5G Technology Components

Building blocks of 5G networks

White Paper

The advent of 5G will bring a new world of possibilities for everyone in the mobile communications world, from vendors and operators, to subscribers, app developers and enterprise users. To make the most of its possibilities, a number of new technologies will need to be adopted and deployed.

This white paper outlines these technologies, showing how techniques such as beamforming and network slicing can take advantage of 5G's attributes to bring substantial benefits across the whole industry.

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1. Executive Summary

Compared to previous technologies, the demands placed on 5G are very high, with data rates of up to 20 Gbps and a capacity a thousand times greater. 5G networks must also provide a flexible platform for new services such as massive IoT and critical machine communication. The demands require a number of new technologies.

The key technology components include new spectrum, allowing 5G to make use of its full abilities to operate on any frequency band between 400 MHz and 90 GHz. These allow it to provide both the high data rates needed and the wide coverage required.

Massive MIMO beamforming is also required to increase spectral efficiency and network coverage. Massive MIMO will be part of 5G from the beginning, including common and control channels.

Network slicing will offer 5G the flexibility to support different use cases, vertical segments and different frequency bands, as well as maximizing energy and spectral efficiency.

Multi-connectivity will allow 5G to be deployed with LTE, with 5G devices connected simultaneously to both 5G and LTE.

In-built support for cloud implementation and edge computing will meet the demand for low latency in 5G by allowing content to be brought closer to the user.

2. Introduction

The success of the coming 5G networks will depend on the adoption of a number of new technologies. These will allow the benefits of 5G to be fully realized, taking advantage of its high data rates and ability to use a wide range of bandwidths, among other things. The main new technology components are shown in Figure 1.

1) New spectrum. The very high data rates of up to 20 Gbps require bandwidth up to 1-2 GHz, which is available at higher frequency bands. This means that 5G must use millimeter wave spectrum above 20 GHz and in fact 5G is the first radio technology designed to operate on any frequency band between 400 MHz and 90 GHz. The low bands are needed for coverage and the high bands for high data rates and capacity. The frequencies above 30 GHz have wavelengths of less than 1 centimeter (10 millimeters) and are commonly known as millimeter waves (mmW). Lower frequencies at 24-28 GHz are also sometimes included in millimeter wave. LTE technology is defined only for frequencies below 6 GHz.
2) Massive MIMO beamforming can increase the spectral efficiency and network coverage substantially. Beamforming becomes more practical at higher frequencies because the antenna size is relative to the wavelength. In practice, massive MIMO can be used at frequencies above 2 GHz in the base stations and at millimeter waves even in the devices. User specific beamforming was not supported by 3GPP Release 8 devices and was only included in Release 9/10 for eight transmit antennas and enhanced in Release 13/14. Massive MIMO will be part of 5G from the beginning, including common and control channels.
3) Network slicing. The physical and protocol layers in 5G need a flexible design to support the different use cases, vertical segments and different frequency bands and to maximize energy and spectral efficiency. Network slicing will create virtual network segments for the different use cases within the same 5G network. The 5G core network is designed to support numerous slices for each end-user device. Nokia can deliver the full end-to-end solution for network slicing.

4) Multi-connectivity. 5G can be deployed as a standalone system but in the early stages will more typically be deployed with LTE. The 5G device can be connected simultaneously to both 5G and LTE, offering a higher user data rate and a more reliable connection.

5) In-built support for cloud implementation and edge computing. The current architecture in LTE networks is fully distributed in the radio and fully centralized in the core network. The demand for low latency in 5G requires the content to be brought closer to the radio, which necessitates local break out and Multi-Access Edge Computing (MEC). The required scalability means bringing the benefits of the cloud to radio networks, using both edge cloud and local cloud architecture. 5G radio and core is also designed for native cloud implementation, including new interfaces inside the radio network.

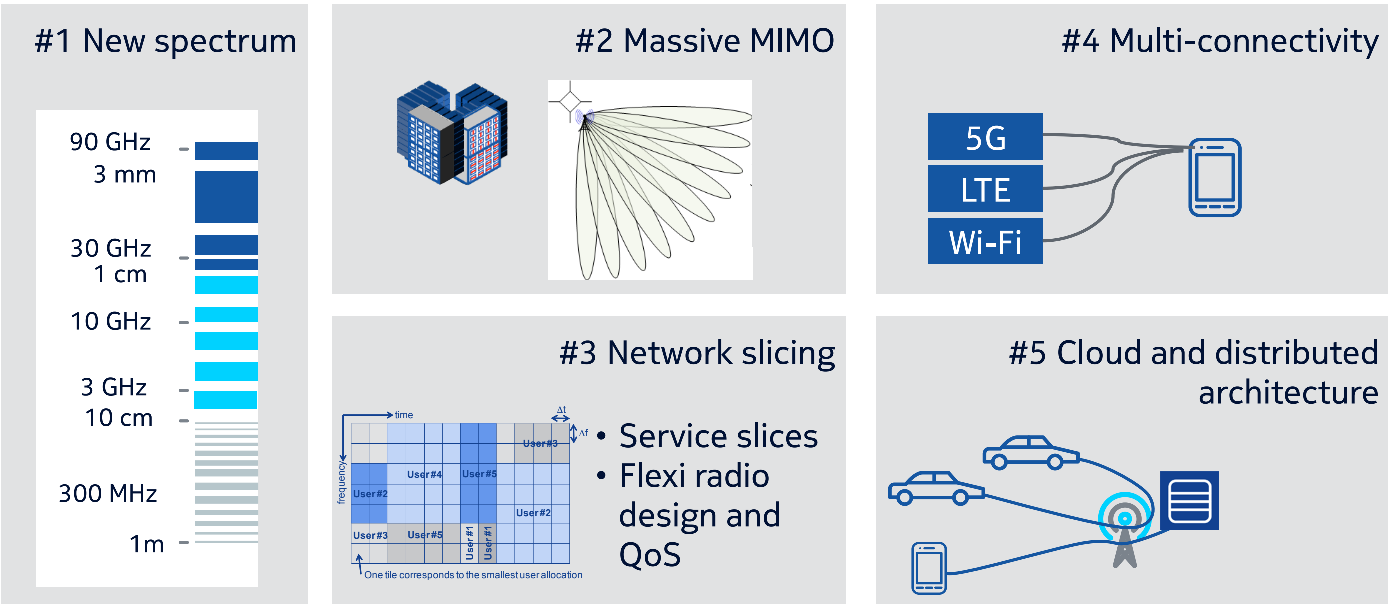


Figure 1. Key 5G technology components

3. Spectrum Options

5G radio is the most flexible way to benefit from all available spectrum options from 400 MHz to 90 GHz, including licensed, shared access and unlicensed, FDD and TDD bands, narrowband and wideband allocations. The three main spectrum options are illustrated in Figure 2. Millimeter wave spectrum above 20 GHz can provide bandwidth up to 1-2 GHz, which offers very high data rates up to 20 Gbps and extreme mobile broadband capacity. Millimeter waves are most suitable for local use such as mass events, outdoor and indoor hotspots and for fixed wireless networks.

Spectrum at 3.5 GHz and 4.5 GHz will be used for 5G coverage and capacity in urban areas by reusing existing base station sites. The spectrum around 3.5 GHz is attractive for 5G because a large amount of spectrum is available across the world. The bandwidth can be up to 100 MHz per operator at that frequency and even up to 200 MHz when refarming some of the existing bands. 5G coverage at 3.5 GHz can be similar to LTE1800 coverage when using massive MIMO beamforming.

Low bands below 1 GHz are needed for wide area rural coverage, for ultra-high reliability and for deep indoor penetration. Extensive coverage is important for new uses cases such as IoT and critical communication. The low band could be 700 MHz, which is available in many countries alongside 5G.

Another option is 900 MHz, which is today mostly used by 2G and 3G. Most operators will keep 2G and 3G running until 2020 but spectrum allocation for legacy radios can be minimized. In the USA, another option for 5G low band is 600 MHz.

Spectrum	5G spectrum per operator	Data rate
20-90 GHz	2000 MHz	20 Gbps
Below 6 GHz	200 MHz	2 Gbps
Below 1 GHz	20 MHz	0.2 Gbps

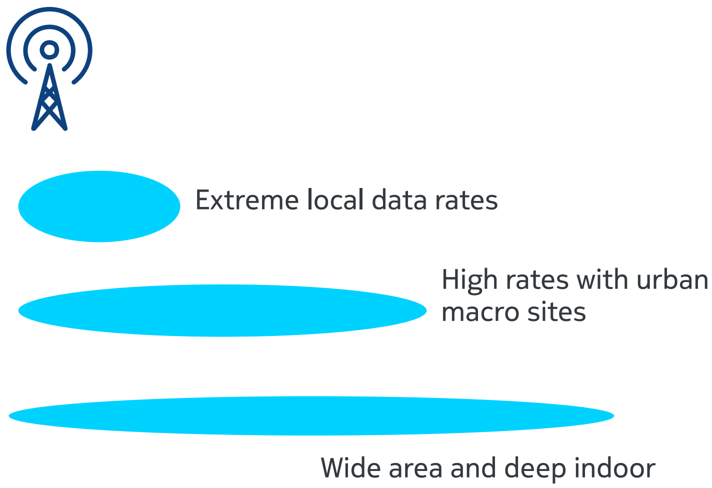


Figure 2. 5G can use all spectrum options

5G radio must have the flexibility to support all the different spectrum options. The solution to this need is flexible numerology, as shown in Table 1. 5G is designed to support several subcarrier spacing and scheduling intervals depending on the bandwidth and on the latency requirements. Sub-carrier spacings of 15 kHz to 120 kHz will be defined in Release 15. With higher sub-carrier spacing, more symbols can be accommodated in a sub-frame, resulting in lower acquisition time.

The narrow spacings are used with narrow 5G bandwidths and are better for providing extreme coverage. If we consider a typical 5G deployment at the 3.5 GHz band, the bandwidth could be 40-100 MHz, the subcarrier spacing 30-60 kHz and minimum scheduling period 0.125 ms. The corresponding numbers in LTE are 20 MHz bandwidth, 15 kHz subcarrier spacing and 1 ms scheduling period. 5G subcarrier spacing is designed to be 2^N multiples of 15 kHz. If the slot length is more than 0.125 ms in the narrowband cases and low latency is required, then so called 'mini-slot' can be used, where the transmission time is shorter than one slot. It is also possible to combine multiple slots together.

Subcarrier spacing [kHz]	15	30	60	120
Spectrum	<6 GHz	<6 GHz	<6..>20	>20 GHz
Max bandwidth [MHz]	50	100	200	400
Symbol duration [us]	66.7	33.3	16.7	8.33
Nominal cyclic prefix [us]	4.7	2.3	1.2	0.59
Scheduling interval (ms)	0.5	0.25	0.125	0.125

Table 1. 5G numerology is designed for all spectrum options

4. Beamforming

Beamforming is an attractive solution for boosting mobile network performance. It can provide higher spectral efficiency, providing much more capacity on existing base station sites. The method can also enhance link performance and increase the coverage area. Beamforming uses massive MIMO (Multiple Input Multiple Output) technology, which is supported by the latest 3GPP releases. Massive MIMO was added into LTE specifications in later 3GPP releases, while massive MIMO will be included in 5G specifications in the first 3GPP release. The aim is make the 5G radio design fully optimized for massive MIMO beamforming. The underlying principle of beamforming is illustrated Figure 3. The traditional solution transmits data over the whole cell area, while beamforming sends the data to users over a narrow beam. Beamforming offers the advantages that the same resources can be reused for multiple users within a sector. It can also minimize interference and increase cell capacity.

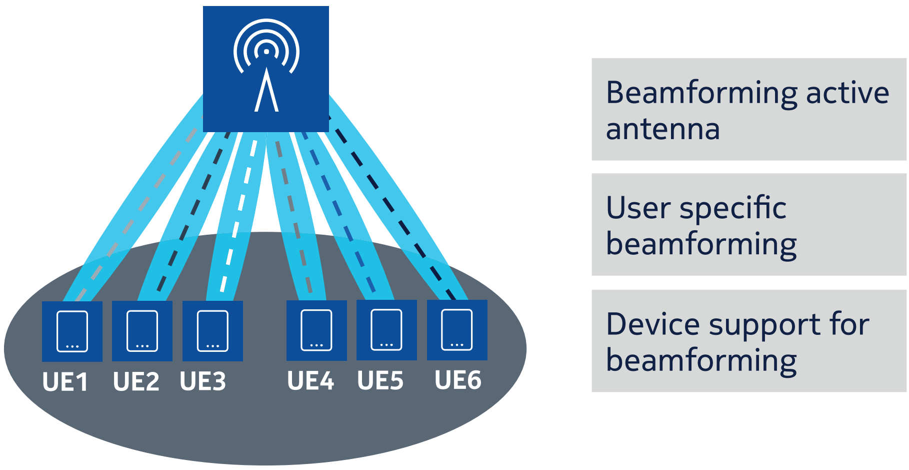


Figure 3. Beamforming enhances radio capacity and coverage

Beamforming can also provide substantial capacity benefits at frequencies below 6 GHz. The aim here is to enhance radio network performance while reusing existing base station sites by adding new active antennas. The performance benefit of beamforming depends on several factors, including antenna configuration, environment, device capability and network algorithms. Massive MIMO beamforming with simulated result from 64 transmitters are shown in Figure 4 and are compared with a case using two transmitters. The expected average gains are more than four times in TDD and more than three times in FDD. The gain is even more substantial in the cell peak rates.

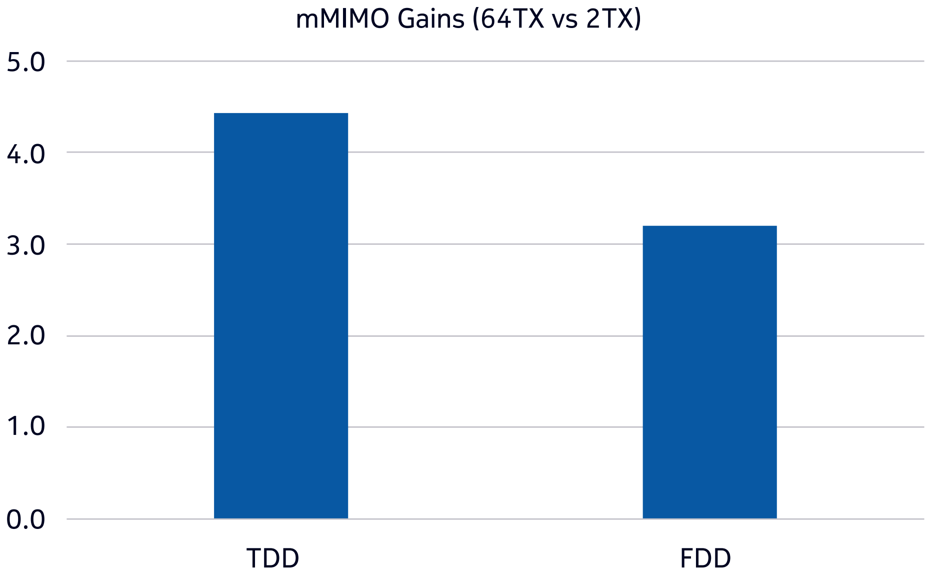


Figure 4. Massive MIMO gains with 64TX compared to 2TX

Active antennas combine an antenna and a large number of small RF units in the same package. The traditional solution has been a separate passive antenna and RF unit. An active antenna enables practical beamforming implementation, as the phasing of the small power amplifiers can be controlled with digital processing. A typical number of RF units inside the active antenna are 64 or 128. Active antennas also bring simpler practical installation since there are no cables between antenna and RF. The power efficiency can also be enhanced since there are no losses in RF cables and connectors. A Nokia active antenna with 64TRX is shown in Figure 5.

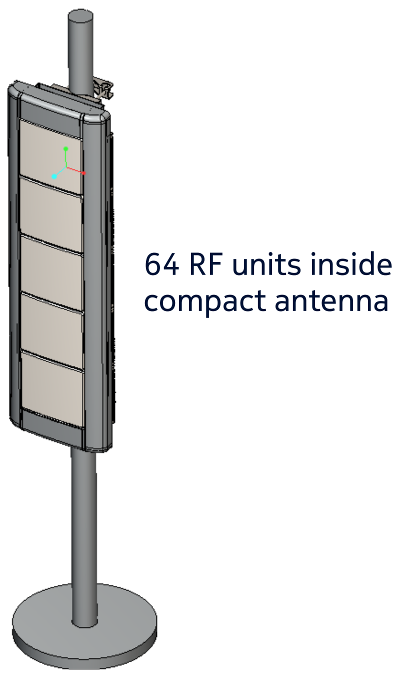


Figure 5. Nokia active antenna

5. Network Slicing

The 5G network is designed to support very diverse and extreme requirements for latency, throughput, capacity and availability. Network slicing offers a solution to meet the requirements of all use cases in a common network infrastructure. The concept of network slicing is illustrated in Figure 6. The same network infrastructure can support, for example, smartphones, tablets, virtual reality connections, personal health devices, critical remote control or automotive connectivity. With network slicing, different end-to-end logical networks with isolated properties are provided and operated independently. These enable operators to support different use cases, with devices able to connect to multiple slices simultaneously.

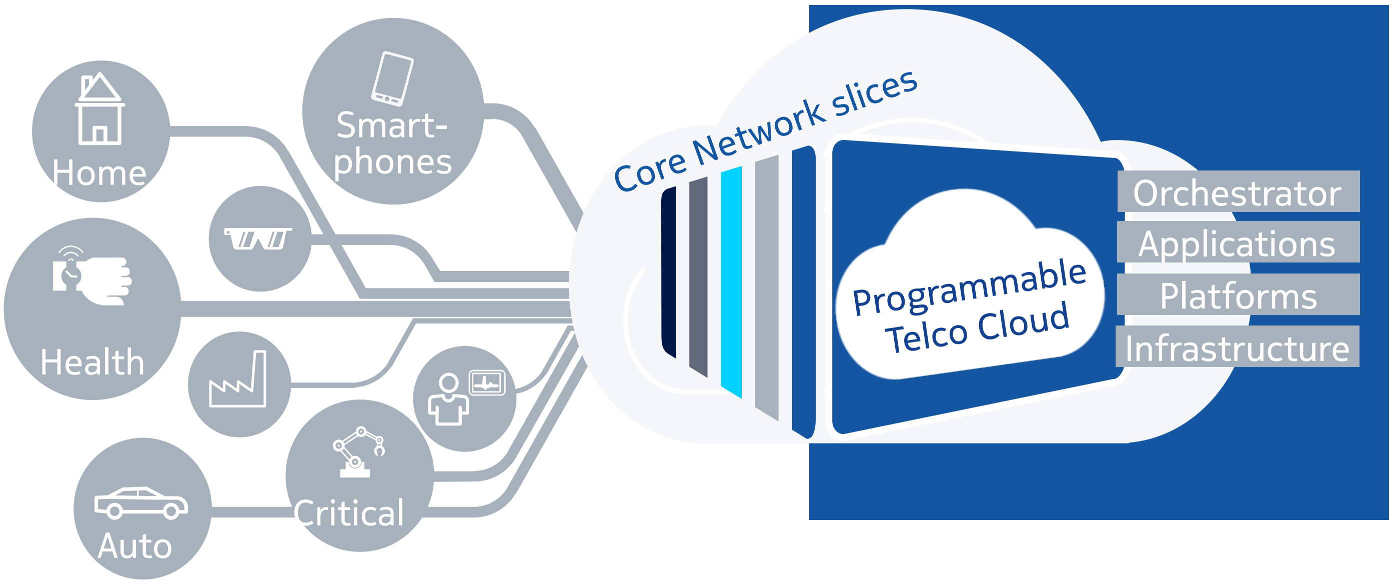


Figure 6. Network slicing concept

A 5G network needs to have tools for network slicing. LTE supports Quality of Service (QoS) differentiation but 5G requires something extra - dynamic, application based Quality of Experience (QoE). This approach is not achievable in LTE where the same QoS is applied for all traffic within a bearer. The difference between LTE QoS and 5G QoS is illustrated in Figure 7 and the difference between bearer based QoS and dynamic QoE in Figure 8. A bearer based solution is fine for operator provided services where the packet filters are easy to define and application sessions are long lived. 5G QoE architecture must detect and differentiate short-lived sub service flows. The control plane signaling of packet filter attributes and related policies is unnecessary when both the radio and the core are application aware and both are capable of deciding on actions to achieve the QoE targets.

LTE Baseline for QoS

QoS enforcement is performed at eNodeB for uplink and Policy and Charging Enforcement (PCEF) for downlink.

QoS differentiation is achieved by enforcing QoS targets such as the delay budget, guaranteed bit rate and relative throughput ratio among bearers.

Radio and core network enforce QoS independently, uplink and downlink QoS are not coordinated.

5G Baseline for QoE

Framework for end-to-end QoS/QoE is built into the baseline architecture.

Both radio and core network elements have capabilities for real-time application awareness, QoE performance awareness and intelligence for dynamic policy modifications.

Both radio and core elements are able to track the unidirectional performance of application flows and take enforcement actions in both directions.

Figure 7. From LTE Quality of Service (QoS) to 5G Quality of Experience (QoE)

Bearer based QoS

EPC/LTE was designed to provide QoS differentiation per bearer - independently for uplink and downlink.

During the release-8 timeframe, the use case for differentiating internet services was not foreseen.

The bearer model is best suited for operato-provided services, where the packet filters are easy to define and application session is long lived.

Dynamic QoE

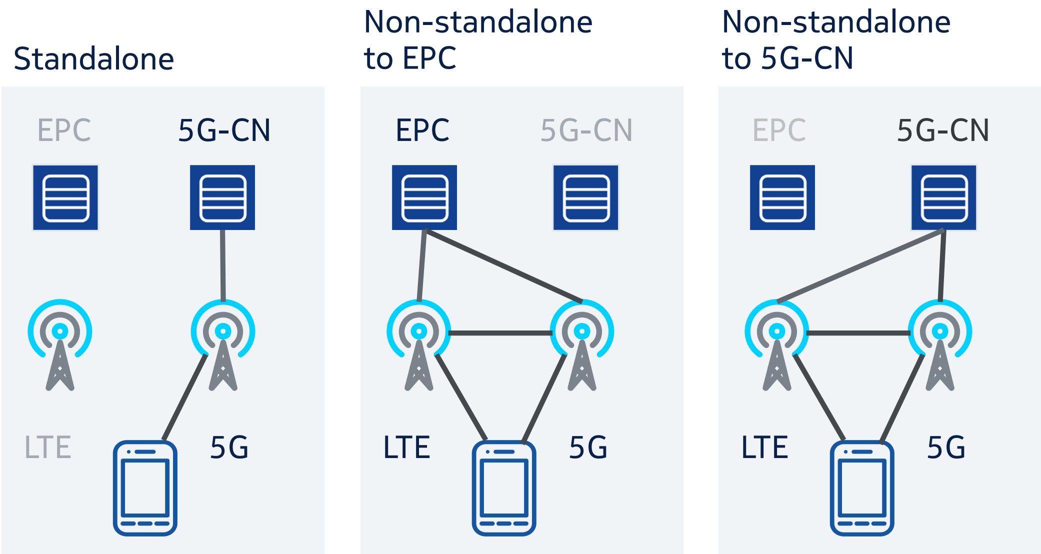
In 5G, the QoS/QoE architecture shall be able to detect and differentiate very short-lived sub-service flows to provide a good application QoE.

The control plane signaling of packet filter attributes and related policies is not necessary when both the RAN and core are application aware and both are capable of making dynamic decisions on actions to achieve QoE targets.

Figure 8. From bearer based QoS to dynamic QoE

6. LTE-5G interworking

5G can be deployed as a standalone solution without LTE. It can also use a non-standalone solution with dual connectivity to LTE where the device has two parallel radio connections: one to 5G and one to LTE. Such an approach is practical during a 5G rollout phase, particularly if the LTE network uses low band and the 5G network uses high band with limited coverage. The first dual connectivity solution is based on the existing Evolved Packet Core (EPC). Both 5G base stations (gNodeB) and LTE base stations (eNodeB) are connected to the EPC. The control plane goes via LTE. It is also possible to subsequently have non-standalone architecture with both 5G and LTE nodes connected to the new 5G core network (5G-CN). The control plane can go via LTE or via 5G. 5G is the first radio solution closely integrated with the existing radio network, offering a smooth rollout and a seamless experience for users.



EPC = Evolved packet core (LTE)

5G-CN = 5G core network

Figure 9. Expected 5G architecture options in Release 15

7. Cloud Implementation and Edge Computing

5G core and radio networks are designed for cloud implementation and for edge computing. The core network design for 5G includes a few innovations for cloud optimization:

- Stateless virtual network functions which radically simplify data centric network and software architecture and bring extreme scalability and plug & play installation
- Shared data layer optimized for cloud for massive scale and data propagation. It offers a unified solution for exposing data and open northbound interface
- Programmable core, offering open application program interfaces that allow flexible creation and modification of services and secure and robust interfaces for service providers

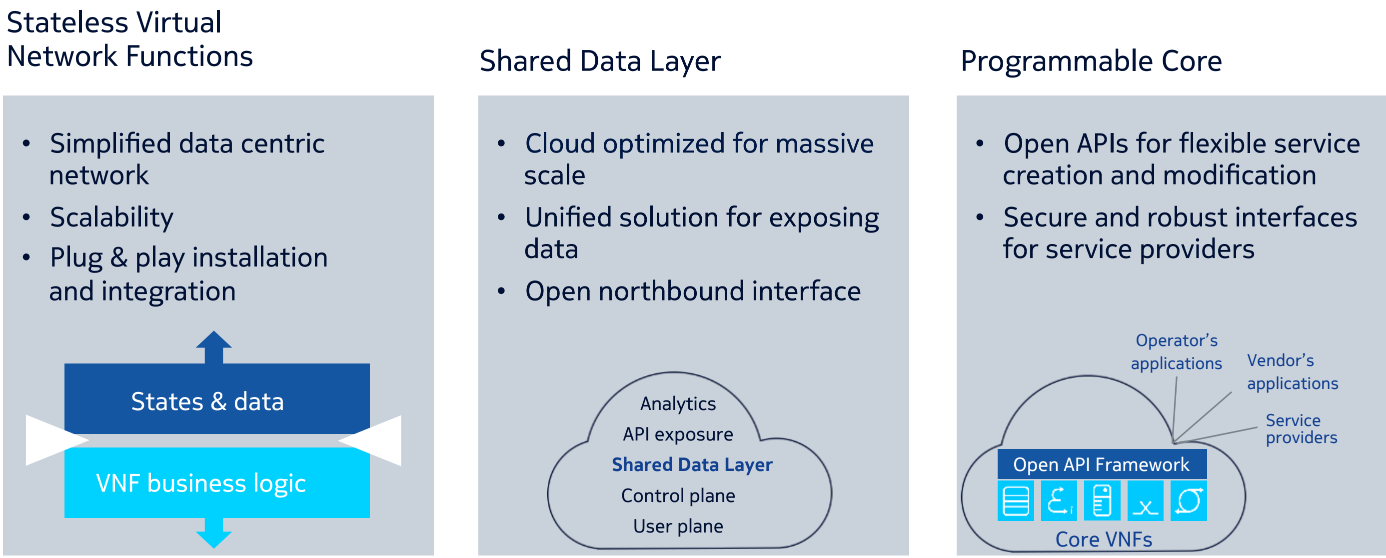


Figure 10. 5G core network innovations for cloud optimization

A 5G radio network includes new interfaces that enable a flexible split of functionalities. The delay critical functions can be located close to the Radio Frequency (RF) and antenna, while the non-delay critical functions can be located in the edge cloud. The cloud implementation enables network scalability, for example, when adding a large number of IoT connected devices. The future network architecture includes edge cloud, where Multi-Access Edge Computing (MEC) enables applications to run close to the radio access or where local breakout can be provided to local intranet or internet. The local cloud is an essential solution to bring low latency. The network architecture is illustrated in Figure 11.

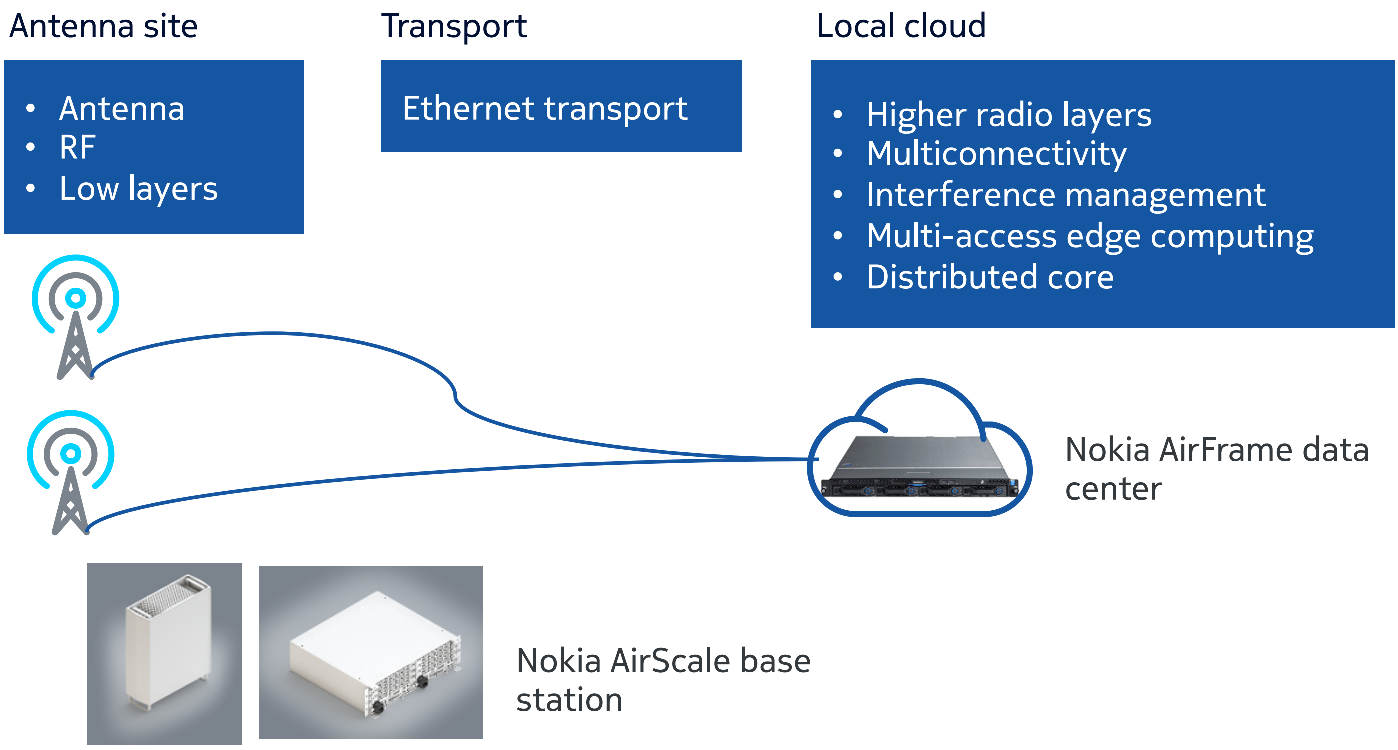


Figure 11. Radio network architecture with edge cloud

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8. Summary and conclusions

The expectations of 5G are very high, with data rates of up to 20 Gbps and a capacity a thousand times greater than previous technologies. 5G networks must also provide a flexible platform for new services such as massive IoT and critical machine communication.

5G has the ability to provide these capabilities and services but to bring them to full fruition, a number of new technologies need to be adopted. Using new spectrum, massive MIMO beamforming, cloud and edge computing, network slicing and multiple connectivity technologies will ensure 5G can provide everything people are expecting of it.

Further reading

Nokia white paper: “5G Master Plan” https://pages.nokia.com/5g-master-plan.html

Nokia white paper: “5G for Mission Critical Communication” https://pages.nokia.com/GC200007.html

Nokia white paper: “Translating 5G use cases into viable business cases” https://resources.ext.nokia.com/asset/201152

Nokia white paper: “Dynamic end-to-end network slicing for 5G white paper” https://pages.nokia.com/GC200339.html

Nokia white paper: “5G System of Systems white paper” https://pages.nokia.com/GC200012.html

Abbreviations

EPC	Evolved Packet Core
IoT	Internet of Things
LTE	Long Term Evolution
MEC	Multi-Access Edge Computing
MIMO	Multiple Input Multiple Output
PCEF	Policy and Charging Enforcement
QoE	Quality of Experience
QoS	Quality of Service
RF	Radio Frequency

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