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5G radio access

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Each generation of mobile communication, from the first-generation introduced in the 1980s to the 4G networks launched in recent years, has had a significant impact on the way people and businesses operate. The next generation – 5G – is a technology solution for 2020 and beyond that will give users – anyone or anything – access to information and the ability to share data anywhere, anytime.

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Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platforms that provide numerous services, and support countless applications used by billions of people around the world.

The rapid growth of mobile communication and equally massive advances in technology are moving technology evolution and the world toward a fully connected networked society – where access to information and data sharing are possible anywhere, anytime, by anyone or anything. And yet despite the great strides that have already been made, the journey has just begun.

Future wireless access will extend beyond people, to support connectivity for anything that may benefit from being connected. A vastly diverse range of things can be connected, everything from household appliances, to medical equipment, individual belongings, and everything in between. To manage all these connected things, a wide range of new functions will be needed.

So, in comparison with the wireless networks of today, next generation systems will need to support a much wider range of use-case characteristics and adhere to a much more complex range of access requirements.

Next-generation mobile communication systems will become commercially available sometime around 2020. To make this possible, a significant amount of research is ongoing all over the globe – METIS[1] is a good example.

The main challenges and many key technology components of 5G radio-access have already been identified, but research activities will continue for a few more years before standardization and commercialization begins.

Based on extrapolations of different predictions[2,3], it is possible to conclude that beyond 2020, wireless communication systems will support more than 1,000 times today's traffic volume. And so by the time commercialization starts, traffic demands will have increased significantly. If wireless networks are going to carry this traffic load in an affordable and sustainable way, cost and energy consumption per bit need to be radically lower than they are today.

BOX A Terms and abbreviations

D2D	device-to-device
METIS	Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society
MIMO	multiple-input, multiple-output
mmW	millimeter wave
MTC	machine-type communication
NFV	Network Functions Virtualization
OFDM	orthogonal frequency division multiplexing
RAT	radio-access technology
RF	radio frequency
SDN	software-defined networking
TDD	time division duplex
WRC	World Radiocommunication Conference

As was the case for 3G and 4G, provisioning higher data rates will continue to be a key driver in network development and evolution. For some specific environments, such as indoor offices and campus-like locations, next-generation wireless-access networks will need to support data rates around 10Gbps. For urban and suburban environments, rates over 100Mbps should be generally available, and several Mbps should be the baseline essentially everywhere else – including distant rural and deep indoor environments.

Demands for greater capacity and higher data rates are just two of the many factors influencing the evolution of wireless access technologies. The impact of other aspects **(Figure 1)** like energy consumption, device cost, spectrum and latency will be fundamental to the success of future networks.

Built on a vision of massive machine-type connectivity, with tens of billions of low-cost connected devices and sensors deployed, the Networked Society requires the mass-availability of truly low-cost devices. These devices not only need to be affordable, they also need to be able to operate on battery for several years without needing to be re-charged – implying strict requirements for low energy consumption.

Full support for mission-critical machine-type applications will require ultra-reliable connectivity with guaranteed availability and reliability-of-service.

Although the level of access latency offered by LTE is sufficient for most mobile-broadband applications, it may however, not be enough for latency-critical applications such as traffic safety, infrastructure protection, or some of the emerging industrial internet applications. To ensure support for this kind of mission-critical machine-type connectivity, next-generation wireless access should support latencies around 1ms.

In short, at any given time next-generation networks will be able to support some or all of the following features: ultra-high data rates, extremely low latency, massive numbers of connected devices, very high volumes of data transfer, low cost devices, ultra-low energy consumption, and exceptionally high reliability.

Implementing 5G

Of all of the aspects influencing how 5G networks will manage the expected traffic increases, additional spectrum for mobile wireless communication is one of the most critical. The 2015 World Radiocommunication Conference (WRC-15)[4] will focus on the allocation of additional spectrum below 6.5GHz for use by mobile communication.

However, to fulfill long-term traffic demands, and perhaps even more important, to enable the very wide transmission bandwidths needed to provide multi-Gbps data rates efficiently, the range of operation for next-generation wireless access needs to be extended into higher frequencies above 10GHz – an agenda item for WRC-19.

The entire spectrum from 10GHz up to 100GHz – which is well into the millimeter wave (mmW) range – is being considered for use by 5G mobile communication systems. As such, any research and concept development carried out in relation to 5G wireless access will need to cater for the entire spectrum: from below 1GHz up to and including mmW frequency bands.

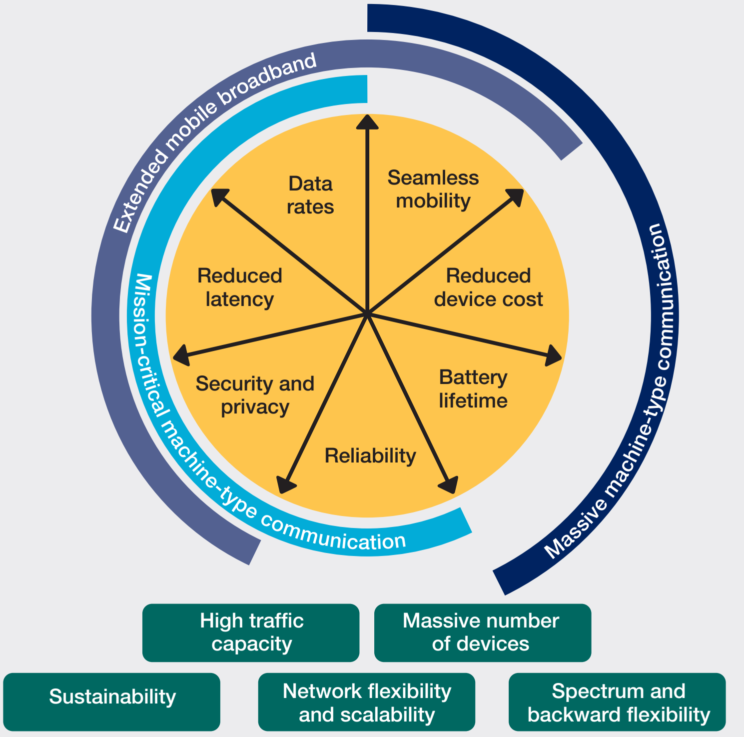
Using one radio-interface structure to address such a wide range of frequencies is probably not the best approach. As illustrated in **Figure 2**, propagation characteristics, implementation aspects, and compatibility issues (required for certain frequency bands) change with frequency, and as such the overall 5G wireless-access solution will most likely consist of multiple well-integrated radio-interface solutions.

Up to a certain frequency range, the radio interface can be built using the same design principles adopted by current cellular technologies, including support for full-area coverage and relying on, for example, high-performance RF technology. An OFDM-based transmission technology will still be a good baseline in these cases, although the detailed numerology will probably need to be adjusted to match frequencies above 10GHz.

However, for higher frequency bands – a few tens of GHz and above – propagation characteristics and implementation aspects speak in favor of a more simplified radio-interface structure targeting short-range communication for ultra-dense deployments. This simplification relaxes the requirements on equipment such as RF parts, however, applying OFDM-based transmission technology may not be the best choice for this frequency range.

By the time next-generation wireless access reaches the market, LTE will be heavily deployed in licensed spectrum below 6.5GHz. To introduce wide-area 5G capabilities smoothly, retaining compatibility with LTE for these frequency bands is highly desirable, as it supports coexistence with existing legacy LTE devices.

FIGURE 1 5G use cases and main corresponding challenges



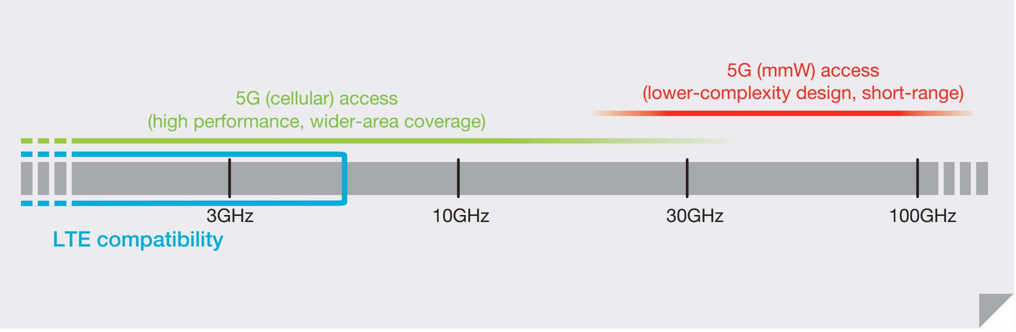
Technical solutions

Advanced antenna solutions

If future network generations are to meet the envisioned requirements in terms of traffic capacity and achievable data rates, several technology components need to be in place. Advanced antenna solutions with multiple antenna elements, including beamforming and spatial multiplexing, are just some examples of the technologies that can be used to achieve high data rates and greater capacity.

Beamforming, which focuses radio transmission from multiple antenna elements using narrow beams, reduces interference and improves overall system performance. Spatial multiplexing exploits propagation properties to provide multiple data streams to one or more terminals simultaneously. These techniques are already integral parts of LTE but their full potential remains to be unleashed, and they are set

FIGURE 2 **5G wireless access in relation to spectrum**



to play an even bigger role in future systems.

At higher frequency bands, where networks are yet to be deployed, propagation conditions are more challenging than what is routinely observed today. Higher diffraction loss and outdoor-to-indoor losses lead to link budgets that are challenging to meet. The output power of equipment, particularly mobile terminals, may for regulatory reasons be more limited at higher frequency bands. As such, these bands are best suited for dense network deployments in highly populated areas such as city centers, airports, train stations, shopping malls and indoor offices. Extensive use of beamforming (in particular at the base station) as a tool to improve link budgets is an essential part of wireless-access networks operating at very high frequencies.

The errors from a large number of RF chains tend to cancel each other out. As such, advanced antenna solutions that include a substantial number of antenna elements (commonly referred to as massive MIMO) can be used to reduce the impact of RF imperfections and control the way interference is distributed in a network.

Ultra-lean design

Current cellular systems transmit reference signals and broadcast system information on a continuous – always-on – basis. As networks become denser and include more and more nodes, such high levels of transmission are not desirable, as this not only increases the amount of interference, it also increases energy consumption.

Cutting always-on transmissions to a bare minimum, so that communication only occurs when there is user data to deliver, allows the transmitter to dynamically – on a millisecond basis – switch off and be silent. Such ultra-lean transmission results in enhanced network energy efficiency and higher achievable user data rate rates due to reduced interference levels. Ultra-lean is a key design principle and a critical enabler for highly dense local-area deployments, without which user experience would be interference-limited even at low-to-medium traffic loads. In a heterogeneous deployment, system information can be broadcast from the overlaid nodes, which enables the underlying nodes to benefit from ultra-lean transmission.

Spectrum flexibility

Traditionally, cellular systems have been deployed exclusively in licensed spectrum. The licensing approach currently plays – and will continue to do so in the future – an important role in controlling interference and guaranteeing coverage. However, especially at higher frequency bands, future systems should support a higher degree of spectrum flexibility. Unlicensed spectrum, for example, can be used to boost capacity, preferably in combination with licensed spectrum for critical control signaling and mobility handling. Flexibility can also be improved through for example authorized-shared access, in which the cellular system can access additional spectrum otherwise apportioned for use by other (non-telecom) services.

Using unpaired spectrum allocations is likely to be more common when large amounts of contiguous spectrum are needed – especially at higher frequency bands. Traditionally, TDD with a more or less static split between uplink and downlink has been used to exploit unpaired spectrum for mobile communication. However, flexible duplex, in which spectrum resources are dynamically assigned to downlink and uplink, enables transmission up to the full bandwidth to be used momentarily in either direction and is a better fit for dynamic traffic conditions. Flexible duplex is particularly suitable for small-cell deployments in which terminal and network transmission power are similar, and strict isolation of the uplink and downlink across cell borders is less important. Full-duplex communication with simultaneous transmission and reception on the same carrier can also be applied if appropriate interference-cancellation techniques are available.

Low latency

Latency over the radio link can be lowered by reducing transmission-time intervals and spreading data over frequency rather than time. To complement this approach, the radio interface should be designed for fast data detection at the receiver. To avoid a scheduling request-grant phase prior to data transmission, the medium-access control should allow for immediate access, which can be achieved by providing instant-access resource allocations dimensioned so that collision risks can be minimized.

For some use cases, such as emergency services, low-latency communication is required between devices that are in close proximity to each other. In this case a direct device-to-device (D2D) communication link may further reduce the latency.

Emerging use cases, like mission-critical machine-type communication (MTC), can require a guaranteed low latency at an extremely high level of reliability. One way to meet such stringent requirements is to maintain multiple connectivity links.

Convergence of access and backhaul

Providing high-capacity backhaul to all network nodes is challenging, particularly in dense deployments. One attractive alternative to deploying optical fibers is wireless backhaul, particularly at higher frequency bands where more spectrum is available. In combination with extensive beamforming and low-latency transmission the additional spectrum makes this approach viable.

Traditionally, there has been a fundamental division between access and backhaul links of spectrum resources. In future systems, the divide should partly diminish, and overall design should no longer need to make a major distinction between the two. Wireless connectivity between radio-network nodes and the rest of the network simplifies deployment – especially in dense deployments that have large numbers of nodes.

In a converged scenario, the same wireless-access technology can be used for both the access and the backhaul link, making more efficient use of spectrum resources as they can be shared dynamically. Using the same wireless access technology also means that the same operation and maintenance systems can be used for both links.

Billions of connected devices

In the transition to the Networked Society, a massive number of devices will be connected to networks. These devices are characterized by their simplicity, the fact that they transmit very small amounts of data from time to time, and will often be embedded into the fabric of the environment. They will tend to be built using lightweight radio-module designs and use communication modes that are streamlined to match their relaxed communication requirements. Such devices are able to operate for years on a single battery charge and low cost connectivity is a key enabler.

The aim is zero-overhead communication, which can be achieved by simplifying connectivity states and providing channel access with minimal signaling. Allowing devices to sleep – switch off their radio circuitry – at every opportunity minimizes energy consumption and leads to longer battery lifetimes.

These small devices can be located anywhere from inside a refrigerator in an urban city center to remote locations with challenging RF conditions and severe path loss. To provide connectivity at the low rates typically required, optional transmission modes should be used with control channels that provide the required robustness efficiently. Communication for machine-type devices will typically take place at frequency bands below 3GHz and often even below 1GHz, where a large number of deployed cellular-communication legacy systems will operate for some time to come. Therefore, spectrum-compatible radio design is highly important to ensure the best coexistence possible with legacy wireless-access technologies.

Overall architecture

The high-level 5G architecture, including radio-access and common-core functionality (to support fixed, 5G, as well as well as legacy radio access) is illustrated in **Figure 3**. The architecture is supported by common 5G network-management and transport functionality.

The key architecture challenge here is integrating the different 5G RATs and associated technologies to provide:

- users with effortless and seamless mobility as they transition from one RAT to another; and
- operators with a single and integrated access network characterized by high resource efficiency (pooled radio and network resources) and excellent user performance (access aggregation when applicable).

The integrated access-network approach is important for efficient operation and management, reducing opex and providing simple migration paths to increase network performance. Efficient integration of 5G RATs is rooted in multi-connectivity solutions, where terminals are connected to several 5G RATs or frequency bands simultaneously. Multiple connectivity not only supports simultaneous data transmission and reception, it also serves as a quick failover method when connection to one layer is lost.

The key architecture challenges for a common 5G core network are:

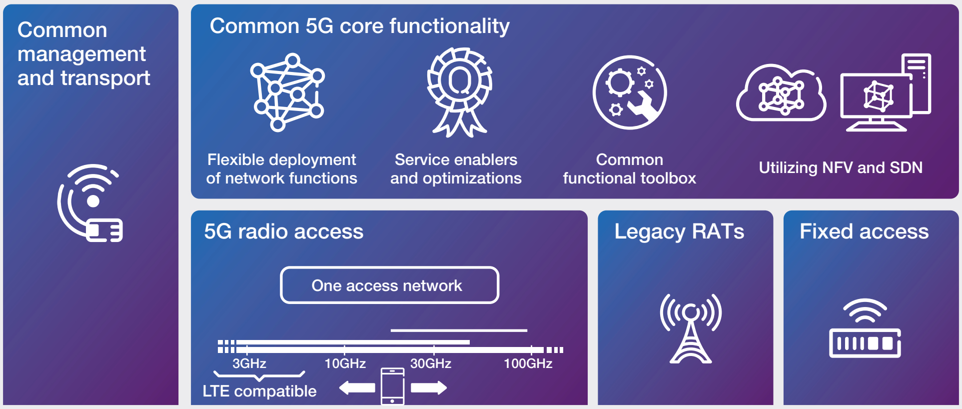
- the ability to address new 5G use cases that are not currently addressed by cellular networks – such as critical machine-type communications and ultra-low latency applications; and
- providing support for optimization of existing use cases – such as media distribution, indoor networks, and machine-type communication.

Supporting these different use cases will probably lead to an increased need for flexibility in how network functions and service-layer enablers are deployed and operated in the network.

For example, in some scenarios it might be necessary to deploy core network and service-layer functions closer to the radio access to provide excellent end-to-end latency performance and support local communication among users at the same site.

In another scenario, parts of the network are be shared with other operators, an enterprise or even the site owner – these shared parts need to be integrated with the rest of the operator

FIGURE 3 **High-level 5G architecture**



network in a flexible and seamless way. Network sharing generates strict security requirements that require solutions to support separation of networks and users to different security domains. The 5G core network will most probably utilize the ongoing evolution in SDN and NFV to provide a high level of flexibility and scalability when supporting different 5G deployments with a common toolbox of network functions.

The evolved 5G network should provide service enablers and optimization functions that can bring additional benefits for network integrated services. Service enablers could, for example, include mechanisms to reduce battery consumption for MTC devices, either by supporting reduced overhead and longer sleep cycles or by providing a higher degree of reliability for critical MTC communication. Other service enablers or optimization functions could include support for more efficient media distribution.

Summary

Next generation – 5G – wireless systems will be commercially available around 2020, enabling the communication needs of the Networked Society, providing access to information and sharing of data anywhere, anytime by anyone or anything. Different use cases for 5G systems will range from enhanced mobile broadband to a number of new use cases, including massive MTC and mission-critical MTC. The requirements of the different use cases span a wide range of traditional mobile-broadband performance metrics (such as achievable data rates and traffic capacity) as well as new requirements related to reliability, support for massive numbers of devices and latency.

To address this wide range of requirements different technology components are needed, which include techniques that are backward compatible with LTE, as well as some more radical techniques. Some of the key components include advanced antenna solutions, ultra-lean design, and spectrum flexibility including the use of higher frequencies.

Depending on the requirements on the network deployment and on the design of the radio interface, the radio access can either be similar to current cellular access (5G cellular access), or focus more on low complexity and short-range deployments (5G mm-wave access). To fully meet the requirements for the 5G system, both access types are likely to be needed.

The overall network architecture should support both enhanced MBB well as the new use cases efficiently. It should also integrate 5G cellular and mm-wave accesses as well as the legacy RATs and fixed access to a single system, and provide effortless and seamless mobility when transitioning from one RAT to another. ◆

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