Preparing for a 5G world:

An overview of the enabling technologies and hardware requirements

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As 5G deployment gains momentum globally, promising ultra-low latency, faster speeds, lower power consumption and many more connections, hardware companies and engineers are preparing their portfolios for 2020 and beyond.

While 4G was all about network capacity for consumers, or putting "the internet in your pocket," 5G will deliver much, much more.

What is 5G?

5G is the communications backbone that will enable revolutionary applications in other markets, including industrial, automotive, medical and even defense. For a world that is becoming increasingly connected with the Internet of Things (IoT), 5G's significant improvements in speed (at least 10 times faster than 4G, up to 10 Gbps), latency (10 times lower than 4G, down to 1 ms) and density (supporting 1 million IoT devices per square kilometer) will make many innovative applications possible – especially those in which security, reliability, quality of service, efficiency and cost are equally important.

As shown in **Figure 1**, 5G will connect things to services, with "things" residing in the consumer or enterprise space, and "services" typically residing in the cloud. The 5G network will be able to slice flexibly parallel connections, sized to best fit the level of service users request, and offer the best cost/performance compromise.

5G is not just another "G" in the communication standards evolution – it is an umbrella term comprising at least three major trends. In keeping with the International Telecommunication Union

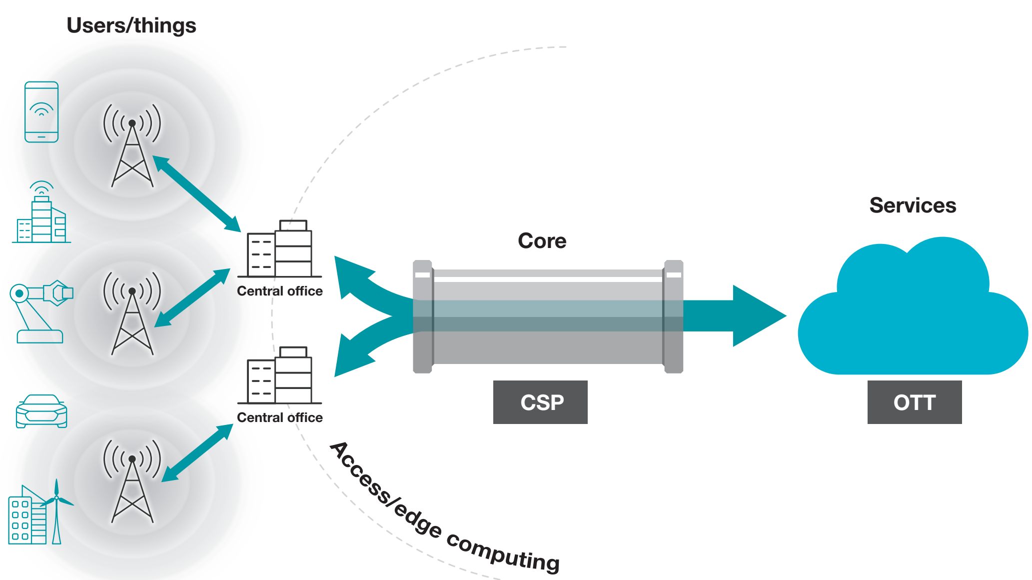

Figure 1*: How 5G connects users/things to services.*

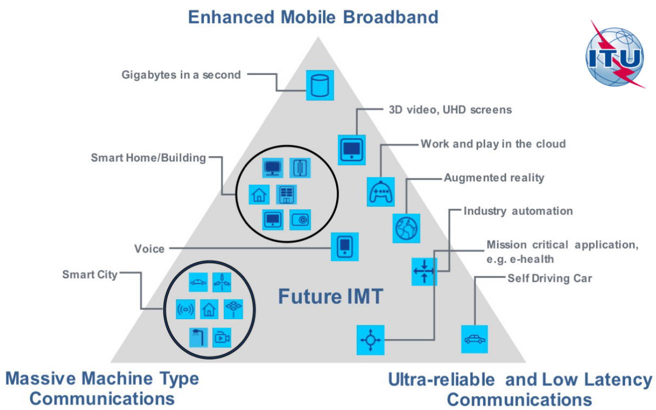

Figure 2: 5G usage scenarios from the [ITU-R IMT-2020 Vision Recommendation](#).

definitions (see **Figure 2**), the first of such trends is enhanced mobile broadband (emBB), which will enhance innovation areas like augmented and virtual reality. The second trend is massive machine-type communication (mMTC), involving ubiquitous sensor connectivity for the IoT. The third is ultra-reliable, low-latency communications for critical applications such as autonomous driving or remote surgery.

5G promises to be everywhere – in smartphones, cars, utilities, wearables, hospital operating rooms, large factories, grids and much more – moving closer to the concept of smart cities, smart manufacturing and a connected world.

Phased rollout

5G New Radio (NR) is linked to LTE-Advanced, which remains an essential part of the 5G platform, to guarantee operation over an existing core network infrastructure. This method has enabled the industry to make steady progress in the sub-6-GHz portion of the spectrum with the rollout of 3rd Generation Partnership Project (3GPP) Release 15, finalized at the end of 2017. Release 15 will power most early deployments of 5G until 2020.

However, the standard that will affect the spectrum above 6 GHz (millimeter wave) is Release 16, due out in the second half of 2019 (see **Figure 3**). Release 16 is instrumental to critical communications services, virtual reality and low-power wide-area (LPWA) IoT. This standard is expected to change the shape of the communications industry altogether by enabling many of the applications often touted as the true potential of the 5G vision, with all of the new capabilities – like spectrum sharing, the Cellular Vehicle-to-Everything (C-V2X) standard for automotive and more – baked in.

The business case for 5G adoption

The first business case for 5G is straightforward: It increases network capacity, speeds, reliability and availability, and lowers latency at the same cost as 4G.

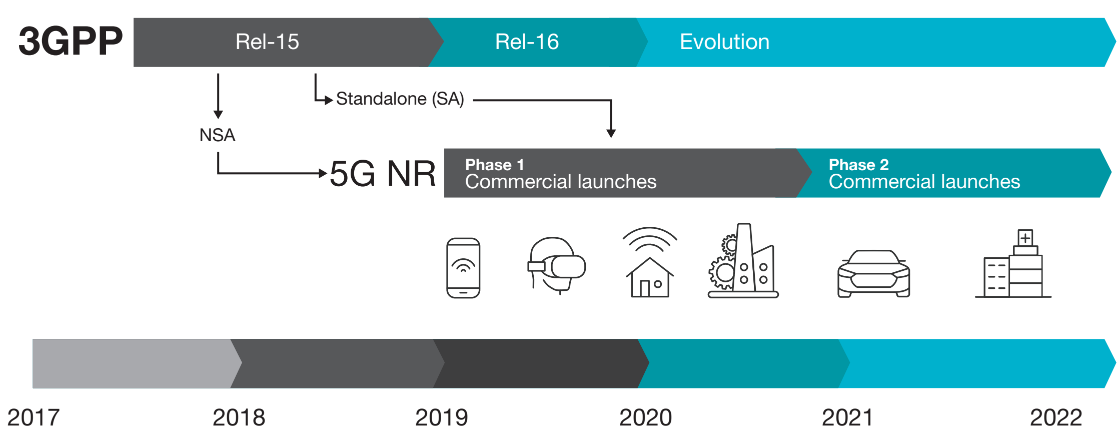

Figure 3: 3GPP release timeline.

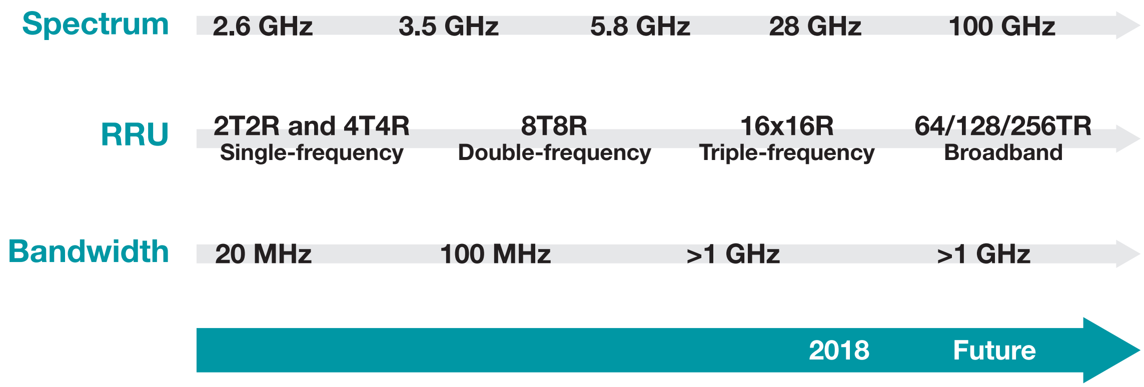

***Figure 4**: Radio parameters evolution.*

The second business case, which has already launched commercially in the United States, is the fixed wireless application, which uses millimeter-wave frequencies (still not 3GPP specified) to reach remote users as a cheaper installation alternative to optical fiber, offering connections of 300 Mbps or more (see **Figure 4**). That's good enough for most mobile operators globally who are participating in early 5G tests and trials, as well as those already building the infrastructure to support a 5G services launch – first in the core network, and also densifying the coverage with heterogeneous new cells.

Of those countries participating in early tests and trials, the U.S. has started its 5G rollout at a faster pace than any other country in order to prepare for the required cell-coverage densification, having lagged in terms of installed base transceiver stations (BTSs). For reference, in 2018 there are approximately 200,000 base stations installed in the U.S., while China maintains approximately 2 million. This, combined with the fact that China also maintains 70% of existing IoT connections globally, makes the respective countries' rollout needs quite different. Auctions for new frequencies have occurred or are scheduled in South Korea, Australia, the U.K., Italy, Spain, the U.S. and Germany as of this writing.

At Mobile World Congress 2018, Groupe Spéciale Mobile Association (GSMA) predicted that by 2023 there would be about 400 million 5G connections – 30% of those in the U.S. – spanning both consumer and enterprise applications.

Communication service providers (CSPs) are not the only ones getting excited about 5G, as plenty of unconventional players are also making moves in the 5G space. Over-the-top (OTT) media providers, including Facebook, Microsoft, Google and Amazon, are looking closely at the business opportunities. These OTT providers own the cloud, where most of the services reside, and therefore they are key players in the 5G mission. But they do not own the access portion, which is still fully managed by CSPs.

Characteristics of 5G

Many network functions have been already virtualized, even during 4G implementation, enabling the public cloud portion of the infrastructure (infrastructure as a service) to grow significantly. However, the pipeline remains firmly in the hands of CSPs. A symbiotically functioning system requires the establishment and smart management of a proper connection between providers and users. The evolution of these connections will include new technologies like network slicing and edge computing, which are significant new characteristics of 5G.

Network slicing

Bringing computing closer to users (edge computing) is an important piece of the 5G puzzle, but another equally critical component of the 5G future is the concept of network slicing, which brings the 4G concept of software-defined networks to another level.

As illustrated in **Figure 5**, network slicing allows operators to separate the packet traffic layer from the control layer, supporting multiple applications and services running in parallel for a range of users who require different levels of quality, latency and bandwidth. This means that 5G systems will have many logical network slices, or "fast-track lanes," to support specific applications and customers.

For example, an operator may have customers who require emBB to use augmented reality tools, but that same operator may also simultaneously support customers who need the network for mMTC, autonomous driving or remote surgery, which require very different network attributes. Each application has its own specific requirements, and by slicing the network into different dedicated sessions or parallel connections, it's possible to optimize the various slices accordingly.

This enables operators to sell networks to customers on an as-a-service basis, allowing every customer to experience its slice of network as if it were entirely physically separate from the whole: a sort of "have your desired slice of cake and eat it" approach, modulating in real time the available ingredients of the recipe. In essence, network slicing enables more operational efficiency and less time to market to implement new services.

Indeed, network slicing will likely be one of the biggest enablers to deliver cost-effective new 5G services to enterprise customers.

Edge computing

Edge computing means taking real-time decisions close to the source of data. By locating computational intelligence close to the individual and different sources of the data, edge computing reduces latency in the implementation of a requested service. Instead of sending data through the entire core network to the cloud for processing, edge computing uses a distributed network architecture to ensure near-real-time processing with reduced delays, which would otherwise simply not be acceptable for the specific service.

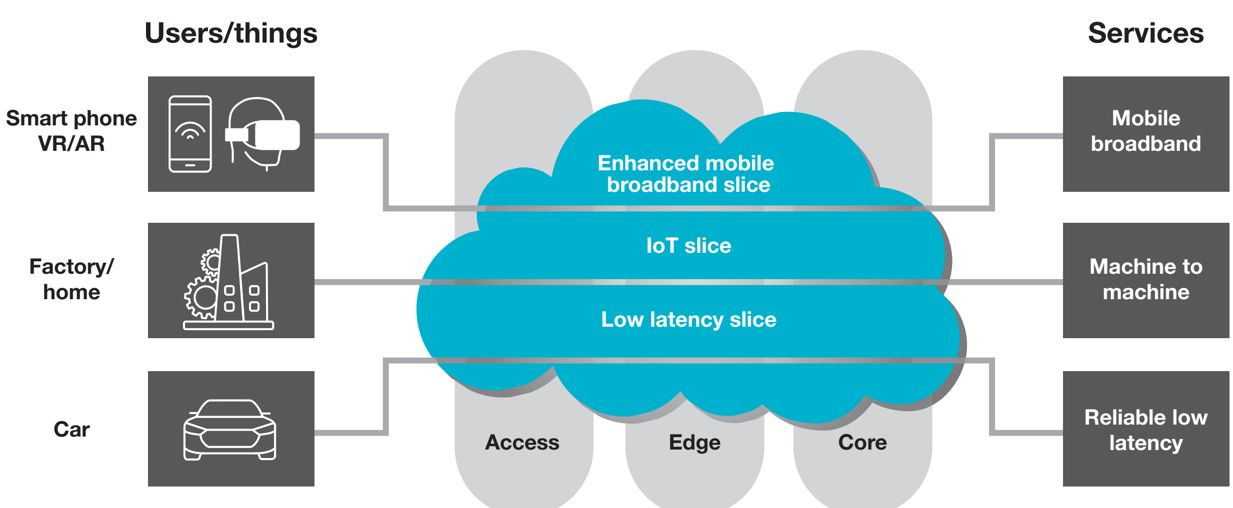

***Figure 5**: 5G network slicing.*

With the proliferation of critical applications that demand instant computing resources, together with smart functions assisted by artificial intelligence (AI) like autonomous driving, remote medical and virtual reality applications, it is paramount that computing moves closer to the end user, and thus the edge. For example, a car would travel several more feet – even after receiving a command to brake – if several tens of milliseconds were lost crossing the entire network and back. Using edge resources, and reducing that latency by a factor of 10, will cut the time from command to braking significantly.

Edge computing resources, or multi-access edge computing, can easily find a home in the traditional central office of a radio access network (RAN). It's possible to locate extra hardware resources and servers with AI accelerators at a variable distance from the clusters of antennas, up to few kilometers. This generates a proliferation of extra hardware infrastructure.

Key hardware of the 5G future

The 5G network boasts NR access standards and features, making it suitable for several vertical markets with diverse applications. This presents a plethora of hardware needs, including those in apparatuses like active antenna systems (AAS), which evolves the concept of the remote radio head by integrating the antenna. This integration helps meet the 5G challenges of enhanced capacity using space diversity and localized beams, implementing massive MIMO (mMIMO) technology.

AAS, mMIMO and beamforming

AAS technology can maximize base-station efficiency, allowing operators to dramatically increase their capacity (by up to five times for 5G), as well as coverage targets for their network. Clusters of power amplifiers (PAs), together with antenna elements, are essential parts of AASs – up to 1,024 PAs today – providing the full-access function of the network to connect to the baseband node, which could be located in the same location as the AAS or in a central office (cloud RAN). Through mMIMO – a technique that supports several simultaneous and separate data paths, based on space diversity, to individual users – frequency reuse is possible, and this becomes the main enabler for higher capacity of the BTS, implementing spatial multiplexing.

Having many different antennas also enables enhanced beamforming, a technique that uses 3D directional and concentrated beams. This technique reduces interferences in adjacent channels and maximizes the reachable distance with same amount of power, directing data traffic to a desired destination. As a result, it's possible to optimize overall capacity and achieve higher radio signal throughput.

Deployment of AASs began in the 4G ending phase, and AASs now proliferate as a new type of installation where capacity and coverage enhancement are needed. The hardware upgrade of the macro BTS will be driven by the implementation of a new frequency spectrum with hardware that is backwards-compatible with 4G and baseband with upgradeable software.

To densify coverage sustaining the new services, small-cell deployment will happen, especially in dense environments like high-rise apartment buildings, stadiums, shopping malls and theme parks, bringing transmission closer to users, at lower power and with more bits per second.

From a hardware perspective, the standout challenge is density: First, how to manage everything thermally inside increasingly smaller encapsulations. Second, how to meet expectations effectively through the large-scale integration of functions and components. And third, doing this all while maintaining high performance at low power.

To achieve that, everything inside an AAS has to be redesigned or adapted, from the transceivers to the clocks to the power management, in order to meet the challenging requirements generated by the increased numbers of components populating this new equipment. This can be achieved starting at the radio-frequency (RF) transceiver, integrating more of those together, adding auxiliary functions and creating smart system solutions to cluster many of new components with common power management.

Clocking, integrated transceivers and power

Multichannel, highly integrated RF transceivers are the core piece of the 5G hardware puzzle. An RF signal bandwidth up to 1 GHz is required, with the possibility to operate in multiband. Implementing an RF sampling technique enables the described characteristics in a simpler architecture and with reduced cost. Serializer-deserializer transceivers with capabilities higher than 10 Gbps, together with integrated low-jitter phase-locked loops (PLLs)/voltage-controlled oscillators (VCXOs), are other key features of these emerging new systems-on-chip, simplifying sampling clock generation by enabling the use of a lower-frequency reference clock.

Meeting the timing requirements of 5G high-bandwidth networks can't be overlooked. As in current mobile networks, timing sources – voltage-controlled crystal oscillator (VCXO)/temperature-compensated crystal oscillator (TCXO) – must be very low jitter and capable of addressing the ever-reducing noise requirements to support higher-order quadrature amplitude modulation for best performance of millimeter wave transmission.

According to cloud RAN architecture, the newest Common Public Radio Interface (CPRI) specification, named eCPRI (Ethernet CPRI), serves as a multi-point link between the baseband unit (BBU) pool and remote radio unit (RRU) network, providing high-bandwidth links to handle the requirements of multiple RRUs. There are also newer timing requirements due to the adoption of 5G eCPRI for the front-haul transport in 5G. Time and frequency synchronization, which was inherently guaranteed in point-to-point CPRI links, is no longer an afterthought and must be addressed as part of the overall 5G timing solution. As a result, the clock tree has evolved from a VCXO-based jitter cleaner solution adopted for CPRI transport to a TCXO-based network synchronizer solution to handle timing needs in eCPRI.

It is also expected that the 5G macro base stations targeting sub-6-GHz transmission will support the multi-carrier Global System for Mobile communications standard (GSM), and thus, the clock tree must also meet spot phase-noise requirements that do not violate the overall GSM blocker specifications. For 5G mMIMO base stations, beamforming enables efficient use of the spectrum while minimizing interference. This poses a tight constraint on the skew between the various outputs in a clock tree for the RF signal chain. Several board- and chip-level techniques, like zero-delay mode, can minimize the delay variation of the clock tree over process, voltage and temperature corners, in addition to system-level antenna calibration schemes to increase efficiency of beamforming.

5G is also changing the point-of-load paradigm to accommodate a range of power-consumption demands for IoT, small cells and active antennas – with power swinging (scaling) from a few tenths of a watt to hundreds of watts. More specifically, increased power/current requirements have moved the value of the distribution bus to 12 V to meet the demands of AASs, distributed antenna systems and next-generation mMIMO radios.

The role of the Power Management Bus (PMBus) is becoming more pronounced due to an increase in power, both in the RRU and the BBU. Meanwhile, high-voltage buck converters are evolving to accommodate an increase in the number of PAs, requiring 3D thermal dissipation and 100-V operating converters with variable current limits. To supply the delicate clocking and transceiver circuits in radios while increasing density, there is also a drive to reduce size and noise with multichannel dedicated converters, using converters as alternatives to low-dropout regulators, switching faster than 1 MHz to reduce size while maintaining efficiency.

Minimizing bill of materials, complexity and cost is key to winning the 5G hardware race, and integrating functions into integrated circuits is the means to achieve these goals. Semiconductor companies will have to work closely with their base-station equipment customers to produce highly integrated RF transceivers, optimized signal chains and power to support the evolving rollout of 5G.

Where does 5G go from here?

Recent history in the communications industry shows a 10-year cycle time to upgrade to the next technology. The pace for 5G adoption looks similar, with consequent expectations for its maturity peak.

5G is poised to breathe new life back into the notion of a connected planet – with new infrastructures, new devices and new use cases. With its high capacity and low latency, 5G will radically change how people and devices connect.

On an enterprise level, 5G could be even more transformative, enabling mission-critical services that will potentially revolutionize entire industries. True 5G will enable the factories of the future, full of machine-to-machine technology and low-powered sensors, mobility management, remote equipment/asset monitoring, smart power grids and more.

When Release 16 enables the higher part of the frequency spectrum, other aspects of 5G will be enhanced. Millimeter-wave mesh networks can be used for cheaper backhauling of small-cell base stations in dense urban areas. These networks will also work well in vehicle-to-vehicle or vehicle-to-everything communication systems, making this technology a key enabler of autonomous driving because cars need to communicate with each other and with traffic signals, as well as update digital mapping information.

5G may be the network of the future, but it's being built by engineers today, and will change the world we live in for the better.

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