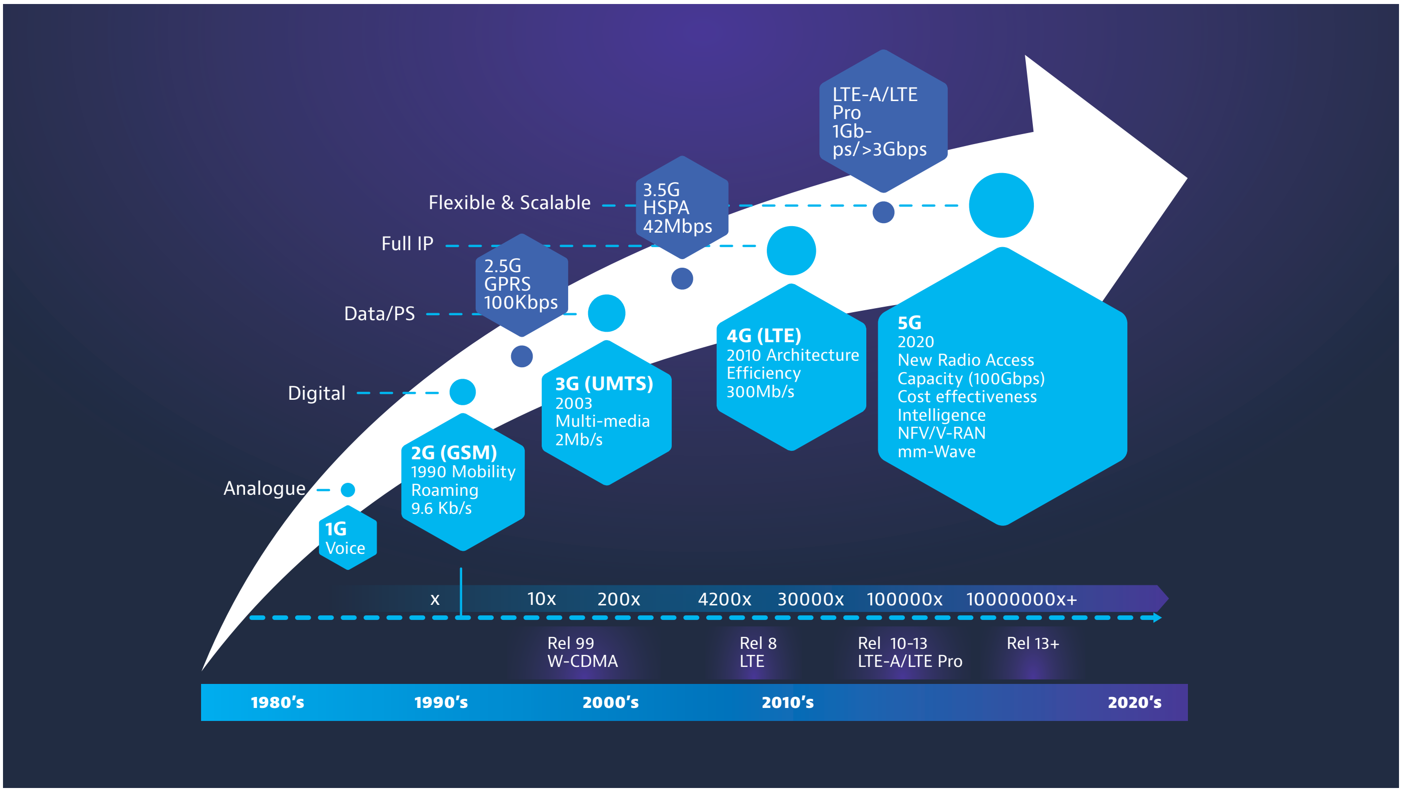
White Paper

The Path to 5G

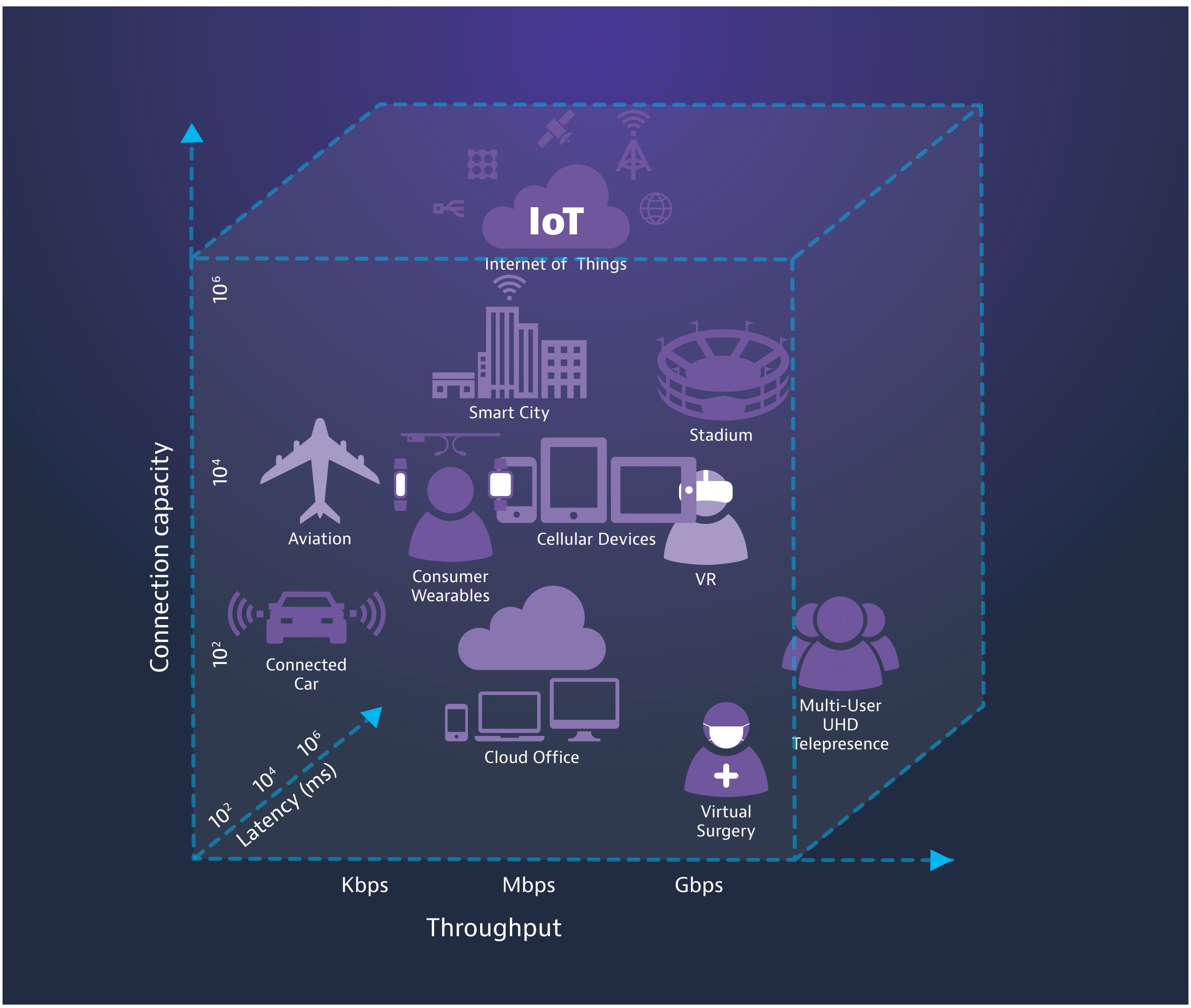
Wireless technology has revolutionized the way we live and the way we work, especially with the introduction of smartphones, wireless sensors, and IoT. We are now so dependent on our mobile devices and our networked environment that wireless connectivity has become part of the basic-human-need pyramid in modern society. While this phenomenon has already greatly improved the quality of life by making things more accessible to us, it continues to challenge us and drive the wireless industry forward. The ever-growing ecosystem of applications for entertainment, business, and mission-critical tasks is propelling the technology change to unprecedented levels.



Evolution of wireless communication

Overall, there is an expectation that 5G will be an innovation platform that provides the ability to bring new services to market quickly. This will enable service providers to take advantage of market opportunities and dynamically meet changing consumer and business needs. Some of these use cases include:

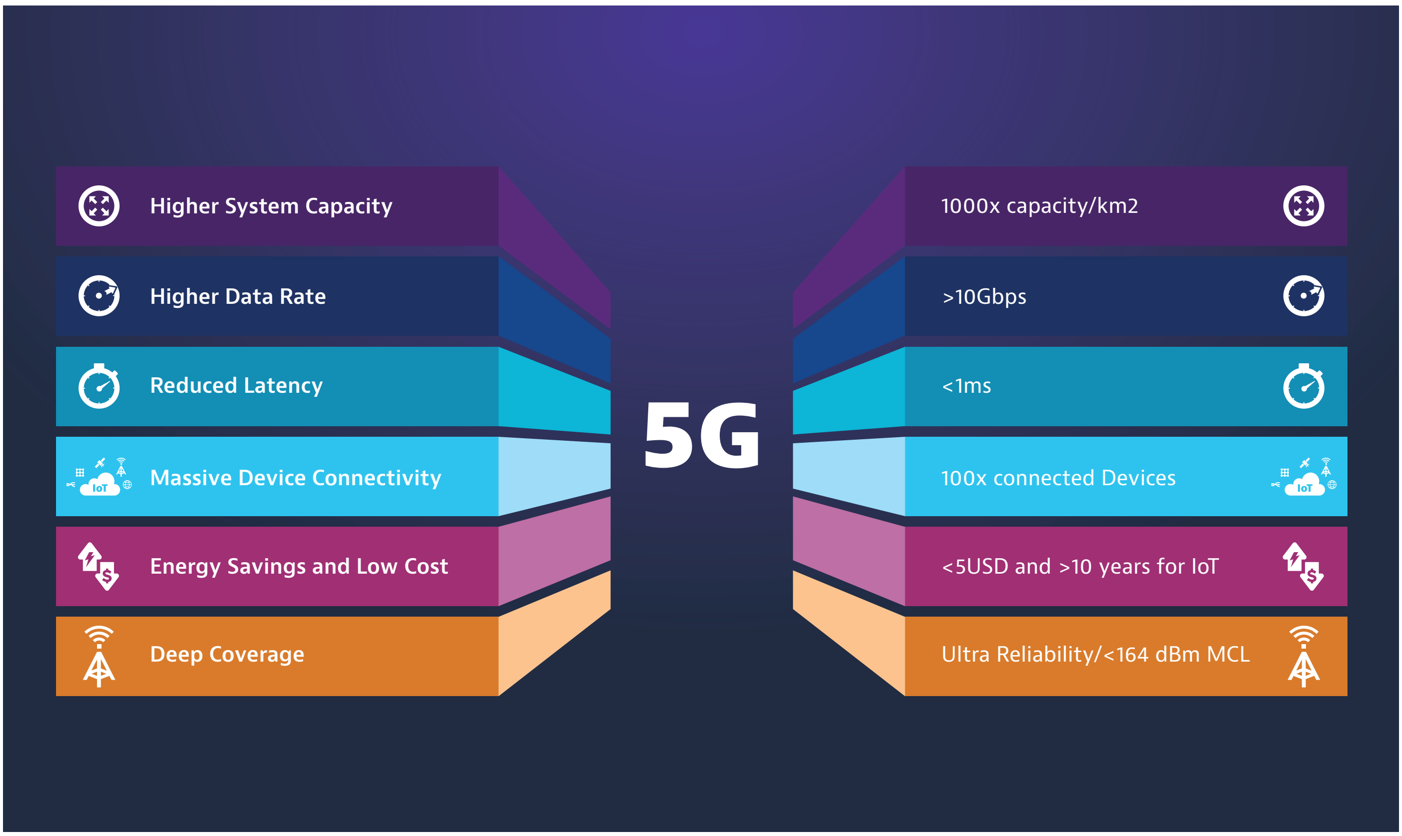
- Mobile Internet of Things (IoT) that connects billions of sensors and machines.
- Ultra-Fast-Broadband that delivers gigabytes of bandwidth on demand.
- Mission-critical communication that allows very low latency and near real-time feedback with high reliability and enables new applications such as autonomous driving and remote surgeries.



5G will offer dynamic opportunities to service providers and their customers

The evolutionary changes to LTE that will help to deliver the above use cases will be spread over multiple network components, interfaces, and releases, of 3GPP. To understand this evolution it is essential to walk through some of the various network enhancements that have been proposed and implemented over the years and how these enhancements complement each other to deliver a comprehensive solution.

5G requirements:

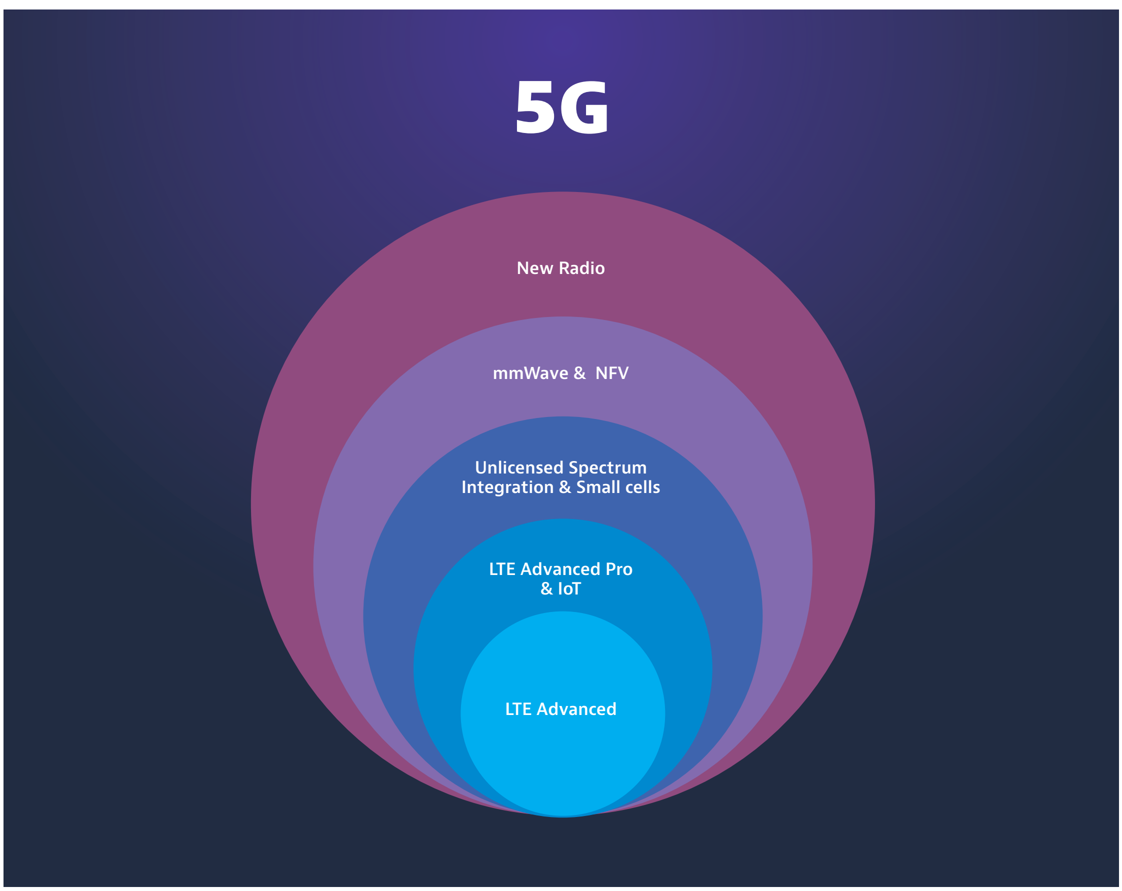


5G requirements

Radio Technology Enhancements

5G RAN requirements involve a heterogenous combination of the enhancements delivered over multiple releases plus new radio (NR) enhancements being proposed to the 3GPP forum. The set of radio access technologies required to satisfy future requirements must be adaptable yet efficient to support a diverse set of services for massive connectivity, massive capacity, ultra-reliability, low latency, etc. The network must adapt to the use case it is serving.

Consider the use case involving connected cars. In this case, a 5G or the 5G network must offer contiguous connectivity to ensure crucial reliable service. Most connected devices produce multiple kinds of data traffic, sending less user data than a typical smartphone. But, the type of continuous data coming from connected cars will require a lot of signaling relative to the small user data volume, which again is dramatically different than the traffic characteristics of standard smartphones. This will require low latency and high-availability, time-sensitive connectivity that requires enhanced security, much higher than a smart phone. The network must also be able to perform over-the-top (OTT) application updates and security patches. Within the same vehicle, multiple passengers may be watching high-definition videos simultaneously; in this case the same network is required to meet multiple distinct sets of performance characteristics. The same network area may also have to support industrial IoT or other services which may have a separate set of service requirements. Add to this mix the use cases of cars connecting to infrastructure like traffic lights control systems and cameras, as well as emergency services network slicing - and you can quickly see how networks for both core and RAN must be able to adapt to the type of the services being offered and that no single solution will satisfy all these extreme requirements at the same time.



5G progression

Unlike previous technology inflexions such as 2G to 3G or 3G to LTE, 5G radio service will be a combination of LTE enhancements plus an overlay of new radio (NR) access technologies. As shown in Figure 1, radio feature enhancements delivered over multiple releases will complement the overall radio access technology (RAT) to keep pushing the boundaries to allow for a more unified air interface for all spectrum and services.

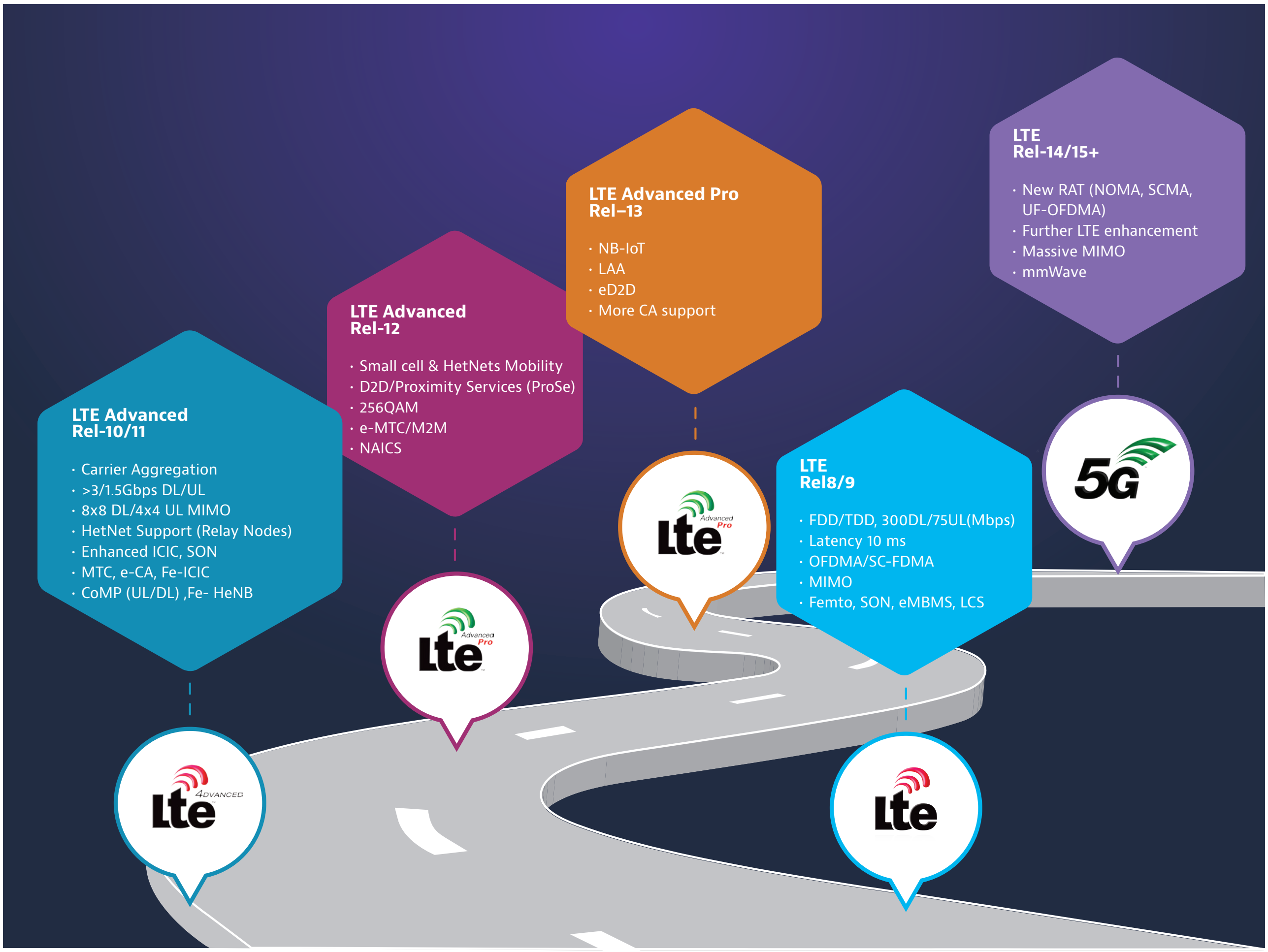


Fig 1: 5G RAT roadmap

Key drivers of 5G RAT

Enhanced Mobile Broadband (eMBB):

eMBB provides higher speeds for applications such as streaming, web access, video conferencing, and virtual reality. Beginning with LTE release 8, LTE has continued to evolve over subsequent releases. Today, different releases (from 8 to 12) are widely deployed offering a series of innovations that have significantly improved RAN performance, efficiency, and capabilities.

Enhancements that are part of 3GPP Releases 10, 11, and 12 are commonly referred to as LTE-Advanced. Enhancements in the subsequent releases, i.e. releases 13 and 14, are specified LTE-Advanced Pro. It is expected that these innovations will continue through the end of this decade, at which time new radio (NR) requirements are expected to be introduced.

The following roughly ranks the most important features of LTE-Advanced and LTE-Advanced Pro delivered during this timeframe:

1. **Carrier Aggregation:** Carrier aggregation allows operators to aggregate radio carriers in the same band or across disparate bands to improve throughputs, capacity, and efficiency. Carrier aggregation can also combine FDD and TDD and is the basis of LTE-Unlicensed (LTE-U) and LTE- License Assisted Access (LTE-LAA). Rel-13 introduced support for carrier aggregation of up to 32 carriers. The basic premise of carrier aggregation is pooling efficiency. A fair comparison will be a single lane road (single carrier) to a multi-lane highway (carrier aggregation), a single high demand user can use the other carriers if they are available vs. being stuck on one assigned busy carrier.
2. **Higher Modulation schemes (256DAM DL/64QAM UL):** Defined in Release 12 and already being deployed, higher-order modulation increases user throughput rates in favorable radio conditions, basically it is possible to transmit more bits per symbol (higher throughput) under excellent radio conditions.

3. **Tighter Integration of LTE with Unlicensed Bands:** Spectrum is the most important asset for any radio network, taking advantage of unlicensed spectrum can significantly improve an operator's business case for eMBB service.

   LTE-U would allow cellphone carriers to boost coverage in their cellular networks by using the unlicensed 5 GHz band already populated by Wi-Fi devices. LTE-U is intended to let cell networks boost data speeds over short distances, without requiring the user to use a separate Wi-Fi network. It differs from Wi-Fi calling as the control channel is served over the cellular LTE network, but all data (not just voice) flows over the unlicensed 5 GHz band, instead of the operator's licensed frequencies. LTE-U became available for testing in 2016.

4. **Higher order MIMO and Massive MIMO:** Extension of MIMO that was already introduced in LTE and enhanced as part of LTE-Advanced to hundreds of antennas at the base station, enabling spatial multiplexing and beamforming. A tripling of spectral-efficiency over LTE-Advanced configurations is expected. Additionally, mmWave deployment will make it possible to deploy massive MIMO.

5. **Coordinated Multi Point (CoMP):** CoMP is a process by which multiple base stations or cell sectors process a User Equipment (UE) signal simultaneously, or coordinate the transmissions to a UE, improving cell-edge performance and network efficiency. Initial usage will be on the uplink because no user device changes are required.

6. **Heterogeneous Network (HetNet) Support:** HetNets integrate macro cells and small cells. A key feature is enhanced inter-cell interference coordination (eICIC), which improves the ability of a macro and a small cell to use the same spectrum. This approach is valuable when the operator cannot dedicate spectrum to small cells. Operators have started to deploy and evaluate eICIC. Further enhanced ICIC (feICIC) introduced in Rel-11 added advanced interference-cancellation receivers into devices.

7. **Dual Connectivity:** Introduced in release 12, dual connectivity also known as Inter-site carrier aggregation, is used to achieve carrier aggregation between sites. This is an attractive solution for HetNets with no ideal backhaul network. Dual connectivity allows mobility management to be maintained on the macro layer while aggregating small cells to provide extra user plane capacity.

Fig. 2 : eMBB Evolution

mm-Wave:

Certain use cases of eMBB demand fiber-like connectivity, meaning the ability to offer multi-gigabit-per-second throughput for services like 3D telepresence and virtual reality. This level of network capacity would only be realized if more spectrum was made available. To accomplish this, the U.S. Federal Communication Commission approved plans to open nearly 11 gigahertz of millimeter wave spectrum in support of mobile telecommunications. Millimeter wave spectrum is the band above 28 GHz.

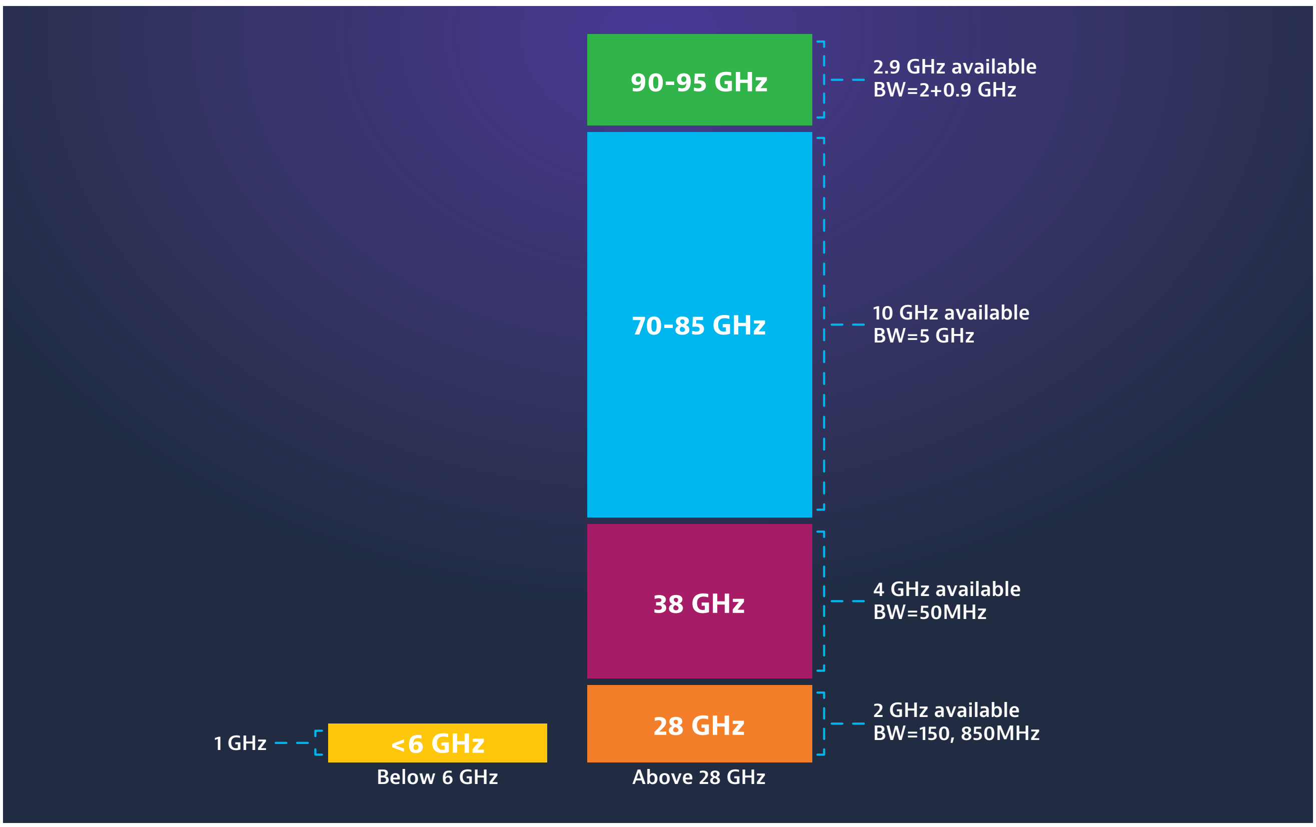


Fig 3: mmWave spectrum comparison with sub 6GHz

The size of the available bands above 28GHz is significantly large when compared to the different licensed and unlicensed services offered below the 6GHz spectrum. Higher band millimeter wave offers higher bandwidth and throughput due to the sheer size of the available transmission bandwidth. The characteristics of the tiny wavelengths, especially in outdoor environments, create challenges that need to be understood and resolved. High frequency means narrow wavelengths, meaning mmWave are more vulnerable to gases, rain and humidity, and as result they suffer from high propagation loss and are more susceptible to blockage.

Although poor propagation is characteristic of mmWave and a major concern, it significantly reduces the size of the antenna array, as wavelength (λ) is directly proportional to the size of the antenna element, allowing larger antenna arrays with smaller antenna elements. Larger antenna arrays can mitigate propagation losses, especially by using advanced beam forming techniques. Experimental systems using antenna arrays have demonstrated reliable communications at 28 GHz, even in dense, urban, non-line-of-sight conditions, for distances up to 200 meters. Arrays at the terminal side are space-constrained, but some basic beamforming at the terminal is possible. On the base station side, the arrays may include hundreds of antennas in an approach called "massive MIMO". Massive MIMO could also improve the SINR through narrow beamforming, pushing the system closer to a noise limited environment.

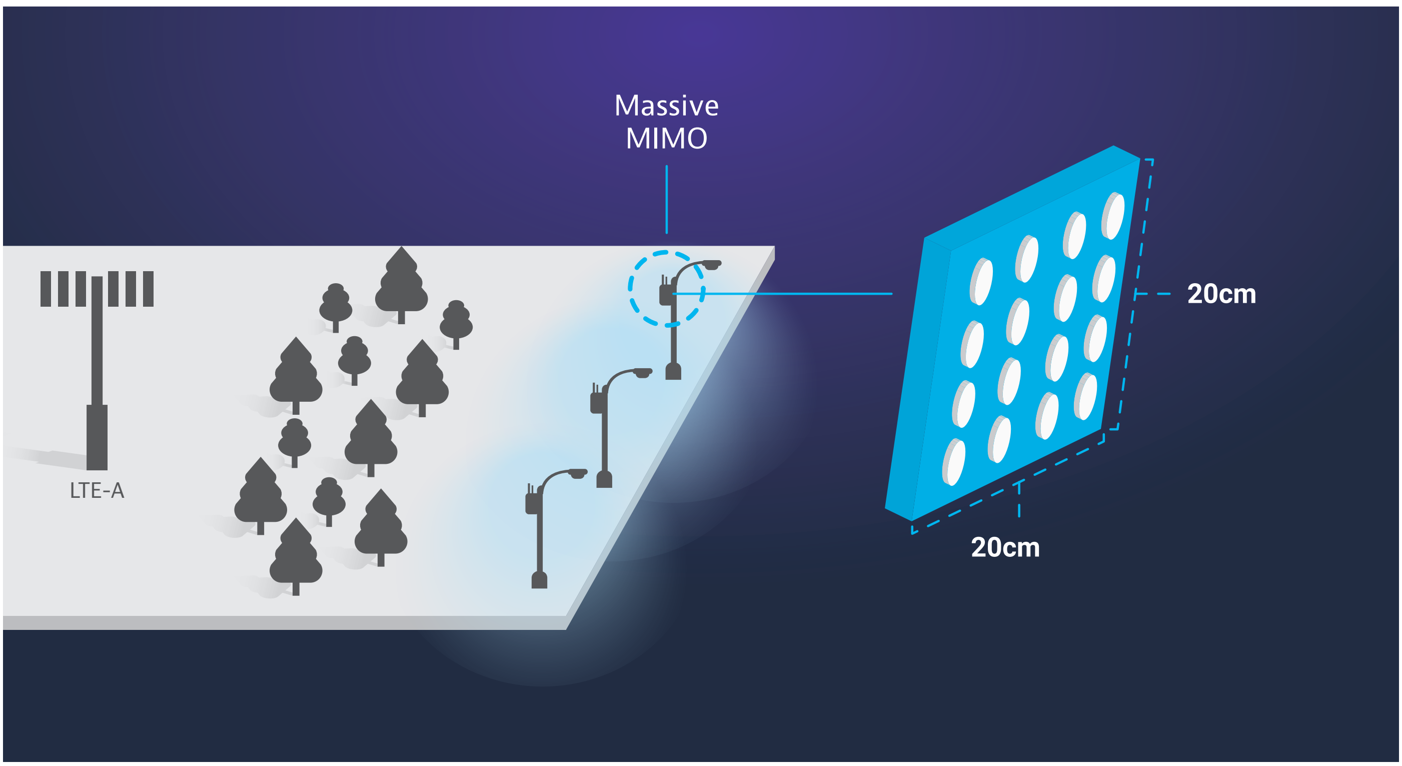


Fig 4: Massive MIMO

Therefore, combining the benefit from the potential availability of ten times the amount of spectrum, and using a combination of lower and higher frequencies, can be instrumental for 5G operation. Lower bands can be used for robust coverage and control, while higher bands can provide opportunistic access for high data rates. The lower and higher spectrum bands could operate in a carrier-aggregation or dual connectivity mode, or could use higher-layer aggregations such as multipath TCP and Multipath Quick UDP Internet Connections (MP-QUIC).

Evolved machine Type communication (eMTC):

IoT is expected to drive the next technological revolution that will change how we live and work. It will enable billions of devices with intelligent sensors and machine-learning capabilities that will communicate, sense, and interact with internal or external systems, all without human intervention. The massive IoT market segment includes several applications widely used in industry and society,, as shown in Figure 5.

Figure 5: MTC industry segments

Current cellular technology is not very well optimized for eMTC. Low-Power Wide-Area (LPWA) solutions and services have been around for many years, but are fragmented and non-standardized- leading to certain shortcomings like poor reliability, poor security, and complex deployment, as well as high operational and maintenance costs.

Narrowband IoT (NB-IoT)

To overcome these challenges, 3GPP started working on standardization of the requirements for new cellular-based narrowband technology targeted for the IoT. The first version of the NB-IoT standard was released in June 2016, as part of Release 13 of the global 3GPP standard. In parallel, a pure LTE-based solution, LTE-M, was also brought into 3GPP, continuing the optimizations already done in Release 12 with the introduction of a new device category cat-M1. However, deployment flexibility and other optimizations offered by NB-IoT may make it a better solution for efficient utilization of spectrum and other network resources.

Some of the key requirements for cellular IoT to enable the above-mentioned services and to efficiently compete with non-cellular technologies can be summarized as follows:

- **Long battery life** – more than 10 years, as many IoT devices will be battery-powered, and often the cost of replacing batteries in the field is not viable.
- **Low device cost** – sub $–5 USD per module, for a positive business case when billions of devices need to be integrated this is a must have.
- **Low deployment cost** – plug-and-play to reduce OpEx.
- **Extended coverage** – 164 dB maximum coupling loss (MCL), 20dB better than General Packet Radio Service (GPRS), typically NB-IoT devices tend to be placed in signal-challenged location like basements and remote rural areas.
- **Support for a massive number of devices** – 40 devices per household or 50K per cell.

Although NB-IoT is integrated into the LTE standard, it can be considered as a new air interface and thus not fully backward compatible with existing 3GPP devices. However, it is designed to achieve excellent co-existence performance with legacy GSM, GPRS, and LTE technologies.

NB-IoT requires 180 kHz minimum system bandwidth for both downlink and uplink, respectively. The choice of minimum system bandwidth enables several deployment options for NB-IoT as shown in figure 6 below.

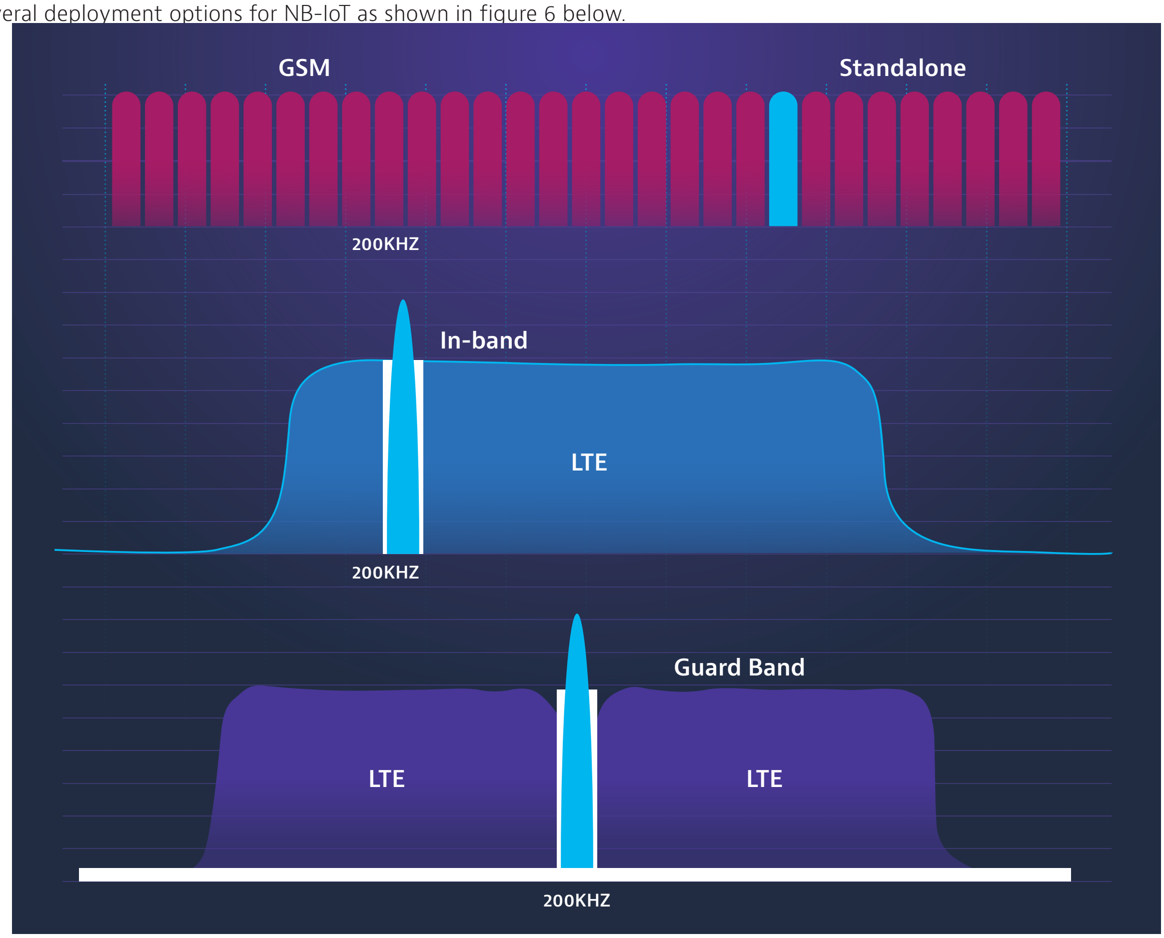


Figure 6: Deployment options for NB-IoT

Deployment options for NB-IoT

There are a few options for deploying NB-IoT:

Standalone – replacing a GSM carrier with an NB-IoT carrier

- GSM is still the dominant mobile technology in many markets and the significant majority of cellular M2M applications today use GPRS/EDGE for connectivity. By reframing one or more of the GSM carriers to carry NB-IoT traffic, GSM operators can ensure a smooth transition to LTE for massive MTC in the future. This approach will also accelerate IoT time-to-market, maximize the benefits of a global-scale infrastructure and future-proof IoT investments.

In-band – flexible use of part of an LTE carrier

- The LTE in-band option provides the most spectrum- and cost-efficient deployment of NB-IoT for service providers with LTE service. The in-band option sets NB-IoT apart from any other LPWA technology. The NB-IoT carrier is a self-contained network element that uses a single physical resource block (PRB). If there is no IoT traffic, a Physical Resource Block (PRB), available for an NB-IoT carrier, may be used instead for other purposes, as the infrastructure and spectrum usage of LTE and NB-IoT are fully integrated. The base station scheduler multiplexes NB-IoT and LTE traffic onto the same spectrum, which minimizes the total cost of operation for MTC, which essentially scales with the volume of MTC traffic.

LTE system bandwidth	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
LTE PRB indices for NB-IoT synchronization	2, 12	2, 7, 17, 22	4, 9, 14, 19, 30, 35, 40, 45	2, 7, 12, 17, 22, 27, 32, 42, 47, 52, 57, 62, 67, 72	4, 9, 14, 19, 24, 29, 34,39, 44, 55, 60, 65, 70, 75, 80, 85, 90, 95

Guard band – Applies to both WCDMA or LTE

- A third alternative is to deploy NB-IoT in a guard band, which allows NB-IoT to operate without causing interference. In contrast to other LPWA technologies, the physical NB-IoT layers have been designed with the requirements of in-LTE-guard-band coexistence specifically taken into consideration.

Again, like LTE, NB-IoT uses OFDMA in the downlink and SC-FDMA in the uplink. The design of NB-IoT has fully adopted LTE numerology, using 15kHz subcarriers in the uplink and downlink, with an additional option for 3.75kHz subcarriers in the uplink to provide capacity in signal-strength-limited scenarios.

NB-IoT Enhancements

Device affordability and battery life are the key to successful deployment of massive MTC. Low data rates and relatively relaxed latency requirements for NB-IoT devices offer an opportunity to reduce solution complexity – and cost. Some of the needed changes for NB-IoT to get to a simpler and cost-reduced device are:

- Reduced peak physical layer data rates-in the range of 100–200kbps or significantly lower for single-tone devices.
- FDD-only and half-duplex User Equipment (UE) support. For half-duplex support, every switch from UL to DL or vice versa there is at least one guard subframe (SF) in between, where the UE has time to switch its transmitter and receiver chain.
- Turbo codes replaced with convolutional codes for downlink transmissions to facilitate low-complexity decoding in devices.
- Coverage extension by trading off data rate through increasing the number of repetitions. Coverage enhancement is ensured also by introducing single subcarrier Narrowband Physical Uplink Shared Channel (NPUSCH) transmission and $\pi/2$-BPSK modulation to maintain close to 0 dB PAPR, thereby reducing the unrealized coverage potential due to power amplifier (PA) back off.
- Preamble-based Random Access on 3.75 kHz.

  NPUSCH provides two subcarrier spacing options: 15 kHz and 3.75 kHz. The additional option of using 3.75 kHz provides deeper coverage to reach challenging locations, such as deep inside buildings, where there is limited signal strength.

- The data subcarriers are modulated using binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) with a phase rotation of $\pi/2$ and $\pi/4$ respectively.
- Both single tone and multi-tone transmission is supported.
- Maximum transport block size (TBS) 680 bits in downlink, 1000 bits in uplink is supported.
- Narrow band physical downlink channels of 180 kHz equivalent to 1 PRB of LTE. Benefit of a narrowband technology lies in the reduced complexity of analog-to-digital (A/D) and digital-to-analog (D/A) conversion, buffering, and channel estimation – all of which bring benefits in terms of power consumption
- A single receiver antenna is used, enabling radio and baseband demodulator parts to be only a single receiver chain.
- Design changed in terms of the placement of the device's power amplifier (PA). Integrating this element directly onto the chip, instead of it being an external component, enables single-chip modem implementations – reducing device cost.
- Single-process, adaptive and asynchronous HARQ for both UL and DL is supported.
- Maximum PDCP SDU size of 1600 bytes is supported.
- Extended Idle mode DRX with up to 3-hour cycle, connected mode DRX with up to 10.24 s cycle, allows battery longevity.
- Offers same authentication and core network signaling security as in normal LTE.
- Data transfer over Non-access stratum (NAS) signaling is also supported, which enables the usage of other delivery protocols than IP as well
- Access stratum (AS) optimization called RRC suspend/resume to minimize the signaling needed to suspend/resume user plane connection.
- No support for circuit switched services
- No support Inter-RAT mobility, intra-RAT mobility will be managed by cell reselection.

Latency

One of the major goals of 5G is to offer Ultra-Reliable and Low Latency Communications (URLLC). URLLC sits at the heart of mission-critical applications like drone control, remote surgeries, and self-driving cars. These types of applications are potentially the ones that will deliver the greatest societal benefits. Driven by high dependability and extremely short network traversal time, URLLC will enable mission-critical applications. Per 3GPP TR 38.913 (V0.3.0, Mar. 2016), the targets are identified as 0.5 msec for DL and 0.5 msec for UL for URLCC and 4 msec for UL and 4 msec for DL for eMBB. Few of the proposed work items under consideration to achieve those targets can be summarized as:

Non-Orthogonal Multiple Transmission: Orthogonality in OFDM avoids interference and creates high capacity but requires extensive signaling and increases delay. Non-Orthogonal Multiple Access (NOMA) and Sparse Coded Multiple Access (SCMA) could complement orthogonal access by taking advantage of advanced interference-cancellation techniques thereby reducing latency for small payloads.

New multi-carrier radio transmission: LTE uses OFDM, but other potential multi-carrier schemes include Filter-Bank Multi-Carrier (FBMC) transmission, Universal Filtered Multi-Carrier (UFMC) transmission, and Generalized Frequency-Division Multiplexing (GFDM) are being studied as part of 5G new radio interface. Potentially it can lower latency on uplink transmission due to lower synchronization requirements.

Mobile-Edge Computing: ETSI is standardizing Mobile-Edge Computing, a technology that empowers a programmable application environment at the edge of the network, within the RAN. Goals include reduced latency, more efficient network operation for certain applications, and an improved user experience. Although MEC emphasizes 5G, it can also be applied to 4G LTE networks.

Applications that will benefit are ones that require server-side processing but are location-specific. Examples include:

- Augmented reality.
- Intelligent video processing, such as transcoding, caching, and acceleration.
- Connected cars.
- Premise-based IoT gateways.

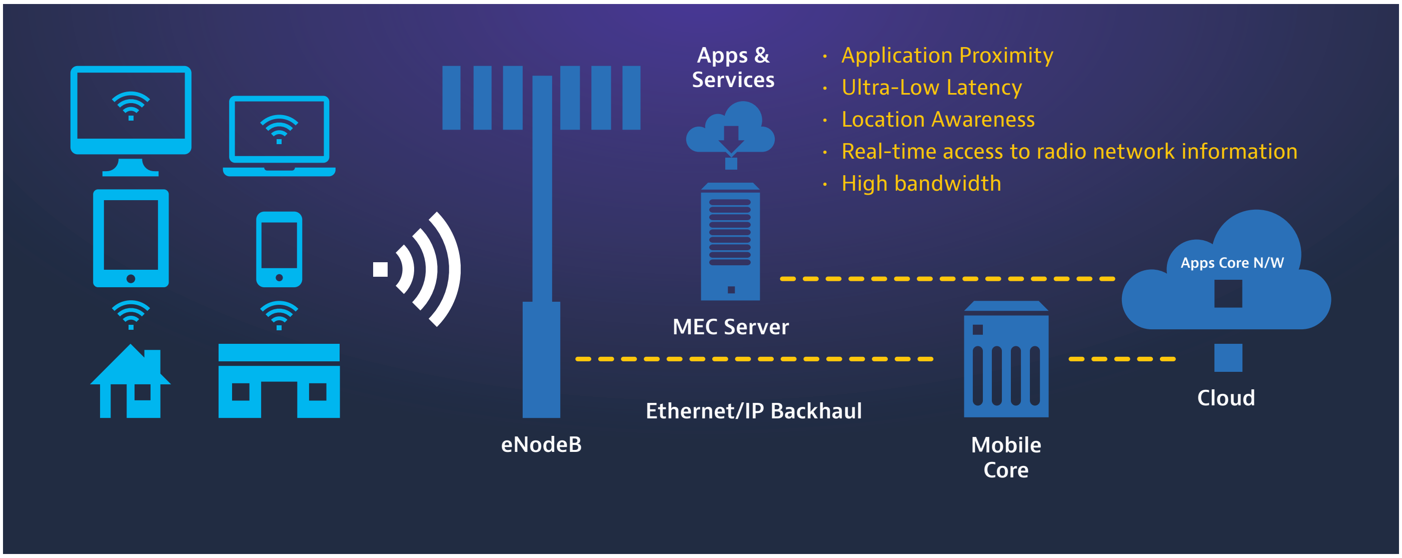


Figure 7: Mobile Edge computing

Backhaul, front haul and cross haul

As discussed earlier, 5G network technologies will demand extreme bandwidth and for certain use cases ultra-low latency. To achieve those objectives an efficient fronthaul, and backhaul solution is required. Fiber fronthaul with CPRI or OBSAI technology which is the link between the RRH and the BBU has been widely deployed in the distributed RAN.

CPRI/OBSAI allow operators to evolve their networks to a Centralized RAN (C-RAN) architecture enabling much more efficient use of resources and differentiated services. In C-RAN, service providers are co-locating a group of BBUs at a remote location; while the remote radios are connected to the BBUs via a fiber link. The co-location of BBUs enables service providers to take full advantage of cell coordination schemes offered in LTE-Advanced. For example, the Coordinated Multipoint (CoMP) feature requires close coordination between several geographically separated eNode-Bs (eNBs). eNBs dynamically coordinate to provide joint scheduling and transmissions as well as joint processing of the received signals. In this way, User Equipment (UE) at the edge of a cell can be served by two or more eNBs to improve signal reception / transmission and increase throughput, particularly under cell edge conditions. However, to achieve that, the eNBs should be able to provide a very low level of latency. The additional processing required for multiple site reception and transmission could add significantly to delays. Having BBUs co-located in a C-RAN architecture helps in those scenarios.

As we move forward from centralized RAN to cloud RAN, BBU pooling, dynamic resource allocation, higher bandwidth, and ultra-low latency will continue to improve CAPEX and OPEX while providing performance benefits. CPRI, based fronthaul links are already known for their stringent delay and jitter requirements. However, in the cloud RAN environment, the need to closely coordinate transmission for dense radio deployments will create unprecedented requirements for throughput, latency, timing, and synchronization.

Currently, CPRI is limited to a 24 Gbps capacity, which is sufficient to carry approximately 2 Gbps of traffic from the cell site. For example, a 20MHz LTE channel that can deliver up to 150 Mbps in the downlink direction will require a CPRI data rate of 2.5 Gbps. This may not be enough for 5G networks, where cell-sites may be delivering data at tens of Gbps per sector. Fronthaul bandwidth is not the only challenge for 5G deployments; CPRI also demands tight delay and delay variation budgets that lead to limitations in the distance and transport technologies that can be used for aggregation and switching. These challenges have created multiple industry initiatives to help mobile network operators manage transport challenges by leveraging a mix of technologies. Projects like Next-Generation Fronthaul Interface (NGFI), and 5G-Xhaul forum are working to provide platforms for vendors and service providers to deploy 5G networks with varying network capacity and latency demands. NGFI proposal is based around two things:

1. Functional split between the BBU and the RRU functionality, where some of the baseband processing functions are moved to the RRU, off course this will change the BBU and RRU architecture.
2. Fronthaul changes from a point-to-point connection into a multiple-to-multiple fronthaul network, using packet switch protocols.

The different functional splits between the wireless protocol stack (RRC, PDCP, RLC, MAC and PHY) will offer multiple options and depending on the application demand, a certain option may be considered. For example in one option where RRC and PDCP functions stay with the BBU, whereas the other functions may reside as part of the radio system, this option is more beneficial for fixed wireless applications that naturally don't rely on cell site coordination and are dependent on a fronthaul interface with relaxed latency budget and low bandwidth requirements. Similarly, for advanced mobility application with cell-coordination demand only PHY layer functionality may reside at the radio. This may be acceptable from a bandwidth perspective but latency and jitter requirements may need to be further analyzed.

Just like fronthaul, backhaul is also expected to evolve with 5G cellular networks. Fiber still is the best option where dark fiber is available, or where it is not cost prohibitive to deploy fiber, but with the availability of large chunks of spectrum in the mmWave band especially in V-band and E-band we expect to see more deployments of hybrid fiber and wireless backhaul solutions. mmWave propagation is limited, and is sensitive to weather conditions, and require LOS, but with technology enhancements such as massive MIMO and since the end points are fixed for backhaul, the above issues will be less challenging to ensure a reliable backhaul connection.

In brief, wireless backhauling is a promising alternative to fiber links and instead of being in competition with fiber, it will complement fiber solutions and can be considered as an extension of fiber, just like we saw fiber and copper being the access solution for the Fiber to the curb and cable business.

Another project that aims at improving the overall efficiency of backhaul and fronthaul is the 5G-Crosshaul project which aims at developing a 5G integrated backhaul and fronthaul transport network, utilizing NFV and SDN technologies. The goal is to develop a 5G X-haul transport network that offers flexibility in interconnecting distributed 5G radio access and core network functions, hosted on cloud nodes, through the implementation of a control plane and a unified data plane encompassing innovative high-capacity transmission technologies and novel deterministic-latency switch architectures.

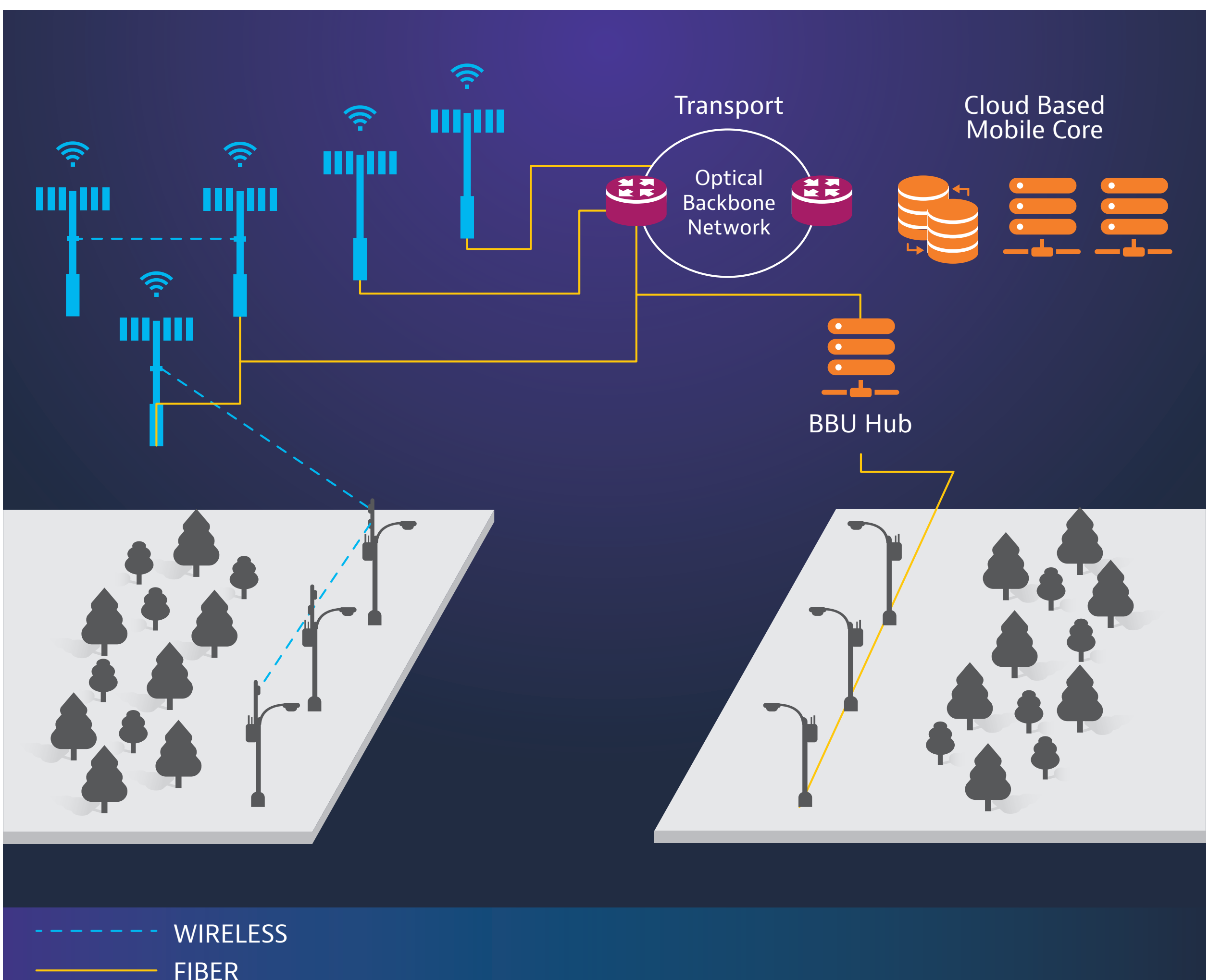


Figure 8: Backhaul/Fronthaul application

Core Network Enhancements

Evolution to 5G is not just about delivering high speed, 5G evolution is going to have a profound impact on how we build, utilize and monetize on network investments. One of the key components of 5G is network function virtualization (NFV). Virtualizing network functions by leveraging software defined network (SDN) will allow service providers to break away from costly and time-consuming network upgrades on their proprietary network framework to open standard-based cloud architectures. NFV/SDN as well as management and orchestration processes, must work in harmony with a flexible radio-access network so that it can adapt to different requirements and deployment models. This revolution will drive cost and network efficiencies and will offer service providers the flexibility and agility not just in deployment but also in offering mission-critical and customized services for their customers. Having the ability to offer logical network slices, will allows operators to offer networks on an as-a-service basis and will prepare them for a wide range of use cases that will be demanded by the technology of the future.

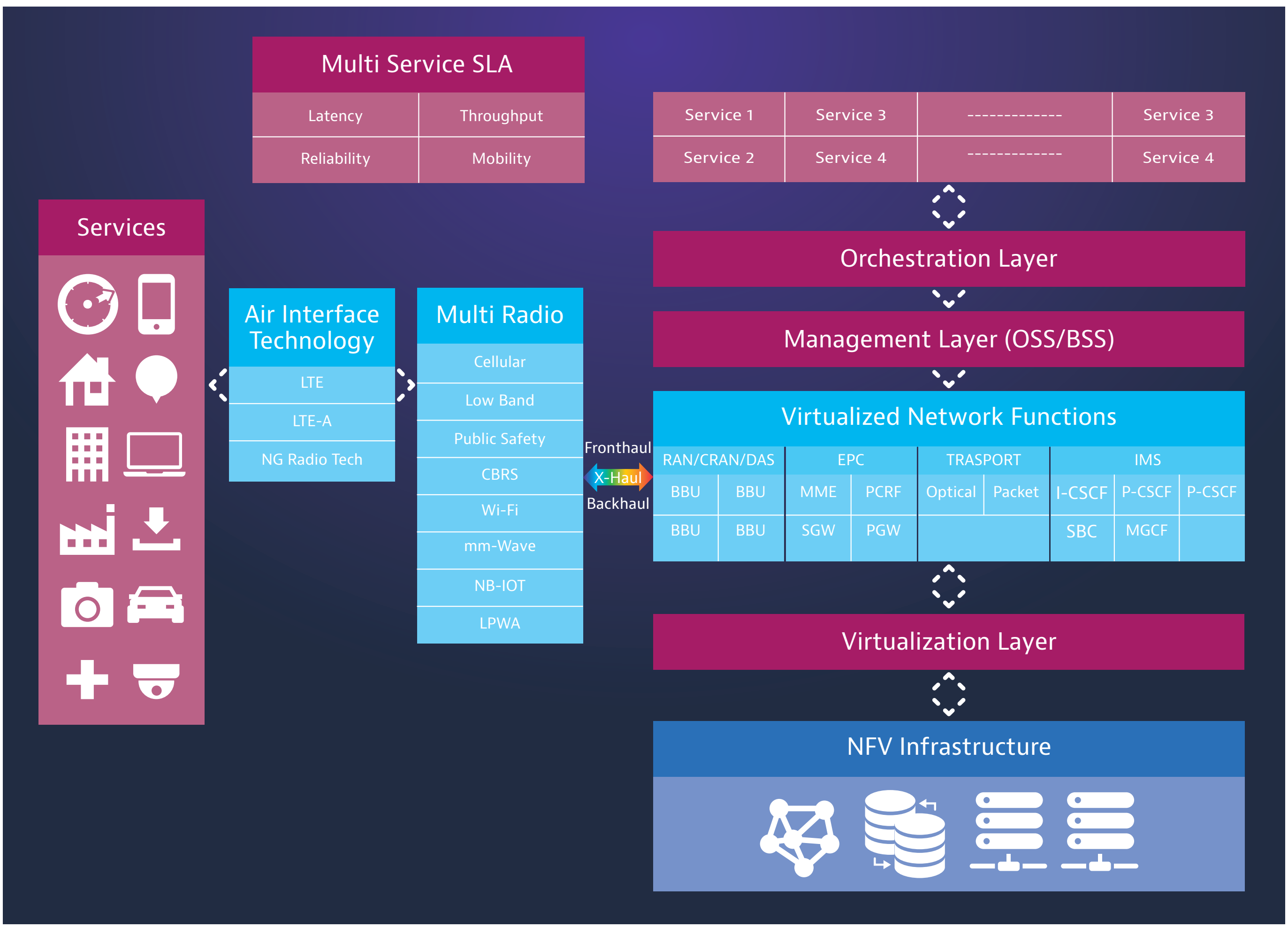


Figure 9: Virtualized Network with multiple network slices for multiple services

5G will also open up the potential where multiple service providers can be allowed to operate from one network and computing infrastructure. This can only be achieved through a sophisticated integration of massive computing and storage infrastructure with potentially different network and user policies. Service providers can also choose to offer their services through one or multiple infrastructure operators. To achieve such a flexibility, network operators must deploy smart orchestrator functions that can allocate appropriate computing, storage and network resources to create diverse and dedicated business-driven logical networks. These logical networks, also known as network virtual functions or network slices, will contain specialized networking and computing functions that meet the desired KPIs of the service providers. Note that in cases where a single infrastructure provider is not on its own able to support the requirements of a service provider, 5G networks will support cross-domain orchestration of services and resources over multiple administration domains allowing for flexible sharing schemes.

Service activation and performance management in 5G Networks

5G encompasses a convergence of a wide array of technologies such as NG-radio, mm-wave, massive MIMO, virtualization of network functions, eCPRI, RFoEthernet, NB-IoT, mobile edge computing with multiple applications with varying performance demands. One thing we can all agree is that the scale of the network will be much larger, where all the different heterogenous network components will have to work in harmony. From a service provider perspective, it will be essential to be able to scale resources to this ever-evolving network of networks. The traditional methods of service activation will not scale. Automation of service activation and performance management will be the key.

Where virtualizing network functions allows service providers the flexibility and agility to launch new services and break away from costly and time-consuming network upgrades on proprietary networks, it also enhances their ability to manage network service level agreements (SLAs) in real time, by virtualizing service activation, performance monitoring and other vital support functions.

Virtual test and assurance will enable operators to leverage generic, off-the-shelf servers in their networks (which host other virtual services for the operators) to host software-based test agents (e.g. VNFs). The virtual probes/test agents will measure network performance prior to a new service activation, and will continue to autonomously monitor service performance thereafter.

Fundamentals for virtualized test and measurement include:

1. Automated service turn-up and acceptance testing
2. End-to-end operations, administration, and management (OAM) performance, optimization, and troubleshooting
3. SLA verification
4. Integration of test and performance measurements into the process of dynamic service orchestration via open software APIs

Some of the key challenges for the evolution of test and measurement in the NFV world can be summarized as follows:

Virtual Traffic Visibility

- Low overhead mechanisms for virtual traffic access
- Performance at Scale
- Hypervisor overhead/shared resource contention
- vSwitch performance

Managing Ever-Changing Network Topology

- Integration with orchestrator and virtual infrastructure management (VIM) to determine when network elements are created, modified and deleted
- Solution Integration Within an Open Ecosystem
- Evolving technology capabilities and standards
- Continuous innovation in an open architecture using open and defined software APIs

Support for Both Hybrid Configurations of Physical and Virtual Networks

- Continue to support and integrate static test and measurement solution while moving forward with virtualized networks

As 5G gets deployed, both physical and virtual networks will continue to coexist for a long time. Service providers need investment protection and the ability to leverage those physical instruments to continue to evolve in the virtualized world. They need virtual test solutions that will continue to work with their existing / planned tools and workflows with both physical and virtual network interfaces, and to be able to correlate data across those interfaces. They should also allow them to make test and performance monitoring an integral part of their service creation chain using standardized methods and interfaces and reduce CapEx/OpEx due to an automated service activation and assurance network lifecycle.

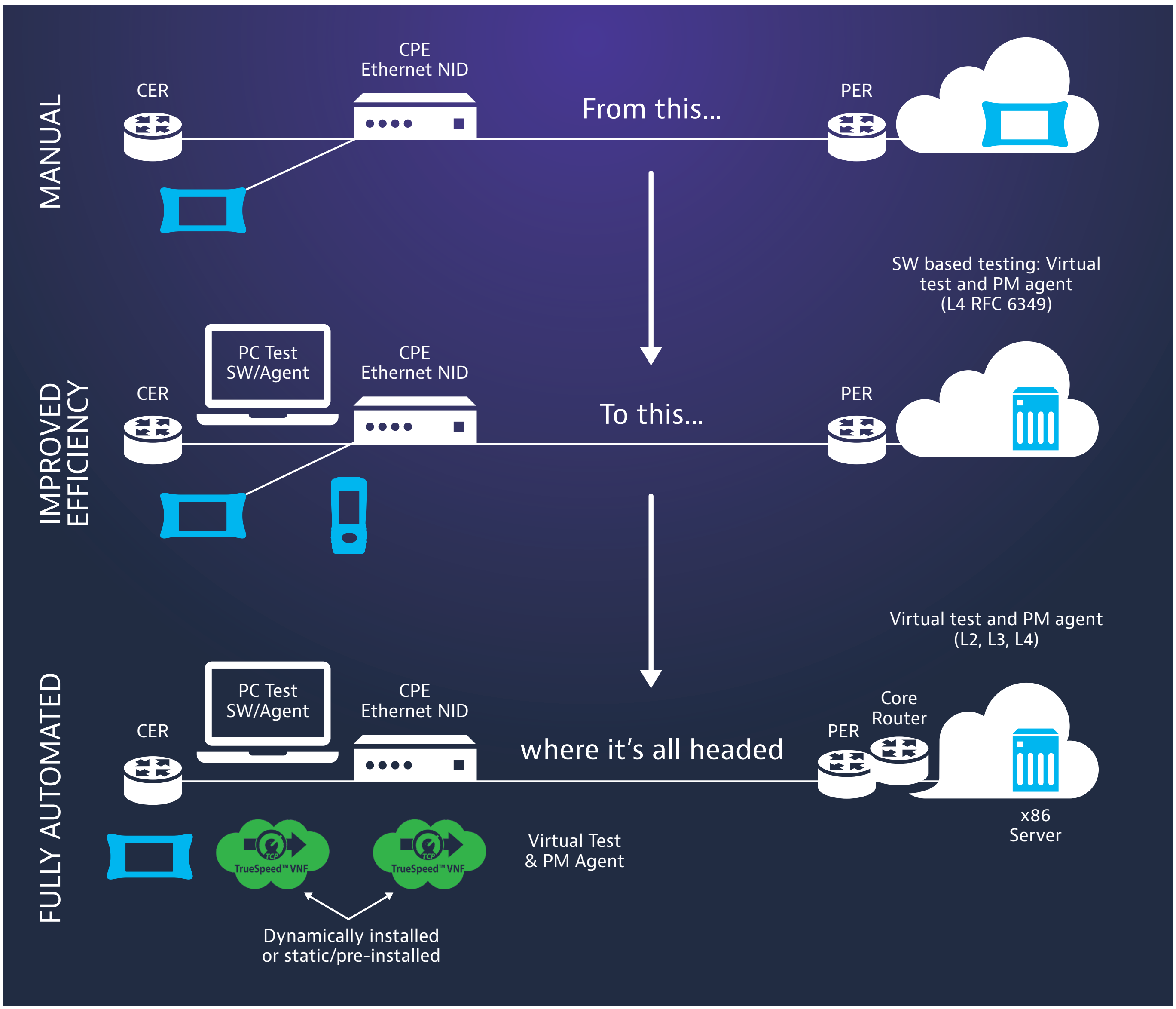


Figure 10: Example of test and measurement evolution

Why testing is becoming more important in 5G

As network user growth is stabilizing, service providers are looking for verticals to improve their ROI. 5G technology offers them the ability to achieve that, however, some of these verticals will offer major challenges in terms of network quality, reliability, and availability. For example, mission-critical applications will demand a network which can't fail, which means ensuring network quality will be at the core of the network deployment and management function. Whether it is the fiber interface, which will do all the heavy lifting in the network, or the air interface which will manage all the critical applications or the agile network core, all of them must be continuously monitored and optimized.

The quality of the network will depend on the rigor of test and measurement during the complete life cycle of the network. It is essential to ensure that all network components and their interfaces are delivering per design limit to reduce CAPEX and OPEX.

Conclusion

In 5G networks, virtual test, diagnostic, self-optimization, AI and analytics functions will be as necessary as the core network functions they support, and must be virtualized along with them. Once deployed, these capabilities enable dynamic optimization, assurance and troubleshooting functions, bridging both physical and virtual networks. With VIAVI's fully-integrated portfolio of cloud-enabled instruments and systems, software automation, and services for network testing, performance optimization, and service assurance, services providers can be assured that their investments will be protected. Highly flexible and interoperable, each solution allows network operators to leverage prior investments and streamline workflows for greater operational and capital efficiency. Customers obtain comprehensive intelligence and insight so they can manage increasingly complex network and service ecosystems.

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