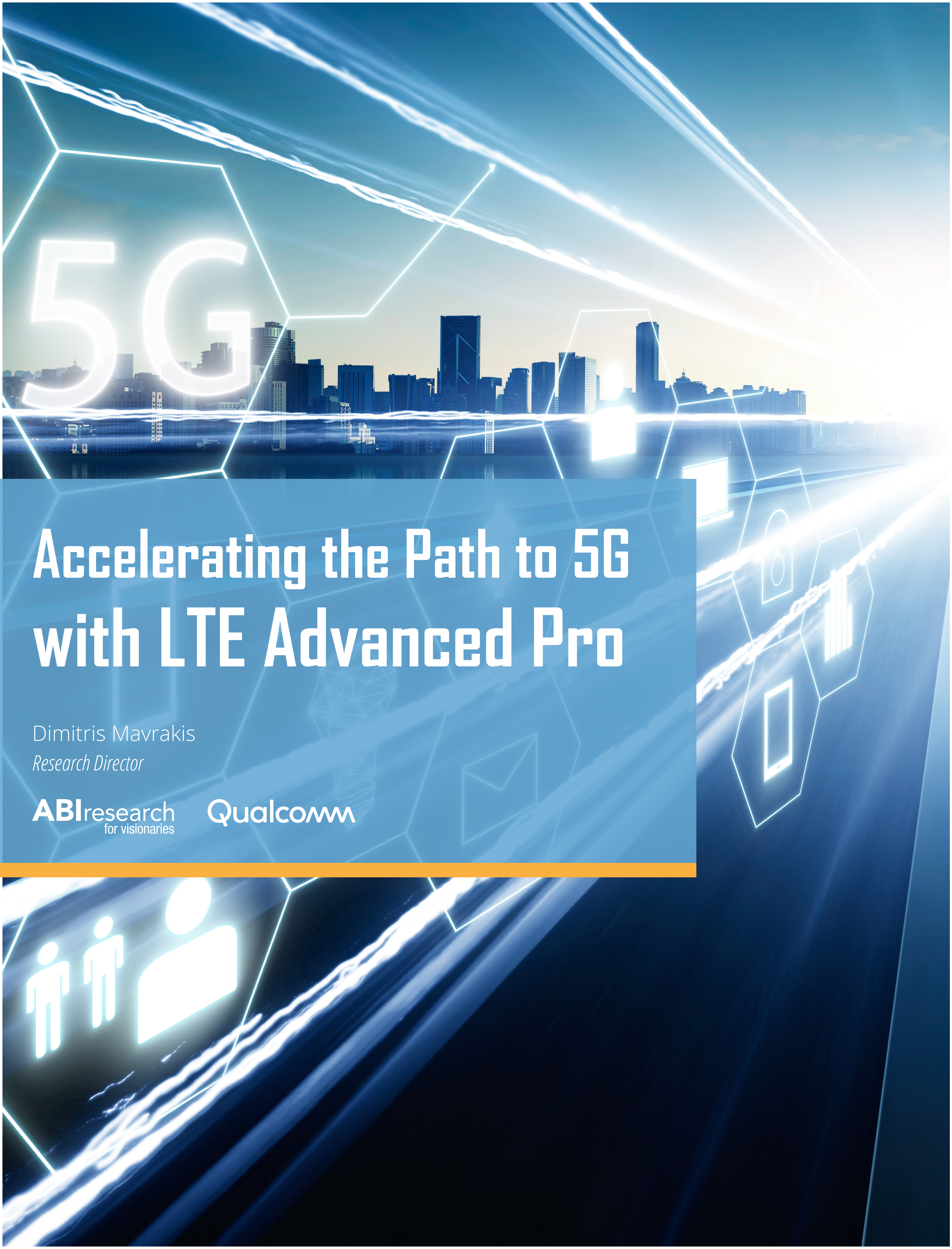

Accelerating the Path to 5G with LTE Advanced Pro

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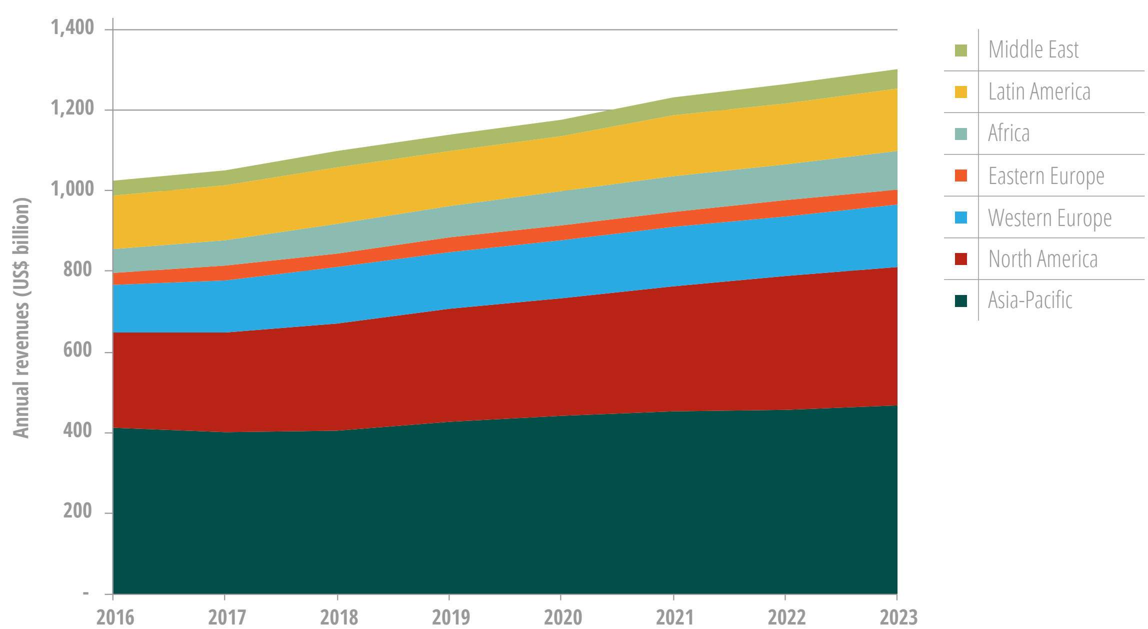
1. MARKET OVERVIEW

Mobile networks are in the middle of a vast transition, one that is more groundbreaking than any other periods of transition in the past 15 years: 5G is expected to bring a much bigger impact to the global economy than 3G and 4G. When operators upgraded to 4G LTE, the migration from a circuit-switched to a fully packet-switched network brought substantial network capacity, data rate, and latency improvements. Mobile service providers transitioned from a voice-centric to a data-driven business model, which not only ushered in the era of the mobile Internet, but is now also creating new business opportunities in adjacent markets, including the Internet of Things (IoT), automotive, and many more. These new growth areas are fueled by the continued LTE evolution that unlocks new network and device functionalities, and they will be an integral part of 5G, where the mobile service provider becomes a service enabler, rather than a pipe to the Internet.

Chart 1 illustrates mobile service provider revenue forecasts throughout the period of early 5G deployments.

Chart 1: Mobile Service Provider Revenue by Region
World Markets, Forecast: 2016 to 2023



(Source: ABI Research)

Along with challenges, new growth opportunities have also arisen: increasing use of mobile broadband, sophisticated smartphone devices driving new use cases, new types of high-quality streaming content such as 360-degree videos for immersive Virtual Reality (VR), and a growing number of new device types across industry verticals connected to the Internet. To meet the insatiable demand for faster, better mobile broadband services, extensive Research and Development (R&D) has led to innovative technologies on the radio side that can enable operators to make substantial gains in data rates and capacity, which enhance the user experiences and, at the same time, lower cost-per-bit that can greatly improve and create new business models (*e.g.*, unlimited data plans).

As of 2018, the mobile service provider community is discussing what the dominant 5G business model will be for the early 5G commercial deployments starting in 2019, with enhanced Mobile Broadband (eMBB) identified as the first choice. Early 5G New Radio will focus on enhancing network capacity and delivering differentiating services (*e.g.*, using 5G NR mmWave), with new networks prioritized for high-demand areas initially and broader deployments expected subsequently. At the same time, 4G LTE networks are rapidly evolving, with Gigabit LTE, LTE IoT, Cellular Vehicle-to-Everything (C-V2X), and other vertical use cases being planned and deployed. These enhancements and new services will help mobile service providers generate revenue without necessarily waiting for 5G NR to be widely deployed. Mobile service providers are now realizing that continuous investment in LTE network enhancements will prepare them for 5G across many facets, including: enhanced radio technology, core networks, and new enterprise business models. This experience, as well as the technical foundation, will be vital for the success of 5G. These enhancements will also enable them to incubate early 5G use cases and provide near-5G experience in areas that are still being studied by 5G standardization.

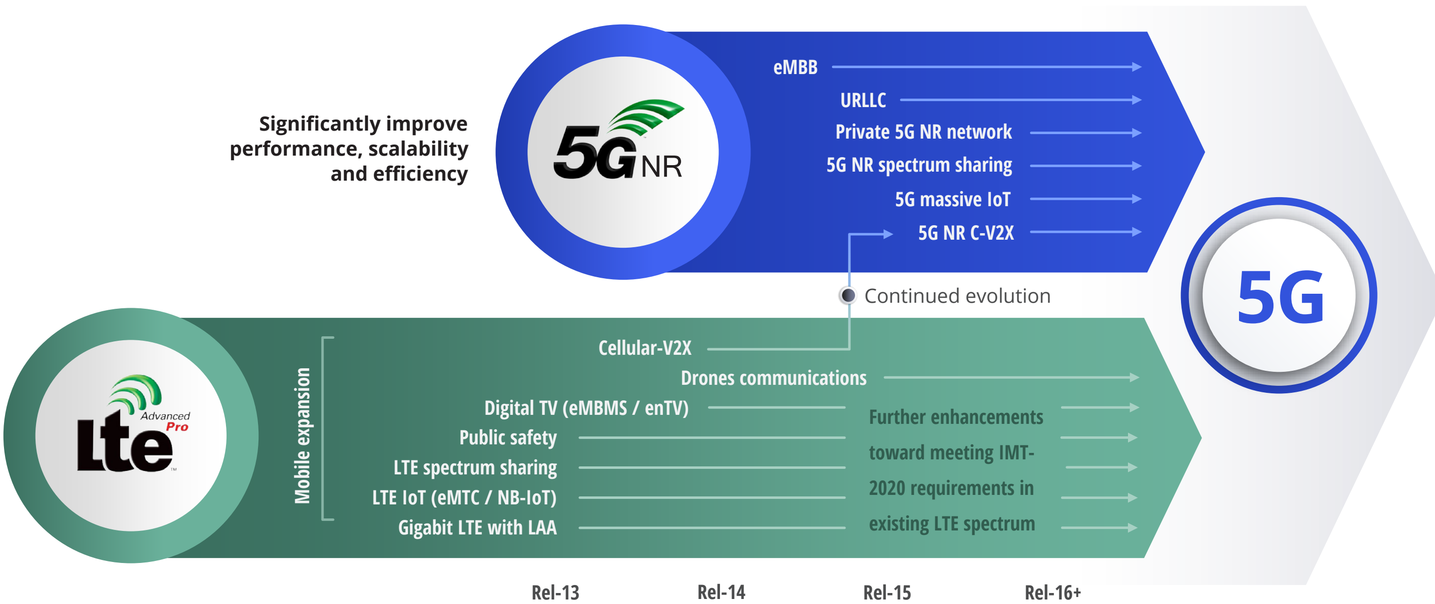
2. LTE ENHANCEMENTS ENABLING NEW BUSINESS MODELS

Commercial LTE networks are currently being updated to Release 13, offering higher speeds more efficiently (*e.g.*, adding the use of unlicensed spectrum for mobile broadband, which is one of the key enablers of Gigabit LTE), as well as enabling new use cases (*e.g.*, LTE IoT) that allow mobile service providers to enter new markets. It should also be noted that LTE will continue to advance, even with 5G NR specifications being defined in parallel.

The LTE Advanced Pro evolution continues in Release 14 and beyond. For mobile broadband, many new functionalities have been introduced, including massive Multiple-Input, Multiple-Output (MIMO) with 32-ports (64 antennas), 1024-Quadrature Amplitude Modulation (QAM), enhanced License Assisted Access (eLAA) for both uplink/downlink aggregation, and Ultra-Low Latency (ULL). For the LTE expansion to new industries, C-V2X was introduced in Release 14, as well as enhanced LTE IoT capabilities and efficiencies.

Because LTE Advanced Pro will be submitted along with 5G NR to meet the International Telecommunication Union's (ITU) IMT-2020 5G requirements, these LTE technologies are part of the 5G platform that will provide many essential services starting from Day 1 of 5G.

Figure 1: Current LTE Advanced Pro Features Setting the Foundation for 5G Technology and Business



(Source: Qualcomm)

2.1. GIGABIT LTE DELIVERS NEAR 5G MOBILE EXPERIENCES

The world's first commercial Gigabit LTE network was lit in Australia by Telstra. Since then, more than 50 operators have embraced the technology, with more than 20 commercially available devices powered by Gigabit LTE modems. Telstra launched its Gigabit LTE network with licensed spectrum only, but many operators have also embraced LAA, offering the Gigabit experience without necessarily having extensive licensed spectrum.

When it comes to Gigabit LTE modems, Qualcomm is the market leader. The company introduced the first commercial Gigabit LTE chip back in February 2016 in the form of its Snapdragon X16 modem. This Cat.16 chip can reach 1 Gbps in the downlink, thanks to the combination of many first-time smartphone technologies, including 4x4 MIMO, 256 QAM, and Carrier Aggregation (CA) of three 20 MHz spectrum (3xCA). Competitors like Huawei and Samsung launched their own Gigabit LTE chips 12 months later. Samsung launched its Gigabit-LTE capable Exynos 8895 chipset in February 2017 followed by its Exynos 9810 chipset in April 2018, a Cat.18 modem combining up to six carriers to offer a downlink speed of 1.2 Gbps, while HiSilicon launched its Kirin 970 in September 2017, which includes a Cat.18 modem capable of reaching up to 1.2 Gbps downlink speed. Intel also announced its Cat.16 Gigabit-capable modem, the XMM7560 during February 2017 and its Cat.19 modem, the XMM7660 in November 2017. With the introduction of its Snapdragon X24 modem, announced in February 2018, Qualcomm is already in the third generation of the Gigabit LTE race. This Cat.20 chip will enable smartphones to offer downlink speeds of up to 2 Gbps for the first time thanks to the support of additional carrier aggregations, up to seven carriers across licensed, and unlicensed spectrum.

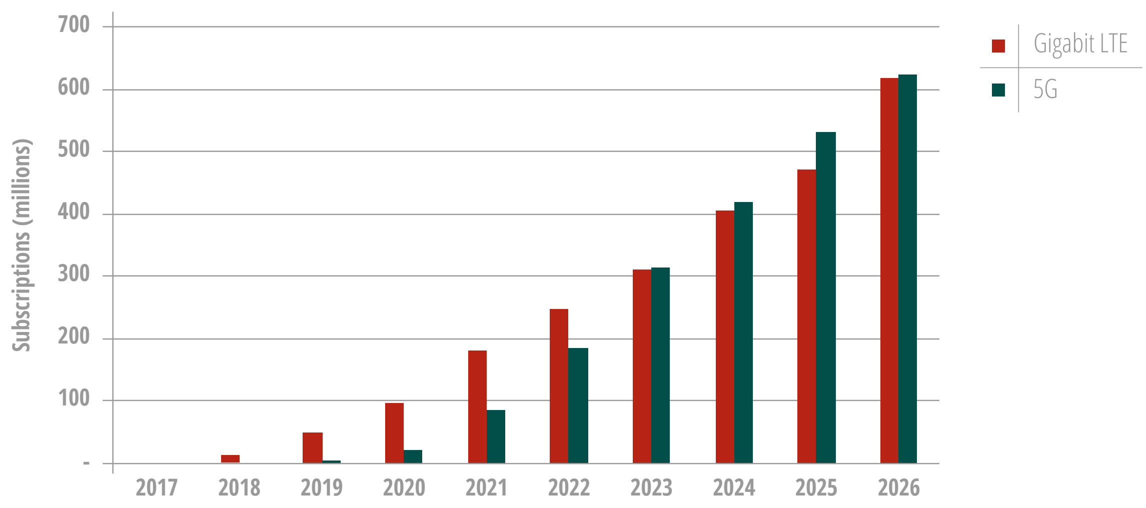
The most important benefits of Gigabit LTE are the enhanced speeds and network performance not only in the center of the cell, but under all conditions. It has been reported that real-world speeds for Gigabit LTE can reach 300 Mbps or higher. Compared with less than 30 Mbps on a typical LTE network, this is a >10X user experience leap.

To illustrate the effect of Gigabit LTE on network congestion, we can use a hypothetical scenario, where a Gigabit LTE-capable basestation is sending 120 MB of a very popular video clip to several users at the same time. The support for Gigabit LTE can bring significant benefits to network utilization, including:

- Cat.16-compatible devices (Gigabit LTE capable in the downlink) can download the clip in approximately 1 second. The basestation can, thus, deliver the same file to a new user, every second.
- Cat.4-compatible devices (max DL speed of ~150 Mbps) can download the file in 6 seconds. This means that the basestation can deliver the file to 1 user every 6 seconds.

At first glance, the difference in the above figures may not be dramatic, but it does create a significant distortion when calculating the data for hundreds of users. For example, a Gigabit LTE-enabled network can deliver the same content to 300 users in 5 minutes, while it would take Cat.4 users more than 30 minutes to do the same.

Chart 2: Gigabit LTE and 5G eMBB Subscriptions World Markets, Forecast: 2017 to 2026



(Source: ABI Research; Note. 5G eMBB devices and subscriptions will likely support Gigabit LTE.)

To achieve Gigabit LTE, there are three enabling foundational technologies: 4x4 MIMO, 256 QAM, and 3+ CA (CA to achieve 60 MHz bandwidth or wider). Depending on the deployment strategy, it is possible that operators can support Gigabit LTE without having to acquire new spectrum (*i.e.*, by leveraging LAA to use unlicensed and shared spectrum bands) or employing one of the traditional cell splitting or cell sectoring methods. The following sections describe some key LTE Advanced Pro technologies that will improve user experiences by enhancing speed, capacity, and latency.

2.1.1. MIMO, CA, and LAA

As pointed out earlier, 4x4 MIMO is one of the key technologies that is essential for Gigabit LTE. Today, 4x4 MIMO is already being deployed in the market and providing a significant boost in user experience for many mobile service providers around the world. At the same time, several networks are also being upgraded to massive MIMO, which refers to a larger transceiver array with more than 32 radiating elements to increase channel capacity, spectral efficiency, and energy efficiency.

For CA, the 3GPP specifications have defined aggregating up to 32 carriers for LTE, and in commercial implementation, Qualcomm has introduced the X24 modem, which combines 20 spatial streams with 7x CA, 256 QAM, and 4x4 MIMO to reach 2 Gbps.

In the end, though, one of the most important aspects of Gigabit LTE is that operators use their most precious assets of cellular spectrum more efficiently. The utilization and efficiency of licensed spectrum is enhanced with the technologies outlined above and operators that are unable to use licensed spectrum can also leverage unlicensed spectrum *via* LAA technology ratified in the 3GPP Release 13. LAA is currently based on the 5 GHz unlicensed spectrum, but the availability of unlicensed spectrum above 6 GHz makes this solution viable in the long term and it may be possible to use 3.5 GHz spectrum in the United States (Citizens Broadband Radio Service (CBRS)) with LAA. The wide availability of unlicensed spectrum can make Gigabit LTE deployable for more than 90% of world's operators who have the minimum 10 MHz of licensed LTE spectrum that will act as an anchor.

It is also becoming clear that Gigabit LTE will provide the coverage foundation for 5G NR, especially during early deployments of 5G NR, where end users will spend most of their time on LTE and hop on 5G NR in very busy metropolitan areas. Mobile service providers will likely deploy Gigabit LTE nationwide and use 5G NR in areas with capacity constraints, or where there is a large concentration of premium users. By doing so, mobile service providers will be able to expand 5G NR coverage incrementally, without users noticing a big difference in user experience between 4G and 5G.

2.1.2. Small Cells and Densification

Network densification is widely exercised in advanced markets, when capacity constraints hamper the user experience. This usually takes place with cell sectorization (*e.g.*, going from three, to six, and even to nine sectored cells) and densification (*e.g.*, splitting one cell into three or more). Today, small cells are being deployed to support Gigabit LTE, and with the advent of 5G NR millimeter wave (mmWave), these small cells can be leveraged to accelerate deployments significantly.

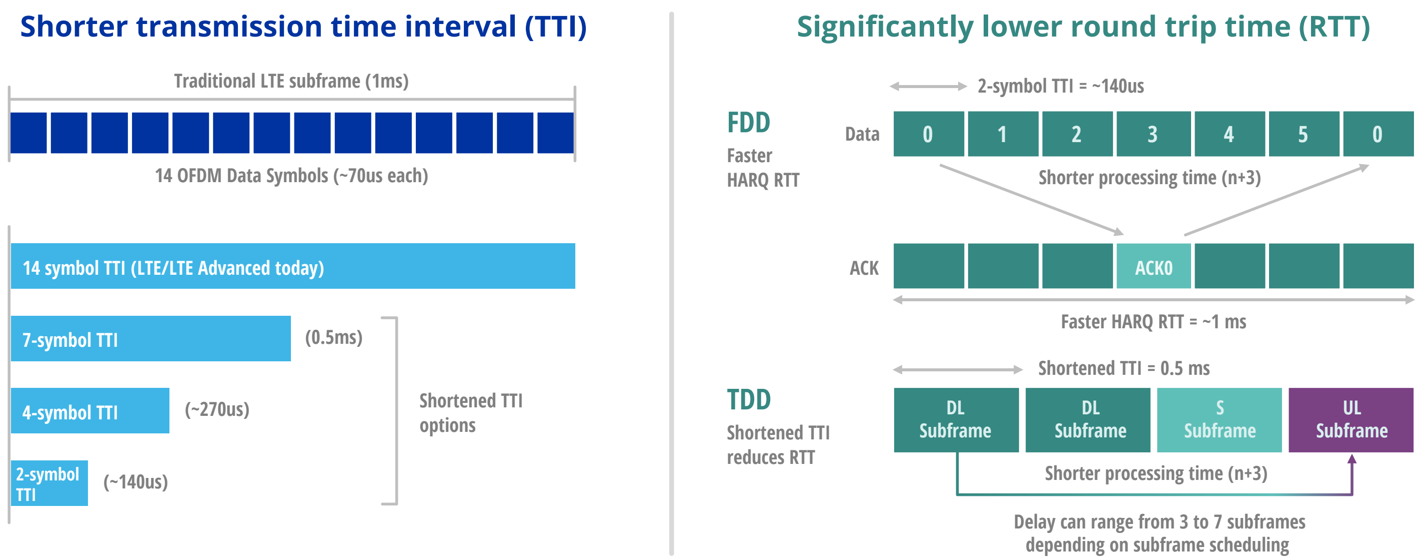
Several mobile service providers, including AT&T, have outlined that 5G will likely depend on small cells and they are now investing into gradually expanding their small cell footprint, to deploy the necessary facilities for 5G. This includes power, backhaul (which will evolve to fronthaul), and, most importantly, understanding where to place these small cells in the crowded and busy urban environment. The importance of these advancements is not necessarily in the network upgrades they will introduce, but in the operational experience and deployment processes they will require even before 5G is being deployed.

Another vital aspect of small cells and 5G is the IoT, where edge computing can be used to create new business models and use cases for the cellular network. By deploying small cells, mobile service providers can gain experience in these new business models today and start their transition toward 5G immediately. Small cells that enable LAA (*e.g.*, 5 GHz) functionality today may evolve to mmWave (*e.g.*, 28 GHz) tomorrow.

2.1.3. Low Latency LTE

3GPP Release 14/15 is introducing ULL features, lowering the network latency down to ~1 millisecond (ms). This is achieved by lowering the number of Orthogonal Frequency Division Multiplexing (OFDM) data symbols in a single LTE subframe, reducing the TTI (short TTI, or sTTI) and enhancing Hybrid Automatic Repeat Request (HARQ), a key component of the basestation scheduler. These options are illustrated below in Figure 2.

Figure 2: Lower Latency Features for LTE



(Source: Qualcomm)

On the other hand, 5G NR will introduce flexible slot structure, where the scheduler may scale the duration of a slot up or down, catering to different use cases. LTE low latency will provide an initial trial of lower latency services and will enable mobile service providers to test whether they can monetize new services (*e.g.*, lower latency for gaming) with their existing infrastructure.

2.2. LTE STARTS TO CONNECT THE IoT TODAY

3GPP Release 13 introduced a suite of two complementary narrowband LTE technologies, collectively referred to as LTE IoT: enhanced Machine-Type Communication (eMTC), and Narrowband IoT (NB-IoT), tailored for low-complexity IoT connectivity.

- eMTC or Cat-M1 allows downlink peak rate of ~1 Mbps over a 1.4 MHz channel
- NB-IoT or Cat-NB1 allows a downlink peak rate of ~100 kbps over a 200 kHz channel

The lower data rate of Cat-NB1 allows better coverage, longer battery life, and a better fit with stationary, sensor-driven IoT use cases. On the other hand, Cat-M1 is suitable for a broader, but more demanding set of applications with full mobility and Voice over LTE (VoLTE) support (NB-IoT does not support either feature). Both are complementary and currently being deployed in the market, with regional differences.

At the start of 2018, 38 Cat-M1 and 107 Cat-NB1 network rollouts had been publicly announced, 13 of the former and 44 of the latter being live.[1] eMTC was strongly adopted in North America and Northeast Asia, and it was being deployed across Europe. Plans to adopt NB-IoT were strong worldwide, except for in the Americas.

Both Cat-M1 and NB-IoT are now being deployed in the market and paving the way for 5G massive IoT, which will eventually connect billions of devices to cellular networks. LTE IoT will operate with both LTE and 5G core networks, thus providing compatibility with future networks. Release 16 is expected to support in-band deployments of eMTC and NB-IoT with 5G NR, as well as to bring enhancements that will further improve efficiencies in the cellular network.

2.3. C-V2X ENABLES SAFER AND MORE AUTONOMOUS DRIVING

The concept of Vehicle-to-Everything (V2X) communications is well understood in the automotive industry, and in the most basic sense refers to the near-instantaneous sharing of safety-relevant data between vehicles to support obstacle detection, collision avoidance, and cooperative mobility more generally. In the context of Advanced Driver Assistance Systems (ADAS) and autonomous driving, C-V2X is intended to support and complement on-board ranging sensors, such as cameras, radar, and Light Detection and Ranging (LiDAR), by providing Non-Line-of-Sight (NLOS) capabilities, in effect giving the vehicle the ability to "see around corners." The 3GPP has standardized C-V2X in Release 14, designed to complement and extend current cellular (4G) network capabilities for the automotive sector. It uses the licensed Intelligent Transportation System (ITS) band at 5.9 GHz and allows for low-latency data exchange between cars and a variety of end points, including Vehicle-to-Infrastructure (V2I), Vehicle-to-Networks (V2N), and Vehicle-to-Pedestrians (V2P). The standard will be improved in 3GPP Release 15, paving the way for 5G NR, while being backwards compatible with previous versions.

Although there is competition for C-V2X in the market (*e.g.*, Dedicated Short Range Communications (DSRC)), C-V2X is technically superior. For example, C-V2X offers longer range or higher reliability for the same range, as well as support for high-speed use cases. Subsequent 3GPP releases enhance C-V2X even further. Furthermore, network-based connections made over cellular infrastructure can enable a host of compelling use cases, including warnings about broken-down vehicles farther ahead, or guidance to vacant parking spaces. In the future, cellular connections made over the 5G network will open up V2X possibilities beyond simply providing a "second opinion" for a vehicle's local ADAS sensors, enabling a collective perception paradigm in driverless vehicles, adding to the safety and efficiency of smart mobility. Indeed, network operators have already begun discussing the "automotive slice" of the 5G network, which will provide the necessary quality of service in terms of latency, bandwidth, and security to enable new use cases, such as cooperative mobility and remote operation.

[1] *GSA NB-IoT and LTE market status report: March 2018*

Table 1: Selection of Announced C-V2X Trials and Market Activities

Trial Partners	Date	Use Case
China Mobile and Huawei, China	*September 2016*	*V2I: Traffic signal communication*
Audi, USA	*October 2016*	*V2I: Traffic signal communication*
Scania Trucks, Singapore	*January 2017*	*Truck platooning*
AT&T, Ford, Nokia and Qualcomm, USA	*October 2017*	*End-to-end C-V2X trials*
LG and Qualcomm, South Korea	*October 2017*	*Development of C-V2X components*
Continental and Huawei, China	*December 2017*	*Reliability and latency tests for C-V2X*
Honda and Qualcomm, USA	*January 2018*	*C-V2X support in new Honda Accord*
NTT DOCOMO, Ericsson, Qualcomm, Japan	*January 2018*	*C-V2X trials at 5 GHz*
Groupe PSA and Qualcomm, France	*February 2018*	*C-V2X showcase and testing*
Ford and Datang, China	*March 2018*	*C-V2X system trials*
Qualcomm, Ford and Panasonic, USA	*June 2018*	*C-V2C deployment*

(Source: ABI Research)

C-V2X has an evident strategic direction toward leveraging 5G NR's (URLLC) and high data rates to support higher levels of predictability, sensors, and intent sharing for autonomous driving, while ensuring backwards compatibility. Although 4G has been used in the automotive industry for infotainment for many years, C-V2X allows mobile service providers to implement a new business model with an existing network.

2.4. PRIVATE LTE NETWORKS ENABLE THE INDUSTRIAL IoT

Private LTE networks have emerged as an alternative for enterprise and industrial connectivity, driven by the ongoing digitization of several end markets. Private networks are not new, but the deployment of LTE in this area is now introducing several key benefits:

- **Carrier-Grade Features:** LTE introduces flexibility, reliability, security, and full mobility in a wireless network deployment that is managed locally, while sensitive traffic is kept on-site.
- **Economies of Scale:** Enterprise verticals can tap into the mass market for chipsets and devices, rather than rely on proprietary technologies and value chains. At the same time, private cellular networks use dedicated equipment on-site.
- **Future-Proof:** LTE allows end markets to upgrade to new 3GPP Releases, and when the time comes, 5G.
- **End-Market Appropriation:** LTE technology is mature and can be customized according to end-market requirements.

There are also several options for spectrum for private networks, ranging from licensed spectrum (private network deployed by operator), to shared spectrum (*e.g.*, CBRS in the United States), and to deploying private LTE in unlicensed frequencies using MulteFire. At the same time, the private 4G network is future proof: the 3GPP has started a study item for 5G NR in unlicensed bands, which will be a key component for 5G industrial applications.

Private LTE networks pave the way for advanced 5G business models. New capabilities are being introduced in the 5G specification that are positioned toward use cases that favor private network applications. For example, previously defined in C-V2X section and edge computing are concepts that may find use in the digital factory. Moreover, 5G will introduce support for more flexible spectrum, including licensed, unlicensed, and shared, thus removing a barrier of entry for the application of cellular systems in the private domain. Finally, the 3GPP has introduced study items that are taking a system approach to private networking, including automation in enterprise verticals, as well as a feasibility study on Local Area Network (LAN) support over 5G NR, which will be essential to enable the factory of the future.

2.5. OTHER NEW USE CASES

LTE networks are now adapting to new use cases, rather than just providing a data pipe for them. For example, LTE Enhanced TV (enTV) can enable next-generation digital Television (TV) delivery over cellular technology, which provides a standardized framework for broadcasters and content providers to deliver digital TV to end users. It also establishes the foundation for the 5G broadcast evolution, while already meeting many of the 5G broadcast requirements. enTV is a strong candidate for terrestrial TV delivery in Europe, leveraging the recently re-farmed 700 MHz spectrum. Other new use cases include LTE network appropriation for drones, public safety (ensuring communications are handled with a critical priority), and more.

3. CASE STUDIES

Although there are many examples of deploying advanced network functionality on 4G networks, there are a few that stand out, creating value well beyond technical superiority and allowing mobile service providers to enter new markets. A selection of these are presented below.

3.1. AT&T'S 5G EVOLUTION NETWORK

AT&T is the first mobile service provider to have named its LTE Advanced Pro network as "5G Evolution". This choice has been met with mixed responses by the media and analyst communities, but AT&T has explained that its continued investment in its LTE Advanced Pro network is creating the foundation for its future 5G eMBB deployment.

AT&T is currently upgrading its LTE footprint with 256 QAM, 4x4MIMO, combination of licensed and unlicensed spectrum (LAA) and claims that its network reached 979Mbps in field tests. The upgrade for peak speeds is not the only headline though; the service provider is spending to upgrade its backhaul network, its cell site infrastructure (to support 4x4MIMO antennas) and more secondary capabilities (e.g. SDN and NFV) that will be pivotal for the easier transition to 5G eMBB. ABI Research expect the majority of mobile service providers in advanced markets to follow a similar deployment strategy and use LTE Advanced Pro as the blanket technology in the initial stages of 5G rollouts. Modern infrastructure at the cell site will also help upgrade to 5G through software upgrades, which will also accelerate 5G NR deployments and reduce costs.

3.2. ORANGE BELGIUM'S "MOBILE IoT" STRATEGY

Orange Belgium is among a few operators to have deployed both NB-IoT and eMTC, in order to reach a 100% cellular IoT strategy across the country for several use cases. As of June 2018, Orange Belgium, Etisalat in the United Arab Emirates (UAE), Dialog Axiata in Sri Lanka, Singtel in Singapore, Turkcell in Turkey, and Telstra in Australia have launched both LTE IoT standards. The common denominator in these deployments is that cellular infrastructure is relatively new, meaning that both eMTC and NB-IoT were rolled out through software upgrades, which minimized the cost and accelerated the deployment of LTE IoT.

For Orange Belgium, and most operators that have launched both eMTC and NB-IoT, the choice to do both has been a strategic one, in order to have a wide IoT toolbox for connectivity and to be able to address several use cases. In short, most operators have deployed the two standards for different purposes: NB-IoT for low-complexity IoT use cases that require the deepest coverage (such as sensors), and eMTC for full mobility and voice support (such as asset tracking).

Deploying both NB-IoT and eMTC allows operators to provide a consistent and multi-faceted connectivity platform to developers, who can, in turn, create devices and use cases for many verticals.

3.3. CHINA MOBILE'S 4G MASSIVE MIMO

China Mobile is among the first mobile service providers to deploy massive MIMO in its existing 4G networks, in order to boost its LTE system capacity and network performance in high traffic areas, including university campuses and dense residential areas. The mobile service provider is testing massive MIMO in its existing LTE footprint and, at the same time, aiming to deploy 100 basestations using massive MIMO at 3.5 GHz and 4.9 GHz to gain experience in the operation of these systems. China Mobile is also one of the few mobile service providers that claims an aggressive deployment plan using Standalone (SA) 5G mode, which means deployment of new 5G core networks, with plans to finalize trials and testing in 2019, beginning large-scale deployments during 2020.

The deployment of massive MIMO for China Mobile will fulfill two major priorities: provide operational experience for this new technology and, at the same time, increase capacity in a rapidly growing market.

4. CONCLUSIONS AND RECOMMENDATIONS

Mobile service providers are currently operating in a transitional period, between 4G and 5G, when infrastructure vendor financials are also being pressured due to lack of heavy investments in cellular infrastructure. Despite this 1- to 2-year pause in heavy infrastructure investment, leading mobile service providers are steadily investing in their existing 4G networks for three reasons:

- Foundational technologies are preparing mobile service providers for 5G, which will be a significant competitive advantage when the time comes to deploy 5G NR. In the meantime, these upgrades are alleviating capacity constraints in saturated markets and even providing a competitive advantage for mobile service providers that have launched Gigabit LTE.
- In the early phase of 5G, Gigabit LTE will likely become the standard mode of connectivity, which will offer nationwide connectivity, on top of which 5G NR will be built in dense urban areas. More than 100 operators globally are upgrading toward Gigabit LTE.
- Most importantly, these 4G network upgrades allow mobile service providers to address new business models, without necessarily waiting for 5G, network slicing, and the advanced network architectures these will bring. LTE IoT and C-V2X allow the gradual introduction and operational transformation to address end markets, long before 5G NR is deployed. This will also act as a major competitive advantage for mobile service providers that move first.

ABI Research's extensive research illustrates that continuous upgrades of 4G networks not only satisfy current network demands, but also secure a future for early 5G NR deployments. ABI Research recommends that all mobile service providers in advanced markets assess these relatively cost-efficient upgrades and exploit them as a transitional step toward 5G.

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