

# 5G masterplan – five keys to create the new communications era

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## 1. 5G: More than just new radio, more than just business as usual

5G is the new generation of radio systems and network architecture that will deliver extreme broadband, ultra-robust, low latency connectivity and massive networking for human beings and the Internet of Things. Enabled by 5G, the programmable world will transform our individual lives, economy and society. It sounds like a bold claim but the reality is starting to take shape as 5G research pushes ahead to make rapid developments.

5G will be far more than just a new radio technology. It will combine existing Radio Access Technologies (RATs) in both licensed and unlicensed bands, and it will add novel RATs optimized for specific bands and deployments, scenarios and use cases. 5G will also implement a radically new network architecture based on Network Function Virtualization (NFV) and Software Defined Networking (SDN) technologies. Programmability will be central to achieving the hyper-flexibility that operators will need to support the new communications demands placed on them from a wide array of users, machines, companies from different industries and other organizations such as municipalities. 5G networks will have to be programmable, software driven and managed holistically to enable a diverse and profitable range of services.

5G is a door opener for new possibilities and use cases, many of which are as yet unknown.

Nokia and the wider telecommunications industry are already well along the road to 5G. Nokia has run several proofs of concept for most of the key elements that will form the future 5G standard and is already preparing 5G for commercial reality.

### 1.1 Five keys to 5G

Nokia Networks has identified five key aspects that describe the transformation of today's communications to the 5G era. Together these five areas outline how 5G will come about, what it will be, the way it will be built and how it will affect all our lives.

- Possibilities defines the new demands that 5G must support and the new opportunities it will create
- Versatile radio explores the different radio access technologies that will combine to provide ultra-flexible connectivity
- System of systems sets out the network architecture that will be needed, how it will support the new demands and provide the great experiences and solid security that people and industries will expect

- Practicalities proposes the key stages of 5G development and how operators will be able to roll out networks in the most efficient ways
- Potential describes how the new 5G communications era will transform people's everyday lives, multiple industries and the entire business of being a communications provider

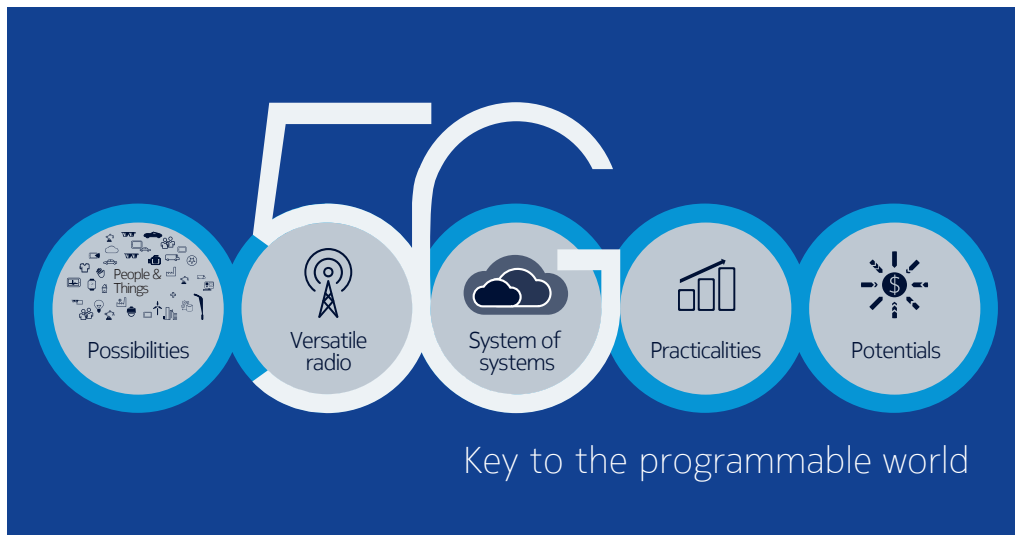


Figure 1. Five key aspects that will describe the transformation of today's communications to 5G

## 1.2 Heterogeneous use cases – diverse requirements

The biggest difference between 5G and legacy design requirements is the diversity of use-cases that 5G networks must support compared to today's networks that were designed primarily to deliver high speed mobile broadband. However, 5G will be about people and things that can be broadly split into three use-case categories:

- Massive broadband that delivers gigabytes of bandwidth on demand
- Critical machine-type communication (MTC) that demands immediate, synchronized eye-to-hand feedback to remotely control robots and deliver the tactile Internet
- Massive MTC that connects billions of sensors and machines

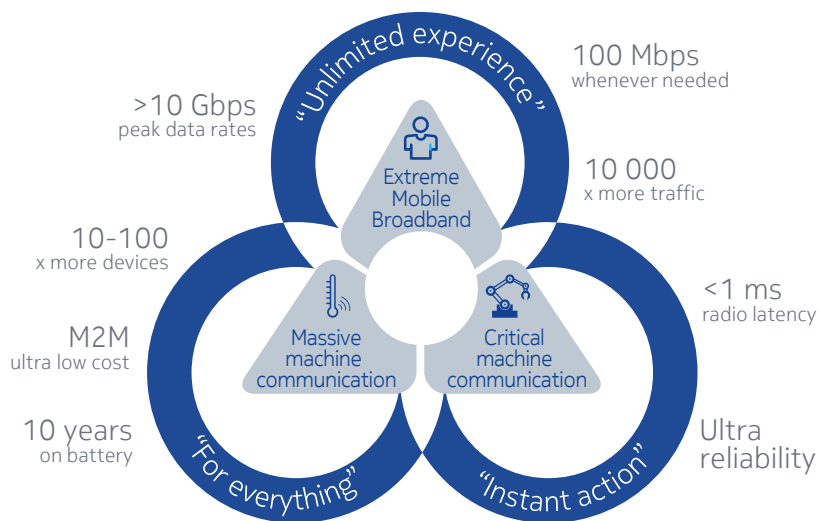


Figure 2. Heterogeneous use cases – diverse requirements

Reliability will be another key design principle. The integration of different technology components will move networks away from best effort mobile broadband towards truly reliable communication. Reliability is not just about equipment up-time, it also encompasses the perception of infinite capacity and coverage that future mobile networks will need to deliver anytime and anywhere.

Objects ranging from cars to appliances to watches and apparel will learn and organize themselves to fulfill our needs by automatically adapting to our behavior, environment or business processes. We already see some trends arising, not only driven by the Internet and telecommunications industry, but also from the other industries such as automotive, healthcare, manufacturing and logistics, the public sector and others who need to reinvent themselves.

A key design principle for 5G networks is flexibility, to support unknown uses that will inevitably arise in the future.

## 2. Possibilities – every industry will benefit from 5G

Networks will offer speeds more than 10 Gbps and extremely low latency. 5G will be the platform that enables growth in many industries, ranging from the IT industry to the car, entertainment, agriculture and manufacturing industries. 5G will connect the factory of the future and help create a fully automated and flexible production system. It will also be the enabler of a super-efficient infrastructure that saves resources.

We can expect that safety and business-critical applications will increasingly run on the wireless network, which necessitates absolutely stringent, reliable and predictable service levels in terms of capacity, throughput and latency. These levels will far exceed those of today.

What will be the possibilities in the real world?

Consider the healthcare industry in which hospitals can arrange remote robotic surgeries via a customized 5G network that minimizes network latency as if the surgeon were physically present next to the patient. Or how skin-embedded and 5G connected healthcare chips could constantly monitor vital signs, prevent conditions from becoming acute, and constantly adapting medication to meet changing conditions.

Creating a safe transportation infrastructure is another major area where self-driving cars and smart road infrastructures enabled by 5G networks can reduce accidents, saving millions of lives every year.

With sensors enabled by 5G networks, every water pipe could be monitored in real-time and utility providers could create a network that can sense, process and transmit exact locations and severity of a leak and alert proper resources in real time without the need for humans to laboriously collect and analyze the data.

Similar 5G-enabled transformations are only to be expected in agriculture, finance, retail, education, trade and tourism. The possibilities are truly endless.



Figure 3. Expanding the human possibilities of technology

## 3. Versatile radio: multiple accesses, multiple capabilities

5G radio is likely to use several bands from 400 MHz to 100 GHz. In November 2015 the World Radiocommunication Conference (WRC) agreed an agenda item for WRC 2019 to identify spectrum for IMT-2020, with the following bands being the focus of further studies in the coming years:

- 24.25-27.5 GHz
- 37-40.5 GHz,
- 42.5-43.5 GHz,
- 45.5-47 GHz,
- 47.2-50.2 GHz,
- 50.4-52.6 GHz,
- 66-76 GHz and
- 81-86 GHz

In addition, the conference decided that the UHF band will be revisited at WRC 2023.

The lower frequency bands being made available for 5G have good penetration characteristics that provide coverage to support applications with high mobility and reliability. Efficiently using sub-6 GHz spectrum will require different carrier bandwidths and flexible spectrum aggregation techniques. Within this range, carrier bandwidths of 40-100 MHz and efficient spectrum aggregation techniques will be needed for sub-3 GHz FDD deployments. For 3-6 GHz spectrum, support for high contiguous carrier bandwidths of more than 100 MHz will be especially relevant.

The higher frequencies have several bands available to provide huge capacity and throughput.

Nokia has proven that it is possible to take advantage of x\*100 MHz bandwidth in the cmWave band (3-40 GHz), or 1-2 GHz bandwidth in the mmWave band (40-100 GHz). Substantial Nokia research, including channel measurements, Proof of Concept verifications and live trials with key operators shows that these bands can be used for access and backhaul to help support large volumes of small cell traffic.

Current spectrum allocations and the work of the WRC indicate that by about 2020 the focus will be on frequencies below 6 GHz and some non-harmonized national / regional spectrum above 6 GHz.

Should no further low bands be made exclusively available for cellular then operators will need to make use of complementary solutions to obtain additional spectrum. These will most likely mean sharing spectrum with other incumbents through Licensed Shared Access (LSA) and Authorized Shared Access (ASA).

Unlicensed bands such as 5 GHz, and in the future 60 GHz, offer additional offload options for best-effort traffic from less critical applications not needing guaranteed Quality of Service (QoS).

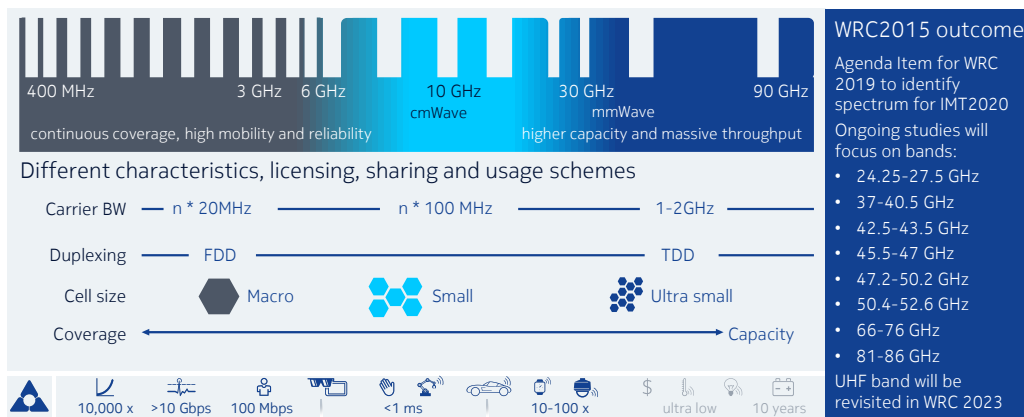


Figure 4. Unlocking new spectrum assets will provide the foundation for 5G

## 3.1 Massive MIMO boosts peak rates and spectral efficiency

MIMO is proven to efficiently boost LTE capacity. Antennas with at least 16 elements are called Massive MIMO and can be used to improve spectral efficiency via multi-stream transmission, or to form a narrow beam to increase transmission distance.

Normally, sub-6 GHz bands have smaller bandwidth, but Massive MIMO multi-stream transmission can achieve high Gbps peak data rates. Antenna size is inversely proportional to the frequency, so the antenna's physical size will set a limit on the possible number of antenna elements.

Higher bands have relatively large bandwidths, but also greater path losses. Massive MIMO is an effective way to compensate path loss on 3-40 GHz bands using high beamforming gain as well as to increase peak data rate by multi stream transmission. For very high frequency bands (e.g. mmW, 30-100 GHz) the antennas focus the transmitted energy towards the receiver to overcome increased path loss caused by radio propagation. Many parallel MIMO streams are not required due to the large bandwidth available at these bands.

Different frequency ranges require different Integrated Circuit technologies, which Nokia is developing in conjunction with technology vendors and academia. Hybrid /RF (digital and analog) beamforming architecture can reduce the transmitter cost and energy consumption for Massive MIMO.



## 3.2 Virtual zero latency, full coverage, low power

The wide range of spectrum available and the diverse use cases for 5G will demand a configurable frame structure with flexible numerology. This is unlike LTE, which has a fixed 10 ms frame and 1 ms Transmission Time Interval (TTI) that are inflexible and limit latency performance.

The new 5G frame structure is self-contained and can accommodate large data packets transmitted efficiently with low overhead, as well as small, low latency performance packets that need be scheduled frequently. The 5G subframe can be in the range of about 0.1–0.25 ms for short latency, and can be configurable to be optimized for wide area or local area needs, or for different bands.

Nokia has developed innovative ways to optimize the frame structure to minimize scheduling latency in small cells by applying bidirectional CTRL (control) signaling to every sub-frame. This works by locating CTRL and reference signals before the data to allow continuous processing at the receiver site without waiting for a response. In addition, Device to Device (D2D) use is supported for local traffic routing. Each subframe can be dynamically set as uplink or downlink to enable resource allocation to follow the actual traffic.

To further improve performance, Nokia has created a robust air interface to cope with cross-link interference. This uses cross-link orthogonal reference signals and interference stabilization to enable efficient interference rejection/cancellation.

Massive machine communication needs low cost, good coverage to support hard-to-reach devices such as utility meters installed in basements. Low band spectrum provides the required coverage, while LTE-A and its evolution will provide the initial support for massive machine communication.

Massive machine communication will also demand very low power consumption to achieve more than 15 years battery life with two AA batteries. Extended Discontinuous Reception (DRX) enables longer sleep cycles, with the device waking only when it needs to transmit data, as well as using less signaling for the wake up.

Meanwhile the costs for machine communication are lowered by removing unnecessary functions in transmitters and receivers, including narrowband transmission, reduced transmit power, limited downlink transmission modes and device processing relaxation. Coverage is increased by repetition, power spectral density boosting and new coding, which lead to four times more coverage compared to LTE Rel. 12.

### 3.3 Multi-Connectivity for enhanced capacity, coverage and mobility

Multi-connectivity refers to the situation where a device's radio resources connect to at least two different network points and can encompass different radio bands, different RATs, or different layers.

Multi-connectivity enhances throughput and the reliability of connection to improve the Quality of Service (QoS). The technology also provides seamless mobility by eliminating handover interruption delays and errors, and optimizes capacity, coverage and mobility for devices connected in a heterogeneous network.

Multi-connectivity supports the smooth introduction of 5G on top of LTE networks and enables 4G/5G real-time radio resource management with dynamic inter-RAT load balancing to maximize output.



Figure 5. Multi-Connectivity: Perception of infinite capacity

#### 4. System of Systems – a programmable multi-service network

5G will be called upon to support a vast array of uses with diverse performance needs. Connecting huge numbers of consumer health sensors is a very different proposition to delivering high quality UHD video to TV sets. Clearly, 5G networks will need to offer a greater range of capabilities than 4G technologies.

Designed primarily to provide mobile broadband, existing LTE and Evolved Packet Core (EPC) architecture will not be able to efficiently support the different demands, ranging from ultra-low latency services with full mobility, to extreme throughput, to the massive number of deployments that will result from the rise of the Internet of Things (IoT). Current EPC architecture does not

allow operators to evolve their radio and core networks independently. 5G architecture will break the dependency between the core and access networks, enabling convergence with Wi-Fi and fixed access and enabling functions such as QoS, session management and security to be decoupled from the underlying access technology.

While it may be possible to build a separate system for each use case, this will not be economically viable and would lead to mammoth network complexity. Instead, 5G will need to be a single ‘System of systems’ that can meet all these requirements invisibly from the user’s perspective.

This new architecture will provide key new capabilities as outlined in the following sections.

## 4.1 Network slicing - heterogeneous use cases on one physical network

5G architecture will provide a common core to support multiple RATs (cellular, Wi-Fi and fixed), multiple services (mobile broadband, massive Machine Type Communications (MTC) and critical MTC) and multiple network and service operators. The required architecture will be enabled by Network Function Virtualization (NFV) and Software defined networking (SDN) technologies which allow systems to be built with a high level of abstraction. In 5G we envision that networks will be further abstracted with the concept of network slices. Operators will then be able to use their physical infrastructure to create ‘network slices’, which are virtual instances of an entire network tailored to the needs of any industry whether automotive, healthcare, logistics, retail or utilities.

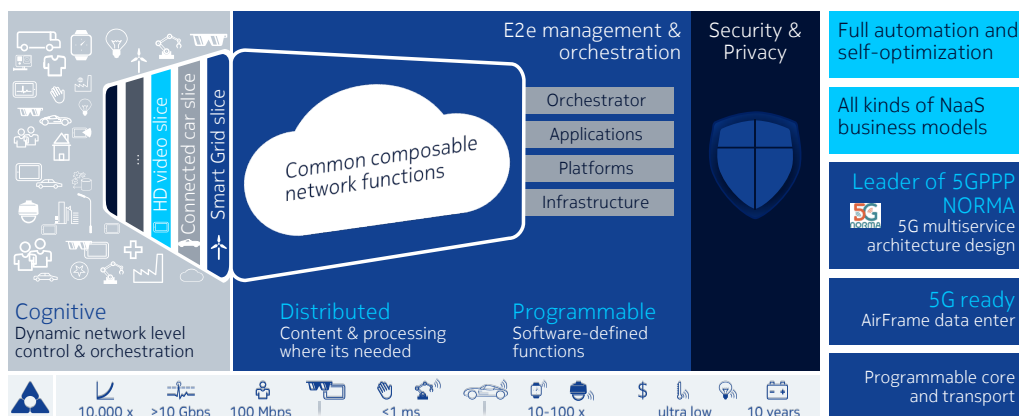


Figure 6. Network Slicing: Optimized service delivery for heterogeneous use cases

## 4.2 Dynamic Experience Management

Operators will need to be able to instantly respond to changing demands and network conditions to substantially improve the Quality of Experience (QoE) while also ensuring network resources are used efficiently during each application session. Conventional Quality of Service (QoS) architecture is not sufficiently aware of the specific needs of the different application sessions in the networks and are not able to automatically initiate the right optimization actions within the necessary short time frame. A major overhaul of the Evolved Packet System (EPS) QoS architecture that goes beyond simply evolving the EPC will be needed to tap the full potential of Dynamic Experience Management to sustain QoE in nearly all sessions, even under high load conditions.

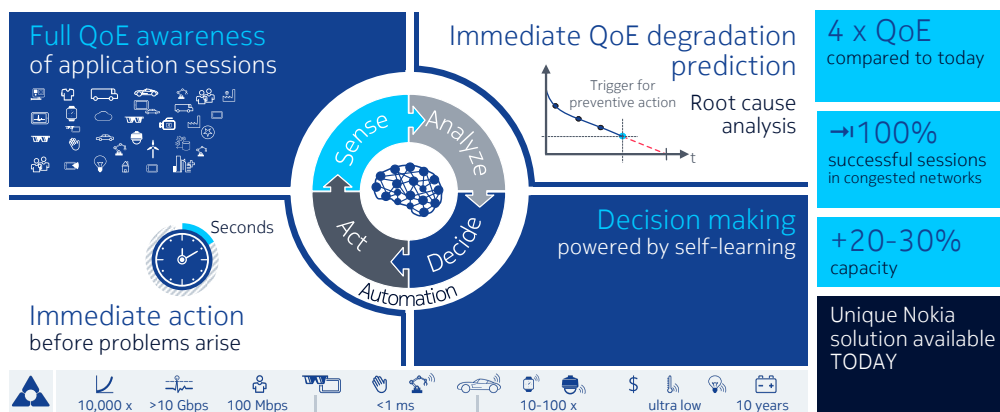


Figure 7. Dynamic Experience Management: Superior quality with fewer resources

## 4.3 Service-determined connectivity / fast traffic forwarding

A variety of services will depend on the network providing low latency access under full mobility conditions. For example, V2X applications will require seamless service continuity as the vehicle moves between the serving areas of local gateways. Another example is to provide simultaneous access to Internet services through a central gateway and access to a local Content Delivery Network (CDN) site through a local gateway. Supporting such re-locatable low latency and high reliability (multi-connectivity) services will require the 5G access point, or an aggregator cloud, to route traffic either to the centralized IP anchor, local IP anchor or directly to the Mobile Edge Computing (MEC) application. This is achieved by introducing service-aware forwarding at the radio.

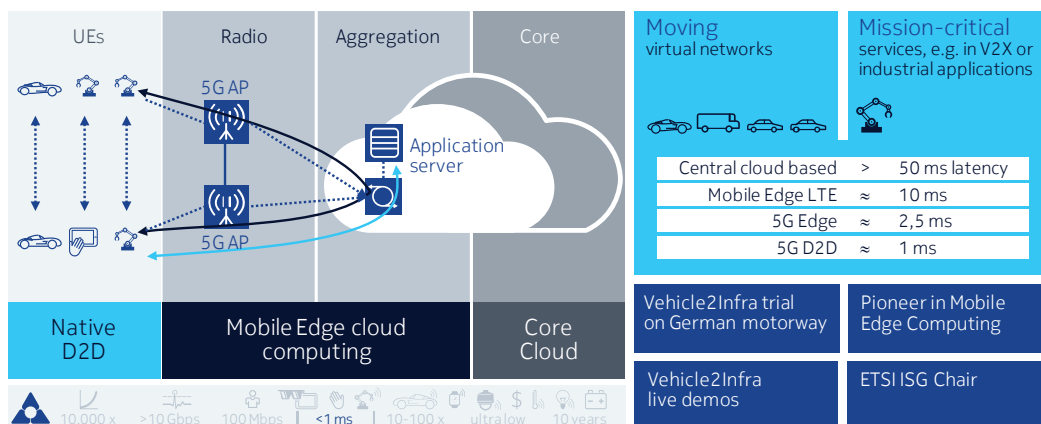


Figure 8. Fast traffic forwarding: Enabling a new generation of latency critical services

## 4.4 Session and Mobility on Demand

5G must offer more efficient connectivity. LTE does not support signaling-only sessions that massive numbers of IoT devices will demand to avoid rapid battery drain. Today to support always on, lots of unnecessary small packets are transmitted. Yet always-on connectivity still needs to be available for smartphones for efficient mobile broadband services.

Meanwhile, offering mobility on demand makes efficient use of network resources. Flexible mobility consists of two components: one for managing mobility of active devices and one for tracking and reaching devices that support a power-saving idle mode. Flexible active mobility will be made possible by supporting flexible IP anchoring and enabling mobility only when needed.

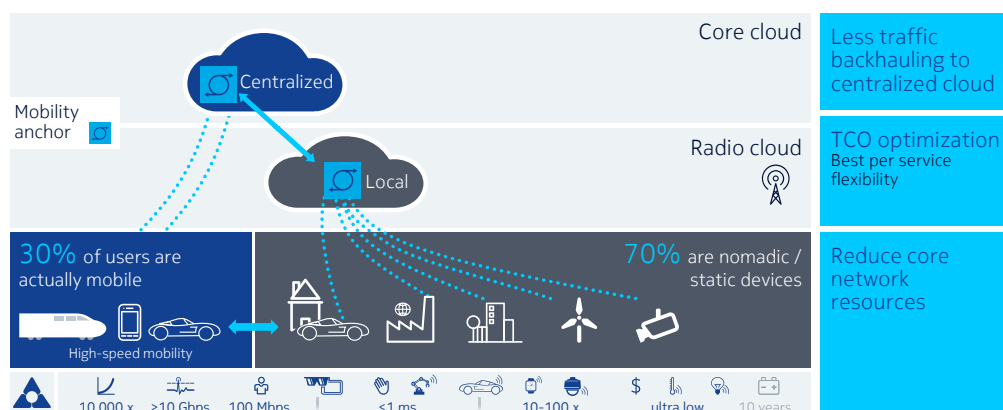


Figure 9. Fast traffic forwarding: Enabling a new generation of latency critical services

## 5. Practicalities: A phased approach to 5G transformation

Some markets, especially Korea and Japan need high capacity mobile broadband to be deployed by 2020. This will require the standards to be agreed and finalized in 2018. This is an ambitious timeline because the wide range of different use cases to be addressed and the new spectrum to be agreed will make standardization complex and time-consuming. In addition, new spectrum for mobile broadband on higher frequencies is likely to be available only after WRC 2019.

These practical considerations mean that 5G will most likely be introduced in phases.

### Phase one

In phase one the architecture is centered on EPC and the deployment of new 5G radio access technologies, especially using sub-6 GHz spectrum. This phase (3GPP Release 15 available end of 2018) would also introduce 5G radio via dual connectivity mode with LTE as an anchor and depending on progress in 3GPP eventually also a standalone option. In this scenario the 5G radio access is connected to EPC but a forward compatibility to the coming 5G core needs to be assured, as well as enabling later releases to be easily backwards-compatible with 5G phase one without sacrificing overall 5G performance.

### Phase two

Phase two will see the introduction of novel layers and architectural changes beyond those implemented in phase one (to enable the full potential of 5G). In this phase, the related 3GPP release 16 available end of 2019 will fully meet the requirements of critical MTC use cases in terms of lowest latency and highest reliability, as well as important mobile broadband enhancements by providing best QoE to end users. The new 5G core will also efficiently support massive MTC.

By phasing in new 5G network architecture in this way, mobile operators will be able to make use of their existing deployments to provide higher data rates, better capacity in the near term and at the same time, introduce future-proof network architecture to support new use cases and services in the longer term.

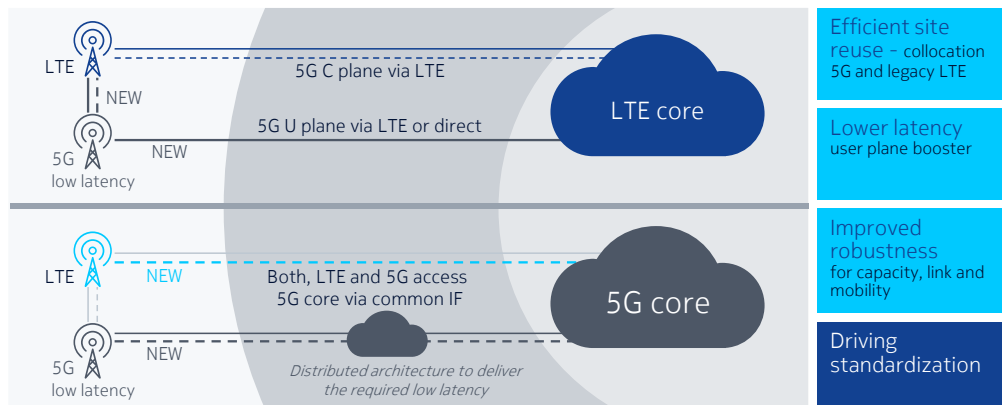


Figure 10. Most operators will have a legacy LTE network when they start to deploy 5G and the phased approach will enable them to take advantage of LTE coverage and early new 5G features

## 6. Potential: Business models powered by network performance, data and slicing

5G will be about connecting people and things profitably. These are entirely different business models, yet the flexibility of 5G radio and architecture will enable operators to be profitable in both. In the 5G era operators will be able to monetize three assets:

- The new performance level of their networks enables extreme broadband to support uses such as HD and UHD services in the home and on the move, but also virtual reality services that are relevant to the business world. These “Connectivity+” business models provide new opportunities through guaranteed high service levels for end users, as well as for content and other service providers.
- The billions of transactional and control data points produced by the network can be used to enable entirely new services that benefit from contextual real-time and non-real-time data. Operators can broker this information to different industries including providers of augmented reality services, traffic steering systems provided by municipalities, factories and logistical systems and utilities. Real-time big data analytics will play a crucial role in the brokering model.
- Dedicated virtual sub-networks, so-called network slices, can be marketed as “Network as Service” which can have different flavors and provide exactly the functionality that is needed for different industries and their diverse use cases. For example, the functionality and capabilities needed for connecting massive numbers of consumer health sensors are completely different to those required for high quality UHD video delivery to TV sets.

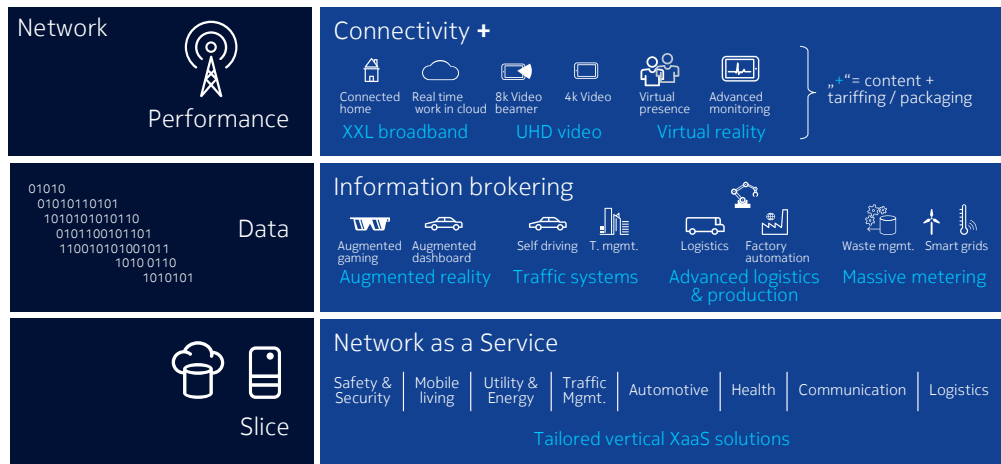


Figure 11. A variety of business models powered by network performance, data and slicing

## 7. Nokia at full speed in 5G Research and commercialization

Nokia is well advanced in its 5G radio and network architecture design, progress made through substantial investment in its research programs. In October 2015 SK Telecom and Nokia Networks achieved 19.1 Gbps over the air in a joint 5G trial using key 5G technologies such as Massive MIMO. Since 5G is much more than a new radio system, Nokia has launched its 5G programmable service architecture and is the consortia leader of the 5G NORMA research project which will deliver innovations & breakthrough ideas for 5G network architecture work in Phase 1 & 2 and later 3GPP releases.

Nokia has established a broad range of innovation partnerships to establish a common direction through collaboration in requirement setting, technology research and finally in standardization. Nokia engages in collaborative research with operators including China Mobile, Deutsche Telekom, Korea Telecom, NTT DOCOMO, SK Telecom, and Verizon, with governmental bodies, regulatory and industry bodies, with industry and the scientific community, and with 5G labs such as the 5G lab at Technical University of Dresden or the 5G Test Networks in Finland.

Nokia's collaboration with top universities globally includes joint research with New York University to explore channel measurements and characterization, and with Technical University of Kaiserslautern to study 5G architecture and its application for other industries.

Nokia leads the 5G NORMA consortium which defines the 5G architecture and is the technical coordinator of the METIS-II project.

Ultimately, the creation of a successful 5G standard requires the best ideas to be adopted, no matter where they come from, so requirements from outside the telecom industry must also be considered. Nokia hosts the



discussion via its '5G Connected Industries Forum' so that telecom and vertical industries can cooperate to pave the way for creating the required 5G capabilities. Nokia also brings together industry, academia and regulators to discuss future 5G key issues in its annual Brooklyn Summit.



Figure 12. Nokia is active in shaping and aligning the global 5G end-to-end ecosystem

## 8. Conclusion: 5G is a door opener for new possibilities and use cases

5G is not only a new air interface but the new generation of radio systems and network architecture in which different radios (legacy and new) work together perfectly. Progress has been rapid, with proofs of concept for many of the technological advances that will be a crucial part of the forthcoming 5G standard.

Nokia has already prototyped future 5G radio design, such as the use of new cmWave and mmWave spectrum and waveforms (6 - 100 GHz) and beam tracking of mobile users including the use of massive MIMO and beamforming. Nokia has also shown how latency targets for time-critical applications will be met by the use of shorter transmission time intervals and flexible dynamic TDD.

Furthermore, Nokia real-time Radio Resource Management for 5G systems has demonstrated seamless as well as massive connectivity e.g. between 4G and 5G and shows an advanced view of how 4G can be integrated into 5G. This enables different mobile generations and layers to be managed as one system.

Furthermore, 5G is not only about radio access because network architecture will play an important role as well. 5G networks will have to be programmable, software-driven and managed holistically to enable a diverse range of profitable services.

5G will provide new assets to operators that they will be able to monetize: an entirely new level of network performance, the huge amount of transactional data in the network and dedicated virtual subnetworks that can be instantiated and managed independently from each other.



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