# Who & How: Making 5G NR Standards

Understanding Key Features of 5G NR Standards and Samsung's Contribution

# Understanding 5G Standards

## Why is it necessary to have global standards?

When travelling abroad, we often find ourselves encountering many problems related to mobile devices like having to look for a particular power converter because of the differently shaped power outlet. Running out of power for your phone in a strange city might be something you have to deal with if you accidentally forget and leave your charger at the hotel. The chances are that the only ones available are incompatible with your phone. These problems exist because countries and manufacturers create and install products based on their own specifications or standards.

Imagine there is an international standard that unites all of these power outlets and chargers so that more electronic appliances are able to operate interchangeably. It will trigger greater competition that would lead to technical advancements. It will also help manufacturers to develop and produce products that target the entire world, rather than a handful of countries or buyers.

Previously, the mobile telecommunications industry had divisions of standards that differed by country, manufacturer and standard organization. Among these, only the strongest in the market, or in this case the most popular standards, emerged as the de-facto standards. Today these divisions are merged into global standards by international organizations – and have become the norm.

For the mobile industry, international standards are the main pillars of mobile telecommunications as using different standards for smartphones and base stations would mean that any form of communication like voice call or Internet access are made unavailable. Thanks to the establishment of global telecommunication standards, we no longer need to rent cell phones or purchase prepaid phones when travelling abroad. We can use our phones wherever and whenever we like via what we call 'global roaming'.

The impact that global standards has on the industry is vast. Not only are manufacturers able to mass produce, R&D costs are saved through preventing investment overlaps. Technologies are shared and democratized. This prompts greater competition among manufacturers to produce high quality equipment that are also affordable.

## What does the 'G' in 5G stand for?

**Mobile communication technologies were labeled 1G, 2G, 3G and 4G as it advanced, the 'G' here an abbreviation of 'generation'.** While 1G is an analog communication technology that made voice communication services possible, 2G is a digital-based technology that introduced voice and text services. It is also responsible for incorporating camera features into phones. Web browsing, email, video downloading, picture sharing and other smartphone technology were introduced in 3G, 4G technology ushered in the era of Internet data services on smartphones.

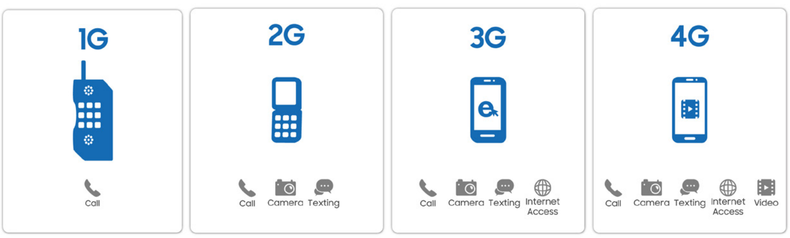



Figure 1 : Evolution of mobile communications technology

**Each phase brings new and exciting capabilities and services to the end user.** Progressing through to the next phase of mobile technology involves new frequencies and radio access technologies. New network technologies are also introduced so as to provide faster connection speeds and new infrastructure for innovative businesses as well as unprecedented services.

Smartphones as a 'service' was already introduced in the 3G era. However, as the use of smartphones became widespread, it became clear that 3G-based solutions are nowhere near enough to handle the ever-growing data traffic. Service providers realized that what they need is a new technology that has wide bandwidth availability in new frequencies. It was this particular need that drove wireless service providers to increase network capacity via 4G.

It was the international standards organization 3GPP (3rd Generation Partnership Project), a standards group that supports new technologies for the next generation, and developed the global standards for 4G LTE (Long Term Evolution). Each new generation offers significant "revolutions" in performance and capabilities compared to its predecessor. New generation, therefore, can be interpreted as new standards.

## So, *who* makes the standards?

**The International Telecommunication Union (ITU) sets the main visions and goals while 3GPP develops the standards.** In the early 2010s when 4G LTE was close to finally being deployed, market experts made a forecast that data traffic will grow astronomically by 2020. This was a huge concern for the entire industry as it meant that the existing technology may be incapable of handling such data traffic. Discussions and preparations for next generation technology began. Industry leaders including mobile operators, manufacturers, organizations and institutions began research and development. **ITU, a specialized agency under the United Nations (UN), also started discussing technologies and technical visions for 'IMT-2020', which was announced in September 2015.**

'IMT-2020' was coined by ITU to define the technical specifications associated with 5G. ITU provides guidance for 5G developments to drive unprecedented next generation services and improved technical definition from 4G, also referred to as 'IMT-Advanced'.

Global standards organizations such as manufacturers, mobile service providers, research institutions, and international agencies develop standards based on the criteria set by ITU, which becomes approved after numerous debates. **Contrary to before when there were several global standards organizations, today, 3GPP is the largest standards body and is in charge of coordinating manufactures and organizations to develop 5G standards.**

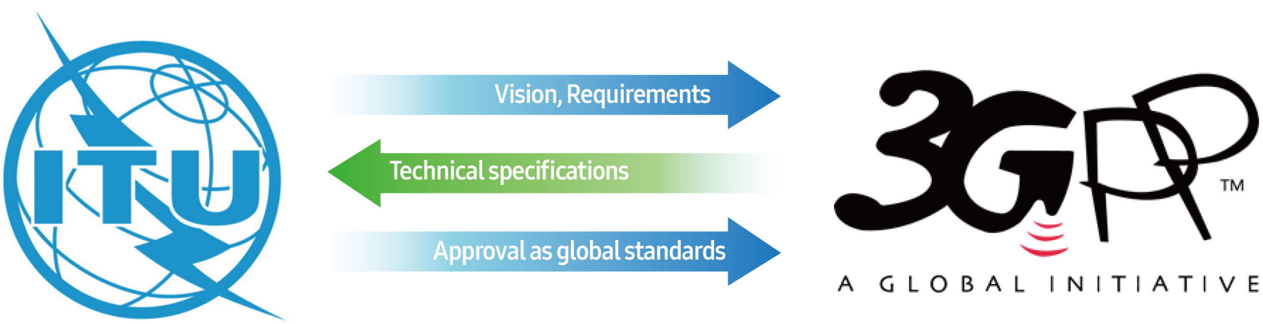



Figure 2 : Relationship between ITU and 3GPP

**3GPP consists of around 500 entities including manufacturers, device producers, chip makers, mobile service providers, and international research institutions.** It has developed WCDMA, HSPA, LTE, LTE-Advanced and many other international telecommunication standards throughout the evolution of mobile communication technology.

3GPP is currently the most influential organization in which global telecommunication leaders are members of. The organization sets deadlines and produces finalized results accordingly, supporting timely advances in technology and its commercialization. 3GPP has Radio Access Network (RAN) group to develop wireless access technology, Service and Systems Aspects (SA) group for service and system architecture, and Core Network and Terminals (CT) group for core network and devices. Each group has smaller Working Groups (WG) for practical level development.

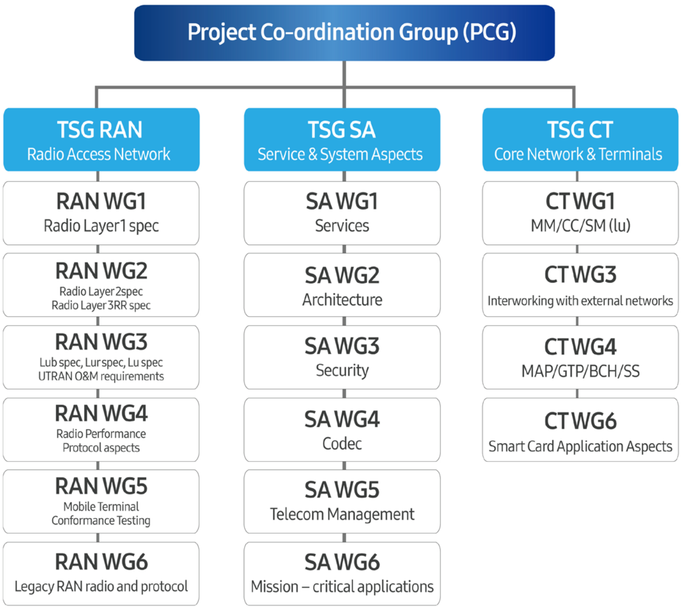



Figure 3 : Organizational structure of 3GPP

## How is 5G standards different from the previous standards?

The three main technical aims of 5G are:
1. Enhanced Mobile Broadband (eMBB)
2. Ultra Reliable and Low Latency Communications (URLLC)
3. Massive Machine-Type Communications (mMTC)
ITU has classified 5G mobile network services into these three categories and has also outlined the different types of services each can offer.

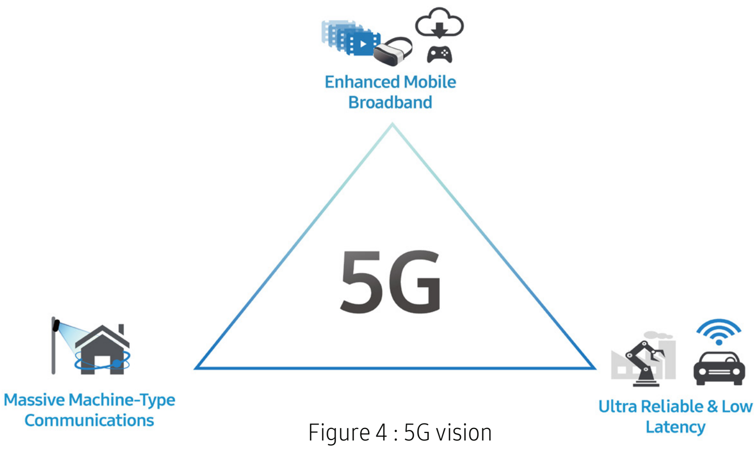



Figure 4 : 5G vision

### 1. Enhanced Mobile Broadband (eMBB)

eMBB aims to provide exceptionally fast data speeds, anywhere from 100Mbps up to 20Gbps per user, to focus on services that have high requirements for bandwidth and antennas such as high definition (HD) videos, virtual reality (VR), and augmented reality (AR). For instance, downloading a 15GB (Giga Byte) High Definition movie will take 240 seconds via 4G at the speed 500Mbps. With 5G however, at 20Gbps, the same movie will only take 6 seconds to download. The goal of eMBB is not to provide faster transmission speed only when you are near a telecommunication base station, but to serve at least 100Mbps data speed where the signal is weak (cell edge). Users in crowded areas such as airports and sports stadiums will be able to enjoy seamless HD streaming services.

### 2. Ultra Reliable and Low Latency Communications (URLLC)

The goal of URLLC is to provide real-time services that require extremely low latency and prompt responses like remote robot control, connected autonomous vehicles and interactive gaming. The delay time which used to be tens of millisecond (1ms = 1/1,000 second) in 4G will be reduced down to one millisecond in 5G via wireless resource management and network architecture optimization. On 4G, a connected autonomous vehicle traveling at 100km/hr will receive an emergency brake order with a delay time of 50 milliseconds(ms) - meaning the vehicle will stop after traveling 1.4m. With 5G however, the delay time will only be 1ms, and the vehicle will stop after traveling 0.028m. (Please note that the example does not represent the stopping distance per-se. Rather, it indicates 'by when' a vehicle will start 'applying' the brakes.)

### 3. Massive Machine-Type Communications (mMTC)

The goal of mMTC is to create an environment where a million homes and industrial IoT devices within 1 km$^2$ can be connected. mMTC aims to meet the demands of a highly developed digital society and focuses on services that include high requirements for connection density, such as smart city and smart agriculture.

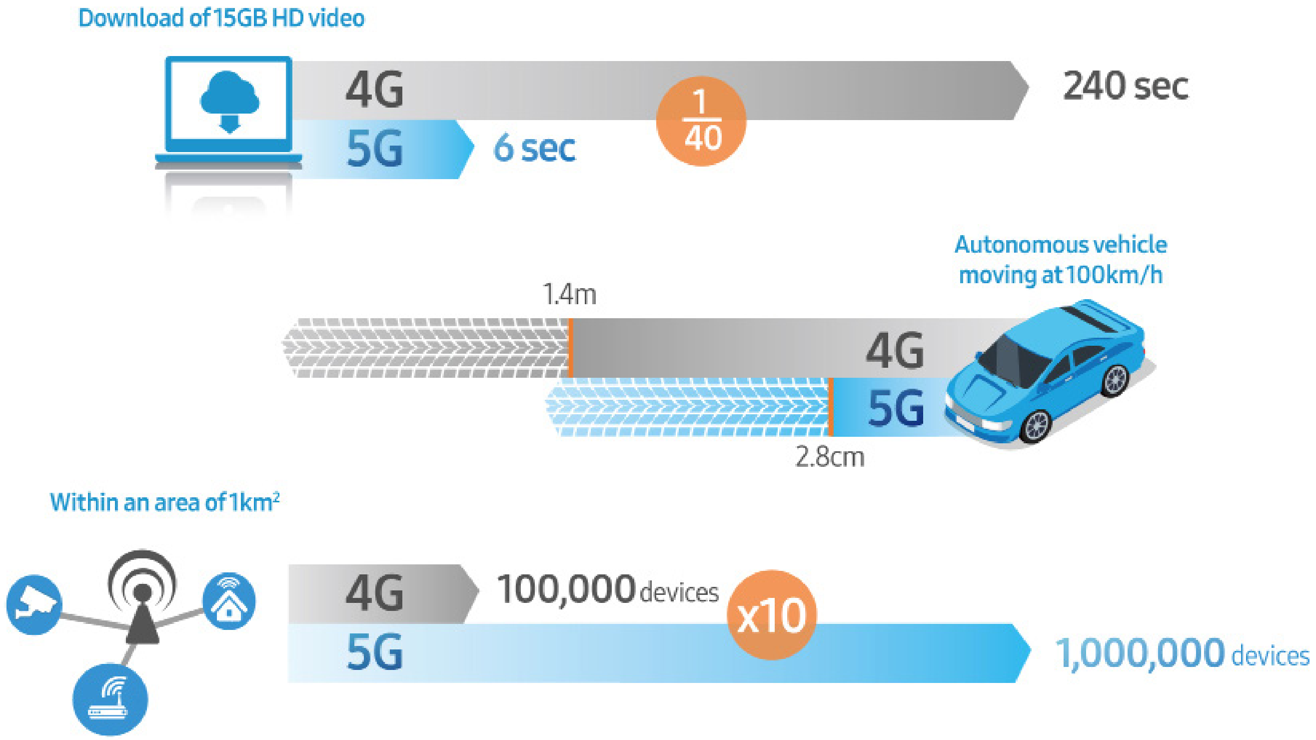
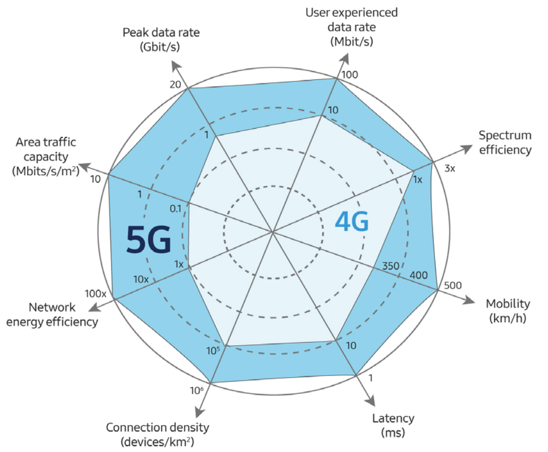



Figure 5 : Performance comparison example between 4G and 5G

The guides set by ITU is summarized in the below table. The comparison between 4G and 5G technologies is outlined in the figure below.




| Item | 4G | 5G |
|---|---|---|
| Peak data rate | 1Gbps | 20Gbps |
| User experienced data rate | 10Mbps | 100Mbps |
| Spectrum efficiency | - | x 3 |
| Area traffic capacity | 0.1Mbps/m$^2$ | 10Mbps/m$^2$ |
| Latency | 10ms | 1ms |
| Connection density | 100,000/km$^2$ | 1,000,000/km$^2$ |
| Network energy efficiency | - | x 100 |
| Mobility | 350km/h | 500km/h |

Figure 6 : Comparison between 4G and 5G

When 4G LTE was first introduced, its peak throughput (or maximum speed) was 75Mbps which is less than one-tenth of what the industry had set as the highest peak throughput for the technology (1Gbps). It is only after the recent introduction of a 1Gbps-supporting device chip—expected to become commercialized in 2018—that 4G LTE was able to achieve this speed. Each generation of mobile communication technology takes several years since its launch to achieve the desired peak throughput. Similarly, 5G will start its services with a peak throughput of only a few Gbps, which will gradually increase to 20Gbps as targeted.

A wide range of frequency bands are required for 5G standards to provide high speed data transmission. **Accordingly, standards bodies are considering using both below and above 6GHz (ultra-high frequency bands like 28GHz and 39GHz).** Unlicensed bands are also considered as an option. While each country has its own rules and allocation policies, the chances are that most of them will assign bands ranging from a few hundred MHz to 1GHz to operators.

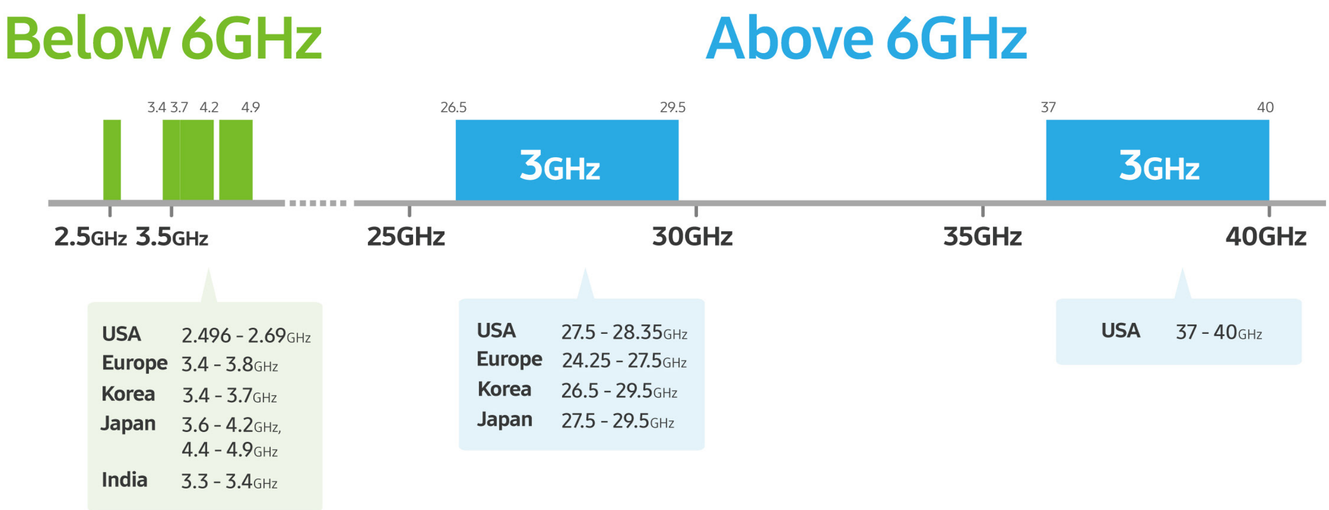



Figure 7 : 5G frequency bands

# Make the Most Out of mmWave Frequencies: Beamforming

It might be relatively easy to secure high frequency bands because they have been avoided for their distinct disadvantages such as small coverage and low penetration rate. Beamforming technology has been introduced as a measure to overcome these weaknesses.

Beamforming technology controls multiple antennas so that strong concentrated signals are transmitted in one particular direction, while making sure that unnecessary signals do not go in different directions. The technology enables mmWave frequencies to travel far with less interference from other signals. The more the antenna elements, the sharper the beam shape. This also means that more energy is concentrated. However, the directionality of millimeter-wave (mmWave) communications creates a significant challenge in serving fast-moving mobile terminals and it is necessary to keep track of the sharp beam continuously.

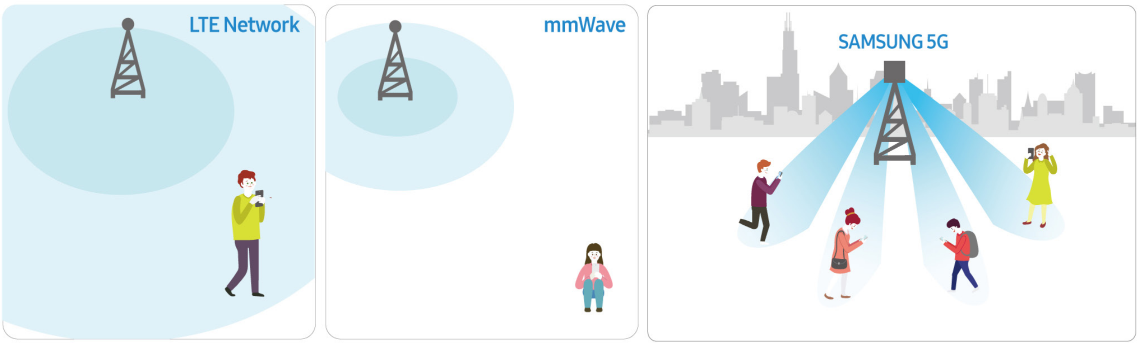



Figure 8 : How beamforming technology works

# Improve Spectral Efficiency: Massive MIMO

Massive MIMO (Multi-Input Multi-Output) technology controls the antenna array of many antenna elements to generate multiple beams simultaneously, and each beam carries a different signal to the user. Spectrum efficiency is enhanced as it allows multiple users to use the same wireless resource simultaneously. A similar MIMO technology is currently being used with 4G. However, the beams are not sharp enough to identify each user, making MIMO a lot less efficient than it will be in the 5G era. MIMO in 4G uses one-dimensional antenna arrays arrangement that limits the freedom of antennas, meaning it can distinguish users in horizontal direction only. In contrast to this, MIMO in 5G supports more users simultaneously by incorporating a two-dimensional antenna array to cover both horizontal and vertical directions.

How massive MIMO technology works

# Make 5G Services Easy & Flexible : Network Slicing

The aim of 5G standards includes distinguishing services via network slicing and quality-of-service (QoS) assurance features. On 4G, data services such as video streaming, Internet surfing and navigation are provided through a single pipeline or mobile resource. This makes it impossible for carriers to distinguish different data services. This also means that QoS cannot be guaranteed for each service.

During the 5G era, network slicing will allow carriers to create virtual data pipelines for each data service. This means that QoS will be assured for every service. Network slicing will also ensure the quality of data transmission for time-sensitive, mission-critical services such as connected cars. Ultimately, the technology allows carriers to develop unprecedented business models.

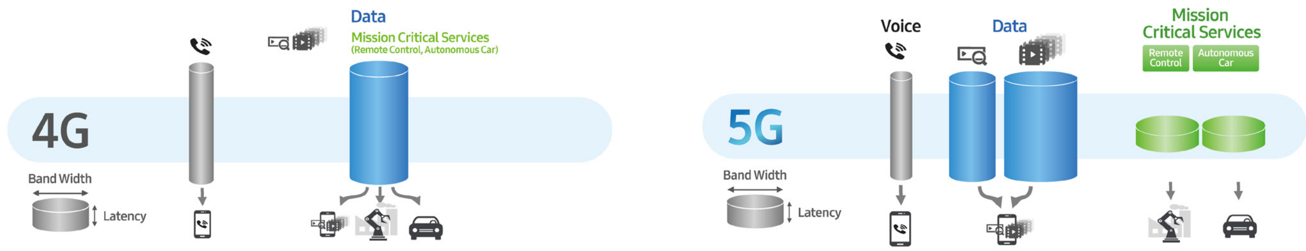



Figure 10 : How network slicing technology works

# What are NSA and SA standards?

3GPP has taken a phased approach and introduced NSA (Non-Standalone) and SA (Standalone) architectures for 5G evolution. While the SA architecture ensures that both control and data channels utilize 5G networks, NSA would leverage the existing LTE radio and core network as an anchor for coverage. The user plane or data plane, which corresponds with data traffic, will be managed via 5G network. The initial 5G deployments are likely to be based on 5G-NSA architecture.

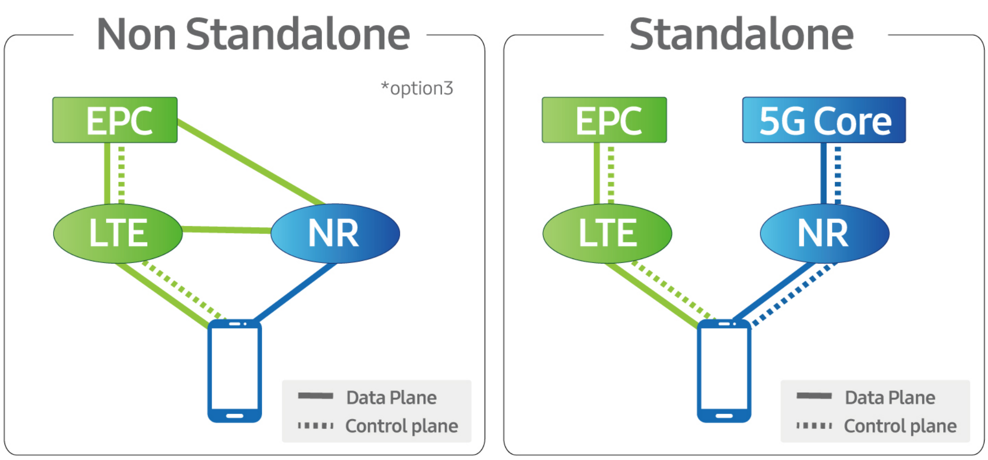



Figure 11 : How NSA and SA work

# When is 5G Standards released? & What does the 'release' exactly mean?

Global telecommunication standards take a long period of time to complete a series of discussions. Even after next generation technology is released, previous generation technology standards are continuously updated and improved. The below figure shows 3GPP's standards release schedule. 3GPP announces different specifications over time and numbers them accordingly. For instance, while Release-14 or Rel-14 focuses on 4G LTE upgrades, Release-15 is dedicated to building the world's first global 5G standards - which will be announced in June 2018.

The areas covered by each release can overlap. For example, LTE enhancements from Rel-14 will be included in Rel-15. As can be seen in the diagram below, 3GPP is planning to split the 5G work into two phases. Phase 1 (Rel-15) will look at the requirements that are important for the commercial needs of the day. Phase 2 (Rel-16) will look at more features, use cases and detailed requirements.

Back in December 2017, 3GPP announced that Release-15's 5G New Radio standards is dedicated to NSA architecture in which LTE system serves as the signaling anchor. The 5G NSA architecture is a technology only for a transitional phase where 5G mobile technology and 4G core networks co-exist. It will not be commercially launched until 5G SA architecture, a complete 5G infrastructure, is deployed. SA architecture will be announced in June 2018.

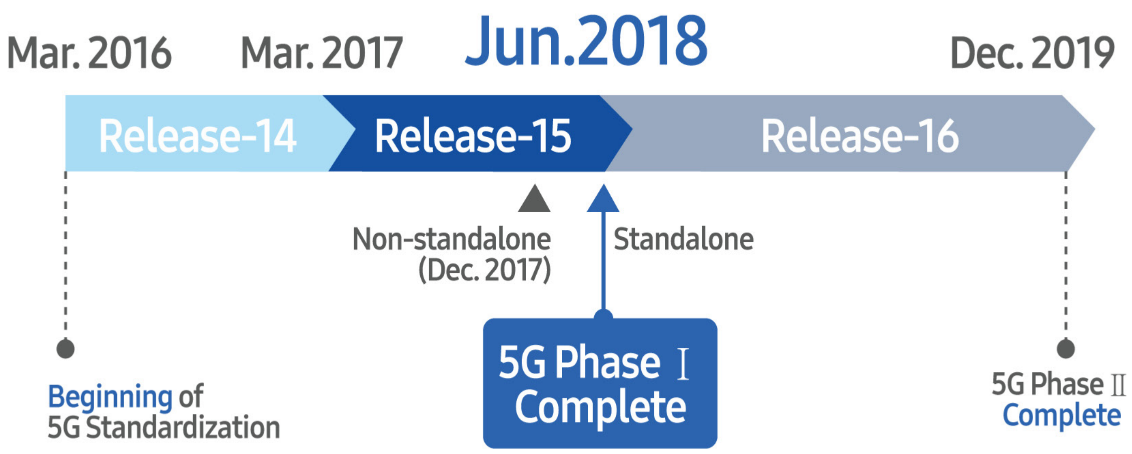



Figure 12 : 3GPP standardization timeline

# Insights from 5G Standards Experts

## In-depth interviews with experts, currently serving as 3GPP standards chair and vice chair persons on behalf of Samsung Electronics

Samsung Electronics actively participates in the development of 5G standards by serving as chair and vice chair for various working groups within 3GPP

### ERIK GUTTMAN /Samsung Research United Kingdom (3GPP SA, CHAIR)

**Q1 / Could you start off by explaining what the role of 3GPP is?**

The 3rd Generation Partnership Project (3GPP) develops, enhances and maintains telecommunications standards. It works on behalf of standards organizations based in several geographies: North America, Europe, China, Korea, Japan and India. It is through these Standards Development Organizations (SDOs) that the standards that complete the process in 3GPP are transcribed and published formally.

Further, there are ties to ITU. Many 3GPP standards development activities are followed closely in ITU Radio communication Sector (ITU-R) and ITU Standardization Sector (ITU-T), and standards formally published by the SDO partners are cited in ITU formal documents.

Essentially 3GPP has two areas of focus. First, ensuring that past standards are corrected and where necessary and advantageous, supplemented and enhanced to meet the needs of the industry. Second, we develop new features and, once every 10 years, even a new system.

**Q2 / Could you describe the role of TSG SA as well as your role as the chair of this group?**

The Technical Specification Group (TSG) Service and System Aspects (SA) have an oversight function for the SA working groups. For example Working Group 1 (WG1) develops service requirements and considers how new services relate to existing standards. Working Group 2 (WG2) is responsible for system architecture, including both end to end and core network aspects. And so on.

SA manages the work of each of these bodies – making the final determination of whether to approve all output of these groups. In addition, SA has a leading role in 3GPP in that it coordinates the work of all TSGs: SA (Service and System Aspects), RAN (Radio Access Network) and CT (Core Network and Terminals).

My role as SA Chairman involves oversight over all activities in 3GPP, both from the perspective of SA working groups and the overall coordination of all TSGs. I also am involved in discussions and problems as they arise between SDOs and other organizations, and I also welcome and guide new parties joining 3GPP.

**Q3 / What is 5G NR?**

5G New Radio (NR) is a new radio specification developed by TSG RAN and RAN working groups. It is a significant advance over past radio network standards in several respects. First, it operates over a greater range of frequencies, which is necessary in 5G to support millimeter wave and other new spectrum domains. Second, it provides 'forward compatibility' to allow for quite different applications to be added without compromising compatibility.

In 5G, there is the expectation and understanding that the radio will support different service delivery characteristics for different kinds of services, essentially differentiating between enhanced mobile broadband, ultra reliable low latency communication and massive Internet of things target services. NR finally will also increase spectral efficiency over LTE, require less energy in operation and be deployed in a wider range of scenarios.

**Q4 / Could you update us on how the 5G NR standardization process is progressing? What are the accomplishments made so far and what remain unsolved?**

The 5G program is divided into two phases, phase 1 in Release-15 and phase 2 in Release-16. Phase 1 is further subdivided into an early drop (December 2017), the freeze of the release (June 2018) and a late drop (December 2018).

The main accomplishment so far is the specification of NR. NR is already available for commercial development in the early access release in a so called ‘non-standalone’ (NSA) deployment scenario, in which NR is a supplemental access to LTE and service is provided by means of the 4G core network: the Evolved Packet Core (EPC). NR as an access capable of supporting a user equipment (UE) directly, without LTE, using the new core network: 5G Core (5GC) will be complete in June 2018.

The focus of Phase 2 has yet to be determined, but there is interest in dozens of areas, mostly to improve the performance and capabilities of the 5GC and NR. It also aims at providing specific enhancements needed for new business sectors, what the 3GPP standards community calls ‘verticals’, including automotive, industrial automation and much more.

## XUTAO ZHOU /Samsung Research China (3GPP RAN WG4, CHAIR)

**Q1 / Could you describe the role of the RAN 4 Working Group as well as your role as the chair of this group?**

3GPP RAN WG4 defines specifications based on operator and industry demands. It defines the radio performance requirements and test cases for terminals and base stations. The minimum requirements defined in here are used by regional regulatory bodies and certificates.

As the chair, my role consists of overseeing meetings and guiding the group to reach a consensus. I also develop plenary leaderships and 3GPP work plans with other groups. It is important that I design effective e-mail discussions, meeting arrangements, meeting agenda and other organizational aspects for each meeting.

**Q2 / Could you tell us about some of the notable achievements made by your group in terms of Release-15?**

In December 2017, RAN4 successfully established the first version of NR specifications v15.0.0 for UE radio frequency (UE RF), base station radio frequency (BS RF), Radio Resource Management (RRM), UE Electromagnetic Compatibility (UE EMC) and BS Electromagnetic Compatibility (BS EMC).

In 2018, RAN4 consolidated the first version of specifications and also developed the minimum requirements for SA specifications by June. We have also completed Release-15 specifications at the last RAN4 meeting (May 21-25), which will be released in June.

In Release-15, RAN4 specified the radiated requirements together with Over The Air (OTA) test methods to verify the radiated requirements for devices.

**Q3 / There seems to be a growing interest for the millimeter waves spectrums across the industry. Please elaborate.**

It is no longer just the operators that are interested in exploring the millimeter wave spectrum. Terminal and base station vendors now link it with their product roadmaps. In RAN4 Release-15 specifications, 4 mmWave bands in total have been defined: n257 (26,500 - 29,500 MHz), n258 (24,250 – 27,500 MHz), n260 (37,000 – 40,000 MHz) and n261 (27,500 – 28,350 MHz).

**Q4 / Which frequency bands do you expect will be supported by the first 5G devices?**

Since the bands included in the Release-15 specifications were specifically requested by operators, these bands will most probably be the ones supported by the first 5G devices. Considering the long time it would take to refarm LTE spectrums, the new NR spectrums—3.5GHz frequency and mmWave bands—are most likely to be supported.

That said, the availability of 3.5GHz and mmWave range differs by countries. This will ultimately determine which bands are supported by the first 5G devices in different countries. For example, the first 5G devices in US are likely to support n261 and n260bands from the mmWave range.

## YOUNSUN KIM /Samsung Research (3GPP RAN WG1, VICE CHAIR)

**Q1 / Could you please describe the role of RAN 1 Group as well as your role as the vice chair of this group?**

RAN WG1 is a working group in 3GPP that is responsible for shaping the physical layer specification of LTE (4G) and NR (5G). We design how signals are transmitted in wireless channels. My role involves overseeing Multiple-Input Multiple-Output (MIMO), power control, and non-terrestrial network sessions in the NR track. For the LTE track, I specifically chair the LTE Vehicle-to-everything (V2X) session.

**Q2 / Back in February 2017, global mobile industry leaders announced their support for the acceleration of the 5G NR standardization schedule. How did this impact your work in the past year?**

It meant that the time we had left to complete NR specifications was shortened by 6 months, from June 2018 to December 2017. Our team was under an immense pressure to meet this date. There are typically 6 RAN1 meetings per year, but this jumped to 9 in 2017. It was a lot of hard work under a tight schedule. That said, we are proud to see that we have directly contributed to the creation of the actual, final NR specifications-based products.

**Q3 / Could you share some of the notable achievements you have made, in terms of RAN specifically, that we can expect to see in Release-15?**

There are a couple of things that can be hailed as achievements for NR Release-15. First is the support for higher frequencies (mmWave) which Samsung has led the way since 2009. Before this, there was no company that seriously considered using higher frequency bands for cellular communications. With NR Release-15, cellular communications can now reach all the way up to 52.6GHz. This is a huge leap from the highest LTE frequency which is around 6GHz. Second is the vast improvement to throughput made via multi-antenna technology (or NR-MIMO). NR-MIMO provides the specification support that allows a base station to simultaneously transmit to multiple terminals using the same wireless resources. We expect to see this game changing technology to increase the current throughput performance by a factor of 3. Third is reduced latency, which is expected to decrease by 3 to 5 times.

Q4 / What can we expect to see from Release-16?

Our 5G vision is only partially fulfilled by NR Release-15. Our vision can be divided into 2 big categories. The first is to simply make improvements to mobile broadband. The other is to generate various verticals using wireless technology. The first has been achieved in NR Release-15 with NR-MIMO and other technologies that focus on higher frequencies. Much to everyone's disappointment, we did not have the time to seriously consider the latter. I think that it will be the main area of discussion for RAN1 and the rest of the 3GPP working groups for the next few years.

## RICKY KAURA /Samsung Research United Kingdom (3GPP CT WG1, VICE CHAIR)

Q1 / Could you please describe the role of CT WG1 Group?

3GPP operates a waterfall method for the development of technical standards where "stage 1" defines the requirements, "stage 2" defines the architecture standards and "stage 3" takes the requirements and architecture and creates the detailed procedures and protocols.

3GPP CT WG1 (CT1) is a "stage 3" working group made up of operators, UE vendors and network vendors representing all the SDO partners of 3GPP. It is responsible for the elaboration of the 3GPP Core and Terminals and is responsible for the protocol development between the UE and the Core Network at the Non-Access Stratum (NAS) layer and at the IP Multimedia Subsystem (IMS) layer. This includes aspects of the IMS that are common to both mobile and fixed networks. CT1 is also the principal stage 3 working group responsible for developing the protocol aspects of mission critical services. As new services emerge, as foreseen in the 5G program, CT1 will define end to end protocol aspects for these as well.

Q2 / How would core networks be changed in the 5G era?

With the need for network functions to be configured, connected, deployed and scaled in a given time, there has been a need to revisit the core network architecture. With the advent of cloud-based computing and network virtualization, there has also been a need to look at how services can be provided.

One of the main changes in the 5G core network compared to previous core networks is the introduction of the service-based architecture. Each network element is defined as a network function and offers services via interfaces of a common framework to any network functions that are permitted to make use of these provided services. This enables a more flexible development of new services.

The 5G Core network is a common Core Network which can operate with different Access Networks, for example NG-RAN and 3GPP defined untrusted WLAN access. One important change from previous releases is the development of a common NAS protocol stack that is used for both non-3GPP and 3GPP access networks.

Another aspect that affects the development of the CT1 standards is the split of the mobility management function and the session management function into different entities, the Access & Mobility Management Function (AMF) and the Session Management Function (SMF).

Network slicing is a distinct key feature of the 5G system architecture. Although LTE did support dedicated core networks, network slicing is a much more powerful concept and its introduction has an impact on the development of the NAS standards. Additionally, a new QoS model has been developed for the 5G system that enables differentiated data services to support diverse application requirements while using radio resources efficiently.

# Interview with Samsung

## Woojune Kim, Senior Vice President and Head of North America Sales at Networks, Samsung Electronics

**Why do you think Verizon has chosen Samsung as its partner for the 5G FWA business?**

From CDMA Femtocell in 2009 to LTE Femtocell in 2015, Samsung has been working closely with Verizon for many years. We have also been an active participant of Verizon's 5G Technical Forum (5G TF) which built an open, early specifications for 5G fixed wireless access. I believe that Verizon has chosen Samsung for two reasons: our long-term partnership that stretches back nearly 10 years, as well as Samsung's innovative approach with using the 28GHz spectrum for 5G.

Samsung has successfully launched the world's first 28GHz-supporting 5G FWA end-to-end solution spanning RFIC/ modem chipset for the base station, device, base station, core and indoor/outdoor CPEs as device for subscribers. This is a momentous industry milestone in that it is the first 5G product to have been granted regulatory approval from the United States Federal Communications Commission (FCC).

**What are Samsung's contributions to 5G NR specifications establishment?**

Specifications establishment process brings together members across the industry and serves as an important foundation for 5G ecosystem. Samsung is contributing actively by holding 5 chair/vice chair positions for SA which handles the structure of the entire system, the RAN4 working group and more. Samsung has also declared the largest number of 5G patents to the European Telecommunications Standards Institute (ETSI), up to 1,254 patents.

**What are Samsung's 5G business strategy and future plans?**

When 3GPP finalizes 5G NR specifications in June 2018, the development of 5G network equipment and devices will start to accelerate. Samsung plans to focus on securing its position in markets like Korea, US and Japan where 5G commercialization will be initiated. This means that we will be exploring and using both below 6GHz and mmWave spectrums.

**It looks like the initial stage of 5G commercialization will involve introducing 5G to the existing LTE network. How is Samsung preparing for this?**

In September 2017, we had successfully completed the world's first 4G-5G interworking trial together with SK Telecom. The trial showed that users in traveling cars can be connected at all times in a 4G-5G intertwined environment by using the current 4G LTE commercial network in the 2.6GHz band and newly built 5G networks using 3.5GHz and 28GHz bands, as well as virtualized core and a test device that supports both 4G and 5G technologies. We are making sure that the 5G solutions we are developing can interwork with 4G LTE technology.

## About Samsung

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