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5G RADIO ACCESS

CAPABILITIES AND TECHNOLOGIES

The capabilities of 5G wireless access must extend far beyond previous generations of mobile communication. Examples of these capabilities include very high data rates, very low latency, ultra-high reliability, energy efficiency and extreme device densities, and will be realized by the development of LTE in combination with new radio-access technologies. Key technology components include extension to higher frequency bands, access/backhaul integration, device-to-device communication, flexible duplex, flexible spectrum usage, multi-antenna transmission, ultra-lean design, and user/control separation.

WHAT IS 5G?

5G radio access technology will be a key component of the Networked Society. It will address high traffic growth and increasing demand for high-bandwidth connectivity. It will also support massive numbers of connected devices and meet the real-time, high-reliability communication needs of mission-critical applications.

5G will provide wireless connectivity for a wide range of new applications and use cases, including wearables, smart homes, traffic safety/control, critical infrastructure, industry processes and very-high-speed media delivery. As a result, it will also accelerate the development of the Internet of Things.

The overall aim of 5G is to provide ubiquitous connectivity for any kind of device and any kind of application that may benefit from being connected.

5G networks will not be based on one specific radio-access technology. Rather, 5G is a portfolio of access and connectivity solutions addressing the demands and requirements of mobile communication beyond 2020.

The specification of 5G will include the development of a new flexible air interface, NX, which will be directed to extreme mobile broadband deployments. NX will also target high-bandwidth and high-traffic-usage scenarios, as well as new scenarios that involve mission-critical and real-time communications with extreme requirements in terms of latency and reliability.

In parallel, the development of Narrow-Band IoT (NB-IoT) in 3GPP is expected to support massive machine connectivity in wide area applications. NB-IoT will most likely be deployed in bands below 2GHz and will provide high capacity and deep coverage for enormous numbers of connected devices.

Ensuring interoperability with past generations of mobile communications has been a key principle of the ICT industry since the development of GSM and later wireless technologies within the 3GPP family of standards. In a similar manner, LTE will evolve in a way that recognizes its role in providing excellent coverage for mobile users, and 5G networks will incorporate LTE access (based on Orthogonal Frequency Division Multiplexing (OFDM)) along with new air interfaces in a transparent manner toward both the service layer and users.

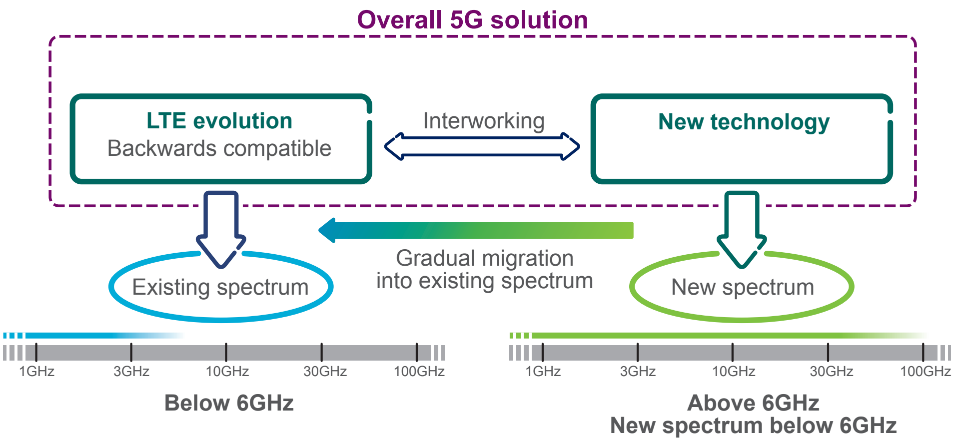

Figure 1: The overall 5G wireless-access solution consisting of LTE evolution and new technology.

Around 2020, much of the available wireless coverage will continue to be provided by LTE, and it is important that operators with deployed 4G networks have the opportunity to transition some – or all – of their spectrum to newer wireless access technologies. For operators with limited spectrum resources, the possibility of introducing 5G capabilities in an interoperable way – thereby allowing legacy devices to continue to be served on a compatible carrier – is highly beneficial and, in some cases, even vital.

At the same time, the evolution of LTE to a point where it is a full member of the 5G family of air interfaces is essential, especially since initial deployment of new air interfaces may not operate in the same bands. The 5G network will enable dual-connectivity between LTE operating within bands below 6GHz and the NX air interface in bands within the range 6GHz to100GHz. NX should also allow for user-plane aggregation, i.e. joint delivery of data via LTE and NX component carriers.

This paper explains the key requirements and capabilities of 5G, along with its technology components and spectrum needs.

5G – REQUIREMENTS AND CAPABILITIES

In order to enable connectivity for a very wide range of applications with new characteristics and requirements, the capabilities of 5G wireless access must extend far beyond those of previous generations of mobile communication. These capabilities will include massive system capacity, very high data rates everywhere, very low latency, ultra-high reliability and availability, very low device cost and energy consumption, and energy-efficient networks.

MASSIVE SYSTEM CAPACITY

Traffic demands for mobile-communication systems are predicted to increase dramatically [1] [2]. To support this traffic in an affordable way, 5G networks must deliver data with much lower cost per bit compared with the networks of today. Furthermore, the increase in data consumption will result in an increased energy footprint from networks. 5G must therefore consume significantly lower energy per delivered bit than current cellular networks.

The exponential increase in connected devices, such as the deployment of billions of wirelessly connected sensors, actuators and similar devices for massive machine connectivity, will place demands on the network to support new paradigms in device and connectivity management that do not compromise security. Each device will generate or consume very small amounts of data, to the extent that they will individually, or even jointly, have limited impact on the overall traffic volume. However, the sheer number of connected devices seriously challenges the ability of the network to provision signaling and manage connections.

VERY HIGH DATA RATES EVERYWHERE

Every generation of mobile communication has been associated with higher data rates compared with the previous generation. In the past, much of the focus has been on the peak data rate that can be supported by a wireless-access technology under ideal conditions. However, a more important capability is the data rate that can actually be provided under real-life conditions in different scenarios.

- 5G should support data rates exceeding 10Gbps in specific scenarios such as indoor and dense outdoor environments.
- Data rates of several 100Mbps should generally be achievable in urban and suburban environments.
- Data rates of at least 10Mbps should be accessible almost everywhere, including sparsely-populated rural areas in both developed and developing countries.

VERY LOW LATENCY

Very low latency will be driven by the need to support new applications. Some envisioned 5G use cases, such as traffic safety and control of critical infrastructure and industry processes, may require much lower latency compared with what is possible with the mobile-communication systems of today.

To support such latency-critical applications, 5G should allow for an application end-to-end latency of 1ms or less, although application-level framing requirements and codec limitations for media may lead to higher latencies in practice. Many services will distribute computational capacity and storage close to the air interface. This will create new capabilities for real-time communication and will allow ultra-high service reliability in a variety of scenarios, ranging from entertainment to industrial process control.

ULTRA-HIGH RELIABILITY AND AVAILABILITY

In addition to very low latency, 5G should also enable connectivity with ultra-high reliability and ultra-high availability. For critical services, such as control of critical infrastructure and traffic safety, connectivity with certain characteristics, such as a specific maximum latency, should not merely be ‘typically available.’ Rather, loss of connectivity and deviation from quality of service requirements must be extremely rare. For example, some industrial applications might need to guarantee successful packet delivery within 1 ms with a probability higher than 99.9999 percent.

VERY LOW DEVICE COST AND ENERGY CONSUMPTION

Low-cost, low-energy mobile devices have been a key market requirement since the early days of mobile communication. However, to enable the vision of billions of wirelessly connected sensors, actuators and similar devices, a further step has to be taken in terms of device cost and energy consumption. It should be possible for 5G devices to be available at very low cost and with a battery life of several years without recharging.

ENERGY-EFFICIENT NETWORKS

While device energy consumption has always been prioritized, energy efficiency on the network side has recently emerged as an additional KPI, for three main reasons:

- Energy efficiency is an important component in reducing operational cost, as well as a driver for better dimensioned nodes, leading to lower total cost of ownership.
- Energy efficiency enables off-grid network deployments that rely on medium-sized solar panels as power supplies, thereby enabling wireless connectivity to reach even the most remote areas.
- Energy efficiency is essential to realizing operators’ ambition of providing wireless access in a sustainable and more resource-efficient way.

The importance of these factors will increase further in the 5G era, and energy efficiency will therefore be an important requirement in the design of 5G wireless access.

MACHINE-TYPE COMMUNICATION

Fundamentally, applications such as mobile telephony, mobile broadband and media delivery are about information for humans. In contrast, many of the new applications and use cases that drive the requirements and capabilities of 5G are about end-to-end communication between machines. To distinguish them from the more human-centric wireless-communication use cases, these applications are often termed machine-type communication (MTC).

Although spanning a wide range of applications, MTC applications can be divided into two main categories – massive MTC and critical MTC – depending on their characteristics and requirements.

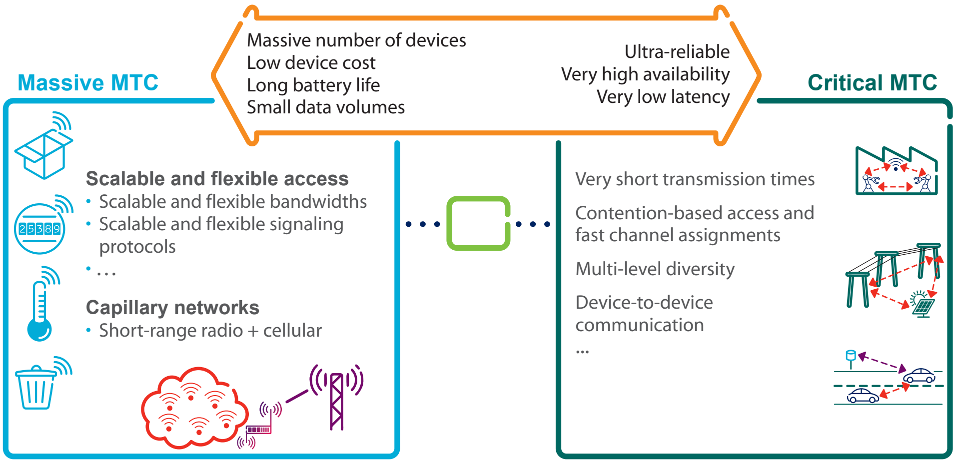

Figure 2: Massive MTC and critical MTC.

Massive MTC refers to services that typically span a very large numbers of devices, usually sensors and actuators. Sensors are extremely low cost and consume very low amounts of energy in order to sustain long battery life. Clearly, the amount of data generated by each sensor is normally very small, and very low latency is not a critical requirement. While actuators are similarly limited in cost, they will likely have varying energy footprints ranging from very low to moderate energy consumption.

Sometimes, the mobile network may be used to bridge connectivity to the device by means of capillary networks. Here, local connectivity is provided by means of a short-range radio access technology, for example Wi-Fi, Bluetooth [3] or 802.15.4/6LoWPAN [4]. Wireless connectivity beyond the local area is then provided by the mobile network via a gateway node.

Critical MTC refers to applications such as traffic safety/control, control of critical infrastructure and wireless connectivity for industrial processes. Such applications require very high reliability and availability in terms of wireless connectivity, as well as very low latency. On the other hand, low device cost and energy consumption is not as critical as for massive MTC applications. While the average volume of data transported to and from devices may not be large, wide instantaneous bandwidths are useful in being able to meet capacity and latency requirements.

There is much to gain from a network being able to handle as many different applications as possible, including mobile broadband, media delivery and a wide range of MTC applications by means of the same basic wireless-access technology and within the same spectrum. This avoids spectrum fragmentation and allows operators to offer support for new MTC services for which the business potential is inherently uncertain, without having to deploy a separate network and reassign spectrum specifically for these applications.

SPECTRUM FOR 5G

In order to support increased traffic capacity and to enable the transmission bandwidths needed to support very high data rates, 5G will extend the range of frequencies used for mobile communication. This includes new spectrum below 6GHz, as well as spectrum in higher frequency bands.

Specific candidate spectrum for mobile communication in higher frequency bands is yet to be identified by the ITU-R or by individual regulatory bodies. The mobile industry remains agnostic about particular choices, and the entire frequency range up to approximately 100GHz is under consideration at this stage, although there is significant interest in large contiguous allocations that can provide dedicated and licensed spectrum for use by multiple competing network providers.

The lower part of this frequency range, below 30GHz, is preferred from the point of view of propagation properties. At the same time, very large amounts of spectrum and the possibility of wide transmission frequency bands of the order of 1GHz or more are more likely above 30GHz.

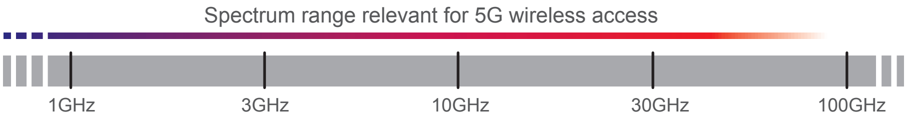

Figure 3: Spectrum relevant for 5G wireless access.

Spectrum relevant for 5G wireless access therefore ranges from below 1GHz up to approximately 100GHz, as Figure 3 shows.

It is important to understand that high frequencies, especially those above 10GHz, can only serve as a complement to lower frequency bands, and will mainly provide additional system capacity and very wide transmission bandwidths for extreme data rates in dense deployments. Spectrum allocations at lower bands will remain the backbone for mobile-communication networks in the 5G era, providing ubiquitous wide-area connectivity.

The World Radio Conference (WRC)-15 discussions have resulted in an agreement to include an agenda item for IMT-2020, the designated ITU-R qualifier for 5G, in WRC-19. The conference also reached agreement on a set of bands that will be studied for 5G, with direct applicability to NX. Many of the proposed bands are in the millimeter wave region and include:

- 24.25GHz to 27.5GHz, 37GHz to 40.5GHz, 42.5GHz to 43.5GHz, 45.5GHz to 47GHz, 47.2GHz to 50.2GHz, 50.4GHz to 52.6GHz, 66 GHz to 76GHz and 81GHz to 86GHz, which have allocations to the mobile service on a primary basis; and
- 31.8GHz to 33.4GHz, 40.5GHz to 42.5GHz and 47GHz to 47.2GHz, which may require additional allocations to the mobile service on a primary basis.

The mobile industry will strive to gain access to spectrum in the 6GHz to 20GHz range, but the policy directions being followed by regulators seem to be focused on frequency bands above 30GHz. In the US, the FCC has issued two Notices of Public Rule Making (NPRM) on bands above 24GHz. Ofcom has likewise indicated a preference for bands above 30GHz within the mobile industry.

The capacity needs of the mobile industry will continue to be served by licensed spectrum, although novel sharing arrangements for spectrum will become progressively more important as restricted opportunities for new spectrum start to impact incumbent services such as satellite communication and radio location. Two examples of sharing arrangements include LSA planned in Europe for the 2.3GHz band and the Citizens Band Radio Service for 3.5GHz in the US.

5G TECHNOLOGY COMPONENTS

Beyond extending operation to higher frequencies, there are several other key technology components relevant for the evolution to 5G wireless access. These components include access/backhaul integration, device-to-device communication, flexible duplex, flexible spectrum usage, multi-antenna transmission, ultra-lean design, and user/control separation.

ACCESS/BACKHAUL INTEGRATION

Wireless technology is already frequently used as part of the backhaul solution. Such wireless-backhaul solutions typically operate under line-of-sight conditions using proprietary radio technology in higher frequency bands, including the millimeter wave (mmW) band.

In the future, the access (base-station-to-device) link will also extend to higher frequencies. Furthermore, to support dense low-power deployments, wireless backhaul will have to extend to cover non-line-of-sight conditions, similar to access links.

In the 5G era, the wireless-access link and wireless backhaul should not therefore be seen as two separate entities with separate technical solutions. Rather, backhaul and access should be seen as an integrated wireless-access solution able to use the same basic technology and operate using a common spectrum pool. This will lead to more efficient overall spectrum utilization as well as reduced operation and management effort.

DIRECT DEVICE-TO-DEVICE COMMUNICATION

The possibility of limited direct device-to-device (D2D) communication has recently been introduced as an extension to the LTE specifications. In the 5G era, support for D2D as part of the overall wireless-access solution should be considered from the start. This includes peer-to-peer user-data communication directly between devices, but also, for example, the use of mobile devices as relays to extend network coverage.

D2D communication in the context of 5G should be an integral part of the overall wireless-access solution, rather than a stand-alone solution. Direct D2D communication can be used to offload traffic, extend capabilities and enhance the overall efficiency of the wireless-access network. Furthermore, in order to avoid uncontrolled interference to other links, direct D2D communication should be under network control. This is especially important for the case of D2D communication in licensed spectrum.

FLEXIBLE DUPLEX

Frequency Division Duplex (FDD) has been the dominating duplex arrangement since the beginning of the mobile communication era. In the 5G era, FDD will remain the main duplex scheme for lower frequency bands. However, for higher frequency bands – especially above 10GHz – targeting very dense deployments, Time Division Duplex (TDD) will play a more important role.

In very dense deployments with low-power nodes, the TDD-specific interference scenarios (direct base-station-to-base-station and device-to-device interference) will be similar to the 'normal' base-station-to-device and device-to-base-station interference that also occurs for FDD.

Furthermore, for the dynamic traffic variations expected in very dense deployments, the ability to dynamically assign transmission resources (time slots) to different transmission directions may allow more efficient utilization of the available spectrum.

To reach its full potential, 5G should therefore allow for very flexible and dynamic assignment of TDD transmission resources. This is in contrast to current TDD-based mobile technologies, including TD-LTE, for which there are restrictions on the downlink/uplink configurations, and for which there typically exist assumptions about the same configuration for neighbor cells and also between neighbor operators.

FLEXIBLE SPECTRUM USAGE

Since its inception, mobile communication has relied on spectrum licensed on a per-operator basis within a geographical area. This will remain the foundation for mobile communication in the 5G era, allowing operators to provide high-quality connectivity in a controlled-interference environment.

However, per-operator licensing of spectrum will be complemented with the possibility to share spectrum. Such sharing may be between a limited set of operators, or may occur in license-exempt scenarios. The

Citizens Band Radio Service in the US in the 3.5GHz band and the 5GHz unlicensed spectrum are examples of managed and unlicensed sharing regimes respectively.

New air interfaces like NX will likely be well served by more conventional licensed allocations of spectrum, mainly due to the need to establish a basic foundation for the technology to operate in an independent manner while interoperability is established with technologies like LTE. At some point, further allocations of spectrum for 5G may leverage the mobile industry's experience of sharing approaches in lower cellular bands.

MULTI-ANTENNA TRANSMISSION

Multi-antenna transmission already plays an important role in current generations of mobile communication and will be even more central in the 5G era, due to the physical limitations of small antennas. Path loss between a transmitter and receiver does not change as a function of frequency, as long as the effective aperture of the transmitting and receiving antennas does not change. The antenna aperture does reduce in proportion to the square of the frequency, and that reduction can be compensated by the use of higher antenna directivity. The 5G radio will employ hundreds of antenna elements to increase antenna aperture beyond what may be possible with current cellular technology.

In addition, the transmitter and receiver will use beamforming to track one another and improve energy transfer over an instantaneously configured link. Beamforming will also improve the radio environment by limiting interference to small fractions of the entire space around a transmitter and likewise limiting the impact of interference on a receiver to infrequent stochastic events. The use of beamforming will also be an important technology for lower frequencies; for example, to extend coverage and to provide higher data rates in sparse deployments.

ULTRA-LEAN DESIGN

Ultra-lean radio-access design is important to achieve high efficiency in 5G networks. The basic principle of ultra-lean design can be expressed as: minimize any transmissions not directly related to the delivery of user data. Such transmissions include signals for synchronization, network acquisition and channel estimation, as well as the broadcast of different types of system and control information.

Ultra-lean design is especially important for dense deployments with a large number of network nodes and highly variable traffic conditions. However, lean transmission is beneficial for all kinds of deployments, including macro deployments.

By enabling network nodes to enter low-energy states rapidly when there is no user-data transmission, ultra-lean design is an important component in delivering high network energy performance. Ultra-lean design will also enable higher achievable data rates by reducing interference from non-user-data-related transmissions.

USER/CONTROL SEPARATION

Another important design principle for 5G is to decouple user data and system control functionality. The latter includes the provisioning of system information; that is, the information and procedures needed for a device to access the system.

Such a decoupling will allow separate scaling of user-plane capacity and basic system control functionality. For example, user data may be delivered by a dense layer of access nodes, while system information is only provided via an overlaid macro layer on which a device also initially accesses the system.

It should be possible to extend the separation of user data delivery and system control functionality over multiple frequency bands and RATs. As an example, the system control functionality for a dense layer based on new high-frequency radio access could be provided by means of an overlaid LTE layer.

User/control separation is also an important component for future radio-access deployments relying heavily on beamforming for user data delivery. Combining ultra-lean design with a logical separation of user-plane data delivery and basic system connectivity functionality will enable a much higher degree of device-centric network optimization of the active radio links in the network. Since only the ultra-lean signals related to the system control plane need to be static, it is possible to design a system where almost everything can be dynamically optimized in real time.

An ultra-lean design combined with a system control plane logically separated from the user data delivery function also provides higher flexibility in terms of evolution of the RAT as, with such separation, the user plane can evolve while retaining system control functionality.

CONCLUSION

5G is the next step in the evolution of mobile communication and will be a key component of the Networked Society. In particular, 5G will accelerate the development of the Internet of Things. To enable connectivity for a wide range of applications and use cases, the capabilities of 5G wireless access must extend far beyond those of previous generations of mobile communications.

These capabilities include very high achievable data rates, very low latency and ultra-high reliability. Furthermore, 5G wireless access needs to support a massive increase in traffic in an affordable and sustainable way, implying a need for a dramatic reduction in the cost and energy consumption per delivered bit.

5G wireless access will be realized by the evolution of LTE for existing spectrum in combination with new radio access technologies that primarily target new spectrum. Key technology components of 5G wireless access include access/backhaul integration, device-to-device communication, flexible duplex, flexible spectrum usage, multi-antenna transmission, ultra-lean design, and user/control separation.

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GLOSSARY

D2D	device-to-device
FDD	Frequency Division Duplex
mmW	millimeter wave
MTC	Machine-Type Communication
NPRM	Notices of Public Rule Making
OFDM	Orthogonal Frequency Division Multiplexing
TDD	Time Division Duplex
WRC	World Radio Conference