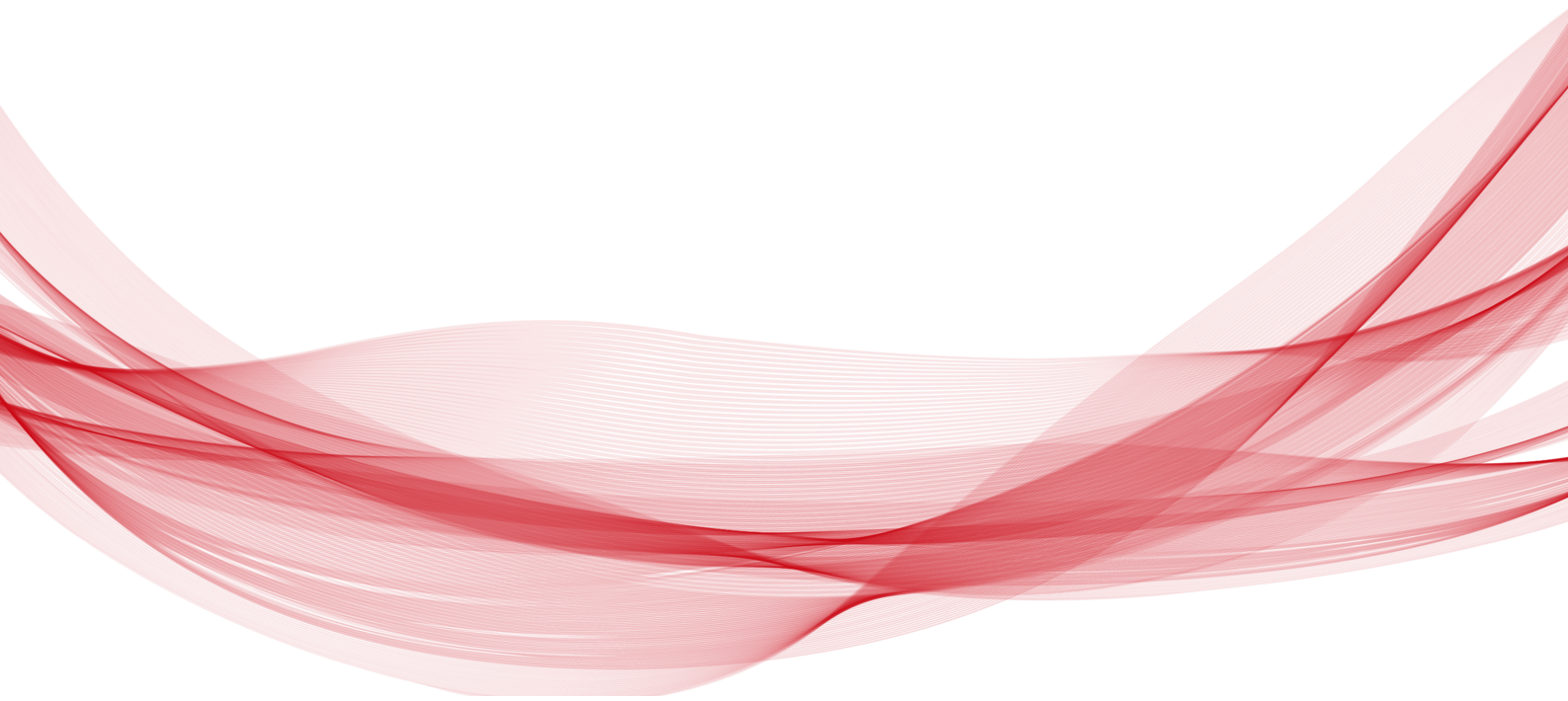
QUECTEL®
Build a Smarter World

PRINCIPLES OF 5G

Connect the Unconnected Things!



Quectel Wireless Solutions Co., Ltd.

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// TABLE OF CONTENT

1. Introduction

As we claimed in our booklet, 5G will have profound impact on the course of human civilization. Mobile subscribers would benefit from 5G in different ways which can be summarized as better User Experiences. However, the greater impact is on Machines, to make the world highly connected and ultra-smart. The foundation for such transformation will be 5G.

2. The Background

As a new wireless access technology, 5G has pushed quite a few important improvements to satisfy business requirements that had been put forward by its initiators.

Historically speaking, the 3rd Generation Partnership Project (3GPP) approach toward introducing new spec and standard are "push" approach. The workgroups usually define some ambitious communication engineering goals, as kind of riddles, to be tackled and solved through tough yet productive round of discussions where major stakeholders are also struggling to achieve more out of them, for their associated companies and/or respective countries.

Global System for Mobile (GSM) never became a truly Global standard, nevertheless was a breakthrough in communication evolution. Then 3GPP was basically formed to develop a Universal Mobile Telecommunications System (UMTS) to avoid issues encountered in GSM (literally they upgraded "Globe" to "Universe"). Unfortunately, no unique standard was agreed upon, as for instance TD-SCDMA was a clear deviation.

After almost a decade, 3GPP then carried on to standardize next generation of Radio Access called LTE (Long Term Evolution) mainly to address a real big threat made by Wi-Max. Wi-Max was an advanced radio access technology advocated by academicians as well as the Internet Engineering Task Force (IETF). The whole industry was divided in between 3GPP based technology which claimed LTE is a natural evolution of UMTS (at the time changed and called 3G) and Wi-Max camp which put forward a completely new idea of redefining everything called Radio Access. Big names like Alcatel-Lucent, ZTE and even Huawei supported Wi-Max, but Qualcomm, Nokia, Ericsson and most importantly, almost all Mobile Network Operators (MNO) supported LTE. The 3GPP smartly started with a shortcut solution to enable LTE vendors to push their equipment out of the door quickly as they could be otherwise beaten by their rival, the Wi-Max.

LTE then started to truly evolve by introducing new categories (Cat-3, 4, 6, etc). In each new category modulation scheme (started with 16QAM) has been improved (Figure-1). Quadrature Amplitude Modulation (QAM) was a 20 years old technology, nevertheless still had capability to offer more bit per hertz while elevating into higher order QAM. In fact, a more powerful DSP (Digital Signal Processor) can handle more vectors to be multiplied and then solve mathematical equations in the receiver to harvest data. As Reduced Instruction Set Computer (RISC) processors were ideal to handle QAM, ARM has become king of QAM modulators/demodulators (Figure-2). Therefore, all LTE modulations have been and will be powered by ARM based processors. Theoretically speaking, LTE can evolve even to 1024QAM, however seems the evolution will continue in the revolutionary way, called 5G (Figure-3).

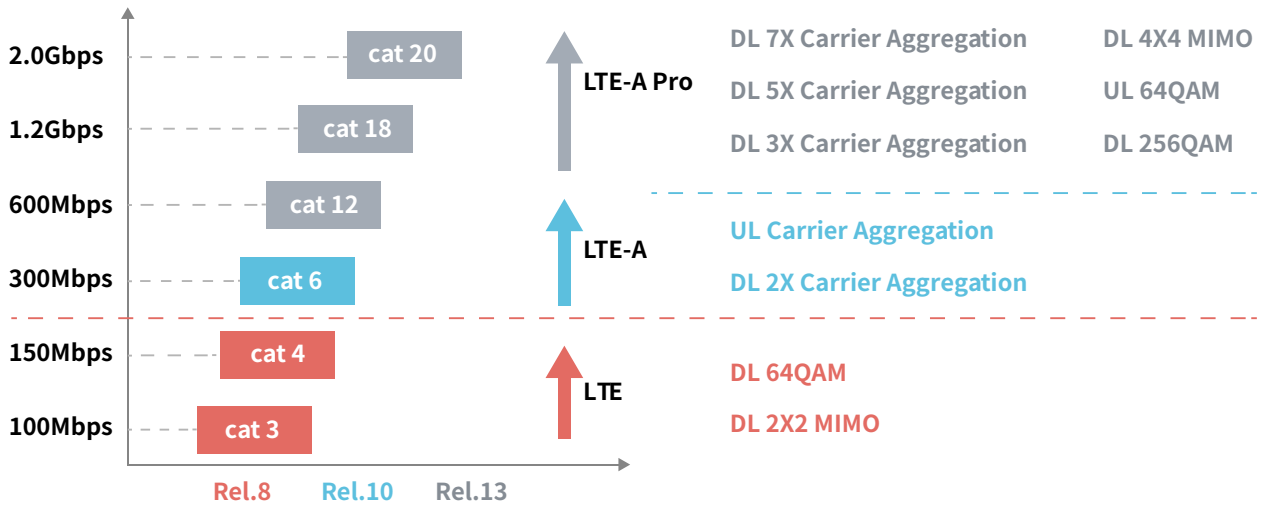

Figure-1 LTE evolution

As LTE was supposed to revolve, 3GPP also introduced at least two new concepts: CA (Carrier Aggregation) and MIMO (Multi-Input Multi-Output). In Cat-6 and above, all new LTE technologies had been commercialized, therefore the industry suddenly was blessed with ultra-fast radio access connectivity, which not only badly defeated Wi-Max but also caused hesitation on investment in VDSL and even FTTH, Fiber to the Home, since LTE proved to be able to satisfy VDSL target market needs, faster and better economically viable.

3. 5G Is a True first Global and Unified Mobile Communication Standards

As described above, each time when a new mobile generation is introduced, the industry was divided in between two or three camps. We can claim that 5G standards have been developed based on a wide global collaboration between all stakeholders with the objective of introducing a new radio technology, with ever seen sophisticated engineering architecture. Probably this is why they called it 5G New Radio (5GNR).

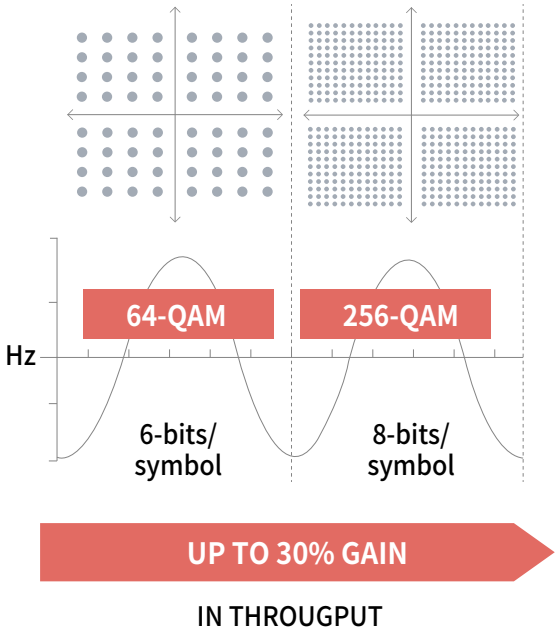

Figure-2 QAM principles

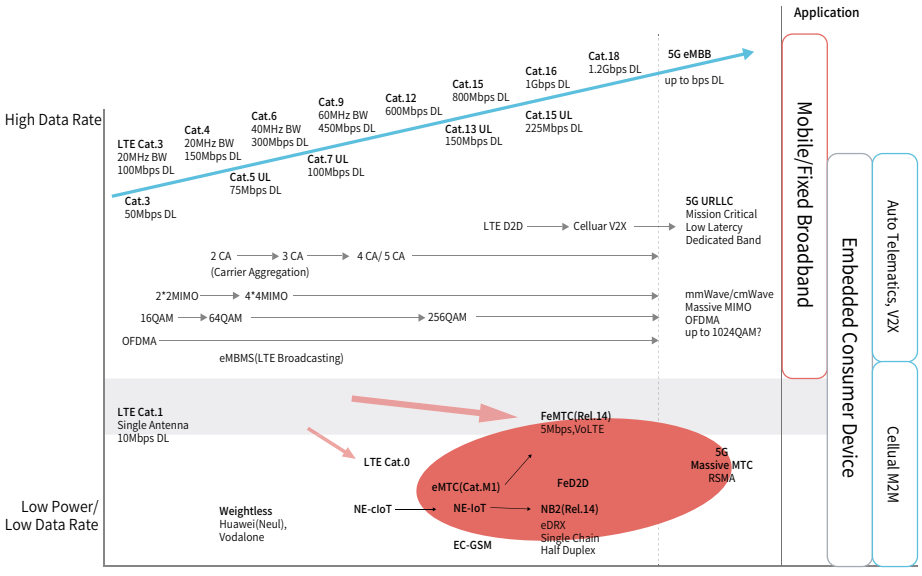

Figure-3 LTE toward 5G roadmap(Source: TSR Techno System Research)

The playground changed. Instead of vendors debating on different technologies, the race becomes introducing ultra-advanced technology with the aim of making life difficult for the other competitors. Obviously 3GPP not only liked the race but also fueled it.

Controversially, 5G standards have been developed based on a wide global collaboration among all main stakeholders. Consequently, what we have today as 5G standards (Rel-15) is the most complicated and challenging standards ever seen in telecom engineering history, but at the same time, it is a real breakthrough in wireless communication industry, as the most advanced yet unified standard. Technical difficulties were at the level that some even were arguing that mmWave antenna could have never been monetarized to be fitted into a mobile phone.

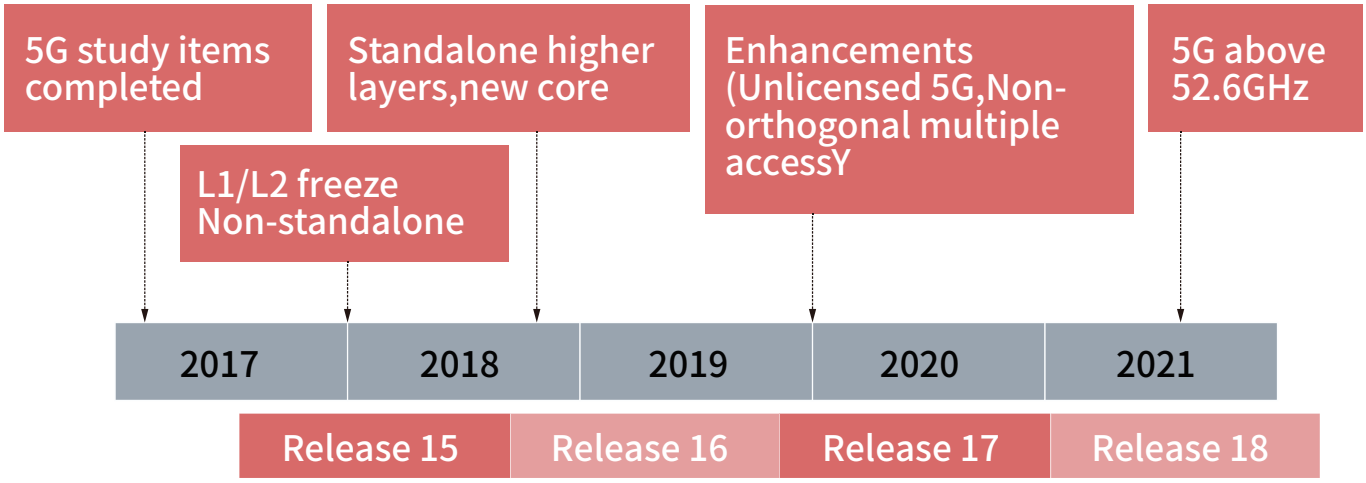

Figure-4 5G Standards release milestones (Source: 3GPP)

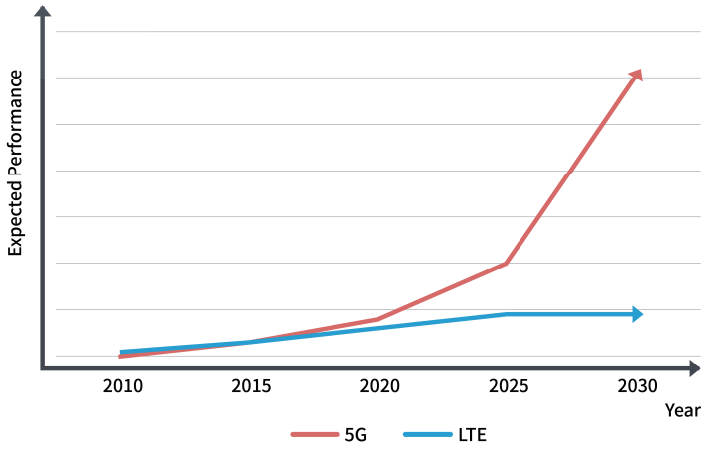

Figure-5 5G expected performance versus LTE

The race is over now as starting 2019 a dozen 5G mobile networks as well as many mobile phones have already been commercialized. But this is only a beginning as 5G will start to evolve to exceed speed 100x faster than what we know as LTE today. We will be witnessing 5G progress, geographically and technologically throughout the next decade, eventually reaching its saturation level by 2030, and opening up a door for even more sophisticated Radio Interface.

4. 5G Is About Machines

We are aware that mobile penetration exceeded 100% in some regions. Figure-6 illustrates that the penetration rate of Internet globally exceeded 52% by year end of 2018; therefore there is little room for more connections in consideration of the number of people. While the number of mobile internet connections increased significantly in between 2005 and 2018 the increase will slow down to less than 50% by 2025 to reach 5 billion[1].

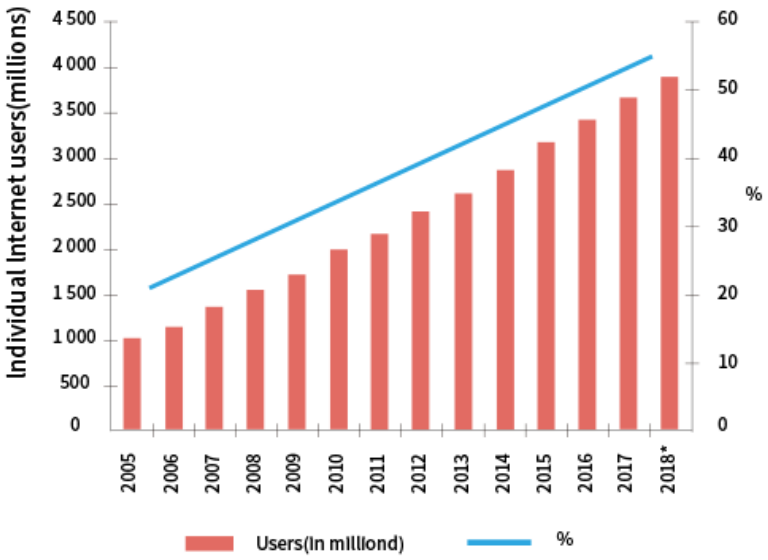

Figure-6 Internet users (Source: ITU)

Consequently, in order to increase the number of connections, the target has to be changed from People to Machines. More connections basically mean higher revenue for MNOs which drives 5G to elevate faster and become commercialized quickly. Otherwise the economy of scale for 5G might not justify its huge CAPEX investment needed. This is where Internet of Things came into the picture. As per Ericsson predication, the number of connected devices is about to reach 25 billion by year end of 2025, among which at least 4 billion are supposed to be cellular based.

Although nowadays even machines need more bandwidth, two main solutions have been specifically developed to address business and technology requirements of IoT segments, which are mMTC (Massive Machine-Type Communication) and URLLC (Ultra-Reliable Low-Latency Communication). Implementation of mMTC or Cellular-based Low Power Wide Area (LPWA) have been accelerated since it had to be launched even before 5G itself as LoRa and Sigfox claimed to offer the same features. Although mMTC is part of 5G but we avoid describing it in this section. You can learn more about LPWA here.

[1]Source: GSMA

5. eMBB

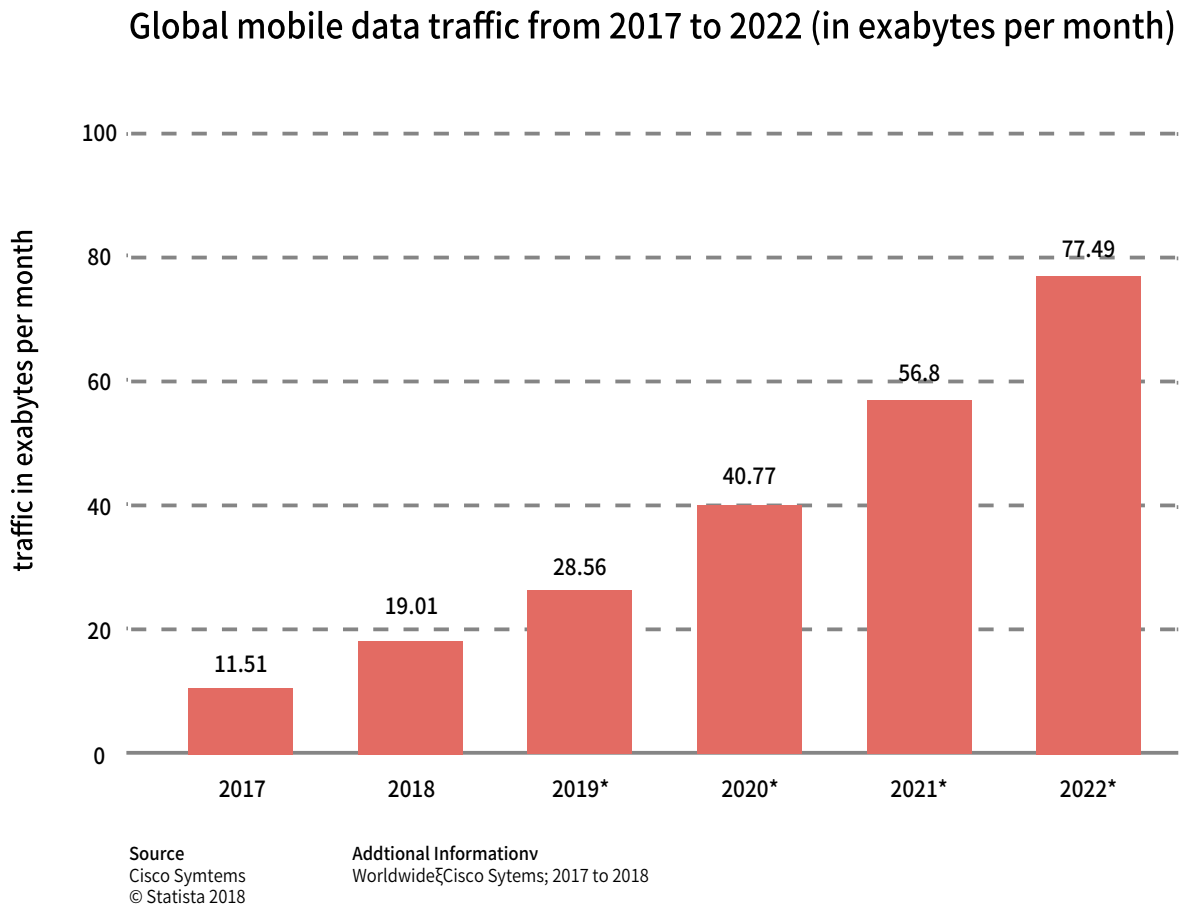

Figure-7 Global Mobile Traffic (Source: CISCO)

The very first motivation behind moving into new generation is to enjoy higher bandwidth. Mobile subscribers are hungrily consuming more data with exponential growth rate. As per Figure-7, global mobile data traffic is projected to increase nearly eightfold between 2017 and 2022 and the trend apparently is about to continue for many years to come. Such surge in demand asks for wider spectrum and basically needs a new radio access technology.

The eMBB, Enhanced Mobile Broadband, is one of the main pillars of 5G to address the increasing demand for more data. eMBB has main data-intensive applications that require broadband connectivity such as 4K video streaming, AR/VR and immersive gaming, to name a few. We will discuss later that industrial routers and FWA (Fixed Wireless Access) are among the very 1st wave of 5G Uses Cases.

6. URLLC

Mission-Critical Control, or latency-sensitive services need extremely high reliability, availability and security, such as Cellular Vehicle-to-Everything (C-V2X), Autonomous Driving, Intelligent Factory, Remote Surgery, Robots and Cloud based Connected Drones. URLLC features were particularly developed to address the 'no-failure' requirements (in fact as per standard at least 99.999% reliability) thus new mechanisms were introduced such as multiplexing to prioritize mission-critical transmissions over regular traffic or redundant links so that "mission-critical" devices can connect across multiple networks.

7. 5G NR

The 3GPP made decisions on some of the technologies to be used in 5G NR as part of the 5G NR Release-14 Study which officially began in March 2016. The first 3GPP 5G NR specification is also part of Release-15, on which work began in June 2016 and was completed in September 2018.

In March 2017, the 3GPP's RAN Group committed to accelerate the 5G NR workplan with an agreement for the early completion of an intermediate milestone for the enhanced Mobile Broadband (eMBB) use case. This non-standalone (NSA) 5G NR variant had been then finalized by March 2018 but in fact was approved in December 2017 as the very first 5G standard. It uses the existing LTE radio and core network.

The first call using the NSA 5G NR standard was completed in February 2018 on a test network in Spain, by Vodafone and Huawei.

The standalone (SA) mode was also completed in June 2018. It implied full user and control plane capability using the 3GPP's new 5G core network architecture.

In a nutshell, the 5G NR is being designed to significantly improve the performance, flexibility, scalability and efficiency of current mobile networks, and to get the most out of the available spectrum, be that licensed, shared or unlicensed, across a wide variety of spectrum bands.

Furthermore, the 5G NR air interface is just one component of the future 5G network, so it must also be designed to work as part of a flexible network architecture.

The 5G NR is able to deliver a huge number of varied services across a diverse set of devices with different performance and latency requirements; support a wide range of deployment models from traditional macro to hotspot deployments; and allow new ways for devices to interconnect, such as device-to-device and multi-hop mesh. And it must do all these at unprecedented levels of cost, power and deployment efficiencies.

7.1 New Spectrum and mmWave

This is typical that new generation calls upon new spectrum and wider carrier and 5G was not an exception. However, business and technical requirements pushed the new frequency to higher bands into mmWave. The big leap and key improvement in 5G was the wider carrier bandwidth as it dramatically increased from 20MHz in LTE to up to 400MHz. Once such wide carrier bandwidth combines with capability of CA (Carrier Aggregation), then 2GHz spectrum (and even higher) per connection is achievable, which ensures that exceeding 10Gbps speed would be practically possible.

Spectrum in general remains a precious asset for the operators and even countries. Three bands have been allocated globally and are going to be auctioned (or already auctioned) in many regions (Figure-8):

(1) Low Frequency below 2GHz. Currently the focus is on 600-700 MHz (band 71 and 82). This is the best possible spectrum that helps MNOs for fast coverage penetration. However, as very precious and limited spectrum resource, they can only offer limited connections. Therefore, we cannot expect full-fledged 5G operating in this band. Stakeholders including MNOs have been actively engaged with broadcasters to accelerate clearing more frequencies from sub-GHz bands. They are assisting TV broadcasters occupying 600Mhz to move into new frequencies. The 5G carriers here will be up to 20MHz paired or unpaired.

(2) Medium Frequency range 2-6 GHz. This is new spectrum to be allocated to 5G and is the 1st one to go auction. This is the best frequency to offer both coverage and capacity. It means while penetration into building are possible, frequency reuse can be well planned. The carrier bandwidth can be up to 100MHz in here.

(3) While above spectrum was literally called sub-6GHz, 3GPP recommended purely new spectrum above 26GHz. The mmWave spectrum is for denser population areas for greater capacity, which offers a greater freedom and more spectral to maneuver in addition to less background noise, excellent for building capacity and offering extremely high data rate to specific use cases. The carrier bandwith can be 400 or 800Mhz depends upon deployment scenarios. However, in engineering there is always tradeoff between what you gain and what you pay. The mmWave is a Line of Sight (LoS) RF technology, which means that it cannot penetrate buildings easily and even trees or other similar obstacles to decrease link budget significantly. Moreover, designing an affordable set of RF Transceivers, frontend RF and even antenna becomes a true engineering challenge.

	Low Frequency Below 2GHz	Medium Frequency 2-6 GHz	Higher Frequency 2-6 GHz
Band	600-700MHz	C-Band (3300-4200 MHz) Band n77 (3300-4200 MHz) Band n78 (3300-3800 MHz) 3.4-3.6 GHz (B42) And 2.6-3.8GHz (B43))	Mm Wave 26GHz-28GHz
Recommended Bandwidth	Up to 20 MHz paired/unpaired	100MHz assignments	400-800 MHz assignments
Expected Use	Wide-area MBB deep indoor coverage and URLLC	Best compromise between Converge and Capacity	Extremely high data rates use cases

Figure-8 5G Spectrums

Complexity of combing three different spectrums radically changed how mobile SoC were used to be designed. Figure-9 illustrates Qualcomm's design changes from LTE to 5G. Part of RF transceiver, RF Front-end and Antenna were redesigned and combined into new active antenna.

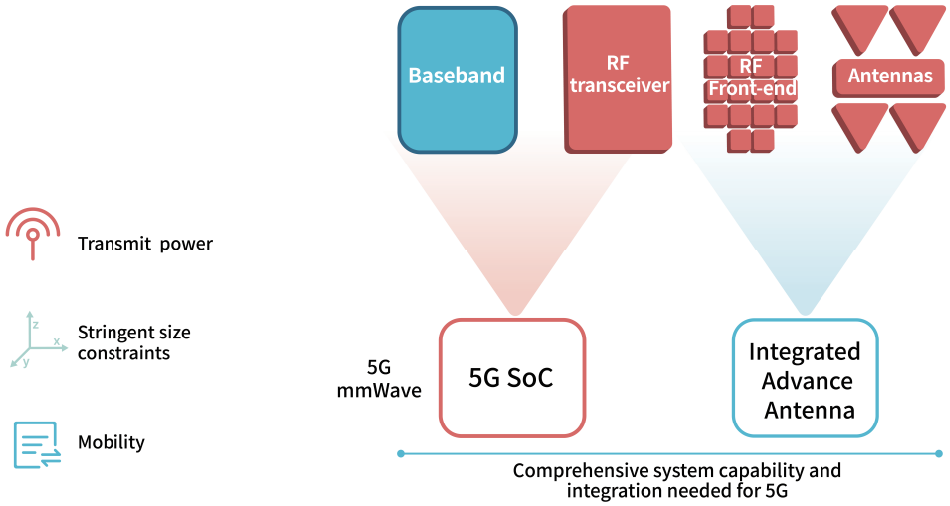

Figure-9 Integrated Advance Antenna

7.2 Massive MIMO

As LTE has proven that MIMO (Multi-Input Multi-Output) can increase performance, the mechanism has been further enhanced in 5G by increasing the number of simulation radio link between device and BTS. Massive MIMO can help boost link quality and reliability, and increase capacity w/o requiring more spectrum as well as superior energy efficiency.

Figure-10 illustrates basic 2x2 MIMO in LTE. The more antennas the transmitter/receiver is equipped with, the more possible signal paths and the better performance in terms of data rate and link reliability.

There's no set figure for what constitutes a Massive MIMO set-up, but the description tends to be applied to systems with tens or even hundreds of antennas. For example, Huawei, ZTE, and Facebook have demonstrated Massive MIMO systems with as many as 96 to 128 antennas. Because MIMO systems need to physically pack more antennas into a small area, they require the use of higher frequencies (and hence shorter wavelengths) than current mobile network standards.

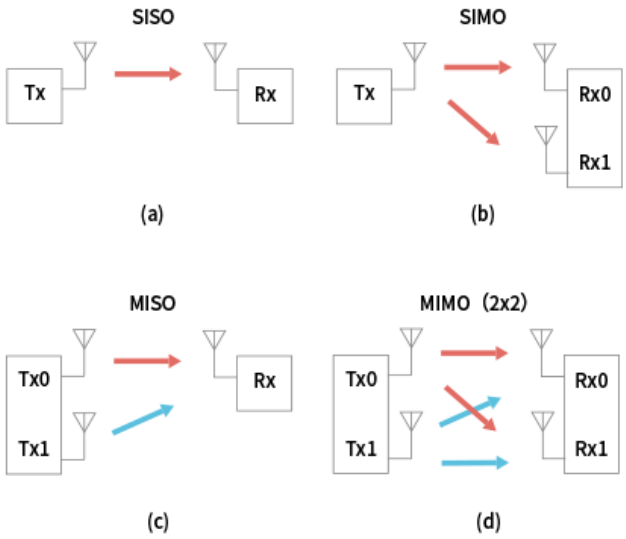

Figure-10 Basic (Standard) MIMO

Indeed, it's widely expected that Massive MIMO will be a key enabler and foundational component of 5G.

7.3 Spectral Efficiency

As described LTE uses a channel width of 20MHz, while 5G NR uses a channel width of 100MHz below 6GHz and 400MHz in mmWave. Therefore, 5G NR at 100MHz can transmit a single set of signaling where LTE at 20MHz would need to aggregate five carriers. Carrier Aggregation is not efficient in LTE when spectrum is divided in between wide variety of bands. 5G has solved this issue by allowing up to 400MHz carrier per connection. 5G NR also uses Reduced Broadcast Overhead mechanism in order to remove many of the constraints posed by LTE on broadcasted overhead transmission, specifically for the number of always-on signals. The 5G NR network smartly turns off the RF circuits to ensure better spectrum usability as well as for higher efficiency and power saving.

7.4 Beamforming

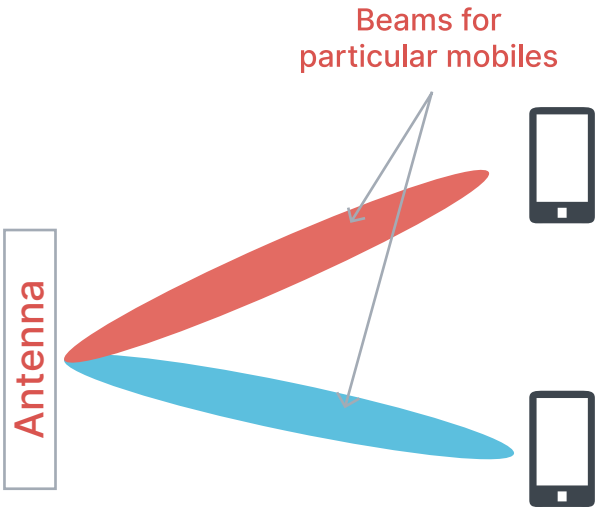

Figure-11 Beamforming

The basic idea of Beamforming is to optimally process signals received over massive MIMO antennas, or the signals which are to be transmitted over different paths, by adjusting the signal amplitudes and phases, to form a strong beam toward the direction of interest, and at the same time, to avoid receiving or creating interference. Figure-11 illustrates a simple Beamforming in between a BTS and two mobile phones. This allows BTS to send a focused streamed of data to specific users. This prevents interference, hence is quite efficient.

7.5 Low Latency

Low Latency is a major advancement of 5G. It basically means how long a data packet needs to travel from device or from mobile to server. You have probably tested it over internet when you use “ping” command to find out how long it takes to send a packet from your PC to a server. If you have not done it before, try it to get feeling about packet Round Time Trip or the latency.

To reduce response time, 5G uses a scalable orthogonal frequency-division multiplexing (OFDM) framework with different numerologies. Within a 1ms time duration, six separate slot configurations are available, e.g. 1, 2, 4, 8, 16 and 32 slots. The minimum size of a transport block could be reduced to a minimum of 0.03125ms based on the new configuration as shown in Figure 12.

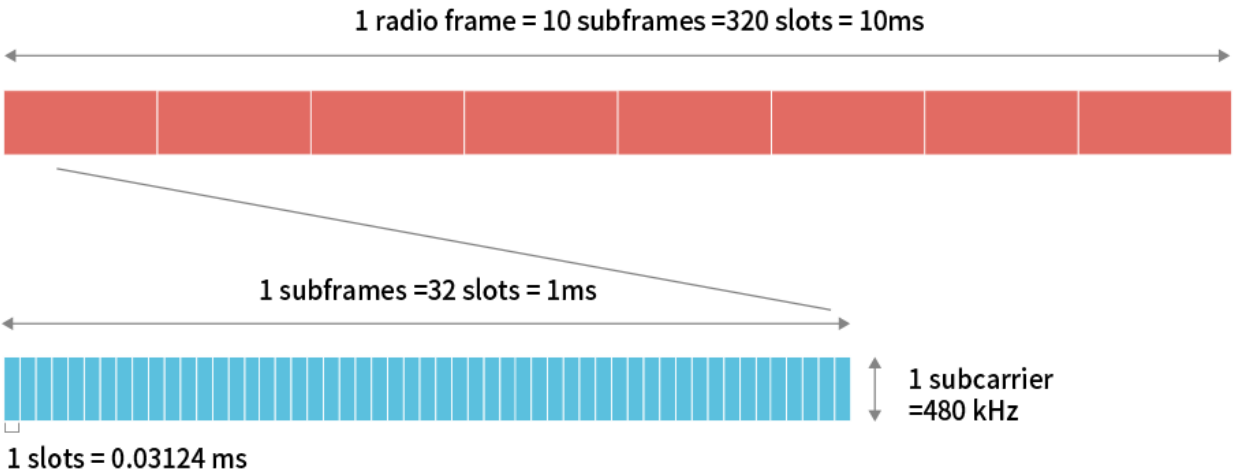

Figure-12 Slot configuration of multiple types of numerologies. (Source: 3GPP)

By assigning the configured grant resources, the 5G network eliminates the packet transmission delay for a scheduling request procedure and increases the utilization ratio of allocated periodic radio resources. Faster switching between uplink and downlink, more advanced scheduling, trimming the minimum scheduling unit and optimization of Inactive State, help 5G NR to achieve 1msec latency.

8. New Core Network

Complexity and advancements describe previously require redefining Core Network. A good example is the latency, even though an excellent radio interface guaranteed 1msec, it cannot cope with the low latency if not supported by a powerful core network.

In the 5G era, different industry verticals are seeking to leverage the power of technology to boost productivity across swathes of the economy. Network Slicing builds on this expectation, and together with the promise of Massive IoT and ultrareliable/low latency services, will support the transformation of vertical industries.

To unlock this opportunity, Network Slicing will enable operators to create pre-defined, differing levels of services to different enterprise verticals, enabling them to customize their own operations.

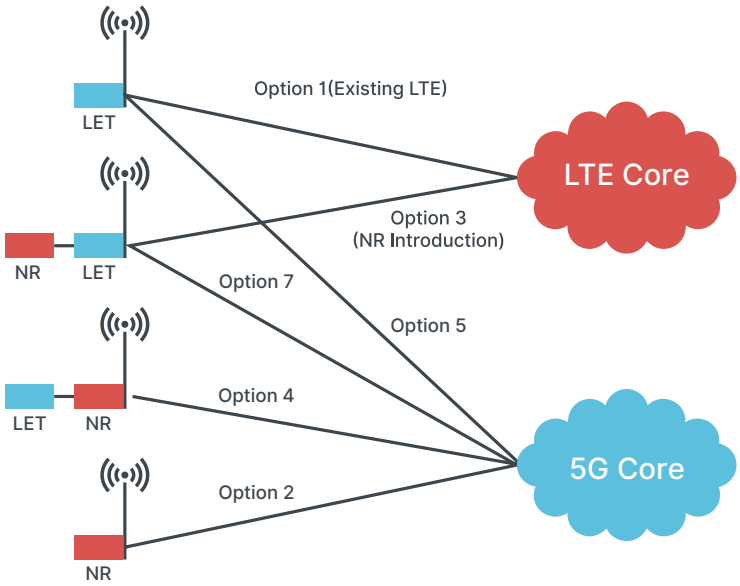

Figure-13 5G Core options

Standalone (SA) mode - Option 2:

- Connect to 5G-Core Network
- Full 5G service (support slicing, low latency)
- Lack of 5G coverage at network initial deployment

Non-standalone (NSA) mode - Option 3/4/7:

- Connect to LTE EPC
- Control channel on LTE, wireless connect guarantee
- Mainly for eMBB service, not fulfill low latency service

9. Design Challenges

As described 5G offers unique advanced features which presumably called for radical design changed in radio interface as well as the core. Capacity, data rate, latency and massive number of connections are four major pillars of 5G (Figure 14). In figure 15, the diagram illustrates how business requirements are addressed by enablers which then turned into design principles.

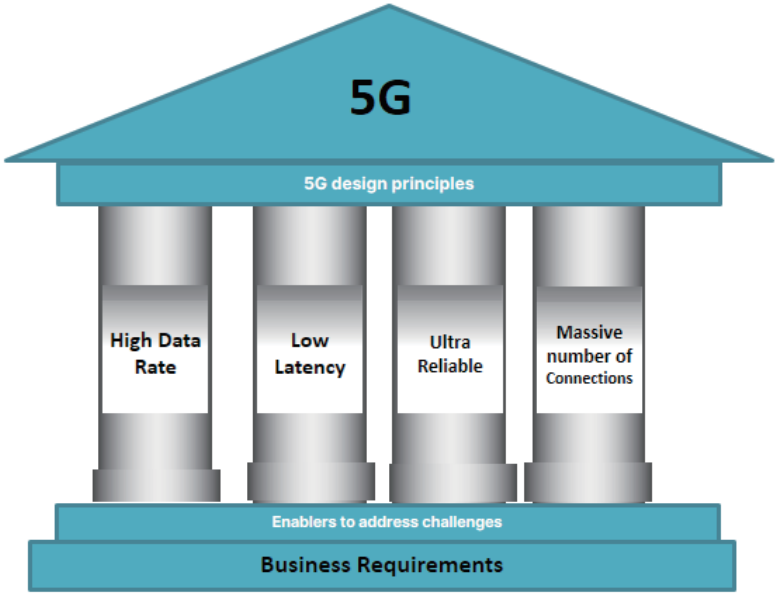

Figure-14 5G Pillars

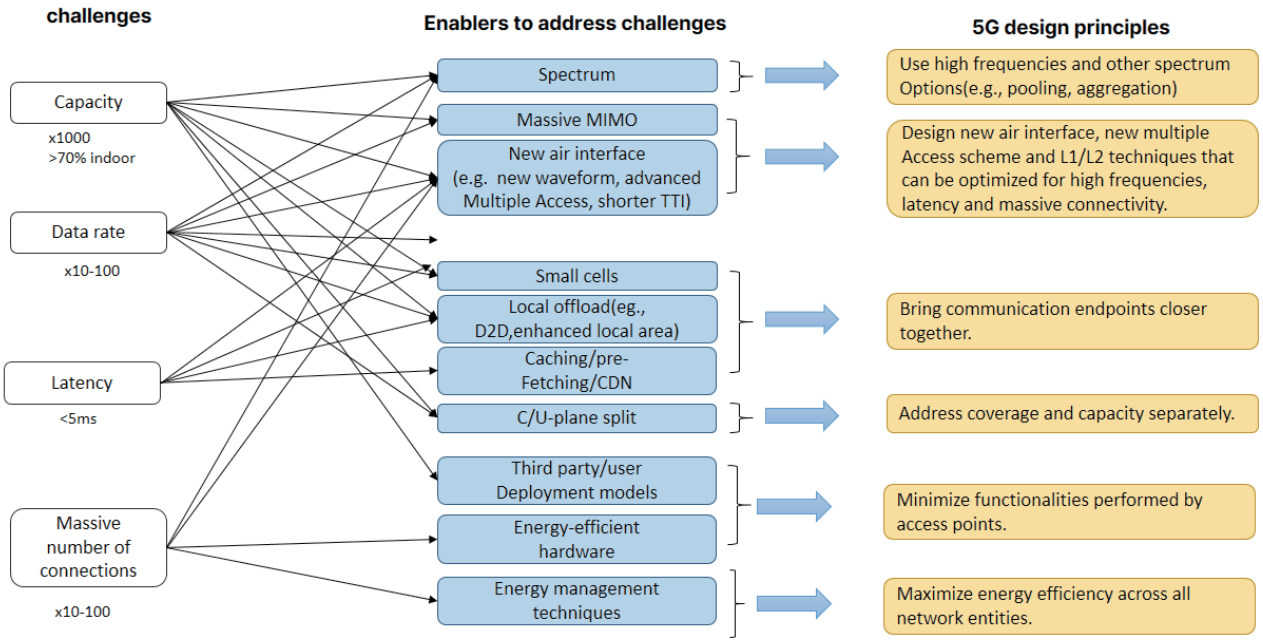

Figure-15 Challenges, Enablers and Design Principles

10. 5G-IoT Adoption and Deployment

It's predicated that the number of 5G subscribers will reach nearly 1.5 billion by the year 2024 (Figure 16). By this point, 5G is forecast to account for around 30 per cent of connections in markets such as China and Europe, and around half of the total in the US[2]. Over a fifth of the world's markets will have launched 5G by 2020[3].

As illustrated in Figure 17, it's also forecasted that the market size of 5G based IoT devices will exceed 62m by the year 2025[4].

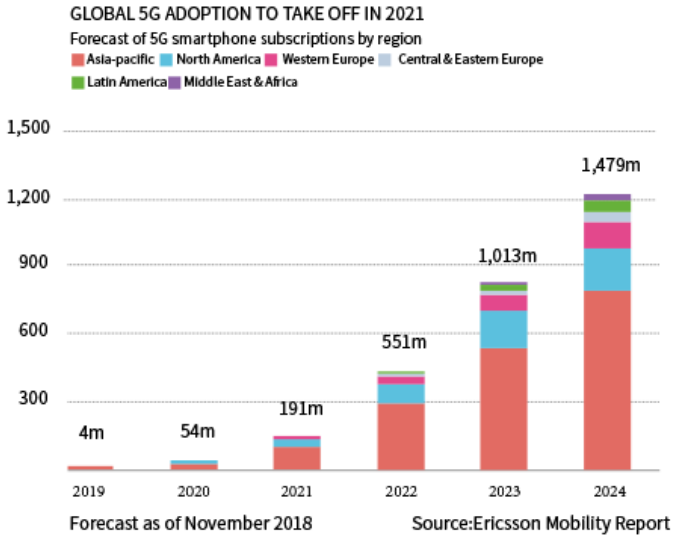

Figure-16 Global 5G Adoption to take off in 2021 (Source: Ericsson)

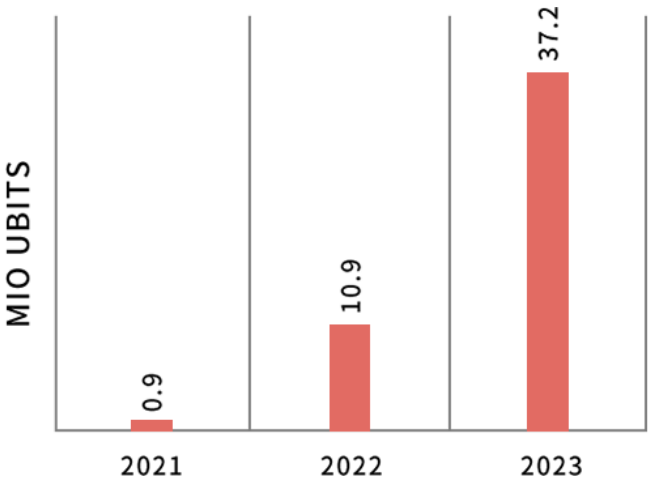

Figure-17: Global 5G IoT device market size (million) (Source: Beecham Research)

[2]Source: GSMA
[3]Source: The Mobile Economy 2019, GSMA Intelligence
[4]Source: Beecham Research customized report for Quectel

11. 5G-IoT, Applications and Use Cases

As we explained earlier, 5G mostly targets IoT as new market segment. Figure 14 divides 5G use cases into 3 areas, known as eMBB, URLLC and FWA use cases. For instance, AR/VR requires both high bandwidths and extremely low latency, while most of automotive use cases only require low latency and high reliability.

Depending upon use cases, MNOs will define Service Level Agreement (SLA). It's quite evident that they will charge IoT customers based on adopted SLA. Hence it will be increasingly important for IoT solution providers to define their equipment into an appropriate circular.

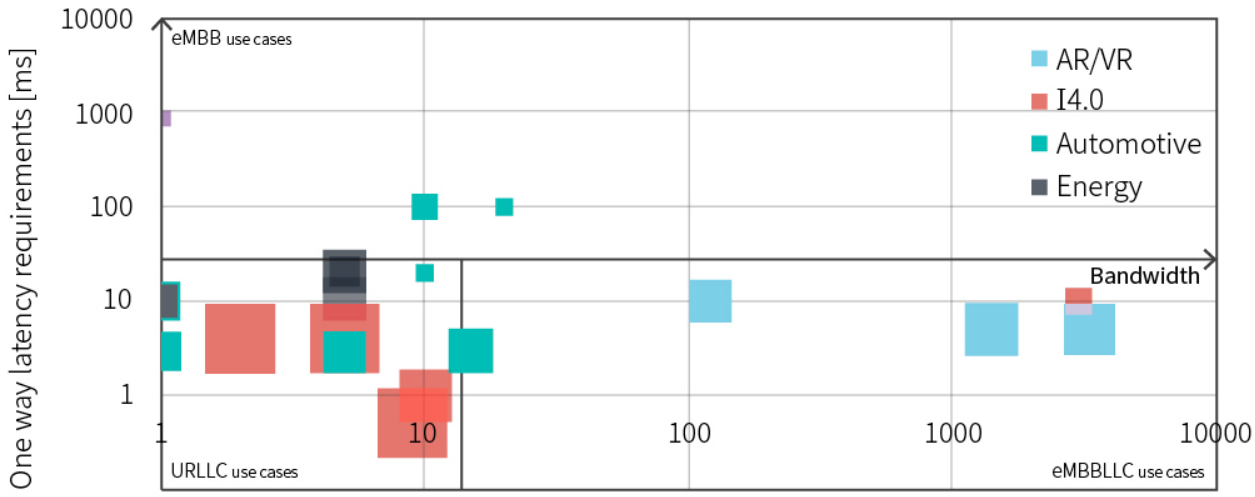

Figure-18 Use Case Clustering in 5G (Source: GSMA)

11.1 Fixed Wireless Access

A very real use case of 5G is to provide higher data bit rate to fixed subscribers. Mobile technology is considered as true murderer of fixed network, since 2G and LTE have been defeating landline and ADSL/VDSL respectively. It's now 5G's turn to omit the need for FTTH (Fiber to the Home) even before the industry gives birth to it. The trend is obvious: Home and Industrial Getaway and 5G Routers are among pioneering products to hit the market which consume bandwidth supposed to be provided by the Fiber.

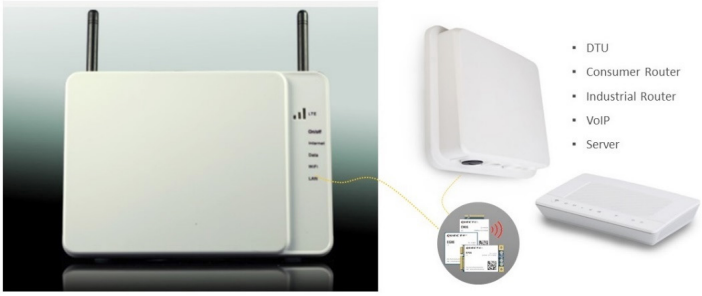

Figure-19 Fixed Wireless Access, Gateway/ Router/CPE

11.2 Consumer Laptop and Industrial Tablet

Figure-20 Connected PC

Always Connected PCs (ACPC) is getting popularity. This trend will be further strengthened by 5G. True virtual offices which allow people to conduct almost all office tasks remotely are becoming part of today's business habits. Offices will be gradually moving back to homes as they are supported with many other sophisticated features, just to name a few, 4K-Video conference call, document sharing, Cloud based ERP, real time translator assistance, robotics, etc. This makes life more joyful and decreases transport cost, traffic jam, fuel consumption and the need for bigger office space.

11.3 Augmented and Virtual Reality (AR/VR)

In the most advanced countries, today's digital consumers (using PCs and smartphones) will likely become tomorrow's augmented customers, adopting emerging technologies such as AI (via smart speakers) and immersive reality.

Mobile users will enjoy the next generation of connected immersive experiences as AR/VR mainly target entertainment market segment. Nevertheless, AR/VR have also become an undoubted part of digital economy and are transforming, for instance, how engineers design new products. You may also imagine a team of doctors conduct a surgery collaboratively by controlling robots remotely using AR/VR.

Figure-21 Augmented and Virtual Reality

11.4 Drones

The Three-Dimensional Transportation (3DT) era will be coming within next decade. The human evolution had commenced with 1D transportation when mankind could stand up on his/her feet and start walking. The 2D transportation arena started with domestication of horses and continued by invention of trains and cars. Airplanes, copters and even spaceships cannot be considered as true 3D transport machines but rather 2.5D.

Drones are machines that can freely fly in three dimensions. However, in order to legally, technically and affordably become widely available, they need to address certain challenges. Drones are poised to be highly connected and intelligent for collision avoidance as well as prevention of entering restricted areas. Therefore, they should be equipped with ultra-sophisticated auto pilot system, which cannot be economically and commercially viable unless it's always connected to the cloud. 5G would be the excellent choice for its communication backbone to satisfy technical needs of the pipe in a cloud-based auto pilot system.

Figure-22 Drone

11.5 C-V2X

Cellular Vehicle-to-Everything (C-V2X) is an obvious use case of 5G as always-connected car and autonomous vehicle need high speed and low latency backbone to be realized. The new radio interface provides ability for higher level of predictability.

C-V2X immediately offers a robust platform to provide the vehicle with enhanced situation awareness. In contrast, the older DSRC/IEEE 802.11p capability will rely on the deployment of new, dedicated DSRC-capable infrastructure along roadways, which has proven not to be easily scalable and even after 15 years of its invention is yet to become a main stream of ITS industry.

This is clear that due to advancements in autonomous diving and commercialization of its level-1 and level-2, the car OEMs are poised to accelerate C-V2X projects more aggressively. The competition to create the best driverless car has never been hotter and it will be further fueled by the 5G rollout.

Author predicates that by 2030 a connected/autonomous/AI driver can win formula-1 car race, if allowed to be a participant.

Needless to add that the 5G will be going to offer more facilities for the connected vehicles as it can provide in-vehicle entertainment, makes journey even more pleasant.

Figure-23 C-V2X

11.6 Other Verticals/Use Cases

There might be countless new Use Case that can leverage 5G value proposition such as 5G-TV, setup box, robots, car sharing, a wider range of asset sharing, high-end surveillance systems, in-vehicle surveillance camera, smart factory, to name a few. Figure-24 depicts how high speed and low latency can enable new use cases.

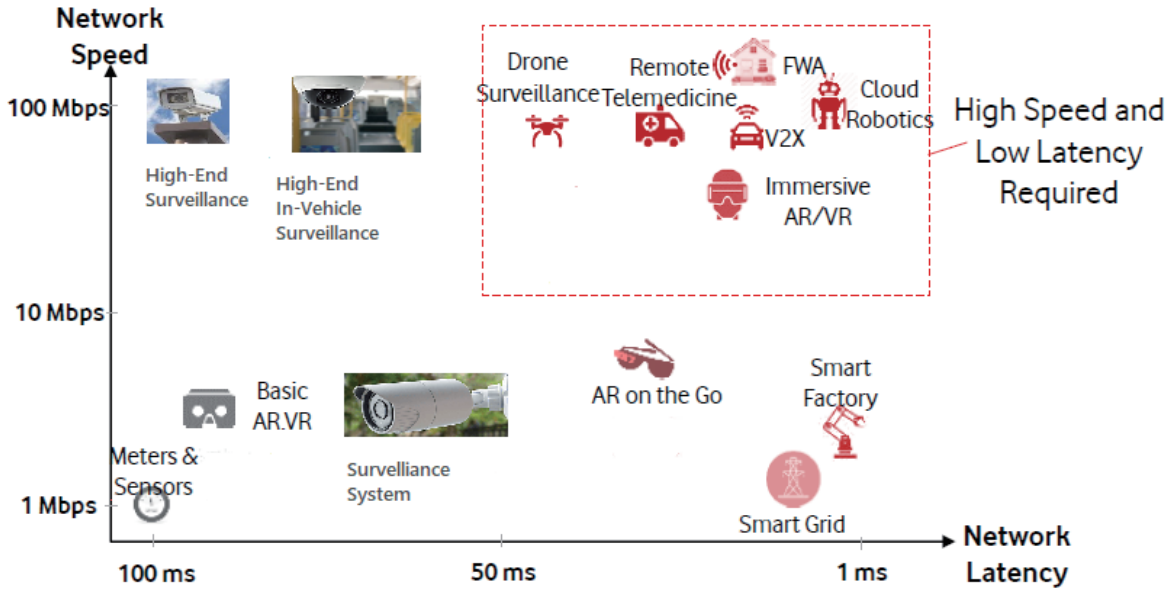

Figure-24 5G Use Cases

12.Convergence of 5G, AI, Blockchain and Cloud

New GSMA report highlights how the 5G, Artificial intelligence and IoT will transform the Americas. The technology burden on IoT was eased somewhat with the introduction of edge devices that combine compute, connectivity, and storage in a single device to provide intelligence to a broad range of IoT use cases, which we have listed a few of them in this article. As 5G offers an excellent pipe, devices can utilize massive cloud computing and processing power whenever needed almost seamlessly. Artificial Intelligence (AI) is very resource intensive and its cost of computation is still high to be built into all tiny devices, however above changes will make AI quite affordable for a wider range of AI based uses cases.

Meanwhile Blockchain offers a unique platform to make IoT secure from inside in, which again needs a peer to peer, ubiquity, pervasive yet very fast communication pipe, simply 5G.

Next generation of IoT, named IoT-2 here, will be secured by Blockchain and will be highly intelligent thanks to AI engines inside devices and outside on the cloud.

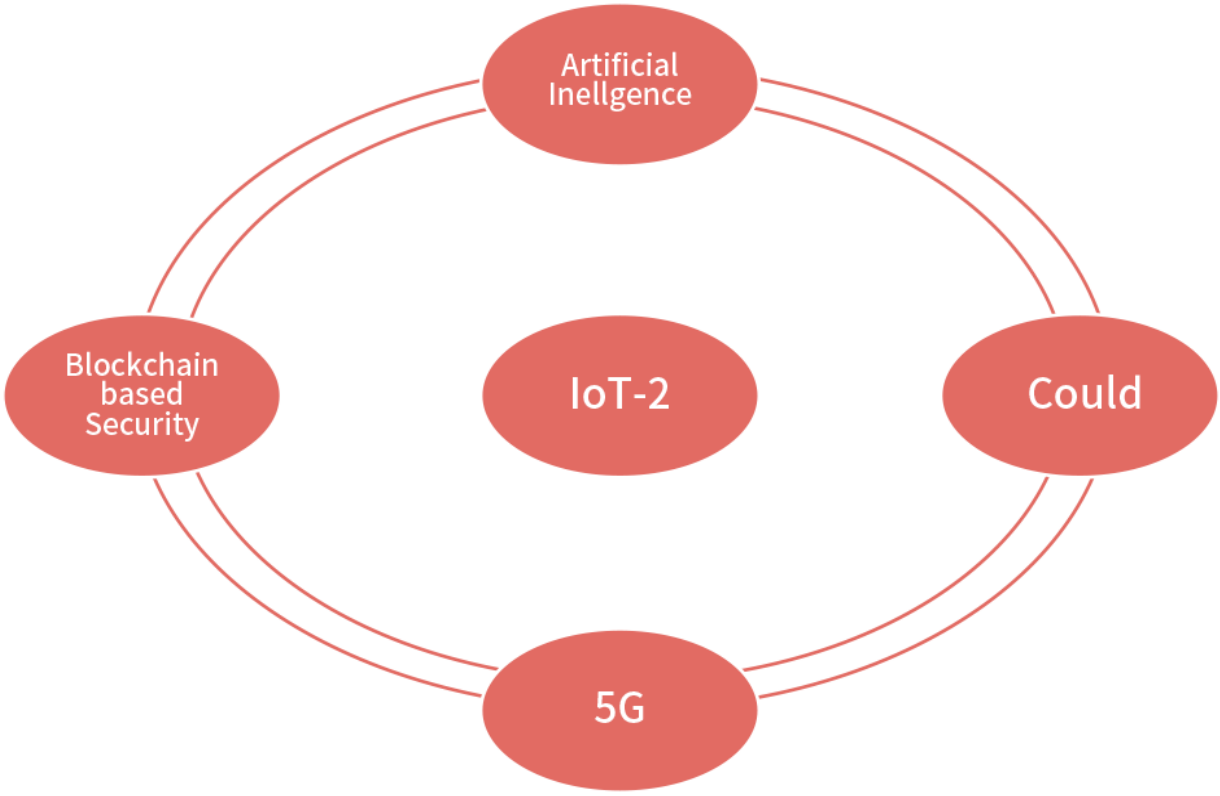

Figure 25: IoT-2, Convergence of 5G, Cloud, Blockchain and Artificial Intelligence[5]

[5]Source: Author

13. Economic and Social Impacts

Depending on the scale and pace of 5G rollout and the development and uptake of the services it supports, it has the potential to produce far-reaching economic benefits by supporting, and even accelerating global digital transformation.

For example, the rise of IoT devices may lead to smarter cities where consumers are able to better avoid, and hence reduce traffic congestion. This benefits households and improves their ability to supply labor to the economy, but also makes transport services more efficient, which should raise productivity.

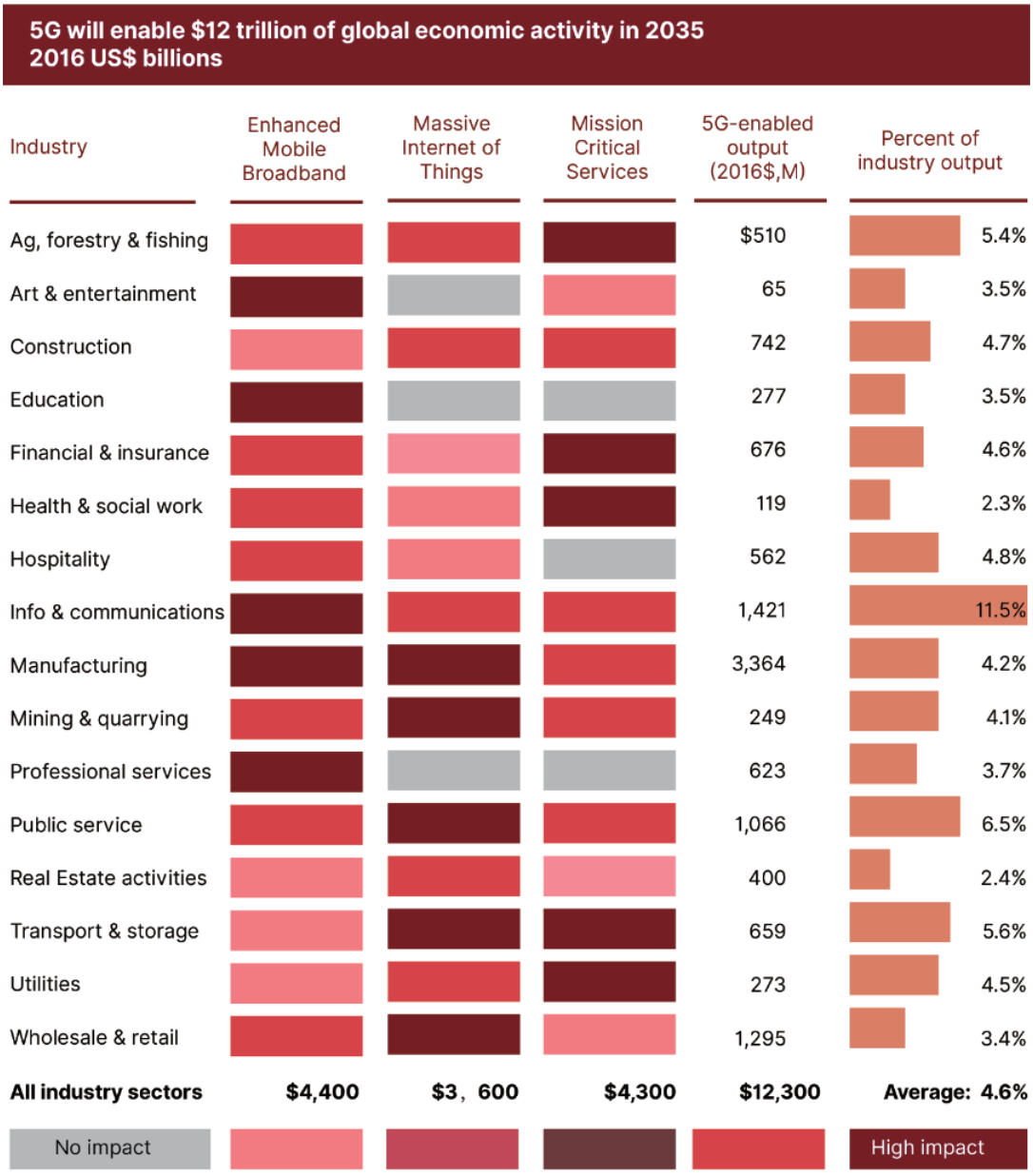

Figure-26 Impact of 5G on various Industries USD (source: IHS)

The scale and scope of 5G's economic impact will depend on many factors:

- How transformative 5G is — where it falls within the range of significant advances in mobile technology, ranging from an incremental improvement to a GPT in its own right. Both will have productivity impacts, but the latter could be expected to affect productivity and prosperity over a longer period.

- How quickly 5G is rolled out — which will be affected by investment choices and regulatory settings.

- How quickly 5G is taken up — which will reflect the readiness of businesses and households to make use of the new technology.

- Legal and regulatory frameworks that may need adjustment to allow for 5G-enabled goods and services.

All these factors will be affected by the demand and supply for mobile data and 5G-enabled products. While much of the expectation around 5G initially focused on consumer use, more technology providers are beginning to see important business use cases that will generate industry demand. In 2016, 90 per cent of telecommunications operators surveyed saw consumers as the central segment in their planning, with only 34 percent focused on IoT. But by 2017, the consumer focus had fallen, with 52 per cent of operators viewing consumers as the central segment in their planning, with planning shifting to IoT and industry/ business users.

As per IHS (2017), 5G will enable $12 trillion of global economy activity in 2035. Figure-25 is an infographic that indicated which industry sector are expected to be impacted the most by 5G with respect to eMBB, mMTC and URLLC features. There are segments like ICT, public service and agriculture which as per the source, are supposed to benefit from 5G penetration significantly.

14. 5G Race

In May 2019, GSA published a report in which it indicated that:

- 231 operators in 91 countries are investing in 5G networks in the form of tests, trials, pilots, planned and actual deployments.

- 41 operators had announced that they had deployed either non-3GPP-compliant or 3GPP-compliant 5G technology in their networks.

- 12 had announced the launch of limited availability 5G mobile or 5G FWA services

- 5 had announced the launch of 5G test-beds/ incubators.

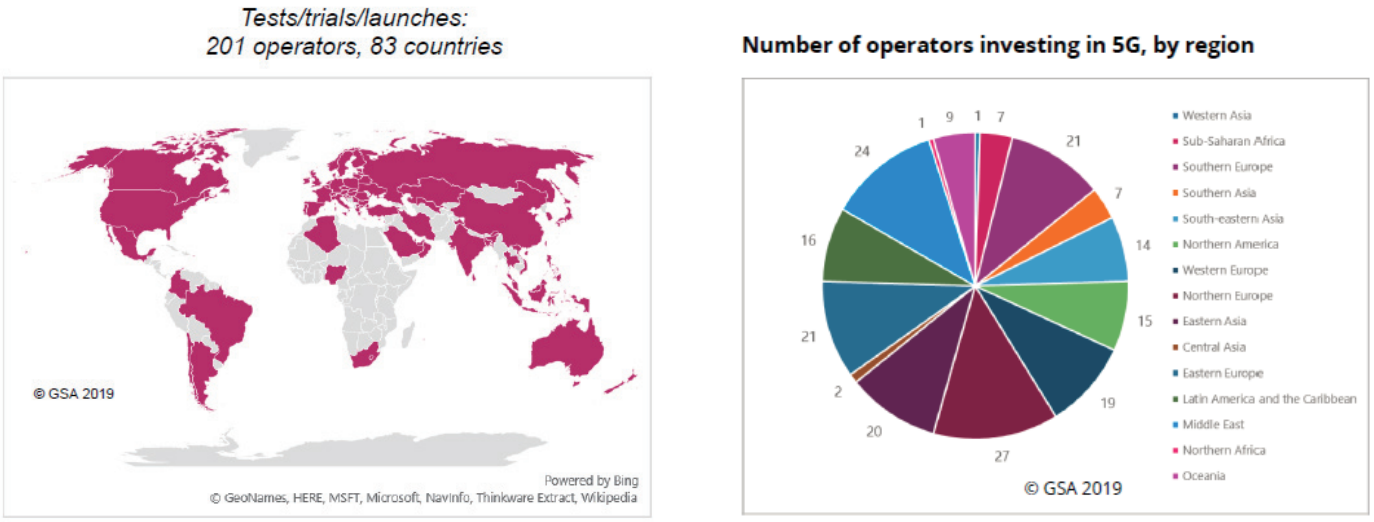

Figure-27 5G Race (Source: GSA)

15. Quectel 5G Modules

As a leader in IoT and mobile module innovations, Quectel has been at the center of 5G technology commercialization and is currently working with global mobile network operators, Qualcomm Technologies and other ecosystem participants in making 5G New Radio (NR) a reality. At Quectel we have clear strategy to be pioneer in offering cutting edge 5G modules, in both sub 6Ghz and mmWave. We have been tirelessly collaborating with our business partners and paving the way swiftly as Quectel is determined to be a strong player in the 5G-based IoT ecosystem. Quectel has been scaled up from a follower to challenger and now is proven to become module market leader. Quectel leverages the richest experiences in LTE-A gigabits modules, to penetrate lucrative 5G market.

15.1 RG500Q/RG510Q

The RG500Q/RG510Q is the first 5G/LTE dual mode LGA modules, best in class, featuring the Qualcomm® Snapdragon™ X55 5G modem. Compliant with 3GPP Release 15 specifications and capable of both 5G standalone (SA) and non-standalone (NSA) modes of operation, the RG500Q/RG510Q modules are designed for enterprise and mobile broadband applications such as fixed wireless access, mobile hotspot devices, and public safety and surveillance applications. Designed in LGA form factor, the RG500Q supports the 5G NR sub-6GHz while the RG510Q supports both 5G NR sub-6 GHz and mmWave spectrum bands. Variants of both modules also support LTE Category 12 or above and embedded GNSS capabilities, and target Asia-Pacific as well as Europe, Middle East and North America regions.

A rich set of Internet protocols, industry standard interfaces and abundant functionalities (USB derivers for Windows 7, Windows 8/8.1/10, Linux and Android) extend applicability of the modules to a wide range of IoT and eMBB applications.

Figure-28 Quectel 5G LGA Modules

15.2 RM500Q/RM510Q

Designed in M.2 form factor, the RM500Q supports the 5G NR sub-6GHz while the RM510Q supports both 5G NR sub-6GHz and mmWave spectrum bands. Both modules also support LTE Category 22 connectivity with integrated GNSS and eSIM. RM500Q and RM510Q are ideal for globally deployed mobile devices including Always Connected PCs (ACPC), industrial PDAs, mobile gateways and more.

A rich set of Internet protocols, industry standard interfaces and abundant functionalities (USB derivers for Windows 7, Windows 8/8.1/10, Linux and Android) extend applicability of the modules to a wide range of IoT and eMBB applications.

Figure-29 Quectel 5G M.2 Modules

16. Conclusion and Beyond

There is little doubt that 5G will have profound impact on the course of human civilization. Mobile subscribers would benefit from 5G in different ways which can be summarized as better User Experiences. However, the greater impact is on Machines, to make the world highly connected and ultra-smart. The foundation for such transformation will be 5G.

The majority of the largest internet companies either did not exist or were in infancy stage when 3G had been launched. LTE also created new wave of startups, some of which became giant with multibillion market cap in less than a decade. In the next decade we will be witnessing rise of new companies which invest their time and money in technologies and businesses in line with how the 5G is going to shape the future of connectivity. We will also see the fall of many big names, who ignore the paradigm shift. This is how evolution works - only smart and most importantly agile companies with capability of adapting to the changes can survive and dominate the world.

Quectel will be offering the broadest module product portfolio from NB-IoT to 5G and as a result, Quectel's mission statement would impress the audiences "To connect the unconnected things and build a highly connected smart world!" since we will be able to practically connect any connectable THING on the planet earth.

Glossary

3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
ACPC	Always Connected PCs
AVL	Approved Vendor List
AI	Artificial Intelligence
AR	Augmented Reality
BOM	Bill of Materials
Cat 1	Category 1
Cat 4	Category 4
Cat 6	Category 6
eMBB	Enhanced Mobile Broadband
eSIM	Electronic Subscriber Interface Module
eUICC	Embedded Universal Integrated Circuit Card
Gbps	Gigabits Per Second
GNSS	Global Navigation Satellite System
GHz	Gigahertz
GSA	Global Mobile Supplier Association (www.gsacom.com)
IIoT	Industrial Internet of Things
IoT	Internet of Things
KHz	Kilohertz
LPWA	Low Power Wide Area
LTE	Long Term Evolution
LTE-M	Long Term Evolution – Category M1
MHz	Megahertz
MIMO	Multiple Input, Multiple Output
NRE	Non-recurring Engineering
NSA	Non-Standalone
ODM	Original Design Manufacturer
OEM	Original Equipment Manufacturer
QAM	Quadrature Amplitude Modulation
RISC	Reduced Instruction Set Computer
SA	Standalone
SC-FDMA	Single Carrier Frequency Division Multiple Access
SKU	Stock Keeping Unit
TDD	Time Division Duplex
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communication
VR	Virtual Reality
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network

About Quectel

Quectel Wireless Solutions is the leading global supplier of 5G, LTE, LTE-A, LPWA, Smart Module, C-V2X, GSM/GPRS, UMTS/HSPA(+) and GNSS modules. As a professional IoT (Internet of Things) technology developer and cellular module supplier, Quectel is able to provide one-stop service for IoT cellular modules. We estimate that globally more than 100 million devices have at least one Quectel module inside or as called, have been Accelerated by Quectel.

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