities, ensure the best utilization of all available resources, and enhance the end-user experience became increasingly important. A leading vendor played an instrumental role in providing solutions in Rel-12 WLAN network selection using HotSpot 2.0, Rel-12 WLAN/3GPP radio level interworking, and Rel-13 efforts on LTE-WLAN aggregation and the integration of WLAN Operations, Administration and Maintenance (OAM) with the cellular network.

[70] *The Prospect of LTE and Wi-Fi Sharing Unlicensed Spectrum*, Signals Research Group, February 2015.
[71] *Small Cells Deployment Market Status Report.* Mobile Experts, February 2016.
[72] *Ibid.*

Machine Type Communications (MTC) is being standardized in Rel-12 and Rel-13. A leading manufacturer enabled cellular M2M services including optimized addressing, identification, small data transmission, device triggering and monitoring and group communication. They also contributed significantly to enabling M2M device feasibility and its requirements for low cost, low power consumption and high coverage. With forecasts for the IoT at some 50 billion connected devices, many of which will be cellular connections, the work in standards development and by leading manufacturers will be increasingly significant. New modem solutions designed and introduced in October 2015 by a leading vendor support reliable, global connectivity to the IoT with scalable, power-efficient and cost-optimized Cat-1 LTE connectivity as well as modems for the LTE eMTC and NB-IoT standards in Release 13.

Leading in the IT strategy space, another vendor long recognized the IoT as a critical enabler of the idea economy and the data-driven enterprise. As such, they launched a Universal IoT Platform for licensed and unlicensed spectrum, 3G-4G-WiFi-LPWAN, including the emerging cellular standards such as LTE-M and NB-IoT. The platform dramatically simplifies integrating diverse devices with different communications protocols. It provides Subscriber Identity Module (SIM) and Device Lifecycle Management and Data Analytics. The company also introduced the industry's first converged system for IoT bringing a robust analytics platform to deliver IoT insights and machine learning at the edge, enhanced IoT security and new IoT services and ecosystem capabilities. Real time analysis is enabled at the edge, rather than forcing companies to transfer vast amounts of sensor data to a central location for processing.

IP converged networks and cloudification are the buzz words of the industry. They provide increased flexibility and agility while insuring there is no disruption to the legacy systems. Leading vendors work to make networks more open, more elastic and more extensible through three key functional layers tightly integrated with security, policy and analytics:

- Infrastructure – foundational layer providing physical and virtual compute, network and storage functions, e.g., routing, mobile core, video processing
- Network Abstraction – orchestration for comprehensive lifecycle service automation, telemetry and analytics for programmability, e.g., streaming telemetry, network analytics
- Cloud-based Services – policy-based consumer, business, IoT, video, mobility services that drive new revenue, e.g., 5G fixed mobile broadband, connected care, virtual managed services, residential video

Another industry development is Network Function Virtualization (NFV). Industry leaders have been instrumental in the evolution of network architecture and the management plane to virtualize current and next generation networks to create enhanced communication services. One leading vendor has been actively enabling the industry to virtualize the cellular network and transition to general purpose hardware based on x86. The vendor has invested in R&D to make x86 processors more efficient for high-speed packet processing while contributing its own set of libraries, such as DPDK (Data Plane Development Kit).

AT&T has been a front runner in the goal of virtualizing and controlling over 75 percent of its network using Software-Defined Networking (SDN) and NFV by 2020 and will help pave the way for the industry. The launch of virtualized core network platforms and NFV/SDN has enabled AT&T to rapidly deploy additional mobile core sites and expand its mobile core network within the U.S as well as build out mobile cores in Mexico and Europe. Deployed on AT&T's Integrated Cloud (AIC) enables gathering and analyzing extremely large volumes of network data which enhances its Big Data based intelligence capabilities. The ability to grow the mobile core in an agile manner using NFV/SDN is a key enabler for new services, IoT growth and 5G. Telefonica has also progressed their NFV/SDN solution, being awarded best in the LTE and 5G World Awards 2016.

Rel-10 based LTE-U cannot be adopted in markets such as Europe or Japan where there are additional unlicensed band regulations, on the channel occupation limit often known as "Listen-Before-Talk" (LBT) and minimum bandwidth occupancy among others. To provide a single global framework that would also work in these markets, 3GPP has started working on Rel-13 LAA. In addition to the LBT regulation, LAA will also meet other regulatory requirements such as channel occupancy bandwidth requirement and the transmission of Power Spectral Density (PSD) in Europe. Preserving coexistence with other unlicensed technologies including Wi-Fi is a requirement for Rel-13 LAA.

T-Mobile committed to bring LAA production trials to life in 2015 in the 5 GHz band and then deliver the technology to customers in the near-future with small cell solutions. Commercial LAA products are expected in the first half of 2016. Verizon announced that it plans to deploy LTE-U technology in the 5 GHz and 3.5 GHz bands starting in 2016.

There are several multimedia-related enhancements for LTE networks such as Region of Interest Zoom and IMS telepresence. Region of Interest Zoom enables users to zoom in on a specific region of interest during an ongoing, interactive IMS based Multimedia Telephony session and is a focus of some industry leaders' developmental work.

Another important area of development in 3GPP Rel-13 is defining MIMO Over-the-Air (OTA) test methodology and performance requirements, which is key to enabling standardized conformance testing for operators and device vendors.

A leading chipset manufacturer led the industry with the first commercially announced Gigabit Class LTE chipset designed to deliver fiber-like LTE Category 16 download speeds of up to 1 Gbps, and is the mobile industry's first announced LTE Advanced Pro modem with support for LAA (Rel-13). In addition, new modem solutions were designed and introduced to support reliable, global connectivity to the IoT such as scalable, power-efficient and cost-optimized Cat 1 LTE connectivity and to provide a path to LTE eMTC and NB-IoT standards in Rel-13.

As 3GPP continues to develop standards for HSPA+ and LTE/LTE-Advanced, the world's leading mobile broadband technologies, discussion on the future network requirements and recommendations for the next generation 5G technologies is beginning to take shape. Many global organizations are joining private and public partnerships including ventures with universities and leading associations such as 5G Americas, NGMN Alliance, 5G PPP and others, along with top industry manufacturers and service providers – all which are developing the framework for 5G. Some world regions such as the European Union, Korea and Japan are investing billions of dollars in research for taking on leadership in 5G technology. Publications such as the white paper, *4G Americas' Recommendations on 5G Requirements and Solutions*[73], demonstrate the forward thinking that is consistent with the cellular industry to keep abreast of unprecedented growth. Standards groups 3GPP and the ITU will be considering the global work that is forming the future for our industry. For a study of the organizations, academia and governments conducting studies for 5G development, see the 5G Americas white paper, *Global Organizations Forge New Frontier of 5G.*[74]

Operators and vendors are supporting these and other standardization features.

[73] *4G Americas' Recommendations on 5G Requirements and Solutions*. 4G Americas, October 2014.
[74] *Global Organizations Forge New Frontier of 5G*, 5G Americas. July 2016.

2.7 ROAD TO 5G – 3GPP RELEASE 15 STANDARDIZATION

Section 5 of this paper explains in detail the current work in Releases 14 and 15 in the progress towards 5G. However, a lot of innovative developmental work is currently underway with numerous commercial announcements. Although there is no globally agreed definition of the requirements for 5G, the requirements being defined for International Mobile Telecommunications (IMT)-2020 by ITU-R provides a good benchmark towards 5G, and will be discussed in detail in Section 4 of this paper. 3GPP is committed to submitting a candidate technology to IMT-2020 for evaluation. In this paper, IMT-2020 and 5G will be used interchangeably with the understanding that the marketplace will potentially define 5G independent of whether or not technologies meet IMT-2020 requirements (similar to the way that 4G was defined in the marketplace vs. following IMT-Advanced requirements).

The first 5G specifications will be published in Release 15. 5G work will involve both the Radio Access Network (RAN) and the System Architecture. The architecture today is based upon a set of assumptions that have been around the mobile system for some time. 3GPP is striving to reconcile the diversity of views and projects that need to be brought in for 5G specification. Some tough decisions about what can be achieved in Release 15 and what must be taken on in Release 16 are now being made.

In early 2016, AT&T began 5G trials in Austin, Texas, having secured special licensing to do so from the U.S. government. Outdoor testing began in the summer and field trials to provide wireless connectivity to fixed locations in Austin were planned prior to the end of the year. AT&T is structuring its trials in such a way that it is able to contribute to the international 5G standards development and pivot to compliant commercial deployments once standards are set by 3GPP. AT&T's fundamental technology approach to 5G is unique. Built on its industry leading positions in Software-Defined Networking (SDN), data analytics, security and open source software, the approach will help deliver a cost-effective wireless experience that can quickly adapt to new consumer and business demands.

In June 2016, Sprint was the first U.S. carrier to demonstrate elements of 5G at a large scale public event (Copa America Centario). The Sprint demonstration with a leading infrastructure vendor utilized 73 GHz millimeter wavelength spectrum to deliver peak download speeds of more than 3 Gbps. With another leading vendor, Sprint demonstrated utilizing 15 GHz centimeter wavelength spectrum to deliver download speeds up to 4 Gbps (Rel-15).

Leading vendors are also driving the 5G standards work from research and pre-standard field trials. Through advances such as 5G Radio Prototypes and cloud-based network slicing, a leading vendor and its operator customers will be key players in defining this next generation of network technology all the way through to commercialization. The 5G Radio Prototypes that operators can deploy in live field trial environments are showing exceptional performance under real-world conditions, achieving a peak throughput of 27.5 Gbps and latency as low as 2ms in a live demonstration in August 2016. The 5G Ready Core is about flexibility and efficient management of that new flexibility; it is based on five key technologies – Virtualization (VNF), Software-Defined Networking (SDN), Distributed Cloud, Network Slicing and Orchestration and Management. By managing resources dynamically, service providers can add value to their offerings by creating "network slices" on-demand, software-defined, and amenable to ecosystems involving third party service providers, at industrial scale. This successful Proof-of-Concept (PoC) for dynamic network slicing technology for 5G core networks was demonstrated in June 2016.

A leading semiconductor company was first to announce a 5G New Radio (NR) sub-6 GHz prototype system and trial platform to test, demonstrate and trial 5G design to drive 3GPP 5G NR standardization (Rel-15). In addition, that vendor demonstrated robust 5G millimeter (mmWave) design for 5G (Rel-15).

One leading vendor is working with 24 major operators worldwide on every continent around the world on their 5G development including America Movil, AT&T, Telefonica, T-Mobile, NTT DoCoMo, Softbank, Singtel, Telstra, Deutsche Telekom, Korea Telecom, SK Telecom, Etisalat, Turkcell, Verizon, Vodafone Group, TeliaSonera, LG Uplus, China Mobile, China Unicom and TIM Italy.

Critical for the success of 5G is research with many industries to gain knowledge and experience in leveraging 5G technology. Projects to spearhead development of innovative use cases for 5G with industries ranging from mining to agriculture to intelligent transportation are ongoing. The understanding of how 5G and IoT capabilities will be used in the real world is working hand-in-hand while building innovative solutions for enterprise customers.

5G Plug-Ins can introduce software-driven innovations that bring essential 5G technology concepts to today's cellular networks. The Plug-Ins include modules for Massive MIMO, Multi-User MIMO, RAN Virtualization, Intelligent Connectivity and Latency Reduction to facilitate a rapid evolution of 5G access networks and the successful adoption of 5G services.

At Mobile World Congress in February 2016, three leading vendors announced collaboration to develop and trial what is expected to be the industry's first 5G (fifth generation mobile networks) router for enterprises. Other announcements at the World Congress focused on a multi-country, multi-services Ultra Services Platform to simplify, automate and accelerate the Mobile Cloud. The Platform makes 5G capabilities like control and user plane separation (CUPS) and network slicing available today. Operators can take advantage of these features without having to wait for end-to-end 5G.

The industry is quickly coalescing a strong 5G ecosystem, a closely interlinked series of symbiotic relationships that includes operators, large infrastructure vendors (e.g., Ericsson and Nokia), semiconductor vendors (e.g., Intel and Qualcomm), IT-infrastructure providers (e.g., Cisco, Mitel and HPE), device manufacturers, antenna system providers (e.g., Commscope and Kathrein), standards bodies (e.g., 3GPP and ITU), associations (5G Americas, 5GPPP, 5MF, 5G Forum, IMT-2020, Next Generation Mobile Networks Alliance (NGMN), Small Cell Forum), academia, governments and more. The result will be a path that is well-paved and researched for a connected future.

3 STATUS OF 3GPP RELEASE 13: HSPA+ AND LTE-ADVANCED

3GPP Rel-13, which was completed in March-June of 2016, continued to provide important enhancements to the HSPA+ and LTE family of technologies. LTE-Advanced enhancements in Rel-13 include active continuing work on the Radio Access Network (RAN) side for the downlink, such as Active Antenna Systems (AAS) and SON for AAS-based deployments, as well as Elevation Beamforming. LTE-Advanced work in Rel-13 also provides for enhanced signaling for Inter-eNB CoMP, LAA, CA enhancements, Network Assisted Interference Cancellation (NAIC) (a/k/a NOMA), RAN sharing enhancements, dual connectivity enhancements, among others. For HSPA+, further work in Rel-13 includes downlink and small data transmission enhancements and HSPA dual-band uplink CA.

Rel-13 network services related enhancements include Wi-Fi integration with Internet Protocol (IP) Flow Mobility and voice and video support in Trusted and Untrusted WLAN, Policy and Charging Control (PCC)/QoS in User Plane Congestion management (UPCON), and public safety features for Push-to-Talk (PTT) over LTE, proximity-based services and MBMS enhancements. Further work on MTC enhancements is also featured in Rel-13 such as: Dedicated Core Networks (DECOR), High Latency Communications, (HLCom) and Architecture Enhancements for Service capability Exposure (AESE), energy saving, monitoring and group calls. Web Real Time Communications (WebRTC) enhancements, support of Enhanced Voice Services (EVS) in 3G Circuit Switched (CS) Networks, Dynamic Adaptive Streaming over HTTP (DASH) and application specific traffic control is also addressed. Finally, release independent features including work in new spectrum bands and CA combinations were also introduced Rel-13.

3.1 E-UTRAN/LTE-ADVANCED ENHANCEMENTS

This section discusses the RAN related enhancements to LTE-Advanced that were introduced in 3GPP Rel-13. Given the significance of these RAN enhancements in Rel-13, 3GPP decided to recognize these features as LTE-Advanced Pro.

3.1.1 ACTIVE ANTENNA SYSTEMS (AAS)

Active Antenna Systems (AAS) introduce advanced antenna systems, usually comprised of radiating elements and transceiver units to Base Stations (BS) installations.

3GPP defines an active antenna system base station, as a base station which combines an antenna array with a transceiver unit array, and optionally a radio distribution network covering single and multi-radio access technologies and coverage scenarios from local to wide area.[75] Active antenna system supported base stations can use multiple transceivers on an antenna array to produce dynamically adjustable radiation pattern. Compared to conventional base stations with a legacy antenna setup (i.e., passive antenna systems), active antenna systems can offer a host of benefits such as:

- System capacity and performance gains by employing flexible cell split (vertical or horizontal) and/or beamforming
- Lower long term costs compared to traditional setups due to smaller real estate footprint and reduced radio frequency (RF) losses

[75] 3GPP TR 37.842 V2.1.0 (2016-09) *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS) (Release 13)*.

- Improved system optimization by meeting new traffic demands and network evolution through adaptive software reconfiguration which would lead to reduce operation expenses and simplified site engineering

These benefits have motivated companies in 3GPP to start studying the specification feasibility of an AAS Base Station in Rel-12. The study was completed in early 2013[76] and a new work item for Rel-12 was approved, which was subsequently moved to Rel-13.[77]

The main objective of the work item is to identify the RF requirements that may be needed for an AAS BS specification and the necessary conformance testing derived from those RF requirements.

Three main functional blocks, the transceiver unit array (TRXUA), the radio distribution network (RDN), and the antenna array (AA), present a general AAS BS radio architecture.[78] As indicated in Figure 3.1 the transceiver unit array consists of NTRXU transceiver units which each are composed of a transmitter unit (TXU) and a receiver unit (RXU); each transceiver unit (TRU/RXU) interfaces with the baseband processing within the eNodeB.

The TRXUA and the RDN are connected via the transceiver array boundary (TAB). This point is equivalent to a legacy "antenna connector". The TAB may consist of several TAB connectors where the total number is given by NTABC.

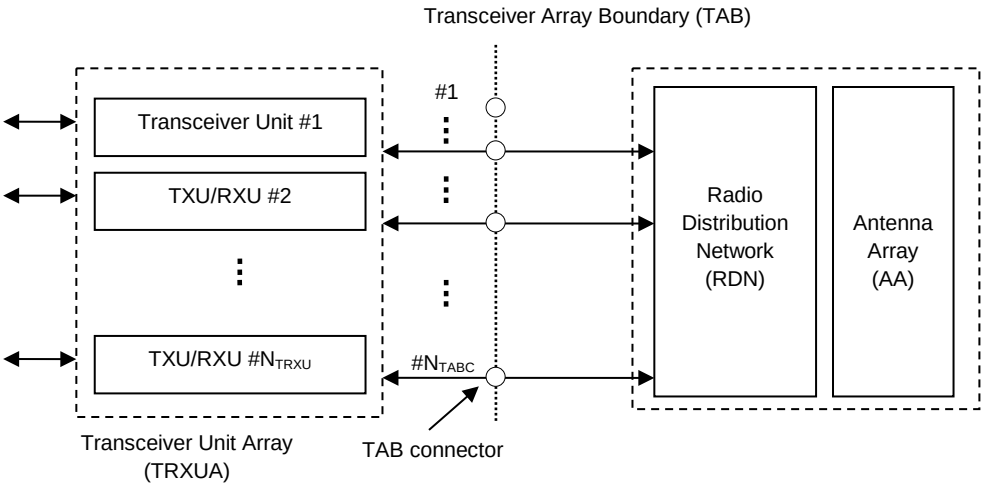

Figure 3.1. General Active Antenna System Base Station Architecture.

The transmitter unit (TXU) takes the baseband input from the AAS BS and provides the radio frequency (RF) TX outputs. The RF TX outputs may be distributed to the antenna array via a radio distribution network; where the antenna array is composed of an arbitrary number of antenna elements. The receiver unit (RXU) performs the reverse of the transmitter unit operations. The radio distribution network, if present, performs

[76] 3GPP TR 37.840 V12.1.0 (2013-12) *Study of Radio Frequency (RF) and Electromagnetic Compatibility (EMC) requirements for Active Antenna Array System (AAS) base station* (Release 12).
[77] 3GPP TR 37.842 V2.1.0 (2016-09) *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS)* (Release 13); 3GPP TR 37.145-1 V1.0.0 (2016-09) *Active Antenna System (AAS) Base Station (BS) conformance testing; Part 1: conducted conformance testing* (Release 13); 3GPP TR 37.145-2 V1.0.0 (2016-09) *Active Antenna System (AAS) Base Station (BS) conformance testing; Part 2: radiated conformance testing* (Release 13).
[78] 3GPP TR 37.842 V2.1.0 (2016-09) *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS)* (Release 13).

the distribution of the TX outputs into the corresponding antenna paths and antenna elements, and a distribution of RX inputs from antenna paths in the reverse direction. The transmitter and receiver unit can be separated and can have different mapping towards radiating elements.

The TAB connector is defined as conducted requirement reference point. The transmitted signal per carrier from one Transmitter Unit appears at one or more TAB connector(s) and the received signals per carrier from one or more TAB connector(s) appear at a single RXU.

Requirements and Reference Points

The 3GPP report[79] introduces radiated requirements in terms of electromagnetic and spatial parameters, where electromagnetic parameters are in terms of power and field strength and the spatial parameter in terms of a spherical coordinate system. As in AAS BS systems, there is an interaction between different subsystems, the minimum requirements for AAS BS shall be placed on one or more beams declared by the manufacturer. Descriptive characteristics are Equivalent Isotropic Radiated Radiated Power (EIRP) for radiated transmit power and Equivalent Isotropic Sensitivity (EIS) for Over-the-Air (OTA) sensitivity.

The Study and Work Item also provides a detailed evaluation of conducted requirements for transmitter, as well as, receiver. Specifically, for the transmitter requirements, the spatial selectivity of an AAS BS is compared to the conventional BS for the Adjacent Channel Leakage Ratio (ACLR) and the unwanted in-band/out-band emissions. Simulations show that the system performance in case of AAS BS aggressors behaves similar to systems with legacy base stations (see Annex A in 3GPP report). Therefore, the existing requirements as specified in other 3GPP reports[80] can be applied. For the unwanted emissions, the manufacturer shall declare the minimum supported number of cells and corresponding TAB connector TX cell groups. The defined emission limits must hold for each of these groups.

At the receiver, the manufacturer shall accordingly declare TAB connector RX cell groups for which the receiver spurious emission limits must hold. The other requirements such as reference sensitivity level, adjacent channel selectivity (ACS) or blocking can be adopted from the specifications of legacy BSs (see 3GPP reports[75]).

It is also found that existing radio frequency (RF) requirements may be inadequate to ensure co-existence for unique AAS applications which may be difficult to support by legacy base stations. Examples of such applications include beam steering in elevation, azimuth or a combination of both.

The Work Item also carried out additional simulation campaigns on transmitter unwanted emissions and receiver in-band blocking for a variety of deployment scenarios with actual propagation channels. From the simulation results, it is concluded that the existence of a different spatial distribution of adjacent channel interference that arises from an AAS base station compared to a legacy base station does not demand any additional types of requirement.[81]

With respect to the specification of conducted RF requirements for AAS base stations, a normative technical document[82] was published in Rel-13 while the specification work on over-the-air requirements is still on-going with scheduled completion in Rel-14. Presently, a consensus was reached on minimum radiated

[79] 3GPP TR 37.842 V2.1.0 (2016-09) *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS)* (Release 13).
[80] 3GPP TS 25.104 *Base Station (BS) radio transmission and reception (FDD)*; 3GPP TS 36.104 E-UTRA *Base Station (BS)* radio transmission and reception; 3GPP TS 37.104 E-UTRA, UTRA and GSM/*EDGE Multi-Standard Radio (MSR) Base Station (BS) radio transmission and reception; 3GPP TS 25.105 Base Station (BS) radio transmission and reception (TDD).*
[81] 3GPP TR 37.842 V2.1.0 (2016-09) *Radio Frequency (RF)* requirement background for *Active Antenna System (AAS) Base Station (BS)* (Release 13).
[82] 3GPP TS 37.105, *Active Antenna System (AAS)* Base Station transmission and reception (REl-13).

transmit power and sensitivity requirements of AAS base stations. The former shall be placed on one or more manufacturer declared beams that are intended for cell-wide coverage; the minimum radiated transmit power requirement will be on the accuracy with which the declared Equivalent Isotropic Radiated Power (EIRP) level is met. As for the latter, the over-the-air sensitivity requirement is based upon the declaration of one or more over-the-air sensitivity direction declarations related to an AAS base station receiver. Some of the issues being discussed and considered in the Work Item are transmitter and receiver characteristics such as in-band unwanted emissions, error vector magnitude, intermodulation and power dynamics, and reference sensitivity, in-band/out-of-band blocking and in-channel selectivity, respectively.

Testing Methodologies

In addition to specifying radiated requirements, the Work Item also considers conformance testing. As of October 2016, the AAS base station conformance testing framework and over-the-air test methods were agreed upon. The specified test methods include indoor anechoic chamber, compact antenna test range, one-dimensional compact range and near-field test range. The measurement set-up using the indoor anechoic chamber method for testing the minimum radiated transmit power and sensitivity requirements is depicted in Figure 3.2 and 3.3, respectively. The 3GPP technical report[83] outlines a conformance testing framework, setting 11 points for developing test requirements related to OTA. For conducted test requirements, it is expected that one test method will be sufficient for each core requirement. Hence the traditional approach for devising test specifications can be followed and will be based on the report[84] and adapted for AAS. It is not intended to change or revise conducted test tolerance.

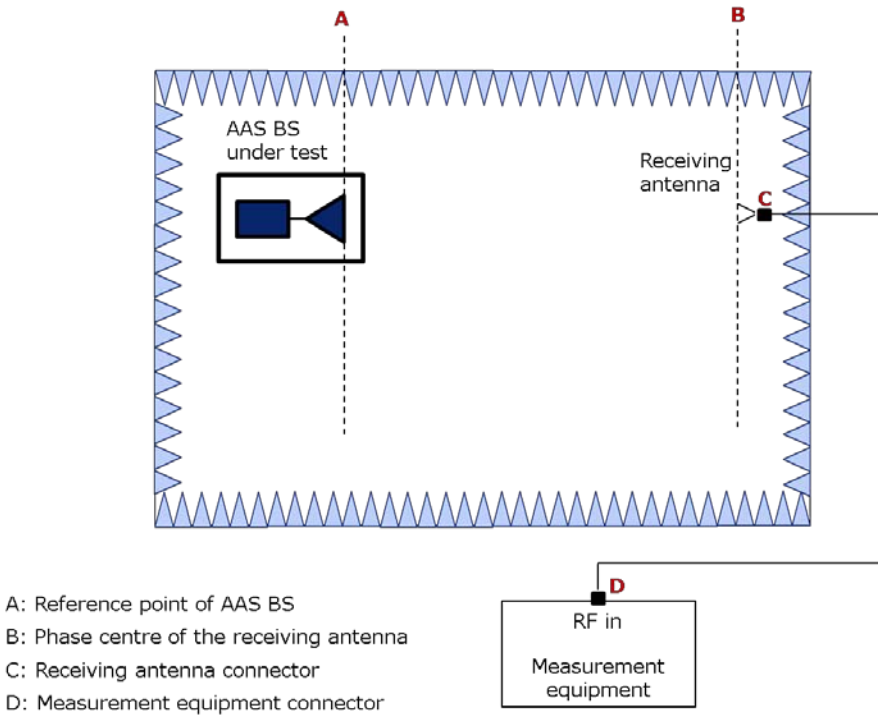

Figure 3.2. Indoor Anechoic Chamber Test Method: Measurement Set-up for Testing Radiated Transmit Power Requirements.

[83] 3GPP TR 37.842 V2.1.0 (2016-09) *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS)* (Release 13).
[84] 3GPP TR 37.141, *E-UTRA, UTRA and GSM/EDGE; Multi-Standard Radio (MSR) Base Station (BS) conformance testing* (Rel-14).

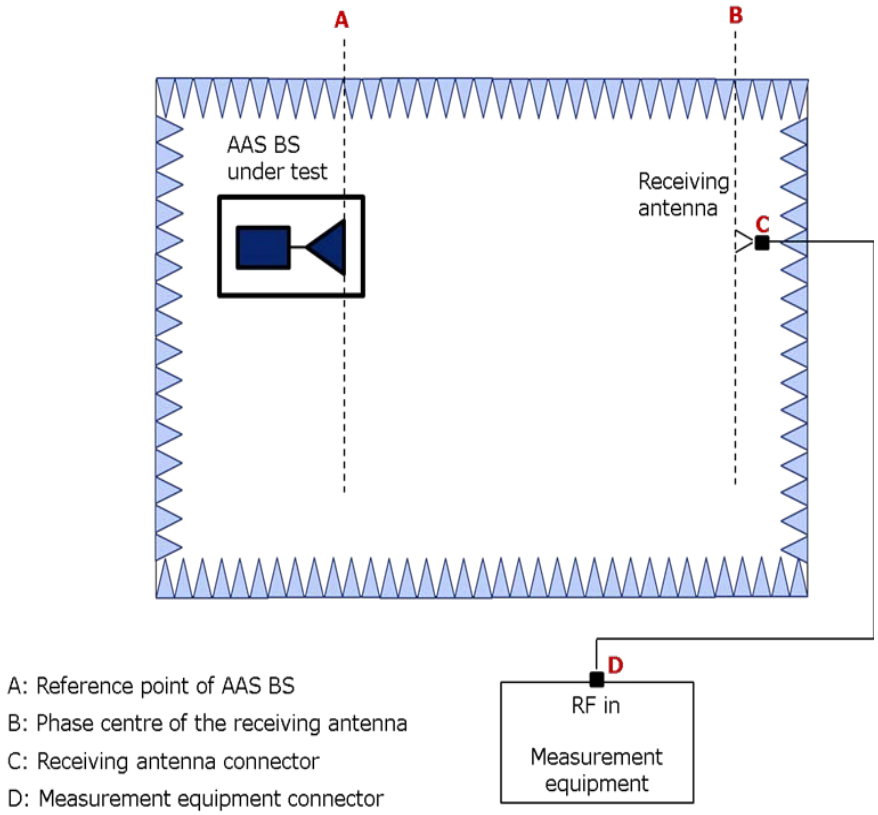

Figure 3.3. Indoor Anechoic Chamber Test Method: Measurement Set-up for Testing Over-the-Air Sensitivity Requirements.

In an anechoic chamber, OTA sensitivity (EIS) and EIRP are measured in the far field. This means the separation between the manufacturer declared coordinate system reference point of the AAS BS and the phase centre of the receiving antenna is no less than $2D^2/\lambda$, where D is the largest dimension of the antenna of AAS BS and λ is the wavelength.

In addition, AAS base station test configurations and specification of the conformance test requirements, both conducted and radiated, are developed in a separate technical specification.[85]

At the end of the AAS Study Item phase, a Work Item was initiated and finalized in October 2016. The objectives of the Work Item are to identify radiated RF requirements as well as the list of conducted RF requirements based on the identified representative deployment scenarios, and then, to develop the AAS base station specifications based on the RF requirements. A further Work Item (Release 14), with the aim to migrate the existing conducted requirements to over-the-air requirements was initiated and in progress as of October 2016.

[85] 3GPP TR 37.145-1 V1.0.0 (2016-09) *Active Antenna System (AAS) Base Station (BS) conformance testing; Part 1: conducted conformance testing* (Release 13); *Part 2: radiated conformance testing* (Release 13).

3.1.2 SELF-OPTIMIZING NETWORKS (SON) FOR ACTIVE ANTENNA SYSTEM (AAS) DEPLOYMENTS

Active Antenna Systems (AAS) allow the creation of multiple vertical and horizontal (or combination) beams to make the cell deployment dynamic. This enables dynamic cell splitting/merging to handle changing load conditions in the cell. For example, beams may be steered to distribute capacity precisely per actual traffic mix, traffic location and user demands. That makes active antennas particularly good for suburban and rural areas where fixed deployment of pico/small cells is expensive; however, the network may face congestion situations and user demand varies intermittently.

The realization of the AAS-based system is already possible even without any standardization support (based on the Operations, Administration and Maintenance (OAM) controlled reconfigurations). However, OAM-based reconfiguration limits the real benefits in the event that reconfiguration is required on a shorter time scale and in the case of inter-vendor deployments. Frequent AAS reconfigurations will result in dynamic deployment changes that require standardization support based on distributed eNB logic. Because of that, additional information is needed to be exchanged between eNBs. The operation period of the AAS has impact on the network stability. Short operation periods of cell splitting/merging are more challenging to fine tune the parameters, such as the mobility and RF parameters, among others.

The Rel-12 study of SON for AAS (completed in June 2014) was focused on evaluating whether a SON mechanism could be beneficial to optimize inter-operability in case of AAS operations. Also, as part of the study, impacts on the existing SON features due to dynamic changes from AAS activities have been performed. Three AAS techniques shown in Figure 3.2 have been considered during the study:

- **Beam forming:** Beam forming is the functionality that optimizes the shape of the antenna beam patterns to better cover the intended service area to improve the coverage and decrease the interference. In general, beam shaping does not increase the number of radio resources but changes the distribution. Focusing beams of certain areas optimizes radio propagation for that area(s) on the expense of the remaining part of the cell. The same Physical Cell ID (PCI) is used in all the cell coverage. These adjustments are on a fast time scale.
    - Problems related to existing SON features or enhancements needed: none (intra-cell activity)
- **Cell shaping:** The cell shaping solution introduces adaptive or reconfigurable antenna systems where the main coverage of each cell is maintained unchanged but the cell edge can be adapted to load demand. The trigger for the change may be OAM reconfiguration (e.g., based on collected Key Performance Indicators (KPIs)) or the control unit may be the base station (implementation based). These adjustments are considered to be on a medium time scale (every hour or more seldom). The same PCI is used in all the cell coverage.
    - Problems related to existing SON features or enhancements needed: depending on the scale of the change, MRO (Mobility Robustness Optimization) may be impacted
- **Cell splitting:** The solution adopts higher order sectorization (vertical, horizontal or a combination) to selected base stations by changing an antenna system to include more antenna beams, each covering a smaller area than before the change. However, the main coverage of the combined beams corresponds to the main cell coverage before the split. Cell splitting can be seen as a special case of beam shaping with creating new cells and thus nearly doubling radio resources.

Cell splitting results in a cell densification which is typically the network planning method for areas where high traffic density is expected. Each of the beams broadcasts different physical cell ID (PCIs).

The trigger for the change may be OAM reconfiguration (e.g., based on collected KPIs) or, if the cell coverage is not affected and the split is pre-planned, the control unit is the base station (implementation based). Cell splitting is typically performed to cope with the high traffic where the coverage of the involved cell may shrink while a new cell may be generated. When the traffic eased off, cell merging may be performed. Cell splitting/merging procedures are considered on a long-term time scale (hours to few times a day).

- Problems related to existing SON features or enhancements needed: MRO

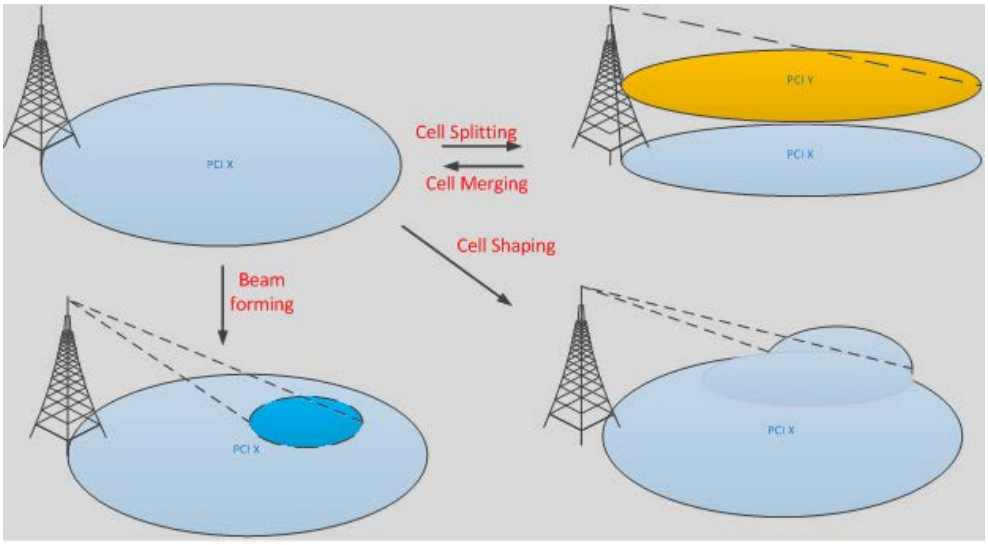

Figure 3.4. SON Mechanism for AAS.[86]

Impacts on Exiting SON Features

During the Rel-12 study, the impact and possible ways to limit the impact on existing SON functionalities in multi-vendor scenarios has been studied. For example, MRO is used to optimize mobility parameters. This optimization is normally assumed to be done for a static coverage scenario, or at least a scenario with infrequent changes to the coverage. An example is an AAS operation, where the coverage changes dynamically occur when cells split or merge, resulting in quick and frequent changes to the coverage of the cells. MRO could probably be given enough time adjust to the new coverage scenario, but in the meantime (while MRO is trying to find the optimal point), the mobility parameters will not be adjusted properly due to cell split/merge which may lead to increased mobility failures. Similarly, the Physical Cell ID (PCI) assignment may be complicated when using AAS to split cells since OAM needs to guarantee that the PCI used in the different configurations does not introduce a conflict in its neighborhood. Likewise, Automatic Neighbor Relation (ANR) is used to identify neighbor cells. In case AAS is used, additional inter-eNB signaling may be needed to inform about configuration change (merge/split).

[86] TR36.897: *Study on Elevation Beamforming/Full-Dimension (FD) MIMO for LTE*.

The Rel-13 work item focused on ensuring the connection continuity and adapting the existing SON/MRO principles during the dynamic deployment changes due to AAS-based deployments without impacting the Radio Resource Management (RRM) mechanism. This will be achieved by synchronous handling between OAM-based configuration and X2 signaling. OAM will semi-statically configure multiple coverage configuration (AAS configuration) for each cell served by an eNB that includes inactive (no coverage) mode as well. The eNB may dynamically select and switch to the most appropriate coverage configuration for its served cells using the Active Antenna system. The eNB triggering AAS (cell splitting/merging) informs its neighbor eNBs over the X2 interface before the planned coverage reconfiguration (cell splitting/merging) of its served cells is executed which would resolve the potential problems related to SON for AAS-based deployments. This also avoids the potential MRO conflicts, Radio Link Failure (RLF), handover failure and re-establishment failure since the neighbor eNBs are notified about the planned AAS deployment change (i.e., split/merge) in advance.

This Rel-13 RAN related Work Item has been completed in June 2015.

3.1.3 ELEVATION BEAMFORMING (EBF) AND FULL DIMENSION (FD) MULTI-INPUT MULTI-OUTPUT (MIMO)

After extensive study of Elevation Beamforming (EBF) - Full Dimension (FD) MIMO,[87] 3GPP has concluded and decided to support several enhancement techniques in Rel-13 including non-precoded Channel State Information Reference Signals (CSI-RS) transmission schemes, beamformed CSI-RS transmission schemes, Sounding Reference Signal (SRS) enhancement for Time Division Duplex (TDD), Demodulation Reference Signal (DMRS) enhancement for higher order multiuser transmission and CSI measurement restriction.

For non-precoded CSI-RS transmission schemes based on Class A CSI reporting, several new codebooks have been designed for 1D and 2D antenna arrays based on CSI measurement over non-precoded CSI-RS ports. In Rel-13, more CSI-RS ports, i.e., 12 and 16 CSI-RS ports, can be used to capture richer channel state information than previous LTE releases. More importantly several 2D CSI-RS port layouts can be supported and greatly improve the flexibility of MIMO deployment. For example, it is feasible from Rel-13 to consider more or less vertical antenna ports in 3D UMa and 3D UMi scenarios depending on UE traffic and UE distribution. Supported 1D and 2D CSI-RS port layout assuming cross-polarized antenna array can be found in Table 3.1 where N1 and O1 define the number of CSI-RS ports in the first spatial dimension (either veridical or horizontal) and corresponding codebook oversampling respectively. And N2 and O2 define the number of ports in the second spatial dimension and corresponding oversampling. The codebook design philosophy in Release 13 is in general similar with dual-stage codebooks adopt in previous releases. W1 can represent a long term and wideband channel component. Due to the introduction of 2D CSI-RS port layouts as shown in Table 3.1, W1 can be virtualized with a Kronecker-product of vertical and horizontal precoders associated with multiple 2D spatial beams. Codebook configuration representing specific spatial subsampling (or a beam pattern) can be selected by the eNB and configured by RRC signaling. Similar with previous releases, W2 can present a short term and wideband (or sub band) channel component with beam selection from W1 if applicable and beam co-phasing among beams.

[87] TR 36.897: *Study on Elevation Beamforming/Full-Dimension (FD) MIMO for LTE.*

Table 3.1. CSI-RS Port Layout.[88]

Number of CSI-RS antenna ports, *P*	(N_1, N_2)	(O_1, O_2)
8	(2,2)	(4,4), (8,8)
12	(2,3)	(8,4), (8,8)
	(3,2)	(8,4), (4,4)
16	(2,4)	(8,4), (8,8)
	(4,2)	(8,4), (4,4)
	(8,1)	(4,-), (8,-)

To support 12 and 16 CSI-RS ports, new CSI-RS resource with 12 and 16 ports per resources are supported by aggregating existing three 4-ports CSI-RS resources and two 8-ports CSI-RS resources respectively. Both CDM2 and CDM4 can be used for 12 and 16 CSI-RS ports. Introduction of CDM4 for CSI-RS ports in Rel-13 is to fully utilize BS transmission power due to the limitation of power boosting factor up to 6 dB.

Another category of CSI measurement and feedback supported in Rel-13 is based on beamformed CSI-RS transmission with Class B CSI reporting. In general, Class B CSI reporting can be categorized as techniques of CSI dimensionality reduction compared to Class A CSI reporting. The basic concept is to obtain a long-term propagation channel component by using channel reciprocity, or long term/periodicity channel feedback, or other implementations. Then the eNB may implicitly embed those long-term CSI components into CSI-RS ports with a UE-transparent way. For example, a 2D antenna array may apply specific vertical precoder to vertical TXRUs per column over CSI-RS ports. Therefore, the UE can measure horizontal channel component by using legacy codebooks since the eNB has known vertical channel component in prior at a certain confidence level. To improve CSI accuracy and implementation flexibility, Class B CSI reporting can use either K=1 or K>1 CSI-RS resources. If K=1, beamformed CSI-RS ports within single CSI-RS resource must follow specific beamforming relationship due to new Rel-13 codebooks designed for this use case (K=1). These codebooks, similar with W2 from dual-stage codebooks, have port selection/port co-phasing components. If K>1, the UE needs to feedback a CSI-RS resource indicator (CRI) which indicates a UE-preferred CSI-RS resource based on which the UE will measure and report Pre-coding Matrix Indicator/Rank Indicator/Channel Quality Indicator (PMI/RI/CQI) as legacy on top of Cross Rate Interference (CRI) reporting. This use case (K>1) is to support a mechanism of beam probing to mitigate the uncertainty of precoders used by the eNB for beamformed CSI-RS resources.

[88] TR 36.213: Table 7.2.4-9.

SRS transmission is further enhanced in Rel-13 because of the implementation of AAS and channel reciprocity-based MIMO operation. With more UEs supported by a large antenna array, the capacity of SRS transmission can be a bottleneck. Therefore, in Rel-13 the repetition factor (RPF) of Sounding Reference Signal (SRS) is increased from 2 to 4 and the maximal cyclic time shift per SRS Comb is also increased from 8 to 12. Such kinds of SRS capacity enhancement can be used for both TDD and FDD. Another TDD-specific way of increasing SRS capacity is to reconfigure some Guard Period (GP) symbols as Uplink Pilot Timeslot (UpPTS) symbols for SRS transmission. By configuring more UpPTS symbols (up to 6 symbols in total), there is more chance for SRS transmission.

From downlink perspective, Demodulation Reference Signal (DMRS) ports 7, 8 and 11 and 13 with Optical Communication Channel (OCC4) can be used for multiuse transmission because of increased likelihood of high order Multi-User (MU) pairing. Therefore, with the combination of four orthogonal DMRS ports using OCC and two non-orthogonal DMRS ports using scrambling identities, up to 8 multi-user layers can be supported from Rel-13. However, the number of SU transmission layers remains same as legacy releases, up to 8 layers. Both OCC2 between ports 7/8 and OCC4 between ports 7/8/11/13 are included in dynamic control signaling to cope with backward compatibility and UE mobility. Thus, one extra bit is added to dynamic control signaling in TM 9 and TM 10. RRC signaling is used to switch legacy and new DMRS tables by the eNB depending on MU implementation.

Finally, Rel-13 can support CSI measurement restriction, with either channel measurement restriction, or interference measurement restriction, or both. With channel measurement restriction, the mechanism of beam probing can be supported at the time domain UE transparently. With such a restriction, the eNB and the UE can build up a proper mutual understanding of channel measurement at specific time instance. So, the eNB may know the result of beam probing by sharing CSI-RS resources in TDM. On the other hand, with interference measurement restriction the UE is forced to measure one shot interference statistics so that the eNB can cope with interference fluctuation more responsively.

3.1.4 ENHANCED SIGNALING FOR INTER-ENB COORDINATED MULTI-POINT (CoMP)

The goal of this work item is to introduce a coordination mechanism to reduce interference between two eNBs. It is believed that Inter-eNB CoMP can provide better performance by improving the coverage of high data rates, cell-edge throughput and overall system throughput coordinated scheduling. A CoMP Study Item was initially introduced in 3GPP Rel-11 (TR.36.819) and its subsequent work item was completed in December 2012. In Rel-12 two options were considered. A centralized (master/slave) approach, where slave eNBs operating in a cluster provide coordination information to a Centralized Coordination Function (CCF), shown in Figure 3.5.

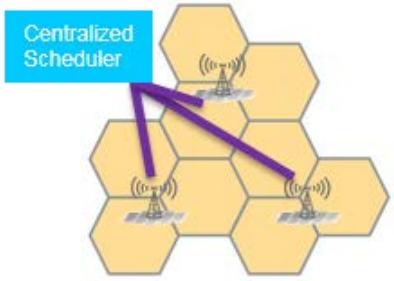

Figure 3.5. Centralized Approach.

One of the challenges with the centralized approach was the introduction of a new node and interface to be defined. However, the benefit of such a centralized approach does not justify a new node/interface. A second option was a distributed (peer to peer) approach, shown in Figure 3.6, where each eNB exchanges coordination information with its neighbor in a cluster over the existing X2 interface.

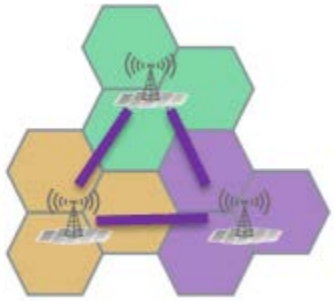

Figure 3.6. Decentralized Approach.

The fact that the distributed approach suggests utilizing existing messages (i.e., LOAD INFORMATION) over the X2 interface resulted in its adoption over the centralized approach. However, there was a common agreement among companies, that the standards shall not preclude centralized coordination as an implementation option since specific information exchanged is left to network implementation.

The load information is exchanged over X2 in a new CoMP Information Element (IE) in LOAD INFORMATION messages as shown in Table 3.2.

Table 3.2 Load Information Elements Exchange.

IE/Group Name	Presence	Range	IE type and reference	Semantics description
CoMP Information Item		*1.. 256*		
>CoMP Hypothesis Set	M		9.2.75	
>Benefit Metric	M		INTEGER (-101..100, …)	Value -100 indicates the maximum cost, and 100 indicates the maximum benefit. Value -101 indicates unknown benefit. Values from -100 to 100 should be calculated on a linear scale.

CoMP Information Start Time		*0..1*		
>Start SFN	M		INTEGER (0..1023, …)	SFN of the radio frame containing the first subframe when the *CoMP Information* IE is valid.
>Start Subframe Number	M		INTEGER (0..9, …)	Subframe number, within the radio frame indicated by the *Start SFN* IE, of the first subframe when the *CoMP Information* IE is valid.

In a possible implementation, an eNB1 sends an X2AP: LOAD INFORMATION message to its neighboring eNB2 including 'coordination information'; eNB2 makes its resource allocation decisions based on the information provided by its neighbor and responds back to eNB1 with resource allocation decisions. Any additional resource allocation decisions made by either eNB considers the information exchanged over X2 from their neighbors. The call flow in Figure 3.7 captures this scenario.

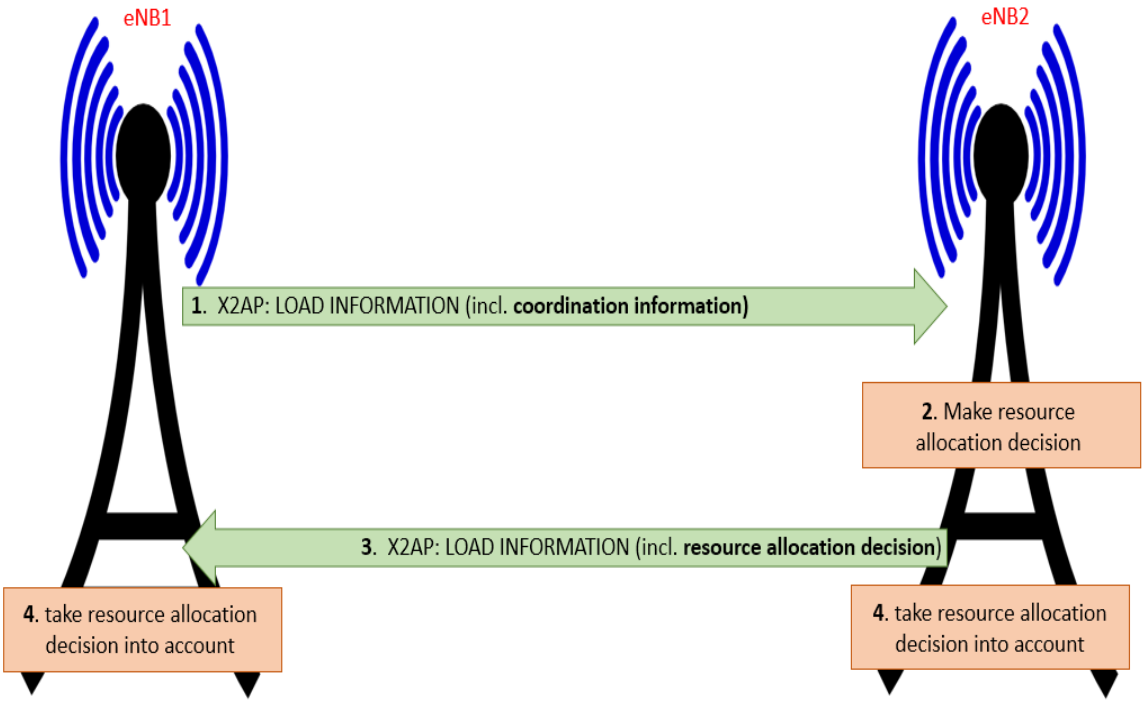

Figure 3.7 Example of Load IE Exchange over X2.[89]

[89] TR 36.423 – X2 Application Protocol.

Another change approved in LTE Rel-12 was the exchange of Reference Signal Received Power (RSRP) measurement reports of individual UEs over X2 interface in the X2AP: RESOURCE STATUS UPDATE message. The status update can be exchanged among eNBs over X2 with configurable reporting interval of 120ms, 240ms, 480ms or 640ms.

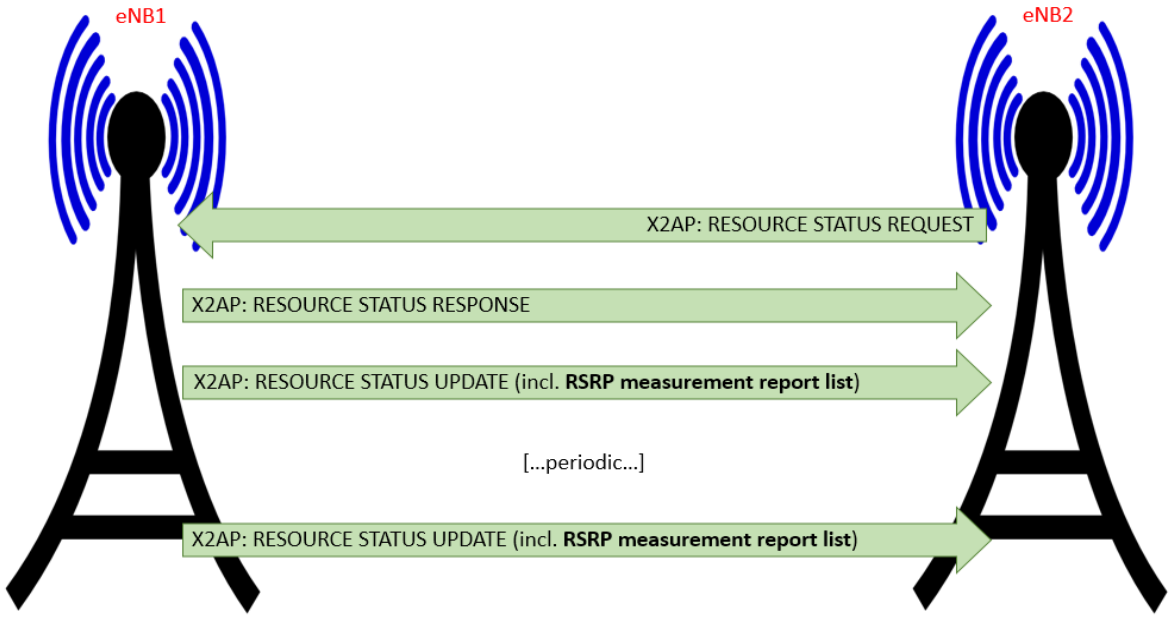

Figure 3.8 Example of Resource Status Update IE Exchange.[90]

The LTE Rel-13 work item "Enhanced Signaling for Inter-eNB CoMP" enhancements were completed as follows. The 'Relative Narrowband Tx Power (RNTP)' Information Element (IE) is exchanged among eNBs over X2 in X2AP: LOAD INFORMATION message. The purpose of this IE is to provide on a per PRB basis, whether the downlink transmission power is lower than the value indicated by the RNTP Threshold IE. The receiving eNB may take such information into account when setting its scheduling policy and will consider the received RNTP IE value valid until reception of a new LOAD INFORMATION message carrying an update. A possible enhancement of the Rel-13 work item is to extend RNTP signaling in the time domain. Other enhancements include UE CSI information (RI, CQI) in the X2-AP: RESOURCE STATUS UPDATE message. If the Reporting Periodicity of CSI Report IE is included in the RESOURCE STATUS REQUEST message, eNB2 shall use its value as the minimum time interval between two subsequent RESOURCE STATUS UPDATE messages that include the CSI Report IE.

Another change agreed in RAN3 for Rel-13 was the inclusion of UE ID in the RSRP Measurement Report List IE of X2-AP: RESOURCE STATUS UPDATE, the eNB1 may use the UE ID IE to link the associated RSRP measurement report with other measurement results (e.g., CSI reports, RSRP measurement reports) of the same UE.

Figure 3.9 summarizes the enhancements to inter-eNB CoMP as part of Rel-13.

[90] *Ibid.*

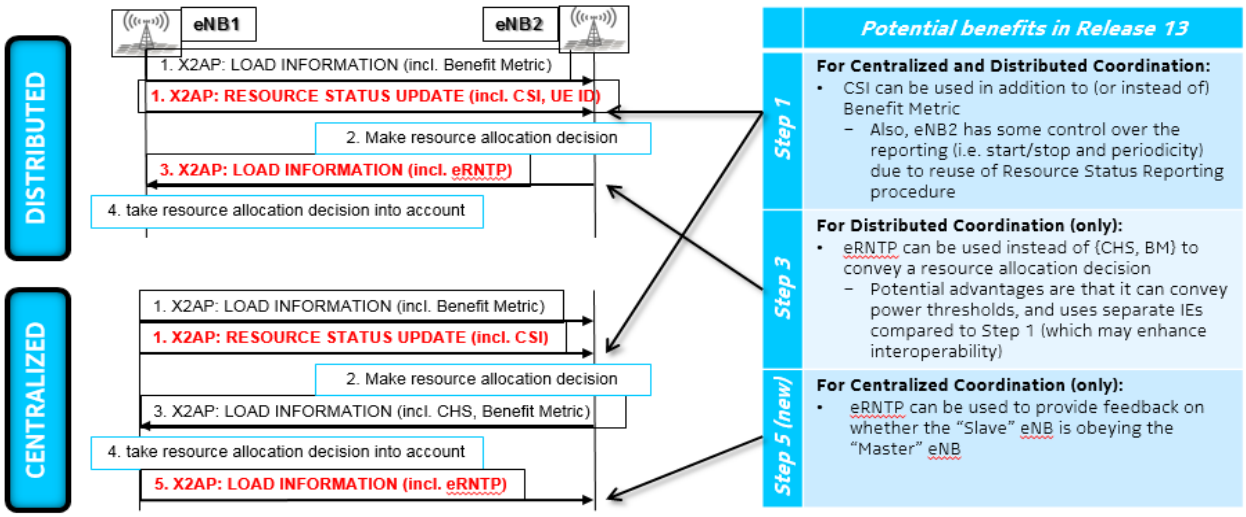

Figure 3.9 Enhancements to inter-eNB CoMP as part of Rel-13.

A new Study Item (SI) "Study on SON for eCoMP for LTE" was approved in RAN#72. The new SI only impacts RAN WG3. In the new SI, it mentions that all previous work on this topic was focused on operability of CoMP itself based on the assumption that the CoMP cooperation sets (CoMP sets) are determined and established as such.

Therefore, the operators will be faced with the problem to define the optimal CoMP sets, i.e., to identify those CoMP transmission points that bring benefits when cooperating. The regular hexagon cell layout, where the generation of CoMP sets follows a clear pattern, does not exist in real network deployments. In contrast, the cells look rather irregular and deformed due to deployment and propagation irregularities. Therefore, the impact of the cell edge problem resulting from inter-cell interference that is to be tackled by CoMP looks very different for each cell border.

The SI also claims that the traffic irregularities play an important role in terms of seeing gains from CoMP, i.e., only if users are staying at the cell edge, do CoMP gains do become visible. The efficiency of CoMP depends heavily on the traffic load situation as well as on the spatial user distribution, i.e., an unpopulated cell edge does not need to be within a CoMP set. Another important criterion for building an optimal CoMP set could be the X2 transmission capability (e.g., latency) needed for the information exchange. Also, if deployment is changing dynamical during operation, either by means of energy savings (ES) or by means of AAS-enabled dynamic deployment changes, the CoMP sets need to be updated accordingly.

Considering these aspects, it becomes obvious that a fixed set of pre-planned cooperation areas would be in most cases far from optimal CoMP operation. A SON mechanism is very helpful to automatically generate an optimal default pattern of CoMP sets for the network area in question which could be based on stationary constraints resulting from propagation and inter-node connectivity capability. Also, a continuous updating of the setting, depending on the dynamics happening in the network like changing spatiotemporal traffic distribution, requires these automatisms.

The objective of the SI is to identify scenarios and requirements for a dynamic and automated SON-based CoMP area generation and to study candidate solutions. Thus, the following objectives should be part of this study item:

- Identify scenarios and implementation requirements on network side needed for autonomous SON-based CoMP coordination sets generation and update
- Identify information and centralized / distributed procedures that may need to be exchanged on X2 to facilitate creation and update of optimal CoMP coordination sets maximizing the average and cell edge User Packet Throughput gain

The output of this SI should be aligned with the existing specifications of other SI/WIs.

This is on-going study item and at a later time the decision will be made whether to create an official Work Item (WI) and for which Release.

3.1.5 FURTHER LTE PHYSICAL LAYER ENHANCEMENTS FOR MACHINE TYPE COMMUNICATION (MTC)

Rel-13 has introduced some physical layer related enhancements for LTE MTC operation (enhanced MTC, also called eMTC), on top of Rel-12 Category-0 (Cat-0) features, e.g.:

- **Cost/complexity reduction:**
  - Narrowband operation: 1.08 MHz
  - New power class: 20 dBm max power
  - Early indication of device capability during access procedure
  - Simpler device capability: reduced control and data channel functionalities

- **Coverage enhancements:**
  - Mode A: no or small repetition, full mobility support (~0-5 dB coverage extension)
  - Mode B: large repetition, limited/no mobility support (~10-15 dB coverage extension)
  - Extended TTI bundling in downlink and uplink

As per design targets, Rel-13 eMTC can be deployed in any LTE spectrum, and coexist with other LTE services within the same bandwidth. Furthermore, FDD, TDD and half duplex (HD) modes are supported. A summary of few key Rel-13 eMTC physical layer characteristics, and comparison with Rel-12, is shown in the following table. A new physical device category is defined for Rel-13 eMTC, called “M1”.

Table 3.3. Rel-13 MTC Physical Layer Characteristics.

	Rel-12 Cat-0	Rel-13 Cat-M1
Deployment	In-band LTE	In-band LTE
Coverage	140.7 dB	155.7 dB
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 64 QAM, 1 Rx	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx
Uplink	SC-FDMA, 15 KHz tone spacing, Turbo code, 16 QAM	SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM
Bandwidth	Same as LTE	1.08 MHz
Peak rate (DL/UL)	1 Mbps DL and UL	For FD: 1 Mbps DL and UL For HD: 300 kbps for DL, 375 kbps for UL
Duplexing	FD, HD (type B), FDD & TDD	FD, HD (type B), FDD & TDD
Power class	23 dBm	23 dBm, 20 dBm

For Narrowband Operation, the main physical layer principles are:

- Reuse legacy channels: Primary Synchronization Signal (PSS) / Secondary Synchronization Signal (SSS)/ Primary Broadcast Channel (PBCH)/ PRACH
- No support of PDCCH, PCFICH, PHICH
- New channels: M-PDCCH
- Retuning for frequency hopping: Allowed retuning time is 2 symbol

For coverage enhancements, the following physical layer principles apply:

- PSS/SSS: no change
    - Rely on UE processing: increased acquisition time for deep coverage

    - Store previous cell information for subsequent wake up for mode B

- PBCH repetition for FTL
    - Same PBCH mapping to allow frequency tracking loop without PBCH decode
    - Repeated in two subframes in 10 ms radio frame (optional)
- MTC_SIB repetition and extended update rate to allow combining
    - System Information Block (SIB) configuration by MIB, no control channel for SIB
- PRACH/ Physical Downlink Shared Channel (PDSCH) / Physical Uplink Shared Channel (PUSCH)/ MPDCCH/PUCCH all support repetition/bundling
    - Repeated RV/scrambling sequence for PDSCH/PUSCH/MPDCCH to allow data channel combining
- Bundled RBG and fixed precoding in time to allow receiver channel estimation averaging

From an upper-layers (L2/L3) point of view, two classes of eMTC UEs can be identified: Bandwidth reduced low complexity (BL) UE and Enhanced coverage (EC) UE. The main properties of a bandwidth reduced low complexity (BL) UE are:

- Can operate in any LTE system bandwidth but with limited bandwidth of 6PRBs in DL and UL
- May access a cell only if the MIB indicates that SIB1-BR is present
- Receives a separate occurrence of SI messages from legacy UEs
- May acquire SI messages by combining across multiple SI windows
- Is not required to detect SIB change in RRC_CONNECTED
- Is paged based on paging occasions in time domain and paging narrow-bands in frequency domain
- Obtains a set of PRACH resources (time/frequency/preamble) in SIB, including number of PRACH repetitions and number of maximum preamble transmissions
- May require measurement gap for intra-frequency measurements
- UL HARQ operation is asynchronous
- A new DRX timer is used to control how long the UE stays awake waiting for a retransmission

The following applies to an enhanced coverage (EC) UE:

- Requires EC functionality to access the cell as defined in cell selection/re-selection procedures
- May access the cell using EC only if the MIB indicates that SIB1-BR is present

- When operating in EC, it also follows BL procedures
- System information procedures are identical to BL UEs
- If needed, acquires and uses legacy SIBs when in normal coverage (if it is not a BL UE)
- When in IDLE mode, it does not inform the network of a change in EC level
- Camps on a suitable cell where S criterion for UEs in enhanced coverage is fulfilled.
- It shall re-select to inter-frequency cells in which its able to operate in normal coverage over cells in which it must be in EC
- Supports connected mode mobility procedures (measurement reporting, handover)

3.1.6 INDOOR POSITIONING ENHANCEMENTS

The Indoor Positioning Study Item was initiated in September of 2014 with the goal of analyzing potential enhancements that would improve positioning both indoors and in other challenging environments. The motivation for the study is driven by the observation that mobile devices are used increasingly indoors. In the U.S., the Federal Communications Commission (FCC) has recognized this and in January of 2015 issued the Fourth Report and Order on Wireless E911 Location Accuracy Requirements.[91] In short, this order requires that wireless providers provide either a dispatchable location or an x/y location within 50 meters for 80 percent of all wireless 911 calls within six years. In addition, within eight years, wireless providers must deploy dispatchable location or z-axis technology that meets yet undetermined z-axis accuracy metric. Further, there are several interim benchmarks that must be met before the final six and eight year requirements. It should be noted that the current Study focuses on methods that provide x/y/z-axis and not dispatchable location.

After the indoor positioning study item was completed [TR 37.857], 3GPP went ahead with a Rel-13 indoor positioning work item (approved in Sep 2015 in RAN#69 with the latest WID in RP-152251). The Rel-13 indoor positioning work item, which completed in December 2015, resulted in the introduction of the following new positioning methods targeted to address the indoor positioning needs [TS 36.305 v13.0.0]:

- Barometric sensor method
- WLAN method
- Bluetooth method
- Terrestrial Beacon System method

The barometric pressure method makes use of barometric sensors for identifying height information and to determine the vertical component of the position of the UE. This method should be combined with other positioning methods to determine the 3D position of the UE [TS 36.305].

The WLAN positioning method makes use of the WLAN measurements (AP identifiers and optionally other measurements) and databases to determine the location of the UE. The UE measures received signals

[91] FCC Fourth Report and Order In the Matter of Wireless E911 Location Accuracy Requirements, PS Docket No. 07-114.

from WLAN access points. Using the measurement results and a references database, the location of the UE is calculated [TS 36.305].

The Bluetooth positioning method makes use of Bluetooth measurements (beacon identifiers and optionally other measurements) to determine the location of the user equipment (UE). The UE measures received signals from Bluetooth beacons. Using the measurement results and a references database, the location of the UE is calculated. The Bluetooth methods may be combined with other positioning methods (e.g., WLAN) to improve positioning accuracy of the UE [TS 36.305].

A Terrestrial Beacon System (TBS) consists of a network of ground-based transmitters, broadcasting signals only for positioning purposes. The current type of TBS positioning signals are the MBS (Metropolitan Beacon System) signals [TS 36.305].

In Rel-13, only the standalone mode and UE-assisted mode (without network assistance) are supported for the above positioning methods. Also, in Rel-13, only the Metropolitan Beacon System (MBS) TBS method is supported. MBS receiver uses global navigation satellite system (GNSS) signal or GNSS like signal transmitted from ground based beacons for positioning measurements.

3.1.7 LICENSED ASSISTED ACCESS (LAA) USING LTE

Wireless broadband data has shown dramatic increase in demand around the world and LTE is the proven platform that is set to meet this demand. Existing and new licensed spectrum remain fundamental for providing seamless wide-area coverage, yet to meet the ever-increasing data traffic demand (e.g., video streaming) from users and in concentrated high traffic buildings or hot spots, more mobile broadband bandwidth is needed. Given the large amount of spectrum available in the unlicensed bands around the globe, unlicensed spectrum is being increasingly considered by cellular operators as a complementary tool to augment their service offering. Coordinated transmission across licensed and unlicensed spectrum is perceived to be a key feature of upcoming fifth generation (5G) radio access networks.

Licensed-assisted access (LAA) is a 3GPP enhancement of Long-Term Evolution (LTE) in the unlicensed spectrum, which has been standardized in LTE Release 13. Under LAA, licensed carriers are aggregated with unlicensed carriers to opportunistically enhance downlink user throughput while still offering seamless mobility support. Early attempts at LTE use of unlicensed spectrum were not standardized and included the use of new algorithms and methods that did not consider regional regulatory restrictions for each given country. One such pre-standards solution is LTE-U which received limited acceptance. Rel-13 LAA specification means to produce a single global solution framework for licensed-assisted access to unlicensed spectrum (5 GHz). Such a solution considers regional regulatory power limits, while enabling LTE to use low power secondary cells in the unlicensed spectrum using carrier aggregation.

In order to coexist with Wi-Fi in the unlicensed spectrum, enhancements include a mechanism for channel sensing based on listen-before-talk (LBT), discontinuous transmission on a carrier with limited maximum transmission duration, dynamic frequency selection (DFS) for radar avoidance in certain bands, and multicarrier transmission across multiple unlicensed channels. The DTX and LBT functionalities will have a major impact on various aspects of LTE ranging from downlink physical channel design, channel state information (CSI) estimation and reporting, hybrid ARQ (HARQ) operation, to radio resource management (RRM) as shown in Figure 3.10.

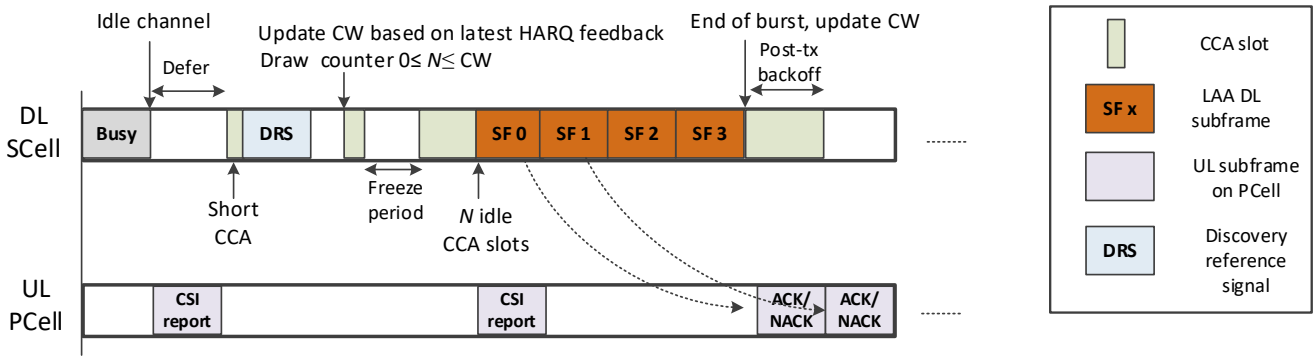

Figure: 3.10. LAA DL Transmissions with LBT CW Updates Based on HARQ ACK/NACK Feedback.[92]

3.1.7.1 CARRIER SELECTION AND DFS

Carrier Selection: Within the 5 GHz band, between 455 MHz to 555 MHz of unlicensed spectrum is currently available for LAA use. This unlicensed band can be divided into multiple carriers of 20 MHz bandwidth each. The careful selection of an LAA carrier(s) with low ambient interference is the first step for an LAA node to co-exist with other technologies (i.e., Wi-Fi) in the unlicensed spectrum. However, when a large number of nodes are present, interference avoidance cannot be guaranteed through channel selection and the sharing of carriers between different technologies will be required. This step of carrier selection can be further performed periodically adding or removing unlicensed carriers as required. These carriers are then configured and activated as Secondary Cells (SCells) for use with LAA user equipment (UE).

Release 13 introduced UE RSSI measurements with configurable measurement granularity and time instances of the reports which can be used for the assessment of hidden nodes by the eNB near specific UEs. For example, if UE measurement shows a high RSSI when the serving cell is inactive due to LBT, this can imply the presence of hidden nodes, and can be considered for channel (re)selection.

Dynamic frequency selection: DFS is a regulatory requirement for certain frequency bands in various regions, e.g., to detect interference from radar systems and to avoid co-channel operation with these systems by selecting a different carrier on a relatively slow time scale. The corresponding time scales for DFS are in the order of seconds and can therefore be at an even slower time scale than carrier selection. It has been agreed in 3GPP that this functionality is an implementation issue and will not have an impact on the LTE specifications.

3.1.7.2 BASELINE LBT FRAMEWORK FOR A SINGLE CARRIER

Listen Before Talk (LBT) procedure is defined as an algorithm by which a UE performs one or more clear channel assessments (CCA) prior to transmitting on the channel. It is the LAA equivalent of the distributed coordination function (DCF) and enhanced distributed channel access (EDCA) MAC protocols in Wi-Fi. Since Japanese and European regulations specified the usage of LBT in the 5 GHz unlicensed bands, and limited the maximum channel occupancy time for a particular transmission, LBT is a required functionality

[92] A post-transmission backoff is applied between DL bursts to prevent monopolizing the unlicensed channel. The UE provides HARQ ACK/NACK feedback and CSI reports on the licensed carrier.

for fair and friendly operation (especially with Wi-Fi) in the unlicensed spectrum under a single global framework.

A straightforward approach to fair coexistence that should facilitate global acceptance is to make the LAA LBT procedure for both data and discovery reference signals (DRS) as similar as possible to the Distributed Coordination Function (DCF)/ Enhanced Multimedia Distributed Control Access (EDCA) protocols of Wi-Fi. This is the guiding principle behind Rel-13 LAA LBT mechanism for detecting the presence of Wi-Fi which can be summarized as follows:

- Before data transmission, an LAA node must sense the carrier to be idle for a random number of 9 µs CCA back off slots
- If the energy in a CCA slot is sensed to be above the Energy Detection (ED) threshold, then the process is suspended and the counter is frozen. The back-off process is resumed and the counter is decremented once the carrier has been idle for the duration of the deferred period
- If the most recent DL transmission burst showed 80 percent or more decoding errors as reported in HARQ feedback (NACKs) from UEs, then the CW is doubled for the next LBT
- Once DL transmission is complete, a new random back-off is drawn and used with the next transmission
- A single, short CCA period of 25 µs can be used to transmit control information without accompanying data, such as DRS. This is well-aligned with the CCA duration used for Wi-Fi beacon frames
- Rel-13 defined an LAA equivalent to the four Wi-Fi priority classes in the form of four sets of minimum and maximum CW sizes, maximum channel occupancy times (MCOT), and deferred period CCA slots

3.1.7.3 MULTICARRIER LBT

LAA Operation on multiple unlicensed carriers is a key requirement for maximizing throughput. The Institute of Electrical and Electronics Engineers (IEEE) 802.11ac supports transmission bandwidths of up to 160 MHz, which would span eight contiguous 20 MHz unlicensed channels in the 5 GHz band. LAA multi-carrier transmission on multiple unlicensed SCells adheres to the principle of fair share with Wi-Fi, while identifying improved transmission opportunities across available spectrum.

Rel-13 LAA supports two options for identifying and utilizing secondary channels in tight alignment with the methods used for Wi-Fi.[93]

Alt. 1: Similar to Wi-Fi, before transmission starts, a single random back-off is completed on any carrier along with quick CCA checks on the other channels

[93] *Licensed-Assisted Access LTE: Coexistence with IEEE 802.11 and the Evolution Towards 5G*, Ericsson White Paper.

Alt. 2: As an extension to the Wi-Fi requirements, parallel random back-off channels: Multiple SCells need to each have individually completed full-fledged random back-offs before transmitting simultaneously

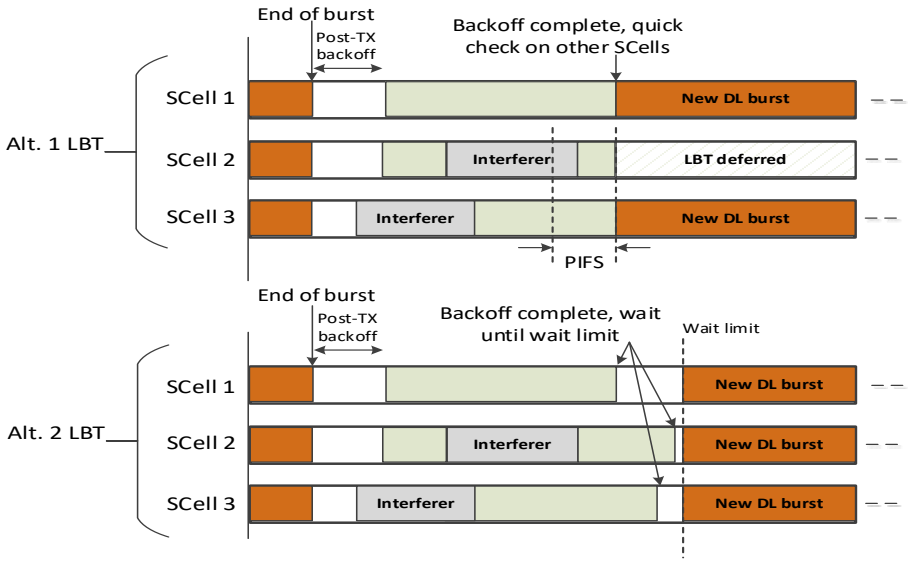

Figure 3.11. Comparison of LAA multicarrier LBT access schemes: Alt.1 with a single random backoff channel, and Alt. 2 with multiple random backoff channels. In the Alt. 2 example, a static, pre-specified wait limit is defined; SCells that have completed backoff before the wait limit defer transmission accordingly.

Both Alt. 1 and Alt. 2 are supported in Release 13 LAA. Representative examples of these multicarrier LBT alternatives are compared in Fig. 3.11, for a scenario with three LAA SCells that are assigned a common random backoff counter. In the case of Alt.1, SCell 1 finishes counting down first and is designated as the channel with the full-fledged random backoff procedure. To determine whether any other channels are eligible for transmission, the most recent slots of the random backoff procedure corresponding to these channels are examined and the channels which are found to have been idle for the duration of a PIFS are also used for transmission, which is SCell 3 in Fig. 3.11. In the case of Alt. 2, all SCells that finish their countdown before a pre-defined wait limit (defined in terms of CCA slots) transmit simultaneously.

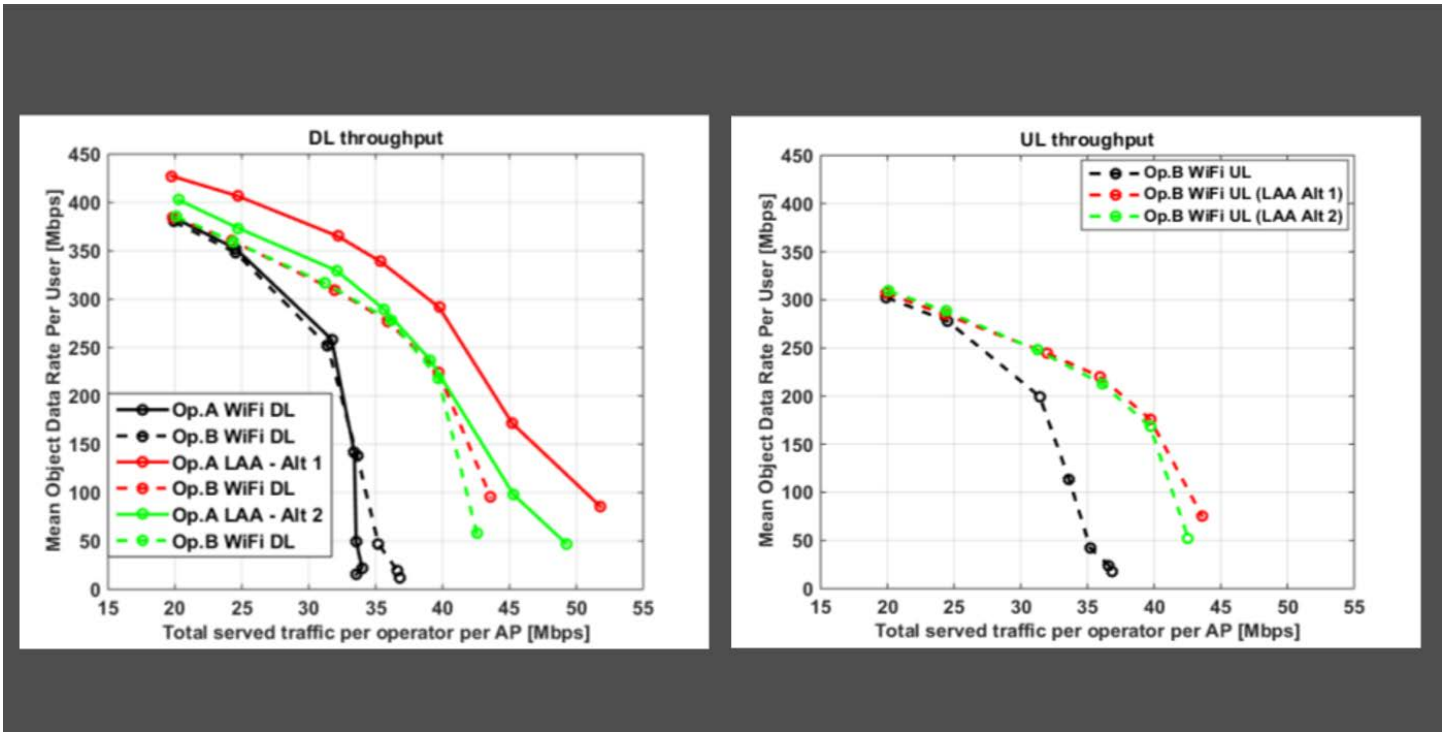

Fig. 3.12. Mean User Throughput vs. Served Traffic per AP per Operator for the Indoor Multi-Carrier Deployment Scenario.[94]

A performance evaluation[95] for multi-carrier LBT over 80 MHz is shown in Figure 3.12. The overall system performance results clearly show that from the coexistence point of view and the impact on the non-replaced Wi-Fi network, both classes of multi-channel LAA LBT schemes are viable and can increase the performance of a multi-carrier Wi-Fi network compared to when it is coexisting with another Wi-Fi network. Also, Alt. 1 with a single random back-off channel offers better coexistence due to the more agile random back-off channel selection and better alignment with the Wi-Fi procedure.

3.1.8 CARRIER AGGREGATION (CA) ENHANCEMENTS

Carrier aggregation was first introduced in Rel-10, allowing operators to use their spectrum assets more efficiently, to boost user throughputs, and increase capacity. Through Rel-12, aggregation of up to five carriers and bandwidths up to 100MHz are supported.

In Rel-13, the carrier aggregation framework was extended to support up to 32 carriers, targeting carriers in unlicensed spectrum to be used in conjunction with LAA.

As with previous 3GPP releases, Rel-13 continued to add a step-by-step introduction of new CA combinations. This includes both contiguous and non-contiguous carriers, inter and Intra band options for both FDD and TDD as driven by various service providers and network vendors. Over 150 new CA combinations have been completed in Rel-13. Standardization efforts have also started for 5 DL CA combinations with 4 new combinations completed in Rel-13. Standardization for 32 CA combinations have

[94]With FTP traffic using up to 80 MHz transmission bandwidth. The non-replaced Wi-Fi network is operator B. Left and right plots correspond to DL and UL per-user throughput results, respectively.
[95] *Licensed-Assisted Access LTE: Coexistence with IEEE 802.11 and the Evolution Towards 5G*, Ericsson White Paper.

not started yet. Finally, enhancements to CA operations in conjunction with several pre-existing and new features have been added, such as, 64 QAM with Carrier Aggregation.

With Rel-13 CA enhancements, in principle, LTE terminals will be able to handle bandwidths up to 640 MHz, most of which will be located in unlicensed spectrum, hence allowing UEs to achieve tremendous data rates.

3.1.9 DOWNLINK MULTI-USER SUPERPOSITION TRANSMISSION (MUST)

MUST is a multiuser joint optimization operation both at the transmitter and the receiver to enhance system capacity in a simultaneous transmission of a large number of non-orthogonal beams and layers where multiple users can share the same resource elements without spatial separation. In MUST, a spatial layer may consist of multiple superposed data layers using the same spatial precoding vector or same diversity transmission scheme for co-scheduled users.

In 3GPP Release 13, TSG RAN#67, a study was conducted [96] to evaluate the system performance of LTE enabling downlink multiuser superposition transmissions. The following are the main objectives of the study item:

1. Identify and study possible enhancements of downlink multiuser transmission schemes for the superposition of PDSCH over PDSCH within one cell. Investigate the potential gain of schemes enabling the simultaneous transmission of more than one layer of data for more than one UE without time, frequency and spatial layer separation over the existing Rel-12 techniques

2. Identify required standard changes needed to assist UE intra-cell interference cancellation or suppression for the objectives listed previously in the first objective

3. As a third priority, investigate the potential gain of the identified transmission schemes in the first objective for the superposition of PMCH over PMCH within an MBSFN area (not necessarily within one cell)

3.1.9.1 OVERVIEW OF MUST CONCEPT

The MUST concept essentially consists of simultaneous signal transmissions for two UEs that are multiplexed in the power domain by using the same precoding but different power allocations. As depicted in Figure 3.13, the far UE is allocated more power to minimize the cell-edge performance loss whereas the near UE is allocated less power due to small propagation loss and the receivers are designed to extract the intended signal at each UE.

[96] 3GPP TR 36.859 V13.0.0 (2015-12), *Study on Downlink Multiuser Superposition Transmission for LTE (Release 13*).

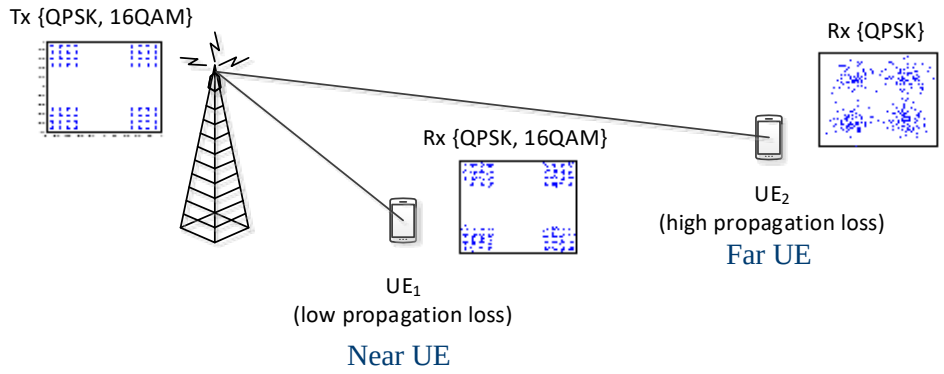

Figure 3.13. Implementation of MUST Scheme with Simultaneous Transmissions for Near-UEs and Far-UEs.

MUST schemes are classified into 3 categories depending on whether Gray coding is maintained after superposition and on the flexibility of power assignment for the superimposed signals.

Category 1: Consists of superposition transmissions with adaptive power ratio on component constellations with a non-Gray-mapped composite constellation

Category 2: Consists of superposition transmissions with adaptive power ratio on component constellations with a Gray-mapped composite constellation

Category 3: Consists of superposition transmissions with label-bit assignment on composite constellation and a Gray-mapped composite constellation. It is essentially category 2 but with additional power constraints.

For the study, several different candidate receiver schemes are considered for near UEs and far UEs. The candidate receivers for the far UEs include the following:

1. Linear Minimum Mean Square Error with Interference Rejection Combining (LMMSE-IRC) receiver
2. Maximum Likelihood (ML) receiver
3. Reduced complexity Maximum Likelihood (R-ML) receiver
4. Symbol Level Interference Cancellation (SLIC) receiver

The candidate receiver schemes for MUST-near UEs include the following:

1. Maximum Likelihood (ML) receiver
2. Reduced complexity maximum likelihood (R-ML) receiver
3. Symbol Level Interference Cancellation (SLIC) receiver
4. Linear Code Word level successive Interference Cancellation (L-CWIC) receiver

Essentially, three network deployment scenarios are considered for evaluation which are described as follows:

1. Scenario 1: A homogeneous network considered using only Macro cells with a ISD
2. Scenario 2: A heterogeneous network with non-co-channel deployment using Macro cells with a ISD of 500m, small cells uniformly distributed within the geographical area of a macro cell
3. Scenario 3: A heterogeneous network with co-channel deployment using Macro cells with a ISD of 500m, small cells uniformly distributed within the geographical area of a macro cell

3.1.9.2 SIGNALING ASSISTANCE

To cancel the inter-superposition-layer interference, signaling assistance information is required for the UE receivers. The type of assistance basically depends on the different MUST categories and receiver types employed. Typically, the methodology that is used for obtaining assistance information are: a) blind detection, b) higher layer or dynamic signaling tied to the UE's scheduling information, or c) procedures tied to specific UE assumptions (e.g., UE assumptions on aligned resource allocation).

3.1.9.3 PERFORMANCE EVALUATION

The study concluded that for multiuser superposition of PDSCH and PDSCH, MUST potentially increases system capacity as well as improves user experience in certain scenarios. The other conclusions drawn from the study is the MUST is generally more beneficial in the following cases:

- When network experiences higher traffic load
- User perceived throughput for wideband scheduling case compared to sub-band scheduling case
- User perceived throughput for cell-edge UEs compared to other UEs

Also, another outcome of the study is that far UEs can be legacy UEs when QPSK is applied or the most two significant bits in the modulation symbol are assigned to far UEs.

3.1.9.4 PERFORMANCE EVALUATION

In summary, it was determined that potential changes to RAN1 specification to enable downlink multiuser superposition transmission for PDSCH are as follows:

1. MUST transmission scheme requires superposed transmission of PDSCH
2. Downlink signaling needs to provide necessary assistance information to MUST-near UE to facilitate interference cancellation, and
3. Potential CSI feedback enhancements are required to assist eNB to perform scheduling

3.1.10 RADIO ACCESS NETWORK (RAN) ASPECTS OF RAN SHARING ENHANCEMENTS

RAN Sharing allows multiple participating operators to share the resources of a single RAN per agreed allocation schemes. The Shared RAN is provided by a Hosting RAN Operator (a provider of a Hosting RAN) which can be one of the participating operators (operator that uses allocated shared RAN resources provided by a Hosting RAN Provider under agreement). With the growing deployment of the shared

network, operators anticipate the scenarios where CN and/or RAN overload can result in a situation where an overloaded PLMN's users can starve another Public Land Mobile Network's (PLMN) users, thus leading to unfairness.

Current mechanisms of EUTRAN sharing do not allow a hosting provider to calculate and enforce policing of DL and UL data volumes used by a participating operator (per PLMN). Hence, new functions need to be introduced to enable aggregated DL and UL data volume collection per PLMN and per QoS profile parameters. Depending on Sharing Operators agreement, a QoS profile may be limited to a subset of standard parameters (e.g., QCI).

Sharing is normally based on agreed quota or share ratio. However, the current Mobility Load Balancing (MLB) mechanism does not take such quota into consideration and may lead to a problem. Therefore, enhancements are required for the current MLB mechanism as well.

SA1 specified following requirements for the RAN sharing enhancements:

- The management and allocation of resources of signaling traffic over the Shared E-UTRAN shall be independent from the management and allocation of resources of the user traffic over the Shared E-UTRAN
- A Shared E-UTRAN shall be capable of differentiating traffic associated with individual Participating Operators
- A Shared E-UTRAN shall be able to conduct admission control based on the allocated E-UTRAN resources for each Participating Operator
- A Hosting E-UTRAN Operator shall be able to control resource usage considering the allocated E-UTRAN resources for each Participating Operator. A means of monitoring the usage of resources shall be provided
- All shared E-UTRAN capabilities offered by the Hosting E-UTRAN Operator shall be individually available for use by each Participating Operator where this is possible

To fulfill the above requirements, RAN3 standardized the solution that allows configuration of the eNB by the OAM-based provisioning for collection of data volume counters on per PLMN ID, per UL/DL traffic direction and per QoS profile criteria that may be used for inter-operator accounting and policing.

The QoS profile criteria may include one or more of the following criteria: one QCI indicator, one GBR Indicator, one ARP Indicator, where:

- a QCI Indicator identifies one specific QCI value. QCI values range from 1 to 256. If the indicator is not set, then all QCI values should be taken into account

- a GBR Indicator identifies one GBR range value defined by OAM. If the indicator is not set then all GBR ranges should be taken into account

- an ARP Indicator identifies one ARP priority value. ARP values range from 1 to 15. If the indicator is not set, then all ARP priority values should be taken into account

The QoS profile criteria are satisfied when all the configured indicators are matched. It is possible that none of the QoS parameters are configured in which case the measurement is collected per configured PLMN ID.

Data volume reports for the DL (or UL) direction of a GBR bearer are collected within a given GBR Range if the E-RAB guaranteed bit rate is within a configured range delimited by a minimum and maximum value.

The GBR Ranges shall be five in number for DL and five in number for UL. GBR Ranges shall be non-overlapping and configurable. The configured set of GBR bands applies to the whole RAN and to all PLMN IDs in the RAN. During a granularity period (as defined in TS32.401), a maximum of 200 counter types and an overall maximum value of 200 counter instances can be recorded.

RAN3 didn't agree on any specific standards-based solution for MLB and left this on the implementation for the time being. RAN3 noted to continue this discussion outside the scope of this work item.

Additionally, RAN3 didn't agree on signaling enhancements for S1AP Overload procedure to address CN overload issue in the case of GWCN. However, RAN3 agreed to capture a configuration/ implementation based solution its Technical Report to address the Overload that mentions that in case of GateWay Core Network (GWCN), CN overload can result in a situation where an overloaded PLMN starves another PLMN, thus leading to unfairness.

The specific solution mentions that in order to reject the UE as a consequence of an Overload Start message, the eNB can make use of the S-TMSI signaled in the RRC Connection Request message. Such S-TMSI contains the MMEC of the last registered MME.

If MMECs are configured in a way that each of them points uniquely at a PLMN ID, the eNB would be able to determine whether the UE is connecting to the same PLMN ID reported in the GUMMEI(s) at Overload Start. The eNB would therefore be able to reject the UE if the MMEC in the S-TMSI is mapped to the same PLMN ID included in one or more GUMMEIs in the Overload Start message. Rejecting UEs has the advantage of avoiding that new RRC Connection Requests are attempted by the UE.

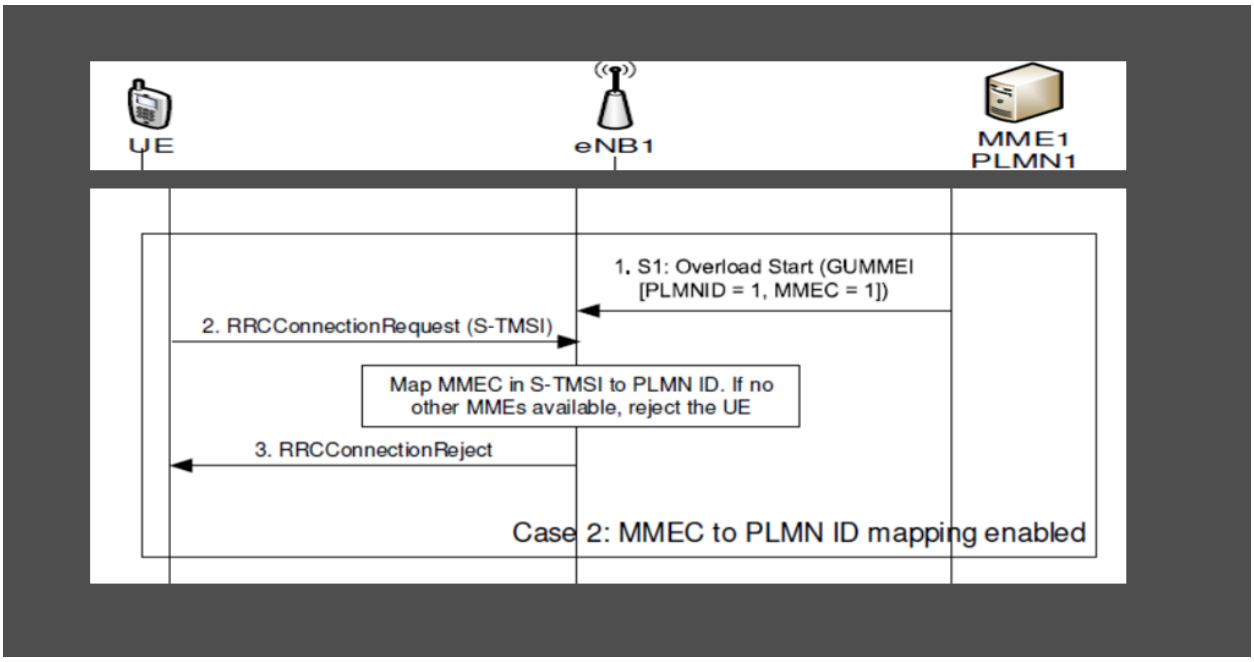

Figure 3.14. Configuration Based Solution for CN Overloading on GWCN Deployments.

This work item was finished in December 2015.

3.1.11 ENHANCED LTE DEVICE-TO-DEVICE (D2D) PROXIMITY SERVICES (PROSE)

During Release 13, 3GPP continued to build on LTE D2D Proximity Services standardized during Release 12.

For D2D discovery several enhancements were standardized. The notion of sidelink gaps was introduced. During a sidelink gap configured by the network the UE was allowed to prioritize sidelink over WAN operations. This allowed without dedicated rx-tx chains for sidelink to participate in discovery during RRC_CONNECTED state.

Another enhancement was the support for inter-frequency D2D discovery, i.e., allowing a UE to transmit and receive D2D discovery on carriers other than uplink. The enhancement was applicable to both intra-PLMN and inter-PLMN cases. In other words, a UE could participate in D2D discovery on a carrier that is different PLMN from its PLMN. Network support to enable such inter-frequency discovery in an efficient manner was also standardized. eNodeB can broadcast information on D2D discovery resources on other carriers (which can belong to other PLMN) making inter-frequency discovery power efficient.

One final enhancement to D2D discovery was support for out of coverage D2D discovery. The target for this use case for this was public safety.

For D2D communication, the main enhancement was support for relaying using D2D. This allowed public safety (PS) UEs that are out of coverage (or have weak coverage) to communicate with network via UEs that are in-coverage. A L3 relay was defined. Procedure and algorithms were defined for discovery and selection of relays. Procedures were also defined for when a UE should start/stop relaying its data. Procedures were also defined for when a UE should start/stop acting as a relay. D2D communication was enhanced to allow for a UE to act as a relay for multiple out of coverage UEs in an efficient manner.

Another additional enhancement was support for priority for D2D communication. The notion of per packet priority was introduced. Mechanisms were introduced to allow for higher priority traffic to be treated with higher priority and potentially pre-empt lower priority traffic.

3.1.12 DUAL CONNECTIVITY ENHANCEMENTS

Higher layer considerations, as part of small cell enhancements, focuses on mobility robustness, reduction in unwanted signaling towards core network and improvement in per-user throughput and system capacity.

Dual Connectivity (DC) introduced in Rel-12 aimed at addressing some of the challenges previously mentioned. In DC, the radio protocol architecture that a particular bearer uses depends on how the bearer is setup. Three bearer types exist: MCG bearer, SCG bearer and split bearer as shown in Figure 3.15. RRC is located in MeNB and SRBs are always configured as MCG bearer type and therefore only use the radio resources of the MeNB.

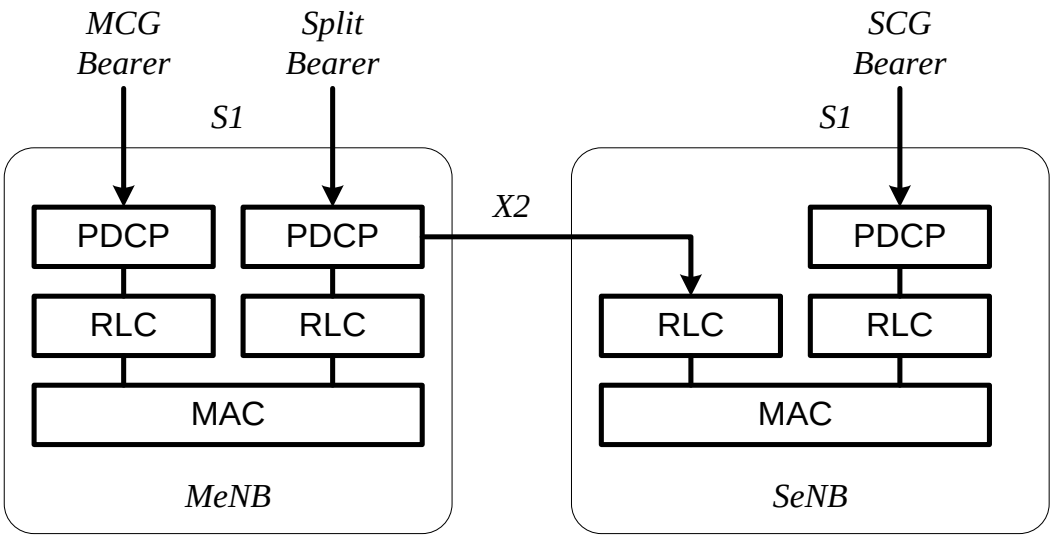

Figure 3.15. Radio Protocol Architecture for Dual Connectivity.

The focus for DC in Rel-12 was mostly on the downlink throughput enhancements. Due to limited time allocated in 3GPP working groups for the development of Rel-12, some aspects of DC were not discussed. For Rel-13[97], new Work Items were proposed to continue with the further development of DC features.

Uplink bearer split was left out from Rel-12 due to time considerations and was therefore addressed in the Rel-13 WI. The uplink split of a bearer is governed by two parameters: a primary link and a threshold value. When the UE buffer is below the threshold for a split bearer, the UE only sends data towards the primary link, i.e., the UE does not use uplink bearer split. But when the amount of data buffered exceeds the threshold for the same split bearer, (which means that the single uplink starts to become a bottleneck for uplink throughput), the UE can send data to both MeNB and SeNB (i.e., UE starts to use the uplink bearer split).

Due to DC particularity that MCG and SCG are in different eNBs, new maximum uplink transmission time difference requirements for dual connectivity are introduced in Release 13. RAN4 defined the maximum uplink transmission timing difference between Primary Cell (PCell) and Primary SCell (PSCell) for synchronous DC scenario as 35.21 μs, while for asynchronous DC, UE shall can handle a maximum uplink transmission timing difference of at least 500 μs, provided the UE indicates that it is capable of asynchronous dual connectivity.[98]

In Rel-12, DC assumes network based determination of System Frame Number (SFN) and sub-frame offset between MeNB and SeNB via OAM in the unsynchronized networks. These methods work well for the case of DC in intra vendor deployments with common OAM but is an issue with inter vendor deployment. In Rel-13 a UE reporting method to determine the time difference between PCell and PSCell has been added. The UE uses the SFN and Sub-Frame number of both the PCell and PSCell to calculate the timing difference between MeNBs and SeNBs which is deemed important for multi-vendor deployments.

The requirements related to intra-frequency, inter-frequency and inter-RAT measurement with DRX remains unchanged in Rel-13 per 3GPP TS 36.133. i.e.:

[97] RP-150490: *Dual Connectivity enhancements for LTE, RP-151798: Extension of Dual Connectivity in E-UTRAN.*
[98] 3GPP TS 36.133, EUTRA: *Requirements for support of radio resource management*, Rel-14.

- Intra-frequency: For MCG, the requirements depend on the MCG DRX, while for SCG, the requirements depend on the SCG DRX

- Inter-frequency: The requirements depend on the MCG DRX (if in use)

Traffic steering during DC operation is also supported in Rel-13. It is believed that the increase in demand for higher data requiring more small cells deployed for coverage could increase the traffic load at the core network significantly. DC can benefit from offloading certain services to minimize core network congestion and hence more flexible traffic steering techniques are necessary for DC. To offload operator network in DC scenario, local breakout is important as it provides the operator with the means for efficient backhaul usage and reduces the load on the core network. Two existing mechanisms for traffic redirection are Local IP Access (LIPA) and Selective IP Traffic Offload (SIPTO) already defined in 3GPP. LIPA is used for HeNB only, whereas SIPTO is used for both HeNB as well as Macro eNBs.

The following data offloading scenarios for DC involving HeNBs are supported as listed in Table 3.4. Membership Verification for the hybrid access HeNB is performed between the MeNB and the MME and is based on membership status information reported by the UE and the Closed Subscriber Group (CSG) ID.

Table 3.4. Support of HeNBs for Dual Connectivity.

MeNB	SeNB
eNB	open access HeNB
eNB	hybrid access HeNB

In Rel-13, the support for SIPTO@LocalNetwork (SIPTO@LN) and LIPA for Dual Connectivity is per the following logical architecture.

- The support for SIPTO@LN with co-located L-GW in the MeNB with the following change:

    - For SCG bearer option, the MeNB sets GTP Tunneling End Identify (TEID) and Transport Layer Address in S1 UL GTP Tunnel Endpoint IE in the SENB ADDITION REQUEST message and SENB MODIFICATION REQUEST messages as the correlation ID received from the MME and the IP address of the collocated L-GW respectively

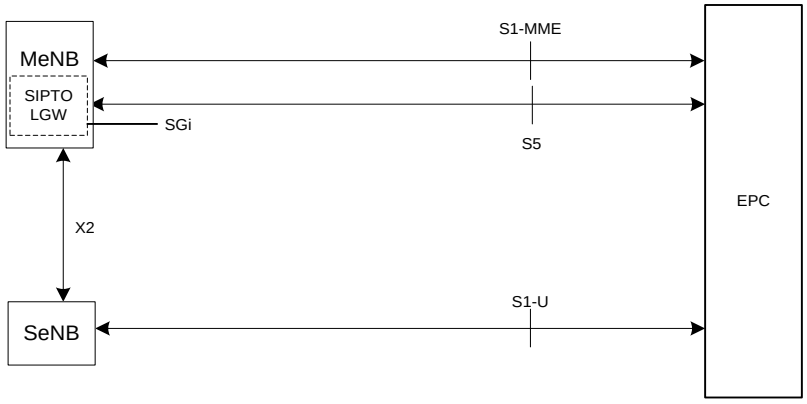

Figure 3.16. SIPTO@LN with Co-Located L-GW in MeNB – Split and SCG Bearer Options.

- For this scenario, only the SCG bearer option is supported for the SIPTO bearer. The SeNB signals its L-GW IP address using the SeNB Addition Preparation procedure, or the MeNB obtains such address via OAM. The MeNB signals the "SIPTO correlation id" to the SeNB using the SeNB Addition Preparation and SeNB Modification Preparation procedures

- SIPTO@LN in SeNB is also supported using a stand-alone gateway (with co-located S-GW and L-GW) deployed in the local network

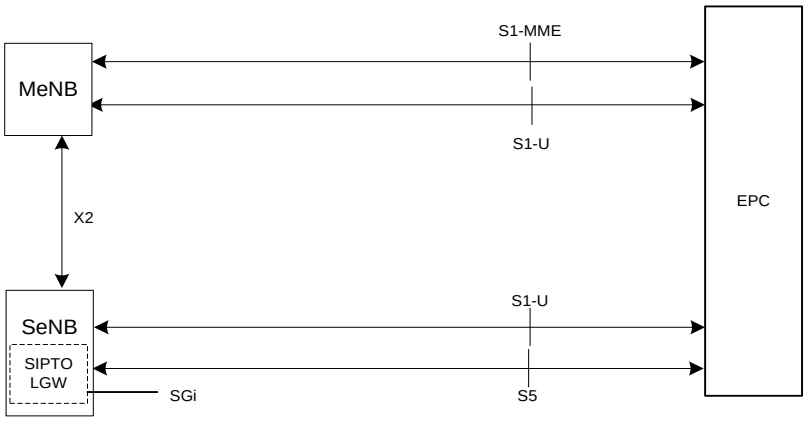

Figure 3.17. SIPTO@LN with Co-Located L-GW in SeNB.

- The MeNB and the SeNB belong to the same LHN (i.e., they have the same LHN ID). The MeNB and the SeNB exchange their LHN ID using the X2 Setup procedure or via OAM. The MeNB initiates the SeNB Modification Preparation procedure to support the MME-triggered S-GW relocation without UE mobility

In Rel-12, during inter-MeNB handover, the bearers in SeNB are switched back to MeNB, followed by the handover of MeNB and later the SeNB is added again as needed. In other words, in the Rel-12 implementation, there was no solution to keep SeNB unchanged even if the SeNB cell signal quality was good enough. In Rel-13, the support to keep SeNB bearer contents during handovers was added, provided the involved cells have good signal quality. By doing so, it will fully utilize the benefit of DC, to keep a constant user throughput and avoid deletion/addition of the SeNB bearer during handovers which could lead to larger data gaps resulting in a bad end user experience.

3.1.13 LTE-WIRELESS LOCAL AREA NETWORK (WLAN) RADIO LEVEL INTEGRATION AND INTERWORKING ENHANCEMENTS

The Rel-13 standard work on LTE-WLAN Radio Level Integration and Interworking Enhancements includes several main components/features:

- LTE-WLAN Aggregation (LWA), which builds upon 3GPP Release 12 Dual Connectivity split-bearer architecture with aggregation of data links at PDCP layer, and allows utilization of radio resources on both LTE and WLAN simultaneously for a data bearer
- LTE-WLAN Radio Level Integration with IPsec Tunnel (LWIP) integrates 3GPP RAN with WLAN network above the PDCP layer using IPsec tunnelling without requiring any modifications to the WLAN network, and allows use of WLAN radio resources for LTE traffic in both uplink and downlink
- RAN Controlled LTE WLAN Interworking (RCLWI), which builds upon 3GPP Release 12 RAN Assisted WLAN Interworking by allowing eNB sending a steering command to the UE for WLAN offload, in part based on UE measurements for WLAN

The main goal of LWA is to allow offloading data from cellular to WLAN more efficiently than earlier solutions for WLAN deployments either by a mobile network operator and/or its partners. In all previous WLAN solutions developed by 3GPP, the anchor point for the traffic was Core Network and S-GW and the decision to offload is done by the UE (with some assistance information in Release 12 solution). LWA uses eNB as the anchor point and decision making node, which allows more dynamic and granular offloading decisions. However, efficient LWA operation also requires feedback from the WLAN nodes, which may require modifications to the existing WLAN deployments (e.g., software updates).

In contrast, LWIP was introduced in Release-13 to address the operator needs to leverage the capacity available from the large incumbent WLAN network base where modifications to WLAN, as required by LWA would not be feasible because of hardware, architectural or operational constraints. The use of WLAN resources in downlink and uplink is controlled by the eNB, and bypasses the LTE user plane protocol stack. LWIP allows use of combined LTE and WLAN capacity for a user by allowing either inter-bearer distribution or intra-bearer per IP flow distribution across the LTE and WLAN radio links.

RCLWI still uses CN based offloading but the eNB can make the decision to steer traffic between LTE and WLAN which can provide better performance compared to previous CN based solutions. The control point is at eNB, allowing better control over individual UEs.

3GPP WLAN offloading solutions always allow the user preferences to have higher priority over standardized mechanisms offered by the network. The same principle also applies to LWA, LWIP and RCLWI.

3.1.13.1 LTE-WLAN AGGREGATION (LWA)

Both collocated eNB and WLAN (e.g., integrated small cell) and non-collocated deployments were considered. In the latter case, a standardized interface, called Xw, between eNB and WLAN was developed to exchange control and data traffic as shown in Figure 3.18. The termination point of Xw at WLAN is a logical node, called WT (WLAN Termination), and it can be implemented at an Access Point, Access Controller, or another physical entity. A crucial benefit of LWA is that it does not require any new CN nodes, interfaces, and signaling. In Figure 3.18, the connection of WLAN to the CN via ePDG or TGAW shows that

the same WLAN network can be used to provide CN based offloading solutions (e.g., S2a, S2b or Non-Seamless WLAN Offload (NSWO)).

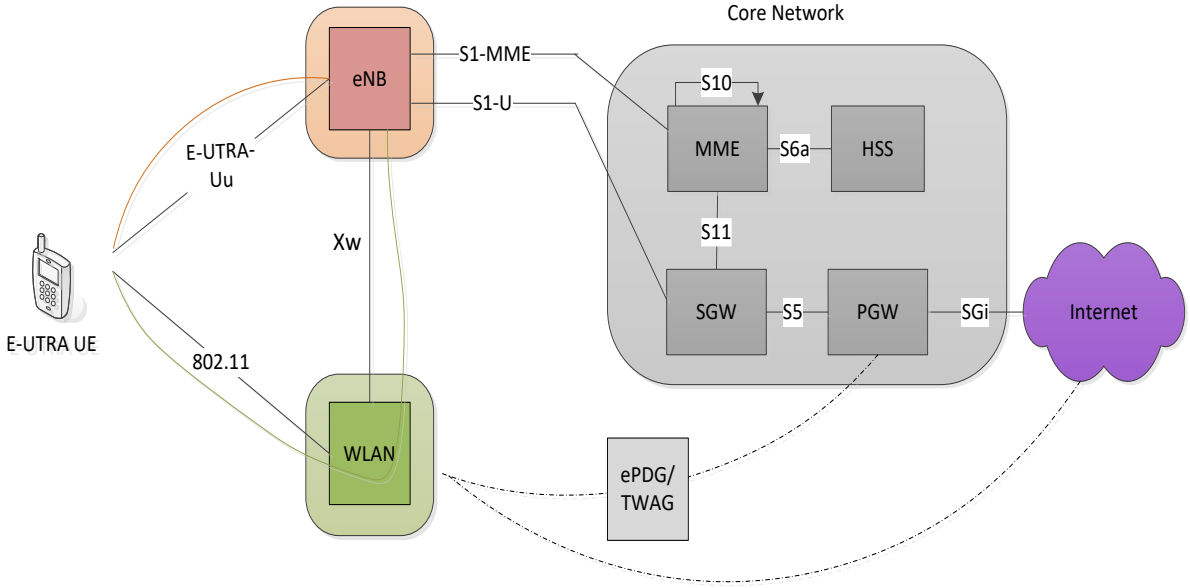

Figure 3.18. Network Architecture for LTE/WLAN Aggregation.

3.1.13.1.1. LWA USER PLANE

The user plane for LWA is similar to the DC split-bearer as shown in Figure 3.19. However, there are several differences from DC:

- The control plane for LWA is only at the eNB and not shared with WLAN unlike SeNB also being involved in RRC in DC
- Since RLC is not supported at WLAN, PDCP Packet Data Units (PDUs) are delivered by WLAN MAC to PDCP directly
- An adaptation layer to deliver PDCP PDUs over WLAN was introduced (as discussed in following)

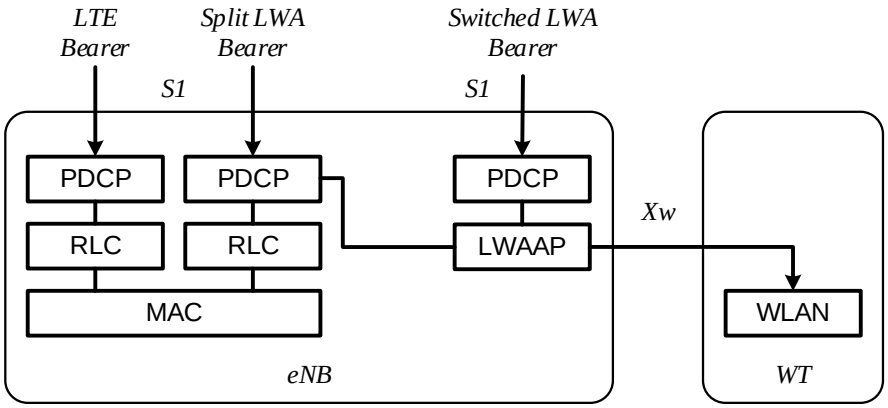

Figure 3.19. LWA Radio Protocol Architecture for the Non-Collocated Scenario.

The data plane aggregation for LTE and WLAN is the Packet Data Convergence Protocol (PDCP) layer located at the eNB and UE while S1-U is terminated at the eNB. On the downlink, the eNB scheduler decides to send a PDCP Packet Data Unit (PDU) on either LTE or WLAN. In Release-13, the uplink is always transmitted over LTE; however, in Release-14, uplink aggregation is being specified as part of the eLWA WI using similar principles as was done for LTE dual connectivity in Release-13.

For LWA, PDCP PDU transmission on the LTE link is same as non-LWA traffic. Only RLC AM can be configured for an LWA bearer, similar to the DC split-bearer. On the WLAN side, the PDCP PDU is encapsulated in a WiFi MAC packet at the WLAN side. At the receiver, the WLAN Station (STA) forwards the received WiFi packet payload to the UE PDCP layer. A new EtherType (0x9E65) is used for LWA traffic transmitted on WLAN, which helps the receiver to differentiate LWA from other WiFi traffic.

Multiple bearers per UE can be supported for LWA. For differentiation of the logical channel, a PDCP PDU transmitted over WLAN belongs to, a new LWA Adaptation Protocol (LWAAP) that was designed. This entity inserts the DRB (Data Radio Bearer) ID to a PDCP PDU before transmitting over WiFi and the same entity at the receiver removes the header before forwarding to the correct PDCP entity.

Since PDCP PDUs can be transmitted on both LTE and WiFi, they may arrive at different times at the receiver and thus a reordering mechanism is needed to deliver the PDCP SDUs to the upper layers in order. This same mechanism adopted for the DC split-bearer in Release-12 is also used for LWA. This is only needed for downlink in Release-13 as uplink is sent only over LTE.

When eNB and WLAN are not collocated, the PDCP PDU is forwarded between the eNB and WT over the so-called Xw-U interface (where U stands for User plane).

Flow control mechanisms from eNB to WT are also implemented to minimize buffer underflow and overflow at WLAN side to improve the performance. The UE can also be configured by the eNB to send PDCP status report or LWA PDCP status report, for example, when feedback from WLAN Termination (WT) is not available. These reports provide the receiver status of PDUs receive on LTE and WLAN and can also help eNB scheduling decisions.

3.1.13.1.2 LWA CONTROL PLANE

The main functionality of the control plane for LWA is the selection of WLAN to configure or de-configure aggregation for data bearers. The eNB also communicates with WT for the addition, removal and change

of the WT. Since the eNB is the anchor point for both the user and control plane, aggregation is only feasible when the UE is in LTE coverage and in RRC connected state.

The main steps for LWA configuration are: 1) determining UE and Network capability for LWA; 2) selection of WLAN AP for aggregation, and; 3) configuration of aggregation for specific data bearers. These steps can be repeated as needed due to UE mobility and/or changing radio and load conditions.

In the first step, the UE signals its capability for LWA which also includes the supported WLAN bands and WLAN MAC address.

The second step is WLAN selection to determine a suitable AP which supports aggregation and the radio and channel conditions. In current WLAN implementations, finding WLAN networks (scanning and association) are done by the STA. For LWA, the eNB signals the identifiers for APs the UE should find report.

The WLAN mobility for LWA allows UE-based mobility within a so-called uses a “WLAN mobility set” which is a group of APs identified via WLAN identifiers (BSSID/HESSID/SSIDs). The eNB signals to the UE the WLAN mobility set in which the UE is allowed to move between APs without informing the eNB. All the APs within the mobility set are controlled by the same WT and a UE is connected to at most one mobility set at a time.

For APs outside the mobility set or for APs within different WTs, the decision to change AP is made by the eNB based on WLAN measurements. These measurements are configured via a measurement object using WLAN identifiers (Basic Service Set IDentification (BSSID), Homogeneous Extended Service Set IDentification (HESSID) and Service Set Identification (SSID)), WLAN channel number and WLAN band. WLAN measurement reporting is triggered using RSSI. WLAN measurement report may contain RSSI, channel utilization, station count, admission capacity, backhaul rate and WLAN identifier. The eNB configures the WLAN RSSI thresholds for the measurement events which trigger the reporting. These reports can be used for LWA activation, inter WLAN mobility set mobility, and LWA deactivation; the corresponding measurement events are called W1 (WLAN becomes better than a threshold), W2 (All mobility set WLANs become worse than threshold1 and some WLAN outside becomes better than a threshold2), and W3 (All mobility set WLANs become worse than threshold1) respectively.

LWA also relies on WLAN Connection Status Reporting procedure which provides feedback to the eNB related to the WLAN status and operation. The reporting is used to inform the eNB about WLAN connection failure and WLAN connection success.

When a UE configured with at least one LWA bearer becomes unable to establish or continue LWA operation, the UE sends WLAN Connection Status report message to indicate "WLAN connection failure" to the eNB. The criteria to determine WLAN connection failure is left to UE implementation. WLAN connection failure does not trigger RRC connection re-establishment and there is no impact to LTE part of the LWA split bearer.

When a UE configured with at least one LWA bearer successfully connects to an AP, the UE sends the WLAN Connection Status report message to indicate “WLAN connection success”, if configured by the eNB to report this. The UE is not required to send success message if it successfully re-associates to another AP within the WLAN mobility set.

3.1.13.1.3 ENB-WLAN INTERFACE (XW)

In the non-collocated LWA scenario, the eNB is connected to one or more WTs via an Xw interface. In the collocated LWA scenario, the interface between LTE and WLAN is up to implementation. For LWA, the only required interfaces to the Core Network are S1-U and S1-MME which are terminated at the eNB. No Core Network interface is required for the WLAN.

Xw control plane interface (Xw-C) supports the signaling protocol referred to as Xw-AP (Xw Application Protocol). The main functions of Xw-AP protocol are transfer of WLAN metrics (e.g., BSS load) from WT to eNB, establishment, Modification and Release of a UE context at the WT, control of user plane tunnels between eNB and WT for a specific UE for LWA bearers. In addition, general management, setup, and error functions, similar to X2, are supported.

Xw user plane interface (Xw-U) supports the transport protocol of PDCP PDUs from eNB to WT. Similar to X2-U, this is done using General Packet Radio Service Tunneling Protocol (GTP) tunneling over UDP/IP where the data for each bearer is exchanged in a different GTP tunnel.

Xw-U also supports flow control mechanisms where WT reports the available buffer size and the status of transmissions (e.g., highest SN of the transmitted PDUs) to the eNB.

3.1.13.2 LTE-WLAN RADIO LEVEL INTEGRATION WITH IPSEC TUNNEL (LWIP)

LWIP integrates LTE and WLAN links at the eNB, allowing opportunistic use of WLAN resources for LTE bearers under the control of eNB. The security of the bearer plane packets over the WLAN is ensured via the IPsec tunnel setup between UE and an LWIP security gateway (SeGW), transparent to the WLAN network. The control plane for configuring the IPsec tunnel is carried over the LTE link. The solution therefore requires zero touch on the WLAN network elements and addresses the need for integrating LTE with unmodified, particularly incumbent, WLAN deployments. LWIP SeGW is a logical function defined to terminate the IPsec tunnel with the UE for securing access to eNB from the WLAN network. The interface between eNB and LWIP SeGW is left unspecified in Release-13 but is expected to be standardized in Release-14.

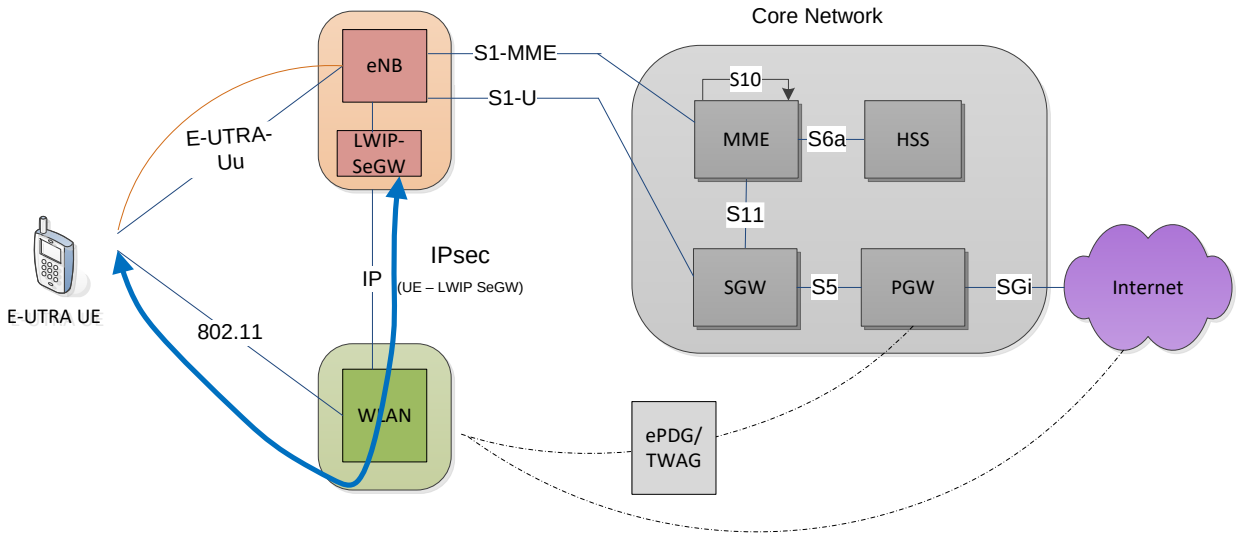

Figure 3.20. Network Architecture for LWIP Integrating LTE with Unmodified WLAN.

3.1.13.2.1 LWIP PROTOCOL ARCHITECTURE

The LWIP protocol architecture is illustrated in Figure 3.21.

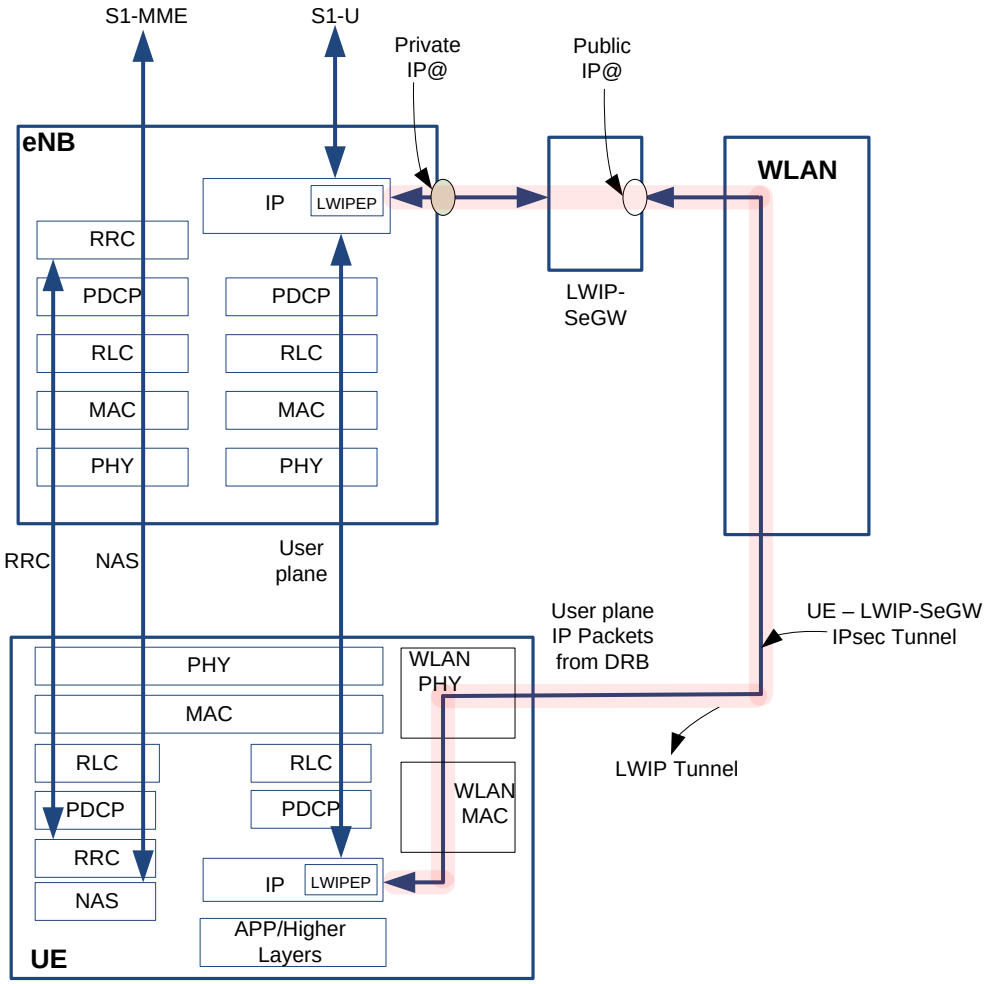

Figure 3.21. Protocol Stack Architecture for LWIP [3GPP TS 36.300].

The control signaling for LWIP is carried over the LTE Signaling Radio Bearer (SRB). The security of user plane packets via the WLAN is ensured via IPsec tunnelling. Once a bearer is configured, i.e., LTE DRB is established, the bearer to be configured to use the WLAN path. When a bearer is configured to use the WLAN path, the LTE DRB is maintained. eNB controls the distribution of PDCP SDUs (IP packets) via the LTE or the WLAN paths. eNB also controls the use of WLAN path for the uplink bearer packets at the UE. For mapping the Uplink LTE bearer packets to the appropriate S1-U tunnel towards the LTE core, the associated DRB identity is needed. An encapsulation protocol, LWIP Encapsulation Protocol (LWIPEP), is defined for the UE to insert the DRB information when uplink bearer packets are sent over the WLAN path.

3.1.13.2.2 LWIP USER PLANE

In LWIP mode of operation the user plane data can be carried via LTE, over the existing LTE user plane (DRB) or via the WLAN path over the LWIP tunnel. The protocol architecture for the LWIP tunnel is depicted in the Figure 3.22.

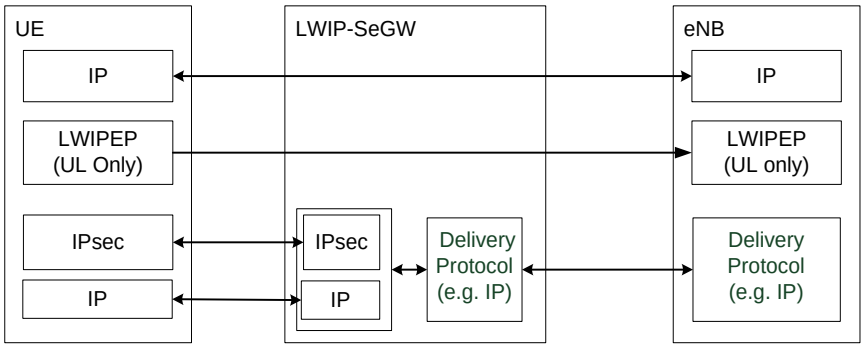

Figure 3.22. Protocol Stack User Plane via WLAN (LWIP Tunnel) for LWIP [3GPP TS 36.300].

The LWIP tunnel represents the user plane path between the UE and eNB. It consists of the IPsec tunnel between the UE and LWIP SeGW and the link between LWIP SeGW and eNB. For the user plane data sent in the uplink over WLAN, from UE to eNB, an encapsulation protocol (LWIPEP) is defined for conveying the DRB identity associated with the user plane packets for use by the eNB for mapping to appropriate S1-U tunnel.

When a bearer is configured to use the LWIP tunnel in the downlink, eNB controls the distribution of the bearer plane above the PDCP layer, i.e., PDCP SDUs j(IP packets), either over the LTE user plane or the WLAN path. The combined LTE and WLAN capacity can be leveraged for the UE by distribution on a per-bearer basis (say, Best Effort bearer on WLAN and VoLTE bearer on LTE) or intra-bearer on a per-IP flow basis. The distribution can be tailored dynamically at the eNB based on the WLAN measurements reported via the control plane signaling. Similarly, eNB configures uplink bearers at the UE for using the LWIP tunnel. The configuration of a bearer to use the LWIP tunnel can be done independently in the uplink and downlink. The user plane over the WLAN path, LWIP tunnel, completely bypasses the LTE protocol stack and hence the throughputs realizable over the WLAN path are independent of the LTE capabilities.

3.1.13.2.3 LWIP CONTROL PLANE

The control messaging for setup of the user plane in LWIP is based on RRC signaling and is carried over the LTE SRB (Signaling Radio Bearer). Therefore, the UE needs to be in the RRC connected state for LWIP mode of operation. LWIP shares and uses the same WLAN mobility set, connection status reporting and measurement framework as LWA. In addition, specific RRC signaling is defined for LWIP purpose that is used for configuring the UE with the parameters to setup IPsec tunnel (also known as LWIP Tunnel) via the WLAN, configure and de-configure bearers to use the LWIP tunnel.

The following call flow describes the steps involved in LWIP configuration.

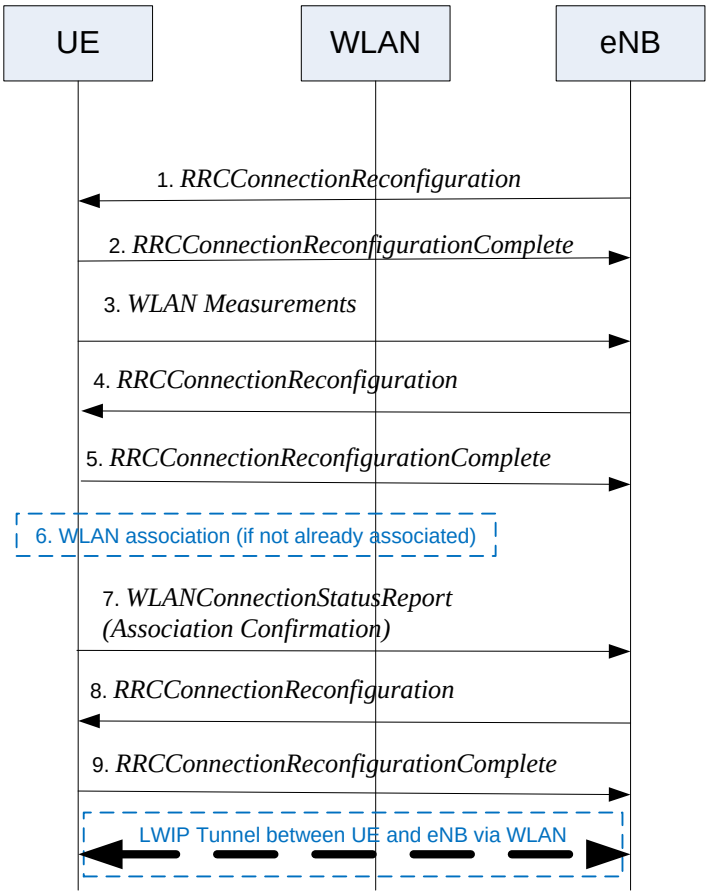

Figure 3.23. Call flow for LWIP Setup [3GPP TS 36.300].

1. The eNB configures the UE to perform WLAN measurements for LWIP operation
2. The UE applies the new configuration and acknowledges the message
3. UE sends WLAN measurements to the eNB
4. eNB provides the LWIP configuration to the UE, including a list of preferred WLAN networks for LWIP operation
5. The UE takes into consideration the LWIP preferred WLAN network identifiers information in addition to its current policies and procedures for connecting to the WLAN
6. UE associates with WLAN (optional: If the UE is already associated)
7. UE sends confirmation of the WLAN association to the eNB
8. The eNB sends the necessary parameters to the UE to establish an IPSec tunnel over WLAN. The eNB may also send information regarding the UE's configuring of DL and UL data packets across the LWIP tunnel
9. The UE applies the new configuration for LWIP operation

Note that the WLAN association and the IPSec tunnel setup are done in two separate steps on purpose: it allows the IPSec setup to happen only after it is known that the UE has successfully connected to the desired WLAN, thus allowing the SeGW better control over LWIP security.

3.1.13.3 RAN CONTROLLED LTE WLAN INTERWORKING (RCLWI)

RCLWI uses the same LWA mobility and measurement procedures in RRC Connected mode. Based on these measurements, the eNB can send a steering command to the UE to move traffic to/from WLAN. The upper layers in the UE are notified upon reception of such a command, which determines the traffic offloadable to the WLAN.

In RRC Idle mode, if the UE supporting RCLWI also supports Release-12 access network selection and traffic steering rules, the UE applies these rules in RRC Idle using WLAN identifiers provided in the WLAN mobility set during connected mode. If the UE is not configured with a WLAN mobility set, it applies the broadcasted WLAN identifiers in SIB17. If the UE supporting RCLWI does not support the traffic steering rules defined, it keeps traffic on WLAN within the configured WLAN mobility set (if any) in RRC_IDLE until WLAN connection fails.

Simultaneous configuration of RCLWI, LWIP and LWA for the same UE is not supported since that would result in multiple conflicting procedures for the UE.

3.1.14 RADIO ACCESS NETWORK (RAN) ENHANCEMENTS FOR EXTENDED DISCONTINUOUS RECEPTION (DRX) IN LTE

As already identified by earlier 3GPP releases, significantly reducing UE power consumption can be very valuable for certain UEs (e.g., for MTC/IOT sensors that run on small batteries may be a major cost to exchange/charge batteries; otherwise the battery duration may simply determine the device's lifetime).

In Rel-12, 3GPP adopted a NAS layer solution-defined Power Saving Mode (PSM), allowing a very low UE power consumption in certain use cases (e.g., Mobile Originated (MO)-only or scheduled Mobile Terminated (MT) data). However, PSM has limited applicability for unscheduled MT data with a certain requirement on delay tolerance. If the maximum allowed delay tolerance is less than the order of many hours, the PSM solution may not be so efficient, due to more frequent periodic registrations. Another approach to provide better UE power consumption in those scenarios is to extend current DRX operation (partly studied in Rel-12).[99]

In Rel-13, 3GPP standardized a RAN-based solution for extended DRX[100] to address the above shortcomings.

- Extend idle mode DRX cycles up to approx. 45 minutes (for non-NB-IoT) or 3 hours for NB-IoT
- Extend connected mode DRX cycles up to 10 seconds

The extended idle mode DRX cycle for the UE is represented by the number of "Hyper-SFN". Hyper-SFN increments by one when SFN wraps around, and ranges from 0 to 1024. NAS signaling is used to configure the UE with an extended DRX cycle.

[99] TR 23.887: *Study on Machine-Type Communications (MTC) and other mobile data applications communications enhancements* and TR 37.869: *Study on Enhancements to Machine-Type Communications (MTC) and other Mobile Data Applications; Radio Access Network (RAN) aspects*.
[100] RP-150493: *RAN enhancements for extended DRX in LTE*.

Extended connected mode DRX is configured by RAN via RRC signaling and does not require Hyper-SFN.

3.1.15 RAN ASPECTS OF CELLULAR INTERNET OF THINGS (CIOT) AND NARROWBAND INTERNET OF THINGS (NB-IOT)

CIOT and NB-IOT are the so-called new slate approaches adopted by 3GPP in order to compete with LPWA arena for providing connectivity in the exponentially growing market of the Internet of Things services.

The requirements that lead their developments are based on the Technical Report TR45.820, for which the main focus was to achieve:

- Reduced UE complexity
- Improved power efficiency
- Improved indoor coverage
- Support of massive number of low throughput devices

With these requirements in mind, the idea of the new slate approaches was to design a not backward compatible communication procedure that could co-exist with current 3GPP systems deployed in the same frequency bands. The aim has been to enable the introduction of new IoT technologies as much as possible with only a “software upgrade” to the current 3GPP RAN nodes. CIOT focused on GSM/GPRS technology (currently the leading M2M technology in many countries due to its low price and good coverage) and NB-IOT focused on LTE.

Therefore, CIOT was designed to share radio resources with existing GSM/GPRS systems, and therefore using the 200 kHz channelization present in this RAT, and to a large extent re-using its design principles. The main characteristics of this technology are shown in the Table 3.5.

Table 3.5. CIOT Characteristics.

Deployment	**In-Band GSM**
MCL (Coverage)	164 dB (33dBm power class UE) 154 dB (23dBm power class UE)
Downlink	TDMA/FDMA GMSK and 8PSK (optional), 1Rx
Uplink	TDMA/FDMA GMSK and 8PSK (optional)
Bandwidth	200KHz channelization. Typical system requirement 1.4MHz (600kHZ under study)

Peak data rate	70 kbps with GMSK and 240 kbps with 8 PSK
Duplex	HD FDD (in order to achieve reduced cost UE with a single RF chain)
Power saving	PSM and ext I-DRX (in order to improve power efficiency)
Power class	23 dBm and 33 dBm

CIOT address the reduced complexity adopting a Half Duplex 200 kHz connectivity, that enables the single chip solution that could easily integrate the single RF chain needed. CIOT also achieves up to 20 dBs increase in the MCL (Maximum Coupling Loss) compared with GSM using blind repetitions, and modifications on the control channels.

It is worthy to note that even when the canalization is 200 kHz width, similarly to GSM there is also a need to establish a Frequency Reuse Pattern to avoid cell edge interferences, leading to a total system frequency requirement of 1.4 MHz if 7 frequencies are used (the performance with 3 frequencies reuse i.e., 600 kHz system bandwidth).

On the other hand, the NB-IOT has been designed to be integrated in LTE eNBs, even when three types of deployments are envisaged for this technology:

- In-band, integrated as part of the resource blocks regularly used for the eNB communication
- Guard band, using 180 kHz of the unused frequency band between the last Physical Resource Block (PRB) used and the channelization edge
- Standalone system in any assigned band, as could be a reframed channel from a previous GSM/GPRS system owned by the operator

In order to achieve the aggressive requirements established in TR45.820 as previously mentioned, a major modification on the LTE physical layer has been needed, since it is a system initially designed with the focus on the requirements of MBB services, which are basically opposite to the IoT services.

NB-IOT operates in one single PRB (i.e. 180 kHz), in order to guarantee that these communication devices (named as UE Cat. NB1) could be a single chip solution, including the RF components. But LTE has been designed for UEs with at least 1.4 MHz bandwidth and therefore capable of receiving and processing 6 PRBs per slot. Therefore, in order to fully operate in a single PRB a substantial redesign of many Physical Layer aspects, including data and control channels, is needed. Since these physical channels should be contained in a single PRB, they need to be spread over time in several sub frames. In fact, for the provision of NB-IOT, new channels and reference signals have been defined:

- **NPBCH** Narrowband Physical Broadcast Channel
- **NPDCCH** Narrowband Physical Downlink Control CHannel
- **NPDSCH** Narrowband Physical Downlink Shared CHannel

- **NPRACH** Narrowband Physical Random Access CHannel
- **NPUSCH** Narrowband Physical Uplink Shared CHannel
- **NPSS** Narrowband Primary Synchronization Signal
- **NSSS** Narrowband Secondary Synchronization Signal
- **NRS** Narrowband Reference Signal

Therefore, legacy LTE control information is not used, and the new LTE NB-IOT deployed in-band can be considered as a parallel RAT, using current eNB radio resources, with the advantage of reusing the same HW (and of course RF components and antennas) which can be software upgraded for it. As an example, the NPDCCH channel provides the required Downlink Control Indicator (DCI), with information required on the NPUSCH as “modulation and coding schemes”, “redundancy version”, "resource assignment" and the total number of allocated subcarriers.

This implies also that basic procedures have been changed accordingly, as:

- Obtaining Cell ID
- New Obtaining Master Information Block-NB
- New System Information Block -NB
- Paging
- Cell Selection Criterion
- Cell Selection and Reselection states
- State transitions from RRC_IDLE

NB-IOT downlink operates OFDM with 12 QPSK modulated sub-carriers, and a sub-carrier spacing of 15 kHz (i.e. similar to one PRB with QPSK modulation), with the possibility to include two antenna ports for transmission diversity.

There are two possible uplinks specified in order to include UE of different characteristics:

- a single sub-carrier with a sub-carrier bandwidth of either 3.75kHz or 15kHz, with BPSK and QPSK modulations
- OFDM with: 3, 6 or 12 sub-carriers with BPSK and QPSK (with a sub-carrier spacing of 15 kHz similar to LTE)

The main characteristics of NB-IOT are summarized in the Table 3.6:

Table 3.6. NB-IOT Characteristics.

Deployment	In-Band LTE, Guard band LTE, Standalone
MCL (Coverage)	164 dB
Downlink	OFDMA (15 KHz subcarrier spacing), 1 Rx, 1 or 2 TX antenna
Uplink	SC-FDMA (15 KHz subcarrier spacing) Turbo Code or Single Tone (15kHz and 3.75 kHz spacing)
Bandwidth	180 kHz (1 PRBs) inside eNB assigned BW
Peak data rate	250 kbps (20 kbps for UL single tone)
Duplex	HD FDD, TDD
Power saving	PSM, ext I-DRX, C-DRX
Power class	23 dBm

UE Cat-NB1 are based on much lower bandwidth usage (just one PRB, i.e., 180 kHz) than any other UE category including UE Cat-M1, and Half Duplex operation for FDD. They therefore present a much reduced complexity by being able to be integrated into a single chip (including the full RF with Power Amplifier required for the provision of the 23 dBms). Of course the trade-off is a lower data rate.

In order to achieve the coverage increase required in the IoT services, up to 2048 repetitions may be used for NPDSCH (up to 16 for NPDSCH carrying System Information Block SIB). Furthermore, taking advantage of the reduced Bandwidth (BW) (compared with Rel-13 Cat-M1 devices), additional boosting of the Power Spectral Density is included for enhancing NB-IOT RAT coverage beyond the achievable with Rel-13 Cat-M1.

For improving the power efficiency, there are several DRX cycles that may be supported by the eNB: 1.28 s, 2.56 s, 5.12 s and 10.24 s. Other features, such as the fact that Cat-NB1UEs are not required to search on other RATs during cell select, also contributes to the low power consumption on NB-IOT.

It is worthy to note that in one eNB, several NBIOT “systems” may be deployed simultaneously, each one using a different PRB of the full eNB BW assignment. This approach enables a progressive increase in the Radio Resources assigned to IoT services, if required by usage demand.

3.2 UTRAN/HSPA+ ENHANCEMENTS

This section includes a few main UMTS/HSPA Rel-13 radio features, namely Downlink enhancements, Extended DRX in Idle mode, and Dual Band UL carrier aggregation.

There are other Rel-13 radio enhancements, which are not covered in this paper, i.e., Dual Carrier UL plus DCH, DL TPC Enhancements, Multiflow Enhancements (3F-4C), Enhanced offloading; plus, jointly with E-UTRA, Indoor Positioning enhancements and RAN assisted application congestion control (ACDC). Further network-only Rel-13 enhancements (no radio/UE impact) are: CS/PS coordination in Shared UTRAN, RAN sharing enhancements and Dedicated Core Networks (DECOR).

3.2.1 DOWNLINK (DL) ENHANCEMENTS

This section discusses the DL enhancements introduced in Rel-13 for HSPA+.

3.2.1.1 ALGORITHM 3 FOR PROCESSING TRANSMIT POWER CONTROL (TPC) COMMANDS

Upon the completion of 3GPP Rel-13, the UMTS standard has three power control algorithms for generating and processing TPC commands transmitted in the downlink direction.

The third power control algorithm referred in the UMTS standard as Algorithm 3 allows the inner loop power control (ILPC) to slow down by applying decimation on the TPC commands transmitted in downlink. This means that when the Algorithm 3 is configured, the downlink TCP commands are generated either once every three slots, or once every five slots. Figure 3.24 illustrates the DL TPC command transmission pattern for both decimation factors.

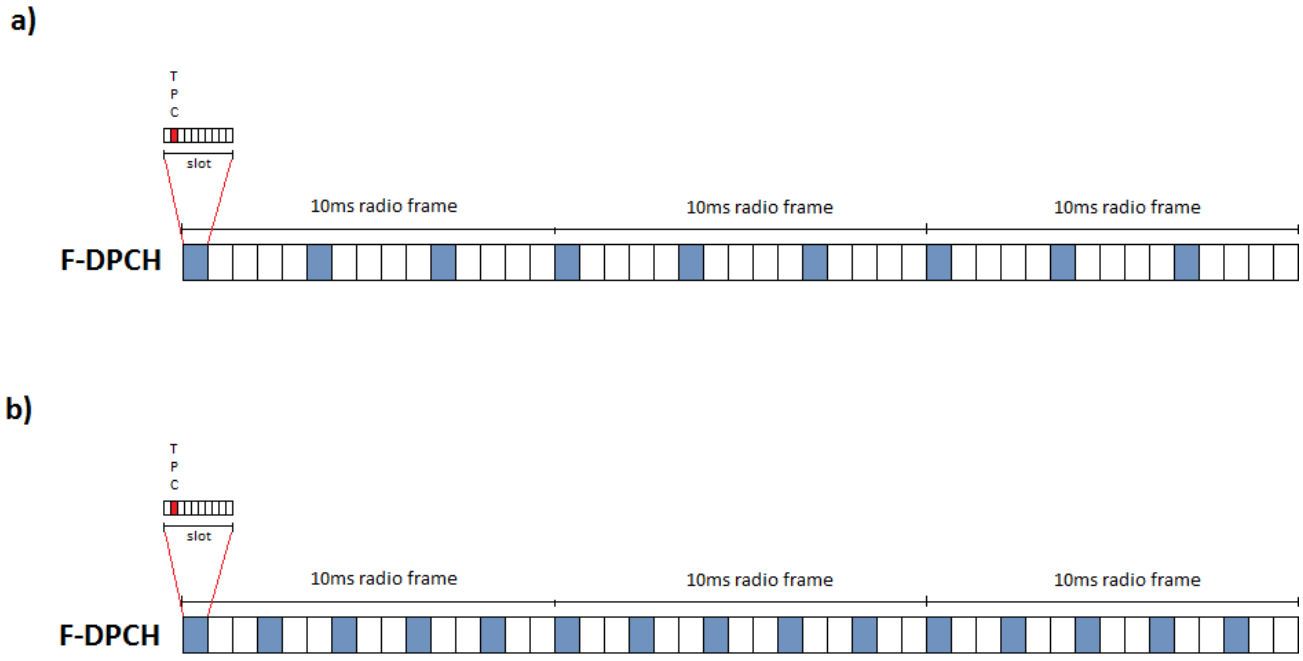

Figure 3.24. DL TPC Command Transmitted in the first slot within the slot-cycle by using: a) Decimation Factor equal to 5 slots, b) Decimation Factor equal to 3 slots.

In addition to the power saving that can be obtained with the Algorithm 3, the decimation can also be used to increase the system's capacity in heavy loaded scenarios by means of allocating more UE on the slots that were decimated.

3.2.1.2 URA_PCH WITH SEAMLESS TRANSITION

When a UE in UTRAN Registration Area Paging CHannel (URA_PCH) wants to transmit data, it first has to perform a Cell Update procedure to acquire cell specific High Speed Downlink Shared CHAnnel - Radio Network Transaction Identifier (H-RNTI) and EUTRAN Dedicated CHannel – Radio Network Transaction Identifier (E-RNTI) identities. The Cell Update signaling is associated with a delay in the state switching. Attempting to reduce the latency by keeping the identities while in URA_PCH would be of limited benefit, since there is no guarantee the UE will be in the same cell when the next state switch occurs.

By introducing unique URA-wide identities, the UE can keep them while in URA_PCH, and can avoid the Cell Update procedure when it has data to send. Theoretical estimations and lab results show that the transition time can be reduced by around 100ms. There is also a gain in reduced signaling load.

3.2.1.3 IMPROVED SYNCHRONIZED RRC PROCEDURES

Synchronized Radio Resource Control (RRC) procedures require the Radio Network Controller (RNC) to calculate an activation time for when the switch to a new configuration should take place. Uncertainties with respect to Radio Link Control Layer (RLC) retransmissions, Iub delays, and UE processing time leads to the procedure being associated with considerable delay, as the calculation has to be dimensioned for the worst case scenario.

With the improved synchronized RRC procedures the RNC sends an indication in the RRC reconfiguration message that the UE and the Node B agree on an activation time. When the UE is ready to switch to the new configuration it indicates this to the Node B. By using this mechanism, the activation of the new configuration can in most cases be done much faster.

3.2.1.4 RETRIEVABLE CONFIGURATIONS

Configuration parameters are typically sent in RRC signaling each time an RRC procedure is executed. When retrievable configurations are used an indication is included in the RRC reconfiguration message telling the UE to store the values of a defined set of parameters together with an identity. The next time the same configuration is used only the identity needs to be sent. Lab results show that the RRC message size can be reduced by 70-80 percent using retrievable configurations. When the message size is reduced the latency for the signaling procedure is improved and capacity is increased.

3.2.1.5 ENHANCED STATE TRANSITION

Enhanced state transition allows UEs to transition to a pre-configured state after finalized data transmission. The pre-configured state can be URA_PCH, CELL_PCH or CELL_FACH. The enhancement leads to reduced signaling load.

3.2.1.6 BLIND HARQ RETRANSMISSIONS

HARQ retransmissions is a fundamental part of HSPA, that allows for fast retransmissions of lost data packets. However, there is a minimum delay of at least 5 sub-frames (10 ms) from the initial data transmission due to a delay in feedback information from the UE.

With the new mechanism, the network can schedule a blind HARQ retransmission within 5 sub-frames after the initial transmission. This leads to more and earlier HARQ retransmissions within a certain period compared to legacy, which leads to increased robustness and improved latency.

3.2.2 SMALL DATA TRANSMISSION ENHANCEMENTS

This feature targets very long battery life (e.g., up to a few years) for MTC/IoT type of devices, by extending the Idle mode UTRA DRX cycle. The extended Idle mode Discontinuous Reception (DRX) (eDRX) ranges from 10.24 seconds up to ~44 minutes (for the PS domain). Legacy Idle DRX could go up to 5.12 seconds.

The Idle eDRX behavior is still based on Paging Occasions (PO) as determined by the CN (PS) domain specific DRX cycle length coefficient, broadcast by the network. However, the UE is not required to monitor every PO, but only the POs that belong to a certain Paging Transmission Window (PTW). See Figure 3.25.

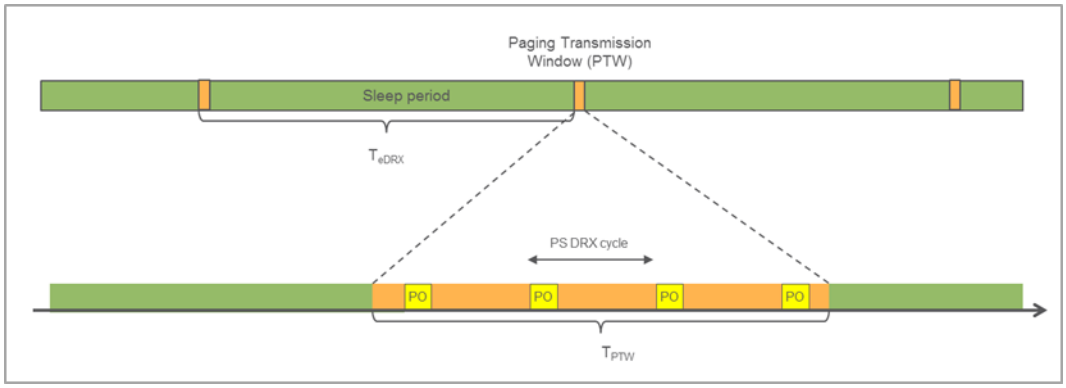

Figure 3.25. Extended DRX in Idle Mode.

The Idle eDRX parameter values, i.e., timer values for T_{eDRX} and T_{PTW} can be negotiated at NAS level (between UE and Core Network) and configured during ATTACH and RAU procedures.

If configured, Timer T_{eDRX} is (re-)started at successful completion of the ATTACH/RAU procedure. When timer T_{eDRX} expires (timer T_{PTW} is started) the UE wakes-up from sleep and starts monitoring the paging occasions as per normal DRX in Idle mode, until timer T_{PTW} expires. Then the cycle repeats.

3.2.3 DUAL BAND UPLINK (UL) CARRIER AGGREGATION (CA)

Leveraging from existing HSPA multi-carrier data aggregation features, such as Dual Band Dual Cell (DB-DC) / 4C-HSDPA (DL) and DC-HSUPA (UL), this new functionality extends UL multi-carrier operation by aggregating two UL carriers across bands.

An example of target dual-band deployment scenario is shown in Figure 3.26.

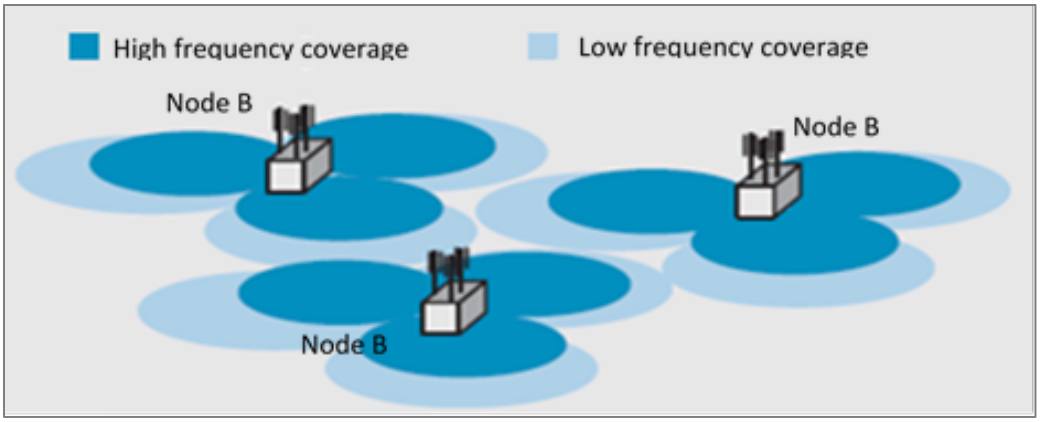

Figure 3.26. Example of (co-located) Dual-Band Deployment.

Dual band UL carrier aggregation is expected to enable better system and capacity performance (e.g., when used in combination with Dual band DL multi-carrier, both UL carriers on the serving and non-serving band may be efficiently exploited, achieving a better UL load balancing).

Furthermore, intra-band DC-HSUPA may not always be suitable for UL data aggregation, particularly in those markets where 10 MHz of contiguous spectrum is not available in a single band (e.g., some 900 MHz markets). In those cases, dual band UL carrier aggregation would enable aggregation of a 5 MHz UL carrier available in a different band, thus providing a more efficient usage of deployed spectrum.

DB-DC-HSUPA is defined for a few Band Combinations: II-V (1900-850 MHz, deployed in Americas), I-VIII (2100-900 MHz, deployed in EU/Asia, and I-V (2100-850 MHz, deployed in Oceania).

Table 3.7 lists the DB-DC-HSUPA configurations that are specified.

Table 3.7. DB-DC-HSUPA Configurations.

DB-HSUPA Configuration together with DB-DC/4C-HSDPA	UL Band A/B	Number of UL carriers in Band A/B	DL Band A	Number of DL carriers in Band A	DL Band B	Number of DL carriers in Band B
I-1-VIII-1	I and VIII	1	I	1	VIII	1
I-2-VIII-1	I and VIII	1	I	2	VIII	1
I-2-VIII-2	I and VIII	1	I	2	VIII	2

I-1-VIII-2	I and VIII	1	I	1	VIII	2
I-3-VIII-1	I and VIII	1	I	3	VIII	1
I-1-V-1	I and V	1	I	1	V	1
I-1-V-2	I and V	1	I	1	V	2
I-2-V-1	I and V	1	I	2	V	1
I-2-V-2	I and V	1	I	2	V	2
II-1-V-1	II and V	1	II	1	V	1
II-1-V-2	II and V	1	II	1	V	2

Dual band 4C-HSDPA configuration is numbered as (X-M-Y-N) where X denotes the DL Band A, M denotes the number DL carriers in the DL Band A, Y denotes the DL Band B, and N denotes the number of DL carriers in the DL Band B

Most of the legacy DB-DC-HSDPA and DC-HSUPA standard functionalities and signaling is reused.

For UL power, legacy (class 3) UE power class is assumed, i.e., for UEs supporting DB-DC-HSUPA operation, and the nominal maximum output power is 24 dBm (with +1/-3dB tolerance) where the nominal transmit power is defined by the sum of transmit powers of both carriers/bands. Minor RAN signaling changes have been introduced, mainly for the UE and RAN to indicate support of the new functionality/capability. As far as the UE capability is concerned, UE can signal to UTRAN support for Dual Band Dual Cell HSUPA operation in specific band combos (among those allowed configurations, as per Table 3.7).

Based on standards, signaling of UE capability for DB-DC-HSUPA has also been ported to earlier RRC/ASN1 specifications releases (from REL-11 onward) allowing earlier (UE) implementation of the feature.

3.3 NETWORK SERVICES RELATED ENHANCEMENTS

This section discusses the system architecture and network services related enhancements introduced in 3GPP Rel-13.

3.3.1 IP FLOW MOBILITY SUPPORT FOR S2A AND S2B INTERFACES

Wi-Fi is an important part of many operators' networks today which provides offload from the macro system and improved in-building coverage. Nearly all smartphones and tablets support Wi-Fi in addition to supporting cellular technologies like UMTS and LTE. Further, dual radio devices able to simultaneously support Wi-Fi and either UMTS or LTE are becoming commonly available. This has led to many use cases where simultaneous support of Wi-Fi and UMTS or LTE becomes desirable. For instance, some operators may want to keep specific real-time delay sensitive applications, like voice, on their cellular network (e.g., with 3G voice or VoLTE) while allowing other non-real-time and non-delay sensitive applications to run over Wi-Fi.

In 3GPP Rel-9, mechanisms ("MAPCON") have been defined for simultaneous connectivity over Wi-Fi and 3GPP based technologies for different PDN connections. In Rel-10, 3GPP defined the capability for Dual Stack Mobile IPv6 (DSMIPv6) capable UEs to dynamically and seamlessly move IP flows belonging to the same PDN between Wi-Fi and 3GPP technologies. However, many operators have deployed alternative network-based mobility protocols (e.g., GPRS Tunneling Protocol (GTP)). Thus, Rel-13 defined solutions for IP Flow Mobility (IFOM) using network-based mobility protocols in the feature named Network-Based Internet Protocol Flow Mobility (NBIFOM).

The 3GPP technical specification for non-3GPP accesses [TR 23.402] provides Figure 3.27 showing the non-roaming architecture for the Enhanced Packet System (EPS). It can be seen from Figure 3.27 that Wi-Fi can be supported by the EPS either through Trusted WLAN access, using the interface S2a, or through Untrusted WLAN access, using the interface S2b through an evolved Packet Data Gateway (ePDG).

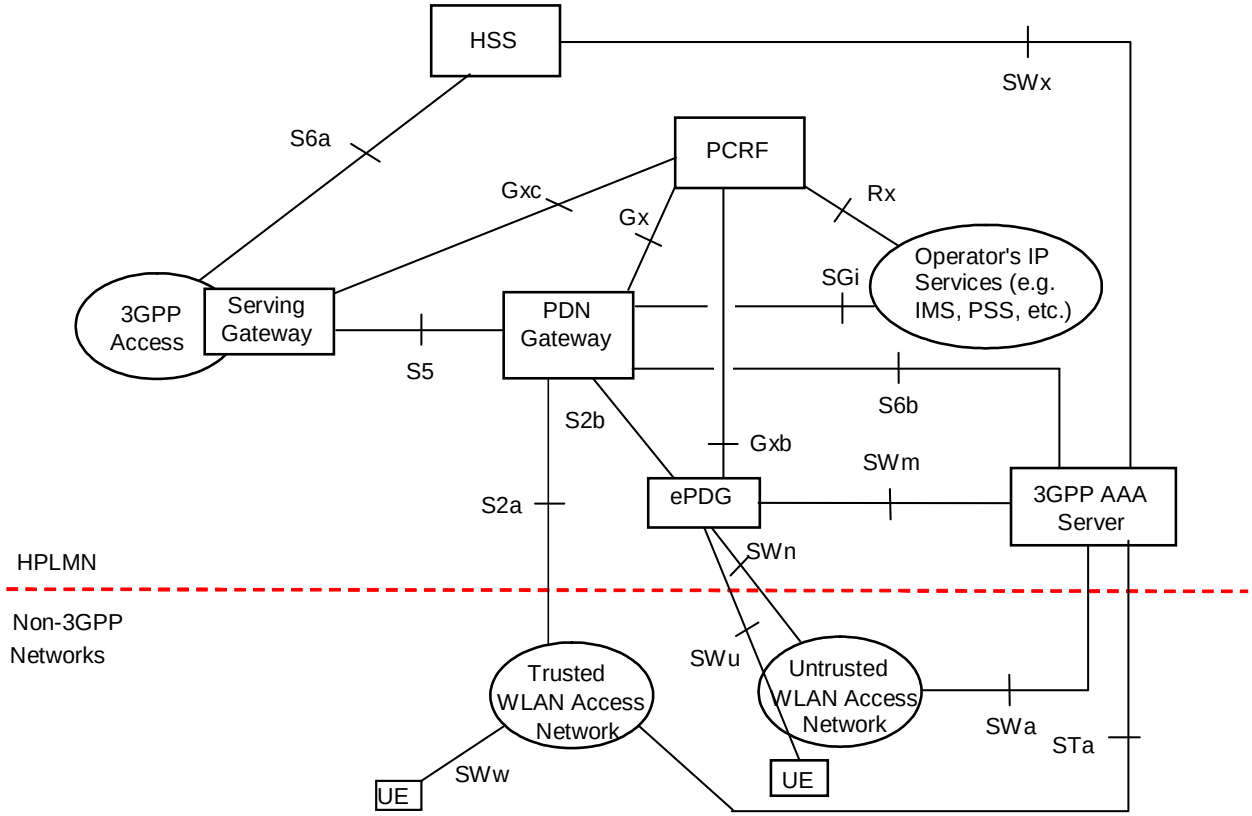

Figure 3.27. Non-Roaming Architecture within EPS Using S5, S2a and S2b.[101]

[101] TR23.861: *Network Based IP Flow Mobility.*

The NBIFOM feature standardized in Rel-13 added the IFOM functionality for the PMIP and GTP-based mobility protocols for both trusted (S2a based) and untrusted (S2b based) WLAN access. Detailed procedures for NBIFOM can be found in [23.261] which describe:

- The support of a PDN Connection active over multiple accesses simultaneously
- The association of one or multiple IP flows belonging to a PDN connection to an access system
- The movement of one or multiple IP flows belonging to a PDN connection between different access systems
- The triggers for IP flow mobility in the UE and the network
- UE-initiated NBIFOM mode and network-initiated NBIFOM mode
    - In the UE-initiated NBIFOM mode, only the UE controls the traffic routing within the multi-access PDN connection by applying its ANDSF for IFOM rules and/or the user-configured routing rules; the routing rules (which contain the access type where the IP flow shall be routed) are provided from the UE to the network
    - In the network-initiated NBIFOM mode, the PCRF makes the decision on when and what flows should be moved to which access, then routing rules are provided to the UE. In this case, the network decides whether RAN rules should apply (in which case the UE has to request updated routing rules to PCRF when it needs to move between 3GPP and WLAN) or should not apply (in which case the UE obeys existing routing rules)

Furthermore, Rel-13 provided charging enhancements for NBIFOM functionality that can be found in [TS 32.251] clause 5.2.1.7A. Specifically, as with NBIFOM, individual IP flows can be moved from one access network to another within the same PDN connection. It is possible to apply different rates depending on the access used to carry a service data flow. Hence, for each service data flow, a different rating group, different measurement and charging methods, and different reporting level may be used for each access.

3.3.1.1 VOICE AND VIDEO SUPPORT IN TRUSTED AND UNTRUSTED WLAN

Wi-Fi is a widely-adopted access technology for broadband Internet access, and MNOs are looking with great interest to VoWi-Fi including roaming and interworking aspects in a cellular environment to: increase the coverage and capacity of mobile networks, e.g., covering LTE coverage gaps with Wi-Fi hotspots and offloading bandwidth intensive traffic from the cellular network; and to provide connectivity to a wider set of devices, e.g., tablets or laptops equipped with Wi-Fi only.

GSMA has also been working on a corresponding profile for voice, SMS and video over Wi-Fi IMS profile (in PRD IR.51), which relies on the WLAN access to EPC specified in 3GPP, and paves the way to support voice and video services over Wi-Fi, by guaranteeing interoperable, high quality IMS-based telephony and conversational video services over Wi-Fi access networks.

In 3GPP, Wi-Fi refers to a WLAN (non-3GPP) access, which can be either considered by MNOs as trusted via a Trusted WLAN (S2a interface with PGW) or untrusted via an ePDG (S2b interface with PGW), as defined in [TS 23.402].

The following additional system enhancements have been defined in 3GPP Rel-13 to harmonize the level of support of voice and video services over Wi-Fi with what is supported over 3GPP accesses:

1. Proxy Call Session Control Function (P-CSCF) discovery and P-CSCF restoration for UEs under WLAN

A new P-CSCF discovery method has been specified, allowing UEs under WLAN to retrieve the P-CSCF addresses (along with other IP parameters) from the P-GW, upon the Public Data Network (PDN) connection establishment to the EPC via WLAN, as already supported over 3GPP accesses.

Besides, the P-CSCF restoration procedures specified in 3GPP Rel-12 for 3GPP accesses have been extended in Rel-13 to support UEs with an IMS PDN connection over WLAN, thus providing the ability to force UEs under WLAN to re-register to IMS following a P-CSCF failure and to deliver mobile terminated calls to such UEs.

2. GPRS Tunneling Protocol-Control (GTP-C) overload control from Trusted WLAN (TWAN) or ePDG to PGW

GTP-C overload control was specified in Rel-12 to enable a GTP-C entity that is becoming overloaded, or is already overloaded, to gracefully reduce its incoming signaling load by instructing its GTP-C peers to reduce sending traffic, according to its available signaling capacity to successfully process the traffic. This was defined over the S2a and S2b interfaces, among others, but only the PGW could signal an overload to the TWAN/ePDG (i.e., the TWAN/ePDG could not send an overload indication towards the PGW).

With Voice over Internet Protocol Multimedia Subsystem (VoIMS) over WLAN, the PGW may initiate dedicated bearer creation/deletion and thus the number of requests from the PGW to the Trusted WLAN Access Gateway (TWAG)/ePDG may rise significantly. An overload may occur at the TWAN/ePDG e.g.: 1) upon an exceptional event locally generating a traffic spike with a large amount of calls with dedicated bearers or; 2) almost simultaneously upon a catastrophic event, or; 3) with an exceptional but predictable event such as Christmas or New Year's Eve; all three events via an IMS connection over a trusted or untrusted WLAN.

Thus, 3GPP introduced in Rel-13 the possibility for the Trusted WLAN Access Gateway (TWAG)/ePDG to send an overload indication to the PGW. The PGW reacts the same way as when it receives an overload indication from an MME/Serving GPRS Support Node (SGSN)/Serving Gateway (SGW) over S5/S8 for a 3GPP access.

3. Reporting the cause of a Public Data Network (PDN) connection Release - from TWAN/ePDG to PGW/Proxy Call Session Control Function (P-CSCF) for Customer Care

Rel-13 adds the capability for the TWAN/ePDG to report to the PGW and the P-CSCF (via the PCRF) the Release-Cause when a PDN connection is being torn down, if this information is available and permitted to be sent to the PGW, according to the operator's policy. Examples of Release-Causes can be e.g., lost carrier, UE requested disassociation, re-authentication failure, session timeout, etc. The Release-Cause can also be further propagated in SIP. When a session is dropped while the UE is under WLAN, this allows the operator to get the real failure cause in the PGW Call Detail Records (CDRs) and at IMS level. This is supported in Rel-12 for LTE access for both performance analysis and for trouble-shooting of problems reported to customer care.

4. Charging extensions for WLAN access

In Rel-13, charging is enhanced to additionally incorporate the Release-Cause (mentioned previously in 3.) for diagnostics available to the PGW when a PDN connection is being torn down: this covers 3GPP accesses, and this is expected to be extended to trusted and untrusted WLAN accesses as well, for charging at EPC and IMS levels. The introduction of charging for TWAN, like Rel-12 charging from ePDG, allows inter-operator charging in roaming situations.

5. IMS emergency calls over WLAN

3GPP is also working on system enhancements to support emergency calls over Wi-Fi accesses. The support of IMS emergency calls using access to the EPC over WLAN was split up into 2 phases. Phase 1, introduced in Release 13, was limited to UEs which (a) have valid credentials to access EPC over WLAN and (b) are authorized to connect to EPC over WLAN in the location where they initiate an emergency session. This phase was also limited to untrusted WLAN. It does not support handovers with 3GPP access, and location information is only based on existing mechanisms. No location accuracy requirements are considered. For phase 1, Rel-13 also agreed that when a UE is requested to set-up an emergency session, the UE will release any PDN connection it may have over WLAN (SWu), which induces the release of the existing IP connectivity services, and then selects an ePDG for emergency services and finally sets-up a PDN connection for emergency.

Phase 2 will focus on support of other cases (e.g., unauthenticated UEs, roaming cases, support for emergency sessions of session continuity with 3GPP access, and TWAN access). This will also cover the case where the UE is authenticated but is in a location where it is restricted from regular service.

3.3.2 USER PLANE CONGESTION MANAGEMENT (UPCON)

The User-Plane Congestion (UPCON) Work Item aims at detecting and mitigating situations where the offered load exceeds the capacity of the RAN to transfer user data for a few seconds or longer (short bursts in offered load are not in scope).

3GPP Working Group (WG) SA1 defined related requirements (see TS 22.101) that not only address detection of congestion ("The network shall be able to detect RAN user plane congestion onset and abatement"), but also specify the foreseen mitigation measures. As a means to mitigate congestion situations, the network is expected to be able to:

- Prioritize traffic (e.g., by adjusting QoS for specific services according to operator policies and subscriber profile)
- Reduce traffic (e.g., by compressing images or by applying adaptations for streaming applications)
- Limit traffic (e.g., by prohibiting or deferring certain services traffic such as unattended data traffic where unattended data traffic is defined as data traffic of which the user is unaware (further exemplified as a Windows update traffic or traffic of other applications running in the background)

3GPP WG SA2 addressed the requirements as follows. As depicted in Figure 3.28, a new architectural entity (RAN Congestion Awareness Function (RCAF)) has been added to 3GPP specifications. The RCAF performs three key tasks:

1. Determines whether a cell is congested

2. If a cell is congested, determines the UEs that are served by the congested cell

3. Informs the PCRF about the UEs which are currently served by a congested cell (and the related congestion level)

Based on receiving congestion indications from the RCAF, the PCRF can subsequently apply different policies to mitigate the congestion.

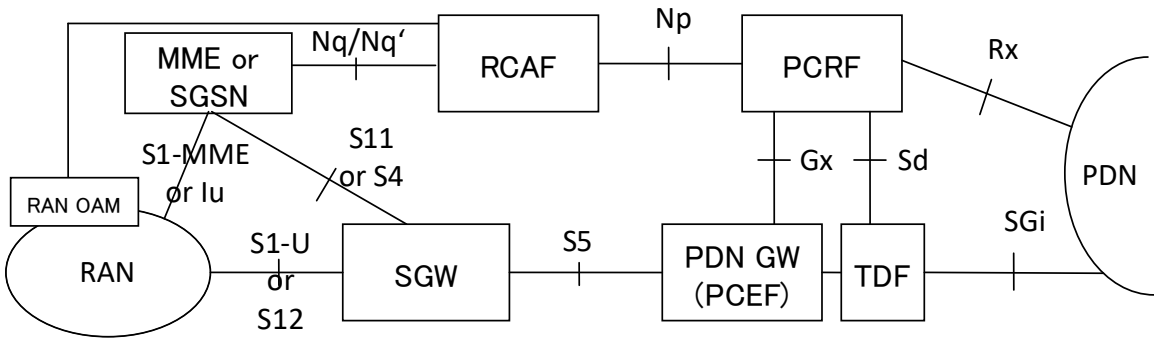

Figure 3.28. Rel-13 UPCON Solution Architecture.[102]

With respect to the RCAF's first task of determining cell congestion, 3GPP WG SA2 agreed that the RCAF detects cell congestion and derives the congestion level of a given congested cell based on information from the RAN's OAM system. The interface to the RAN's OAM system and the details of congestion detection based on information from the OAM system have not been specified (i.e., are implementation specific).

To enable the RCAF to fulfill the remaining two tasks (determining the list of UEs served by a given congested cell and reporting of congestion information to the PCRF); three new interfaces have been specified:

- Nq interface (applicable to E-UTRAN access): Via the Nq interface, the RCAF queries the MME for the list of UEs, identified by their International Mobile Subscriber Identities (IMSI), in a given congested cell. In addition, the RCAF also queries the MME for the list of active PDN connections for each of the UEs in the congested cell. The PDN information is needed to determine the serving PCRF(s) for the UEs in the congested cell.

- Nq' interface (applicable to UTRAN access): Via the Nq' interface, the RCAF queries the SGSN for the list of active PDN connections for each of the UEs in the congested cell.

  The background for specifying a different interface to the SGSN compared to the MME is as follows: for UTRAN access, the RCAF is assumed to receive the list of UEs (identified by the IMSIs) currently served by a given congested 3G Serving Area from the RAN's OAM system; hence, the RCAF does not need to query the SGSN for the list of UEs in a given congested area.

- Np interface (applicable to both E-UTRAN and UTRAN accesses): Via the Np interface, the RCAF reports the congestion level for a given IMSI and Access Point Name (APN) to the serving PCRF. In addition, the RCAF reports the location for UEs in a congested cell (identified by the E-UTRAN

[102] 3GPP TR 23.705: *Study on system enhancements for user plane congestion management.*

Cell Global Identifier (ECGI) or eNB Identifier (ID) (in case of E-UTRAN access) or Serving Area ID (in case of UTRAN access) to the PCRF.

When the PCRF receives an indication that a UE is served by a congested cell, the PCRF may modify or apply different Policy and Charging Control (PCC) rules via the Gx interface) and/or Application Detection and Control (ADC) rules via the Sd interface for the UEs in the congested cell. The same applies when the PCRF learns that a cell is not congested anymore or when a UE has left a congested cell.

In addition to modifying PCC and/or ADC rules in PGW and TDF, respectively, the PCRF may also decide to defer the delivery of non-time-critical services in case of user-plane congestion. To allow for this, 3GPP WG SA2 agreed on an extension to the Receive (Rx) interface, which enables the PCRF to send a re-try interval in response to an Application Function's (AF) request. When receiving a re-try interval from the PCRF, the AF shall not send the same service information to the PCRF again until the re-try interval has elapsed.

3.3.3 PUBLIC SAFETY

There is an acknowledged need for expansion of public safety radio systems to take advantage of broadband technologies, particularly LTE. The advantage to the police, fire and emergency medical personnel of having voice, video and high speed data capabilities integrated into their communications devices is significant and widely sought around the world. This need has led to the beginning of work in 3GPP to create such capabilities over the LTE radio interface.

3.3.3.1 MISSION CRITICAL PUSH-TO-TALK OVER LTE (MCPTT)

Work on Mission Critical Push-to-Talk (MCPTT) began in 2014 in 3GPP with the creation of a set of requirements by 3GPP SA1 in TS 22.179. Work then expanded into 3GPP SA2 to begin to examine architectural needs. At the same time, parallel work was ongoing in the European Telecommunications Standards Institute (ETSI), Terrestrial Trunked Radio (TETRA) and Critical Communications Evolution (TCCE) and Open Mobile Alliance (OMA) organizations to create an MCPTT capability based on broadband networks. The industry converged in 2014 by agreeing to do a single set of work in 3GPP. In recognition of the importance of the work, and to manage its work load better, 3GPP decided to create a new working group, SA6, focused on Critical Applications. The work done in SA2 was transferred in January 2015 to SA6. In 4Q 2014, ETSI TCCE experts and OMA experts held a meeting in the UK to create a merged architecture from their separate works. This merged work was presented to SA2 and SA6 in December 2014 and January 2015.

The goal of the MCPTT work in 3GPP Rel-13 was to create specifications for mission critical voice over LTE.

Support for video and data for public safety users is not in the scope of the Rel-13 work. Group calls will take advantage of both unicast and broadcast (such as evolved Multimedia Broadcast Multicast Service or eMBMS) bearers to distribute voice content to members of the group.

Interworking of MCPTT over LTE with existing Land Mobile Radio (LMR) systems such as P25 and Terrestrial Trunked Radio (TETRA) will be required to provide a migration path to countries and jurisdictions from LMR systems to LTE-based public safety communications. Interworking with existing LRM systems is not part of Rel-13 but is expected to be addressed in subsequent releases.

An aspect of MCPTT is the use of 3GPP Proximity Services (ProSe) to allow two public safety devices to communicate directly with each other both in and out of regular LTE network coverage. The MCPTT application that will operate over the lower layer ProSe capabilities was part of the work of SA6 during 2015. The results of the SA6 work are captured in 3GPP TS 23.379.

The MCPTT capabilities, based on the requirements in 3GPP TS 22.179, will include group calls, person-to-person calls, prioritization of calls and of individuals, group management, user management, configuration management, security, operation in relay-to-network mode, operation in off-network mode and several other related features.

The work on group calls will include the basic abilities to push-to-talk and to have the voice content delivered to other members of the group, and will also include special prioritization of calls to handle, for example, situations where public safety first responders encounter an emergency and push the “red button” on their device. Distribution of group call content will make use of normal unicast bearers to individual devices, and will also make use of MBMS to deliver the same group content to multiple group members in one area. MBMS enhancements in Rel-13 are discussed in section 3.3.3.3.

Priority management in MCPTT includes recognition that individuals, particularly in public safety first responder situations, will have different roles and will need different abilities to access and even pre-empt other individuals. For example, the fire chief will need a higher priority than other fire personnel to be able to give the orders necessary to efficiently and safely contain and put out a fire. In addition, the need exists for individuals, regardless of the priority of their role, to be able to obtain immediate priority when a situation of emergency arises. In this case, depending on system policy and configuration, the priority given by the system may allow the individual fireman to override the fire chief to alert others of a life-threatening situation.

Group management involves the ability of the administrator to pre-configure groups of individuals for group communications. For example, all police personnel in the North Police Station may be automatically included in a group “North Police.” Groups can also be formed dynamically by a dispatcher or by individuals to meet the needs of the situations encountered.

Direct communication of devices without the use of network infrastructure is an important aspect of public safety. To support such direct communication, the MCPTT work includes support for devices that need to communicate with each other directly, regardless of whether the devices are in or out of network radio coverage. The work also includes support for relaying communications from devices that are out of network radio coverage to devices that are in network radio coverage and performing a relay function to the network.

Expansion of the mission critical communications is part of 3GPP Rel-14. In particular, extension to other media types (e.g., video and data) is important to public safety operations.

3.3.3.2 ENHANCEMENTS TO PROXIMITY BASED SERVICES

In Rel-13, further enhancements to Proximity-based Services (ProSe) have been standardized in SA2 in order to support the Public Safety and non-Public Safety use cases that could not be completed in Rel-12 and to fulfill the requirements of Mission Critical Push to Talk (MCPTT).

The following topics have been completed as of October 2016:

- Enhancements to Direct Discovery, including Restricted Discovery (discovery with explicit authorization) and Request/Response Discovery (Model B) to support Public Safety and non-Public Safety use cases

- Enhancements to Direct Communication (applicable only to Public Safety use cases), including:
    - Support for one-to-one communication
    - Support for ProSe UE-Network Relay
    - Support for ProSe Per Packet Priority for ProSe Direct Communication

Enhancements to Direct Discovery are applicable to all types of UEs (public safety or not), whereas enhancements to Direct Communication are only applicable to public safety UEs.

3.3.3.3 MBMS ENHANCEMENTS

MBMS access was made available in Rel-12 to applications by the creation of the MB2 interface. This work was primarily done to support MCPTT (see section 3.3.3.1), but also, supports any application implementing the MB2 interface. Two areas in MBMS that were found to need improvement in Rel-13 are service continuity and greater independence of the application from knowing the service areas defined in the network.

MCPTT group voice calls may have long periods of silence when downlink capacity is not needed. Due to the length of time needed to establish an MBMS bearer, including all of the signaling among the Broadcast Multicast-Service Center (BM-SC), Multimedia Broadcast Multicast Services-Gateway (MBMS-GW), MME and Multi-cell/Multicast Coordination Entity (MCE), an MCPTT group voice call must have an MBMS bearer already established for use immediately when voice spurt must be delivered to group members. Thus, overbooking of MBMS bearer resources can occur at the MCE/eNB level. When the MCE/eNB receives downlink MBMS bearer content beyond what can be supported with existing resources (subframe capacity), the MCE/eNB must pre-empt the lower priority bearers and give those resources to the higher priority bearers.

The way that has been devised to support pre-emption of MBMS bearers and support service continuity for the devices is to alert the devices that a MBMS bearer is about to be suspended. This work is handled in RAN2 and RAN3. This gives the devices some time to be able to request a unicast bearer from the application, and this is precisely the method of service continuity already present in Rel-12. The additional warning provides the ability to have a smaller content gap at the application level when the switch from broadcast to unicast occurs.

The other MBMS improvement in Rel-13 involves the ability of the application Group Communication System Application Server (GCS AS) to request an MBMS bearer using a list of cells, rather than a list of MBMS service areas. This is based on the availability of the cell ID at the device. The application in the device can send the cell ID to the application in the network, allowing the network application to count the number of devices needing the same content in the same cell. So, the network application can easily determine a list of cells where a broadcast bearer is needed to avoid multiple unicast bearers. However, the network application may not be affiliated directly with any given network, and could in fact be using the services of multiple networks. Keeping all such applications updated on the mapping of cells to MBMS service areas can cause much operational complexity. The solution is to allow the network application to provide the list of cells to the BM-SC over the MB2 interface.

When the list of cells is given to the BM-SC in a request for an MBMS bearer, the BM-SC maps the cells to a list of MBMS service areas and can forward the list of MBMS service areas to the lower MBMS nodes (MBMS-GW, MME, and MCE). However, there was also seen to be a need to limit the broadcast to the smallest possible set of cells needed, and supported, to perform the broadcast. To achieve that, the list of

cells will also be passed down from the BM-SC to the MCE. It is at the MCE that the mapping of cells and of MBMS service areas to MBSFNs occurs. An MBMS Service Area may include multiple MBSFNs that may cover an area larger than requested by the application, but as the MCE receives the list of cells, it can identify the MBMS Service Area's MBSFNs that do not contain any of the cells provided by the application. Thus, the MCE can choose to initiate the broadcast MBMS bearer in only the MBSFNs that contain cells in that list. This helps to preserve radio resources that would otherwise be wasted.

3.3.4 MACHINE TYPE COMMUNICATION (MTC) ENHANCEMENTS

In this section, the enhancements considered relevant and applicable towards Machine Type Communications are described. These enhancements are Architecture Enhancements for Services capability exposer (AESE), optimizations to support high latency communication (HLCom), Group Based Enhancements (GROUPE), Extended DRX Cycle optimization and Monitoring Enhancements (MONTE).

3.3.4.1 DEDICATED CORE NETWORKS (DÉCOR)

This work studies and defines architectural enhancements required to support dedicated core networks for specific type(s) of subscribers. The use of Dedicated Core Network (DCN) can be to provide specific characteristics and/or functions or isolate specific UEs or subscribers (e.g., M2M subscribers, subscribers belonging to a specific enterprise or separate administrative domain, etc.). The main architecture enhancements are to route and maintain UEs in their respective dedicated core network (for UEs with assigned DCN).

A dedicated core network is comprised of one or more MMEs/SGSNs and it may be comprised of one or more SGWs/PGWs/PCRFs. A DCN may be deployed to support one RAT only, multiple RATs or all RATs. The dedicated MME/SGSN which serves the UE selects the dedicated S-GW and P-GW based on UE Usage Type.

A new optional subscription information parameter ("UE Usage Type") is defined for the Home Subscriber Server (HSS) subscriber profile and is used by the serving network to select which of its CNs shall serve the UE. For the MME, the MME Group Identity (MMEGI)(s) identifies a DCN within the PLMN. For SGSNs, a group identifier(s) identifies a DCN within the PLMN. That is, the group of SGSNs that belong to a DCN within a PLMN. This identifier can have the same format as a Network Resource Identifier (NRI) value that does not identify a specific SGSN node in the serving area, or; "SGSN Group ID" provided by an SGSN to the RAN which triggers the NAS Node Selection Function (NNSF) procedure to select an SGSN from the group of SGSNs corresponding to the Null-NRI/SGSN Group ID.

The specification TS 23.401 (mainly in Section 5.19 of TS 23.401) has been updated for the following purposes:

- Definition of DÉCOR
- Inclusion of MME/SGSN and SGW/PGW selection procedures. When DCNs with dedicated MME/SGSN and S/PDN GWs are used, the DNS procedure for MME/SGSN and PDN GW selection may be used such that the MME/SGSN or PDN GW belonging to a DCN serving a particular category of UEs (e.g., identified by UE Usage Type) is selected

  When DCNs are deployed, to maintain UE in same CN when the UE enters a new MME pool area, the eNodeB's NNSF should have a configuration that selects, based on the MMEGIs or NRIs of neighboring pool areas, a connected MME from the same CN. Alternately, for PLMN wide inter-

pool intra-RAT mobility, the operator may divide up the entire MMEGI and NRI value space into non-overlapping sets with each set allocated to a particular CN. In this case, all eNodeBs may be configured with the same MME selection configuration

- Non-Access Stratum (NAS) message redirection procedure as illustrated in Figure 3.29

  Updated Attach and Target Acquisition and Tracking Unit/Routing Area Update (TAU/RAU) procedures: in the step that the RAN forwards the NAS message, it may also include the MMEGI or Null-NRI/SGSN Group ID in case the NAS message has been rerouted. In the Context Response message, the old MME/SGSN provides the UE Usage Type parameter if that value is available

- Definition of the HSS initiated Core Network change procedure for the case when the UE's subscription parameter is changed, to allow the HSS to update the UE Usage Type subscription parameter in the serving node. This procedure may result in change of serving node of the UE

- Addition of "UE usage type" for HSS data and MME Mobility Management (MM) and EPS Bearer Context

- The use of Authentication Information Request and Authentication Information Answer procedure for retrieving the UE Usage Type from the HSS

  Impact to handover/relocation procedures: UE usage type and optionally the IMSI are sent form the source MME/SGSN to the target MME/SGSN during handover

- Considerations of Network Sharing: If the network supports the Multi-Operator Core Network (MOCN) configuration for network sharing, each network sharing operator has separate CN(s). Mechanisms for selection of serving operator for supporting and non-supporting UEs are defined in TS 23.251. Each of the sharing operators may deploy one or more DCNs. If Selected PLMN information is provided by the UE, the RAN selects the CN operator based on this provided information and then DECOR rerouting may, if needed, be initiated within the CN of the selected operator

- If Selected PLMN information is not provided by the UE (may only happen in GERAN and UTRAN), the network initiates MOCN redirection, including CS/PS coordination, to select a CN operator that can serve the UE. After this, DECOR rerouting is initiated if needed. The serving node in the selected DCN ends the MOCN redirection

Similar changes are made in TS 23.060 for corresponding procedures and data as in TS 23.401.

The flow in Figure 3.29 shows NAS message redirection procedure. If DCNs are deployed, these steps are used to reroute a NAS message (and thereby a UE) from one CN node to another CN node during Attach, Tracking Area Update (TAU) or Routing Area Update (RAU) procedure.

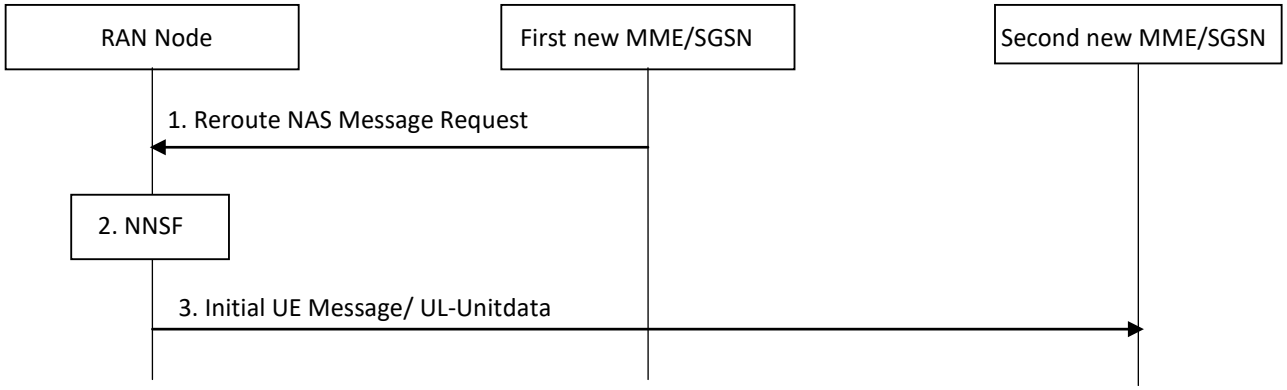

Figure 3.29. NAS Message Redirection Procedure.

The procedure is started when a first new MME/SGSN decides to move the handling of an Attach Request, TAU Request or RAU Request to another CN node.

1. The first new MME/SGSN sends a Reroute NAS Message Request (original NAS Request message, reroute parameters, Additional GUTI/P-TMSI, UE Usage Type, and optionally the IMSI) to the RAN Node. The reroute parameter is a MME Group Identity (MMEGI) for E-UTRAN or Null-NRI/SGSN Group Identity for UTRAN/GERAN, corresponding to the DCN that corresponds to the UE Usage Type. A UE provided Additional GUTI/P-TMSI (if available) from the NAS Request message is included. The MME/SGSN may determine the MMEGI or Null-NRI/SGSN Group ID corresponding to the DCN using DNS procedures. The additional IEs are the IEs that were contained in the Initial UE message sent to the first new MME/SGSN. The UE Usage Type will be included, if available.

2. The RAN node's NNSF selects a new MME/SGSN based on the MMEGI or Null-NRI/SGSN Group ID and possibly also based on an additional Globally Unique Temporary Identify (GUTI)/ Packet Temporary Mobile Subscriber Identity (P-TMSI). If Additional GUTI/P-TMSI identifies an MME/SGSN within the set of valid nodes identified by MMEGI or Null-NRI/SGSN Group ID, it shall be the selected node. Otherwise a valid CN node corresponding to the MMEGI or Null-NRI/SGSN Group ID will be selected. If no valid MME/SGSN is available within the set of valid nodes identified by MMEGI or Null-NRI/SGSN Group ID, the RAN node selects an MME/SGSN from the default CN or selects the MME/SGSN that sent the Reroute Request, based on operator configuration. The MME/SGSN is selected from the network corresponding to the PLMN selected by the UE.

3. Dependent on RAT, the eNodeB/RNC sends the Initial UE message to the selected MME/SGSN or the Base Station Controller (BSC) sends the UL-Unitdata message to the selected SGSN. The initial UE message/UL-Unitdata message includes the NAS Request message, the MMEGI or Null-NRI/SGSN Group ID, UE Usage Type and the IMSI if received from the first SGSN/MME in step 1. The MMEGI or Null-NRI/SGSN Group ID indicates that the message is a rerouted message and the second new MME/SGSN will not reroute the NAS message. The UE Usage Type shall be included if received in the Reroute NAS Message Request to be used by the second new MME/SGSN to select SGW and PGW.

The study result is captured in TR 23.707. Technical Specification TS 23.236 is updated with example NRI configuration to support DCN.

3.3.4.2 ARCHITECTURE ENHANCEMENTS FOR SERVICES CAPABILITY EXPOSURE (AESE)

The 3GPP system has unique core assets, denoted as 3GPP service capabilities, such as Communications, Context, Subscription and Control that may be valuable to application providers. 3GPP Mobile Network Operators (MNO) can offer value added services by exposing these 3GPP service capabilities to external application providers, businesses and partners using web based APIs. In addition, 3GPP MNOs can combine other internal or external services with their network capabilities to provide richer, composite API services to their partners. This Rel-13 project studies and evaluates architecture enhancements for a service capability exposure framework wherein the 3GPP system provided service capabilities are exposed via one or more standardized APIs, e.g., the OMA-API(s).

Key issue 1: The main key issue studied is the architecture enhancement with the definition of the Service Capability Exposure Function (SCEF) in 3GPP core network. TS 23.682 has been updated with the Service Capability Exposure Function (SCEF) as shown in Figure 3.30

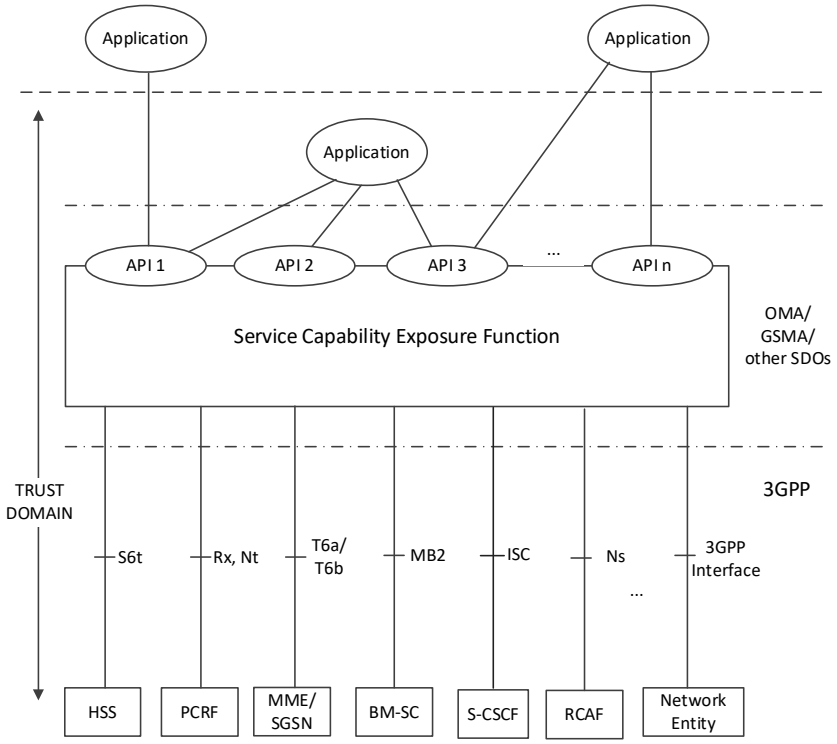

Figure 3.30. 3GPP Architecture for Service Capability Exposure.[103]

The Service Capability Exposure Function (SCEF) provides the means to securely expose the services and capabilities provided by 3GPP network interfaces, for external parties to discover the exposed service capabilities and access to network capabilities through homogenous network application programming

[103] TS 23.682.

interfaces (e.g., Network API) defined by OMA, GSMA and other standardization bodies. The SCEF abstracts the services from the underlying 3GPP network interfaces and protocols.

The SCEF is always within the trust domain of a network operator. An application can belong to the trust domain or may lie outside the trust domain.

The functionality of the SCEF includes the following:

- Authentication and Authorization of external entities connecting/querying SECF
- Ability for the external entities to discover the exposed service capabilities
- Policy enforcement: e.g., infrastructural policies to protect platforms and network, business policies and application layer policies
- Assurance: including integration with O&M systems, assurance process related to usage of APIs
- Charging: record Monitoring Events
- Access: issues related to external interconnection and point of contact
- Abstraction: hides the underlying 3GPP network interfaces and protocols to allow full network integration

Besides defining the SCEF, the AESE study has also concluded with solutions to the additional key issues:

Key issue 2: setting up an AS session with required QoS: the solution with SCEF interworking with the PCRF is agreed

The main idea is when the SCEF receives the API request from the 3rd party AS to provide QoS for an AS session, the SCEF transfers the request to provide QoS for an AS session to the PCRF via Rx interface.

Figure 3.31 illustrates the interactions between AS, SCEF and PCRF in this solution.

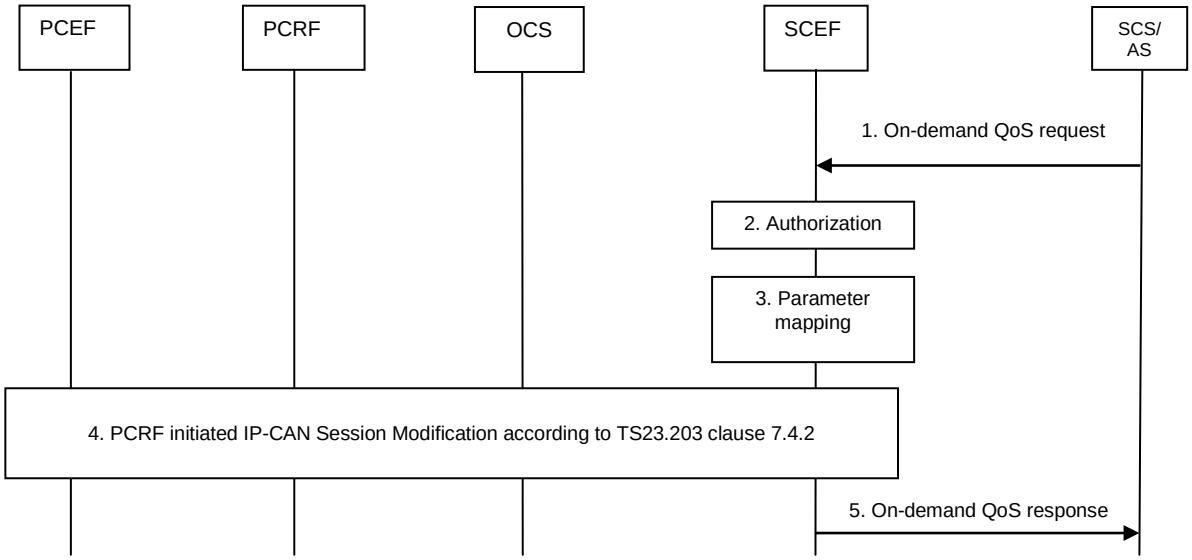

Figure 3.31. Setting up an AS session with required QoS.[104]

When setting up the connection between the AS (Application Server) and the UE with required QoS for the service, the AS sends an on-demand QoS request (UE IP address, SCS/AS Identifier, SCS/AS Reference ID, and/or description of the application flows reference to a pre-defined QoS) to the SCEF. Optionally, a period of time or a traffic volume for the requested QoS can be included in the Service Capability Server (SCS)/AS request. The SCEF authorizes the AS for the connection and QoS request and may apply policies to control the overall amount of pre-defined QoS authorized for the SCS/AS.

The SCEF then transfers the request to provide QoS for an AS session to the Policy Control and Charging Rules Function (PCRF) via the Rx interface. The PCRF derives the required QoS based on the information provided by the AS and determines whether this QoS is allowed based on network policy and the current network load status, and notifies the result to the SCEF. As specified in TS 23.203, the PCRF generates the PCC rules for the service based on the requested QoS and provides these PCC rules to the Policy and Charging Enforcement Function (PCEF).

NOTE: The concept of requesting a pre-defined QoS is specified by OMA in the Representation State Transfer (RESTful) Network Application program Interface (API) for Quality of Service. The pre-defined QoS is part of the Service Level Agreement (SLA) between the operator and the 3rd party AS.

Key issue 3: change the chargeable party at the session set-up or during the session: the solution with SCEF and PCRF interworking is agreed

The main idea is that for sessions terminating to an AS, the 3rd party indicates the expected chargeable party to the SCEF, and then the SCEF transfers the request to change the chargeable party to the PCRF via the Rx interface. When setting up the connection between the AS and UE, the AS may request to become the chargeable party at the beginning or may request to become the chargeable party at a later point in time for the session to be set up according to the procedure in clause 6.4.1.1 of TR 23.708 (AESE). This is existing PCRF functionality defined in TS 23.203 for sponsor connectivity that is now exposed via the SCEF.

[104] TS23.682: *Architecture enhancements to facilitate communications with packet data networks and applications.*

Key issue 4: support of network resource optimization: the solution with 3rd party AS interaction on information for predictable communication patterns is agreed

The solution defines the mechanism to provide relevant information of a communication pattern of a UE or a group of UEs to the corresponding core network node in order to provide the derived network resource optimizations for such UE(s).

The SCEF may receive communication patterns for the data traffic and/or the mobility pattern. Examples of parameters that may be contained in these communication patterns include: the UE's data traffic and mobility communication patterns, such as: periodic communication indicator, timer, duration and average data value per communication, stationary indication and location, mobility area and average speed, etc.

The SCEF derives appropriate network parameters based on the received communication pattern from the 3rd party service provider, and provides the derived network parameters to selected appropriate functional entities (e.g., MME, eNodeB, etc.). For example, the AS provides the corresponding Communication Pattern (CP) to the SCEF, which then authenticates and authorizes the request and selects appropriate network parameters based on operator policy and provides them to the corresponding MME(s). The MME uses the CP for deriving the CN assisted eNB parameters and also takes the local network conditions and local configuration into account and stores them.

The possible use of these parameters includes: the CN assisted parameters provide the eNB with a way to interpret the UE behavior like expected "UE activity behavior" and/or "expected Handover (HO) interval"; or the MME provides CN assistance information to the eNodeB if available, during the setup of the S1 signaling connection (e.g., Attach, Service Request, etc.).

Key issue 5: informing the 3rd party about potential network issues: the solution using the RAN user plane congestion solution (defined as part of Rel-13 UPCON work along with the SCEF framework) is agreed

Key issue 6: 3GPP resource management for background data transfer. The agreed solution is described as follows:

> The SCEF receives the API request from the 3rd party for a background data transfer to UEs, including the desired time window for the data transfer and the volume of the data expected to be transferred. The SCEF identifies the corresponding policy group as well as the PCRF responsible for it and sends the request to the PCRF. The PCRF determines a transfer offer including one or more recommended time windows for the AS data transfer together with a maximum aggregated bitrate for the set of UEs and a charging rate. The SCEF forwards the transfer offer to the 3rd party AS. If the transfer offer contains more than one time window, the 3rd party AS selects one of the time windows and informs the SCEF about it (which forwards this to the PCRF). When the selected time window starts the PCRF triggers PCC procedures according to 3GPP TS 23.203 [7] to provide the respective group policing and charging information to the PCEF.

More details on AESE are captured in TR 23.708.

3.3.4.3 OPTIMIZATIONS TO SUPPORT HIGH LATENCY COMMUNICATION (HLCOM)

This Work Item studies system enhancements to support: the scenario where applications communicate with temporarily unreachable devices (could be for a long period) over the 3GPP IP connectivity; and the

ability to support large numbers of such devices in the system without negatively affecting the system performance.

The specific scenario is the downlink access for devices that are not reachable for a long period, e.g., due to the UE being in Power Saving Mode (PSM) and the problems associated with such devices such as packet discard when the UE sleeps, frequent retransmissions, load on the CN network, waste of radio resources and UE power when the network unnecessarily conveys retransmit packets, etc.

Currently, when downlink data arrives for a UE that is in EPS Connection Management Idle (ECM-IDLE) mode, at least one IP packet is buffered in the SGW and the UE is paged. When the UE responds to the paging, the buffered IP packet(s) is transmitted to the UE. If there is no paging response within an SGW implementation specific period of time, the packets are discarded. When downlink data arrive for a UE that is in a power saving state, such as PSM, or is temporarily unavailable, or in extended idle mode due to DRX (Discontinuous Reception), the IP packets are immediately discarded in the SGW. No paging is done for the UE. This can result in:

- Higher load on the network
- Difficulty to reach devices that use power saving functions
- Applications being required to handle frequent transmission failures of transport protocols
- Frequent use of device triggering at network initiated communication with devices using power saving functions

Particularly for the cases where the device is reachable again in a reasonable amount of time, the current behavior may lead to:

- Application layer attempts which may be out of sync with the actual UE availability, which would cause extended latency to reach the UE or lack of reachability
- Difficulty to reach devices that use extended DRX, which could make cellular a less preferred choice, for example for Internet of Things and MTC applications

To solve or minimize the above problems, multiple solutions are agreed:

- For cases where the expected temporary unavailability for DL data reachability is compatible with the delay tolerance of the application layer and transport protocols, the DL data can be buffered in the SGW/Gn-SGSN so that when the UE is available again, the data can be immediately delivered. The MME/SGSN, when it receives a Downlink Data Notification (DDN), would check whether this optimization for HL communications is applicable, i.e., it checks whether the UE applies features that cause high latencies like PSM or eDRX. If so, it would immediately return a DDN ACK with the request to store packets for up to a DL buffering time T and to not send any further DDNs until the timer T expires. The MME/SGSN remembers that paging is needed at the next occasion or that RAB(s) need to be set up when the UE becomes reachable. The SGW then buffers the DL packet(s) and waits for the establishment of the S1-U/S12/Iu bearers for the UE, or until time T has elapsed. The SGW may discard all buffered packets that are stored longer than time T. While there are packets in the buffer or the timer T is running, the SGW does not issue any additional DDN upon receiving any additional DL packet for the same UE. And if more than a SGW-decided number of packets are received, the SGW also starts discarding packets.

- For coordinating with the AS/SCS when downlink data can be sent to a UE that uses PSM or eDRX, two solutions are agreed to allow AS registering with network nodes for UE availability notice:

    - The AS registers with the SCEF. If an SCS/AS wants to send downlink data to a sleeping UE (e.g., to a UE that is adopting Power Saving Mode), the SCS/AS registers a new onetime "UE reachability" monitoring event via the SCEF-interface/API in order to detect delivery availability. Then the SCS/AS sends MT data only when the UE is reachable (i.e., when the SCS/AS receives a 'UE reachability' notification)

    - The AS registers with the HSS via the SCEF. In this solution, the AS contacts the SCEF to subscribe with the HSS for "Notify on available" event notification. The registration is made known to MME/SGSN. The AS will get notification from the MME/SGSN via the SCEF only when the UE becomes reachable

- For coordination of maximum latency between the application and the network, two solutions are agreed:

    - Through the use of coordination between the UE and the application for setting of PSM maximum response time (with which the application is tolerant for the initial IP packet transmission). The application either pre-configures the UE or coordinates online with the UE for the "maximum response time". When the parameters for PSM and eDRX are set in the EMM/GMM NAS requests and sent to the MME/SGSN, the MME/SGSN checks the received parameters and time values and sets relevant MME/SGSN timers based on the received time values, operator policies and network configuration, and returns the negotiated Active time and Extended Periodic Timer in the NAS response. The end-to-end experience should be that any (initial) MT data does not exceed the maximum response time conveyed.

    - Through the parameter setting on Maximum latency in monitoring event configuration from the SCS/AS to the SCEF, as defined in MONTE for the UE Reachability event. This is documented in TR 23.789 for MONTE.

The HL com study result is captured in TR 23.709.

3.3.4.4 GROUP BASED ENHANCEMENT (GROUPE)

Based on the requirements in TS 22.368 sec 7.2.14, to optimize handling of groups of MTC devices in the network, this work studies and evaluates architectural enhancements required for Group-based features. In Rel-13, the following key issues have been studied and concluded:

1. Message Delivery to a Group of Devices

Group-based messaging can be used to efficiently distribute the same message (e.g., a trigger request) to those members of an MTC group that are located in a particular geographical area on request of the SCS (Service Capability Server).

Proposed solutions based on cell broadcasting, MBMS, using PDN connections, and T4 message delivery are studied. It is agreed that the MBMS architecture is re-used for group message delivery. The BM-SC (Broadcast Multicast Service Centre) allocates a TMGI (Temporary Mobile Group Identity) for a specific MBMS user service.

In the solution, the SCEF is connected to the BM-SC. SCS/AS provides both the content to be broadcasted and additional information to SCEF.

Figure 3.32 shows the group message delivery architecture.

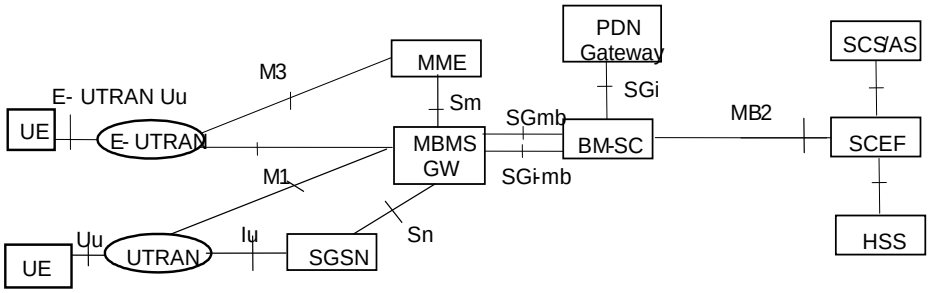

Figure 3.32. MBMS Based Group Messaging Architecture.[105]

The SCEF authenticates and authorizes the SCS/AS requests. SCEF interrogates the appropriate HSS to determine if a SCS/AS is allowed to send a group messaging request to a particular group, and to ask for a TMGI allocation. If the TMGI and frequency are not provided by the SCS/AS, SCEF obtains the TMGI and frequency of the MBMS bearer from the BM-SC; otherwise, the TMGI that was provided by the SCS/AS in the group message delivery request is used. The SCEF optionally includes some parameters, such as TMGI, geographic area of delivery, delivery schedule, and group message content in the Activate MBMS Bearer Request message and forwards the message to the BM-SC. This will trigger the session start procedure based on the service areas. The SCEF or SCS/AS provides the group message content to the BM-SC on the MB2-U interface at the scheduled time; the SCEF can also generate Call Detail Records (CDR) for the session.

Group message delivery using MBMS is more suitable to deliver a group message to a large group membership in a geographical area. This solution has limited applicability and does not support all the scenarios (e.g., UEs not supporting MBMS and UEs sitting in areas where MBMS is not deployed).

2. Group Based NAS Level Congestion Control

Devices that belong to a predefined group may overload the MME by generating a large amount of NAS signalling. For example, a particular group of devices may continuously try to connect to a non-responding server and do so by repeatedly (and successfully) re-attaching to the network during the recovery phase of this particular server. This causes a significant amount of unnecessary attach procedures and, depending on the number of affected devices, this may disturb or even hinder the attach procedures of other UEs that do not relate to the failure of the MTC server.

The key issue is how the network determines that UEs belonging to a specific group are causing NAS signalling overload/congestion, in order to provide a mechanism for the MME/SGSN to distinguish attach requests originating from this group of devices, which is to be identified by the proposed group identifier, and in order to apply existing NAS level mobility management congestion control schemes.

[105] TR23.769: *Group based Enhancements.*

A 3GPP internal group identifier “internal-group-id” is used to identify the group to which the UE belongs. It is part of the subscriber data in the HSS and is sent by the HSS to the MME/SGSN as part of normal EPS signaling.

The determination of NAS signaling overload/congestion is at individual MME/SGSN granularity. The MME/SGSN may detect the NAS signaling congestion associated with the Group and start and stop performing the Group-based congestion control based on criteria such as:

- Maximum rate of EPS Bearer activations per Group
- Maximum rate of mobility management signaling requests associated with the devices of a particular Group based on per Group thresholds
- Maximum rate of EPS Bearer activations per Group and APN
- Maximum rate of session management signaling requests associated with the devices of a particular Group and a particular subscribed APN based on Group and APN thresholds
- Settings in network management

Similar mechanisms as defined in TS 23.401 for APN-based congestion control will be used to address congestion control for group based mobility management and session management signaling. Group_ID-list is added in HSS data and MME MM bearer control data in TS 23.401.

4. Group Based Addressing and Identifiers

Group-based addressing and identifiers are essential to support group-based features such as: delivery of group messaging and group policing; to determine if a subscription is a member of a specific group; or to address the individual devices within a group. A group membership can involve 100s or 1000s of group members. Different types of groups exist, including those that have a relatively static membership and those that have more dynamic memberships.

SCS/AS specific groups are identified by External-Group-IDs. A 3GPP device can host multiple applications, and the identity of a 3GPP device can be bound to more than one External-Group-ID. The Service Capability Server (SCS) / Application Server (AS) can create new groups with associated group members, and can remove existing groups.

Some group operations require that core network nodes, e.g., the HSS or MME, be aware of the membership of UEs in the group, for example, group-based APN congestion, roaming status of all members of a group, and counting of devices belonging to a group in a given area. This solution uses maintenance of the group membership at the HSS, and so will be more applicable to groups that have a relatively static membership (to avoid heavy impact on the HSS) and require that the HSS and other core network nodes be aware of the group membership.

The proposed solution provides two building blocks that other SCEF services can use:

- the ability to determine the Internal-Group-ID and the Internal-IDs of group members based on an External-Group-ID and optional External-IDs provided by the SCS/AS, and
- the ability to request that the HSS add or remove an Internal-ID from a group that the HSS maintains

The study result is documented in TR 23.769. Technical Specification TS 23.401 and 23.682 have been updated for group-based enhancement features. The 3GPP Architecture for Service Capability Exposure diagram (Figure 3.30) in TS 23.682 is updated with the BM-SC to SCEF interface (MB2).

3.3.4.5 EXTENDED DRX CYCLE FOR POWER CONSUMPTION OPTIMIZATION

In Rel-13, a work item for extended DRX cycle for UE power consumption optimization provided the means to substantially extend the normal DRX cycle. This work was initiated as part of Rel-12 work on MTC Power Consumption Optimization. Extended DRX for idle mode and connected mode are both addressed. The SA2 and CT1 work focuses on the implications in the core network and the 3GPP system in general, considering especially WB-E-UTRAN and NB-IoT access. For detailed RAN aspects, see clauses 3.1.14 and 3.2.2.

The following aspects are being studied for long extended DRX cycles of up to about 44 minutes in WB-E-UTRAN and almost 3 hours in WB-IoT:

For Idle Mode DRX:

- Support for NAS-protocol extensions to enable an extended DRX cycle. There needs to be coordination between UE and Core Network (SGSN/MME) for use of extended DRX
- Paging strategy in CN that fits the needs of the extended DRX cycle and normal DRX cycle
- Handling of MT SMS and MT CIoT Small Data retransmissions during long DRX cycles
- Determination of whether to buffer the MT message or to indicate UE unreachability (using HLCOM procedures)
- Impact in S/P-GW and SCEF retransmissions when handling Network originated control plane procedure
- Handling CN entity restart
- Interaction between eDRX and PSM (Power Saving Mode)
- MT Location services support

For Connected Mode DRX:

- How SGSN/MME is aware of GERAN/RAN enabling extended connected mode DRX, particularly for long DRX values
- Handling NAS retransmissions timers for DRX values longer than the currently specified values
- Handling of MT Short Messaging Services (SMS) and MT location services (e.g., avoiding retransmissions for long DRX cycles)
- Impact in S/P-GW retransmissions when handling network originated control plane procedure

The standards work has been completed as part of 3GPP Rel-13. The Extended DRX cycle is negotiated between the UE and the network during attach and TAU procedures. The MME will store the negotiated eDRX parameters (eDRX cycle length, Paging Transmission Window length) for later use in MT message delivery towards eDRX UE.

When there is an incoming MT message, either SMS or CIoT small data, the stored eDRX cycle parameters allow the MME to determine when the next Paging Opportunity is going to occur. Based on this, the MME may choose to buffer the MT message, or request SGW or SCEF to do the buffering. For very long UE unavailability period, the MME may also use the HLCOM procedures to indicate UE unreachability.

The main eDRX requirements for the UE and the network are captured in 3GPP TS 23.682, 23.401 and 24.302.

3.3.4.6 MONITORING ENHANCEMENTS (MONTE)

As part of Rel-13 Machine Type Communications (MTC) projects, this work item studies, in particular, the ability to monitor various aspects of device operation. A primary mechanism was defined that allows an application (e.g., an SCS/AS as defined by oneM2M) to be able to access the set of capabilities required for monitoring via different 3GPP interfaces/nodes, e.g., HSS via Sh (with enhancements), or PCRF via Rx (with enhancements), or MME/SGSN via the new interface T6a/T6b to SCEF.

The mechanism defined involves the use of the AESE architecture as described in section 3.3.4.2 of this paper. The SCS/AS accesses the Service Capability Exposure Function (SCEF) which can use any of the 3GPP defined interfaces that the PLMN operator has chosen to expose. The SCEF is inside of the PLMN operator's trust domain and therefore able to apply PLMN operator policies. The SCEF can use a new interface (S6t) to insert the trigger into the HSS. If the HSS can supply the answer in a single report, it does so immediately to finish the request. If the serving MME/SGSN is the entity that must satisfy the request, the HSS uses existing procedures to send the trigger to the serving MME/SGSN. If the request can be satisfied by a single report, the report can be sent to the HSS to be sent to the SCEF, and finally back to the SCS/AS. If, however, the request involves multiple reports, the serving MME/SGSN can send the reports directly to the SCEF. Of course, since the SCEF can apply PLMN operator policies, the reports may be filtered before being sent to the SCS/AS.

The events and data that are supported in Rel-13 are:

- Single report of roaming status or serving network of UE
- Change in roaming status or serving network of UE
- Single report of current location of UE
- Single report of last known location of UE
- Reporting upon change of location area
- Continuous reporting of location
- Change in association of the MTC device and UICC
- Loss of connectivity

- UE reachability
- Communication failure
- Reporting the number of UEs present in a certain area

A new interface, named T6a/T6b, from the MME/SGSN to the SCEF is defined in Rel-13 to support delivery of reports from the MME/SGSN to the SCEF.

The mechanism for monitoring described here is generic, in the sense that additional events and data requests can be supported using this same mechanism, if there is an agreed need in the future to do so.

The study report is captured in TR 23.789, and the specification TS 23.682 is updated for the architecture and features.

3.3.5 PAGING POLICY DIFFERENTIATION FOR INTERNET PROTOCOL MULTIMEDIA SUBSYSTEM (IMS) VOICE OVER E-UTRAN AND OTHER PAGING OPTIMIZATIONS

Packet core signaling in the early deployments of large-scale LTE networks is significantly higher than in existing 2G/3G core networks. The paging traffic generated by MMEs to UEs in idle state to support a network service request appears to be significant and to represent a substantial part of the total signaling load on the MME (e.g., in dense metropolitan areas). This is partly due to the flatter IP architecture of LTE where the macro and metro cells are directly connected to the MME, and to the increase of the paging load caused by M2M or other applications installed on smart phones.

Prior to 3GPP Rel-13, MNOs can apply different paging strategies for services carried over different EPS bearers (the MME can use the EPS bearer context information identified by the EPS bearer Identity received in the Downlink Data Notification message from the SGW in order to control the paging based on operator policy). Paging strategies may include:

- The paging retransmission scheme (e.g., how frequently the paging is repeated or with what time interval)
- Determining whether to send the Paging message to the eNodeBs during certain MME high load conditions
- Whether to apply sub-area based paging (e.g., first page the UE in the last known E-UTRAN Cell Global Identifier (ECGI) or Tracking Area (TA) and retransmission in all registered TAs)

Tailoring the MME paging strategy for each type of service allows for reduction of the paging signaling load while still matching the expectations for each type of service in terms of quality of service.

Prior to 3GPP Rel-13, IMS Voice and other IMS services (e.g., SMS and other non-voice services) could only share the same paging strategy as they are using the same IMS signaling bearer.

Voice over E-UTRAN calls typically require a more aggressive paging strategy (e.g., due to the user awareness of the call setup time) than other non-voice services. A more aggressive paging scheme maximizes the probability of success on first page attempt. Applying the same aggressive paging strategy for all services using the IMS signaling bearer, regardless of whether these services correspond to IMS voice or not, causes an undesirable increase of the paging load for non-voice over E-UTRAN services.

When termination attempts for non-voice over E-UTRAN services occurs at a rate of 2 to 3 times that of termination attempts for voice over E-UTRAN services, a significant savings of radio and MME resources can be achieved by using a less aggressive paging strategy for the non-voice services.

Paging Policy Differentiation for IMS Voice over E-UTRAN is a new optional feature specified in Rel-13, which allows the MME, based on operator configuration, to apply different paging strategies in LTE access for VoLTE vs. other services carried over the IMS signaling bearer.

This feature is illustrated in an example shown in Figure 3.33.

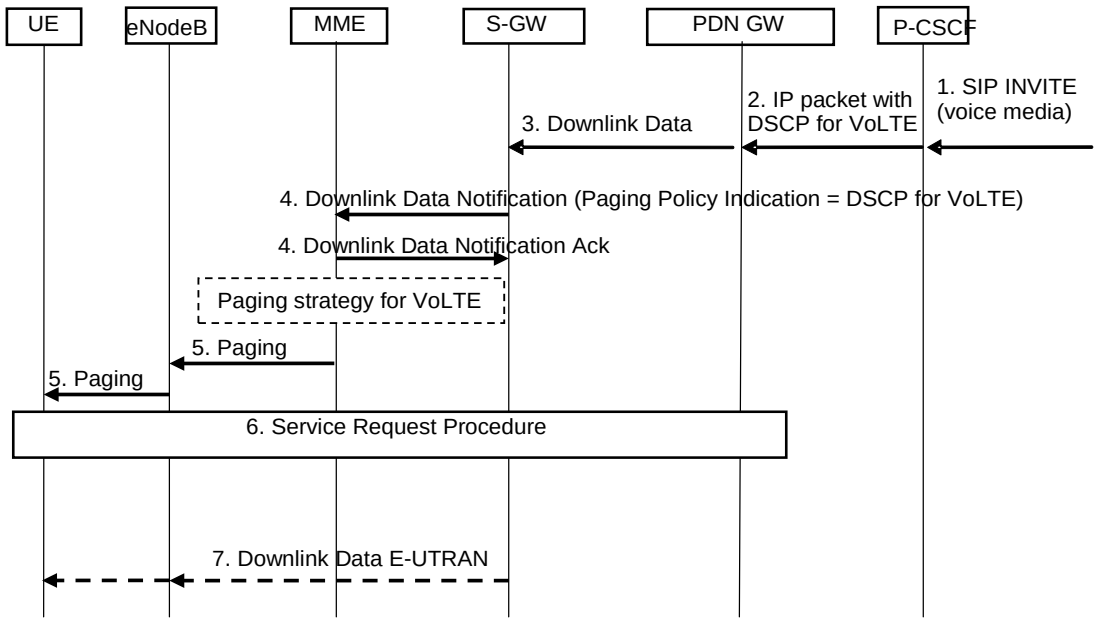

Figure 3.33. Paging Policy Differentiation for IMS Voice over E-UTRAN.

1. The determination of whether an IMS signaling packet sent towards the UE should be subject to paging policy differentiation for IMS Voice is made by the P-CSCF. The P-CSCF indicates whether a packet carrying IMS signaling deserves a specific paging strategy using a specific Differentiated Services Codepoint (DSCP) (IPv4) / Traffic Class (IPv6) value, which is configured on the P-CSCF and the MME. PGW remains unchanged.

2. When it supports Paging Policy Differentiation feature, the Serving GW provides the MME with a Paging Policy Indication, containing the DSCP in Type of Service (TOS) (IPv4) / Traffic Class (TC) (IPv6) information received in the IP payload of the GPRS Tunneling Protocol User Plane (GTP-U) packet from the PGW, in the Downlink Data Notification.

3. The Paging Policy Indication received in the Downlink Data Notification is used by the MME to determine whether Paging Policy Differentiation for VoLTE is required for a UE in idle mode.

Operators can configure the MME in such a way that the Paging Policy Indication only applies to certain Home Public Land Mobile Networks (HPLMNs) and/or APNs and/or QCIs.

The previously described enhancements are expected to be finalized in Rel-13. It should be noted that there is no RAN impact.

Rel-13 also brings two additional paging optimizations:

- The first paging optimization, for MTC UEs in enhanced coverage, consists in the eNB uploading the Enhanced Coverage capability to the MME in the S1 UE CAPABILITY INFO INDICATION message. The MME stores this information in the MME context and, when it needs to page the UE, the MME forwards it to the eNB as part of the S1 paging message. This information is transparent to the MME and contains the list of frequency bands supported by the UE. The eNBs selected for paging will use it to optimize over the air paging.

  Additionally, when S1 is released, the eNB provides the MME with the Enhanced Coverage level for paging (number of repetitions for MPDCCH) and the cell ID provided by the last eNB the UE was connected to. The MME stores this information and includes them in every subsequent Paging message to eNBs selected for paging.

- The second optimization, called "general paging optimization", consists of the following features:
  - At S1 Release, the eNB may provide the MME with a list of recommended cells and eNBs for paging. This information is derived by the eNB from, among other things, the list of cells the UE has visited and the corresponding durations of stay. The MME stores this information and, when it needs to page the UE, the MME takes the eNB related part of this information into account to determine the eNBs to be paged.
  - Furthermore, the MME provides the information on recommended cells (which is transparent to the MME) within the S1 Paging message to each of these eNBs.

The MME may provide the paged eNBs with a Paging Attempt Information, containing a Paging Attempt Count and the Intended Number of Paging Attempts. The Paging Attempt Count shall be increased by one at each new paging attempt.

3.3.6 ENHANCEMENTS TO WEBRTC INTEROPERABILITY (eWebRTCi)

Continued from Rel-12 WebRTC (Web Real-Time Communications) work, this work item studied the use case that WebRTC clients' IMS subscription correspond to the third party managed users, e.g., corporate users or the users of a web service such as a game, where a range-IMPU corresponds to a set of IMPU (called "individual IP Multimedia Public Identity (IMPU)") that share the same IMS services. The characteristics of this scenario can be:

- The number of the third party managed users may scale from a small number to a huge number

- The assignment for Public Service ID (PSI) for the third party managed users is left to a 3rd party (Corporate/Web service). This supports flexibility for the 3rd party to manage their services and users. For example, such range-IMPU may be defined in the format of "!.*!@my-game.company.com"

The architecture working group studied three proposed solutions:

Solution 1: uses single HSS subscription for a range of IMPU which is shared by the range of IMPU. An IMS registration of this individual IMPU takes place, including the allocation of the Serving Call Session Control Function (S-CSCF) for this individual IMPU and the retrieval of user subscription from the HSS. The 3rd party is responsible for (where needed) authenticating the end-user and of allocating individual IMPU within the scope of the range-IMPU. The HSS does not perform registration for an individual IMPU. The relationship between individual IMPU and S-CSCF is stored in another Database (DB): the WUDB ("WWW users DB"). I-CSCF is modified to consider the IMPU belonging to the domain associated with WWW users

(e.g., *.*.www@operator.com) as some kind of PSI (Public Service ID). For any incoming request, the I-CSCF looks up the WUDB, instead of issuing a Location information Request (LIR) to the HSS, to find the S-CSCF for the terminating user.

The architecture is shown in Figure 3.34.

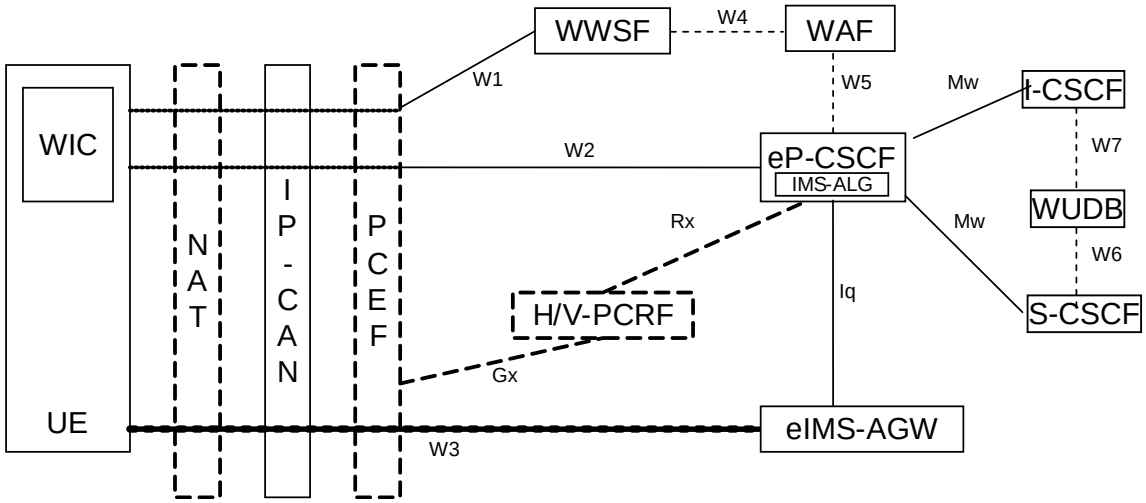

Figure 3.34. Solution 1 Architecture.[106]

This solution has impacts on procedures in the S-CSCF and the Interrogating CSCF (I-CSCF), as well as the new WWW users DB (WUDB) and interfaces W6, W7.

Solution 2: is similar to solution 1, but with different content in WUDB and procedures. It supports 3rd party allocated external identities (non-IMS identities). The solution proposed wIMPU (wildcard IMS Public Identity) with single HSS subscription and with wIMPU Registrar (WUDB) to hold the registration status of WebRTC IMS Clients (WICs) that have been allocated an individual IMPU.

Figure 3.35 shows the solution 2 architecture.

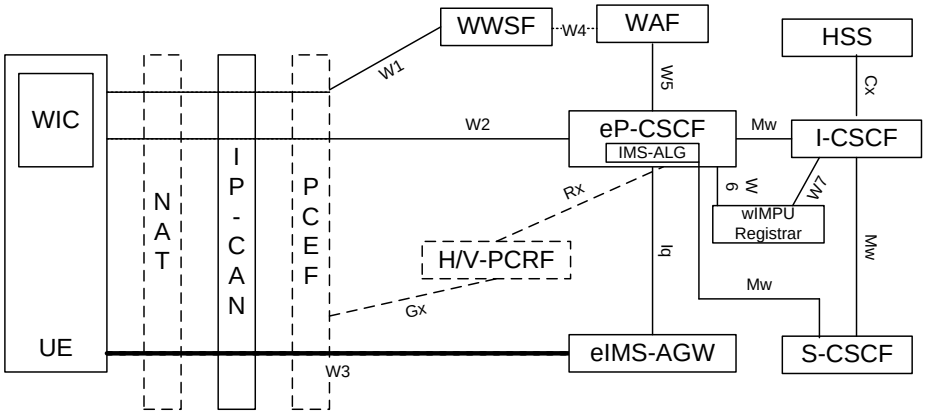

Figure 3.35. Solution 2 Architecture.[107]

[106] TR23.706: *Study on enhancements to Web Real Time Communication (WebRTC) access to IP Multimedia Subsystem (IMS).*
[107] *Ibid.*

The solution supports two options: identities are allocated by the third-party provider or by the IMS provider.

In the second option, WICs (WebRTC IMS Client) can use their external identities for session initiation and termination. IMS identities are allocated to a third-party external user at registration by the eP-CSCF and are only used within the IMS domain. Upon successful WIC authorization of an incoming WIC Registration Request, the enhanced P-CSCF (eP-CSCF) stores the binding between the external (non-IMS) identity and the allocated individual IMPU in the wIMPU Registrar, as well as other relevant registration information for the WIC.

When identities are allocated by the eP-CSCF, the eP-CSCF shall query the wIMPU Registrar for originating sessions to retrieve the registration context and perform the necessary request modification before routing the session using standard IMS originating procedures. When identities are allocated by the third party, the eP-CSCF uses standard IMS originating procedures to handle the request. For terminating sessions, the I-CSCF shall query the wIMPU Registrar to validate the registration status of a called IMPU (or an external WIC identity if identities are allocated by the eP-CSCF), and query the HSS for routing information using standard IMS terminating procedures. The I-CSCF shall use the domain name of the target WebRTC user to distinguish WebRTC users from other IMS users.

This solution has impacts to the I-CSCF and the eP-CSCF and the addition of new WUDB, as well as the W6/W7 interfaces.

Solution 3: proposed using Home Subscriber Server (HSS) to support IMS subscriptions corresponding to users managed by third parties. This solution re-uses Rel-12 WebRTC architecture as shown in Figure 3.36 without modifications.

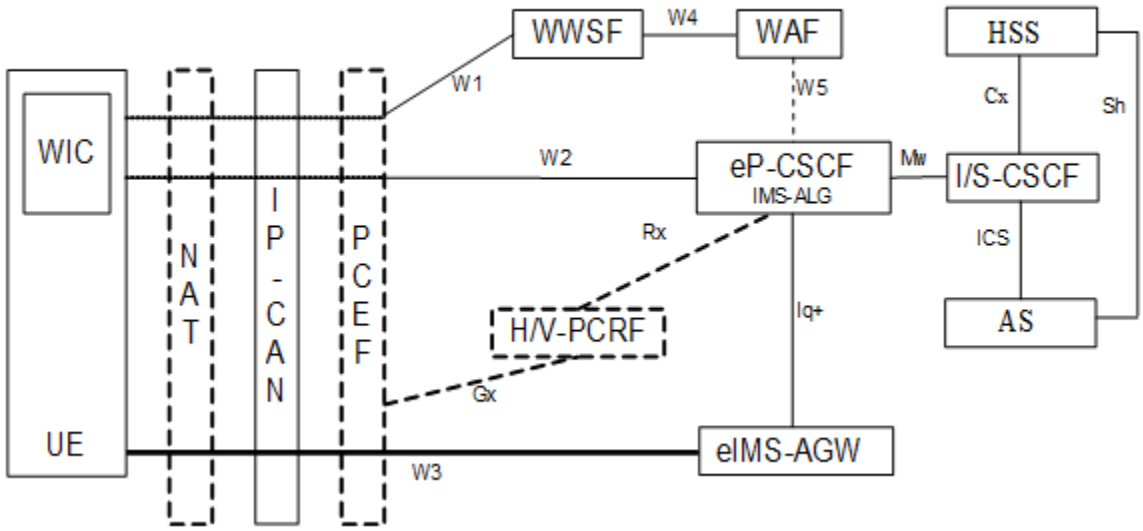

Figure 3.36. Standard WebRTC IMS Architecture.[108]

The 3rd party assigns the IMPUs with a maximum freedom on the IMPU format, i.e., it is not restricted to IMPUs as *.*@operator.com but is also allowed to allocate public IDs as *.*@3rdParty.operator.com without configuring the I/S-CSCF.

[108] TS23.228.

The HSS uses a profile which is configured or provisioned for each class IMPU as a template. During the registration process the HSS creates a normal user profile for the requested IMPU (based on the template) and stores the related S-CSCF address. The HSS may control the number of IMPUs created out of a certain template, if needed. During de-registration of an IMPU, the related user profile may be deleted and becomes free for reuse.

The HSS can also use a profile which is additionally configured or provisioned for each class of IP Multimedia Private Identity (IMPI) as a template. During the registration process the HSS creates a normal IMPI for the requested IMPU/IMPI pair (based on the IMPI template). The HSS may control the number of IMPIs created out of a certain template, if needed. During de-registration of an IMPU/IMPI pair the related IMPI may be deleted and becomes free for reuse. Only if no IMPI is registered with an IMPU, which was created from an IMPU template, can the profile related to that IMPU be deleted and become free for reuse. Such an IMPI template may be associated to a provisioned IMPU or a provisioned/configured IMPU template.

All registrations are handled as individual registrations, i.e., an allocated IMPU looks like a dedicated IMPU towards the I-CSCF and S-CSCF; changes to the I-CSCF and S-CSCF are not required. In this case, the Cx interface remains unchanged and no new interfaces or new protocols are required.

Normal termination call handling is supported. The HSS keeps correct registration states supporting interworking with existing application services (e.g., Network Location (NetLoc), Termination - Access Domain Selection (T-ADS)).

After evaluations and debates, the working group agreed that solution 3 is endorsed for the key issue “Single HSS subscription for an unbounded number of users”. The study result is captured in TR 23.706, and no specification change is needed.

In Rel-13, media plane optimization is possible between Web Real-Time Communication (WebRTC) clients. Basically, when session is between WebRTC clients, IMS (eP-CSCF) is able to disable the media plane interworking at the eIMS-AGWs to allow the audio and chat session to be conveyed without bearer level protocol conversion.

3.3.7 SUPPORT OF ENHANCED VOICE SERVICES (EVS) IN 3G CIRCUIT SWITCHED NETWORKS

The Enhanced Voice Service (EVS) codec was introduced in 3GPP Release 12 to improve IMS VoIP (or MTSI: Multimedia Telephony Service for IMS), mainly for VoLTE. Release 13 has extended the support of the EVS codec to 3G CS voice (over UMTS CS networks), providing higher radio capacity (e.g., at low codec rates) and/or better voice quality for 3G users.

One more general benefit of supporting EVS (also) over UMTS is the seamless / consistent user experience and voice quality between VoLTE and 3G CS, e.g., Transcoding-less operation between a VoLTE user and a 3G user (if both using EVS), as well as no codec-switch during mobility between VoLTE and 3G CS.

Figure 3.37 illustrates some improved user experience examples. Assuming all UEs are EVS capable, e.g., UE1 (VoLTE) can talk seamlessly to UE3 over 3G CS; UE3 can move between LTE and UMTS without codec change/transcoding (likewise for the other end UE, e.g., UE1 or UE2).

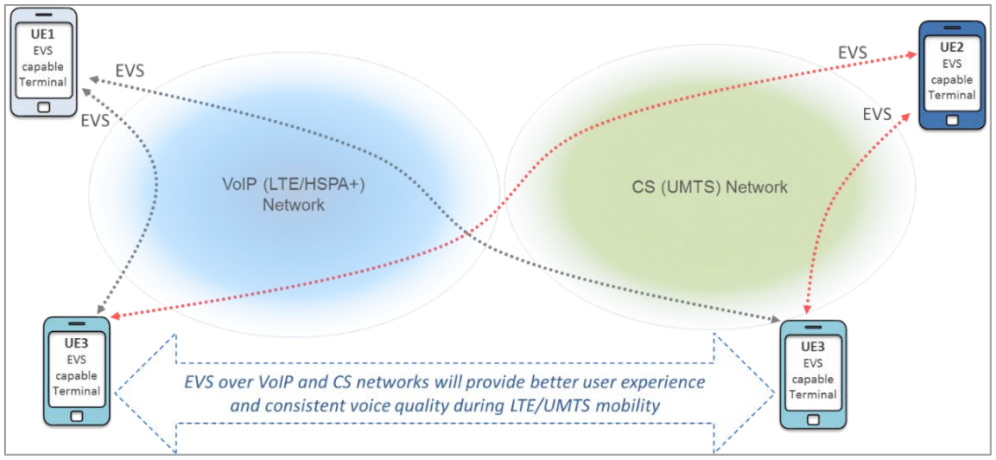

Figure 3.37. Seamless EVS User Experience between/across LTE and 3G Networks.

The EVS codec also supports AMR-WB Interoperable (IO) Modes, i.e., EVS mode sets include AMR-WB codec formats (see more details below) to support backward/seamless interoperability with AMR-WB UEs (i.e., no fallback to AMR-NB or transcoding). Such aspect is shown in Figure 3.38.

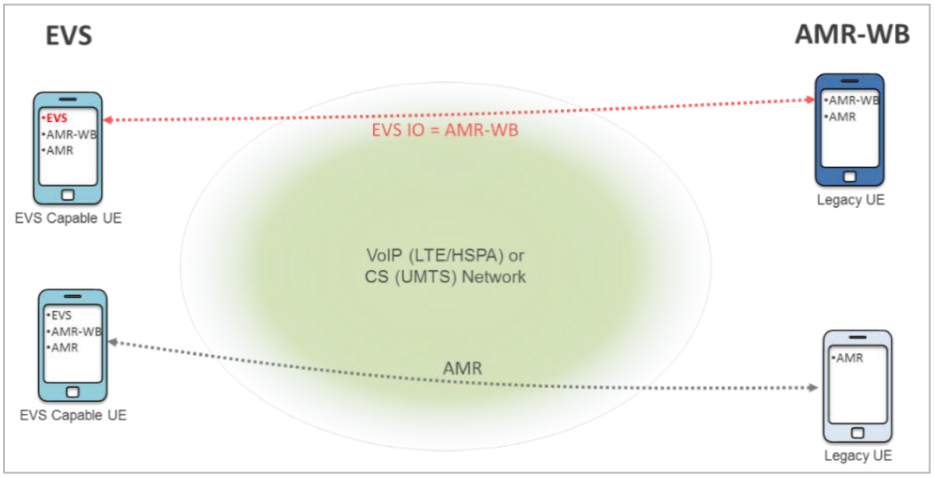

Figure 3.38. Interoperability (Transcoder free) between EVS and Legacy (AMR-WB) Devices.

From an end-to-end implementation and deployment perspective, EVS over CS requires support (small SW upgrade) in various UMTS “CS entities”, i.e., UE, RNC/NodeB, Mobile Switching Center – Server (MSC-S)/Media Gateway (MGW), Media Gateway Control Function (MGCF)/IP Multimedia (IM)-MGW. Existing RAN/CN protocols/signaling can be re-used; main RAN update is the support of new EVS RABs; main CN updates regard the addition of EVS support to those existing “codec” functionalities, e.g., NAS negotiation, Out-of-Band Transcoder Control (OoBTC)/Transcoder Free Operation (TrFO), EVS Session Description Protocol (SDP)-to-Circuit Switched (CS) config translation, transcoding (MGW/Trancoders (TCs)).

On the other hand, if following the rollout of EVS for VoIP, the extra support/cost of EVS over CS is expected to be very minimal. Moreover, EVS over CS can nicely leverage from available/deployed features today, e.g., wide support of TrFO (not the case for earlier codecs, in fact contributing to some rollout delays/issues).

Technical Aspects

Only a subset of EVS codec bit-rates (or modes) are defined for UMTS conversational speech (CS), as listed in following table, together with their bandwidth and source-control attributes.

Table 3.8. Source Codec Bit-Rates for the EVS Codec over UMTS CS.

Source Codec Bit-Rate (kbit/s)	Audio Bandwidths Supported (*)	Source Controlled
5.9 (SC-VBR)	NB, WB	Yes (Always On)
7.2	NB, WB	Yes
8.0	NB, WB	Yes
9.6	NB, WB, SWB	Yes
13.2	NB, WB, SWB	Yes
16.4	NB, WB, SWB, FB	Yes
24.4	NB, WB, SWB, FB	Yes

(*) NB: Narrowband; WB: Wideband; SWB: Super Wideband; FB: Full band

In addition, three codec bit-rates are defined for the AMR-WB Interoperable (IO) Modes: 6.6, 8.85 and 12.65 kbps.

Table 3.9. EVS mode sets for EVS over UMTS CS.

EVS Configuration (Mode Set)→ **↓ Codec Rate (kbps)**	**0**	**1**	**2**	**3**
Typical SF on downlink	256	128	64	128
EVS Primary 24.4			NB-FB	
EVS Primary 16.4			NB-FB	

EVS Primary 13.2		NB-SWB	NB-SWB	SWB
EVS Primary 9.6		NB-SWB	NB-SWB	SWB
EVS Primary 8	NB-WB	NB-WB	NB-WB	
EVS Primary 7.2	NB-WB	NB-WB	NB-WB	
EVS Primary 5.9VBR (NOTE 2)	NB-WB	NB-WB	NB-WB	
EVS Primary SID	NB-WB	NB-SWB	NB-FB	SWB
EVS AMR-WB IO 12.65		WB	WB	WB
EVS AMR-WB IO 8.85		WB	WB	WB
EVS AMR-WB IO 6.60	WB	WB	WB	WB
EVS AMR-WB IO SID	WB	WB	WB	WB

NOTE 1: Speech / SID payload is complemented by a 7-bit EVS-CMR field for Maximum Rate and Bandwidth Control.

NOTE 2: EVS 5.9 VBR mode includes bit rates 2.8, 7.2 and 8.0 kb/s to achieve 5.9 kb/s average bit rate in active speech segments.

Likewise AMR and AMR-WB, the EVS codec can be used in a number of different configurations over UMTS. These allowed EVS CS configurations, or mode sets, are defined in Table 3.9.

In terms of EVS CS payload sizes, Table 3.10 lists all EVS Primary and EVS AMR-WB IO payload sizes and rates for the application in CS Networks (EVS AMR-WB IO do not include CMR overhead).

Table 3.10. Payload Sizes for EVS Primary Rates in CS Networks.

Rate	Payload Size (bits)	Net Bit Rate for Active Speech (kbps)
No_Data	0	-
EVS Primary SID	48	-

EVS Primary 2.8	56	2,8
EVS Primary 7.2	144	7,2
EVS Primary 8.0	160	8,0
EVS Primary 9.6	192	9,6
EVS Primary 13.2	264	13,2
EVS Primary 16.4	328	16,4
EVS Primary 24.4	488	24,4
EVS-AMR-WB IO SID	40	-
EVS AMR-WB IO 6.6 / 8.85 / 12.65	132 / 177 / 253	6,6 / 8.85 / 12.65

Based on the defined EVS CS mode sets, payload sizes, and other specific radio parameters, new EVS RABs have been defined over the radio interface. Given the improved robustness of the EVS codec, and the good performance of "Equal" Error Protection (EEP) over UTRA-CS (relative to "Unequal" schemes), it was decided to adopt EEP, which simplifies significantly the RAB configuration (e.g., no need for different bit classes and RAB-subflows).

Two types of RABs have been introduced, for each EVS mode set (0-3) listed previously:

- *EVS voice only*: CS (speech) EVS RAB + 3.4kbps SRB
- *CS+PS Multi-RAB (mRAB)*: EVS RAB + PS RAB + 3.4kbps SRB; where PS RAB can be R99 UL/DL (0/0 or 8/8 kbps), R99 UL (8/16 kbps) + HS DL, or HS UL/DL.

3.3.8 ENHANCED DYNAMIC ADAPTIVE STREAMING OVER HTTP (DASH) IN 3GPP

Following the outcomes of a previous study on Improved Support for Dynamic Adaptive Streaming over HTTP (DASH)[109], 3GPP worked on Rel-13 enhancements for DASH-based services, targeting normative aspects and operational guidelines as per relevant gaps identified during the study. DASH was originally defined in 3GPP in Rel-10, and was then moved into a joint project with Moving Pictures Experts Group (MPEG) to develop a global and cross-domain Over-the-Top (OTT) adaptive streaming format. The 3GPP Rel-10 version and the first edition of MPEG-DASH in International Organization for Standards (ISO)/ International Electrotechnical Commission (IEC) 23009-1:2012 were identical for the core parts. After the completion of the first edition in MPEG, DASH was adopted broadly in different industries and also by larger

[109] SP-140485: *New WID on Support of EVS in 3G Circuit-Switched Networks*.

OTT providers. Based on new requirements and deployment experiences MPEG extended DASH over the last few years and created a second edition in 2014. At the same time the DASH Industry Forum developed guidelines, test vectors and an open source reference client to enable broad interoperability across different domains.

DASH was chosen as the media distribution format for many MBMS services. This also resulted in additional requirements with respect to timing, robustness and interoperability.

In the course of the Rel-13 work item, 3GPP SA4 reviewed the 3GPP-DASH specification and updated TS 26.247 in order to align with the development in the industry.

Specifically, the Rel-13 work addressed the following aspects:

- A profile was generated with restrictions and extensions to align with common industry deployments. This enables that the same content can be used in 3GP-DASH as well as for OTT services outside 3GPP user services
- For Live Services, additional tools had added consistent end-to-end latency, robustness and minimum network traffic, also addressing use cases and requirements for MBMS based delivery of DASH formats
- Ad Insertion is a relevant aspect for streaming services, for targeted and personalized ads. The work item addressed different use cases for advanced ad insertion, primarily based on server-side ad insertion. In this case, for ad insertion opportunities, the content may be target to specific user preferences, whereas the main content is identical for all users
- The specification addressed the addition of metadata to support client-based bitrate adaptation using Quality of Experience (QoE) metrics. Specific metadata can be added in order to support this in tracks
- The work also addressed guidelines on how to offer DASH content in MBMS services as well as on potential interfaces between the DASH client and the MBMS client in the device
- Complementary to the work on distribution formats, additional video codecs were added to support full HD and UHD distribution of video services

All work was coordinated in multiple liaison exchanges with the DASH Industry Forum and MPEG DASH to address the harmonization of the industry. With the Rel-13 DASH specification, service providers can address advanced user experiences and use cases, potentially creating new revenue opportunities.

3.3.9 APPLICATION SPECIFIC CONGESTION CONTROL FOR DATA COMMUNICATION (ACDC)

ACDC is an access control mechanism allowing the operator to prioritize/restrict access attempts from specific applications, so as to mitigate overload of the access network and/or the core network. This mechanism is:

- optional at both the network side and the UE side
- applicable to UTRAN (PS Domain only) and E-UTRAN access technologies
- applicable to UEs in idle mode and not applicable to UEs in connected mode

- not applicable to high priority UEs (UEs that are a member of one or more Access Classes 11 to 15)
- not applicable to MMTEL voice, MMTEL video and SMS over IMS (SMS over IP) applications

At a high level, the overall procedure consists of the following:

- The home network configures the UE (e.g., via OMA-DM or the USIM) with up to 16 ACDC categories, ranked in increasing order of probability of being restricted (i.e., ACDC category 1 having the lowest probability of being restricted), and with a list of applications in each of these ACDC categories

- The network broadcasts access control information for each ACDC category as well as an indication of whether ACDC applies to roaming UEs. For E-UTRAN, the access control information consists of a barring factor and a barring timer for each ACDC category. For UTRAN, the access control information consists of a bitmap indicating whether or not each ACDC category is barred

- When an application at the UE triggers an access attempt, the UE checks the ACDC category to which this application belongs, then applies access control per the information broadcast by the network for the corresponding ACDC category. If the application does not belong to any ACDC category, or belongs to an ACDC category not broadcast by the network (for instance if the UE is configured with ACDC categories 1 through 6 but the network only broadcasts ACDC categories 1 through 4), the UE applies access control per the information for the lowest ranked ACDC category broadcast by the network

- If both ACB and ACDC are configured by the network, ACDC overrides ACB

- If the UE is configured for both EAB and ACDC, the UE performs the EAB check before performing the ACDC check

3.3.10 CIOT & NB-IOT

In order to enhance 3GPP systems for the provisioning of IoT E2E communication, between IoT-UEs and service provider platforms, architecture modifications have been introduced on 3GPP systems. The targets are to adapt current 3GPP system to the new IoT requirements (low energy consumption with small and infrequent packets transmissions) and also include new services as subscriber management, security, control plane device triggering, etc.

Figure 3.39 (TS 23.682) shows the current architecture for 3GPP systems for IOT service provision, and connectivity to external Application Servers.

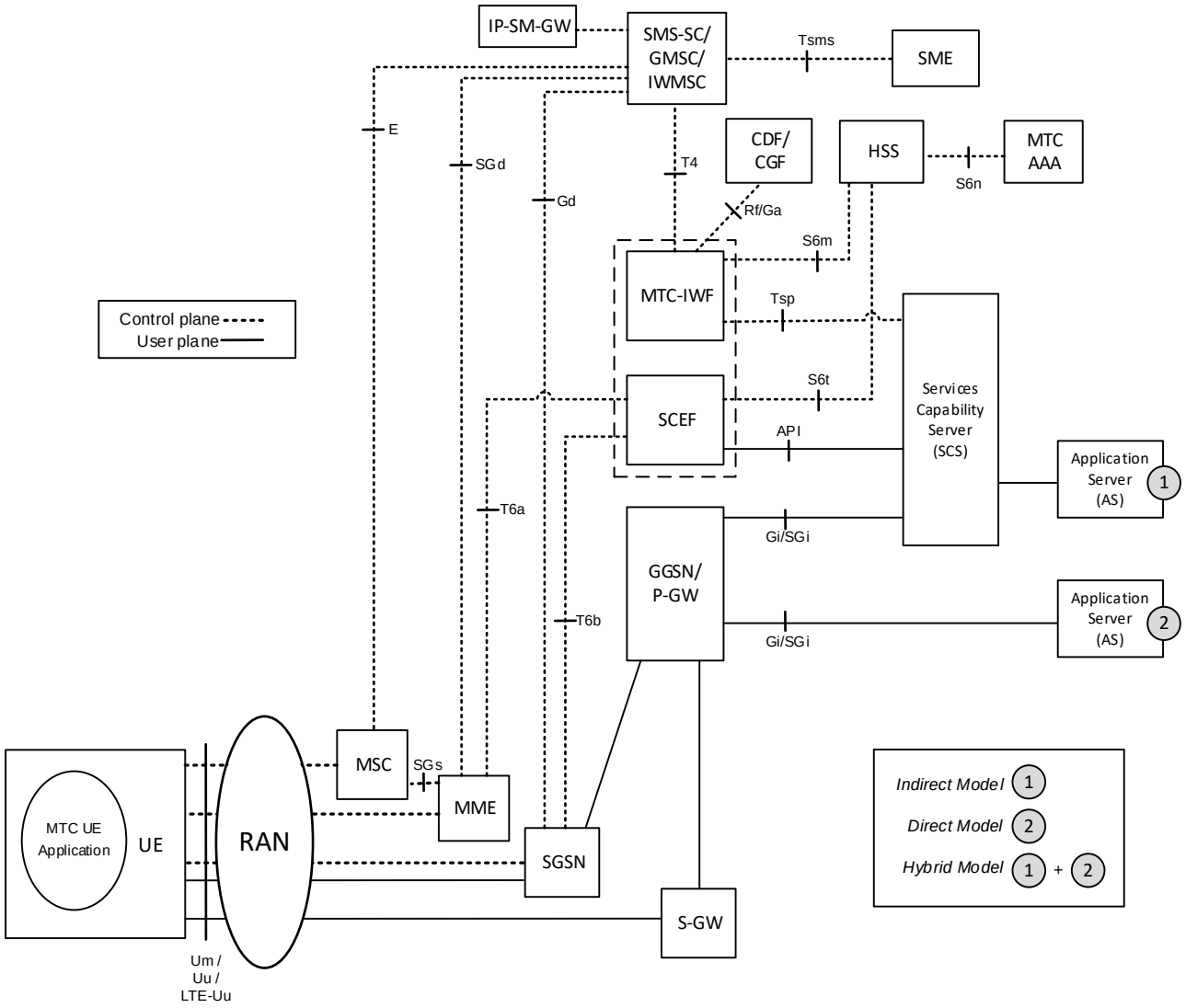

Figure 3.39. Current Architecture for 3GPP Systems for IOT Service Provision and Connectivity to External Application Servers.

As shown in Figure 3.39, external Application Servers may connect directly to the 3GPP network, enabling a direct user plane communication with the UE, or may connect making use of a Service Capability Server (SCS) in order to utilize additional value added services as control plane device triggering. The application server may also use simultaneously both type of connections.

The SCS may be either a 3GPP Network node or external to the 3GPP Network, being the standardized interface (Tsp) connection to the 3GPP MTC Interworking Function (MTC-IWF) as defined in TS 29.368. This interface facilitates MTC value-added services as device triggering.

In Rel-13, Cellular IoT EPS Optimizations provide improved support of small data transfer over control plane and user plane. Control Plane CIoT EPS Optimization transports user data (measurements, ID, status, etc.) via MME by encapsulating user data in NAS PDUs and reduces the total number of control plane messages when handling a short data transaction. Control Plane CIoT EPS optimization, designed for small infrequent data packets, can also be used for larger data bursts depending in UE Radio capability.

User data transported using the Control Plane CIoT EPS Optimization, has special characteristics, as different mobility anchor and termination nodes.

Therefore, the Preferred Network Behavior signaling must include information on:

- Whether Control Plane CIoT EPS optimization is supported

- Whether User Plane CIoT EPS optimization is supported

- Whether Control Plane CIoT EPS optimization is preferred or whether User Plane CIoT EPS optimization is preferred

These optimizations have enabled:

- Non-IP Data Delivery (NIDD) for both: mobile originated and mobile terminated communications, by using SCEF (Service Capability Exposure Function) or SGi tunneling. However, it has to be taken into account that Non-IP PDUs may be lost and its sequence is not guaranteed
- For IP data, the UE and MME may perform header compression based on Robust Header Compression (ROHC) framework
- NB-IoT UE can attach but not activate any PDN connection
- High latency communication handled by the buffering of downlink data (in the Serving GW or the MME)
- SMS transfer
- EPS Attach, TA Update and EPS Detach procedures for NB-IoT only UEs, with SMS service request
- Procedures for connection suspend and resume are added
- Support for transfer of user plane data without the need for using the Service Request procedure to establish Access Stratum context in the serving eNodeB and UE

When selecting an MME for a UE that is using the NB-IoT RAT, and/or for a UE that signals support for CIoT EPS Optimizations in RRC signaling, the eNodeB's MME selection algorithm shall select an MME taking into account its Release 13 NAS signaling protocol.

3.4 RELEASE INDEPENDENT FEATURES

Some 3GPP features are considered release independent. Implementation of a release independent feature in the UE and network is not strictly constrained to the release that first introduces the feature itself, or the releases afterward; its implementation is allowed to go back to earlier releases. One important release independent category is spectrum-related features, including frequency bands and carrier aggregation (CA) combinations.

This section provides information for Rel-13 frequency bands and CA combinations.

3.4.1 FREQUENCY BANDS

Up until the end of Rel-13, 3GPP had defined a total of 48 UTRA/E-UTRA operating bands, as shown in Appendix A Table A-1. Of those 48 bands, 34 are FDD and 14 TDD.

During the Rel-13 time frame, 3GPP defined 6 new E-UTRA bands, four FDD and 2 TDD. They are:

- Band 45 - 1447-1467MHz Band for TD-LTE in China

  Based on TD-LTE technology, the 1447~1467MHz band has been used for radio government trial networks in China to provide data and Push-To-Talk (PTT) voice services in order to achieve instant data collection and real-time visualized command and dispatch. [RP-151037]

- Band 46 - Licensed-Assisted Access to Unlicensed Spectrum

  This work item specifies LTE enhancements for a single global solution framework for licensed-assisted access to unlicensed spectrum which enables operation of LTE in the 5GHz unlicensed spectrum for low power secondary cells using carrier aggregation. [RP-151045]

- Band 65 - 2 GHz LTE Band for Region 1

  Within the European Union, the frequency bands 1980-2010 MHz and 2170-2200 MHz can be used for terrestrial mobile networks. This work item defines a band for LTE in Region 1. [RP-141710]

- Band 66 - AWS Extension Band

  This band comprises and extends E-UTRA Band 4. It features asymmetrical paring, 70 MHz uplink and 90 MHz downlink, fixed duplex, and downlink intra-band CA across 90 MHz span. [RP-150428]

- Band 67 - European 700 Supplemental Downlink band (738-758 MHz) in E-UTRA

  This work item defines an E-UTRA band for the spectrum 738-758 MHz. This spectrum can be used in Europe for Supplemental Downlink.

- Band 68 - 700MHz E-UTRA FDD Band for Arab Region

  This 700MHz band is a potential global band that is planned to be used for LTE/LTE-A networks deployment. The Arab League has recommended that the spectrum of 698-703MHz uplink and 753-758MHz downlinnk can be implemented for IMT. [RP-151042]

The 6 new Rel-13 E-UTRA operating bands are captured in Table 3.11.

Table 3.11. Rel-13 New E-UTRA Operating Bands.

Frequency Band Description	E-UTRA/ UTRA	Band Number	FDD/ TDD	Work Item Description (WID)
1447-1467MHz Band for TD-LTE in China	E-UTRA	45	TDD	RP-151037
Licensed-Assisted Access to Unlicensed Spectrum	E-UTRA	46	TDD	RP-151045
2 GHz LTE Band for Region 1	E-UTRA	65	FDD	RP-141710
AWS Extension Band	E-UTRA	66	FDD	RP-150428
European 700 Supplemental Downlink band (738-758 MHz) in E-UTRA	E-UTRA	67	FDD	RP-150861
700MHz E-UTRA FDD Band for Arab Region	E-UTRA	68	FDD	RP-151042

3.4.2 LTE CARRIER AGGREGATION COMBINATIONS

The number of CA combinations continue to rise in the Release 13 time frame due to new CA band combinations being introduced and new CA configurations being added to the existing band combinations, such as new bandwidth classes, bandwidth combination sets, uplink CA support, etc. This white paper intends to discuss CA in terms of band combinations only, in order to keep the discussion simple.

Compared to Rel-12, Rel-13 had further pushed the CA envelope, to include:

- Inter-band CA with four bands
- Licensed-Assisted-Access – a form of CA that aggregates unlicensed carriers in Band 46 with licensed carriers

Up until the end of Rel-13, there are a total of 212 CA band combinations defined in 3GPP TS 36.101. All the 212 CA band combinations can be grouped into five groups, and the number of CA band combinations are broken down to each group in Table 3.12.

1. Intra-band contiguous CA
2. Inter-band CA (two bands)
3. Inter-band CA (three bands)
4. Inter-band CA (four bands)

5. Intra-band non-contiguous CA (with two sub-blocks)

Table 3.12. CA Band Combinations up to Rel-13 by Groups.

CA Category	CA Band Combination Counts
Intra-band contiguous CA	15
Inter-band CA (two bands)	113
Inter-band CA (three bands)	61
Inter-band CA (four bands)	12
Intra-band non-contiguous CA (with two sub-blocks)	11
Total	212

All CA band combinations up to Rel-13 can be found in 3GPP TS 36.101 V13.4.0, Table 5.5A-1, Table 5.5A-2, Table 5.5A-2a, Table 5.5A-2b, and Table 5.5A-3.

During Rel-13, there were a total of 96 new CA band combinations added. These 96 Rel-13 added CA band combinations are broken down to the five groups in Table 3.13.

Table 3.13. Rel-13 CA Band Combinations by Groups.

CA category	CA band combination counts
Intra-band contiguous CA	3
Inter-band CA (two bands)	43
Inter-band CA (three bands)	35
Inter-band CA (four bands)	12
Intra-band non-contiguous CA (with two sub-blocks)	3

Total	96

All Rel-13 added CA band combinations are captured in Tables 3.14, 3.15, 3.16, 3.17 and 3.18.

Table 3.14 shows the Intra-band contiguous CA operating bands added in Rel-13.

Table 3.14. Rel-13 Intra-Band Contiguous CA Operating Bands.

E-UTRA CA Band	E-UTRA Band
CA_5	5
CA_8	8
CA_66	66

Table 3.15 shows the Inter-band CA operating bands (two bands) added in Rel-13.

Table 3.15. Rel-13 Inter-Band CA Operating Bands.

E-UTRA CA Band	E-UTRA Band			
CA_1-3-3	1, 3		CA_7-40	7, 40
CA_1-40	1, 40		CA_7-42	7, 42
CA_1-46	1, 46		CA_7-42-42	7, 42
CA_2-7	2, 7		CA_7-46	7, 46
CA_2-2-12	2, 12		CA_8-41	8, 41
CA_2-28	2, 28		CA_8-42	8, 42
CA_2-46	2, 46		CA_19-28	19, 28
CA_3-3-5	3, 5		CA_20-31	20, 31

CA_3-3-8	3, 8		CA_20-38	20, 38
CA_3-31	3, 31		CA_20-40	20, 40
CA_3-38	3, 38		CA_20-42	20, 42
CA_3-40	3, 40		CA_20-42-42	20, 42
CA_3-41	3, 41		CA_20-67	20, 67
CA_3-46	3, 46		CA_21-42	21, 42
CA_4-28	4, 28		CA_25-26	25, 26
CA_4-4-29	4, 29		CA_28-40	28, 40
CA_4-4-30	4, 30		CA_28-41	28, 41
CA_4-46	4, 46		CA_28-42	28, 42
CA_5-29	5, 29		CA_38-40	38, 40
CA_5-38	5, 38		CA_41-46	41, 46
CA_5-40	5, 40		CA_42-46	42, 46
CA_7-22	7, 22			

Table 3.16 shows the Inter-band CA operating bands (three bands) added in Rel-13.

Table 3.16. Rel-13 Inter-Band CA Operating Bands (3 bands).

E-UTRA CA Band	E-UTRA Band			
CA_1-3-7	1, 3, 7		CA_2-5-29	2, 5, 29
CA_1-3-28	1, 3, 28		CA_2-7-12	2, 7, 12

CA_1-3-40	1, 3, 40		CA_3-5-40	3, 5, 40
CA_1-3-42	1, 3, 42		CA_3-7-8	3, 7, 8
CA_1-5-40	1, 5, 40		CA_3-7-28	3, 7, 28
CA_1-7-8	1, 7, 8		CA_3-8-40	3, 19, 40
CA_1-7-28	1, 7, 28		CA_3-19-42	3, 19, 42
CA_1-8-11	1, 8, 11		CA_3-7-38	3, 7, 38
CA_1-8-40	1, 8, 40		CA_3-28-40	3, 28, 40
CA_1-11-18	1, 11, 18		CA_3-41-42	3, 41, 42
CA_1-19-28	1, 19, 28		CA_4-4-5-12	4, 5, 12
CA_1-19-42	1, 19, 42		CA_4-5-29	4, 5, 29
CA_1-21-42	1, 21, 42		CA_4-4-5-30	4, 5, 30
CA_2-2-4-5	2, 4, 5		CA_4-4-12-30	4, 12, 30
CA_2-4-4-5	2, 4, 5		CA_4-4-29-30	4, 29, 30
CA_2-4-7	2, 4, 7		CA_7-20-38	7, 20, 38
CA_2-4-30	2, 4, 30		CA_19-21-42	19, 21, 42
CA_2-2-5-12	2, 5, 12			

Table 3.17 shows the Inter-band CA operating bands (four bands) added in Rel-13.

Table 3.17. Rel-13 Inter-Band CA Operating Bands (4 bands).

E-UTRA CA Band	E-UTRA Band
CA_1-3-5-40	1, 3, 5, 40
CA_1-3-7-8	1, 3, 7, 8
CA_1-3-7-28	1, 3, 7, 28
CA_1-3-8-40	1, 3, 8, 40
CA_1-3-19-42	1, 3,19, 42
CA_1-19-21-42	1, 19, 21, 42
CA_2-4-5-12	2, 4, 5, 12
CA_2-4-5-29	2, 4, 29
CA_2-4-5-30	2, 4, 5, 30
CA_2-4-7-12	2, 4, 7, 12
CA_2-4-12-30	2, 4, 12, 30
CA_2-4-29-30	2, 4, 29, 30

Table 3.18 shows the Intra-band non-contiguous CA operating bands (with two sub-blocks) added in Rel-13.

Table 3.18. Rel-13 Intra-Band Non-Contiguous CA Operating Bands.

E-UTRA CA Band	E-UTRA Band
CA_5-5	5

CA_40-40	40
CA_66-66	66

3.4.3 HSPA CARRIER AGGREGATION COMBINATIONS

For HSPA, the only Release-independent band combinations standardized as part of Rel-13 are those related to dual band UL carrier aggregation. In particular, the following configurations have been introduced.

Table 3.19. Dual-Band DL/UL Release Independent Combinations.

UL Bands	Number of UL carriers in Band A/B	DL Band A	Number of DL carriers in Band A	DL Band B	Number of DL carriers in Band B
I and VIII	1	I	1	VIII	1
I and VIII	1	I	2	VIII	1
I and VIII	1	I	2	VIII	2
I and VIII	1	I	1	VIII	2
I and VIII	1	I	3	VIII	1
I and V	1	I	1	V	1
I and V	1	I	1	V	2
I and V	1	I	2	V	1
I and V	1	I	2	V	2
II and V	1	II	1	V	1

II and V	1	II	1	V	2

4 STATUS OF IMT-2020 IN ITU AND 5G IN 3GPP

The International Telecommunications Union (ITU) has played an important role over the past few decades in defining requirements to advance the mobile wireless broadband industry from one technology generation to the next. IMT-2000 was a driving force towards the definition and specification of 3G technologies, and likewise IMT-Advanced played a similar role for 4G technologies. Now the ITU is setting the stage to drive the 5th Generation of mobile wireless broadband technologies, and this section of the paper will discuss the role that IMT-2020 will play towards 5G, and the status of the work on IMT-2020.

4.1 SPECIFYING IMT-2020 – THE ITU-R ROLE

This section discusses in detail the work occurring in ITU-Radiocommunication Sector (ITU-R) including the vision towards 5G and the timeline, process and scope of work for IMT-2020.

4.1.1 ITU-R & WORKING PARTY 5D

ITU continues to work closely with administrations, network operators, equipment manufacturers and national and regional standardization organizations to include today's 5G research and development activities in the IMT-2020 global standard for mobile broadband communications. Coordination among ITU-R, ITU-Telecommunication Standardization Bureau (ITU-T), Standards Development Organizations (SDOs) and industry organizations at national and regional levels is in place, and information is being bi-directionally liaised to provide a unified perspective on the development of the 5G technology at both the radio access and core network levels.

With the finalization of its work on the vision for 5G systems, ITU-R has now defined the overall goals, process and timeline for the development of 5G mobile systems. ITU-R has also agreed that the work should be conducted under the name of IMT-2020, as an extension of the ITU's existing family of global standards for International Mobile Telecommunication systems (IMT-2000 and IMT-Advanced), which serve as the basis for all of today's 3G and 4G mobile systems.

Working Party 5D has moved forward in its published work plans continuing to focus on the finalization of IMT-2020 technical performance requirements, relevant evaluation criteria for IMT-2020 and impacts related to current spectrum, recent spectrum decisions stemming from World Radio Conference 2015 (WRC-15) and future spectrum in the newly initiated activities for the World Radio Conference 2019 (WRC-19).

Figure 4.1 illustrates the IMT-2020 roadmap. For additional details, see www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx.

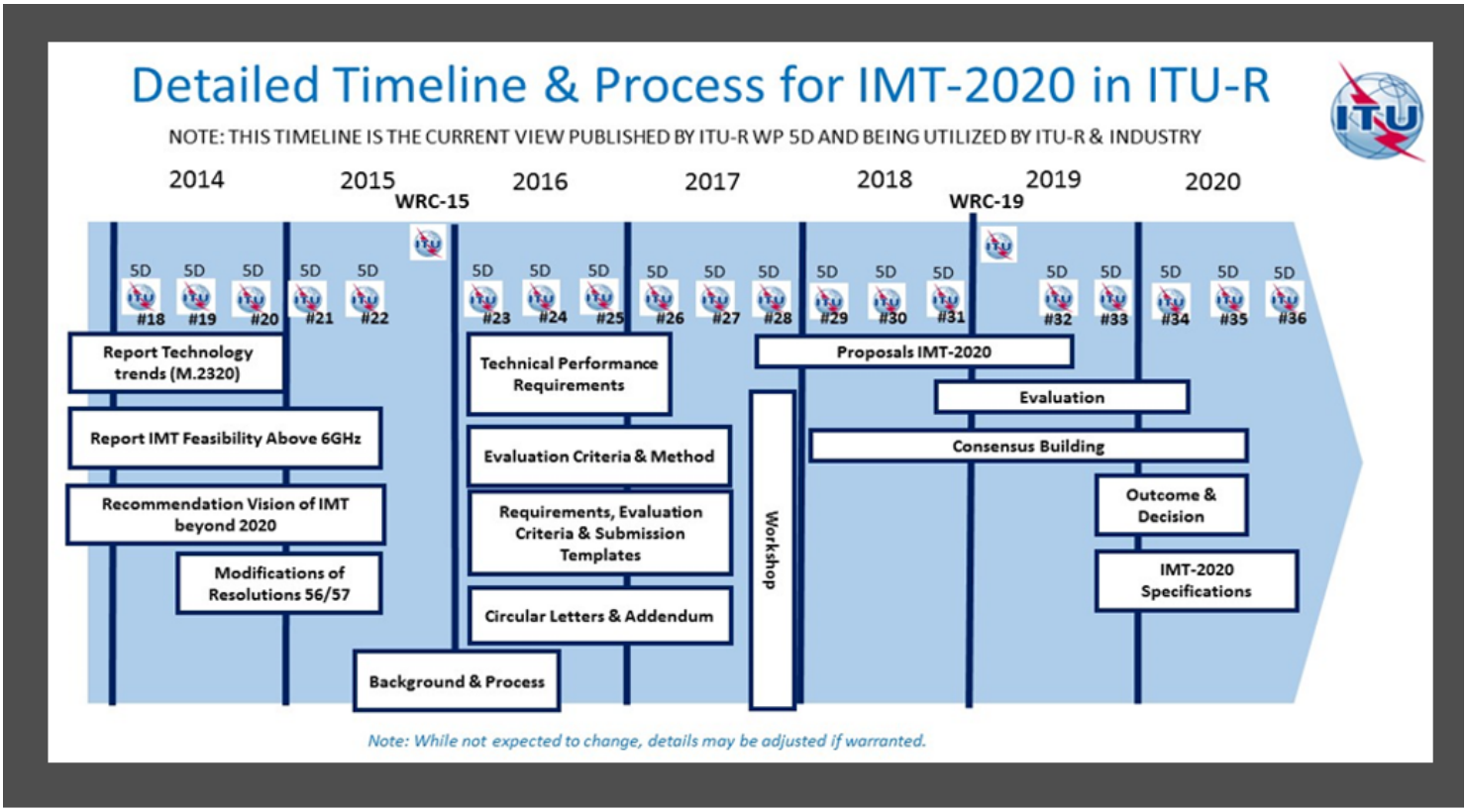

Figure 4.1. The ITU-R IMT-2020 Planned Timeline.

4.1.2 THE ITU-R "VISION" TOWARD 5G

In 2015, the ITU published Recommendation ITU-R M.2083: *IMT Vision – Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond*[110] on the vision of the 5G mobile broadband connected society and future IMT. This Recommendation defines the framework and overall objectives of the future development of International Mobile Telecommunications (IMT) for 2020 and beyond in light of the roles that IMT could play to better serve the future needs of the networked society in both developed and developing countries. It includes a broad variety of capabilities associated with envisaged usage scenarios. Furthermore, this Recommendation addresses the objectives of the future development of IMT for 2020 and beyond, which includes further enhancement of existing IMT and the development of IMT-2020. It should be noted that this Recommendation is defined considering the development of IMT to date based on Recommendation ITU-R M.1645.

The ITU-R Vision Recommendation provides insight on envisaged usage scenarios and presents this information in three main groupings.

4.1.3 USAGE SCENARIOS FOR IMT FOR 2020 AND BEYOND

IMT for 2020 and beyond is envisaged to expand and support diverse usage scenarios and applications that will continue beyond the current IMT. Furthermore, a broad variety of capabilities would be tightly

[110] http://www.itu.int/rec/R-REC-M.2083-0-201509-I/en.

coupled with these intended different usage scenarios and applications for IMT for 2020 and beyond. The three usage scenarios for IMT for 2020 and beyond include:

- **Enhanced Mobile Broadband:** Mobile broadband addresses the human-centric use cases for access to multi-media content, services and data. The demand for mobile broadband will continue to increase, leading to enhanced mobile broadband. The enhanced mobile broadband usage scenario will come with new application areas and requirements, in addition to existing mobile broadband applications, for improved performance and an increasingly seamless user experience. This usage scenario covers a range of cases, including wide-area coverage and hotspots, which have different requirements. Hotspots are areas with high user density, where very high traffic capacity is needed but mobility requirements are low and user data rates are higher than in wide area environments. For the wide area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However, the data rate requirement may be lower compared to hotspot environments.

- **Ultra-reliable and low latency communications:** This use case has stringent requirements for capabilities such as throughput, latency and availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid and transportation safety.

- **Massive machine-type communications:** This use case is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost and have a very long battery life, such as five years or longer.

Additional use cases are expected to emerge that are currently not foreseen. For future IMT, flexibility will be necessary to adapt to new use cases that come with a wide range of requirements.

Future IMT systems will encompass a large number of different features. Depending on the circumstances and the different needs in different countries, future IMT systems should be designed in a highly modular manner so that not all features have to be implemented in all networks.

Figure 4.2 illustrates some examples of envisioned usage scenarios for IMT for 2020 and beyond.

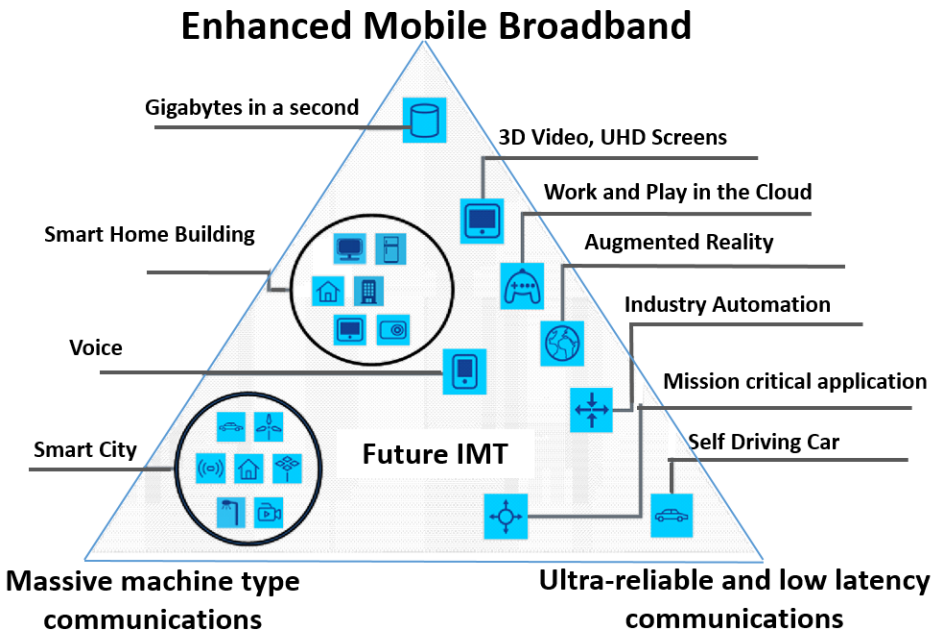

Figure 4.2. Enhanced Mobile Broadband Usage Scenarios.[111]

In particular, two figures from this recommendation capture many of the main perspectives for IMT-2020 and 5G capabilities with a focus on the RAN. Figure 4.3 illustrates these perspectives.

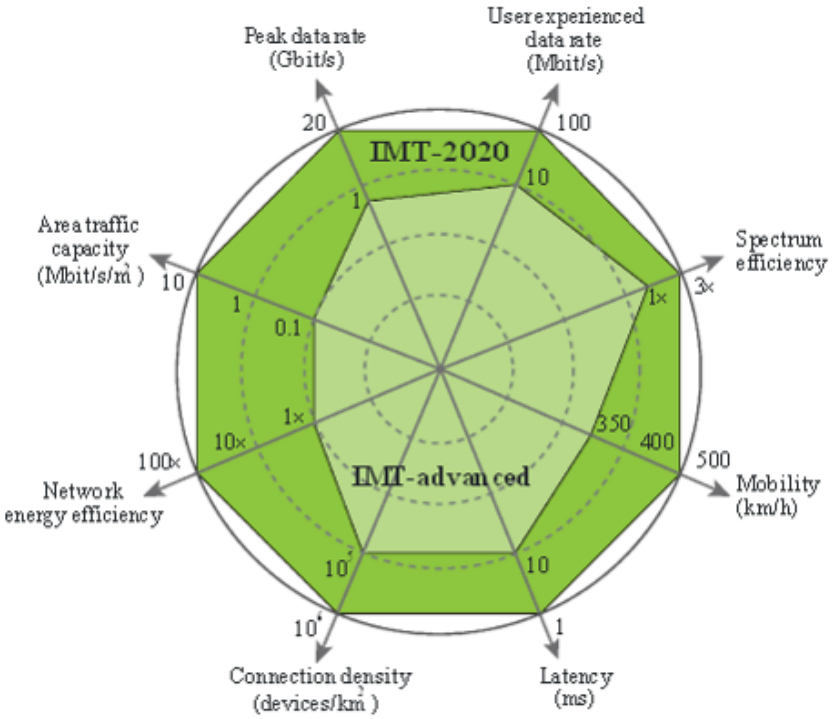

Figure 4.3 Enhancement of Key Capabilities from IMT-Advanced to IMT-2020.

[111] Recommendation ITU-R M.2083-2.

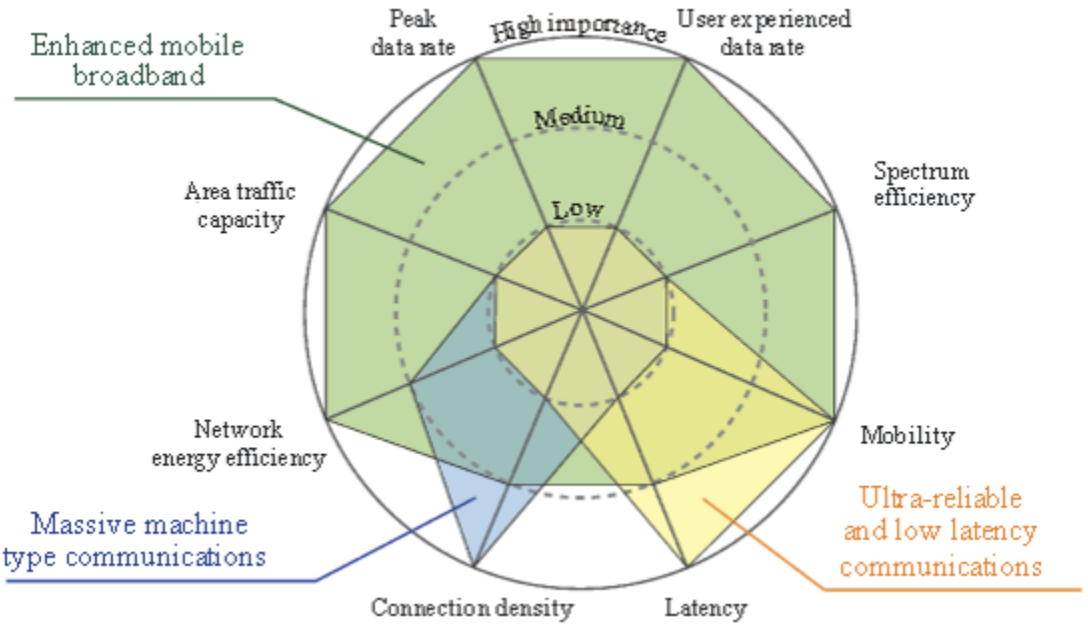

Figure 4.4. The Importance of Key Capabilities in Different Usage Scenarios.

The values in Figure 4.3 above are targets for research and investigation for IMT-2020 and may be further developed in other ITU-R Recommendations, and may be revised in light of future studies. Additional descriptions for both Figure 4.3 and Figure 4.4 are found in IMT-2020 Vision Recommendation ITU-R M 2083.

4.1.4 IMT STANDARDS

The framework of standards for IMT encompassing both IMT-2000 and IMT-Advanced spans the 3G and 4G industry perspectives, and the framework is being further expanded to incorporate IMT-2020. Hence, the mission in both ITU and ITU-R is establishing IMT as the preeminent global means for connecting people and devices everywhere and is firmly entrenched in driving the 5G vision to reality.

4.1.5 WP 5D WORK SCOPE IMPACTING 5G

Figure 4.4 offers a high-level snapshot of the actions completed, underway and planned in Working Party 5D towards IMT-2020 in support of 5G.

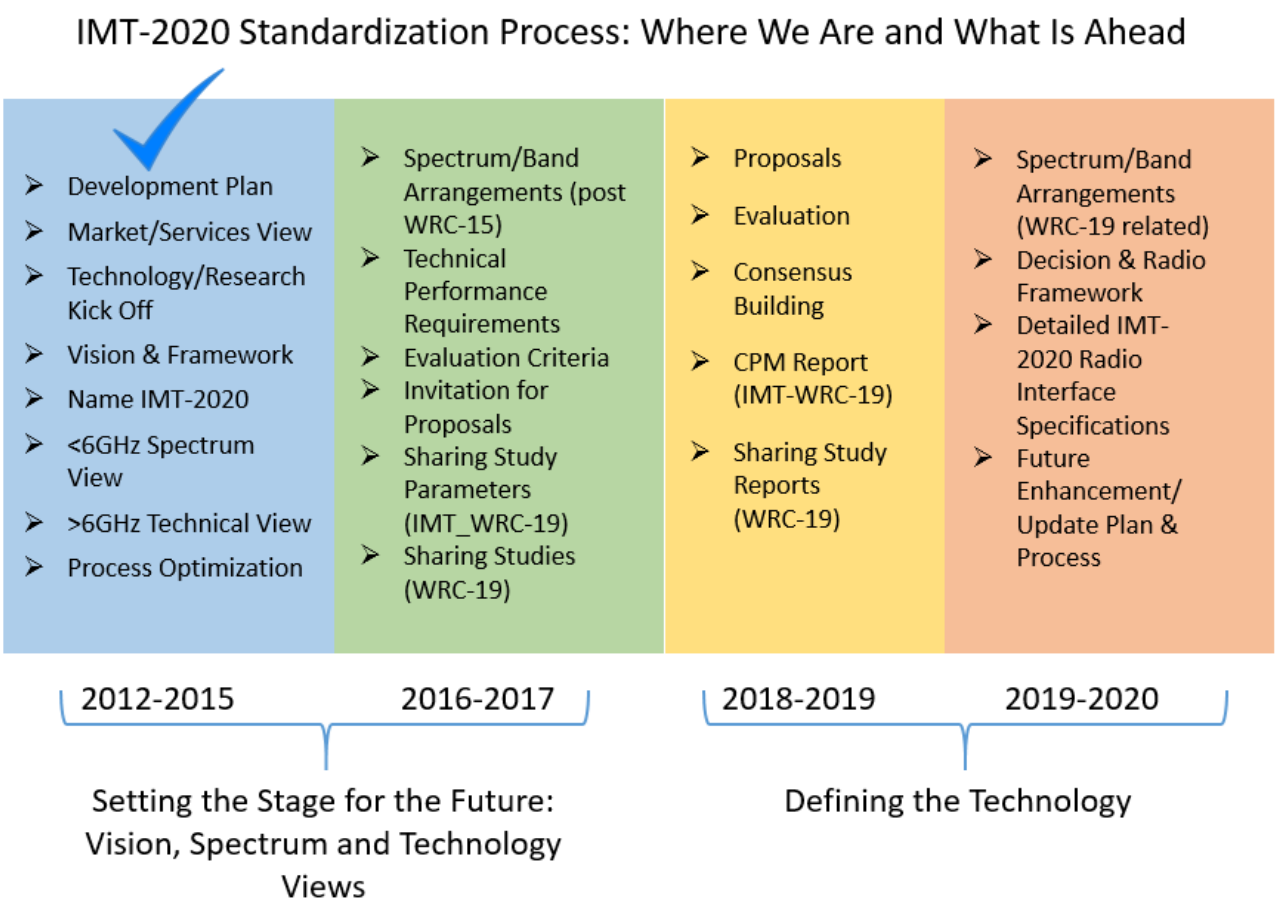

Figure 4.5. IMT-2020 Standardization Roadmap.

4.1.6 ADDITIONAL INFORMATION ON IMT-2020 AND ITU-R PUBLICATIONS RELATED TO IMT

For further details on the ITU-R's individual deliverables and work program for the future IMT, visit the ITU-R Working Party 5D home page at www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/Pages/default.aspx, which has a dedicated section (IMT-2020) providing relevant information on the background and development of IMT-2020 in support of 5G.

ITU-R published documents for the Radiocommunications Sector may be found on the main ITU home page at www.itu.int/en/publications/ITU-R/Pages/default.aspx

4.1.7 ITU-T FG IMT-2020

ITU-T Focus Group on IMT-2020 (FG IMT-2020) was created in April 2015 to study how emerging 5G technologies will interact in future networks. The final output of the focus group included studies on high-level network architecture, an end-to-end QoS framework, emerging network technologies, mobile front haul and back haul and network softwarization. The focus group created a report on "standards gaps" in the five focus areas. The report can be found at www.itu.int/en/ITU-T/focusgroups/imt-2020/Documents/T13-SG13-151130-TD-PLEN-0208!!MSW-E.docx

In December 2015, the focus group received an extension with new terms of reference to engage open-source communities, influencing and taking advantage of their work by introducing them to the challenges that telecoms players must overcome in the development of the 5G ecosystem. One of the specific tasks will be to enhance aspects of network softwarization and information-centric networking.

4.2 PLANNING FOR REL-14, REL-15 AND REL-16 – THE 3GPP ROLE.

3GPP technologies have been an essential and widely deployed part of the 3G and 4G technology families under the ITU-R IMT-2000 and IMT-Advanced families since the onset of these recommendations released by the ITU-R. 3GPP is continuing its role of enhancing its members of the IMT-2000 and IMT-Advanced families through the development of a New Radio (NR) access technology and next generation system architecture that will meet the recommendations of IMT-2020. 3GPP plays an important role in IMT-2020 and has had a program underway for developing these new 5G technology solutions for IMT-2020 since early 2015 (see Figure 4.6).

A study on general service requirements (SMARTER) started in 1Q 2015 (some description is provided in next section), was in its normative phase in 4Q 2016. At a radio/RAN level, 3GPP activities started with an initial 5G RAN workshop in September of 2015.

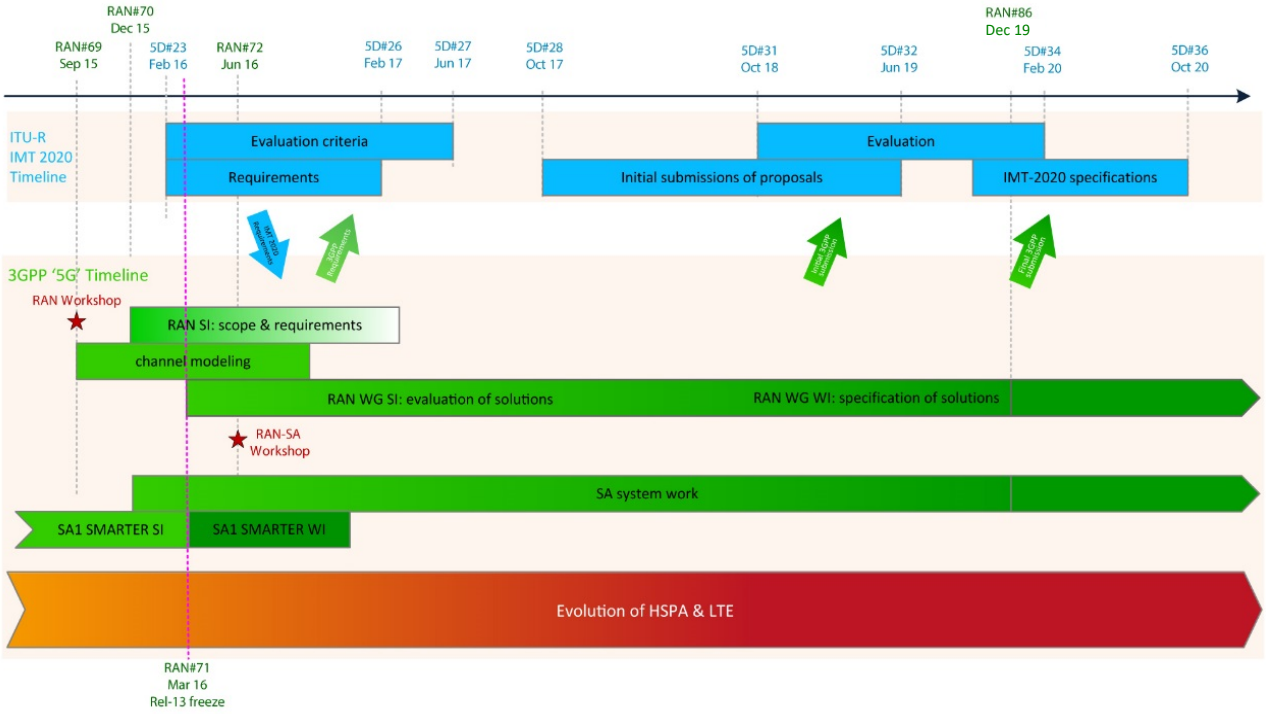

Fig. 4.6. Initial 3GPP timeline for 5G.

The purpose of this workshop was to share information around IMT-2020 and collect ideas and requirements for the development towards a next generation 5G RAN. Some of the key outcomes of the workshop were:

1. The identification of three high level use cases for 5G: Enhanced Mobile Broadband, Massive Machine-Type Communications and Ultra-Reliable and Low Latency Communications

2. A consensus that there will be a new, non-backward compatible, radio access technology as part of 5G, supported by the need for LTE-Advanced evolution in parallel. The need for "forward compatibility to be a design requirement for the new radio from the get-go" was stressed
3. Spectrum wise, both sub-6GHz and above 6 GHz (i.e., including mmWave) should be supported
4. There would be two phases for the specification work:
    a. Phase 1 to be completed by the end of Rel-15
    b. Phase 2 to be completed by the end of Rel-16 (to be part of the IMT-2020 submission)

Afterwards, in December 2015, 3GPP RAN started a study on New Radio (NR) and RAN Requirements, and subsequently a 5G Technology study, to identify target solutions (more details are provided in the next section).

In June 2016, 3GPP agreed on a detailed work plan for the first phase of 5G through Rel-15 as shown in Fig. 4.7.

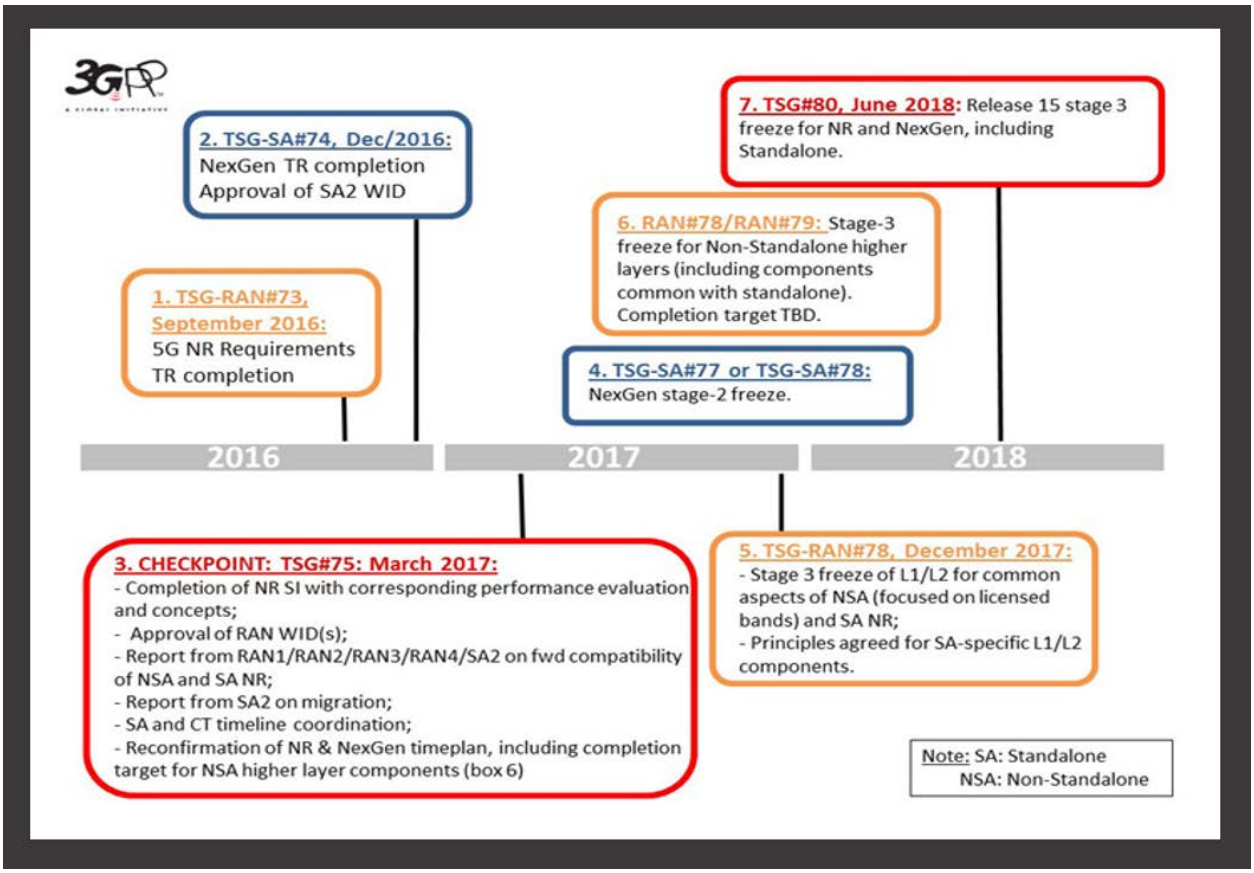

Fig. 4.7. Work Plan for first phase of 5G.

The plan includes a set of intermediate tasks and check-points, for both Next Generation (NextGen) architecture and the New Radio/RAN that will guide the Working Groups from the study item phase in Rel-14 to the normative phase in Rel-15, targeted to be complete by June 2018.

Section 5 provides a status of the work on Rel-14 and Rel-15 towards the first phase of 3GPP 5G standards.

5 PROGRESS OF 3GPP REL-14 AND REL-15

Rel-14 and Rel-15 represent the first phase of work in 3GPP towards 5G standards with Rel-14 focused on the study items towards 5G and Rel-15 on the first phase of normative specifications for 5G. This section provides detailed discussion on the progress of work in 3GPP on Rel-14 and Rel-15. Most discussion in this section is on the study item work for Rel-14, but there are a few areas where Rel-15 work is identified.

5.1 5G RAN

One of the requirements for 5G is to be able to optimally support a wider range of frequency bands in 5G, and in particular mmWave bands. Given that radio accesses like LTE and HSPA were not designed to be optimized for mmWave frequency bands, 3GPP has agreed that Rel-14/15 will introduce a New Radio (NR) access technology for 5G that will be flexible enough to support not only frequency bands < 6 Ghz but also mmWave bands up to 100 GHz. This section of the paper will provide details towards the definition of the 5G NR access technology and provide some detail on the mmWave channel modeling work that has been performed in 3GPP in support of studying the performance aspects of potential mmWave NR access technologies.

5.1.1 NEW RADIO (NR) ACCESS TECHNOLOGY

3GPP RAN has started, in Rel-14, a few studies on the New Radio (NR) Access Technology, including a study on Channel Modeling (complete), a study on overall RAN Requirements (almost complete) and a study on Radio/RAN technologies and potential solutions (still ongoing). The studies aim to ultimately develop an NR access technology and network to meet a broad range of use cases and the identified requirements and targets. The main use cases are those envisioned by IMT-2020, such as enhanced mobile broadband (eMBB), massive MTC (mMTC), and ultra-reliable low latency communications (URLLC).

The following paragraphs summarize the status of the RAN studies on Requirements and Technologies, while some aspects of 5G channel model are described in section 5.1.2.

5.1.1.1 NEW RADIO REQUIREMENTS

The RAN study item on requirements aims to identify typical deployment scenarios for next generation access technologies and the required performance and main functional capabilities.

The RAN requirements, as currently captured in the RAN TR (38.913), have been defined in terms of:

- A range of Key Performance Indicators (KPIs), and their target requirements
- Several target deployment scenarios, covering eMBB, URLLC, mMTC, and also enhanced Vehicle to Everything (eV2X)
- Other requirements, e.g., covering architecture, services and operation

A summary of KPIs, performance targets, and main applicable usage scenarios, is provided in Table 5.1.

Table 5.1. NR Radio requirements – KPIs and Targets.

KPI	Target	Applicability
Bandwidth	No target KPI (defined by ITU)	Generic
Peak data rate	DL: 20 Gbps; UL: 10 Gbps	Mainly for eMBB
Peak spectral efficiency	DL: 30 bps/Hz; UL: 15 bps/Hz	Mainly for eMBB
Cell spectral efficiency	3x IMT-A	Mainly for eMBB- Indoor Hotspot, Dense Urban, Rural, Urban Macro
5th %-tile User spectral efficiency	3x IMT-A	
User experienced data rate	No target KPI	
Area traffic capacity	No target KPI	
Latency (Control Plane)	10ms	Mainly for eMBB and URLLC
Latency (User Plane)	eMBB: 4ms for UL, and 4ms for DL URLLC: 0.5ms for UL, and 0.5ms for DL	Mainly for eMBB and URLLC
Latency for infreq. small packets	< 10 sec in UL, at MCL = 164dB	Mainly for mMTC
Mobility interruption time	0ms	Mainly for eMBB and URLLC
Reliability	General URRLC: (1-10-5)/1ms eV2X : (1-10-5) /[2-10] ms	For URLLC, and also eV2X
Connection density	1Million devices/km2	For mMTC Urban environment

UE battery life	Beyond 10 years, 15 years desirable	For mMTC
Coverage	MCL = 164dB, for a data rate of 160bps	Mainly for mMTC
Extreme Coverage	MCL = 140dB @2Mbps/60kbps DL/UL; 143dB @ 1M/30k	For “basic” MBB service
Mobility (UE Speed)	Up to 500 km/h	For eMBB High speed train
Network energy efficiency	Efficient data delivery and granular DTX/DRX	Mainly for eMBB
UE energy efficiency	Efficient data delivery and granular DTX/DRX	Mainly for eMBB

The deployment scenarios identified during the study are:

- (eMBB) Indoor Hotspot, Dense urban, Urban Macro, Rural, High speed, Extreme long distance
- (URLLC) Indoor Hotspot, Urban Macro
- (mMTC) Urban coverage for massive connections
- (V2X) Urban Grid for connected car, and Highway
- Others: Air to Ground and Satellite

NOTE: Detailed evaluation of the above KPIs in the appropriate deployment scenarios will be performed by the technical Working Groups (WGs) (mainly RAN1), based on agreed sets of simulation assumptions, parameters and models, and the identified/selected design solutions.

Other Radio/RAN qualitative or functional requirements identified during the study include the following:

- Spectrum related requirements, e.g.,
    - Spectrum range, i.e., support potential use of frequency range up to 100 GHz
    - Channel bandwidth scalability, i.e., the ability to operate with different bandwidth allocations (with max aggregated BW up to e.g., 1GHz, at least for evaluation purpose).
    - Duplexing flexibility, i.e., the ability to adapt allocation of resources flexibly for uplink and downlink for both paired and unpaired spectrum.
    - Support of shared spectrum, i.e., efficient mechanisms to share either licensed or unlicensed spectrum with other IMT/Non-IMT systems.
- Requirements for architecture and migration

- Service related requirements, e.g., MBMS, Location/Positioning Service, Critical Communications services (Public safety/Emergency, Public warning, V2X)
- Operational requirements, e.g., on UL Link Budget, interworking with legacy RATs, Interworking with non-3GPP systems, Lawful Interception, Backhaul/Relay, and a few others

5.1.1.2 IDENTIFICATION OF NR TECHONOLOGIES AND SOLUTIONS

Following the outcome of the RAN requirements study, the technology study was started in March 2016 for the identification and evaluation of technical solutions.

The study has been split into multiple studies (handled by different Working Groups), to cover and focus on the four main RAN specification areas: Physical layer aspects, Radio interface protocols and procedures, Radio Network architecture, interfaces and protocols/procedures, RF and performance requirements. The study outcomes will be captured in the following Technical Reports (with the last one being a merge/summary from the other 4 TRs).

Table 5.2. RAN Technology Study - Technical Reports.

Spec No.	Title	Lead WG
TR 38.802	Study on New Radio Access Technology: Physical Layer Aspects	RAN1
TR 38.804	Study on New Radio Access Technology: Radio Interface Protocol Aspects	RAN2
TR 38.801	Study on New Radio Access Technology: Radio Access Architecture and Interface	RAN3
TR 38.803	Study on New Radio Access Technology: RF and co-existence aspects	RAN4
TR 38.912	Study on New Radio Access Technology	RAN

Some of the main objectives listed in the technology study proposal are:

- Target a single technical framework addressing all identified deployment scenarios and requirements
- Ensure the new RAT can be forward compatible, e.g., the Rel-15 new RAT must be forward compatible (in terms of efficient co-cell/site/carrier operation) with Rel-16 and beyond
- Identify and evaluate the necessary technical features and functionalities, including:
    - Standalone operation in licensed bands (paired and unpaired)

- Licensed assisted operations in unlicensed bands (unlicensed standalone operation is For Further Study (FFS))
- Tight interworking with LTE (including non-standalone operation)
- Interworking with non-3GPP systems
- Efficient spectrum multiplexing of traffic for different services and use cases
- Performance evaluation of the technologies identified for the new RAT
- Relevant RF parameters used to be used for sharing and co-existence studies

Note: Based on the latest prioritization agreements, the following study areas have been identified as lower priority (for the upcoming Rel-15 work item phase): Waveforms above 40 GHz, mMTC, Wireless relay, Sidelink, V2V/V2X, MBMS, Shared/unlicensed spectrum, Public warning/emergency alert, Interworking with non-3GPP systems, SON, Satellite and Air-to-Ground Communications, Extreme long distance and For Further Study (FFS) location/positioning functionality and flexible duplex of paired spectrum.

5.1.1.2.1 HIGH LEVEL OVERVIEW OF THE TECHNOLOGY STUDY AREAS

Main design/solution aspects and study areas, currently under investigation for the new Radio Interface and Radio Network, are listed below, mostly based on the structure/skeleton of the latest RAN1/2/3 TRs.

Table 5.3. RAN Technology Study Areas.

Physical Layer Aspects	**Radio Interface Protocol Aspects**	**Radio Access Architecture and Interfaces**
General PHY aspects • **Duplexing** • **Forward compatibility** • **Numerology** • **Frame structure** **DL/UL concepts** • **Basic transmission scheme** o **Modulation scheme** o **Physical Data/Control channels & Multiplexing** o **Waveform**	Radio architecture and protocols • Functional split • User/COntrol plane protocols • Layer 2 o MAC Sublayer o RLC Sublayer o PDCP Sublayer • RRC o Functions o RRC states	RAN scenarios • Centralized/Non-centralized deployment • Co-sited deployment with LTE • Shared RAN deployment Radio access network architecture • Functional split o RAN-CN functional split o Split between central and distributed unit o UP-CP Separation

o **Multiple access scheme** o **Channel coding** • **Multi-antenna scheme** o **Beam management** o **MIMO schemes** • **Physical layer procedures** o **Synchronization/reference signals** o **DL Broadcast** o **UL Initial/Random access** o **Scheduling** o **HARQ** o **Mobility** • **Physical layer measurements** **Sidelink concepts** • **Basic transmission scheme** • **Procedures and measurements** **Performance/KPIs evaluation**	o System information o Measurements Main Procedures • ARQ and HARQ • Scheduling • QoS control • Initial access o Cell selection o Random Access • Mobility o Intra NR o Inter RAT o Dual Connectivity with LTE • Security • NR-WLAN interworking	• RAN architecture, nodes & interfaces o RAN-CN interface o RAN internal interface Radio access network procedures • Tight interworking with LTE • Standalone new RAT operation o Intra-RAT mobility o Inter-RAT handover with LTE Other RAN functionalities • Network Slicing • QoS • SON • Wireless relay • Interworking with non-3GPP systems

Given the ongoing status of the study, and many aspects/options still under discussion and/or selection/conclusion, it is a bit premature to provide a comprehensive description of the above items at this stage. More details should be found in the latest/current version of the referenced TRs.

The following sections synthesize only few agreements concerning main Physical layer characteristics, together with some aspects or options regarding RAN architecture, functionalities, and protocols.

NOTE: Information is mostly based on the November 2016 version of the RAN WG TRs; a few parts are based on an agreed way forwards (not yet captured in the TRs), or sometimes may not be available (TBD/FFS).

5.1.1.2.2 PHYSICAL LAYER ASPECTS

This section covers only a few main physical layer technology aspects for which some initial agreement has been reached, as summarized in the following table. Functionalities are split in UL and DL, unless commonly applicable to both.

Table 5.4. New Radio PHY Characteristics – Study Agreements/Assumptions.

PHY functionality	**Downlink (DL)**	Uplink (UL)
Duplexing	Both FDD operation on a paired spectrum (including different TX directions) and TDD operation on an unpaired spectrum (where TX direction can also change dynamically).	
Forward compatibility	To ensure forward compatibility of NR, explicit signaling to NR UEs can indicate reserved resources.	
Numerology and Multiplexing	Multiple numerologies are supported, derived by scaling a basic subcarrier spacing, i.e., subframe duration in ms for a reference numerology with subcarrier spacing $2^m \times 15$ kHz is 1/2m ms where m is an integer. A subframe duration is fixed to 1ms. Scalable numerology should allow at least from 15kHz to 480kHz subcarrier spacing. Multiplexing different numerologies within a same NR carrier bandwidth (from the network perspective) is supported in TDM and/or FDM manner for both downlink and uplink. From UE perspective, multiplexing different numerologies is performed in TDM and/or FDM manner within/across (a) subframe duration(s)	
Frame structure	With normal CP, a slot is defined as 7 and 14 OFDM symbols for subcarrier spacing of up to 60kHz, while 14 OFDM symbols for higher spacing. The physical layer design can support also an extended CP. A slot can contain all downlink, all uplink, or at least one downlink part and at least one uplink part. Slot aggregation is supported, i.e., data transmission can be scheduled to span one or multiple slots Physical resource block (PRB): the number of subcarriers per PRB is 12 (for all numerologies). No explicit DC subcarrier is reserved both for downlink and uplink.	
Modulation	QPSK, 16QAM, 64QAM and 256QAM	QPSK, 16QAM, 64QAM and 256QAM

Waveform	OFDM-based. At least up to 40 GHz for eMBB and URLLC services, CP-OFDM based waveform supports spectral utilization greater than LTE (90%)	OFDM-based; both CP-OFDM and DFT-S-OFDM. At least up to 40 GHz for eMBB and URLLC services, CP-OFDM based waveform supports spectral utilization greater than LTE (90%) DFT-S-OFDM based waveform is also supported, at least for eMBB uplink for up to 40GHz
Multiple access scheme	Synchronous/scheduling-based orthogonal multiple access, at least targeting eMBB	Synchronous/scheduling-based orthogonal multiple access, at least targeting eMBB
Channel coding	(Working assumption) eMBB: LDPC for data; Polar for control channels. Rest is FFS	
Multi-antenna - Beam management	Beam management is supported, e.g., mechanisms for Beam determination, measurement, reporting, and sweeping	TBD
Multi-antenna - MIMO	DL DMRS based spatial multiplexing (SU-MIMO/MU-MIMO) is supported. At least 8 orthogonal DL DMRS ports are supported for SU-MIMO scheduling and at least 8 orthogonal DL DMRS ports are supported for MU-MIMO scheduling Dynamic switching between transmission methods / schemes is supported	UL DMRS based spatial multiplexing (SU-MIMO/MU-MIMO) is supported. At least a maximum of 4 layers uplink SU-MIMO transmission is supported At least one of precoded and non-precoded SRS based UL link adaptation procedure is supported Dynamic switching between transmission methods/schemes is supported
Synchronization / Reference signals	NR synchronization signal is based on CP-OFDM Two types of synchronization signals; NR-PSS and NR-SSS. NR-PSS is defined at least for initial symbol boundary synchronization to the NR cell. NR-SSS is defined for detection of NR cell ID or at least part of it (number of NR cell IDs is targeted to be at least 504)	The following NR UL RSs are at least supported: -SRS: Reference signal with main functionalities of CSI acquisition, beam management -DM-RS: Reference signal with main functionalities of data and control demodulation -Reference signal for phase tracking
DL Broadcast	At least one broadcast channel (NR-PBCH) is defined. NR-PBCH decoding is based on the fixed relationship with NR-PSS and/or NR-SSS resource position	N/A
UL Initial/Random access	N/A	NR supports multiple RACH preamble formats, and both single and multiple/repeated RACH preambles in a RACH resource. Numerology for RACH preamble can vary with frequency range, and may be same or different than other UL data/control channels

		RACH procedure including RACH preamble (Msg. 1), random access response (Msg. 2), message 3, and message 4 is assumed for NR from physical layer perspective
Scheduling	NR supports at least same-slot and cross-slot scheduling for DL. NR supports both data and control with the same numerology	NR supports at least same-slot and cross-slot scheduling for UL. NR supports both data and control with the same numerology
HARQ	Asynch and adaptive DL HARQ, at least for eMBB >1 DL HARQ processes is supported for a given UE, while operation of 1 DL HARQ process is supported for some UEs Timing between DL data RX and corresponding ACK can be indicated to a UE dynamically by L1 signaling (e.g., DCI), semi-statically via higher layer, or a mix	Asynchronous and adaptive UL HARQ is supported at least for eMBB >1 UL HARQ processes is supported for a given UE, while operation of one UL HARQ process is also supported for some UEs
Mobility / PHY Measurements	For RRM measurements in NR, DL measurement is supported, considering both single-beam based operation and multi-beam based operation NR supports cell-level mobility based on DL cell-level measurement (e.g., RSRP for each cell) in IDLE (or similar) mode For DL measurement in CONNECTED mode, non-UE-specific DL signals can be used	At least one of cell-level and beam-level measurement quantities is supported for UL RRM reporting

5.1.1.2.3 RADIO NETWORK ARCHITECTURE, INTERFACES, PROTOCOLS AND FUNCTIONALITIES

Note: The following terminology and abbreviations (from the RAN3 TR) are used hereafter:

- New RAN: a Radio Network which supports either NR or E-UTRA or both, interfacing with NGC (Next Generation Core), NG-C/U is the Control/User Plane interface toward NGC
- gNB: NR eNB; eLTE eNB: evolution of eNB that supports connectivity to EPC and NGC
- Non-standalone NR: a deployment configuration where the gNB requires an LTE eNB as anchor for control plane connectivity to EPC, or an eLTE eNB as anchor for control plane connectivity to NGC
- Non-standalone E-UTRA: a deployment configuration where the eLTE eNB requires a gNB as anchor for control plane connectivity to NGC

RAN architecture and interfaces

The New RAN consists of the following logical nodes:

- gNBs providing the NR U-plane and C-plane protocol terminations towards the UE; and/or
- eLTE eNBs providing the E-UTRA U-plane and C-plane protocol terminations towards the UE

The logical nodes in New RAN are interconnected with each other by means of the Xn interface.

The logical nodes in New RAN are connected to the NGC by means of the NG interface. The NG interface supports a many-to-many relationship between NG-CP/UPGWs and the logical nodes in New RAN.

The New RAN architecture is illustrated, at high level, in Figure 5.1.

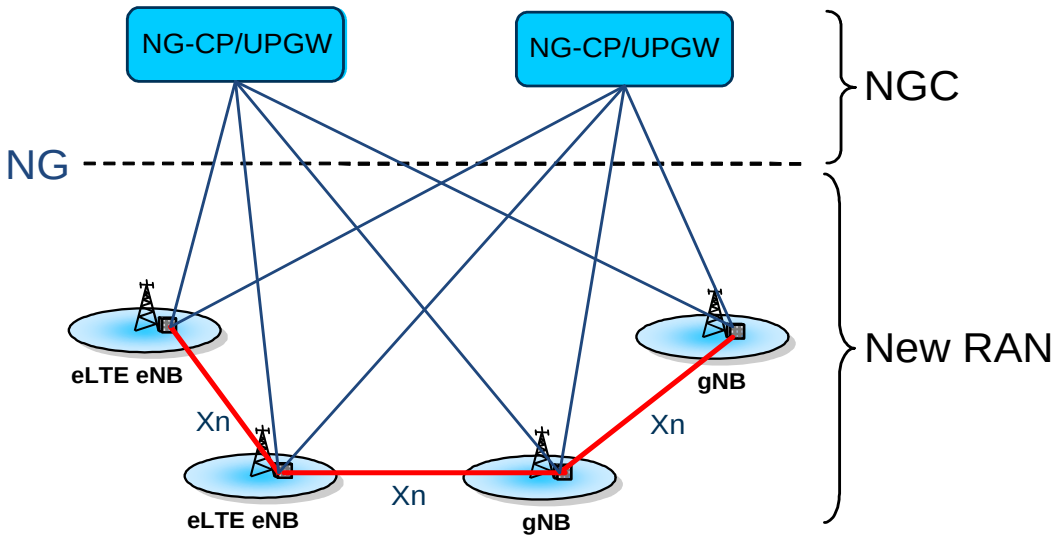

Figure 5.1. New RAN Architecture.

Regarding the RAN-CN interface, there are several options under consideration, listed here, and described in more in detail in Section 5.2.2 (5G system architecture).

- Option 2: the gNB is connected to the NGC
- Option 3/3A, the LTE eNB is connected to the EPC with Non-standalone NR. The NR user plane connection to the EPC goes via the LTE eNB (Option 3) or directly (Option 3A)
- Option 4/4A, the gNB is connected to the NGC with Non-standalone E-UTRA. The E-UTRA user plane connection to the NGC goes via the gNB (Option 4) or directly (Option 4A)
- Option 5, the eLTE eNB is connected to the NGC
- Option 7/7A, the eLTE eNB is connected to the NGC with Non-standalone NR. The NR user plane connection to the NGC goes via the eLTE eNB (Option 7) or directly (Option 7A)

RAN Protocols

NG interface: control and user plane protocol stacks are shown in Figure 5.2. The application layer signaling protocol is referred to as NG-AP (NG Application Protocol). The working assumption is that GTP-U is used as protocol for NG-U.

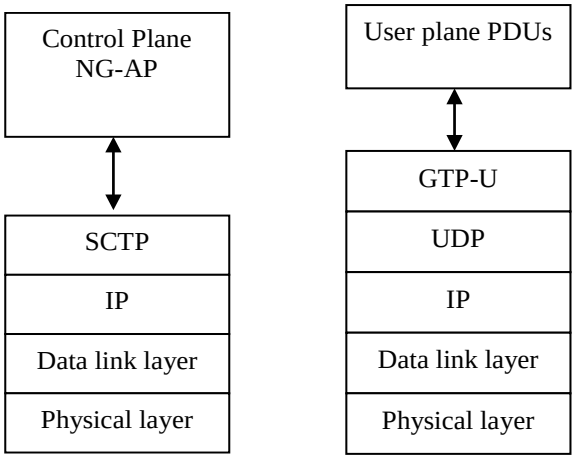

Figure 5.2. NG Interface Control and User Plane.

Xn Interface: control and user plane protocol stack are shown in Figure 5.3. The application layer signaling protocol is referred to as Xn-AP (Xn Application Protocol).

The working assumption is that the transport protocol of Xn-CP is SCTP, and GTP-U is used as protocol for Xn-U.

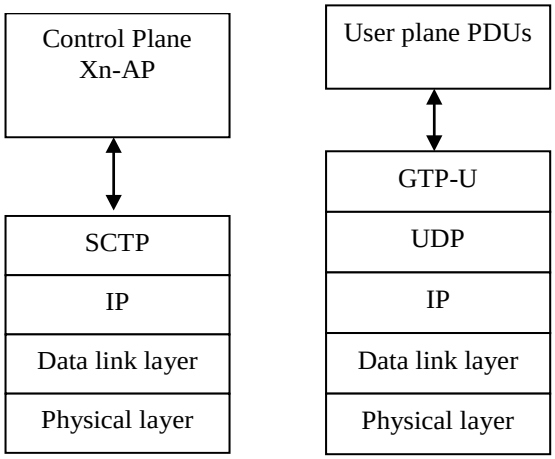

Figure 5.3: Xn Interface Control and User Plane.

New RAN functions

Besides many "traditional" RAN functions, mostly inherited from E-UTRAN, few specific or new functions have been identified and under study for the New RAN, e.g.:

- Network Slice support: this function provides the capability for New RAN to support network slicing
- Multi-connectivity: for connectivity between a New RAN node and multiple New RAN nodes by means of data flow aggregation
- Tight Interworking with E-UTRA: for both collocated and non-collocated site deployments, including also the means for E-UTRA-NR handover via the direct interface between an eLTE eNB and a gNB

- Session Management: This function provides means for the NGC to create/modify/release a context in the New RAN associated with a particular PDU session of a UE and the corresponding tunnel between the eNB and the User Plane Gateway (UPGW)

5.1.1.2.4 RADIO INTERFACE PROTOCOLS

This section captures a few relevant radio protocol aspects for which some initial agreement has been reached, as well as some options under consideration.

General principles (for both control plane and user plane)

- LTE layer 2 and RRC functions are taken as a baseline for NR
- NR Radio protocols and procedures should be designed to have as much commonality as possible between tight interworking with LTE and standalone operations
- Most essential functions (e.g., initial system access) should be future proof and designed to be common to various use cases and services

Control plane aspects

System information delivery:

- System information distribution should target a single technical framework, ensuring future-proof and smooth introduction of new services and features
- System information distribution should enable a high level of configurability enabling optimization of KPIs such as energy savings and accessibility
- Minimum SI needs to be broadcasted periodically. Other mechanisms than periodic broadcast will be studied for other system information

With regards to RRC states, one relatively new state is under study (in addition to the traditional Idle and connected states), e.g., a “RAN controlled inactive state.”

For LTE-NR aggregation, UE has a single RRC state machine based on the master, and single control plane connection to CN. Network has two RRC entities. Some coordination is required between LTE (respectively NR) master node and NR (respectively LTE) secondary node.

User Plane and QoS aspects

From MAC perspective, it is preferable for NR to support only asynchronous HARQ in UL and DL.

The ARQ will be supported in RLC. RLC adds an RLC Sequence Number (SN). In NR, the segmentation function is only placed in the RLC layer RLC delivers PDCP PDUs to PDCP after the PDU is reassembled.

Complete PDCP PDUs can be delivered out-of-order from RLC to PDCP. PDCP reordering is always enabled if in sequence delivery to layers above PDCP is needed.

NR User Plane (UP) protocol stack supports maintaining of multiple parallel "logical channels" that can be configured with different characteristics and priorities.

The "data radio bearer" (DRB) defines the Over-The-Air packet treatments in the RAN, i.e., a DRB serves a set of packets requiring the same packet forwarding treatment; some functionality is required to

differentiate flows from different PDN-connections over the radio interface (e.g., by using separate DRBs or by an explicit indication in a header).

Intra-NR mobility

Two types of UE states are taken as a baseline; one is network controlled mobility and the other is UE based mobility. There are two levels of network controlled mobility: 1) RRC driven at 'cell' level; and 2) no/minimum RRC involvement (e.g. it could be handled at MAC /PHY in case of beam based mobility).

Data aggregation and interworking with other RATs

For NR, a technology of aggregating NR carriers is studied. Both lower layer aggregation like Carrier Aggregation (CA) for LTE and upper layer aggregation like DC are investigated. From a layer 2/3 point of view, aggregation of carriers with different numerologies is supported in NR.

To support tight interworking between LTE and NR, a technology of aggregating data flows between the two RATs is studied based on LTE Dual Connectivity (DC) functionality. In DC between LTE and NR, both (e)LTE eNB and NR gNB can act as a master node.

Three types of bearers are studied for Dual Connectivity between LTE and NR: 1) Split bearer via MCG; 2) SCG bearer; and 3) Split bearer via SCG, as illustrated in Figures 5.4 to 5.6 (MCG: Master Cell Group; SCG: Secondary Cell Group).

Regarding NR-WLAN interworking, one initial agreement is that LTE features such as LWA, LWIP and RCLWI are the baseline for NR-WLAN interworking.

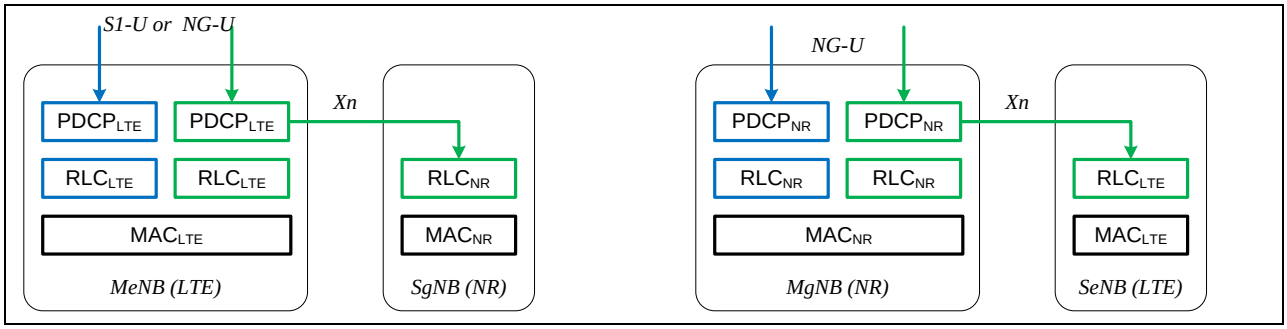

Figure 5.4. DC between LTE and NR - Split Bearer via MCG.

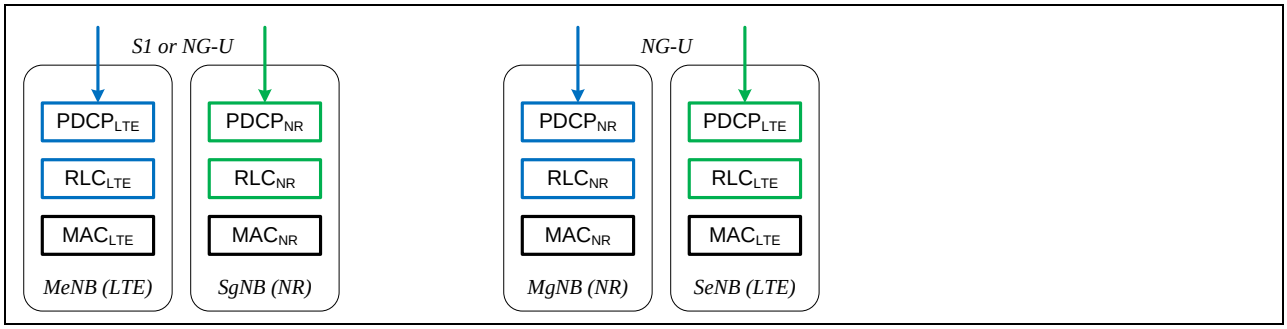

Figure 5.5. DC between LTE and NR - SCG Bearer.

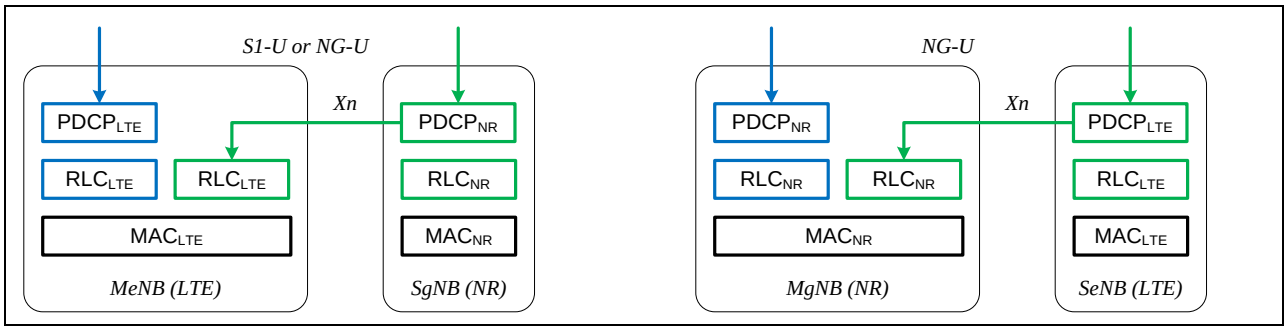

Figure 5.6. DC between LTE and NR - Split Bearer via SCG.

5.1.2 CHANNEL MODELING FOR NR

As previously explained, the cellular industry is exploring new spectrum opportunities to address the expected growth in capacity and data rates. One promising path is the utilization of spectrum from 6 GHz to 100 GHz for future 5G networks coupled with the densification of networks. By their nature, the centimeter wave (cmWave) and mmWave frequencies provide much more bandwidth than the current spectrum below 6 GHz that is currently being used for mobile communication and are more amenable to small cell deployments. Bands having a worldwide (co) primary allocation to Mobile Service have the most potential for spectrum designation. Specifically, in the United States, the FCC recently published rules which opened 10.85 GHz of spectrum for flexible use wireless broadband. The rules create 3.85 GHz of licensed flexible use spectrum in the 28–40 GHz bands, and an unlicensed band at 64-71 GHz.[112] The FCC has released a Further Notice of Proposed Rule Making (FNPRM) on the following new bands: 24-25 GHz, 32 GHz, 42 GHz, 48 GHz, 51 GHz, 70 GHz, and 80 GHz. The FCC mmWave band plan is illustrated in Figure 5.7.

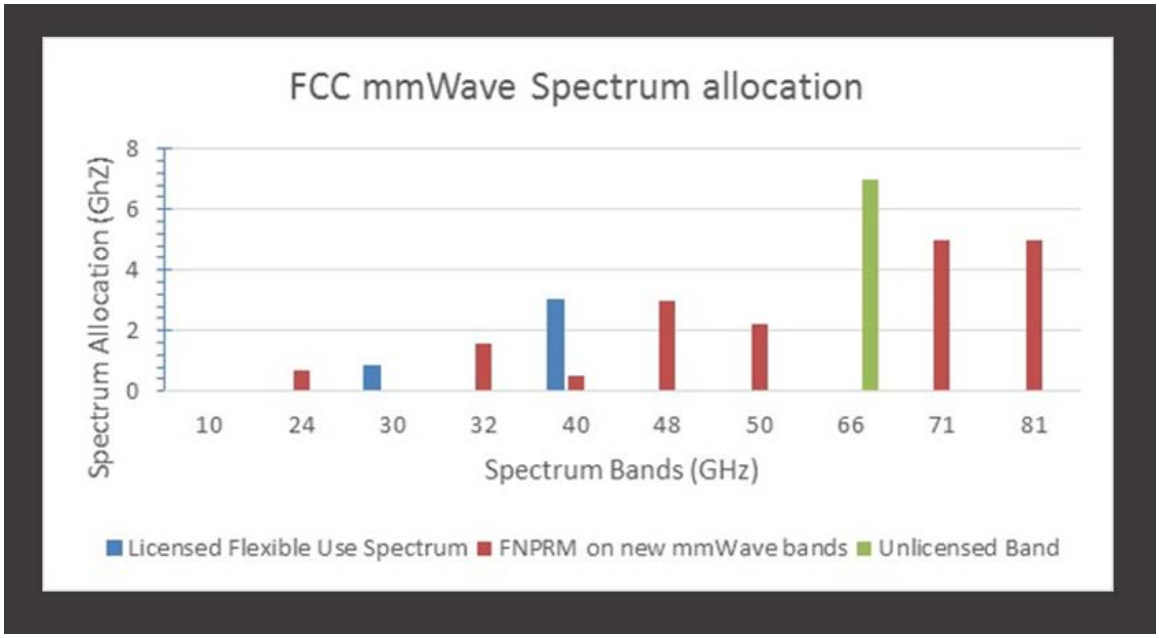

Figure 5.7. Proposed 5G Spectrum @ mmWave Frequencies.

[112] FCC Spectrum Frontiers (mmW) Order on 28/37/39/64-71GHz and Further Notice of Proposed Rulemaking(FNPRM): http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0714/FCC-16-89A1.pdf

For the development of the new 5G systems to operate in bands up to 100 GHz there is a need for accurate radio propagation models for these bands which are not addressed by existing 3GPP 3D channel models[113] developed for bands below 6 GHz. In this section, we provide a short summary of studies and references around channel models for 5G systems for bands up to 100 GHz.

From the 3GPP side, RAN has performed a study on 5G CM, whose outcome is captured in TR38.900.[114]

Furthermore, there have been multiple channel measurements activities around the world on 5G systems, a few of them still ongoing, including METIS2020,[115] COST2100/COST,[116] ETSI mmWave SIG,[117] MiWEBA,[118] mmMagic,[119] NYU WIRELESS[120] [121] [122] and Globecom 2015[123] to name a few. The 5G channel model for bands up to 100 GHz have been derived based on extensive measurements and ray tracing studies. The following procedure was used to derive the 5G channel model.[124]

Figure 5.8. Process to Derive 5G Channel Model.

The 5G Channel Models were derived in the following environments: 1) Urban Micro (UMi) comprising of street canyon and open square with cell radii less than 100 meters and access points (APs) mounted below rooftops;[125] 2) Urban Macro (Uma) with cell radii greater than 200 meters and APs mounted above rooftops;[126] 3) Suburban Micro (SMi) with residential houses in a suburban setting with cell radii around 200 meters and APs mounted at 6-8 meters;[127] and 4) Indoor Hotspot (InH) comprising of indoor office with desk, cube and offices and indoor shopping malls which are 3-5 stories high and APs at 2-3 meters height.[128]

The baseline model incorporating path loss, shadow fading, line of sight probability, penetration loss and blockage models for the above scenarios were first derived along with fast fading models and the findings of this extensive effort were published at Globecom 2015.[129] Next, important modeling features, such as

[113] *Study on 3G Channel Model for LTE*, 3GPP TR 36.873
[114] 3GPP TR38.900 (http://www.3gpp.org/ftp//Specs/archive/38_series/38.900/38900-100.zip).
[115] *METIS Channel Model*, METIS2020, Deliverable D1.4 v3. July 2015. https://www.metis2020.com/wpcontent/uploads/METIS_D1.4_v3.pdf
[116] COST, http://www.cost2100.org/
[117] *New ETSI Group on Millimetre Wave Transmission starts work,* ETSI, http://www.etsi.org/news-events/news/866-2015-01-press-new-etsi-group-on-millimetre-wave-transmission-starts-work.
[118] *Channel modeling and characterization,* MiWEBA, Deliverable D5.1. June, 2014, http://www.miweba.eu/wp-content/uploads/2014/07/MiWEBA_D5.1_v1.011.pdf.
[119] mmMagic, https://5g-ppp.eu/mmmagic/.
[120] *Wideband Millimeter-Wave Propagation Measurements and Channel Models for Future Wireless Communication System Design,* T. S. Rappaport, et. al., IEEE Trans. Communications, Vol. 63, No. 9, pp. 3029-3056, Sept. 2015.
[121] *Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!,* T. S. Rappaport et al., in IEEE Access, vol.1, pp. 335-349, 2013.
[122] *Indoor Office Wideband Millimeter-Wave Propagation Measurements and Channel Models at 28 GHz and 73 GHz for Ultra-Dense 5G Wireless Networks*, G. MacCartney, et. al, IEEE Access, October 2015.
[123] *5G Channel Model*, White Paper, Globecom 2015 (http://www.5gworkshops.com/5GCM.html).
[124] *Ibid.*
[125] *5G 3GPP-like Channel Models for Outdoor Urban Microcellular (UMi) and Macrocellular (UMa) Environments for Frequencies up to 100 GHz*, A. Ghosh et.al, VTC. Spring 2016.
[126] *Ibid.*
[127] *Preliminary 5G suburban micro (SMi) channel model for different foliage conditions*, T. A. Thomas, M. Rybakowski, P. Krysiak, to appear in IEEE Globecom 2016. December 2016.
[128] *5G 3GPP-like Channel Models for Office & Shopping Malls (InH) for Frequencies up to 100 GHz*, K. Haneda et.al, ICC-2016.
[129] *5G Channel Model*, White Paper, Globecom 2015 (http://www.5gworkshops.com/5GCM.html).

outdoor to indoor path loss, dynamic blockage, and spatial consistency were incorporated including significant updates to large and small-scale parameter modeling and a newly proposed clustering algorithm and models that capture frequency dependency of various large and small-scale parameters.[130] Also for the SMi scenario, foliage loss due to vegetation was introduced[131] and includes three different foliage levels. Finally, 3GPP derived the channel model based on[132] with certain enhancements like additional scenarios (Rural Macro (RMa)), large scale antenna and large bandwidth modeling and inclusion of oxygen absorption.[133]

The measurements indicate that smaller wavelengths introduce increased sensitivity in the propagation models due to the scale of the environment and show frequency dependence about path loss and certain large scale parameters. Diffraction, which is the bending of rays around building corners/roofs, decreases with frequency and is no longer a dominant effect after around 10 GHz in outdoor channels. The atmospheric and rain losses are frequency dependent but are small (less than around 2.0 dB for worst-case rain) for cells radii less than 100 m even at 100 GHz. One of the important considerations in channel modeling is penetration loss which is highly dependent on materials and tends to increase with frequency as illustrated in Figure 5.9.[134]

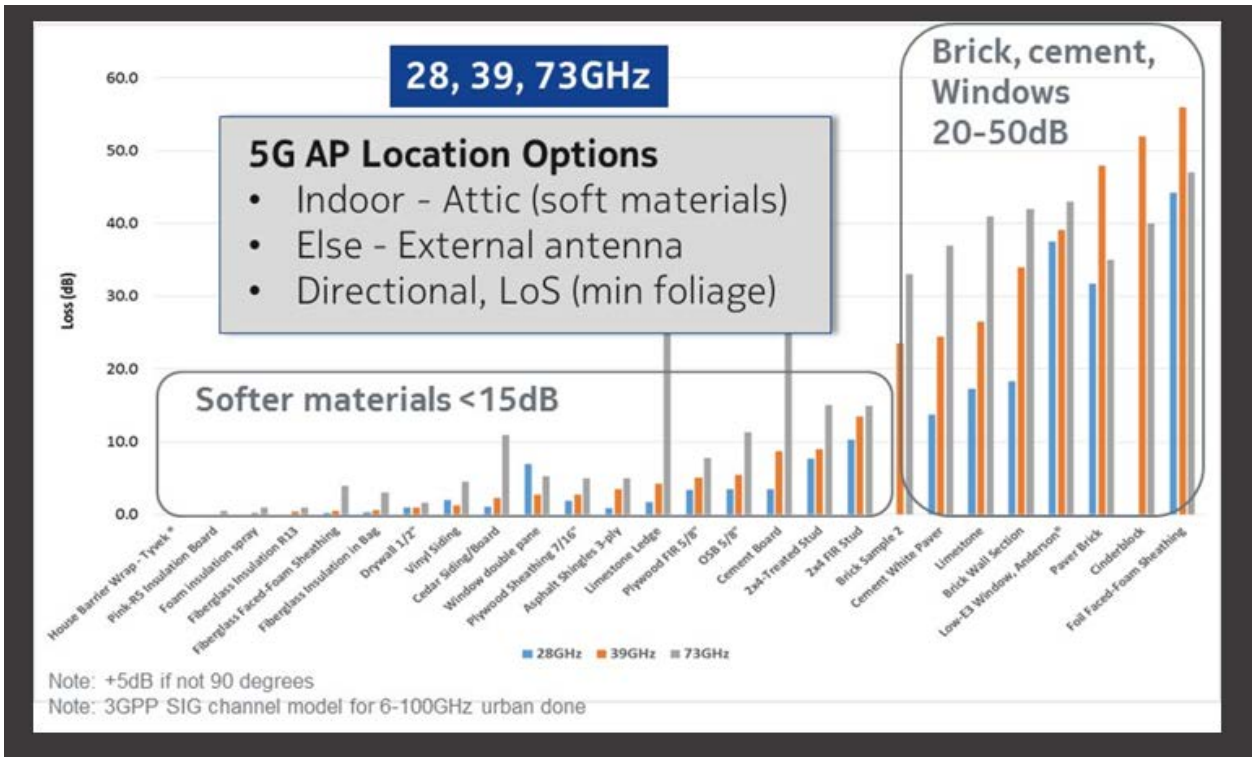

Figure 5.9. Penetration Loss Measurements at Different Frequencies.

[130] *Ibid.*
[131] *Preliminary 5G suburban micro (SMi) channel model for different foliage conditions*, T. A. Thomas, M. Rybakowski, P. Krysiak, to appear in IEEE Globecom 2016. December 2016.
[132] *5G Channel Model*, White Paper, Globecom 2015 (http://www.5gworkshops.com/5GCM.html).
[133] 3GPP TR38.900 (http://www.3gpp.org/ftp//Specs/archive/38_series/38.900/38900-100.zip).
[134] *Building penetration loss measurements for mmWave with a range of materials*, Nokia Networks, Alcatel-Lucent Shanghai Bell, Alcatel-Lucent, 3GPP R1-161642, available at: http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_AH/LTE_ChM_1603/Docs/R1-161642.zip.

5.2 5G SYSTEM ARCHITECTURE

In addition to the work to define the 5G NR access technology, 3GPP has also agreed to define a new system architecture in support of 5G. This work started with a study on new services and market technology enablers for 5G as part of the SMARTER study in 3GPP SA1, and has now progressed towards architecture principles, requirements and key issues that need to be addressed in defining the next generation system architecture for 5G. This section provides details on the Rel-14 work in the 3GPP SA groups towards the 5G system architecture to be normatively specified in Rel-15.

5.2.1 NEW SERVICES AND MARKETS TECHNOLOGY ENABLERS (SMARTER)

As part of Rel-14, 3GPP has undertaken numerous studies relevant to 5G. At the service requirements level, these studies include TR 22.891, *Feasibility Study on New Services and Markets Technology Enablers*, which includes over 70 use cases for new opportunities in the next generation of telecommunications systems. These use cases cover a range of new markets from the Internet of Things (IoT) to factory automation, drone control, vehicular communications and control, and tactile internet as well as new services, such as temporary service in a crisis, information caching and distribution, and device theft prevention and recovery. The study, which was completed May 2016, also addressed many system improvements, such as resource efficiencies, support for various access technologies, network slicing, and network flexibility. Based on several industry white papers, the overarching objective defined a new system that can efficiently and effectively support multiple service dimensions. Figure 5.10 illustrates the proposed enhancements.

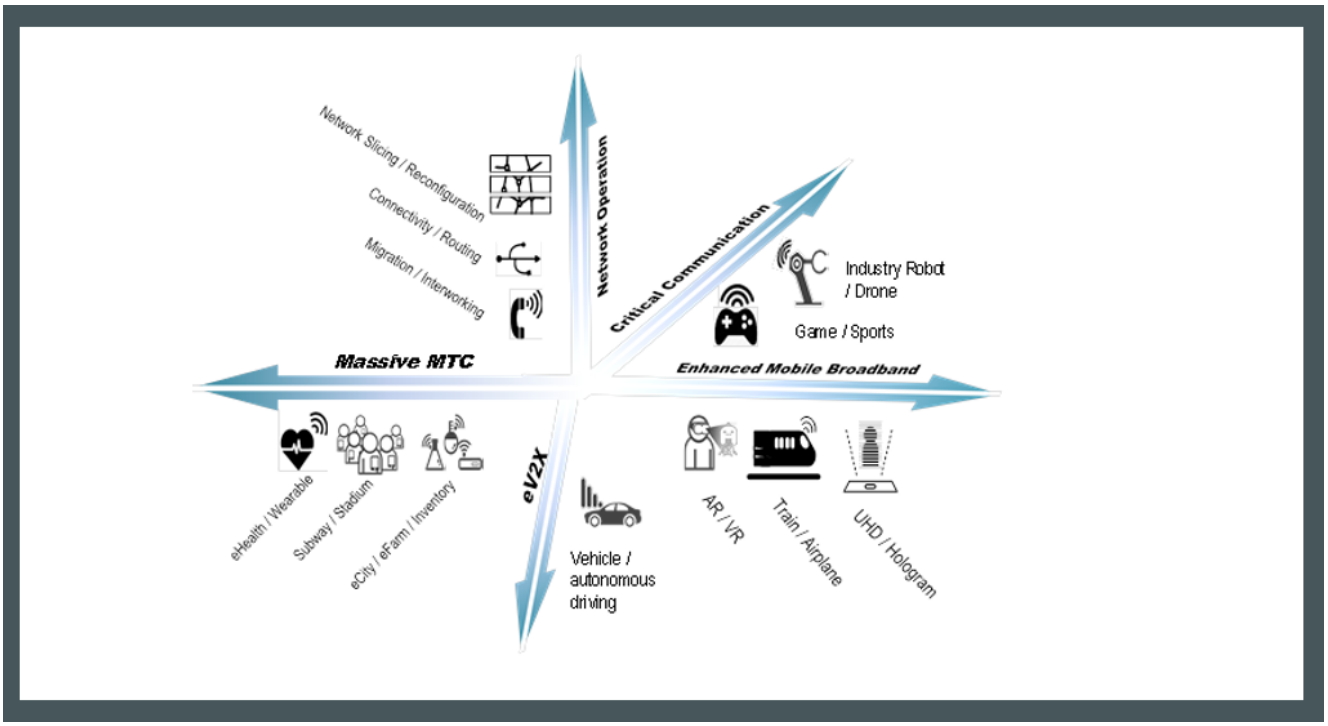

Figure 5.10. New Service Dimension.

These use cases were further developed in the following four secondary studies: TR 22.861, *Feasibility Study on Massive Internet of Things*, TR 22.862, *Feasibility Study on Critical Communications*, TR 22.863,

Feasibility Study on Enhanced Mobile Broadband, and TR 22.864, *Feasibility Study on Network Operation*. These secondary studies, which were completed May 2016, became the basis for the Rel-15 normative requirements currently being captured in TS 22.261, *Service requirements for next generation*[135] *new services and markets*. These requirements are expected to be complete in March 2017. An additional study, TR 22.886, *Study on 5G V2X Services*, is ongoing and the expected normative requirements will also be included in the Rel-15 TS 22.261.

The new 3GPP Rel-15 system is expected to provide optimized support for a variety of different 5G services, different traffic loads, and different end user communities. This is achievable with the introduction of new technologies, both in the access networks and the core network, such as flexible and scalable assignment of network resources. Additionally, the new system needs to support very challenging KPIs for latency, reliability, and throughput. Enhancements in the air interface contribute to meeting these KPIs as do enhancements in the core network, such as network slicing, in-network caching, and hosting services closer to the end-points.

Flexible network operations are the mainstay of the new system. The capabilities to provide this flexibility include network slicing, network capability exposure, scalability, and diverse mobility. Other network operations requirements address the necessary control and data plane resource efficiencies, as well as network configurations that streamline service delivery by optimizing routing between end-users and application servers. Alternative security and charging mechanisms handle new types of devices connecting to the network in different ways.

Mobile Broadband enhancements have also been identified, leading to a number of new KPIs. These pertain to high data rates, high density, high user mobility, highly variable data rates, and deployment and coverage. High data rates are driven by the increasing use of data for services such as streaming (e.g., video, music, and user generated content), augmented reality, and IoT (e.g., drone control). These services come with very challenging requirements for data rates, both downlink and uplink, as well as associated requirements pertaining to latency to meet service performance expectations. Additionally, increased coverage in densely populated areas, such as sports arenas, urban areas, and transportation hubs has become essential. New KPIs on density enable both the transport of high volumes of data traffic per area and transport of data for a high number of connections. Many new devices are expected to support a variety of services which exchange either a very large (e.g., streaming video) or very small amount of data (e.g., data burst). The new system will handle this variability in a resource efficient manner. These cases introduce new deployment requirements for indoor and outdoor, local area connectivity, wide area connectivity, and UEs travelling at high speeds.

Another aspect addressed by the new KPIs includes requirements for various combinations of latency and reliability, as well as higher accuracy for positioning. These KPIs are driven by support for both commercial and public safety services. On the commercial side, new use cases for factory automation, industrial process automation, drone and other UAV control, augmented reality, and more have been identified.

Support for massive Internet of Things (MIOT) brings many new requirements in addition to those for the enhanced KPIs. The expansion of connected things introduces a need for significant improvements in resource efficiency in all system components (e.g., devices, radio, access network, core network). The use of device to device communication established in LTE is expanded to address new opportunities introduced by IoT devices that need to communicate among themselves (e.g., wearables, medical monitoring equipment). New business models are evolving around MIOT for managing groups of devices, for example, sensors embedded in a road or building. In the new system, resource efficiencies can be achieved by

[135] 3GPP is developing a brand name for the next generation system. The title will be updated once 3GPP determines the name.

associating multiple sensors in a single subscription and providing common activation, deactivation and mobility management procedures. Mobility management is also being optimized to handle stationary, geographically restricted and fully mobile devices.

5.2.2 ARCHITECTURE FOR NEXT GENERATION SYSTEM

A large part of the planning in 3GPP for Rel-14, Rel-15 and Rel-16 as discussed in section 4.2 is around the next generation system architecture for mobile networks. There are many issues that the next generation system architecture must address, including the support of new RAT(s) defined by 3GPP RAN, the integration and or interworking with Evolved E-UTRA, the plans for support of non-3GPP accesses, and many more. It has been agreed that both evolution of the current E-UTRA architecture, as well as "clean slate" approaches will be considered and studied.

5.2.2.1 ARCHITECTURE PRINCIPLES

Work is well under way in 3GPP SA on the next generation system architecture, and many high-level architecture principles have already been agreed. A full list of high level requirements can be found in 3GPP TR 23.799, and are summarized in Key Architecture Principles. Note that the timing on which 3GPP release will support these requirements (i.e., Rel-15 or Rel-16) is still to be determined, in many cases.

Key Architecture Principles:

- Separate the UP and CP functions, allowing independent scalability and evolution
- Allow for a flexible deployment of UP separate from CP functions, i.e., central or distributed (remote) location
- Modularize the function design, e.g., to enable flexible and efficient network slicing
    - Support unified authentication framework for UEs which may support only subset of NGS functionality (e.g., not supporting mobility)
    - Separated access and mobility management (AMF) as well as session management (SMF) which enables independent evolution and scaling; supports UE simultaneously connected to multiple network slices
- Support a flexible information model with subscription and policy separated from network functions and nodes
- Minimize access and core network dependencies by specifying a converged access-agnostic core with a common AN - CN interface which integrates different 3GPP and non-3GPP access types
- To support "stateless" NFs (where the "compute" resource is decoupled from the "storage" resource that stores state as opaque data), 3GPP will specify (possibly by referencing) interfaces from NFs to a data storage function. NFs may use data storage function to store opaque data

Key Architecture Requirements:

- The architecture shall support capability exposure
- Each Network function can interact with the other NF directly. The architecture shall not preclude the use of an intermediate function to help route control plane messages (e.g., like a DRA)

- Support transmission of different PDU types, e.g., IP, Ethernet
- Support separate Policy function to govern the network behavior and end user experience
- Allow for different network configurations in different network slices
- The architecture supports roaming with both Home routed traffic as well as Local breakout traffic in the visited PLMN in an efficient way

Control Plane Requirements:

- Enable multi-vendor interworking between access network, and network functions within the core network, and between the network functions within the core network. At the same time, it is sufficient that a single interface is exposed towards the radio while abstracting the modular (elementary) functions supported in the core network
- Procedures (i.e., set of interactions between two NFs) are defined as a service, wherever applicable, so that its re-use is possible and enables support for modularity; this will be evaluated on a case by case basis when specifying the procedure

User Plane Requirements:

- A generic user-plane function (UPF) is defined, which supports various user-plane operations (incl. forwarding operations to other UP functions/data networks/the control-plane, bitrate enforcement operations, service detection operations, etc.)
- The control plane configures the UP functions to provide the traffic handling functionality needed for a session. One or multiple UP functions per session can be activated and configured by the control-plane as needed for a given user-plane scenario.
- To support low latency services and access to local data networks, user plane functions can be deployed close to the radio. For central data networks, UPFs can be deployed centrally.
- To support home routed roaming at least a UP function is located in the HPLMN, and there also needs to be at least another UP function located in the VPLMN which includes roaming functionality such as Charging, LI, etc.

Support of Concurrent Access to Local and Centralized Services:

- Multiple PDU sessions including a PDU session providing access to a local UP function (providing access to local data networks) and a PDU session providing access to central data networks (central UP function)
- A single PDU session, for which the control plane may configure multiple UP functions

Interim Agreements on Overall Architecture:

- In Rel-15, AMF and SMF functions should be standardized as separate functions with standardized interactions.
- NAS, MM and SM protocol messages terminate in AMF and SMF respectively; this is independent of whether SM protocol terminates in the H-SMF or V-SMF

- NAS SM messages are routed by AMF
- Each NF can interact with each other directly
- The architecture does not describe an intermediate function between control plane functions but it does not preclude the use of an intermediate function for routing and forwarding of messages (e.g., like a DRA) between control plane functions

5.2.2.2 DEPLOYMENT SCENARIOS

Given the requirement for the next generation system architecture to support both the E-UTRA as well as new next generation RAT(s), several possible deployment strategies have been discussed in 3GPP for introducing components of the next generation system architecture. Currently, the main deployment scenarios still under consideration (see Annex J in 3GPP TR 23.799) are in sections 5.2.2.2.1 to 5.2.2.2.5.

5.2.2.2.1 STANDALONE NR IN NEXTGEN SYSTEM

This deployment scenario is shown in Figure 5.11 and introduces the New Radio (NR) access and NextGen Core (NGC) in a standalone mode (i.e., no requirements for legacy EPC or E-UTRAN support), where:

- NG1 represents the control plane reference point between the NextGen UE and NextGen Core
- NG2 represents the control plane reference point between the NextGen RAN and NextGen Core
- NG3 represents the user plane reference point between the NextGen RAN and NextGen Core

This deployment scenario is particularly interesting in cases where NR access systems are to be deployed and no legacy EPC/LTE systems exist.

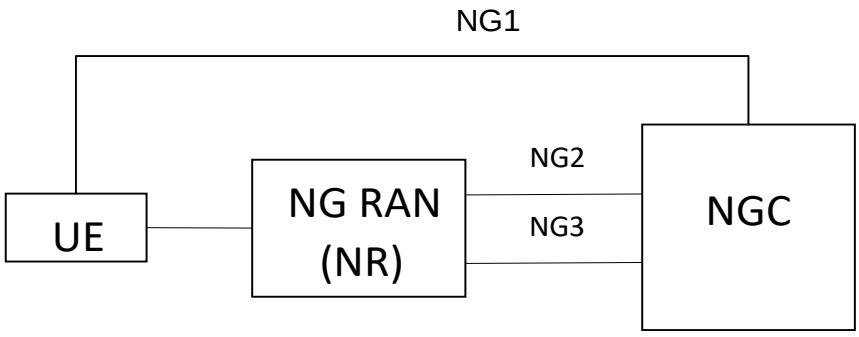

Figure 5.11. High Level Architecture for Standalone NR in NextGen System (3GPP TR 23.799).

5.2.2.2.2 STANDALONE EVOLVED E-UTRA IN NEXTGEN SYSTEM

This deployment scenario is shown in Figure 5.12 and is the same as the Standalone NR architecture discussed in the previous section except that the radio access here is the Evolved E-UTRA (i.e., LTE based) instead of the newly defined NR radio access. This mode is again standalone in the sense that there are no requirements for legacy EPC or E-UTRAN support. The NG1/NG2/NG3 interfaces represent the same reference points as discussed in the previous section.

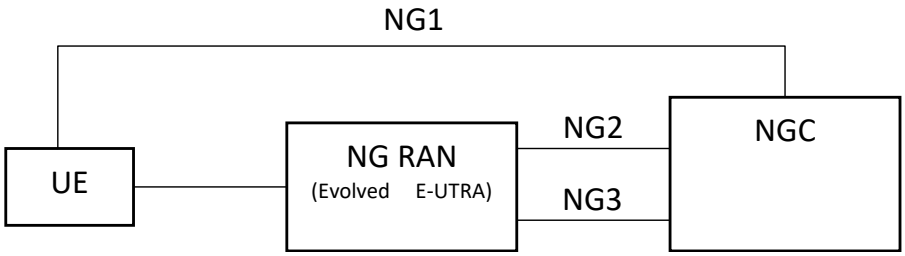

Figure 5.12. High Level Architecture for Standalone Evolved E-UTRA in NextGen System (3GPP TR 23. 799).

This deployment scenario is particularly interesting in cases where Evolved E-UTRA access systems are to be deployed and no legacy EPC/LTE systems exist.

5.2.2.2.3 NON-STANDALONE NR IN EPS

This deployment scenario is shown in Figure 5.13 and leverages the dual connectivity architecture from E-UTRA where an eNB acts as the anchor component carrier for both UP and CP traffic, while the NR access is a secondary component carrier on the UP only. Furthermore, this architecture leverages an EPC for the core network using legacy defined S1-U, S1-MME and NAS signaling interfaces. This mode is Non-Standalone since it requires legacy defined eNB and EPC network functions to support the deployment of the NR radio access UP. Note that the two options shown in Figure 5.13 represent the cases where the UP traffic is either routed from the NR radio access through the eNB to the EPC (left figure) or routed directly from the NR radio access node to the EPC through an S1-U interface (right figure).

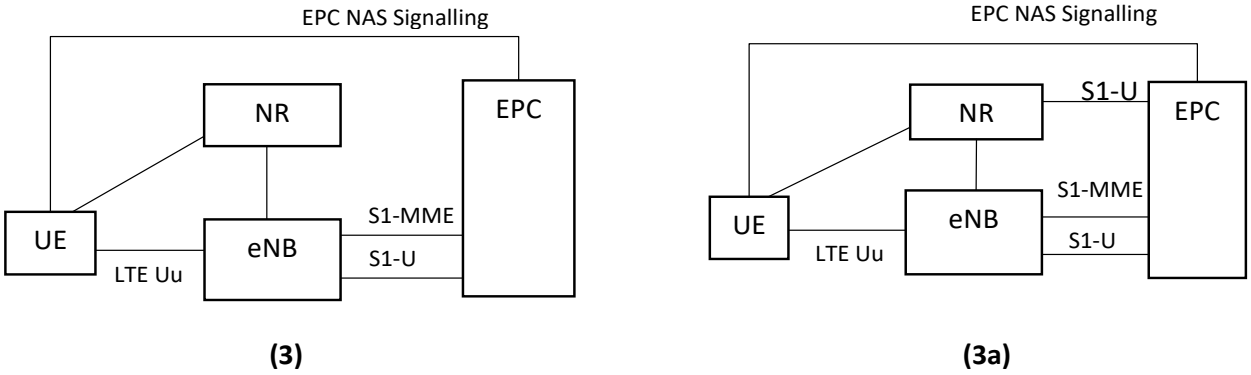

Figure 5.13. High Level Architecture for Non-Standalone NR in EPS (3GPP TR 23.799).

This deployment scenario is particularly interesting for early deployments of NR access systems (since only the UP of the NR access is required) in areas where legacy eNBs and EPCs exist.

5.2.2.2.4 NON-STANDALONE NR IN NEXTGEN SYSTEMS

This deployment scenario is shown in Figure 5.14 and also leverages the dual connectivity architecture from E-UTRA to support the NR radio access UP. However, this architecture introduces a NextGen Core network rather than leveraging a legacy EPC. This mode is Non-Standalone since it requires legacy defined eNB network functions to support the deployment of the NR radio access UP. The introduction of the NGC also requires use of the newly defined NG1/NG2/NG3 interfaces as defined in section 5.2.2.2.1, which means that the eNB will need to be upgraded to support these new interfaces (and hence is labeled as an Evolved eNB in Figure 5.14). Note that the two options shown in Fig. 5.14 represent the cases where the

UP traffic is either routed from the NR radio access through the Evolved eNB to the NGC (left figure) or routed directly from the NR radio access node to the EPC through an NG3 interface (right figure).

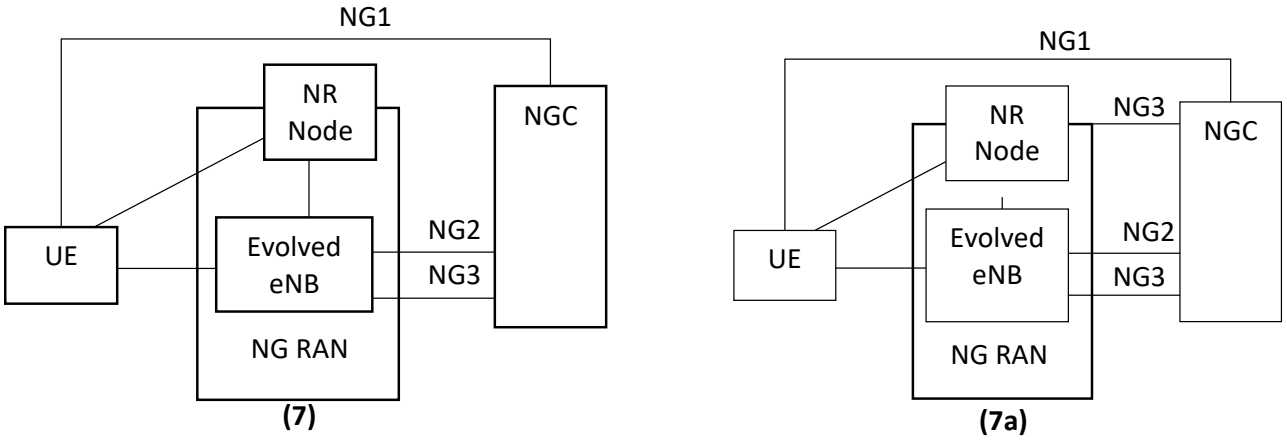

Figure 5.14. High Level Architecture for Non-Standalone NR in NextGen systems (3GPP TR 23.799).

This deployment scenario is particularly interesting for deployments of NR access systems in areas where legacy eNBs and EPCs are ready to be upgraded/replaced with Evolved eNBs and the new NGC to take advantage of the new features and benefits that these new/enhanced network elements offer.

5.2.2.2.5 NON-STANDALONE EVOLVED E-UTRA IN NEXTGEN SYSTEMS

This deployment scenario is shown in Figure 5.15 and leverages a dual connectivity architecture where now an NR radio access node acts as the anchor component carrier for both UP and CP traffic, while an Evolved eNB is used as a secondary component carrier on the UP only. This architecture still leverages the NGC for the core network using the NG1/NG2/NG3 signaling interfaces. This mode is Non-Standalone from the point of view of the Evolved eNB UP, which requires an NR access node anchor point. Note that the two options shown in Figure 5.15 represent the cases where the UP traffic is either routed from the Evolved eNB radio access through the NR radio access to the NGC (left figure) or routed directly from the Evolved eNB radio access node to the NGC through an NG3 interface (right figure).

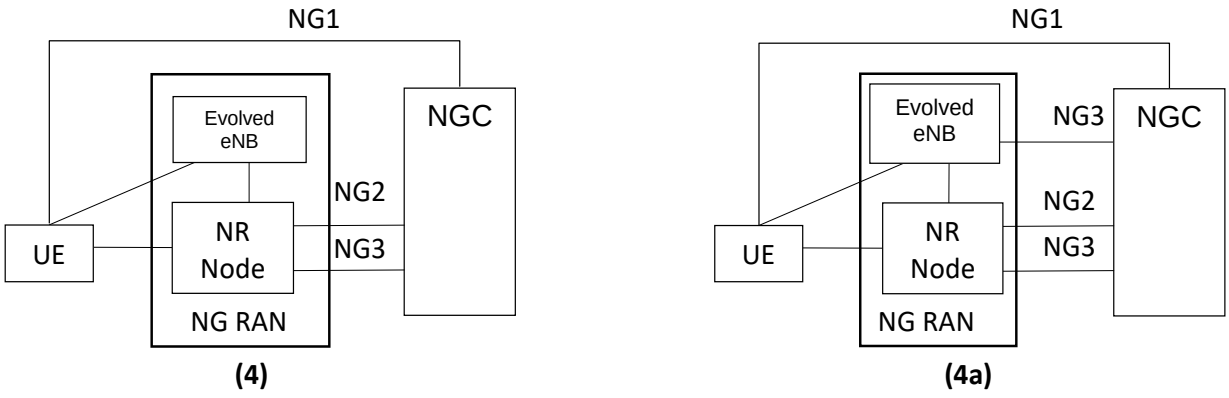

Figure 5.15. High Level Architecture for Non-Standalone E-UTRA in NextGen Systems (3GPP TR 23.799).

This deployment scenario is particularly interesting for deployments of NR access systems in areas where legacy eNBs and EPCs are ready to be upgraded/replaced with Evolved eNBs and the new NGC to take

advantage of the new features and benefits that these new/enhanced network elements offer, but in scenarios where it makes more sense for the NR radio access to be the dual connectivity anchor point rather than the Evolved eNB radio access (e.g., where NR may be using a lower frequency band than the Evolved eNBs).

5.2.2.3 REFERENCE ARCHITECTURE

Based on the architecture principles and deployment scenarios discussed in the previous two sections, Figure 5.16 shows the interim agreements as of November 2016 for the non-roaming reference architecture.

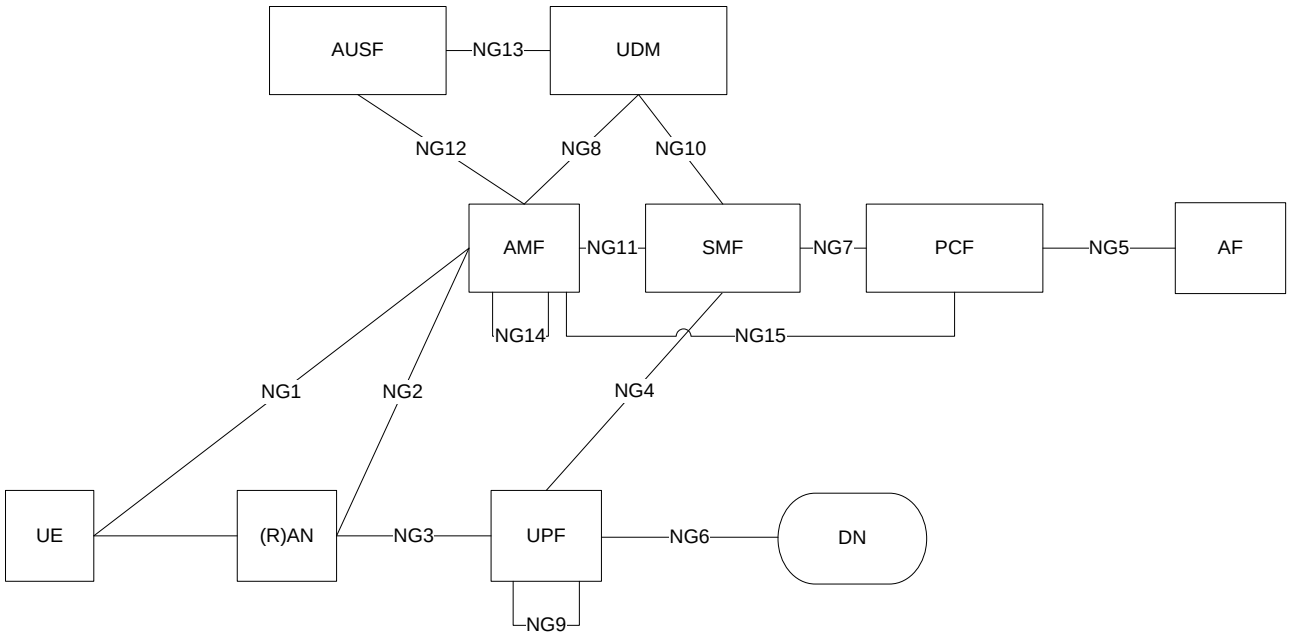

Figure 5.16. Non-Roaming NextGen Reference Architecture (3GPP TR 23.799).

The elements shown in Fig. 5.16 are defined as:

- **Authentication Server Function (AUSF) -** Performs authentication processes with the UE
- **Unified Data Management (UDM)** – Supports:
  - Authentication Credential Repository and Processing Function (ARPF); this function stores the long-term security credentials used in authentication for AKA
  - Storing of Subscription information
- **Core Access and Mobility Management Function (AMF) –** Supports:
  - Termination of RAN CP interface (NG2)
  - Termination of NAS (NG1), NAS ciphering and integrity protection
  - Mobility Management

- Lawful intercept (for AMF events and interface to LI System)
- Transparent proxy for routing access authentication and SM messages
- Access Authentication
- Access Authorization
- Security Anchor Function (SEA). It interacts with the UDM and the UE, receives the intermediate key that was established as a result of the UE authentication process; in case of USIM based authentication, the AMF retrieves the security material from the UDM
- Security Context Management (SCM); the SCM receives a key from the SEA that it uses to derive access-network specific keys

- **Session Management Control Function (SMF)** – Supports:
  - Session Management
  - UE IP address allocation & management (including optional Authorization)
  - Selection and control of UP function
  - Termination of interfaces towards Policy control and Charging functions
  - Control part of policy enforcement and QoS
  - Lawful intercept (for SM events and interface to LI System)
  - Termination of SM parts of NAS messages
  - Downlink Data Notification
  - Initiator of AN specific SM information, sent via AMF over NG2 to AN
  - Roaming functionality
    - Handle local enforcement to apply QoS SLAs (VPLMN)
    - Charging data collection and charging interface (VPLMN)
    - Lawful intercept (in VPLMN for SM events and interface to LI System)
- **Policy Control Function (PCF) –** Provides:
  - Support of unified policy framework to govern network behavior
  - Policy rules to control plane function(s) that enforce them
- **Application Function (AF) -** Requests dynamic policies and/or charging control
- **User plane Function (UPF) –** Provides:
  - Anchor point for Intra-/Inter-RAT mobility (when applicable)

- External PDU session point of interconnect (e.g., IP)
- Packet routing & forwarding
- QoS handling for User plane
- Packet inspection and Policy rule enforcement
- Lawful intercept (UP collection)
- Traffic accounting and reporting
- Support for interaction with external DN for transport of signaling for PDU session authorization/authentication by external DN

- **Radio Access Network (RAN)**
- **User Equipment (UE)**
- **Data Network (DN),** e.g., operator services, Internet access or 3rd party services

The interfaces shown in Fig. 5.16 are defined as:

NG1: Reference point between the UE and the Access and Mobility Management function

NG2: Reference point between the (R)AN and the Access and Mobility Management function

NG3: Reference point between the (R)AN and the User plane function (UPF)

NG4: Reference point between the Session Management function (SMF) and the User plane function (UPF)

NG5: Reference point between the Policy Function (PCF) and an Application Function (AF)

NG6: Reference point between the UP function (UPF) and a Data Network (DN)

NG7: Reference point between the Session Management function (SMF) and the Policy Control function (PCF)

NG8: Reference point between Unified Data Management and AMF

NG9: Reference point between two Core User plane functions (UPFs)

NG10: Reference point between UDM and SMF

NG11: Reference point between Access and Mobility Management function (AMF) and Session Management function (SMF)

NG12: Reference point between Access and Mobility Management function (AMF) and Authentication Server function (AUSF)

NG13: Reference point between UDM and Authentication Server function (AUSF)

NG14: Reference point between 2 Access and Mobility Management function (AMF)

NG15: Reference point between the PCF and the AMF in case of non-roaming scenario, V-PCF and AMF in case of roaming scenario

More information on the NG reference architecture related to roaming scenarios (local breakout and home routed scenarios), concurrent access to local and central data networks (multiple PDU session option), and concurrent access to two (e.g., local and central) data networks (single PDU session option) can be found in 3GPP S2-167226.

5.2.2.4 KEY ISSUES

As discussed in in section 4.2, there will be two Phases of normative specifications, with Rel-15 being the Phase 1 normative specifications and Rel-16 being the Phase 2 normative specifications. In order to progress towards defining more details on the next generation reference system architecture shown in Fig. 5.16, 3GPP SA has agreed for Phase 1 that a deployable 5G architecture with the following features be specified:

- network slicing
- use of virtual environments
- service-based architecture
- network capability exposure
- support for edge computing
- access and mobility management
- session management separate from mobility management
- (re)selection of efficient user plane path
- session and service continuity
- QoS
- policy framework
- network discovery and selection
- network sharing
- untrusted non-3GPP accesses
- roaming with EPS
- interworking with and migration from EPS
- IMS services (including support for emergency calls)
- Public Warning System (PWS)
- location services as per related service requirements and in alignment with NG RAN

- SMS over NAS

Many of the above features relate to a long list of key issues that 3GPP SA has identified (see 3GPP TR 23.799) that need to be discussed and for which solutions need to be agreed upon. There has been discussion already in 3GPP on some of these issues, and this section will present at a high level the status in October 2016 of some of the key areas of work including Network Slicing, QoS Framework, Mobility Management and Session Management. It should be understood, that much of the information presented in this section is still under discussion and final agreements have yet to be made. Readers interested in further details on the status of the various solution proposals for each key issue should refer to 3GPP TR 23.799). Note that some of the interim agreements made so far on some of the key issues are provided in Section 8 of 3GPP TR 23.799.

5.2.2.4.1 NETWORK SLICING

The goal of network slicing is to enable the management of multiple logical networks as virtually independent business operations on a common physical infrastructure. In practice, this corresponds to the idea that the mobile network could be partitioned into a set of resources (which may be virtual), each called a “slice” that can be allocated for different purposes. For instance, a “slice” can be allocated to an MVNO, an Enterprise customer, an Internet of Things Domain (IoT), or some other convenient set of services (“Mobility as a Service”). A “network slice” extends the APN concept used in the mobile network today. A more detailed description of network slicing is provided by NGMN and referenced in Annex B of 3GPP TR 23.799).

This key issue looks at solutions defining the functionalities and capabilities to enable Network Slicing (including roaming issues). Some of the key issues to address are:

- How to create, modify, delete and isolate/separate different network slice instances
- What type of resource sharing can be used between network slice instances and how are network functions defined within, between or outside of network slices?
- How does a UE simultaneously obtain services from one or more network slice instances (which could be from different operators/roaming scenarios) and what are the procedures for a UE to select a Network Slice?

There has been significant discussion in 3GPP on the key issue of network slicing. Some preliminary agreements made as of October 2016, include (see 3GPP S2-167227):

1. The network slice is a complete logical network (providing Telecommunication Services and Network Capabilities) including AN and CN; whether RAN is sliced is up to RAN WGs to determine
2. A UE may provide network slice selection assistance information (NSSAI) consisting of a set of parameters to the network to select the set of RAN and CN part of the network slice instances (NSIs) for the UE
3. If a network deploys network slicing, then it may use UE provided network slice selection assistance information to select a network slice; in addition, the UE capabilities and UE subscription data may be used

4. A UE may access multiple slices simultaneously via a single RAN. In such case, those slices share some control plane functions, e.g., AMF and Network Slice Instance Selection Function; these common functions are collectively identified as CCNF (Common Control Network functions)

5. The CN part of network slice instance(s) serving a UE is selected by CN not RAN

6. Regarding Annex D: move forward with Group B type of solution in Rel-15 (Group C is subsumed under Group B); Group A is not pursued in Rel-15

7. It shall be possible to handover a UE from a slice in NGC to a DCN in EPC; there is not necessarily a one-to-one mapping between slice and DCN

8. The UE needs to be able to associate an application with one out of multiple parallel established PDU sessions; different PDU sessions may belong to different slices

9. The UE may cause the network to change the set of network slices it is using by submitting in an MM procedure the value of a new NSSAI; the final decision is up to the network

Some of the initial work has focused on the network slicing architecture in Fig 5.13 (see 3GPP TR 23.799), which assumes no slicing of the RAN (RAN slicing is to be determined by RAN working groups). In this case, a slice routing and selection function is needed to link the radio access bearer(s) of a UE with the appropriate core network instance. The main characteristics is that the RAN appears as one RAT+PLMN to the UE and any association with network instance is performed network internally, without the network slices being visible to the UE.

Besides the Subscriber Repository function, the control plane of the NextGen Core is partitioned into three types of Network Functions (NFs).

- Slice Selection Function (SSF): The SSF handles the UE's initial Attach Request and New Session establishment request by selecting an appropriate slice for the UE based on the UE's subscription information, UE usage type, service type and UE capabilities. The SSF is not specific to a particular network slice

- Common CP NF: The Common CP NF is the CP entry function, which at least includes the MM function, AU function, and NAS Proxy function. The Common CP is shared parts among different slices. When different types of Network Slice do the sharing, the required Common CP function can be different; one UE can only access one Common CP simultaneously

- Slice Specific CP NF: the NFs which are located on the non-shared Slice parts, e.g., SM NF

- No direct interface from RAN to the slice specific CP NFs

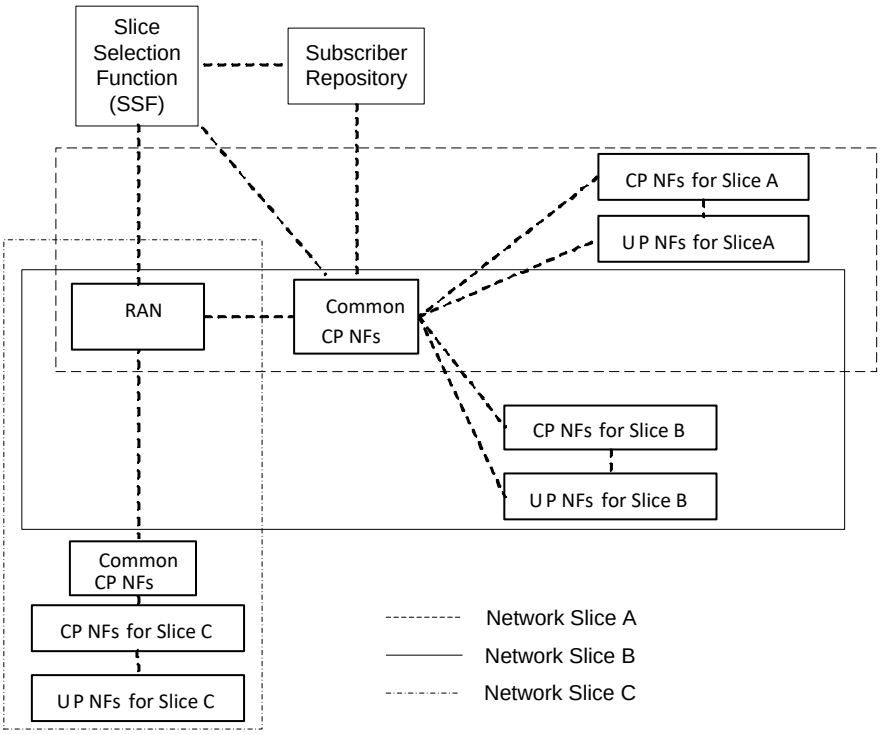

Figure 5.17. Control Plane Interfaces for Network Slicing with Common and Slice Specific Functions.

There has also been discussion on the roaming scenarios for network slicing. Figure 5.18 from 3GPP TR 23.799 shows the home routing roaming reference architecture for network slicing. In this scenario, the end-to-end network slice is composed of HPLMN and VPLMN parts, each which needs to be selected to provide the end-to-end services for the roaming UE.

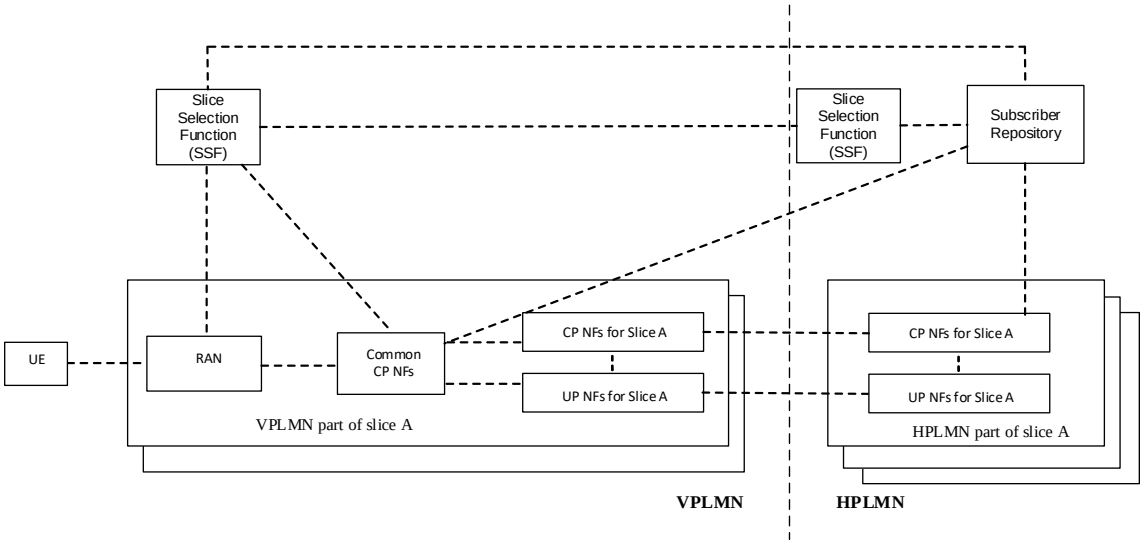

Figure 5.18. Home Routed Roaming Reference Architecture with Network Slicing.

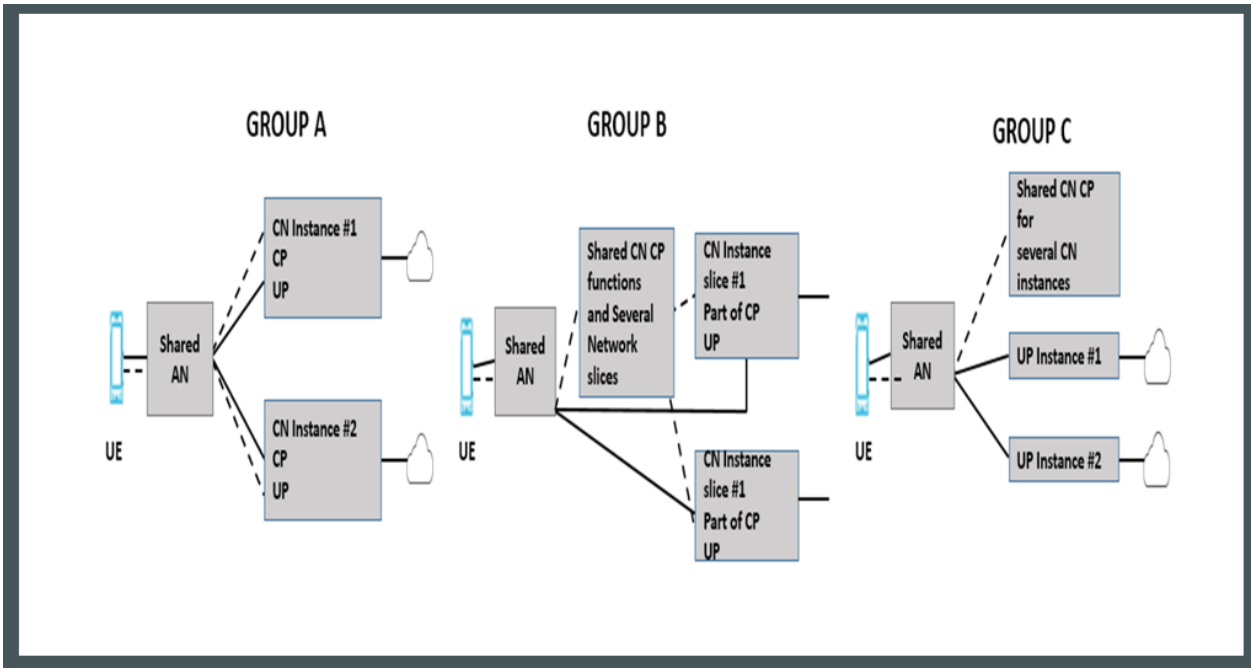

Fig. 5.19. Different Approaches Defined in [TR 23.799] to Support Multiple Network Slices per UE.

Note that in the proposed architectures shown in Figure 5.19, a given UE may be able to connect to multiple network slices simultaneously. 3GPP has been discussing three different groups of network slicing solutions for the support of multiple network slices per UE as shown in Figure 5.19 (see 3GPP TR 23.799). The three groups are defined as follows:

- **Group A** includes the interpretation that the UE obtains services from different network slices and different CN instances, aiming at logical separation/isolation between the CN instances. This group is characterised by independent subscription management/mobility management for each network slice handling the UE, with the potential side effects of additional signaling in the network and over the air. On the other hand, it can be argued that the isolation in the CN part of the network is easiest to achieve

- **Group B** assumes that some Network Functions are common between the network slices, while other functions reside in its individual network slices

- **Group C** assumes that the control plane handling is common between the slices, while the user plane(s) are handled as different network slices

More details of the discussions in 3GPP related to network slicing regarding network slice (instance) selection, reselection and association, the support of multiple connections to multiple network slices per UE and the support of roaming for network slicing is provided in 3GPP TR 23.799.

5.2.2.4.2 QOS FRAMEWORK

3GPP defined an extensive QoS framework for the LTE Enhanced Packet System architecture through the definition of QCI classes [see 3GPP TRs 36.300, 23.401, 23.203]. The QoS framework for the next generation system architecture should build off this framework and address the key issues introduced by the next generation system architecture. For instance, the QoS framework for the next generation system architecture should:

- account for the split of CP and UP
- support independent evolution of access (both 3GPP and non-3GPP) and core based on a non–access specific framework
- support the wide range of use cases and applications expected for the next generation RAN and core
- define the QoS control and enforcement points, particularly as it relates to whatever centralized RAN architectures are agreed
- define the QoS model: reference points, parameters, traffic identification, traffic separation, signaling, etc.

Some of the guiding principles for the QoS framework for the NG architecture are discussed in 3GPP TR 23.799:

- Solution for QoS framework should allow ease of reuse of Next Generation core for various access technologies (i.e., 3GPP access, non-3GPP access)
- Solution for QoS framework should allow independent evolution of core and access technologies (i.e., 3GPP access, non-3GPP access)
- Solution for QoS framework within NextGen core network is not access specific
- Solution for QoS framework enables optimal service level quality as per application needs, optimizing network capacity utilization
- A QoS framework that can provide adequate QoS handling for:
    - Services whose characteristics have been explicitly provided to the 3GPP system (e.g., via Rx interface)
    - Services/applications whose characteristics have been explicitly deduced by the 3GPP system.
    - Services whose characteristics have been implicitly deduced by the 3GPP system (e.g., by subscription)
    - Applications with non-deducible service data flows
- Solution for QoS framework should identify proper QoS granularities (e.g., per-UE, per-flow) and QoS parameters (e.g., maximum bit rate, guaranteed bit rate, priority level)
- Solution for QoS framework should be able to support E2E QoS control (i.e., it should consider QoS control in RAN, CN, and transport network)

There are many QoS models being discussed in 3GPP currently for the QoS framework that can accommodate the above objectives based on flow, bearer, content/application awareness, etc. and addressing authorization and request, traffic differentiation, ID and resource management (including Mission Critical Group Communications). Once agreement is made on the QoS framework for the NG architecture, the normative specifications will describe the following:

- **Functions:** the required functions (including both CP and UP) and a functional split between UE, Access Networks and CN
- **Functional entities:** indication of QoS control points, QoS enforcement points and the associated reference points
- **QoS model:** how is QoS handled on each reference point (e.g., per packet, per flow, aggregation of flows etc.)
- **QoS characteristics:** the list of parameters (e.g., maximum bit rate, guaranteed bit rate, priority level) needed for the QoS framework
- **QoS related information exchange:** how is QoS information conveyed to entities where it is enforced (e.g., to UE, to RAN, or to user plane gateways)
- **Traffic identification:** how is traffic identified (e.g., means beyond traffic identification based on L3/L4 information such as the IP-5-tuple for IP traffic) at the various QoS provisioning/enforcement points and at what level (e.g., per packet, per flow or as an aggregate of flow etc.) for both uplink and downlink direction? How is traffic identified at the UE for both uplink and downlink direction?
- **Traffic separation:** how is traffic separation achieved (in the core as well as on the CN-RAN interface) for QoS treatment; solutions shall also clarify the granularity of the traffic separation

5.2.2.4.3 MOBILITY MANAGEMENT (MM) FRAMEWORK

Mobility management is a critical part of any mobile network as it is the key for locating and tracking users and to provide session continuity as users are on the move. The MME was the focal point for mobility management in LTE. Given the wide range of use cases expected for next generation wireless systems, some which may require very high mobility (railways) to some that require essentially no mobility (IoT sensors), the work in 3GPP is focused on defining a next generation mobility on demand framework that is adaptive, flexible and intelligent. The MM solutions should define the level of mobility support for a given UE, describe how and when the level of mobility is determined, and evaluate the benefits achieved as a result of the mobility on demand concept. The solutions will define the MM signaling, mobility states, all the intricacies around how and when to support and change between different mobility levels and interworking with 3GPP and non-3GPP legacy systems (including migration strategies).

Figure 5.16 shows a high-level diagram of the proposed mobility framework for Evolved E-UTRA and the next generation system architecture. The mapping of the functions in Figure 5.16 to 3GPP networks functions in the next generation system architecture is for further study. The current work in 3GPP on MM has a strong focus on the mobility state framework to address things such as stateless context management for data network sessions, mobility states for optimized UE power consumption, and simplified mobility states for stationary and Mobile Originating data transmission only UEs. Also, being discussed are solutions for RAN level, 2-layer and RAN-CN split location tracking, RAN specific paging, dynamic MM, idle mode mobility, mobility levels using mobility and session classes, UE reachability in power saving state and devices with only MO communication and support for different mobility levels.

5.2.2.4.4 SESSION MANAGEMENT

Session management is responsible for the setup of the IP or non-IP traffic connectivity for the UE and managing the user plane for that connectivity.

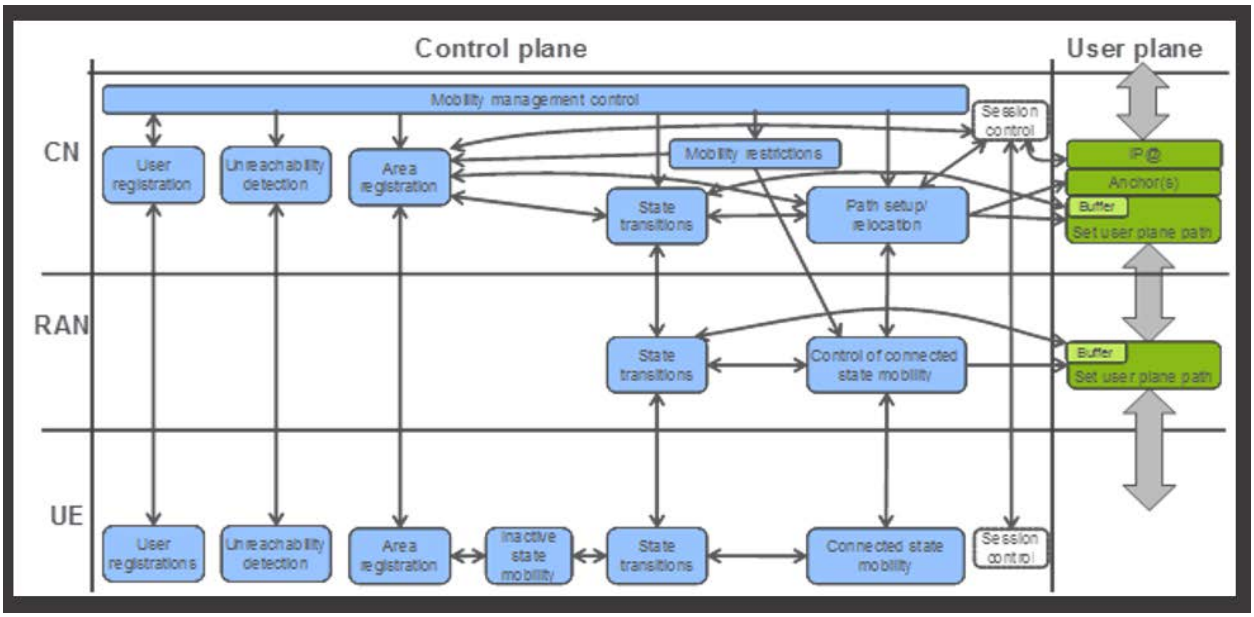

Figure 5.20. High-Level Functions of the Mobility Framework.

Session management specifications will define:

- Session management model
- Support for UEs connected via multiple accesses, multiple connectivity, and/or multiple transport paths, including providing multiple simultaneous traffic connectivity for the UE
- Support for CP signalling for session management between the UE and CN with certain granularity
- Correlation between session management and mobility management functionality, including studying whether separation of session management and mobility management is possible
- How session management and mobility management can be decoupled for scenarios requiring it, if identified feasible (as previous)
- Solutions to coordinate the relocation of user-plane flows with the relocation of applications (hosted close to the point of attachment of the UE) due to the mobility of users
- Solutions to optimally support intermittent connections due to unreliable links or energy saving strategies
- How to efficiently transmit and receive infrequent small amounts of data and short data bursts through the Next Generation System, including studying whether sessions need to be established to enable such services
- How to allow for unidirectional transmission (i.e., uplink or downlink only transmission), efficient security mechanisms depending on user and/or operator needs, different options for addressing, charging, policing, inter-operator interworking

One of the key areas of work on session management will be the allocation of Session Management functions to UE, AN and CN, as shown in the Figure 5.21. Note that the figure does not assume any specific grouping of these functions into logical Network Functions / Network Entities.

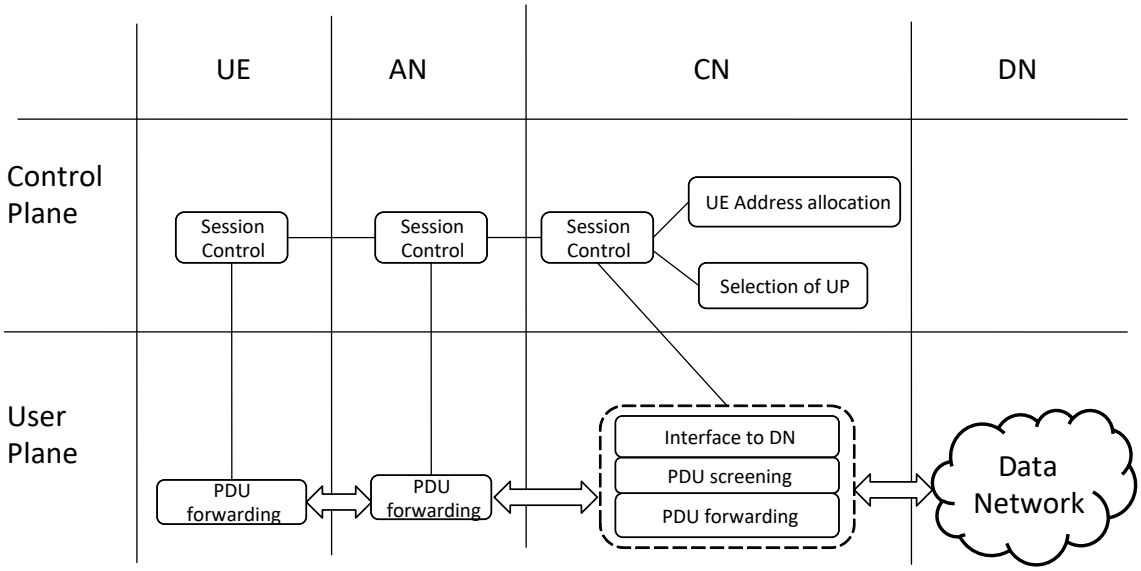

Figure 5.21. Session Management Functions [23.799].

Figure 5.21 provides one example of how session management functions may be allocated by the NG architecture. More details of the work towards Session Management for the NG Architecture are provided in 3GPP TR 23.799, where detailed proposals are discussed related to:

- Session Setup Procedures
  - o Network triggered, on-demand procedures
  - o Common interfaces towards UE and AN
  - o Flexible multiple UP GW(s) assignment
  - o Interaction between mm and SM
  - o Asynchronous models
  - o For Local Area Data Networks
- Session Management with Multiple PDU Sessions (including different accesses)
- Infrequent Small Data Transfer
- Data Transmission with Connectionless RAN-Core Interface
- UP Protocol Models

- Per QoS class tunnel protocol
- Per PDU session tunnel protocol
- Per Node-level tunnel
- SDN-based approach

5.2.2.4.5 OTHER KEY ISSUES

In addition to the key issues discussed in this section, 3GPP TR 23.799 has identified the following key issues to be worked going forward:

- Enabling (re)selection of efficient user plane paths
- Support for session and service continuity
- Network function granularity and interactions between them
- Next Generation core and access - functional division and interface
- 3GPP architecture impacts to support network capability exposure & context information awareness
- Policy framework
- Charging
- Security framework
- Broadcast/Multicast Capabilities
- Support for off-network communication
- NextGen core support for IMS
- 3GPP system aspects to support the connectivity of remote UEs via relay UEs
- 3GPP architecture impacts to support network discovery and selection
- Interworking and migration
- Architecture impacts when using virtual environments
- Traffic steering, switching and splitting between 3GPP and non-3GPP accesses
- Minimal connectivity within extreme rural deployments
- Support of “5G connectivity via satellite” use case

5.3 E-UTRAN/LTE-ADVANCED PRO ENHANCEMENTS

Although a strong focus of Rel-14 is on the study items for 5G, in parallel, 3GPP continues to define further enhancements to LTE-Advanced Pro. This section provides detailed discussion on the LTE enhancements being worked on in Rel-14.

5.3.1 ENHANCEMENTS FOR FULL DIMENSION MIMO

From Rel-13 onward, RAN1 is developing some further extensions including aspects as follows:

- The support of larger numbers of CSI-RS antenna ports 20, 24, 28 and 32: in general, increasing the number of reference ports is an effective method of boosting channel capacity due to richer channel state information. Therefore, Class A CSI reporting in Rel-14 is extended with more numbers of CSI-RS ports for capacity improvement and more flexible 1D/2D port layouts for antenna implementation. Consequently, a number of codebooks associated with 20, 24, 28 and 32 ports will be specified. Moreover, CSI-RS resources supporting 20, 24, 28 and 32 ports will be designed with a mechanism of CSI-RS resource aggregation similar with Rel-13. To mitigate the burden of RS overhead, it is an ongoing discussion whether and how to reduce overhead due to large numbers of CSI-RS antenna ports.

- **UL DMRS enhancement:** before Rel-14, orthogonal DMRS transmission is relatively limited, with up to 2 UE with non-overlapped bandwidth allocation or up to 6 UEs with identical bandwidth allocation. Aligning bandwidth allocation for UL MU-MIMO leads to serious eNB implementation restriction. Therefore, in Rel-14, discussion is ongoing whether and how to support more UL users with non-overlapped bandwidth allocation. Similar with DL DMRS enhancement in Rel-13, the likelihood of supporting more UL multi-users is increasing with more and more UL receivers. Therefore, UL DMRS enhancement will improve UL channel capacity.

- **Aperiodic CSI-RS and hybrid CSI reporting:** To reduce the overhead of CSI-RS from both Class A and Class B CSI reporting, aperiodic CSI-RS and hybrid CSI reporting are considered. Aperiodic CSI-RS is to support one shot CSI-RS transmission which lasts only single or multiple sub frames. Therefore, the UE does not expect a continuous and periodic CSI-RS transmission unless the eNB specifically indicates to the UE a time instance of CSI-RS transmission. Therefore, from the eNB perspective, the eNB may configure a CSI-RS pool to be shared among multiple UEs by TDM since CSI-RS is UE specific strictly speaking. On the other hand, hybrid CSI reporting involves in two advanced CSI-RS types, either non-precoded CSI-RS or beamformed CSI-RS, which are termed as eMIMO-Types. Generally, a rough and long-term CSI report will be feedback from UE side based on the first eMIMO-Type. This report will then be utilized to beamform the second eMIMO-Type CSI-RS, based on which a finer and short-term CSI is reported back to BS side. With such a hybrid CSI reporting, CSI-RS overhead, e.g., Class A, can be further reduced since the first eMIMO-type generally can be configured with a long periodicity of CSI-RS for rough beam tracking.

- **DMRS-based semi-open loop transmission**. The objective of DMRS-based semi-open loop transmission is to improve the support of AAS at a high-speed scenario, i.e., 120km/h. With such a high mobility, existing PMI based CSI measurement and feedback is not reliable and sub-optimal. Therefore, RAN1 is exploring solutions of utilizing AAS more efficiently for DL transmission for high speed UEs. DMRS-based solutions are preferred so that the eNB implementation will not switch transmission modes due to UE mobility and also support DMRS-based MU if applicable. From CSI feedback perspective, DMRS-based semi-open loop transmission may still feedback a partial of or

a long-term CSI component for loose beam tracking for high speed UEs. From a transmission perspective, several transmission schemes, e.g. precoder cycling, Tx diversity, LD-CDD, layer permutation, etc. are available for further discussion.

- **Advanced CSI reporting:** advanced CSI generally considers some selective aspects of CSI measurement and reporting. There are several mechanisms available for RAN1 discussion. As an example, new codebook design framework may consider to use a new channel quantization methodology within W1 (orthogonal and non-orthogonal) and W2 (beam selection and beam combination). Interference measurement may be enhanced to improve the measurement quality of MU interference at the mean time to remain low RS overhead. Analog feedback may embed DL CSI measurement into UL sounding channel to improve the quality of channel quantization, similar to the concept of SRS. Whether and how to support those advanced CSI mechanisms in Rel-14 are for further discussion.

5.3.2 DOWNLINK SUPERPOSITION TRANSMISSION FOR LTE (MUST)

In Release-14, a work item is proposed to specify MUST transmission schemes, for the implementation and the associated signaling to realize the potential performance gains observed in the study phase as described in section 4.3.2.

In the study phase, 3GPP RAN1 identified three MUST categories and candidate receiver schemes for MUST near and far users with potential parameters of assistance information for each receiver type to support MUST operation. These parameters are signaled either through higher-layer signaling or physical-layer control channel, blind detection by receivers, tied to UE's scheduling information or tied to specific UE assumptions. CSI enhancement is also identified as a potential way to increase the probability of MUST user pairing.

The scope of the work item is to specify necessary mechanisms to enable downlink intra-cell multiuser superposition transmission for PDSCH using assistance information about the intra-cell interference experienced by the serving eNB to a UE. A MUST UE receiver is expected to be capable to cancel or suppress intra-cell interference between co-scheduled MUST users for the following cases.

Case 1: Superposed PDSCHs are transmitted using the same transmission scheme and the same spatial precoding vector

Case 2: Superposed PDSCHs are transmitted using the same transmit diversity scheme

Case 3: Superposed PDSCHs are transmitted using the same transmission scheme, but their spatial precoding vectors are different

The following are the detailed objectives of Release-14 work item for MUST mechanism:

For Case 1 and 2:

- Specify downlink multiuser superposition transmission schemes with multiple transmission power ratios
- Specify necessary mechanisms to enable efficient MUST operation
    - Determine the configuration of downlink multiuser superposition transmission

- Provide MUST assistance information to a UE with R-ML receiver, which may include assistance signalling and blind detection.

For Case 3:

- Evaluate the benefits of supporting MUST enhancement to support transmission with different precoding

DESIGN AGREEMENTS FOR CASES 1 AND 2

As for the modulation orders that are supported, the agreement for the far UE is only QPSK and for the near UE, the agreement is to support QPSK, 16QAM and 64QAM. The power ratios between near and far UEs are agreed as follows:

- QPSK+QPSK: {8/10, 50/58, 264.5/289}
- 16QAM+QPSK: { 32/42, 144.5/167, 128/138}
- 64QAM+QPSK: {128/170, 40.5/51, 288/330}

The diagram in Figure 5.22 illustrates the constellations after superposition of various modulations between near and far UEs

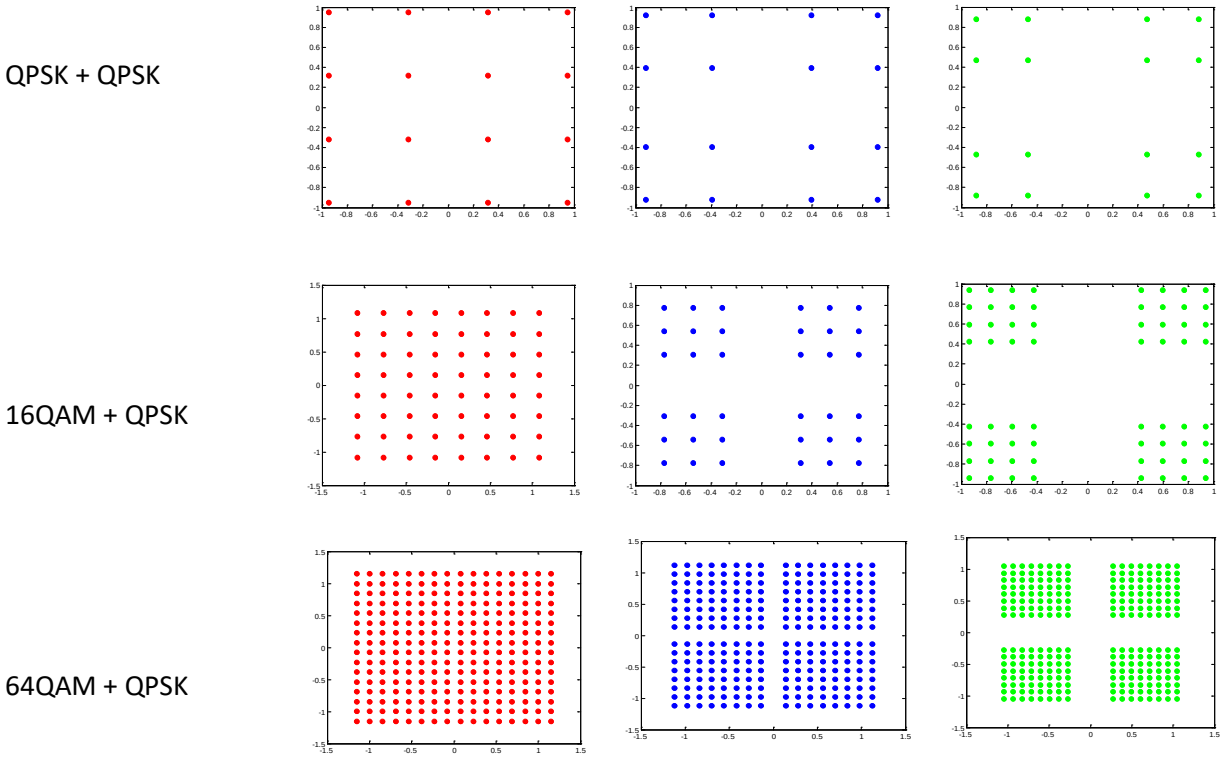

Figure 5.22. Constellations after Superposition of various Modulations between near and far UEs.

The 3GPP RAN4 concluded that blind detection of interference presence and power offset is not supported. As for the resource allocation alignment of interference within near-UE allocation, it was agreed to have a single DCI to indicate the parameters of interfering signal where DCI Includes bits for indication of the

wideband power ratio and interference presence. Also, the design agreement is to provide support for FFS MUST operation in the case where there is no alignment of resource allocation of interference within near-UE allocation.

DESIGN AGREEMENTS FOR CASE 3

MUST Case 3 is a conventional MU-MIMO transmission with multiplexing of different UEs by using different precoding on multiple antennas of the eNB, i.e., there is no near and far UE concept as in Cases 1 and 2. The design agreement for Case 3 is that DM-RS based transmission schemes (i.e., TM8, TM9, TM10) support multi-user superposition transmission using orthogonal DM-RS ports which sufficiently details FFS, e.g., signalling in DCI of the interference presence and modulation order of interfering signal. The modulation combinations in Case 3 can be more flexibly assigned comparing to Cases 1 and 2.

5.3.3 LTE-ADVANCED INTER-BAND CARRIER AGGREGATION (CA)

3GPP Release 14 aims to add interband carrier aggregation combinations for xDL/yUL with x=3,4,5 and y= 1 or 2, as well as specific band combinations as driven by operators and the industry. It also includes the UE Conformance Test Aspects for the newly introduced CA configurations. As of November 2016, work was still in progress against those goals.

5.3.4 ENHANCED LAA FOR LTE (ELAA)

3GPP Rel-13 3GPP created a global standard for the operation of LTE in unlicensed spectrum while adhering closely to Wi-Fi operations and guaranteeing fair co-existence and no performance impact on Wi-Fi. Release 13 however, produced a DL-only LAA framework which is in need for further enhancements in order to create an LAA design with both DL and UL transmissions and to allow aggregation of a large number of unlicensed channels. Below are the key evolution opportunities for LAA.

1. **UL LAA**

Several aspects of UL LAA, such as HARQ and UL LBT, were discussed during Release 13. The exact specification of UL LBT and enhancements to UL scheduling, Physical Uplink Control Channel (PUCCH) design, and data transmission are expected to be finalized in a Release 14 work item.

2. **Dual connectivity support**

To enable new deployment scenarios in the unlicensed spectrum, it is important to enhance the use of carrier aggregation and the associated stringent time synchronization requirements. It is therefore proposed to extend the design to also allow for dual connectivity (DC) operation between LTE in licensed and unlicensed spectrum with non-ideal backhaul in Release 14, which would have much looser synchronization requirements compared to CA.

3. **LAA with 32 carriers**

Wideband transmissions are a key feature for enabling high user data rates, and this is especially true in the evolution towards 5G. In Release 13, a separate 3GPP work item specified aggregation of up to 16 or 32 carriers, which is a natural candidate for application to LAA. With 32 aggregated carriers, LAA will then be able to support a transmission bandwidth of 640 MHz to a single UE.

5.3.5 ENHANCED LTE-WLAN AGGREGATION (LWA)

The enhanced LWA (eLWA) feature in Rel-14 builds on the Rel-13 LWA framework and architecture. The main areas of focus for eLWA in Rel-14 are discussed in [RP-160600] and listed below:

1. Uplink data transmission on WLAN, including uplink bearer switch and bearer split
2. Mobility optimizations, e.g., intra and inter eNB handover without WT change and improvements for Change of WT
3. Potential enhancements to support 60 GHz new band and channels (e.g., in measurements) and increased data rates for 802.11ax, 802.11ad, and 802.11ay (e.g., by PDCP optimizations)
4. Additional information collection and feedback e.g., for better estimation of available WLAN capacity (by additional signaling on both Uu and Xw) to improve LWA performance
5. Automatic Neighbour Relation (ANR) for LWA e.g., for discovery of WLANs under eNB coverage

Both RAN2 and RAN3 working groups are dedicating time towards defining the above enhancements for Rel-14 eLWA.

5.3.6 ENHANCEMENT OF VOLTE

VOLTE was commercially launched in 2012 with highly customized IMS solutions. Since then, more operators, mainly in North America, have made VoLTE available nationwide. Through years of technology development by carriers and new feature enhancement by 3GPP, VoLTE is hitting its prime time.

The goal for operators that are launching VoLTE is to be able to phase out the legacy circuit switched network such as HSPA/UMTS, GSM or CDMA 2000 in the future. So, the baseline performance target for VoLTE has already been set, that is the end-to-end performance shall be equal or better than that of the CS voice in all aspects: UE battery drain, voice quality, mobility, call retainability and call features/functions. Early VoLTE deployment by leading wireless carriers have indicated that the following areas are key factors to meet such a goal:

- Current drain during idle and active call
- End-to-end path latency
- Mobility management
- QoS, radio resource allocation, transport, core…
- Voice and video codec

Enhancements introduced in earlier 3GPP releases, such as DTX/DRX, (Robust Header Compression) ROHC, TTI bundling, eSRVCC/aSRVCC etc, have been proven very effective and significantly improved the end-to-end performance of VoLTE in the above areas. VoLTE device battery life is almost on par with that of traditional CS devices. The efficiency of the LTE scheduler and robustness of LTE air interface have

made the VoLTE call setup and mobility performance comparable or better than that of the CS domain. Call quality of VoLTE was further enhanced over WB AMR after the deployment of EVS in 2016.

Moving voice service to all packet domain brings the potential and flexibilities to further expand end user's experience. Video over LTE (ViLTE), i.e., IR 94 video calling is one of the main features being introduced by operators. Due to the interrelation between VoLTE and ViLTE services, technology features implemented for VoLTE also apply to conversational ViLTE.

In Releases 14 and 15, on the RAN side, the focus has been given to further improvement of the efficiency and robustness of the VoLTE/ViLTE services, while on the core side, main consideration has been on VoLTE roaming deployment simplification (S8HR as an example which will be covered in 5.5.12).

Lack of real time communications between the application layers and the RAN has been a major issue in current VOLTE implementation. Voice codec selection/adaptation is pretty much transparent to the radio network. The link adaptation on the radio layer is not directly influencing the decision making on the codec selection/adaptation on the IMS layer. This leads to degraded VoLTE call performance, especially in challenging radio conditions. In 3GPP Release 14 and beyond, the focus has been on adding mechanisms on the RAN that are applicable to different codec types including AMR, EVS and video in both downlink and uplink to enable:

- Codec mode and rate selection at call setup
- Codec rate adaptation during an on-going call
- Coder adaptation can be triggered cell-wide or on a per-UE or per DRB basis
- Up/down-side tuning of codec rate

Enhancements proposed to improve the VoLTE/video quality are:

- Re-use the coverage enhancement techniques that have been already discussed in previous releases
- Further enhanced HARQ for TTI bundling beyond Rel-12 enhancements

Enhancements to prioritize VoLTE/video access and/or VoLTE/video related signaling and reduce call drop probability (e.g., potential call drop during mobility) by signaling enhancement for VoLTE/video are:

- Use the MO voice cause value to prioritize MO Video call over e.g., MO data/signaling
- Keep the voice bearer in both UE and core network during redirection procedure to improve the mobility performance

The proposed changes all require certain levels of modification of the existing E-UTRAN protocol layers and only devices supporting those features will gain benefits from them. The overall network performance gain will gradually improve with the increased penetration rate of the devices with new features.

5.3.7 FURTHER ENHANCEMENTS TO LTE DEVICE-TO-DEVICE (D2D)

In Rel-12 and Rel-13, 3GPP defined D2D communication and discovery. D2D discovery was defined primarily for commercial services. Whereas intention of D2D communication was for the public safety use cases. Rel-12 D2D (Device 2 Device) communication was based on broadcast communication, with

groupcast and unicast support from upper layers of LTE protocol stack. D2D communication works in-coverage, out-of-coverage and with partial coverage of EUTRAN. In Rel-13, layer 3 relay was introduced to help out-of-coverage UEs to access network via relay UEs. D2D communication and D2D relay are gaining popularity even for commercial use cases. Important examples of such use cases are MTC and wearables, which could benefit by being in close proximity to a higher capability device such as smartphone to relay their traffic. Limited battery capacity of MTC or wearable devices make direct connection to eNB less practical. This limitation of remote UEs (NTC, wearable) opens up door for D2D relay usage, as relaying can enable significant power savings. The aim of Rel-14 Further enhancements (Fe) D2D Study Item in 3GPP is to explore possibility of using D2D communications including non-3GPP technologies to relay traffic from wearable/MTC. There are two areas of interest for Rel-14 FeD2D study Item:

- Enhancement of D2D relay functionality to provide better control of radio resources, end to end security and QoS for remote devices
- Enhancements to PC5 link for low cost, low power communications between device

Out of these two areas of interest, enhancement of D2D relay functionality is getting more attention. There are three types of relay mechanisms possible:

1. Bidirectional UE-to-Network Relay:[136] In this case, Relay UE is utilized to relay both UL and DL UE specific data to/from Remote UE. To support this form of relaying Remote UE is required to have both D2D transmission and reception capability along with Uu reception capability.

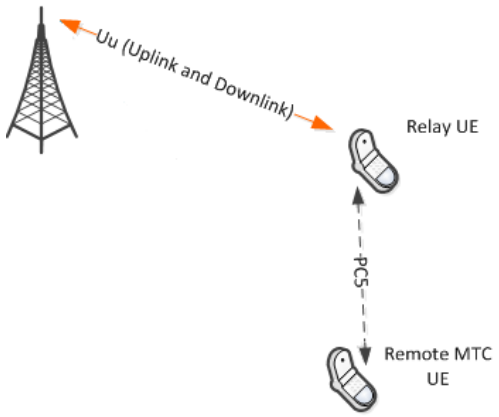

Figure 5.23. Bidirectional Relay.[137]

2. Unidirectional UE-to-Network Relay UE for uplink data:[138] In this case, Relay UE is utilized to relay only UL data from Remote UE. The advantage of this approach is its lower cost because D2D transmission capability 'comes for free' as it utilizes same transmission chain for both Uu and D2D. Rel-13 ProSe UE-to-Network Relay is Layer 3 Relay, which can be enhanced to Layer 2 relay to assist eNB. An additional advantage of uni-directional relay is that a UE-to-Network relay device does not suffer from the half duplex issues of thePC5 interface as it only receives on the PC5 interface.

[136] *Scenarios for FeD2D*, Qualcomm Incorporated. R2-162741.
[137] *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS) (Release 13),* 3GPP TR 37.842 V1.12.0 (2016-08)
[138] *Scenarios for FeD2D*, Qualcomm Incorporated. R2-162741.

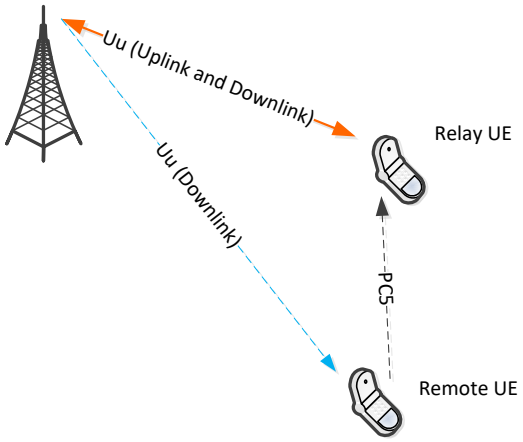

Figure 5.24. Uni-Directional Relay.[125]

3. UE to network relaying over non-3GPP access (Bluetooth/Wi-Fi): This type of relay is to use the existing capability (i.e., Bluetooth or Wi-Fi) of wearable to connect to smartphone and in turn relay its traffic. All non-3GPP technologies should be considered transparent for generic relay architecture over them.

As an example, figure 5.25 shows some performance of unidirectional relay, for Arad/Neptune water meter type usage (2Tx/day, 4KB/TX, Cat-M, 20dBm, 15Wh battery).[139]

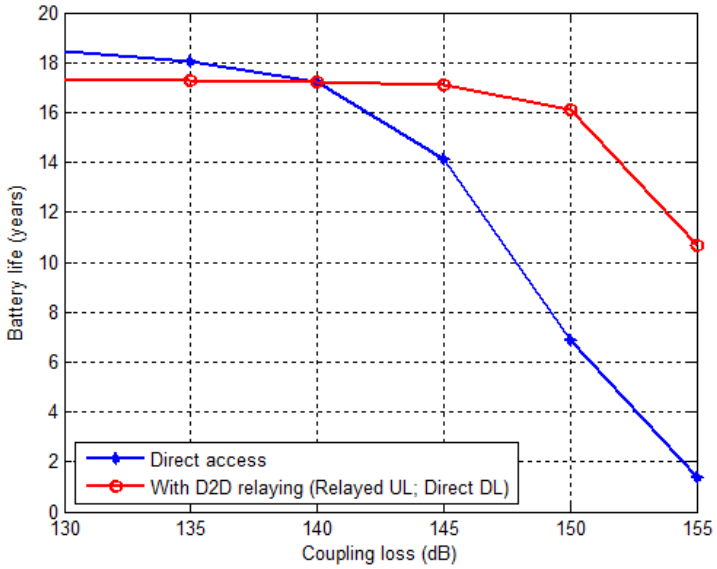

Figure 5.25. Performance of D2D Relay for Cat-M Remote UE.

5.3.8 INDOOR POSITIONING ENHANCEMENTS

The Work Item for further indoor positioning enhancement in LTE Rel-14 started in March 2016, and targeted completion in December 2016, with the objectives of further positioning enhancements for barometric pressure positioning, Terrestrial Beacon System (TBS) positioning, Wireless Local Area Network (WLAN) positioning, observed time difference of arrival Observed Time Difference of Arrival (OTDOA) positioning and enhanced cell ID (E-CID) positioning. For example, this applies to the support of

[139] *Ibid.*

UE-based mode for barometric pressure positioning, TBS positioning and WLAN positioning, as well as the support of network assistance data from the location server to the target UE for both UE-assisted mode and UE-based mode of these positioning solutions.

Barometric Pressure Positioning

The barometric pressure method, which was introduced in LTE Rel-13, utilizes barometric pressure sensors for height information identification and vertical information determination, and should be combined with other positioning methods for 3D positioning together [TS 36.305]. This barometric pressure method in LTE Rel-13 includes UE-assisted mode and standalone mode. In the UE-assisted mode, the UE performs the barometric pressure sensor measurements without network assistance and then sends the measurement results to the E-SMLC for vertical information derivation. While in the standalone mode, the UE performs the barometric pressure sensor measurements and calculates its own vertical information without network assistance. LTE Rel-14 further introduces new UE-based mode, where the UE calculates its own vertical information with possible network assistance information from E-SMLC, and meanwhile enhances UE-assisted mode with optional assistance data from E-SMLC too. The barometric sensor assistance data may include reference pressure, reference area and corresponding reference temperature.

TBS Positioning

The TBS in LTE network includes Metropolitan Beacon System (MBS) introduced in LTE Rel-13 and PRS-Based Beacon System introduced in LTE Rel-14. Like barometric pressure method above, MBS positioning supports UE-assisted mode and standalone mode without network assistance in LTE Rel-13 and Rel-14, and UE-assisted mode and UE-based mode with optional network assistance in LTE Rel-14. In the UE-assisted mode, the E-SMLC calculates the UE position based on at least the TBS measurement results from the UE. While in the UE-based mode and the standalone mode, the UE performs TBS measurements and calculates its own location. The assistance data for both UE-assisted and UE-based modes from the E-SMLC to the UE include acquisition assistance information and almanac information. The acquisition assistance information is about visible beacons, PN Codes, and other information of the MBS signals to enable a fast acquisition of the MBS signals. The almanac information is about the MBS beacon position. PRS-Based Beacon is a new network node for PRS transmission and can work with conventional LTE network together for OTDOA positioning purpose. However, compared to the existing eNB, PRS-Based Beacon can transmit PRS signal more densely, for example, more PRS subframes in one PRS occasion and/or shorter PRS periodicity.

WLAN Positioning

The WLAN positioning method was introduced in LTE Rel-13 and uses the WLAN measurements (AP identifiers and optionally other measurements) and databases for UE positioning (see 3GPP TS 36.305). WLAN positioning in LTE Rel-13 supports UE-assisted mode and standalone mode. In the standalone mode, the UE performs WLAN position measurements and location computation without network assistance. While in the UE-assisted mode, the UE provides WLAN position measurements with or without assistance from the network to the E-SMLC for location calculation. LTE Rel-14 introduces the UE-based mode, in which the UE performs WLAN position measurements and location derivation with network assistance. The assistance data for both UE-assisted and UE-based modes that may be sent from the E-SMLC to the UE include Basic Service Set IDentifier (BSSID) of WLAN access point, Service Set IDentifier (SSID), Access Point (AP) Type Data and AP location.

OTDOA Positioning

In some network deployments, the transmission points (for example RRH) may have the identical PCI with their associated network nodes (for example macro cell). In this case, these transmission points would not be used for PRS transmission and consequently the number of possible RSTD measurements for OTDOA positioning is reduced due to unexploited transmission points. Additionally, if multiple network nodes transmit PRS over same time and frequency resources and meanwhile by using same PRS sequence due to same PCI, then the UE is unable to derive the ToA corresponding to one specific network node. In order to solve these problems, the transmission-point-specific PRS sequence generation, PRS configuration is supported in LTE Rel-14 for OTDOA positioning. For the purpose of RSTD measurement accuracy improvement, LTE Rel-14 allows RSTD measurement reporting with higher resolution, supports RSTD measurement reporting with multipath information and meanwhile enables CRS-plus-PRS-based RSTD measurement. Additionally, due to possible different CP lengths used by same TP for PRS transmission in different subframes, the MBSFN subframe configuration information could be sent from eNB to location server and then from location server to UE.

E-CID positioning

To improve the UE location estimates in E-CID positioning, LTE Rel-14 enables the eNB to report such information to the location server as WLAN Received Signal Strength Indicator (RSSI), BSSID, SSID, Homogeneous Extended Service Set IDentifier (HESSID), channel(s), operating class, country code and band if corresponding WLAN measurement information is already available in the eNB.

5.3.9 ENHANCEMENTS OF BASE STATION (BS) RF AND EMC REQUIREMENTS FOR ACTIVE ANTENNA SYSTEM (AAS)

The Release 13 Active Antenna System (AAS) Work Item[140] was completed by RAN#73 in September 2016 and has determined a full set of conducted requirements and introduced two radiated requirements, namely EIRP (Equivalent Isotropic Radiated Power) for radiated transmit power and EIS (Equivalent Isotropic Sensitivity) for Over-The-Air (OTA) sensitivity.

Over-The-Air requirements are significantly more complex than conducted antenna port requirements, as already visible in the OTA requirements of user equipment (UE).[141] In the end, all new AAS requirements shall be transformed from conducted antenna port requirements, no new or additional requirements shall be introduced. Release 13 takes first steps in shaping requirements for multiport transceiver units (see chapter 3.1.1), applicable only for conducted measurements. The technical report[142] describes in detail measurement methods and corresponding uncertainties. A new Release 14 AAS Work Item,[143] started in RAN#71, and shall enhance the current AAS core and conformance requirements to implement a full set of OTA requirements.

[140] *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS)* (Release 13), 3GPP TR 37.842 V1.12.0 (2016-08).
[141] *User Equipment (UE) and Mobile Station (MS) GSM, UTRA and E-UTRA over the air performance requirements* (Release 14), 3GPP TS 37.144 V14.1.0 (2016-09).
[142] *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS) (Release 13*), 3GPP TR 37.842 V1.12.0 (2016-08).
[143] *Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS) radiated requirements* (Release 14), 3GPP TR 37.843 V0.0.1 (2016-10).

The main enhancements[144] [145] foreseen to be included in Release 14 are:

- **In-band requirements:** in legacy BS the transmitted power is characterized at the antenna port. For AAS this concept is hardly applicable and is defined as EIRP in angular dependence.

  The parameter defining the signal quality is the Error Vector Magnitude (EVM). This value is measurable in the same way as conventional antenna port measurements.

  Unwanted in-band emissions are described by two parameters. The Spectrum Emission Mask (SEM) as an absolute value, and the adjacent channel power as a relative value to the transmitted power. In Release 14 new definitions for OTA requirements are necessary.

  The intermodulation resistance requirements of power amplifiers, representing the robustness against external disturbance, need be newly defined for OTA. In the requirement, angular dependence and number of amplifiers shall be taken into consideration.

  In uplink the most important parameter is the reference sensitivity. This value is already present in the over air requirements of the Equivalent Isotropic Sensitivity (EIS). All other requirements are a degradation of EIS due to external influence.

  Adjacent Channel Selectivity (ACS) is a measure of the receiver ability to receive a wanted signal at its assigned channel frequency in the presence of an adjacent channel signal with a specified centre frequency offset of the interfering signal to the band edge of a victim system.

  Antenna parameters are not standardised in 3GPP; all antenna parameters have to be declared by the vendor.

- **Out of band requirements:** interference to other systems is inherently a radiated problem; some of the current conducted requirements can be traced from EIRP requirements and antenna gain assumptions, although many cannot. For a radiated requirement, which is equivalent to the existing conducted requirements, it will be necessary to decide if EIRP or TRP requirements are more valid and antenna gain assumptions must be made. A balance between robustness and practicality must be found, considering that the requirements cover a large frequency range and many different measurement directions.

- **EMC requirements:** EMC radiated requirements are like the out of band radiated requirements, however for both the EMC emissions immunity must be considered as well as how to handle the radiated wanted signal (the conducted wanted signal is currently put into a resistive load during EMC testing).

The Release 14 AAS Work Item[146] is separated into two tasks: 1) core RF requirements, and 2) conformance testing requirements and demodulation testing requirements. The core part specifies the radiated requirements, the conformance part develops the appropriate test requirements including the suitable methods, required test coverage and test tolerances.

[144] *Motivation for new work item proposal: Further Enhancement of Base Station (BS) RF and EMC requirements for Active Antenna System (AAS)*, 3GPP TSG RAN meeting #71, Göteborg, Sweden, March 2016. 3GPP RP-160303.
[145] *Work item proposal: Enhancements of Base Station (BS) RF and EMC requirements for Active Antenna System (AAS)*, 3GPP TSG RAN meeting #72, Busan, Korea, June 2016. 3GPP RP-160940.
[146] Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS) radiated requirements (Release 14), 3GPP TR 37.843 V0.0.1 (2016-10).

5.4 UTRAN/HSPA+ ENHANCEMENTS

3GPP Rel-14 also includes a few enhancements to High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA) (HSPA+) which will be discussed in this section.

5.4.1 MULTI-CARRIER ENHANCEMENTS

Existing HSPA multi-carrier aggregation features enable data scheduling on multiple carriers/bands to achieve higher data rates and more efficient load balancing.

With the introduction of intra-band and dual band multi-carrier UL and DL aggregation features, such as DC-HSPA and DB-DC-HSPA, downlink and uplink data can be scheduled across two carriers using a 2ms TTI. However the uplink coverage of cells deployed in different carriers/bands may be different.

A Rel-14 study item on multi-carrier enhancements has identified that performance of legacy multi-carrier in the uplink can be enhanced by configuring 10ms TTI on one of the carriers or on both carriers. Following the outcomes of that study, 3GPP is currently working on introducing new UL TTI configurations for DC-HSUPA and DB-DC-HSUPA scenarios, i.e., 2ms+10ms and 10ms+10ms TTI.

The work has started in June 2016, and is still ongoing, focusing on the specification of RRC based (re)configuration of the new TTI combinations, and also considering potential TTI switching mechanisms.

5.4.2 HSPA & LTE JOINT OPERATION

A Rel-14 study item is currently ongoing. In the area of optimized Inter-RAT CS and Packet Switched (PS) operation, particularly to study some possible solutions to support CS in UMTS and PS in LTE, four main scenarios under study are:

- An idle UE initiating a MT/MO voice call
- A connected UE in LTE initiating a MT/MO voice call
- A connected UE in UMTS with CS service, establishing PS service
- Concurrent UMTS CS and LTE PS operation

A few basic assumptions have been identified, such as:

- Single stand-by UE is supposed to camp on LTE (whenever LTE coverage is available)
- When a UE served by LTE has CS voice services, the CS voice service is provided by the UMTS network while the data service is provided by the LTE network
- New interfaces, e.g., interface between RNC and eNB, are not needed
- The UE is equipped with Single Tx and Dual Rx
- Support of UMTS DCH Enhancement 10ms mode is assumed

The following paragraphs provide a high-level description of the identified solutions and procedures, covering the four scenarios listed above. Overall, there is one common operation for UEs in connected mode (CS and/or PS), and two options for Idle mode (i.e., single stand-by and dual stand-by).

Idle Mode: In this scenario, the UE is idle, with no CS or PS connection. The UE monitors LTE paging and transitions to LTE connected following legacy procedures. For CS paging, two possible solutions have been identified:

1) Single stand-by / LTE camping: UE is EPS/IMSI combined registered in LTE; CS paging is received from LTE air interface

2) Dual standby: UE camps on both UMTS and LTE; CS paging is received from UMTS air interface

Single RAT connected modes (CS or PS): In these modes, the UE is either LTE connected, with an ongoing PS/data-only call, or CS connected, with an ongoing 3G CS call. Connected operation in these scenarios is similar to legacy from a radio perspective, as the UE does not need to handle concurrent use of the transmitter for the two RATs.

High level illustrations are shown in Figure 5.26 for the PS connected mode, and Figure 5.27 for the CS connected mode.

a - Connected Mode – PS only

b - Connected Mode – CS only

Figure 5.26. PS and CS Connected Modes.

In the CS connected mode, the UE has an ongoing 3G CS call, and is idle in LTE. UE dual-Rx allows independent LTE monitoring of PS pages and other LTE idle mode tasks. CS paging for the single stand-by cases is also shown (red line).

Connected Mode – Concurrent 3G CS + LTE PS: In Concurrent 3G CS + LTE PS mode, the UE is simultaneously connected to 3G CS and LTE PS, as shown in Figure 5.26.

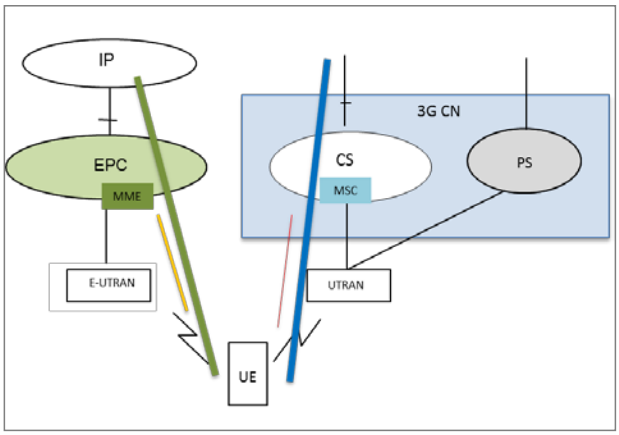

Figure 5.27. Connected Mode – Concurrent 3G CS + LTE PS.

In such state/condition, the following capabilities and functionalities are considered:

- Dual/Independent (control/user plane) connections (over 3G CS and LTE PS), with independent mobility and other connected mode procedures
- No inter-RAN connection/coordination/communication
- UE Dual-Rx and Single-Tx concurrent operation/transmission
    - UL Tx sharing between UMTS and LTE is enabled by UL transmission gaps (of 10 ms duration) given by (existing) LTE C-DRX operation and UMTS enhanced DCH transmission (10ms mode).

The Study was planned to be completed by December 2016. More details of the identified solutions and specification impacts can be found in the SI Technical Report (37.805).

5.4.3 DTX/DRX ENHANCEMENTS

HS-DSCH/E-DCH transmission in CELL_FACH was introduced in Releases 7 and 8, and was deployed in 3G networks. This feature is useful for smart phone services to improve resource utilization and latency of state transition between CELL_FACH and CELL_DCH. In Release 11, other enhancements for CELL_FACH were introduced, e.g., stand-alone HS-DPCCH without E-DCH transmission, concurrent support for 2ms and 10ms TTI in a cell, fallback to R99 PRACH, second UE DRX in CELL_FACH, etc.

3GPP Rel-14 has looked at two further enhancements for CELL_FACH operation:

- Improvements in DTX operation during the common E-DCH transmission
- Mechanisms to reduce UE power consumption in CELL_FACH, i.e., shorter wake-up time during DRX operation

For the two enhancements noted, the ultimate normative work has focused only on DRX enhancements in CELL_FACH, introducing a feature called *HS-SCCH DRX in CELL_FACH*. In short, with this enhancement, a UE in CELL_FACH can periodically monitor the HS-SCCH channel only, without having to decode HS-DSCH, unless a specific HS-SCCH order is received.

Going into some further operation details, for the HS-SCCH DRX in CELL_FACH, the UTRAN indicates to the UEs a HS-SCCH DRX cycle length and a HS-SCCH RX burst length by dedicated signaling, in addition to the legacy parameters broadcasting in SIBs for HS-DSCH DRX operation in CELL_FACH state. The HS-SCCH DRX operation is initialized when, during a period of no data transmission, a certain inactivity timer expires. At this point, the UE is required to monitor High Speed Shared Control Channel (HS-SCCH) order continuously for the length for the Rx burst length of the DRX Cycle configured, and it does not have to decode HS-DSCH. If the UE receives a HS-SCCH order, it starts receiving High Speed Downlink Shared Channel (HS-DSCH) continuously a certain time (8ms) after the HS-SCCH order. This operation is illustrated in Figure 5.28.

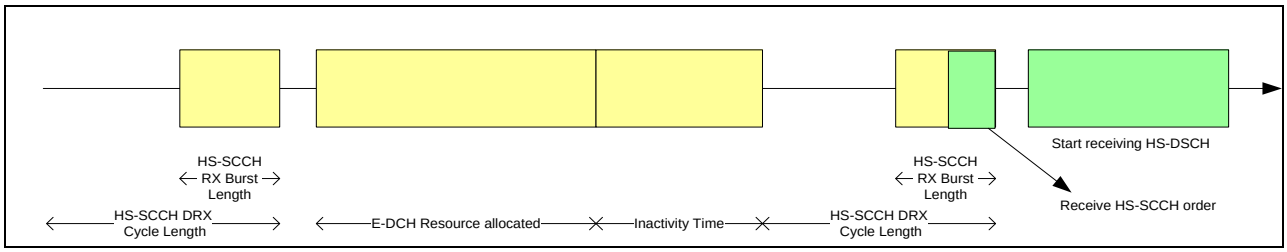

Figure 5.28. Discontinuous HS-SCCH Reception in CELL_FACH State.

5.5 NETWORK SERVICES RELATED ENHANCEMENTS

In order to set the stage for 5G, some very important system architecture features are being worked on for the E-UTRAN such as Control and User Plane Separation (CUPS), NB-IoT, enhanced DÉCOR (eDECOR) in support of network slicing, V2X enhancements, and others. This section provides details on these network architecture and services related features for E-UTRAN being defined in Rel-14 which are expected to be fully leveraged by 5G NR and the new 5G system architecture being defined in parallel.

5.5.1 CONTROL AND USER PLANE SEPARATION (CUPS)

The goal of the Control and User Plane Separation (CUPS) architecture enhancements is to define a more flexible, distributed architecture that can provide greater function utilization efficiencies, leveraging the evolution to NFV and SDN implementations as well as the introduction of capabilities such as network slicing and mobile edge compute and storage (e.g., MEC), by placing exact services and functions where needed and optimal for the QoE of the applications. Specifically, CUPS has studied the separation of user plane functionality from control plane functionality in the S-GW, P-GW and TDF functions to further enable flexible (i.e., distributed or centralized) network deployment and operation. This separation must be done while not affecting the overall functionality provided by these nodes. This feature will define the reference points, interfaces and procedures between these nodes and identify any impacts to other EPC entities and interfaces required to enable a wide range of deployment scenarios that can take advantage of flexible, independent placement of control and user plane functions.

One of the key advantages to a CUPS architecture is that it will a primary enabler for realizing Mobile Edge Compute (MEC) deployments that can benefit from a distributed user plane with centralized control plane as shown in figure 5.29. As shown in this figure, there are various deployment scenarios and use cases from Enterprise, to connected commerce to providing optimized video delivery through MEC that will benefit from a CUPS architecture that allows the distribution of user plane and SDN forwarding functions out to the edge of the network, while still maintaining centralized control plane to support functions such as mobility, charging, policy, Authentication, security and Legal Intercept. And using NFV/SDN implementations with network slicing, each of the applications shown in Figure 5.29 can be configured and orchestrated to support only the needed set of user plane and control plane functions at the optimized locations to improve utilization efficiency and enhance QoE for the specific application.

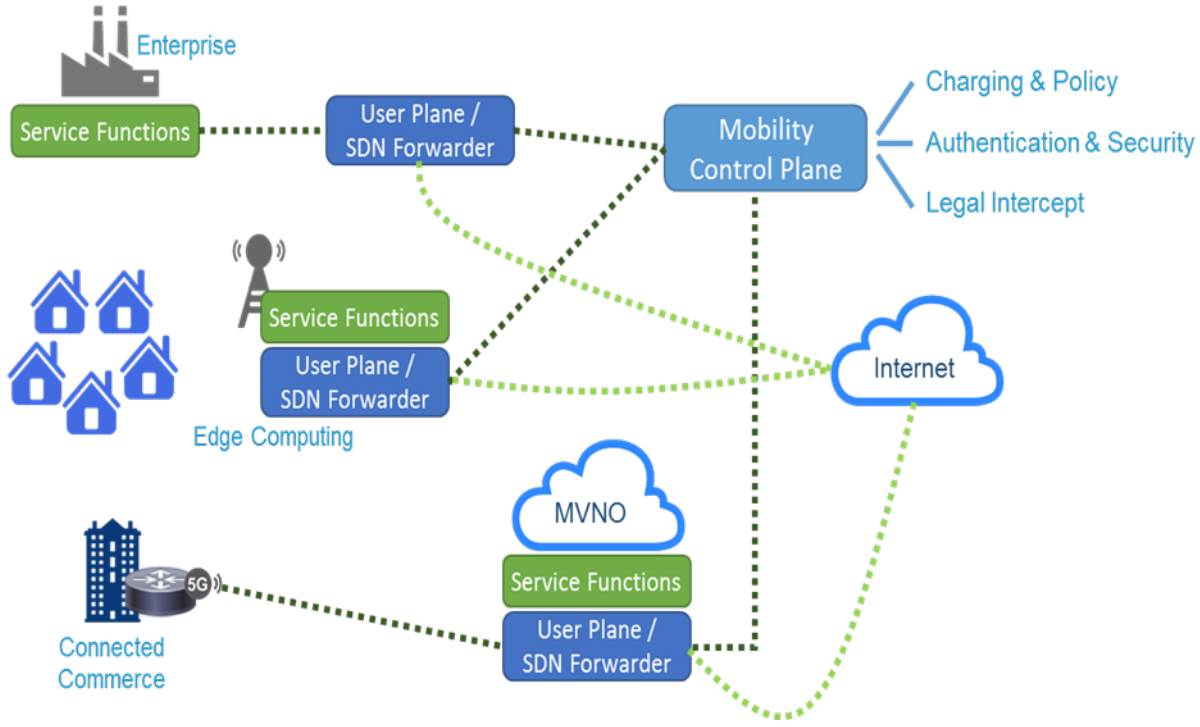

Figure 5.29. Example of Distributed UP with Centralized CP Using CUPS.

The initial studies in 3GPP on CUPS are starting from the existing EPC architecture, with Figure 5.30 showing the baseline EPC architecture, interfaces and reference points from 3GPP TR 23.714, These interfaces and reference points are explained below and consistent with the existing EPC architecture, with explicit identification of user plane (solid lines) and control plane (dotted lines).

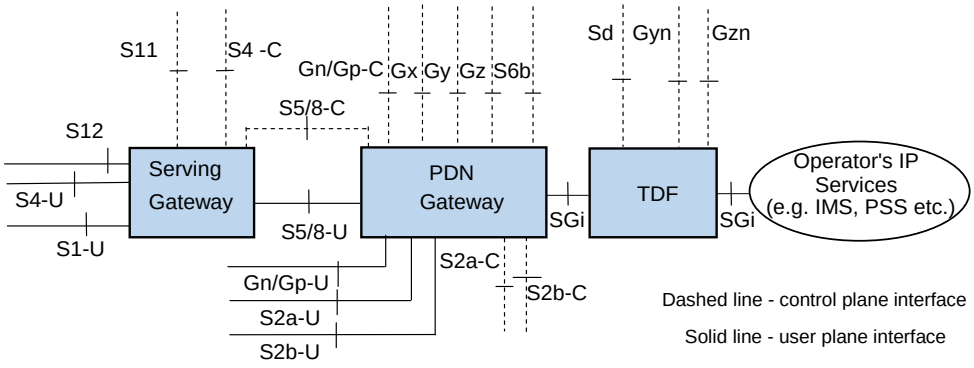

Figure 5.30. Baseline S-GW, P-GW, TDF and their Reference Points from 3GPP TS 23.401.

S1-U Reference point between E-UTRAN and Serving GW for the per bearer user plane tunneling and inter eNodeB path switching during handover. S1-U does not apply to the Control Plane CIoT EPS optimization.

S2a-U User Plane Reference point between P-GW and Trusted Non-3GPP IP Access

S2a-C Control Plane Reference point between P-GW and Trusted Non-3GPP IP Access

S2b-U User Plane Reference point between P-GW and ePDG for Untrusted Non-3GPP IP Access

S2b-C Control Plane Reference point between P-GW and ePDG for Untrusted Non-3GPP IP Access

S4-U User Plane Reference point between S-GW and SGSN (from 2G/3G packet core)

S4-C Control Plane Reference point between S-GW and SGSN (from 2G/3G packet core)

S5/8-U User Plane Reference point between P-GW and S-GW (S8 for inter-PLMN scenario)

S5/8-C Control Plane Reference point between P-GW and S-GW (S8 for inter-PLMN scenario)

S6b Reference point between P-GW and AAA

S11 Reference point between MME and Serving GW

S12 Reference point between UTRAN and Serving GW for user plane tunneling when Direct Tunnel is established. It is based on the Iu-u/Gn-u reference point using the GTP-U protocol as defined between SGSN and UTRAN or respectively between SGSN and GGSN. Usage of S12 is an operator configuration option

Gn/Gp Control Plane Reference point based on GGSN to SGSN interface

Gx, Gy, Gz Reference points between EPC Policy, Charging & Rules functions

SGi It is the reference point between the PDN GW and the packet data network. Packet data network may be an operator external public or private packet data network or an intra operator packet data network, e.g., for provision of IMS services. This reference point corresponds to Gi for 3GPP accesses.

Sd Reference point between Traffic Detection Function (TDF) and Policy Control and charging Rules Function (PCRF)

Gyn, Gzn Reference point between TDF and Online Charging System (OCS) and Offline Charging System (OFCS)

The CUPS architecture model in Rel-14 builds off the EPS architecture shown above and is based on the following general concepts:

- Interworking with networks not applying control and user plane separation is possible (i.e., in case of roaming scenarios)
- Split network entities can interwork with network entities that are not split within the same network;
- Split network entities have no requirement to update UE, and Radio Access Network
- The SGW/PGW selection function of the MME/ePDG/TWAN described in 3GPP TS 23.401 and TS 23.402 [yy] is used for the selection of the respective CP function
- The configuration based mechanism (in PGW or PCRF) described in 3GPP TS 23.203 is used for the selection of the CP function of the TDF
- A CP function can interface with one or more UP functions (e.g., to enable independent scalability of CP functions and UP functions)

Based on the above concepts, 3GPP TS 23.214 has defined the architecture reference model for CUPS shown in Figure 5.31 below. Note that for S2a, S2b, S5 and S8 reference points, this architecture reference model is only supported with GTP-based interface (PMIP-based interfaces and S2c interface are not supported).

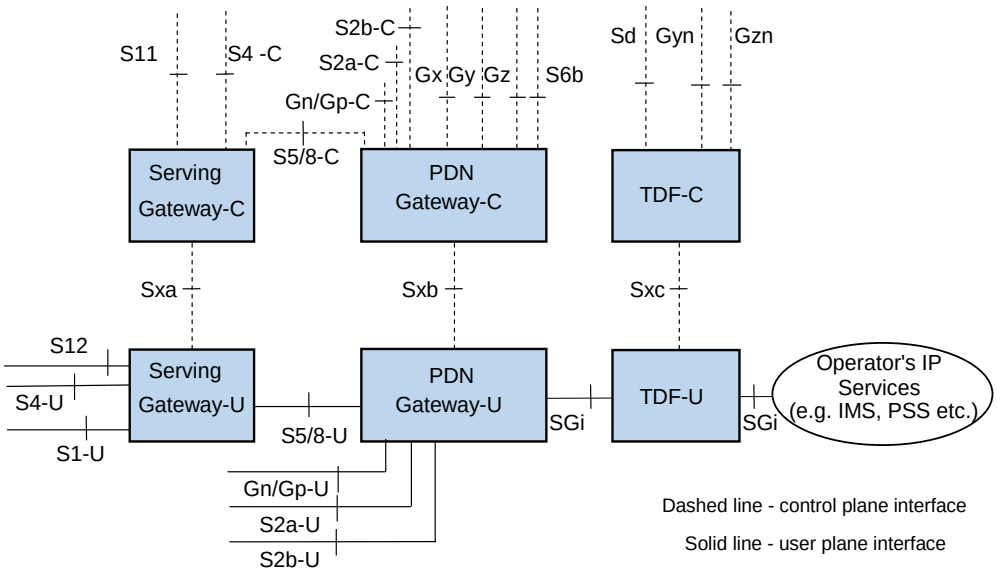

Figure 5.31. Architecture Reference Model with Separation of User Plane and Control Plane.

Compared to the baseline architecture in Figure 5.30, three new interfaces are introduced in Figure 5.31:

Sxa – Interface between the S-GW CP and UP functions

Sxb – Interface between the P-GW CP and UP functions

Sxc – Interface between the TDF CP and UP functions

These are generically defined interfaces that will carry signaling traffic between the defined functions/nodes as needed based on the high level functions and the functional splits between UP and CP as defined in 3GPP TS 23.214.

5.5.2 CELLULAR INTERNET OF THINGS (CIOT) & ENHANCED MACHINE TYPE COMMUNICATION (EMTC) ENHANCEMENTS

eMTC is the first Rel-13 feature targeting: 1) LPWA (Low Power Wide Area) use cases, i.e. low complexity IoT devices with a long battery life; 2) able to work in extended coverage conditions (e.g. basements) and; 3) for which the traffic model corresponds to the infrequent and small data case. Both eMTC and NB-IoT features correspond to different LPWA use cases compared to NB-IoT. Because of its larger bandwidth (1.08 MHz), eMTC offers higher throughputs and support of VoLTE. eMTC is backward compatible with LTE and may be deployed in-band within the LTE DL/UL RF bandwidth.

CIoT EPS Optimizations described for NB-IoT are also available for eMTC with their support by the network/UE being optional in this case.

Rel-14 is now focused on the provision of further enhancements (some of them being also available in NB-IoT), to the already specified basic eMTC connectivity, in order to enable some of the more relevant services foreseen to be deployed in the years to come.

The main enhancements to be included in Rel-14 are:

- **Positioning**. Support of Observed Time Difference Of Arrival (OTDOA) technology, with the same benefits as for NB-IoT
- **Multicast**. For NB-IoT Down Link Transmissions, using SC-MTCH/SC-MCCH multicast channels, with the same benefits as for NB-IoT

Other enhancements are also in the focus of Rel-14, as mobility enhancements, support of larger bandwidths, higher DL/UL throughputs and VoLTE enhancements.

5.5.3 CELLULAR INTERNET OF THINGS (CIOT) & NARROWBAND IOT (NB-IOT) ENHANCEMENTS

NB-IoT has been the lastest feature included in Rel-13, in fact it has been developed in an impressively fast manner to be included as a feature in Rel-13, taking into account that it is a main change introducing a new RAT (derived from the regular LTE one), which has required modifications in more than ten Technical Standards.

The focus was to enable the provision of IoT services integrated in GSM/LTE RATs, with very high requirements in terms of the most relevant topics for IoT (as specified in Report 3GPP TR 45.820), namely: reduced UE complexity, improved power efficiency, improved indoor coverage, support of massive number of low throughput devices and seamless deployment on top of existing networks.

Three deployment modes are available for NB-IoT, allowing optimal spectrum resources usage:

- In-band, using 180 kHz carrier(s) within the LTE DL/UL RF bandwidth
- Guard-band, using 180 kHz carrier(s) within the LTE bandwidth guard-bands
- Standalone, within 200 kHz carrier(s) e.g. from refarmed GSM spectrum

Additionally, to the new NB-IoT radio, a feature set for CIoT EPS Optimizations that can run on any 3GPP radio were developed to optimize the infrequent and small data use case. The main optimizations enable: attach without PDN connection; Control Plane CIoT EPS Optimizations; and User Plane CIoT EPS Optimizations to reduce the signaling overhead for Low Power Wide Area (LPWA) networks.

Rel-14 is now focused in the provision of further enhancements (most of them already available in regular LTE), to the already specified basic NB-IoT RAT connectivity, in order to enable some of the more relevant services foreseen to be deployed in the years to come.

The main enhancements to be included in Rel-14 are:

- **Positioning**: Two technologies are currently under study: Uplink Time Difference of Arrival (UTDOA) and Observed Time Difference Of Arrival (OTDOA). In the study, not only performance in terms of accuracy has to be taken into account, but also impacts upon network/UE complexity and power consumption.

From business case point of view, some of the most relevant services to be provided by IoT devices is the location of assessments. UE identification is already something provided in 3GPP, therefore if positioning may also be provided by the radio interface itself, there will not be need to include any sensor for the provision of these services with a very low cost.

- **Multicast**: For NB-IOT Downlink Transmissions, using SC-MTCH/SC-MCCH multicast channels.

  This feature will allow to lower the OPEX of UE Cat NB1 massive deployments, providing a suitable procedure for software upgrading on already deployed terminals, as well as services requiring the delivery of messages to a group of nodes as could be the update of any configuration parameter.

- **New Power Class UEs:** The aim is to specify new UEs with lower Power Transmission Capabilities, as could be devices with maximum transmitted power or 14 dBms.

  The main aim with these new UEs is to match market requirements for devices with better coverage (MCL may obviously be reduced in the TX power difference), but requiring small form-factor batteries, in order to further reduce the overall device cost and size.

Other enhancements are also in the focus of Rel-14, as to increase the resources available for UE CAT NB1 paging and random access channels, as well as enhancements in the mobility and service continuity, latency reduction and DL/UL throughputs without increasing the UE power consumption.

mMTC (massive Machine Type Communications) is one of the three main drivers beyond the so called New Radio (NR) specification in 3GPP aiming to match the 5G challenges. This will imply that IoT is being taken into account from the very beginning for the new RAT, which was not the case in LTE. In fact, the three family of scenarios that will shape the future NR are enhanced Mobile Broadband (eMBB) Ultra-Reliable and Low Latency Communications (URLLC) and massive Machine-Type Communication (mMTC).

Therefore, further enhancements for IoT services may be expected, apart from a finer integration in the RAN nodes, as increase in: battery life (currently up to 15 years are being considered) and connection density with 1 000 000 device/km2 in urban environment targeted.

5.5.4 MISSION CRITICAL IMPROVEMENTS INCL. PUBLIC SAFETY

After the Mission Critical Push-to-Talk over LTE service specified in Release 13, two new Mission Critical services were specified in Release 14: Mission Critical Video over LTE and Mission Critical Data over LTE. These services are intended to be used in conjunction with the Mission Critical PTT service in order to provide more data for use by first responders.

The Mission Critical Video service will provide useful video functionality for first responders. When a first responder's UE is equipped with a camera, display or both, this will allow functions such as video group calls, video private calls, video pull, video push, capability information sharing and transmission control and reception control for both on-network and off-network operation. Additional functions allow emergency and imminent peril group calls, remotely initiated procedures for video push and support for local and remotely initiated ambient viewing. The full set of Mission Critical Video services and their descriptions can be found in 3GPP TS 22.281 and 3GPP TS 23.281.

The Mission Critical Data service will provide additional data functionality such as short data service (SDS) for on and off network, file distribution (on network), data streaming (on network), conversation management (on network), transmission and reception control (on network), communication termination (on network), secure internet browsing and secure database enquiries (on network) and enhanced status

reports (on and off network). The full set of Mission Critical Data services and their descriptions can be found in 3GPP TS 22.282 and 3GPP TS 23.282.

Although these Mission Critical services were defined with Public Safety in mind, they can also be used for general commercial applications, such as utility companies.

5.5.5 SUPPORT FOR V2X SERVICES

Cellular Vehicle-to-Everything (V2X) communication is another major feature introduced in LTE Release 14, which expands the LTE system's reach to new vertical markets. By meeting the needs of automotive industry, vendors and mobile operators are presented with new business opportunities and revenue sources. The Cellular V2X study started in SA1 in 1Q 2015, followed by RAN, which is now completing the stage-3 specification work, and is expected to end by March 2017. Further enhancements to the feature making use of both LTE and 5G are already under study by SA1.

Cellular V2X provides support of vehicular communication both in terms of direct communication (between vehicles, vehicle to pedestrians, and vehicle to infrastructure) and communications via mobile network. This not only allows the communications required by existing automotive standards, e.g., SAE and ETSI ITS specifications, but also enables new services and features to be created. The existing upper layers applications are expected to be able to use Cellular V2X as transport with no or minimum adaptation.

The direct communication mode is based on D2D communications defined as part of the Proximity-based Services (ProSe) in Release 12 and Release 13 of LTE. As part of ProSe, a new D2D interface (designated as PC5, also known as “sidelink” at physical layer) was introduced and it has been enhanced as part of the V2X work item to support the vehicular use cases, addressing high speed (up to 250Kph) and high density (thousands of nodes).

The fundamental enhancements introduced to PC5 include the following (not an exhaustive list):

- Support of non-IP message Service Data Unit (SDU) type over Packet Data Convergence Protocol (PDCP) natively, in order to transport safety related V2X messages
- Additional DMRS symbols to handle Doppler associated with relative speed up to 500 kph at high frequency (5.9 GHz ITS band)
- New arrangement of scheduling assignment and data resources, in order to enhance system level performance to meet the latency requirement of V2X communication even at high density
- Sensing mechanism with semi persistent transmission for distributed scheduling mode, in order to optimize the use of the channel

The direct communication mode (a/k/a PC5 mode) is scalable for different bandwidths, including 10 MHz bandwidth. Based on deployment configurations, the system allows the direct communication to operate in either distributed scheduling (UE autonomous resources selection) mode or eNB scheduling mode. In both modes, Global Navigation Satellite System (GNSS) is used for the time synchronization. The distributed scheduling mode is the baseline mode and mandatory to support in order to allow the UE to operate even when there is no LTE coverage. In the distributed scheduling mode, besides the sensing with semi-persistent transmission mechanism, a geo-location based resource allocation mechanism is introduced to counter the near far effect caused by in-band emissions. For eNB scheduling mode, the scheduling and interference management of the V2X communication is assisted by eNB via control signaling over the Uu interface. This allows more efficient use of the resources when LTE coverage is available.

The communication via network mode (a/k/a Uu mode) allows the UE to communicate with a V2X server in the network via LTE-Uu link. It is suitable for the V2X services that require many UEs to be reached over a wide geographical area, for example distributing traffic congestion information to all potentially affected vehicles. When MBMS system is available, the downlink distribution of the V2X message can go through MBMS. In a region in which multiple PLMNs are involved in the V2X operation, the UE can use Receive Only Mode to receive the V2X via MBMS from PLMNs different from its serving PLMN or even without a USIM.

The direct communication mode and communication via network mode can be used by a UE independently. For example, a UE can transmit and receive V2V messages via PC5, and at the same time receive V2X messages via MBMS. In order to support reduction of the delay involved in MBMS distribution, the V2X design allows the MBMS system for V2X to be localized and placed near to the RAN. In addition, MB2 based architecture that was designed for the MCPTT is used by the V2X to allow the localized distribution of V2X messages, i.e., to send the V2X messages only to the relevant cells within a SAI area.

The Road Side Unit (RSU) concept of the automotive industry can be supported in two different manners, e.g., as a V2X capable UE that can send and receive V2X message via PC5, or an eNB with a collocated V2X Application Server. This allows flexible deployment options, and various ways for mobile operators to participate in the V2X services.

5.5.6 DEDICATED CORE NETWORKS ENHANCEMENTS (EDECOR)

Specification work on the eDECOR concept (Enhancements of Dedicated Core Networks selection mechanism) is part of 3GPP Rel-14. In October 2016, stage 3 work was ongoing and targeted to be concluded in June 2017. This work is a complementing solution and a continuation of the Rel-13 DECOR architecture work, allowing separation of different classes of devices and customers to be served by dedicated core networks, with potentially different feature sets and characteristics. A limitation in Rel-13 DECOR was that the solution must not impact the user device. The Rel-14 eDECOR scope does not have such limitation, and instead targets enhanced core network selection mechanisms, assisted by the user devices.

The eDECOR devices may be pre-configured with a default Dedicated Core Network (DCN) preference information used at first visit in a PLMN, and the network provides the UE with an eDECOR identity per PLMN at registration. The Radio network is configured based on signaling with the core networks. RAN uses this UE indicated eDECOR identity to select a matching core network node.

The pre-configured DCN information may be suitable to use in the HPLMN but may or may not be suitable in roaming scenarios. If the pre-configure DCN information is applicable to the VPLMN, it will be used. If not, the fallback is to use DECOR functionality instead. The UE will learn the VPLMN eDECOR preference, the Dedicated Core Network (DCN) to be served by, from information provided by the visited network. Subsequent signaling in a roaming condition will gain from this knowledge, reducing the signaling also in the roaming case.

Besides reducing the signaling between Core and Radio networks, eDECOR provides improved isolation as compared to Rel-13 DECOR, and may also provide more flexible load balancing capabilities, depending on the final outcome of the protocol specification work in 3GPP Rel-14 stage 3.

In Rel-15, the network slicing concept is introduced and work to select one or more network slices to serve the UE is ongoing.

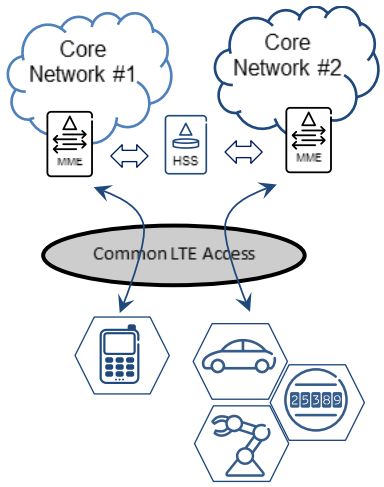

Figure 5.32. eDECOR Network Slicing.

5.5.7 PAGING ENHANCEMENTS

In Release 14, 3GPP continued the efforts to provide more efficient and accurate paging policies. The work item, *Paging Policy Enhancements and Procedure Optimizations in LTE* provided requirements to further optimize paging policies in LTE based on application characteristics known and trusted at the serving network. This work included optimizing signaling load and radio resource usage by selecting an appropriate paging policy based on:

- mobility of the UE (e.g., stationary, restricted mobility)
- application characteristics that are known and trusted at the serving network (e.g., expected QoS, priority)
- likely location of the UE within the paging area

There is no stage 2/3 work related to this requirement. It is expected that the internal policy of the MME can be enhanced to take these additional criterial into account for paging policy selection.

5.5.8 STUDY ON FUTURE RAILWAY MOBILE COMMUNICATION SYSTEM

Analogous to public safety systems, railway communications also need to evolve to take advantage of broadband capabilities. As an example, streaming video to and from the train could provide significant safety enhancements by providing a view of the surrounding area and any obstacles on the tracks, and by alerting nearby devices of the oncoming train. Railway communications such as operational voice communication as well as the Train control application (ETCS L2) are currently defined by GSM-R. The International Railway Union (UIC) sees the need to start replacing GSM-R starting from 2022, preceded with trials by 2020. There are many railway specific functionalities, like train to dispatcher communication or voice connection indication to increase work safety for shunters. Other requirements, like robustness, group and emergency call functions are similar to those from public safety communications. Monitoring or control of critical infrastructure systems, such as train detection and signals, could be done by reliable Mobile-IoT on LTE in a cost-efficient way. 3GPP, with rapporteur ship by Nokia, has started a related study item on the Future Railway Mobile Communication System (FRMCS) in 2016 to meet the requirements with

3GPP Rel-15. LTE for broadband services to passengers has been field proven even on high-speed trains. By extending LTE with the railway specific functionalities, one system could be used for both serving passengers and operational railway communication needs between staff and machines on the trains, along the tracks, at shunting areas, and at stations.

The following figure 5.33 depicts the relationship, as currently envisaged, of FRMCS and the existing legacy GSM-R system used to provide services to railway staff members.

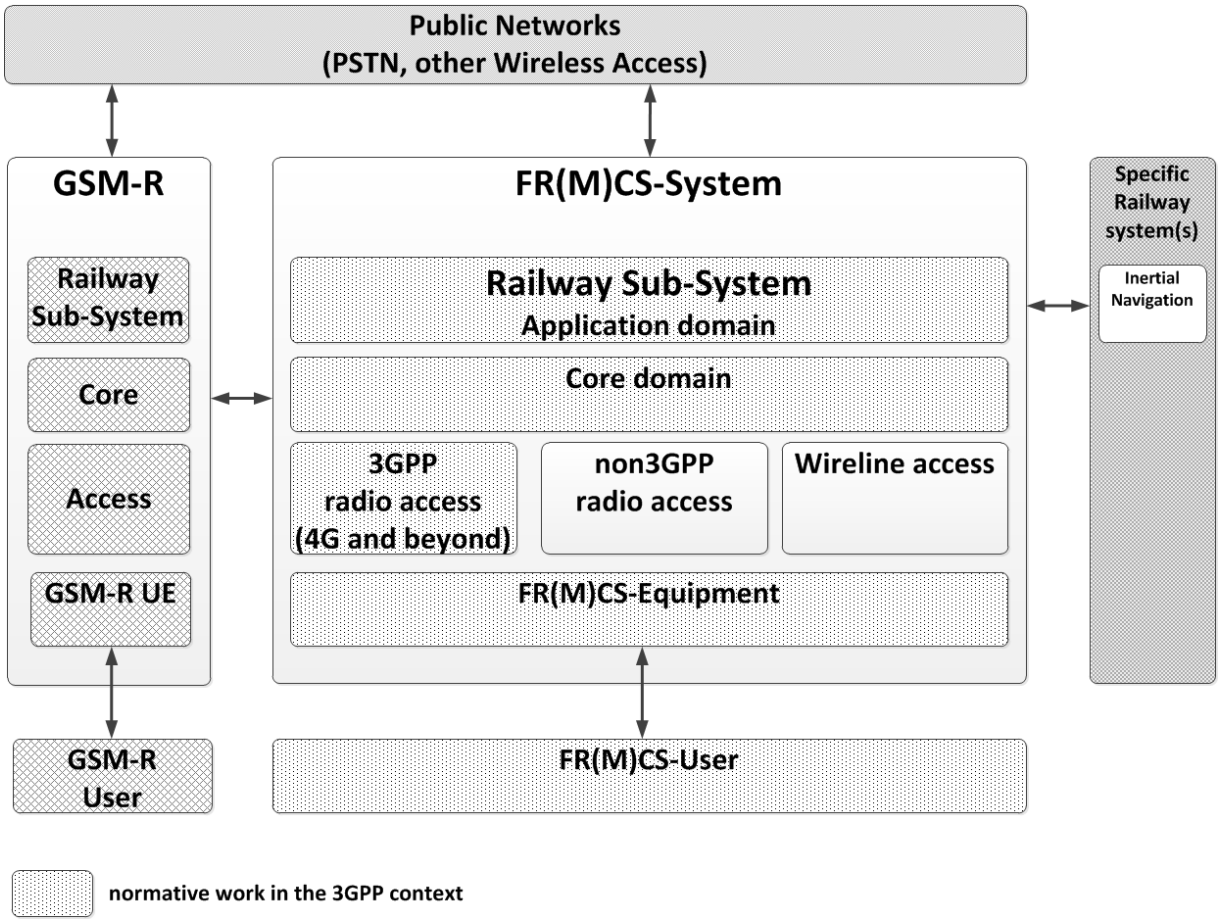

Figure 5.33. Relationship of FRMCS and Legacy GSM-R System.

5.5.9 OAM & SON

Operations, Administrations and Management (OAM) and Self Optimizing Networks (SON) have been an important part of all 2G, 3G and 4G systems over the years. The introduction of NFV-based networks creates a whole new set of challenges for management of virtualized networks. This section discusses the studies and work being done in Rel-14 on NFV management for the EPC/LTE networks, most of which will also apply to the next generation networks (5G) which are all expected to be NFV-based. This section also discusses the studies being performed in Rel-14 to look at 5G specific aspects of NFV management, and concludes with a discussion on the studies beginning for Rel-15 which are looking at the management and orchestration aspects including SON.

5.5.9.1 RELEASE 14 NFV MANAGEMENT

One of main aspects of 3GPP Rel-14 OAM is management of virtualized networks that applies to mobile networks the concept developed by ETSI NFV ISG. 3GPP SA5 is working on management of networks composed of virtualized network functions and non-virtualized network elements in line with the NFV architecture. This development is targeting the management concept, requirements and architecture for mobile networks that include virtualized network functions. Virtualization of network functions (VNFs) requires extension of classic Configuration Management (CM), Fault Management (FM) and Performance Management (PM) aspects. Life Cycle Management (LCM) of VNFs and Network Services are required new additions.

Management concept, architecture and regulations for mobile networks that include virtualized network functions

NFV Management architecture developed by 3GPP SA5 clarifies the relationship between 3GPP management architecture and ETSI ISG NFV Management and Orchestration architecture (see Figure 5.34.)

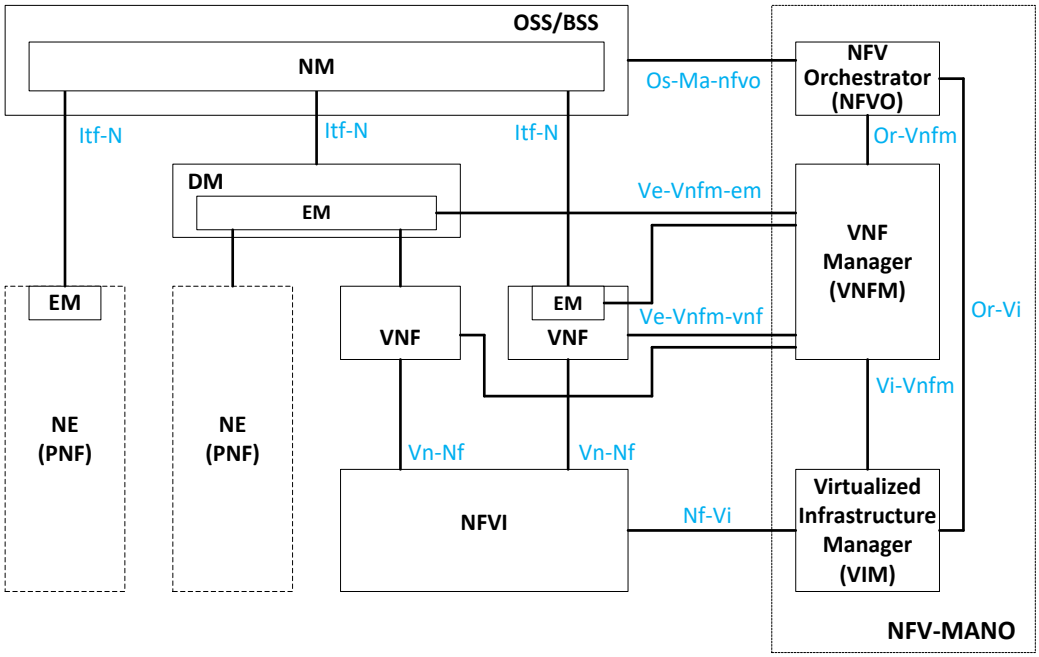

Figure 5.34. NFV Management Architecture.

The legacy 3GPP management system is composed of NM and DM/EM which provide for classic FCAPS management functionalities. For the networks where some Network Elements (NEs) are virtualized, system the combined architecture in addition provides for connection with NFV management nodes (MANO) via the reference points Os-Ma-nfvo, Ve-Vnfm-em, Ve-Vnfm-vnf. Details can be found in the 3GPP TS 28.500.

For the virtualized part of the network, the concept of Network Element (NE) in this new architecture has been transformed into VNF. Relation between these two concepts is outlined by Figure 5.35.

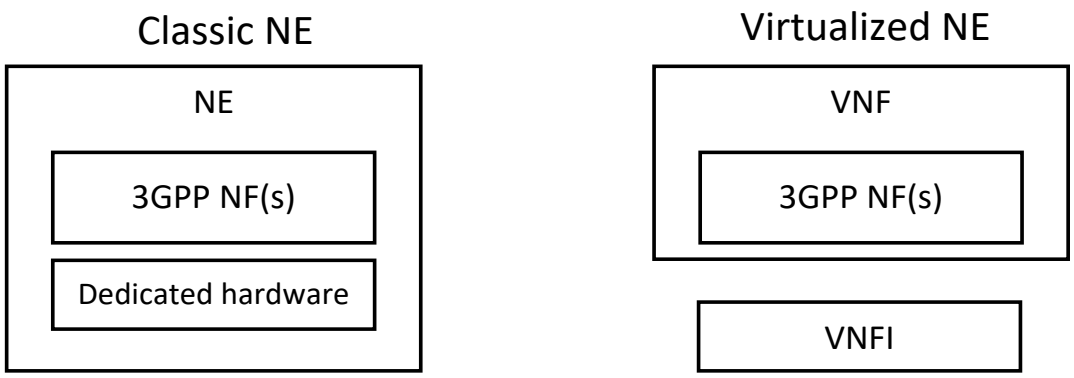

Figure 5.35. Relation between NE and VNF.

Configuration Management for mobile networks that include virtualized network functions

The Configuration Management (CM) specifications are provided in 3GPP TS 28.510/1/2/3. CM of virtualized networks includes the following aspects:

- Legacy Configuration Management (often called “application level” management) of the network functions; this part is basically the same as non-virtualized network functions. The CM is performed from the NM layer to the EM via Itf-N interface and further to the Network Elements (NEs) such as MME or PGW
- Configuration Management of the virtualization part is a new aspect that includes communication between the NM and EM (the left side of the Fig. 5.34 diagram) and the MANO block (the right hand side of the Figure 5.34 diagram)

Example of Use Cases for this aspect are:

- VNF instance information retrieving and modification
- Creation, deletion and update of the Management Object Instance (MOI) associated with the VNF with connection to the VNF life cycle management (LCM) operations such as VNF instantiation and termination

Fault Management for mobile networks that include virtualized network functions

The Fault Management specifications are provided in 3GPP TSs 28.515/6/7/8. Fault Management (FM) functionality traditionally includes fault detection, generation of alarms, clearing of alarms, alarm forwarding and filtering, storage and retrieval of alarms, correlation of alarms and events, alarm root cause analysis and fault recovery. With the introduction of virtualized network functions (VNFs) into mobile networks, Fault Management functionality is distributed over different functional blocks located at different levels such as NFV Infrastructure (NFVI) level, NE level, NFV Management and Orchestration level and 3GPP network management levels NM and EM.

Network virtualization adds new category of faults: physical hardware faults of NFVI are detected by NFVI and corrected jointly with the support from NFV-MANO. Only information about those faults that affect the proper functioning of VNF needs to be provided to 3GPP management system. Virtualization-specific fault information, sometimes called Virtual Resources FM information or VR FM, is detected by the NFVI. The collection of FM data is performed by the Virtual Infrastructure Manager (VIM) and VNF Manager (VNFM) from which the FM notifications are transferred to the EM where they can be correlated with application level FM information. From the EM, correlated or uncorrelated VR FM information is delivered to the NM, through the Itf-N interface.

Performance management for mobile networks that include virtualized network functions

The Performance Management (PM) specifications are provided in 3GPP TSs 28.520/1/2/3. Figure 5.36 outlines PM data collection methods for virtualized networks. The performance data provides information on "application level" performance (legacy PM data related to 3GPP Network Function) and the PM data related to Virtual Resources (VR), sometimes called Virtual Resources PM information or VR PM, for example, utilization of Compute, Storage or Networking resources.

For PM data related to 3GPP Network Function, EM requests VNF(s) to collect the PM data, typically by request of the NM. For VR PM collection, NM creates a PM collection task at the EM and specifies the measurement types, the measured resources, the recording periods, etc. Then the EM creates a PM collection task at the VNFM, and the VNFM in turn creates a PM collection task at VIM. The VIM requests NFVI to collect the VR PM data as specified by VNFM. The collected information is transferred through the chain of PM collection tasks to the NM. As usual, various PM data is stored in data repositories from which it may be fetched by NM (or any authorized user).

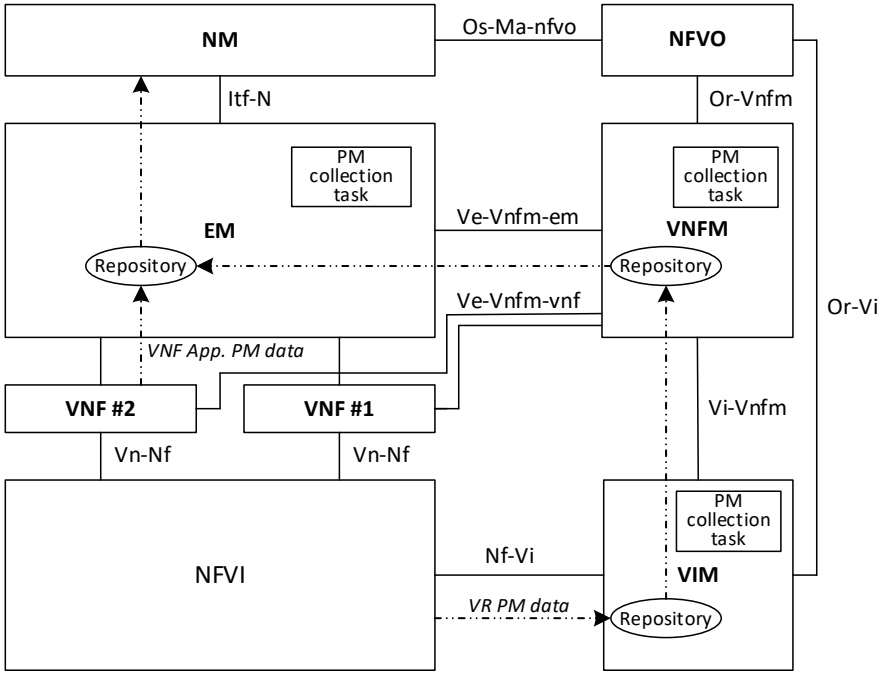

Figure 5.36. PM Data Collection Methods for Virtualized Networks.

Lifecycle management for mobile networks that include virtualized network functions

The Lifecycle Management (LCM) specifications are provided in 3GPP TSs 28.525/6/7/8. This includes the lifecycle management of:

- Virtual Network Functions (VNFs) including such operations as VNF instantiation, scaling and termination
- Network Services (NSs), which are essentially collections of VNFs and PNFs interconnected with virtual links. The LCM operations for the NSs include instantiation, scaling, querying, termination
- VNF Packages that are used for VNF instantiation and specify properties of the VNF; The LCM operations for the VNF Package include VNF package on-boarding, enabling, disabling, deletion
- Network Service descriptors (NSDs) that are used in LCM operations with the NS have a set of LCM operations of their own, such as on-boarding, enabling, disabling, update, etc.

5.5.9.2 RELEASE 14 OAM WORK ITEMS

Filtering of PM measurements and data volume measurements for shared networks

3GPP RAN has defined in TS 36.314 data volume measurements for RAN Sharing, such as Data Volume for Shared Networks. For the latter, the measured quantity is the data volume transmitted or received by the eNB in a configured measurement period, for one of multiple PLMNs in a shared RAN. The measurement is performed per configured QoS profile criteria, such as QCI, GBR range, ARP, etc.

To follow up, 3GPP SA5 started the Study on management of measurement collection in the context of RAN sharing, the outcome of which was summarized in 3GPP TR 32.817. One example of requirements defined by SA5 is that the management system should enable the Master Operator (or MOP; the one that controls / owns the shared RAN), to charge the Participating Operators (POPs) for the data volume used by POP's users per selected QCI criteria via statistical measurements defined for shared networks.

The findings of the Study were implemented in 3GPP TS 32.130, 3GPP TS 32.412 and 3GPP TS 32.416.

OAM support for Licensed Shared Access (LSA)

A new concept for sharing of spectrum has resulted in ECC Report 205 on Licensed Shared Access and ETSI RRS-defined system requirements for operation of mobile broadband services in 2300 – 2400 MHz band under Licensed Shared Access (LSA), ETSI TS 103 154. LSA is a new licensing method that allows current spectrum owners (Incumbents) to share their spectrum with Mobile Network Operators (Licensees) according to this regulatory framework (sharing framework) issued by a National Regulatory Authority (NRA). The advantage of LSA is that QoS is supported even with that shared spectrum. The Study on OAM support for Licensed Shared Access (LSA), resulting in the 3GPP TR 32.855, was targeting to identify the solutions for LSA within the 3GPP Network Management architecture.

Implementation of these solutions is planned in the 3GPP TS 28.301/2/3.

5.5.9.3 RELEASE 14 OAM STUDIES

Study on OAM support for assessment of energy efficiency in mobile access networks

The target of the Study was to support assessment of energy efficiency in radio access networks as defined by ETSI ES 202 336-12. Energy efficiency is defined in ETSI ES 203 228 as a ratio between performance

and energy consumption. The study identified potential use cases and requirements, provided gap analysis as well as implementation recommendations.

Study on OAM aspects of SON for AAS-based deployments[147]

The Active Antenna Systems (AAS) enables system optimization to adapt to traffic demands and address network evolution issues through flexible software re-configuration of the BS and antenna system.

AAS operations include:

- Cell Shaping: where the main coverage of each cell is maintained unchanged but the cell edge can be adapted to load demand
- Cell splitting: it adopts higher order vectorization (vertical, horizontal or a combination) by changing an antenna system to include more antenna beams, each covering a smaller area than before the change, however, the main coverage of the combined beams still corresponds to the main cell coverage before the split
- Cell merging: the contrary functionality of cell splitting

Self-optimization aspects are addressed by the SA5 in *Study on Operations, Administration and Maintenance (OAM) aspects of Self-Organizing Network (SON) for Active Antenna System (AAS) based deployments* resulting in 3GPP TR 32.865. SON mechanism for AAS-based deployments may be supported by OAM (NM/EM) centralized architecture or distributed architecture with OAM supervision and control:

- OAM (NM/EM) centralized architecture: AAS-based deployment changes are fully OAM-controlled
- Distributed architecture: AAS-based deployment changes are controlled by the eNB using OAM preset configurations

The latter model may, for example, include that the eNB autonomously selects a coverage configuration from a set of coverage configurations defined by OAM means. Each allowed configuration is defined as:

- a set of activated and deactivated cells, and
- a cell shape associated to each active cell(s), where no more than 15 cell shapes shall be configured per cell

5.5.9.4 RELEASE 14 STUDIES ON MANAGEMENT ASPECTS OF NEXT GENERATION NETWORK

The ongoing Release 14 studies should be completed by March 2017. The outcome of the studies will be recorded in 3GPP TRs 28.800, 28.801, 28.802. The normative work targets Release 15. It will start in March 2017; the target closure date is June 2018.

Rel-14 Study on Management & Orchestration Architecture of Next Generation Network & Service
Scope of the study (3GPP TR 28.800) is defined as follows:

[147] *3GPP SA5 Update on SON, NFV and 5G*, SON Conference, London, UK, 3GPP S5-166053, Oct. 18-19, 2016.

- Clarify the terminology and use cases
- Support of network operational features such as real-time, on demand, automation etc. as evolution from 4G management aspects
- Support of vertical applications (e.g., V2X)
- Support of the scenario in which the applications are hosted close to the access network
- Support of management and orchestration aspect of E2E user services
- Potential reuse of existing 3GPP management arch. & architectural framework defined by ETSI NFV ISG

Release 14 Study on Management and Orchestration of Network Slicing

The network slicing is a key feature for next generation network. It is about transforming the network/system from a static “one size fits all” paradigm, to a new paradigm where logical networks/partitions are created, with appropriate resources and optimized topology to serve a particular purpose or service category (e.g., use case/traffic category, or for internal reasons) or even individual customers (logical system created “on demand”). It can be enriched by use of NFV and SDN.

As the network slice instances, may be isolated from each other, the management of the network slice instances should enable the possibility to be separated as well. Scope of the study (3GPP TR 28.801) is defined as follows:

- Define terminology, use cases and requirements for management and orchestration of network slicing
- Management of network function sharing in the context of network slicing
- Impacts to management when a slice instance is shared between multiple parties
- Isolation of management data between different parties within a slice instance if needed
- Automation of management and orchestration of network slice instances and the related policy configurations
- Management and orchestration mechanisms to support the isolation/separation of mobile network resources used by different network slice instances
- Study solution for management and orchestration of network slicing and how it affects existing SA5 specifications

A network slice instance is a managed entity in the operator’s network with a lifecycle independent of the lifecycle of the service instance(s). The network slice instance lifecycle typically includes instantiation, configuration and activation phase, a run-time phase and a decommissioning phase. The lifecycle of a network slice is described by the following phases:

- Preparation phase
- Instantiation, Configuration and Activation phase

- Run-time phase
- Decommissioning phase

The lifecycle operations may be performed on slice instances that include components (Network Functions) shared with other slice instances, in which case certain restrictions are in order, for example, when the slice instance is deleted, some components should be preserved if used by other slice instances.

Release 14 Study on Management Aspects of Next Generation Network Architecture and Features

Scope of the study (3GPP TR 28.802) is defined as follows:

- Identify the use cases for management aspects of the next generation network in terms of network architecture and high level features such as mobility on demand and QoE/QoS
- Investigate the potential impact of the next generation network architecture and high level features to the functional blocks of 3GPP management system
- Figure out the location and role of management functionality to support next generation network architecture
- Study and develop the potential management related requirements for the next generation network in terms of network architecture and high level features
- Study the possible solutions to support the management requirements brought from the end to end next generation network architecture
- Study the possible solutions of management aspects to support the key features of next generation network

5.5.9.5 RELEASE 15 SON

SA5 has just started studying[148] the Management and Orchestration of 5G, where SON is included. The following aspects of 5G SON are currently under discussion in 3GPP and other industry bodies:

- SON is essential for 5G to address the increasing network dimension and complexity and the more and more challenging demand for OPEX reduction. The addition of new Radio Access Technology (RAT) will trigger the need for automated tools to help Operators in operating multi-RAT networks
- The Next Generation network will be based on NFV and SDN and this could imply some SON-MANO cooperation
- The 5G network architecture is built to address verticals (connected automotive, IoT, smart city, etc.) and this could lead to per vertical SON features
- The new concept of network slicing could lead to per network slice SON features. The Rel-14 SA5 5G Study Item on Slicing includes *Automation of management and orchestration of network slice instances and the related policy configurations*

[148] *3GPP SA5 Update on SON, NFV and 5G*, 3GPP S5-166053, SON Conference, London, UK, Oct. 18-19, 2016.

- SON in 5G may apply to the optimization of network, services, and business features
- The 5G network needs to be deployed, adapted and operated as much as possible in automated manner in order to efficiently support diverse 5G services
- The volume and diversity of services in 5G make the network unmanageable without advanced automation, hence the need for SON
- The diversity of technology as described in the NGMN 5G White Paper[149], and the need for seamless inter-working between these, make SON a must
- NGMN has defined requirements for *Network Deployment, Operation and Management* (see NGMN 5G White Paper, Section 4.6[150]) and there is a need for assessing if SON can bring a solution to any of these requirements

5.5.10 SERVER AND NETWORK ASSISTED DASH FOR 3GPP

MPEG and 3GPP share a common basis for their Dynamic Adaptive Streaming over HTTP (DASH) specifications, as they jointly developed the first edition of the only standardized HTTP streaming protocol. MPEG recently developed a set of extensions to DASH under the name Server and Network assisted DASH (SAND) (ISO/IEC 23009-5). MPEG SAND defines message formats and interfaces among server, client, edge proxy and network elements toward enhancing streaming quality of experience (QoE), as well as monitoring DASH's performance. For example, MPEG SAND addresses the following:

- Unidirectional/bidirectional, point-to-point/multipoint communication with and without session (management) between servers/CDNs and DASH clients
- Mechanisms for providing content-awareness and service-awareness towards the underlying protocol stack including server and/or network assistance
- QoS and QoE support for DASH-based services
- Scalability in general and specifically for logging interfaces
- Analytics and monitoring of DASH-based services

3GPP Rel-14 includes a study to evaluate the MPEG DASH SAND (ISO/IEC 23009-5) specification, and to identify suitable enhancements applicable to the 3GPP environment, together with recommended 3GPP specifications changes. The following functionalities have been identified and are under study:

- Streaming enhancements via intelligent caching, processing and delivery optimizations on the server and/or network side, based on feedback from clients on anticipated DASH Segments, accepted alternative DASH Representations and Adaptation Sets, and requested bandwidth
- Improved adaptation on the client side, based on network/server-side information such as cached Segments, alternative Segment availability, and network throughput/QoS

[149] *NGMN 5G White Paper,* 17 February 2015. https://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2015/NGMN_5G_White_Paper_V1_0.pdf
[150] Ibid.

The work is coordinated with MPEG and the DASH Industry Forum to ensure broad consensus among OTT content providers and 3GPP defined technologies.

5.5.11 ENHANCEMENT FOR TV SERVICE

To cope with the expected growth of HD TV content accessed over cellular networks, 3GPP Rel-14 has introduced important MBMS-based enhancements to enable efficient and dynamix/flexible TV service over EPS (including linear TV, Live, Video on Demand, smart TV, managed and OTT content).

As a general service definition, the Rel-14 *enhancement for TV service* is a feature whereby 3GPP networks can provide unicast and broadcast transport, referred to as “TV transport services”, to support distribution of TV programs. TV transport services can support the three types of TV services – Free-to-Air (FTA), Free-to-View (FTV) and Subscribed services.

From a technology and architecture point view, enhanced TV service over EPS/E-UTRAN enables operators and service providers to deliver TV services from broadcasters as well as third party service providers, allowing separate content delivery and transport services. At high level, the following key architectural enhancements and functionalities have been standardized:

- A broadcast component, with mechanisms to enable decoupling of content, MBMS service and MBMS transport; this allows the system to offer MBMS transport only, a shared MBMS network, and/or a broadcast only TV service (including devices with no PLMN-MBMS subscription, i.e., operating in receive only mode)
- A unicast component, via PDN connectivity through operator's EPC network, in which operator subscription for TV service may be achieved via dedicated APN
- Mechanisms for broadcast/unicast fallback support, and switching between unicast/broadcast (e.g., consumption-based)
- A standardized interface between BM-SC and the content provider in order to facilitate both transport and user services delivery for TV services via MBMS (for broadcast) and EPC (for unicast)

System-wise, two main MBMS Service Types can be eventually identified for TV service:

- MBMS transport only mode
- The 3GPP network provides only transport of data/TV content in a transparent manner
- The 3rd party content provider's signaling and data transferred via MBMS bearer(s) are transparent to BM-SC and the MBMS bearer service
- All other service aspects, e.g., decision of whether to send data over broadcast or unicast, is not within 3GPP network, and assumed to be performed by application server
- MBMS full service mode
- 3GPP MBMS system provides full service layer capability
- BM-SC is aware of the content stream and is capable of transforming the content stream into 3GPP compliant stream

BM-SC can perform the decision on whether to switch an MBMS user service between broadcast or unicast service.

5.5.12 DATA OFF SERVICE

Many users associate data roaming with very high costs, having experienced surprisingly high bills after a trip away from home. This experience has led users to disable data services locally in the UE when roaming and to only use the basic communication services, with well understood per-minute or per-message costs (e.g., voice calls and SMS). This has worked well in 2G and 3G networks, both of which support CS services in addition to data services. Not being able to use data services when roaming has been acceptable. For most users, it has been acceptable to postpone their Facebook and Instagram updates to times when close to a WLAN hotspot.

When 4G was introduced, everything changed. As 4G does not have any CS component, a simple on-off data off switch local to the UE would block all communications to and from the device because even the CS-like services depend on data services. 3GPP has worked in Rel-14 to define mechanisms to allow a set of services (i.e., 3GPP PS Data Off Exempt Services) that would be available even when the user has switched off "all" data services. This set of services covers basic communications services (e.g., voice, video, SMS), some GSMA-defined IMS services, and signaling required for supplementary services, configuration, and device management.

The study phase has been completed in SA2 November meeting, but because Rel-14 had tight schedule, the normative phase has been split into a phase 1 (Rel-14) and a phase 2 (potentially Rel-15). In Release 14, the list of Data Off Exempt Services will be the same for all the visited PLMNs the UE is roaming in. In Release 15, it will be possible to have per VPLMN list of Data Off Exempt Services.

The main principles are the following:

- In Rel-14, the UE is configured using device management or UICC tools with the list of PS Data Off Exempt Services. When PS Data Off is activated by the user, the UE shall only allow uplink PS Data corresponding to PS Data Off Exempt Services. In Rel-15, the UE will receive the list of PS Data Off Exempt Services from the HSS

- In Rel-14, the PCRF is configured with the list of non-SIP PS Data Off Exempt Services, and provides two sets of PCC rules to the PGW during the IPCAN session creation or modification: one set to be used when PS Data Off is not activated and one set to be used when PS Data Off is activated. In Rel-15, the exempted APNs and related IP flow filters will come from the HSS via the MME/SGSN

- The UE provides its PS Data Off status (activated/deactivated) to the PDN GWs it has a connection with using the Session Management messages via the PCO, i.e. transparently to the MME/SGSN/SGW, and this allows the PGW to only allow PS data that correspond to PS Data Off Exempt Services in the downlink

- The UE also provides its PS Data Off status (activated/deactivated) to the IMS network using IMS register / IMS re-register SIP message, and this allows the IMS network to only allow mobile terminating IMS PS Data Off Exempt Services. The S-CSCF is configured with the list of IMS services that are exempted when PS Data Off is activated

Stage 2 normative specifications for phase 1 were available in December 2016. SA5 agreed during their November meeting to start a Rel-14 WID to address the charging part of SA2 phase 1. UE

activation/deactivation of PS Data Off will be considered in offline and online charging (non-roaming and in roaming) so that potential traffic associated with the PS Data Off status can be appropriately identified for customer care purpose.

5.5.13 S8 HOME ROUTING FOR VOLTE

With more operators starting to deploy VoLTE on their LTE networks, VOLTE roaming has become an urgent topic on many operator's agenda.

In general, there are two VoLTE roaming models that can be implemented by a mobile operator: Local Breakout (LBO) and S8-Home Routed (S8HR). LBO was initially proposed as the preferred roaming architecture by some operators, however, due to the fact that the pace in VoLTE development varies among carriers and VoLTE inter-carrier operability is still an outstanding issue even among carriers in the same region, the challenges for partner operators to use LBO architecture for VOLTE roaming is substantial considering the amount of tight integration and customization work that have to be done for an operator to be able to achieve commercial grade VOLTE performance on their own network. It will require tremendous efforts and collaboration among carriers to make VOLTE work seamlessly across multiple operators' IMS platforms if LBO is adopted. In the meantime, the need to make VOLTE roaming work is becoming increasingly prominent. As a result, S8HR based architecture has gained a lot momentum recently.

GSMA has been actively engaging major operators, vendors and 3GPP to address the issues related to VOLTE roaming. Although LBO is still be discussed as an option, the main focus has been shifted to S8HR due to the fact that many operators, especially the regional carriers, are eager to make VOLTE roaming work quickly. With S8HR architecture, IMS support is not required on visited network. Since the IMS traffic is routed home, interoperability tests between carriers are not necessary. It greatly simplifies the VOLTE roaming implementation and reduces the amount of testing needed for inter-carrier interoperability.

For comparison purpose, the general VoLTE roaming architecture with LBO is shown in Figure 5.37 (from 3GPP TS. 23.228).

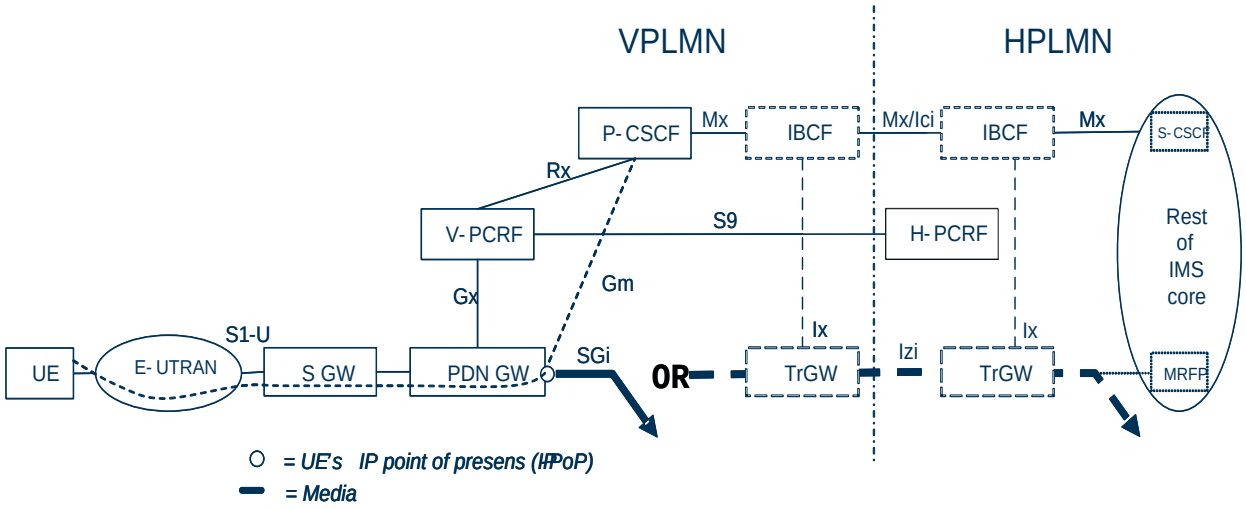

Figure 5.37. VoLTE Roaming Architecture with LBO.

In the LBO model, the enhanced packet core network (EPC) and P-CSCF are located in the visited network for a VoLTE roaming user. The roaming user attaches in a visited network, with the IMS PDN anchored on

a PGW in the visited network and registers for IMS services in its home IMS network. The P-CSCF then interacts with the S-CSCF and TAS in the home network for SIP signaling and setting up a VoLTE session.

In the S8HR VoLTE roaming architecture as shown below, the PGW, PCRF and the IMS core network are located in the home network. IMS services are home routed via the S8 interface. The well-known IMS APN is used for the home routing, SIP signaling and RTP media transferring with the HPLMN. The HPLMN has full control of call routing and VoLTE service logic for its users in the VPLMN. The VPLMN supports the required capabilities for inbound roamers, such as the 'IMS Voice over PS' (IMSVoPS) supported indication and specific QCIs required for SIP signaling (QCI=5) and voice media (QCI=1). The IMS APN configuration in the user's profile in the HSS must be set to 'VPLMN address not allowed'.

The S8HR roaming architecture is shown in Figure 5.38.

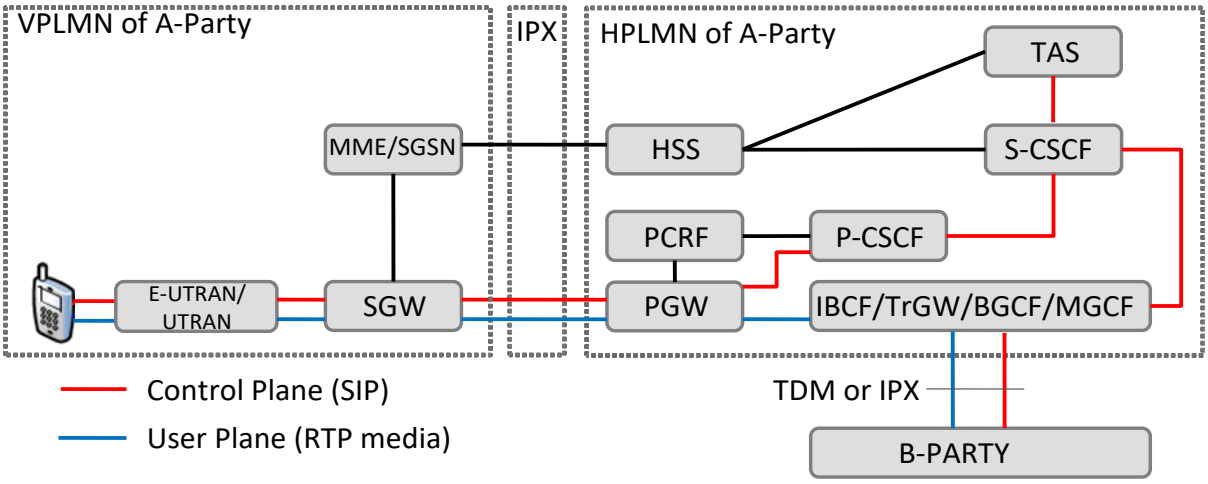

Figure 5.38. S8HR Roaming Architecture.

Although S8HR allows quick implementations of VOLTE roaming among carriers, there are certain impacts/limitations with S8 HR. For instance, the call quality for users travelling outside of the home country could be degraded due to the long path latency since all calls are routed home even if the calls are made to local numbers. S8HR also poses limitations on SRVCC, causing the call quality degradation due to delayed handover signaling (when NNI exists), or disabling certain SRVCC enhancement features such as SRVCC mid-call features. More importantly, when the visited network is not service aware, or doesn't have IMS support under S8HR, emergency call and Lawful Interception for the roaming end users will not be fully supported. This can be a critical issue in countries where emergency call and Lawful Intercept are required by the local regulator.

GSMA Product and Services Management Committee (PSMC) has informed 3GPP that they endorsed S8HR architecture as a candidate for VoLTE roaming under the assumption that the related issues (inclusive of Lawful Interception, Emergency Call, SRVCC, and others) will be resolved by 3GPP in Release 14 and future releases.

5.5.14 WEBRTC ENHANCEMENTS

In Rel-14, the option to allow Datagram Transport Layer Security (DTLS) over TCP between WICs and eIMS-AGW is added. This enhances the user experiences by allowing the media to traverse thru UDP blocking NATs/firewalls. The requirement of having MSRP B2BUA at the eIMS-AGW is removed because protocol interworking defined in TS 23.334 allows MSRP to be transparently forwarded by eIMS-AGW.

In Rel-14, Media Plane Optimization handling at the eIMS-AGW allows the option to either terminate the DTLS layer or also forward the DTLS layer transparently. Forwarding the DTLS layer is also ideal for enterprise use cases as Lawful Interception is normally not required.

In Rel-14, the support of non-multiplexed RTP and RTCP is optional for WebRTC entities while the support of multiplexed RTP and RTCP is mandatory (this is due to the recent development in IETF RTCWEB WG). Corresponding protocol requirement in 3GPP TS 24.371 has also been modified to make the support of multiplexed RTP and RTCP mandatory. To allow for backward compatibility, eP-CSCF shall negotiate with the WICs via signaling whether RTP and RTCP flows of an RTP stream are multiplexed onto the same port, and shall configure the eIMS-AGW to (de)multiplex such flows if entities anchoring the session media path in the IMS domain do not support that capability.

5.6 RELEASE INDEPENDENT FEATURES

This section provides detail on the new frequency bands and CA combinations being introduced in Rel-14.

5.6.1 FREQUENCY BANDS

New LTE bands continue to be introduced. The following LTE bands are completed in Rel-14 and can be found in 36.101 version 14.1.0:

- Band 47: Specifies enhancements to both Uu transport and PC5 transport in E-UTRAN to support LTE-based V2X; support of UE maximum transmission power up to 33 dBm (considering the regulatory limit on the maximum e.i.r.p.) for PC5 in 5855 MHz ~ 5925 MHz
- Band 69: Specifies the band numbering and RF characteristics of the new LTE FDD 2.6GHz SDL band (2570-2620 MHz) for region 1
    - E-UTRA channel bandwidths 5, 10, 15 and 20 MHz
    - This band is restricted to be used on CA configuration for LTE
- Band 70 - Standardization of new FDD E-UTRA band 1695-1710 MHz uplink and 1995-2020 MHz downlink in North America
    - Primary UL/DL symmetric pairing with a 300 MHz duplex spacing
    - Secondary UL/DL symmetric pairing with a 295 MHz duplex spacing

In addition to those bands completed, the following new bands were still being worked at 3GPP in October 2016:

- Band TBD: Specifies a new LTE TDD operating band (3550-3700 MHz) with support of 5, 10, 15 and 20MHz channel bandwidths to operate in U.S.A. On April 21, 2015, the FCC released a Report and Order (R&O) and Second Further Notice of Proposed Rulemaking (Second FNPRM) to establish new rules for commercial use of the 3550-3700 MHz band. This framework creates a contiguous 150 MHz block at 3550-3700 MHz (3.5 GHz) for mobile broadband that FCC calls “Citizens Broadband Radio Service (CBRS).” This band is targeted to complete within Rel-14.

Rel-14 new E-UTRA operating bands are captured in Table 5.5.

Table 5.5. Rel-14 new E-UTRA Frequency Operating Bands.

Frequency Band Description	E-UTRA/ UTRA	Band Number	FDD/ TDD	WID
LTE-based V2X Services	**E-UTRA**	**47**	**TDD**	**RP-161606**
CBRS 3.5GHz band for LTE in the United States	**E-UTRA**	**TBD**	**TDD**	**RP-161291**
LTE 2.6 GHz FDD SDL band (2570-2620 MHz) and LTE Carrier Aggregation (2DL/1UL) with Band 3 for Region 1	**E-UTRA**	**69**	**FDD**	**RP-160378**
New AWS3/4 Band for LTE	**E-UTRA**	**70**	**FDD**	**RP-151731**

5.6.2 LTE CARRIER AGGREGATION COMBINATIONS

New CA band combinations continue to be introduced. Up to the first release of Rel-14 technical specification TS 36.101 version 14.0.0, there are a total of 42 CA band combinations added to TS 36.101. All Rel-14 added CA band combinations can be properly grouped into the five groups employed since Rel-13, namely:

1. Intra-band contiguous CA
2. Inter-band CA (two bands)
3. Inter-band CA (three bands)
4. Inter-band CA (four bands)
5. Intra-band non-contiguous CA (with two sub-blocks)

A breakdown of the 42 new CA band combinations is shown in Tables 5.6 through 5.11.

Table 5.6. New CA Band Combination Counts Added to Rel-14 TS 36.101 version 14.0.0.

CA category	CA band combination counts
Intra-band contiguous CA	1
Inter-band CA (two bands)	29
Inter-band CA (three bands)	10

Inter-band CA (four bands)	2
Intra-band non-contiguous CA (with two sub-blocks)	0
Total	**42**

Table 5.7. New Intra-band Contiguous CA Operating Bands added to Rel-14 TS 36.101 version 14.0.0.

E-UTRA CA Band	E-UTRA Band
CA_70	70

Table 5.8. New Inter-band CA Operating Bands (two bands) added to Rel-14 TS 36.101 version 14.0.0.

E-UTRA CA Band	E-UTRA Band			
CA_1-38	1, 38		CA_7-7-8	7, 8
CA_2-7-7	2, 7		CA_8-28	8, 28
CA_2-66	2, 66		CA_8-39	8, 39
CA_2-66	2, 66		CA_8-42-42	8, 42
CA_2-66-66	2, 66		CA_11-41	11, 41
CA_3-3-7	3, 7		CA_11-42	11, 42
CA_3-7-7	3, 7		CA_12-66	12, 66
CA_3-3-20	3, 20		CA_12-66-66	12, 66

CA_3-21	3, 21		CA_13-66	13, 66
CA_3-69	3, 69		CA_13-66-66	13, 66
CA_4-7-7	4, 7		CA_20-28	20, 28
CA_5-46	5, 46		CA_21-28	21, 28
CA_5-66	5, 66		CA_29-66	29, 66
CA_5-5-66	5, 66		CA_46-66	46, 66
CA_5-66-66	5, 66			

Table 5.9. New Inter-band CA Operating Bands (three bands) added to Rel-14 TS 36.101 version 14.0.0.

E-UTRA CA Band	E-UTRA Band
CA_1-3-41	1, 3, 41
CA_1-7-40	1, 7, 40
CA_1-20-42	1, 20, 42
CA_1-41-42	1, 41, 42
CA_2-4-7-7	2, 4, 7
CA_2-5-66	2, 5, 66
CA_2-12-66	2, 12, 66

CA_2-12-66	2, 12, 66
CA_3-5-7	3, 5, 7
CA_3-7-40	3, 7, 40

Table 5.10. New Inter-band CA Operating Bands (four bands) added to Rel-14 TS 36.101 version 14.0.0.

E-UTRA CA Band	E-UTRA Band
CA_1-3-5-7	1, 3, 5, 7
CA_1-3-7-40	1, 3, 7, 40

Table 5.11. New Intra-Band Non-contiguous CA Operating Bands (with two sub-blocks) added to Rel-14 TS 36.101 version 14.0.0.

E-UTRA CA Band	E-UTRA Band
n/a	**n/a**

6 CONCLUSION

3GPP has had a strong history of defining the technologies that drive the largest mobile wireless ecosystems from GSM to HSPA and now to LTE which has for the first time has brought together the entire global ecosystem for mobile networks to a single technology. The success of LTE since its early definition in Rel-8 and Rel-9 has driven continued enhancements through LTE-Advanced in Rel-10 through Rel-12, and now through LTE-Advanced Pro in Rel-13, which was just completed in March-June of 2016. This white paper has provided a detailed discussion on the key feature enhancements that were included in 3GPP Rel-13 such as enhancements to support active antennas, LTE in unlicensed spectrum (LAA), aggregation of LTE and WLAN (LWA and LWIP), low power / wide area coverage for IoT applications through NB-IoT, as well as enhancements to previously introduced LTE technologies such as advanced MIMO, SON, Carrier Aggregation and Dual Connectivity (DC), and Proximity Services and Device-to-Device Communication for Public Safety. This white paper also provides a detailed discussion of the LTE enhancements being worked on as part of Rel-14 including further MIMO enhancements, CA enhancements, enhanced LAA (eLAA), enhanced LWA (eLWA), VoLTE enhancements and enhancements to ProSe/D2D. LTE is expected to be the dominant mobile wireless technology well into the next decade and 3GPP Rel-13 and Rel-14 features and enhancements will be a critical part of the LTE-Advanced Pro evolution.

In parallel to the rollout and continued evolution of LTE, the mobile wireless industry has identified the need for a 5th generation technology that supports a wider range of frequency bands from <6 GHz to up to 100 GHz, and enables the continued support of growing Mobile Broadband demands as well as to more optimally support new verticals and the wide range of applications in the areas of IoT and Ultra Reliable Low Latency Communications. The ITU is well into its IMT-2020 process towards 5G, and this paper provides details on the ITU's work towards defining the requirements and framework for IMT-2020 solution proposals, evaluation and certification. The IMT-2020 process is in part driving the work in 3GPP to define a 5G technology meeting the IMT-2020 requirements, and this paper discusses the work plan in 3GPP towards this goal, which consists of a two-phased approach with Phase I focusing on 5G New Radio and Next Generation System Architecture studies (Rel-14) and normative specs (Rel-15) by 2018, and Phase II including everything needed to meet IMT-2020 requirements in Rel-16 by 2019.

Details on the 5G New Radio requirements, technology and solution study areas, architecture, protocols, interfaces and physical layers' aspects towards the 5G RAN in Rel-14 and Rel-15 are explained. Given the need to include mmWave frequency bands up to 100 GHz in 5G, this paper also discusses the work in 3GPP on new channel modeling for mmWave bands. Related to the Next Generation System Architecture, this white paper summarizes the work on new Services and Market Technology Enablers, Deployment scenarios and key issues related to Network Slicing, QoS, Mobility and Session Management, and many more.

LTE deployments and coverage globally is accelerating very quickly and will be the dominant mobile wireless technology well into the next decade. In parallel, the industry is already working towards demonstrations and trials of 5th Generation technologies that are expected to be introduced over the next several years. This paper has demonstrated 3GPP's significant and critical role in driving both continued LTE evolution through LTE-Advance Pro as well as supporting the introduction of 5G through Rel-14 and Rel-15, preparing the industry once again for the continued growing and expanding demands of the mobile wireless network.

APPENDIX A: LTE E-UTRA OPERATING (TDD AND FDD) BANDS

Table A.1. LTE E-UTRA Operating (TDD and FDD) Bands.[151]

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD

[151] 3GPP Technical Specification 36.101, V14.1.0. (2016-09).

14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23[1]	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
29	N/A			717 MHz	–	728 MHz	FDD[2]
30	2305 MHz	–	2315 MHz	2350 MHz	–	2360 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
32		N/A		1452 MHz	–	1496 MHz	FDD[2]

33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD
45	1447 MHz	–	1467 MHz	1447 MHz	–	1467 MHz	TDD
46	5150 MHz	–	5925 MHz	5150 MHz	–	5925 MHz	TDD[8,9]
47	5855 MHz	–	5925 MHz	5855 MHz	–	5925 MHz	TDD
…							
64	Reserved						
65	1920 MHz	–	2010 MHz	2110 MHz	–	2200 MHz	FDD
66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz	FDD[4]

67		N/A		738 MHz	–	758 MHz	FDD[2]
68	698 MHz	–	728 MHz	753 MHz	–	783 MHz	FDD
69	N/A			2570 MHz	–	2620 MHz	FDD[2]
70	1695 MHz	–	1710 MHz	1995 MHz	–	2020 MHz	FDD[10]

NOTE 1: Band 6, 23 is not applicable

NOTE 2: Restricted to E-UTRA operation when carrier aggregation is configured. The downlink operating band is paired with the uplink operating band (external) of the carrier aggregation configuration that is supporting the configured Pcell

NOTE 3: A UE that complies with the E-UTRA Band 65 minimum requirements in this specification shall also comply with the E-UTRA Band 1 minimum requirements

NOTE 4: The range 2180-2200 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured

NOTE 5: A UE that supports E-UTRA Band 66 shall receive in the entire DL operating band

NOTE 6: A UE that supports E-UTRA Band 66 and CA operation in any CA band shall also comply with the minimum requirements specified for the DL CA configurations CA_66B, CA_66C and CA_66A-66A

NOTE 7: A UE that complies with the E-UTRA Band 66 minimum requirements in this specification shall also comply with the E-UTRA Band 4 minimum requirements

NOTE 8: This band is an unlicensed band restricted to licensed-assisted operation using Frame Structure Type 3

NOTE 9: In this version of the specification, restricted to E-UTRA DL operation when carrier aggregation is configured

NOTE 10: The range 2010-2020 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured and TX-RX separation is 300 MHz The range 2005-2020 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured and TX-RX separation is 295 MHz

APPENDIX B: MEMBER PROGRESS

AT&T

AT&T Inc. is a premier communication holding company and one of the most honored companies in the world. Its subsidiaries and affiliates – AT&T operating companies – are the providers of AT&T services in the United States and internationally. With a powerful array of network resources, AT&T helps millions around the globe connect with leading entertainment, mobile, high speed internet and voice services. AT&T also offers the best global coverage of any U.S. wireless provider*. AT&T is the world's largest provider of pay TV. Its AT&T GigaPower service provides customers with ultra-fast internet speeds up to 1 gigabit per second in 26 major markets thus far nationwide with more to come. The company's suite of IP-based business communications services is one of the most advanced in the world.

AT&T's wireless network is based on the 3rd Generation Partnership Project (3GPP) family of technologies that includes LTE and HSPA+ mobile broadband. The 3GPP family of technologies is the most open and widely-used wireless network platforms in the world. This means that AT&T customers benefit from broader global roaming capability, more efficient research and development, the best options in cutting-edge devices, and smoother evolution to newer technologies.

AT&T builds its networks for speed, performance and reliability to support services such as video. Network radio components are placed near the antennas which minimizes power loss. This translates into fast speeds and great reliability across AT&T's 4G LTE network. The network is designed with its core elements distributed across the country, meaning data traffic gets on the Internet faster, which increases mobile data speeds.

AT&T also launched one of the world's first virtualized core network platforms. The launch of virtualized core network platforms and NFV/SDN has enabled AT&T to rapidly deploy additional mobile core sites and expand its mobile core network within the US, as well as build out mobile cores in Mexico and in Europe. AT&T's virtualized core network functions are deployed onto AT&T Integrated Cloud (AIC) locations across the globe. Running virtual core network functions on AIC enables AT&T to gather and analyze extremely large volumes of network data which enhances its Big Data based intelligence capabilities. The ability to grow the mobile core in an agile manner using NFV/SDN is a key enabler for new services, IoT growth, and 5G.

In early 2016, AT&T began 5G trials in Austin, Texas. Outdoor testing began in the summer and field trials to provide wireless connectivity to fixed locations in Austin will begin before the end of the year. AT&T is structuring its trials in such a way that it is able to contribute to the international 5G standards development and pivot to compliant commercial deployments once standards are set by 3GPP. AT&T's fundamental technology approach to 5G is unique. Built on its industry-leading positions in SDN, data analytics, security

and open source software, the approach will help deliver a cost-effective wireless experience that can quickly adapt to new consumer and business demands.

AT&T is implementing a variety of LTE-Advanced features within its network and will continue to add more over the next few years to take full advantage of its rich functionality. These features include carrier aggregation, high-order MIMO and self-optimizing networks, to name a few. AT&T launched HD Voice service utilizing Voice over LTE technology in the U.S. during 2014, following on with Wi-Fi Calling, Advanced Messaging and Video Calling. They are also working with Verizon to offer Voice over LTE interoperability between their customers.

Since 2011, AT&T invested more than $140 billion in its wireless and wireline networks, including capital investment and acquisitions of wireless spectrum and operations. From 2011-2015, AT&T invested more in the U.S. than any other public company.

** Global coverage claim based on offering discounted voice and data roaming; LTE roaming; voice roaming; and world-capable smartphone and tablets in more countries than any other U.S. based carrier. International service required. Coverage not available in all areas. Coverage may vary per country and be limited/restricted in some countries.*

CISCO

Cisco is the worldwide leader in IT that helps companies seize the opportunities of tomorrow by proving that amazing things can happen when you connect the previously unconnected. We are an industry leader in the 5G transformation of service provider network architectures.

The Cisco Open Network Architecture provides a cross-domain platform to deliver business transformation through network agility. Cisco Open Network Architecture for service providers is a comprehensive framework to make networks more open, more elastic and more extensible. This architecture consists of three key functional layers that are tightly integrated with security, policy, and analytics:

- **Infrastructure** – foundational layer providing physical and virtual compute, network, and storage functions. Examples: routing, switching, mobile core, video processing
- **Network Abstraction** – orchestration for comprehensive lifecycle service automation; telemetry and analytics for programmability. Examples: physical/virtual services orchestration, streaming telemetry, network analytics
- **Cloud-based Services** – policy-based consumer, business, IoT, video, mobility services that drive new revenue. Examples: 5G fixed mobile broadband, connected car, virtual managed services (VPN, security), residential video

A Service Creation function which includes design, assurance, and catalog provides a wrapper across these layers for simplified cloud deployment.

Cisco's market presence is the culmination of a deep understanding of the emerging needs of our service provider customers by providing complete solutions to address real business challenges and opportunity. This includes leadership in not only in IP transport, but also Mobile Services Core, SON, policy, IoT, video, and security.

The Cisco® mobile software portfolio is a key building block of the Cisco Open Network Architecture programmable framework. It provides new monetization opportunities while optimizing networks for the fullest utilization.

- Cisco Ultra Services Platform providing industry leading fully orchestrated VPC for the greatest elasticity and scale.
- Cisco Policy Suite for Service Providers provides next-gen policy management to deliver customized user experiences.
- Cisco SON provides real-time intelligence into the Radio Access Network (RAN) for optimized performance.

Cisco is deployed globally by more than 350 service providers in more than 75 countries.

Some recent customer success stories include:

- Ericsson, Intel, Cisco partner to develop 5G router
- Ultra Services Platform launched for 5G and Mobile Cloud
- CenturyLink, Inc. introduces Smart Spaces, a location-based, mobile engagement, analytics and marketing Internet of Things (IoT) solution
- 3Italia (H3G) – Ericsson and Cisco partner to protect the mobile packet core for improved performance and service stability

COMMSCOPE

For the carrier market, **CommScope** (www.commscope.com) is a global leader in wired and wireless network infrastructure, supplying all the integral building blocks for base station sites, converged networks and indoor coverage and capacity. CommScope products support current 3GPP releases and product roadmaps and will continue to be developed to ensure future compliance to 3GPP specifications. CommScope also is a leading global provider of wireless network planning, installation and optimization products and services.

***Rapid development of a focused outdoor footprint**:*

CommScope's wireless solutions address all areas of RF path and coverage needs for UMTS, LTE and LTE-Advanced networks. The company's RF solutions enable operators to synchronize investments with revenue, using scalable deployment strategies and technologies; accelerate payback by expanding macro and small cell coverage effectively; and manage coverage, capacity and interference in key areas such as urban settings, indoors, and along transportation corridors.

CommScope solutions specifically address the unique needs of wireless operators deploying LTE networks in site acquisition, power and backhaul. CommScope solutions enable small footprint rooftop deployments; supplement macro coverage with microcell-based capacity for outdoor hotspots; simplify greenfield site builds with kits and bundles; and broaden wireless coverage and capacity indoors with distributed antenna systems (DAS) and small cells. The company's most recent innovations for outdoor wireless networks include:

- **PowerShift**, which CommScope believes is the wireless industry's first intelligent, plug-and-play direct current (DC) power supply solution for remote radio units (RRUs). PowerShift can help operators re-utilize existing power cable infrastructure, eliminate the need for deploying higher

gauge conductors when installing new cabling and increase the useable length for cables by over four times. It can also extend RF battery uptime by up to 35 percent.

- **Powered Fiber Cable System**, which speeds and simplifies the installation of, powering and communication with dc-powered devices. The hybrid fiber/copper cabling and remote powering unit correct for electrical line loss and reduce the need for local utility negotiations. Powered fiber enables C-RAN site deployments, carrying power and data from a centralized location for up to three kilometers.
- **Integrated Structural Site Solution**, which integrates the pole and cabinet to ease the challenges of site acquisition and installation. Intended for monopole sites such as mini-macros or metro cells, this solution connects AC power, radio equipment, transmission lines and antennas in one unit and supports both Wi-Fi and cellular networks. It is the latest addition to CommScope's Metro Cell Concealment Solutions portfolio.

At the cell tower top, CommScope continues to promote the advantages of SiteRise™, the complete, factory-assembled fiber to the antenna solution that makes it easy to standardize macro site deployments. In SiteRise, CommScope combines and pre-configures all RF equipment—antennas, remote radio units, cable assemblies—in one, tower-mountable unit. SiteRise avoids installation errors while streamlining deployments and mitigating against passive intermodulation (PIM) interference. SiteRise is especially helpful in regions where skilled installers are few.

At the bottom of cell towers, CommScope is manufacturing cabinets designed specifically for Cloud-RAN architectures in the macro wireless network and for small cell or outdoor distributed antenna system (DAS) applications. CommScope's C-RAN Cabinets include enclosures for hub sites where baseband processing is centralized and node sites at the network edge. The C-RAN Cabinets support fiber connections and cable management while flexibly integrating power and other equipment.

CommScope also helps operators maximize efficiency, coverage and spectrum usage in their outdoor networks through the concept of sector sculpting, a creative approach to antenna pattern shaping that carves out more capacity, improves coverage and limits interference. Sector sculpting boosts network performance by better controlling interference between sectors and increasing the number of accessible subscriber channels. Sector sculpting antenna offerings include a Six Sector Solution and Five Beam, 18-Beam, UltraBand™ and SmartBeam® base station antennas. In addition, the Andrew Sentinel™ microwave backhaul antenna uses a similar pattern shaping approach to boost capacity between microwave links.

Cost-effective coverage and capacity:

Eighty percent of wireless calls originate from indoors—yet only 2 percent of commercial buildings offer in-building wireless solutions (IBW) to manage the traffic. IBW solutions can offload this traffic in high-rise buildings, across sprawling campuses, through massive stadiums and other high-density demand areas. CommScope offers a full portfolio of IBW solutions for a variety of applications, including the following:.

- **ION®-E**, the low-power unified wireless infrastructure solution that converges wired and wireless networks on economical Category 6A and fiber-optic cable. It dynamically transports capacity wherever it's needed via software—no remote reconfigurations or patch changes necessary—so you building owners add new operators, bands or technologies without adding hardware.

- **ION-U**, the combination low- and high-power DAS solution that can cover massive indoor spaces, sprawling outdoor spaces or both in one compact, space-saving headend. It simplifies deployments

with powerful planning, commissioning and optimization tools, making for a virtually error-proof installation.

- **OneCell**, the Cloud-RAN small cell system that delivers superior LTE performance for enterprises and public venues at dramatically lower deployment costs. OneCell® consists of a baseband controller and multiple radio points that form a single “super cell”—eliminating handovers and interference across large areas. Using a technique pioneered by CommScope, multiple users can share the same frequencies, effectively multiplying system capacity.

These, along with CommScope’s other in-building wireless solutions, provide the power and flexibility to design an economical and powerful indoor network that keeps customers connected, productive and happy.

Educational Resources:

As a trusted advisor for communications networks around the world, CommScope offers comprehensive training and educational programs and resources.

- The ***LTE Best Practices*** ebook is filled with answers, tips and insights that will demystify LTE implementation complexity. It covers 10 subject areas including noise and interference mitigation, co-siting, passive intermodulation (PIM) avoidance, distributed antenna system (DAS) implementation, microwave backhaul, small cells and more.

- The ***Connected and Efficient Buildings*** ebook offers a meaningful look into the applications, design and technologies that are a part of today’s modern building. Topics covered include the Internet of Things, Universal Connectivity Grid, Automated Infrastructure Management, Power over Ethernet, and more.

- The **Microwave Communication Basics** ebook explains the components, systems and practices that go into an efficient, reliable microwave communications network for wireless backhaul. It discusses communication and path design, the importance of patterns and regulatory compliance, environmental considerations, and more.

- The CommScope Infrastructure Academy offers a comprehensive suite of online and in-person training resources to help organizations achieve high quality designs and installations.

ERICSSON

Ericsson is driving the 5G standards work from today's research and pre-standard field trials, through influential standards bodies and industry groups. Through key technology advances like the Ericsson 5G Radio Prototypes and cloud-based network slicing, Ericsson and its operator customers will be key players in defining this next generation of network technology all the way through to commercialization.

Our 5G Radio Prototypes that operators can deploy in live field trial environments are showing exceptional performance under real-world conditions, achieving a peak throughput of 27.5Gbps and latency as low as 2ms in a live demonstration in August 2016.

Our 5G Ready Core is all about flexibility and efficient management of that new flexibility. It is based on five key technologies: Virtualization (VNF), Software Defined Networking (SDN), Distributed Cloud, Network Slicing and Orchestration & Automation. By managing resources dynamically, service providers can add value to their offerings by creating “network slices,” on-demand, software-defined, and amenable to

ecosystems involving third-party service providers, at industrial scale. We successfully completed a Proof of Concept (PoC) of dynamic network slicing technology for 5G core networks in June 2016.

Ericsson is working on 5G in over 15 industry pilots and with 24 major operators on every continent around the world including NTT DoCoMo, Softbank, Singtel, Telstra. Deutsche Telekom, Korea Telecom, SK Telecom, Etisalat, Turkcell, Verizon, LG Uplus, America Movil, Ooredoo Group, KDDI, MTS, China Mobile, AT&T, TeliaSonera, Telefonica, Vodafone Group, T-Mobile, China Unicom, Alfa (Lebanon), and TIM Italy.

In addition, we've been doing extensive research together with many industries to gain knowledge and experience in leveraging 5G technology. We are spearheading projects developing innovative use cases for 5G with industries ranging from mining to agriculture to intelligent transportation, including companies such as Volvo, Boliden, SICS, Scania, Saab, SKF, Zuchetti (5G Cloud Robotics), and Weiss Robotics. We are gaining an understanding of how 5G and IoT capabilities will be used in the real world while building innovative solutions for enterprise customers.

We introduced 5G Plug-Ins, software-driven innovations that bring essential 5G technology concepts to today's cellular networks. The Plug-Ins, which include modules for Massive MIMO, Multi-User MIMO, RAN Virtualization, Intelligent Connectivity, and Latency Reduction, will facilitate a rapid evolution of 5G access networks and the successful adoption of 5G services.

Ericsson is building the industry's strongest 5G ecosystem, a closely interlinked series of symbiotic relationships that include operators, semiconductor vendors (e.g., Intel and Qualcomm), IT-infrastructure providers (e.g., IBM and Cisco), device manufacturers, standards bodies, and more. Ericsson's 5G solutions are purpose-built for real-world applications, based on our years of R&D experience and technology leadership. With four generations of mobile technology shifts, and 66,000 service professionals, we have the experience and expertise to advise on how to transform networks with maximum revenue gain and minimal risk. We're known for successful, large-scale, advanced, technology rollouts, and we help our customers make the right technology, business, and organizational changes to optimize your 5G implementation.

HEWLETT PACKARD ENTERPRISE

Hewlett Packard Enterprise carries forth a legacy of innovation that began in a Palo Alto, California garage more than 75 years ago. With more than 200,000 employees across the globe, HPE is the largest technology company in the world and a leading provider of solutions organizations need to optimize their traditional information while building a secure, cloud-enabled, mobile-ready future.

As Information Technology ("IT") strategies and business strategies become inseparable, HPE's portfolio of hardware, software, services and financial services provide a complete solution that accelerates the time it takes customers to go from idea to value. This enables organizations to act rapidly, seize opportunities and quickly respond to threats as they arise.

HPE is the leading IT vendor supporting Service Provider evolution towards all IP convergent networks and cloudification: https://www.hpe.com/us/en/solutions/transform-hybrid.html**.** This provides customers with increased flexibility and agility while ensuring there is no disruption to the legacy systems that run their businesses.

HPE Helion offers an innovative suite of products, solutions, services, and expertise to help customers create a flexible, open, and secure hybrid cloud. Helion Cloud Suite includes tools for operations

management, cloud orchestration, big data analytics, and service-based compliance. Helion CloudSystem 10 is an engineered hardware and software solution for both traditional and cloud-native workloads. HPE Cloudline 3100 storage server targets service providers, and at 1U, it is 75 per cent smaller than its predecessor. HPE also introduced composable infrastructure, expanding hypervisor based virtualization to containers and docker support. Additional information can be found here:
https://www.hpe.com/us/en/solutions/infrastructure/composable-infrastructure.html

HPE is leading NFV. HPE has been driving the NFV initiative across the industry and within standard organizations, with leadership positions in ETSI NFV and 3GPP SA5 alignment on management and orchestration. HPE OpenNFV program offers the most complete and open solution offering with HPE NFV System, Helion OpenStack Carrier Grade, SDN for NFV with ContextNet, NFV Director & Virtualization of the HPE telecom Solution Portfolio and a wide ecosystem of partners. http://www8.hp.com/us/en/cloud/nfv-products.html

HPE offers IoT platform to build and analyze data. The company has long recognized the Internet of Things as a critical enabler of the idea economy and the data-driven enterprise. As such, HPE launched U-IoT, Universal IoT Platform for licensed and unlicensed spectrum, 3G-4G-Wifi-LPWAN, including emerging cellular standards such as LTE-M and narrowband IoT (NB-IoT) recently introduced by 3GPP. The platform dramatically simplifies integrating diverse devices with different communications protocols. It provides SIM & Device Lifecycle Management and Data Analytics and has a developer portal where IoT applications can be built with the platforms connectivity plumbing available to the application. Developers may use HPE Vertica column-oriented database system for analytics or HPE Haven OnDemand, a set of APIs providing access to 60 machine-learning functions. Objenious, French operator Bouygues Telecom subsidiary for IoT, is using HPE U-IoT Platform to deliver IoT-based services for vehicle fleet management, remote meter reading, predictive maintenance, and geolocation. HPE also introduced the industry's first converged system for IoT with new Edgeline systems, bringing robust analytics platform to deliver IoT insights and machine learning at the edge, enhanced IoT security with HPE Aruba, and new IoT services and ecosystem capabilities to help customers define their Internet of Things. Launched in 2016, HPE's Edgeline EL1000 and Edgeline EL4000 integrate data capture, control, compute and storage to enable real-time analyses at the edge, rather than forcing companies to transfer vast amounts of sensor data to a central location for processing. HPE's Vertica Analytics Platform runs on the EL4000.
https://www.hpe.com/us/en/solutions/internet-of-things.html

HPE provides actionable insights and better network utilization with Telecom Analytics. HPE Telecom Analytics, developed for communication service providers, expands on HPE Haven, HPE's enterprise-class analytics platform, to enable CSP to store, analyze, explore, and predict 100% of data, regardless of type, source or location. With 3GPP evolution towards self-organized networks and autonomous networks, this platform empowers network operators with real-time analytics and subscriber intelligence with HPE TAPS (Telecom Analytics Smart Profile Server).

Hewlett Packard Enterprise simplifies mobility modernization with an end-to-end portfolio of mobility software, infrastructure and unified communications. HPE provides products, services and integration specialists—including market-leading offerings from HPE CMS (Communication Media Entertainment Solutions) and HPE Aruba, a Hewlett Packard Enterprise company.

Recent HPE Innovation News:

Hewlett Packard Enterprise Simplifies Connectivity Across the IoT Ecosystem
http://www8.hp.com/us/en/hp-news/press-release.html?wireId=2051970

Hewlett Packard Enterprise Virtualizes Network Functions for Swisscom
http://www8.hp.com/us/en/hp-news/press-release.html?id=2176034#.V7R7bk0rJD

INTEL CORPORATION

Headquartered in Santa Clara, California, Intel Corporation is a U.S. multinational corporation and the largest semiconductor chip maker. Intel develops advanced integrated digital technology, primarily integrated circuits, for industries such as computing and communications. Intel is also a leading manufacturer of computing and communications components, such as microprocessors, chipsets, motherboards, and wireless and wired connectivity products, as well as platforms that incorporate these components.

At the core of Intel's foundation is the relentless pursuit of Moore's law, enabling computing systems to become faster, more efficient and more pervasive with each succeeding generation. Today, Intel leads the Industry with Tri-gate transistors and 14-nanometer technology-based devices with higher functionality and complexity while controlling power, cost, and size.

Earlier in January, 2017, Intel introduced its 7th generation Intel CoreTM processors, Intel's latest, most advanced 14nm+ process technology that delivers new levels of performance and security. These processors open up a world of rich and immersive experiences for consumers, enterprises, and performance-hungry gaming and media enthusiasts.

With a range of smart designs and functionality, Intel Core processor-based devices provide an array of form factors to choose from, including: compute sticks, ultra-thin 2 in 1 detachables and convertibles, thin and light laptops, high-performance laptops, a range of desktops, All-in-Ones and minis, and Intel® Xeon® processor-based mobile workstations. Well known for our best-in-class inventions in the area of microprocessors that are found in most personal computers today, Intel continues to build on its strengths to accelerate innovation and drive growth in the fields of computing and communications.

As Intel works to expand the boundaries of technology to make the most amazing experiences possible, it powers 98% of the world's data centers, connecting hundreds of millions of mobile and Internet of Things (IoT) devices and is helping to secure and protect enterprise and government IT systems.

Intel has an extensive and growing portfolio of products and technologies that deliver solutions to help communication service providers transform their networks, bringing advanced performance and intelligence from the core of the data center to the network edge. Intel's commitment to network transformation is long and deep – with years invested in delivering reference architectures, growing a strong ecosystem, and partnering with end-users.

Intel continues to make enormous strides in advancing its communication capabilities. There has been an increasing drive in integrating 3G and 4G technologies to power the next generation of tablets, phones, vehicles, and a range of IOT devices.

Another major initiative that Intel is driving is the design and development of 5G technologies which represent the true convergence of computing and communications. 5G is a fundamental shift for the industry where networks will transform to become faster, smarter, and more efficient - realizing the potential for IoT and mobility and enabling richer experiences throughout daily life in areas such as augmented reality, smart cities, telemedicine, and more.

Intel debuted its Mobile Trial Platform (MTP) at Mobile World Congress in February of 2016 and with the announcement of the second generation of MTP in August of the same year, is aiding manufacturers, operators and ecosystem players to understand the emerging requirements related to the technologies, standards and chipset requirements of 5G.

Intel is a leading contributor to the 3GPP standards in the evolution of LTE Advanced and 5G technologies. The overall focus of Intel's 3GPP Standards team has been the continuation of Release 13 and Release 14 technology standards development. In a march to provide increased capabilities for mobile computing, Intel has been actively addressing several areas in 3GPP RAN1-4 that includes 5G NR, LTE-Advanced Pro, MTC in various modes, LAA & LWA enhancements in unlicensed spectrum, multimedia delivery, positioning and eMBB enhancements. Intel is well on its way to establish a clear vision, plans and execution of Release 15 5G standards development.

In January of 2017, Intel revealed its latest effort in commercializing 5G, with the announcement of the first 5G global modem. The new Intel® 5G Modem is a key milestone for the industry, enabling businesses across the globe to develop and launch early 5G solutions. It will accelerate the development of 5G-enabled devices and provide opportunities for leaders across diverse industries to innovate with early deployments. This comes on the heels of four generations of commercial product releases of wireless modems released in within the last few years.

KATHREIN

Kathrein is recognized as the worldwide leader in professional antenna systems (ABI Research 2014, 2015) with global headquarters located in Rosenheim, Germany. Kathrein's RF solutions ensure the highest quality and enable operators to expand macro and small cell coverage and capacity for wireless densification. Quality has played a major role since our inception and is the primary focus for the company. As a result of this key principle, Kathrein products and solutions are well regarded for their durability, maturity, sophisticated design, and sustainability.

Kathrein's technicians, engineers and scientists drive innovation for densification on the road to 5G. To maintain its market leadership, Kathrein annually invests 7.5% of revenue back into Research & Development, which is represented in our over 1,000 actively used patents, patents pending and utility models. Kathrein generates more than 60% of revenues annually with products which are less than two years old. Kathrein's leadership is established not only in RF solutions, but also in Satellite, RFID, Broadcast, and Connected Car solutions. Kathrein is an active member in many of the standards bodies for 3G, 4G, LTE, and 5G.

- The Kathrein Communication Products Portfolio optimizes networks for full utilization and monetization for carriers around the globe.

- Kathrein's Small Cell site solutions optimize network performance and accelerate deployments. Encompassing RF delivery, equipment housing, and concealment, Kathrein Small Cell antennas improve performance of the RF air link, expedite construction and enable faster zoning approvals, thereby decreasing CapEx and OpEx and improving time to revenue.

- In 2015, Kathrein Street Connect™ was introduced as a revolutionary in-ground antenna solution to provide coverage in dense urban areas or hotspots such as downtown pedestrian zones. The solution is a micro cell in which the base station is incorporated into existing cable manholes of the landline infrastructure and the antenna is embedded into the ground in the immediate vicinity by

way of a core drilling, with a cover similar to a manhole. Multiple trials are underway in the U.S. and Canada alone.

- As the innovation and technology leader in the field of base station antennas for mobile cellular networks, Kathrein manufactures over a million antenna systems per year. Our customer base includes all major system manufacturers as well as hundreds of network operators worldwide.

- The product range in the mobile communications segment extends from 25 to 6,000 MHz, featuring directional and omni-directional antennas tailored to specific customer needs, as well as special antennas for buses and trains and for ground-to-air communications. Kathrein's extensive product range features over 250 types for technologies such as CDMA, GSM, UMTS, LTE, WIMAX and WLAN.

Learn more here: https://youtu.be/v7YxhAAZItE

NOKIA

Nokia is a global leader in the technologies that connect people and things. Powered by the innovation of Nokia Bell Labs and Nokia Technologies, the company is at the forefront of creating and licensing the technologies that are increasingly at the heart of our connected lives.

With state-of-the-art software, hardware and services for any type of network, Nokia is uniquely positioned to help communication service providers, governments, and large enterprises deliver on the promise of 5G, the Cloud and the Internet of Things.

A longstanding leader in the commercialization and innovation of LTE, Nokia serves millions of LTE subscribers in commercial FDD-LTE and TD-LTE networks worldwide, deploying LTE on all major frequency bands. Nokia's Global Services enable operators to safely move towards LTE with the highest quality possible and ensure fast and reliable network rollouts with end-to-end network integration to Customer Experience Management. The company's industry-leading Security solutions enable operators to provide secure subscriber services while its Network Planning and Optimization services support a smooth transition with Re-farming Services, LTE Planning, iSON Services, LTE Optimization and Services for VoLTE.

Building upon its LTE leadership, Nokia is an industry frontrunner in making 5G a commercial reality, providing a clear focus on what really matters to operators and the wider ecosystem. Nokia has conducted 5G technology trials and lab testing with operators in North America and across the globe. The company's end-to-end 5G readiness services and 5G-ready solutions, ecosystem and innovation enables customers to accelerate their path to 5G now. Nokia is also the leading contributor to 5G standardization in 3GPP and acting as lead for many projects within 5G-PPP. Since 2014, Nokia has sponsored the annual Brooklyn 5G Summit in conjunction with the NYU WIRELESS research center at NYU Tandon School of Engineering.

Recent 5G achievements:

- At 5G World, Nokia made the first-ever demonstration of a 5G ready network running on commercially-available platforms. Nokia implemented all the key 5G technology ingredients currently in standardization, including an entirely new 5G frame structure on Nokia's AirScale radio access, working together with the commercially available Cloud Packet Core, and running on a Nokia AirFrame data center platform – the foundation of a commercial 5G architecture. No matter

how the standard will look in detail, these commercial platforms can handle it with the necessary performance and scalability.

- Nokia has demonstrated a new concept in Network Slicing, which creates and automatically maps capabilities for the radio, transport, core and application layers into a discreet network 'slice'. Using cloud orchestration, new services can be created instantly and delivered to meet the specific and diverse demands of any customer or application, such as providing low-latency support to control machines in a factory, or providing extreme high-speed broadband to enterprises and homes.

- Nokia introduced 4.5G Pro, an advanced mobile technology including 3GPP Release 13 capabilities, to deliver the significant capacity and speed enhancements needed by operators as they build towards next-generation networks, including meeting the demands of ultra-connected megacities. Powered by the Nokia AirScale radio portfolio, 4.5G Pro can deliver 10 times the speeds of initial 4G networks, making it possible for operators to offer gigabit peak data rates to meet growing demands from the programmable world, aligned with upcoming next-generation device launches.

- While 4.5G Pro focuses on the 2017 user device ecosystem and 5G-readiness of the network, Nokia 4.9G brings significant capacity and data rate enhancements and network latency reductions to let users maintain a continuous 5G service experience complementing 5G radio coverage. Nokia 4.9G comprises features to further increase capacity and speeds to several gigabits per second, including allowing additional numbers of carriers to be aggregated, opening the door to additional licensed and unlicensed spectrum, and advancing the radio systems to allow highly directional antennas to be used and to allow signals sent via multiple transmit / receive paths to be added together.

Nokia LTE achievements:

- Nokia is LTE supplier to largest operator group of top 25 operators including largest FDD LTE operator and largest TD-LTE operator.

- Nokia has brought the benefits of LTE-Advanced carrier aggregation to SK Telecom, LG U+ and Korea Telecom, helping them reach up to 150 Mbps throughput.

- Nokia is the driving force behind TD-LTE innovation and commercialization, with many world firsts since 2009. These include unprecedented speed records such as 4.1 Gbps (3GPP Release-13) throughput using TDD-FDD carrier aggregation and 8X8 MIMO over the commercial Flexi Multiradio 10 Base Station. Nokia is globalizing TD-LTE with the first 4G/TD-LTE network in Latin America, the first TD-LTE network in Russia and the first TD-LTE network in Saudi Arabia.

- Nokia has been positioned by Gartner, Inc. in the “Leaders” quadrant of its “Magic Quadrant for LTE Network Infrastructure” for six consecutive years.

QUALCOMM

Qualcomm Incorporated is a world leader in 3G, 4G, Wi-Fi, Bluetooth, and next-generation wireless technologies. For over three decades, Qualcomm ideas and inventions have driven the evolution of mobile, linking people everywhere more closely to information, entertainment and each another. Today, Qualcomm and its subsidiaries are helping shape this new, interconnected world by engineering ground-breaking mobile chipsets and software, developing technologies and creating solutions to tackle the growing demand for mobile data.

Qualcomm Technologies has been instrumental in driving the 3G/4G evolution, and now, Qualcomm is leading the world to 5G. Qualcomm is pioneering 5G technologies today to enable a truly connected world, transforming the way people live, work, and play. Qualcomm's vision for a 5G unifying connectivity fabric will take on a significantly larger role than previously generations: empowering a variety of industries to benefit from 5G as a platform for their services. Qualcomm is fueling progress across an array of world-changing use cases and ushering in a better future. Qualcomm is:

- Leading the path to 5G through its own R&D and technology development, as well as through collaborations with infrastructure vendors, operators and OEMs on 5G technology development, early interoperability testing and coordination on early 5G initiatives.

- Engaging in early trials and verification of key 5G technology components to support the technical work required for 3GPP standardization (starting from Release 15). In order to enable rapid adoption of standards-compliant and forward-compatible 5G infrastructure and devices, Qualcomm is driving interoperability in close alignment with 3GPP.

Here are some of Qualcomm Technologies' recent key milestones in the advancement of 5G and LTE Advanced/LTE Advanced Pro:

- First to announce 5G NR sub-6 GHz prototype system and trial platform to test, demonstrate, and trial 5G design to drive 3GPP 5G NR standardization [3GPP Release 15] – June, 2016.

- Announced the 6th generation Snapdragon X16 LTE modem, the first commercially announced Gigabit Class LTE chipset designed to deliver fiber-like LTE Category 16 download speeds of up to 1 Gbps, and is the mobile industry's first announced LTE Advanced Pro modem with support for Licensed Assisted Access [3GPP Release 13] – February, 2016.

- Qualcomm Research demonstrates robust 5G mmWave design for 5G [3GPP Release 15] – November, 2015.

- Qualcomm announces new modem solutions designed to support reliable, global connectivity to the Internet of Things; new MDM9207-1 enables scalable, power-efficient and cost-optimized Cat 1 LTE connectivity and MDM9206 provides a path to LTE eMTC and NB-IoT standards [3GPP Release 13] – October 2015.

Being a key contributor to 3GPP, Qualcomm Technologies not only excels in pioneering new technologies but also making them a commercial reality through proof of concept development, prototyping and finally delivering commercial chipset solutions.

SPRINT

Sprint (NYSE: S) is a communications services company that creates more and better ways to connect its customers to the things they care about most. Sprint served more than 59.4 million connections as of June 30, 2016 and is widely recognized for developing, engineering and deploying innovative technologies, including the first wireless 4G service from a national carrier in the United States; leading no-contract brands including Virgin Mobile USA, Boost Mobile, and Assurance Wireless; instant national and international push-to-talk capabilities; and a global Tier 1 Internet backbone. Sprint has been named to the Dow Jones Sustainability Index (DJSI) North America for the past five years.

Today the Sprint LTE network covers nearly 300 million people, or more than 90% of the U.S. population. Sprint's LTE Plus Network, available in 237 markets, takes advantage some of the world's most advanced technologies in wireless – carrier aggregation for higher speeds, 8T8R radios for enhanced coverage, and multi-antenna processing techniques like MIMO for higher capacity, along with tri-band LTE devices to deliver the consistent reliability, capacity and speed that its customers demand.

In June, Sprint was proud to be the first U.S. carrier to demonstrate elements of 5G at a large scale public event such as Copa América Centenario. The Sprint and Nokia demonstration utilized 73 GHz millimeter wavelength spectrum to deliver peak download speeds of more than 2 Gbps. Meanwhile, the Sprint and Ericsson demonstration utilized 15 GHz centimeter wavelength spectrum to deliver download speeds up to 4 Gbps.

Other network milestones include:

- June 2016: Sprint LTE Plus Posts Strong Gains in Network Reliability
- June 2016: PC Magazine's Fastest Mobile Networks Report Validates Sprint's Improved Network Performance
- May 2016: Sprint Launches Free Wi-Fi Service as Part of Kansas City's Smart City Initiative
- April 2016: Sprint Launches LTE Plus in New York City
- March 2016: Sprint Demonstrates Speeds of More Than 300 Mbps on Samsung Galaxy S7
- February 2016: Sprint Recognized for its Outstanding Contribution Furthering the Development of TD-LTE
- January 2016: Sprint's LTE Plus Network Delivers Fastest Download Speeds
- November 2015: Sprint Celebrates Launch of LTE Plus Network

Looking ahead Sprint will continue to build a competitive, capacity-rich network by leveraging its deep 2.5 GHz spectrum holdings and executing its Densification and Optimization strategy. Sprint is focused on building a strong foundation for 5G by densifying its network with more cell site solutions across its 2.5 GHz, 1.9 GHz and 800 MHz spectrum bands.

T-MOBILE

T-Mobile US, Inc. is a mobile Internet company designed for the Internet-born generation. The company's data-hungry customers are surfing, streaming, shopping, FaceTiming, downloading, tweeting and Facebooking with wild abandon; therefore, T-Mobile designed their network to be Data Strong™.

T-Mobile's 4G LTE network is concentrated and strengthened in the areas where data demand is highest – where people live, work, and play. The company continues to offer the fastest nationwide 4G LTE network in the U.S. and delivers the most consistent LTE speeds, all while continuing to build their network at a pace unprecedented in the wireless industry.

T-Mobile has been rapidly expanding and enhancing its 4G LTE network across America. Since the beginning of the Un-carrier™ movement over three years ago, the network has gone from zero LTE to currently covering more than 312 million Americans.

Key Network Milestones:

2012:

- February: T-Mobile announced a $4 billion plan to re-build the metropolitan areas of its network, refarming its spectrum holdings to free up spectrum for LTE and align its HSPA+ to the PCS 1900 MHz band
- October: T-Mobile and MetroPCS announce a merger to create a publicly-traded company

2013:

- January: T-Mobile was the first major national U.S. provider to enable nationwide HD Voice
- March: T-Mobile launches its first LTE market and first LTE devices available in market
- May: T-Mobile and MetroPCS merger complete and the process of harvesting spectrum for LTE begins immediately
- November: T-Mobile's first Wideband LTE[152] market launches, MetroPCS adds 15 new markets, tripling its reach across the U.S.

2014:

- January: T-Mobile boasts the fastest nationwide 4G LTE network
- March: T-Mobile announced a major project to upgrade its 2G/EDGE coverage with new LTE coverage in the PCS 1900 MHz band
- April: 700 MHz A-Block acquisition closes May: T-Mobile was the first major US wireless provider to launch Voice over LTE (VoLTE)
- July: T-Mobile was the first major national U.S. provider to launch nationwide VoLTE
- September 2014: T-Mobile launched next-gen Wi-Fi Calling, allowing customers to move seamlessly between a LTE network and any available Wi-Fi connection with a capable device for HD Voice quality coverage
- December: At the end of 2014, T-Mobile covered 265 million Americans with 4G LTE coverage, smashing their year-end goal of covering 250 million people; Wideband LTE, which increases bandwidth and capacity on its LTE network, is available in 121 markets; T-Mobile's first 700 MHz low-band LTE went live; and, in the 2nd half of 2014, T-Mobile entered into agreements to expand its 700 MHz holdings

2015:

- January: T-Mobile commits to bringing Licensed Assisted Access[153] (LAA) production trials to life in 2015 and the technology to customers in the near-future; T-Mobile was the winning bidder of AWS-3 spectrum licenses covering 97 million people for an aggregate bid price of $1.8 billion

[152] Wideband LTE –T-Mobile refers to carrier bandwidth of 15+15 MHz or greater in a particular market, allowing for faster speeds and greater capacity. Wider carrier bandwidths (of which 20+20MHz is the LTE maximum, after which you'd need carrier aggregation) are basic LTE features and have been a part of 3GPP standards since the beginning, i.e., Release-8.
[153] 3GPP specified LAA for downlink operation in Release 13 and is further working on specifying LAA for uplink operation in Release 14. LAA provides operators and consumers with an additional mechanism to utilize unlicensed spectrum for improved user experience, while coexisting with other Wi-Fi and other technologies in the 5GHz unlicensed band.

- July: T-Mobile delivers Mobile Without Borders, giving customers coverage and calling at no extra cost across North America

- September: T-Mobile launches Video Calling, as part of its Advanced Messaging (Rich Communication Services, RCS) technologies, and expanded the reach of Simple Global

- November: T-Mobile introduces its 4G LTE CellSpot, and then with Un-carrier 10, Binge On, unleashing mobile video streaming without using customer's high-speed data

- By year-end, T-Mobile covered 304 million Americans with LTE – doubling the square miles of LTE coverage – which included 300+ Extended Range LTE markets and 268 metro areas with Wideband LTE

2016:

- T-Mobile enhanced coverage breadth and depth of its 4G LTE network, expanding its 4G LTE network coverage to 312 million people, and remained the fastest 4G LTE network for downloads and upload speeds for the eleventh consecutive quarter (as of 3Q 2016)

- At the end of 3Q 2016, T-Mobile had further deployed Wideband LTE, which increases bandwidth and capacity on its LTE network, to cover more than 231 million people; in addition to the deployment of its Extended Range LTE[154] (700 MHz A-Block spectrum), now covering more than 225 million people in 366 markets

- In support Internet of Things and machine-to-machine customers, T-Mobile announced it would maintain its 2G network through 2020

- T-Mobile led the industry with new technology advancements like Enhanced Voice Services[155](EVS), 4x4 MIMO [156] , and 256 QAM [157] – in fact, here's all of T-Mobile's network "firsts"

- T-Mobile improved and expanded Binge On, technology which allows customers to stream video data without hitting their data bucket, to more than 100 streaming partners

- Internationally, T-Mobile gave customers unlimited high-speed data while traveling in Europe and South America until 2017, and added roaming in Cuba

- Introduced T-Mobile ONE and One Plus – the wireless industry's first truly all-in unlimited plan

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[154] Extended Range LTE – T-Mobile refers to deployment of low-band spectrum / POPs in a particular market, most recently 700 MHz A-Block, allowing for better breadth as well as in-building coverage.
[155] Enhanced Voice Services (EVS) Codec was completed in 3GPP Release 12. EVS is the first 3GPP conversational codec offering up to 20 kHz audio bandwidth, delivering speech quality that matches other audio input such as stored music, while offering high robustness to delay jitter and packet losses.
[156]4x4 MIMO – 4-layer spatial multiplexing was introduced since 3GPP Rel-8, but it's use with TM3/4 had been limited to only UE categories 5 and 8 due to lack of signaling to indicate the used number of layers. In September 2015, 3GPP enhanced the support of 4-layer MIMO with TM3/4 to be able to work with UE categories 6 and above from Rel-10 onwards. T-Mobile's 4x4 MIMO deployment is based on this enhancement.
[157] 256 QAM - Downlink 256 QAM was introduced in 3GPP Rel-12 in order to improve spectral efficiency.

- T-Mobile unveiled the company's vision for 5G

About T-Mobile US, Inc.: As America's Un-carrier, T-Mobile US, Inc. (NASDAQ: TMUS) is redefining the way consumers and businesses buy wireless services through leading product and service innovation. The Company's advanced nationwide 4G LTE network delivers outstanding wireless experiences to 69.4 million customers who are unwilling to compromise on quality and value. Based in Bellevue, Washington, T-Mobile US provides services through its subsidiaries and operates its flagship brands, T-Mobile and MetroPCS.

TELEFONICA

In the past few years, Telefónica (founded in 1924) has become one of the world's leading integrated telecommunications operators, with an innovative and attentive spirit and immense technological potential that multiplies its ability to serve its more than 322 million clients (of which more than 246.85 million are mobile phones accesses) in 21 different countries.

As a key player in the new digital universe, Telefónica is a company that is aware of the new challenges posed by today's society. That is why it offers the means to facilitate communication between people, providing them with the most secure, state-of-the-art technology in order for them to live better, and for them to achieve their goals. Telefónica had identified talent and entrepreneurship as key components of the digital revolution. Therefore, the company has launched Telefónica Open Future, a global and open program designed to connect entrepreneurs, startups, investors and public and private organizations from all over the world, which integrates all initiatives to support open innovation and entrepreneurship such as Wayra, Talentum or Think Big as well as investment vehicles like Amérigo and Telefónica Ventures. The objective is to direct innovation towards the development of viable projects, using a model that provides visibility to talent and puts it in contact with organizations, investors and companies that are looking for it through collaboration with China Unicom Open and Tsinghua Holdings Technology and Innovation Open (THTI).

Main achievements in mobile network operation in 2016 have been:

- Increased LTE customers, with net additions of 6.2 million, a customer base 2.1 times greater than that of the previous year and penetration of 19% (+10 percentage points year-on-year)
- Increased LTE network to more than 46,000 sites, providing population coverage at: 86% in Spain, 77% in Germany, 91% in the United Kingdom, 47% in Brazil and 45% in others
- Deployment of solutions auto-optimized (SON-Self Optimizing Networks) to improve the user experience of more than 70 million customers
- The deployment of a mobile radio access solution in the cloud (Cloud RAN) to cover the need for greater mobile traffic capacity in Buenos Aires
- The deployment of mobile rural solution in Peru, with base stations of low cost and consumption which provide mobile coverage using satellite transport
- Best NFV-SDN solution awarded in the "LTE & 5G World Award 2016"

APPENDIX C: ACRONYMS

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation Mobile Networks
64QAM	64-Quadrature Amplitude ModulationUL
AAS	Active Antenna Systems
ACDC	Application Specific Congestion Control for Data Communication
ACS	Adjacent Channel Selectivity
ADC	Application Detection and Control
AESE	Architecture Enhancements for Service Capability Exposure
AF	Application Function
AMF	Access and Mobility Management Function
ANR	Automatic Neighbor Relation
API	Application Program Interface
APs	Access Points
ARPF	Authentication Credential Repository and Processing Function
AUSF	Authentication Server Function
BF	Beamforming
BL	Bandwidth Reduced Low Complexity
BM-SC	Broadcast Multicast Service Center
BS	Base Station
BSSID	Basic Service Set Identification
CA	Carrier Aggregation
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenses
CCA	Clear Channel Assessments
CDMA	Code Division Multiple Access
CELL_PCH	Cell Paging CHannel
CELL_FACH	Cell Forward Access CHannel
CIOT	Cellular IoT
CM	Configuration Management
CMS	Communication and Media Solutions
CN	Core Network
CoMP	Coordinated Multi-Point Transmission and Reception
CRI	CSI-RS Resource Indicator
CS	Circuit Swiched
CSI	Channel State Information
CSI-RS	Channel-State Information Reference Symbol
CTIA	Cellular Telecommunication Industry Association
C-U	Control/ User Plane
C Plane	Control Plane
CUPS	Control and User Plane Separation
D2D	Device-to-Device
DASH	Dynamic Adaptive Streaming Over HTTP
DB	Database/ Dual Band
DB-DC	Dual Band Dual Cell
DC	Dual Connectivity
DC-HSPA	Dual Cell High Speed Packet Access
DCN	Dedicated Core Network
DDN	Downlink Data Notification
DCF	Distributed Coordination Function
DCI	Downlink Control Indicator
DC-HSPA	Dual Carrier-High Speed Packet Access
DCN/DECOR	Dedicated Core Network
DÉCOR	Dedicated Core Networks
DFS	Dynamic Frequency Selection

DL	Downlink
DMRS	Demodulation Reference Signal
DN	Data Network
DPDK	Data Plane Development Kit
DRB	Data Radio Bearer
DRS	Discovery Reference Signals
DSCP	Differentiated Services Codepoint
DRX	Discontinuous Reception
DSMIPv6	Dual Stack-Mobile Internet Protocol version 6
DTLS	Datagram Transport Layer Security
DTX	Discontinuous Transmissions
EBF	Elevation Beam Forming
EC	Enhanced Coverage
ECGI	E-UTRAN Cell Global Identifier
ECM-IDLE	EPS Connection Management IDLE
ED	Energy Detection
eLAA	Enhanced LAA
eLWA	Enhanced LWA
EIRP	Equivalent Isotropic Radiated Power
EIS	Equivalent Isotropic Sensitivity
eMBB	Enhanced Mobile Broadband
eMBMS	Evolved Multimedia Broadcast Multicast Service
EMTC	Enhanced Machine Type Communication
eNodeB	Evolved NodeB
EPC	Evolved Packet Core also known as System Architecture Evolution (SAE)
EPC/SAE	Evolved Packet Core/System Architecture Evolutions
ePDG	Evolved Packet Data Gateway
EPDCCH	Enhanced Physical Downlink Control Channel
EPS	Evolved Packet System
E-RNTI	E-DCH Radio Network Transaction Identifier
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
EVS	Enhanced Voice Services
EVR	Error Vector Magnitude
eV2X	Enhanced V2X
FCC	Federal Communications Commission
FCAPS	Fault, Configuration, Accounting, Performance, Security
FD	Frequency Division
FD	Full Dimension as in FD-MIMO
FDD	Frequency Division Duplex
F-DPCH	Fractional Dedicated Physical Channel
Fe	Further Enhancements
FeICIC	Further Enhanced Inter-Cell Interference Coordination
FFS	Further Study
FM	Fault Management
FNPRM	Further Notice of Proposed Rule Making
FOMA	Freedom of Mobile Multimedia Access
FTA	Free-To-Air
FTL	Frequency Tracking Loop
FTV	Free-to-View
GBR	Guaranteed Bit Rate
GCS AS	Group Communication System Application Server
GGSNs	Gateway GPRS Support Nodes

GHz	Gigahertz
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GROUPE	Group Based Enhancement
GTP	General Packet Radio Service Tunneling Protocol
GTP-C	GPRS Tunneling Protocol - Control
GTP-U	GPRS Tunneling Protocol User Plane
GUMMEI	Globally Unique Mobility Management Entity Identifier
GUTI	Globally Unique Temporary Identify
GW	GateWay
GWCN	GateWay Core Network
HARQ	Hybrid Automatic Retransmission Request
HESSID	Homogeneous Extended Service Set IDentification
HLCom	High Latency Communications
HLR	Home Location Register
HO	Handover
HPLMNs	Home Public Land Mobile Networks
H-RNTI	HS-DSCH Radio Network Transaction Identifier
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA)
HS-SCCH	High Speed Shared Control Channel
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
ICIC	Inter-Cell Interference Coordination
ICS	IMS Centralized Services
ICSCF	Interrogating Cell Session Control Fun -ction
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IFOM	Internet Protocol Flow Mobility and seamless WLAN Offload
IMPI	IP Multimedia Private Identity
IMPU	IP Multimedia Public User identity
IMS	Internet Protocol Multimedia Subsystem
IMT	International Mobile Telecommunications
InH	Indoor Hotspot
IoT	Internet of Things
ISD	Inter-Site Distance
ISG	Information Services Group
ISO	International Standards Organization
ILPC	Inner Loop Power Control
IP	Internet Protocol
ITU	International Telecommunications Union
ITU-T	ITU-Telecommunication Standardization Bureau
KPIs	Key Performance Indicators
LAA	Licensed Assisted Access
LBT	Listen-Before-Talk
L-CWIC	Linear - CodeWord level successive - Interference Cancellation
LCM	Life Cycle Management
LI	Lawful Intercept
LIR	Location Information Request
LSA	Licensed Shared Access
LPWA	Low Power Wide Area
LTE	Long Term Evolution
LTE-U	LTE for Unlicensed Spectrum

4G LTE	Fourth-Generation Long Term Evolution
LWA	LTE Wireless Local Area Network Aggregation
LWIP	LTE-WLAN Radio Level Integration with IPsec Tunnel
LWIPEP	LWIP Encapsulation Protocol
M2M	Machine-to-Machine
MANO	Management Nodes
MBMS	Multimedia Broadcast Multicast Services
MBMS-GW	Multimedia Broadcast Multicast Services – Gateway
MBS	Metropolitan Beacon System
MBSFN	Multicast Broadcast Single Frequency Networks
MCE	Multi-cell/Multicast Coordination Entity
MCG	MeNB Cell Group
MCCH	Needs to be defined in sec 5.5.2
MCPTT	Mission Critical Push-to-Talk
MCOT	Maximum Channel Occupancy Times
MGCF	Media Gateway Control Function
MEC	Mobile Edge Computing
MMEGI	MME Group Identity
MeNB	Macro Evolved NodeB
MIMO	Multiple-Input Multiple-Output
MIOT	Massive Internet of Things
MLB	Mobility Load Balancing
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MO	Mobile Originated
MOCN	Multi-Operator Core Network
MOI	Management Object Instance
MONTE	Monitoring Enhancement
MPDCCH	MTC Physical Downlink Control CHannel
MPS	Multimedia Priority Service
MRO	Mobility Robustness Optimization
MSC-S/MGW	Mobile Switching Center – Server/Media Getaway
MT	Mobile Terminated
MTC	Machine Type Communications
MTC-M2M	Machine Type Communications/Machine-to-Machine
MTC_SIB	Machine Type Communication System Information Block
MU-MIMO	Multi-User Multiple-Input Multiple-Output
MUST	Multi-User Superposition Transmission
MWC	Mobile World Congress
NAIC	Network Assisted Interference Cancellation
NAS	Non-Access Stratum
NBIFOM	Network-Based Internet Protocol Flow Mobility
NB-IoT	Narrowband IoT
NFC	Near Field Communications
NG	Next Generation
NGAP	NG Application Protocol
NGC	Next Generation Core
NGMN	Next Generation Mobile Networks Alliance
NFV	Network Function Virtualization
NPBCH	Narrowband Physical Broadcast Channel

NPDCCH	Narrowband Physical Downlink Control CHannel
NPDSCH	Narrowband Physical Downlink Shared CHannel
NPRACH	Narrowband Physical Random Access CHannel
NPUSCH	Narrowband Physical Uplink Shared CHannel
NPSS	Narrowband Primary Synchronization Signal
NSD	Network Service Descriptors
NSSS	Narrowband Secondary Synchronization Signal
NRS	Narrowband Reference Signal
NR	New Radio
NSWO	Non-Seamless WLAN Offload
OAM	Operations, Administration and Maintenance
OCC	Optical Communication Channel
OCS	Online Charging System
OFCS	Offline Charging System
OFDM	Orthogonal Frequency Division Multiplexing
OEMs	Original Equipment Manufacturers
OMA	Open Mobile Alliance
OoBTC	Out-of-Band Transcoder Control
OPEX	Operating Expenses
OTA	Over-The-Air
OTDOA	Observed Time Difference of Arrival
OTT	Over-the-Top
PBCH	Primary Broadcast Channel
PCC	Policy and Charging Control
PCEF	Policy and Charging Enforcement Function
PCF	Policy Control Function
PCI	Physical Cell ID
PCRF	Policy Control and Charging Rules Function
PC-SCF	Proxy Call Session Control Function
PDCCH	Physical Downlink Control CHannel
PDCP	Packet Data Convergence Protocol
PDN	Public Data Network
PDSCH	Physical Downlink Shared Channel
PDU	Packet Data Unit
P-GW	Public Data Network Gateway
PLMN	Public Land Mobile Network
PM	Performance Management
PMCH	Physical Multicast Channel
PRACH	Physical Random Access CHannel
PCell	Primary Cell
PS	Packet Switched
PSCell	Primary SCell
PSID	Public Service ID
PSM	Power Saving Mode
P-TMSI	Packet Temporary Subscriber Identity Mode
PO	Paging Occasions
ProSe	Proximity Services
ProSe/D2D	Proximity Services / Device to Device
PSD	Power Spectral Density
PSM	Power Saving Mode
PSS/SSS	Primary Synchronization Signal/Secondary Synchronization Signal
PTT	Push-to-Talk
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RACH	Random Access Channel

RADIUS AAA	Remote Authentication Dial In User Service for Authentication, Authorization, and Accounting management for computers to connect and use a network service
RAN	Radio Access Network
RATG	Radio Access Technique Group
RAU	Routing Area Update
REST	Representation State Transfer
RESTful	Representation State Transfer based
RLC	Radio Link Control Layer
RLF	Radio Link Failure
RMa	Rural Macro
R-ML	Reduced Complexity ML
RNC	Radio Network Controller
ROHC	Robust Header Compression
RNTP	Relative Narrowband Tx Power
RPF	Repetition Factor
RRC	Radio Resource Control
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSU	Road Side Unit
RTP	Real-time Transport Protocol
RV	Redundancy Version
Rx	Receive
RXU	Receiver Units
SA	System Architecture
SAND	Server and Network Assisted DASH
SC	Service Continuity
SC-FDMA	Synchronization Channel-Frequency Division Multiple Access
SCG	SeNB Cell Group
SCG	Secondary Cell Group
SCM	Security Context Management
SCEF	Service Capability Exposure Function
SD	Interface between PCRF and TDF
SDN	Software-Defined Networking
SDOs	Standards Development Organization
SDS	Short Data Service
SDU	Service Data Unit
SEA	Security Anchor Function
SEM	Spectrum Emissions Mask
SeGW	Security Gateway
SFN	Single Frequency Network
SGSNs	Serving GPRS Support Nodes
SGW	Serving Gateway
SIB	System Information Block
SIM	Subscriber Identity Module
SIPTO	Selected Internet Protocol Traffic Offload
SLIC	Symbol Level - Interference Cancellation
SM	Spatial Multiplexing
SMi	Suburban Micro
SMARTER Study	Services and Markets Technology Enablers
SMF	Session Management Control Function
SN	Sequence Number
SON	Self-Optimizing or Self-Organizing Network
SRS	Sounding Reference Signal
SRVCC	Single Radio Voice Call Continuity
SSID	Service Set Identification
STA	Station
TA	Tracking Area
TAB	Transceiver Array Boundary
TAS	Telephony Application Server

TAU	Tracking Area Update
TBS	Transport Block Size/Terrestrial Beacon System
TC	Traffic Class
TCCE	TETRA and Critical Communications Evolution
TDD	Time Division Duplex
TDF	Traffic Detection Function
TD-LTE	Time Division LTE
TETRA	Terrestrial Trunked Radio
ToS	Type of Service
TPC	Transmit Power Control
TrFO	Transcoder Free Operation
TDD	Time Division Duplex
Tx	Transmit
TXU	Transmitter Unit
UDM	Unified Data Management
UE	User Equipment
UIC	International Union of Railways
UL	Uplink
Uma	Urban Macro
UMi	Urban Micro
UMTS	Universal Mobile Telecommunication System (also known as WCDMA)
U Plane	User Plane
UPCON	User Plane Congestion Management
UPGW	User Plane Gateway
UPF	User-Plane Function
UpPTS	Uplink Pilot Timeslot
URA_PCH	UTRAN Registration Area Paging Channel
URLLC	Ultra-Reliable Low Latency Communications
USIM	Universal Subscriber Identity Module
UTDOA	Uplink Time Difference of Arrival
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
V2X	Vehicle-to-Everything
VCC	Voice Call Continuity
VNF	Virtualization of Network Functions
VoLTE	Voice-over-LTE
ViLTE	Video over LTE
WI	Work Item
WID	Work Item Description
WebRTC	Web Real-Time Communication
wIMPU	wildcard IMS Public Identity
WLAN	Wireless Local Area Network
WT	WLAN Termination
XnAP	Xn Application Protocol
Xw-C	Xw Control Plane Interface
Xw-AP	Xw Application Protocol
Xw-U	Xw User Plane Interface

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