Network Experience Evolution to 5G

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Executive Summary

While the 5G era introduces a great variety of services, it also poses new challenges to LTE network capabilities. This document describes typical mobile broadband (MBB) services in the 5G era, analyses the requirements of these services on network experience, and explores the evolution of LTE networks to meet such requirements.

Service Trend

1. VR, FHD video, and mobile gaming services raise the bar for network experience in the 5G era, resulting in higher network throughput and latency requirements.

2. VoLTE has become an essential service in the 5G era. Operators need to accelerate VoLTE deployment to achieve network-wide coverage.

Network Evolution Trend

1. LTE will replace GSM and UMTS as the basic bearer network for voice, data, and IoT, significantly improving service experience.

2. LTE+NR is the goal for future networks. These two modes, through long-term concurrent evolution, will provide an improved experience for 5G users.

3. With LTE users and traffic volumes constantly increasing, LTE will continue to perform as the main bearer of data traffic for some time to come.

New LTE Technologies

1. Capacity improvement: multiple antennas, multiple sectors, and multiple carriers

2. Rate improvement: Massive CA

3. Lower latency: optimized scheduling, fast uplink access, and short TTI

4. Voice enhancement: EVS

5. LTE-NR inter-operation: LTE-NR DC, LTE connectivity to 5GC

Industry Requirements

To accelerate the implementation of new technologies, it is recommended that the entire industry focus on experience evolution technologies, perform interworking verification on networks and terminals, and promote terminals to follow the evolution of protocols, so to lay a solid foundation for wide adoption of 5G era service.

1. Introduction

1.1. Definition of Terms

Term	Description
AMR-WB	Adaptive Multi-Rate Wideband
AR	Augmented Reality
CA	Carrier Aggregation
CD	Compact Disc
CPE	Customer-Premises Equipment
CSFB	Circuit-Switched Fallback
DC	Dual Connectivity
DNS	Domain Name Server
DOU	Data of Usage
eLTE	Evolution LTE
eNB	Evolved Node B
EPS FB	Evolved Packet System Fallback
EVS	Enhanced Voice Services
FDD	Frequency-Division Duplexing
FHD	Full HD
FOV	Field of View
FPS	First Person Shooting
FTTB	Fiber to the Building
FTTH	Fiber to the Home
FUA	Fast Uplink Access
FWA	Fixed Wireless Access
HBB	Home Broadband
HD	High Definition
HSPA	High Speed Packet Access
IMS	IP Multimedia Subsystem
IOV	Internet of Vehicles
LTE	Long-Term Evolution
MBB	Mobile Broadband
MIMO	Multiple Input Multiple Output
MU-MIMO	Multi-User MIMO
NR	New Radio
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operating Expense
OTT	Over the Top
PPD	Pixel Per Degree

QAM	Quadrature Amplitude Modulation
RAC	Racing Game
RTS	Real-Time Strategy Game
RTT	Round-Trip Time
SA	Standalone
SD	Standard Definition
SRS	Sounding Reference Signal
STTI	Short TTI
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TM9	Transmission Mode 9
TTI	Transmission Time Interval
TV	Television
UMTS	Universal Mobile Terrestrial System
VoD	Video on Demand
VoLTE	Voice over Long Term Evolution
VoNR	Voice over NR
VR	Virtual Reality
xDSLs	X Digital Subscriber Lines
YOY	Year on Year

2. Typical MBB Services and Network Experience Requirements in the 5G Era

From 2G (voice) to 3G (image) to 4G (video), technological advances drive ever increasing data consumption requirements. 5G networks provide ultra-high bandwidth, ultra-low latency, and massive connection capabilities, enabling more diversified services such as VR/AR and cloud applications, enabling more users to watch live sports events and concerts using VR technologies, or handle office tasks on cloud applications anytime and anywhere. In the 5G era, user behaviour and habits are changing. According to statistics on South Korean commercial 5G networks, nearly one third of 5G users have subscribed to VR/AR services. Newer services, such as education, travel, shopping, and social media, will drive the improvement of network experience standards.

In recent years, traditional MBB services, such as video streaming, web browsing, and mobile gaming, have been evolving towards higher definition and lower latency. Video services have evolved from 480P to 720P, 1080P, or even higher definitions. 1080P has become the benchmark in many countries. On the other hand, users now place lower patience on video latency, 1 second to open a video has become the general experience requirement. Mobile game players are also pursuing improved network experiences. To be successful in their game of choice, players are willing to pay for better game experience.

5G will usher in vastly improved user experience. However, the construction of optimal networks cannot be completed overnight. With its coverage advantages, LTE will become the foundation network of the 5G era. Once 5G users move out of the NR coverage, their services need to continue on the LTE network. In addition, 4G terminals are mature and inexpensive. Currently, the proportion of 4G users has exceeded 50%, with further increases expected in the next few years. As large numbers of MBB services will still be carried on LTE networks for a considerable time to come, LTE network experience needs to be further improved to meet increasing data requirements, in addition to the bearing requirements of the service in 5G era.

The following sections describe typical services in the 5G era and related requirements for network capabilities.

2.1. VR

VR blocks out the real world, and presents a virtual environment through computer rendering. This environment can be a replica of the real world or an imaginary setting, allowing user interaction through the utilization of 3D space information.

VR applications can take many forms. Video-on-demand (VOD) and live events utilize 360° panoramic video, while VR gaming and simulation experiences call on advanced computer graphics.

360° VR video offers an all-encompassing virtual view, consisting of 360° on the horizontal plane (longitude) and 180° on the vertical plane (latitude). Users can immerse themselves in the experience by moving their head position or by switching viewing angles through an input device (such as a mouse or remote control).

VR evolution is represented by the following four stages, each of which varies in network requirements: Pre-VR, Entry-Level VR, Advanced VR, and Ultimate VR.

Standard	Pre-VR	Entry-Level VR	Advanced VR	Ultimate VR
Video Resolution	Full-view 4K 2D video (YouTube) (full-view resolution 3840 x 1920)	Full-view 8K 2D video (full-view resolution 7680 x 3840)	Full-view 12K 2D video (full-view resolution 11520 x 5760)	Full-view 24K 3D video (full-view resolution 23040 x 11520)
Single-Eye Resolution	960 x 960 (wearing VR glasses, 90° FOV)	1920 x 1920 (wearing VR glasses, 90° FOV)	3840 x 3840 (wearing dedicated HMD terminal, 120° FOV)	7680 x 7680 (wearing dedicated HMD terminal, 120° FOV)
PPD	11	21	32	64
Equivalent Traditional TV Screen Resolution	240P	480P	2K	4K
Frame Rate	30	30	60	120
Typical Video Bit Rate	16 Mbit/s	64 Mbit/s	279 Mbit/s	3.29 Gbit/s
Typical Network Bandwidth Requirement	25 Mbit/s (full-view transmission, the mainstream solution in this stage)	100 Mbit/s (full-view transmission, the mainstream solution in this stage)	418 Mbit/s (full-view transmission, the mainstream solution in this stage)	1 Gbit/s (FOV solution)
Typical Network RTT Requirement (ms)	40	30	20	10

2.2. Video

Video has become a primary contributor to MBB network traffic. As such, video experience is a key indicator for measuring the quality of service (QoS) of MBB networks. Modern video services place higher requirements on networks as video resolution increases (from 360p/720p to 1080p/2K), and therefore experience assurance is important for both users and operators.

A complete video service includes buffering, download, and playback, and user experience can be affected by video quality (definition), initial buffering delay, and frame freezing (smoothness).

Video quality: Video quality is determined by resolution and bit rate. The higher the resolution and bit rate, the clearer the video. Generally, video quality is more affected by over the top (OTT) content provider video sources and user behaviour than by mobile networks. A higher video resolution or bit rate requires a higher download rate (bandwidth).

Initial buffering delay: This indicates the time a user needs to wait before a video is played, also called the initial play delay. It includes time required to access the video service (through DNS query, TCP link setup, and directory download) and for the initial buffering and download.

Frame freezing: Frame freezing occurs during video playback and can severely affect user experience. A freeze-free ratio helps to measure video experience, and is calculated using the following formula: Number of samples of video call data records (CDRs) without freezing/Total number of samples of video CDRs.

According to the general standard, video experience is considered acceptable with an initial buffering delay of less than three seconds and zero frame freezing. If the initial buffering delay is one second or less, and no frame freezing occurs, video experience is considered excellent. Short initial buffering delay places high requirements on network throughput. If we take a 1080P YouTube video as an example, the throughput must reach 5 Mbit/s in order to achieve a zero frame freezing rate of 98% during video playback. However, to reach an initial buffering delay of one second, the throughput must reach 32.8 Mbit/s if the 50 ms RTT delay is required.

2.3. Voice

In the 5G era, voice services are still considered a basic requirement by operators. 5G will continue to use the voice architecture of 4G, and provide voice services based on the IMS. LTE radio access technology is used for 4G networks, and the voice service carried on LTE networks is known as VoLTE. In the meantime, NR radio access technology is used for 5G networks, and the voice service carried on NR networks is known as Voice over NR (VoNR). VoLTE and VoNR are different access modes for IMS voice services.

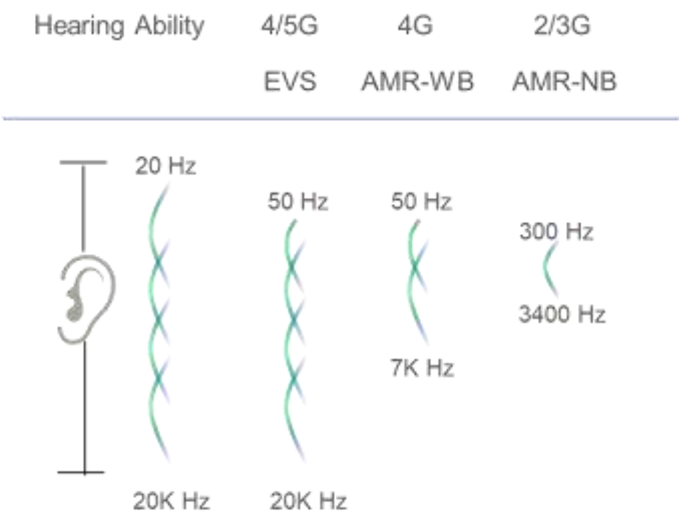
During the 5G NSA phase, circuit-switched fallback (CSFB) is still feasible. However, it is recommended that operators enable VoLTE services for these subscribers by default when providing 5G services. Otherwise, subscribers may fall back to 2G/3G for voice connection during voice calls, and data services may be interrupted or drop to 3G standards (about 1/100 of the 5G data rate). In addition, call connection time is prolonged (to more than six seconds) as users fall back to 2G/3G networks. This negatively impacts the overall 5G experience.

During the initial 5G SA phase, 5G SA subscribers who do not subscribe to VoLTE will be unable to make voice calls at all, which is unacceptable. As specified in 3GPP R15, 5G UEs cannot perform CSFB to a 2G/3G network. This means that 5G SA subscribers need to register with the IMS when they attach to the 5G core. After a voice call is set up, it falls backs to the LTE network using evolved packet system fallback (EPS FB) technology, and the voice connection is maintained through VoLTE.

The mature 5G SA phase will see an extension of NR coverage, however 100% nationwide coverage will still be challenging. By then the industry eco-system will be also more mature, with terminals in particular supporting 5G SA and VoNR by default. In this phase, voice services will primarily utilize VoNR. Once a call is set up, and when the user moves to the edge of 5G coverage, the packet switched handover (PSHO) technology can be used to switch the call from NR to LTE, with VoLTE called on to bear voice services. The call itself will experience no interruptions.

As a result, VoLTE is an essential service, and operators will need to accelerate VoLTE deployment to achieve nationwide coverage, so to utilize LTE as the basic voice network.

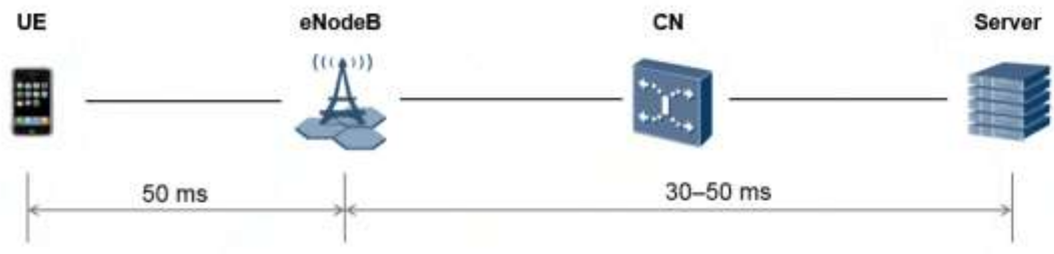
At the same time, requirements for voice service experiences are higher than ever. Simple voice information transmission is no longer enough for modern users, with HD or even original voice quality fast becoming the expectation. The hearing range of the human ear is 20Hz~20KHz, and in the 5G era EVS ultra-HD voice quality will become mainstream, delivering a CD-quality voice experience.



2.4. Mobile Gaming

Mobile games, running on mobile phones or tablets, have developed rapidly thanks to the prevalence of smart phones and mobile Internet. According to Newzoo, the global revenue from mobile games is estimated to be US$ 68.5 billion this year, with a year-on-year (YOY) growth rate of 10.2%.

Games, especially first-person shooters (FPS), real-time strategy (RTS), and racing games, have low requirements on network bandwidth but high requirements on latency in player-vs-player (PvP) sessions. Delays will cause a game to freeze or even crash. According to the video game industry estimation, an E2E delay under 100 ms is the basic requirement for acceptable mobile game experiences.

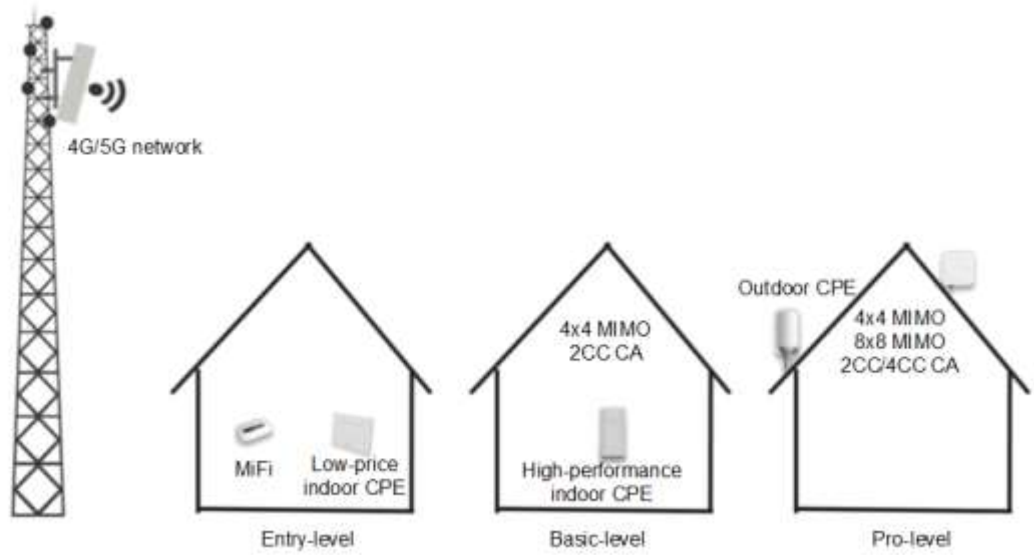


The RTT latency between a base station and a game server depends on the backhaul latency, core network processing latency, and the processing latency of the game server. The backhaul latency depends on the distance and the number of hops between the base station and the game server, while the processing latency depends on the processing capability of the network element. According to live network tests, the latency between a base station and a game server is generally within 30–50 ms. As a result, the latency on the radio access network (RAN) side must be within 50 ms to ensure smooth user experience.

2.5. FWA

Fixed Wireless Access (FWA) is a typical business scenario defined by 5G. Currently, a large number of mobile operators have placed FWA services into commercial use based on 4G technologies. It is predicted that 4G FWA will be deployed on more than 230 networks, serving more than 90 million users by the end of 2019.

The following figure illustrates the 4G/5G FWA schematic.



4G/5G FWA provides varying service levels to adapt to customer requirements.

Entry-level FWA: Cost-effective broadband data connections for low-income families. Data volumes are approximately 5–50 GB, meeting the requirements of most Internet browsing services in addition to some video on demand (VoD) services. Entry-level FWA cannot guarantee high speeds during peak hours, but the price per GB is much lower when compared with fixed or mobile broadband. Low-cost CPEs greatly reduce the barriers to Internet access, while satisfying the requirements of many of the low-income families as much as possible.

Basic-level FWA: Primarily used to migrate low-speed copper-based fixed broadband services. High-performance CPEs (with 4x4 MIMO and 2CC CA) can provide a peak rate of up to 600 Mbit/s at the near point, and an average rate of 10–20 Mbit/s (40 MHz spectrum) during busy hours. Basic-level broadband can satisfy the main service requirements of home broadband (HBB), including standard definition (SD) and high definition (HD) video.

Professional-level FWA: High-performance outdoor CPEs (with 4x4 MIMO and 4CC CA or 8x8 MIMO and 2CC CA) can provide a peak rate of up to Gbit/s and an average rate of 50 to 100 Mbit/s during busy hours. Outdoor CPEs provide more stable wireless broadband connections than indoor devices, particularly at the cell edge. Professional-level broadband is designed to meet the requirements of large families, delivering Full HD (FHD)/4K TV, augmented reality (AR), and virtual reality (VR).

Currently, the penetration rate of mobile networks in most countries approaches 100%. However, more than half of homes have no fixed broadband, while only 51% of fixed broadband users are fibre to the building (FTTB) or fibre to the home (FTTH) users, with the rest relying on cables or x digital subscriber lines (xDSLs). With the development of LTE-A and 5G technologies, 4G/5G FWA will play an important role in the fixed broadband industry, helping to accelerate the broadband penetration rate as well as the upgrade of low-speed broadband.

Compared with mobile broadband (MBB) services, FWA services demand higher reliability. As a result, the user perceived rate must meet basic service requirements even during busy hours.

Typical fixed home broadband services include video, Internet browsing, and IoT services. With video services occupying the largest network bandwidth. Common video resolutions are SD (480p), HD (720p), FHD (1080p), and UHD (4K).

Based on current network testing and theoretical calculation, video service experience baseline is suggested as follows:

Resolution	Typical Bit Rate (YouTube)	Required Average Throughput	Required Perfect Throughput	Typical Value
		Zero-frame-freezing Playback Percentage ≥ 90%	Zero- frame-freezing Playback Percentage ≥ 98%	
4K	15 Mbit/s	24 Mbit/s	31 Mbit/s	25 Mbit/s
2K	6 Mbit/s	9 Mbit/s	12 Mbit/s	10 Mbit/s
1080p	3 Mbit/s	4.5 Mbit/s	6 Mbit/s	5 Mbit/s
720p	1.5 Mbit/s	2.3 Mbit/s	3 Mbit/s	2.5 Mbit/s
480p	700 kbit/s	1 Mbit/s	1.4 Mbit/s	1.2 Mbit/s

To ensure 4K video service experience at home, the average experience rate of FWA home broadband services must reach 25 Mbit/s. With radio resource sharing in mind, the cell edge experience rate must reach 100 Mbit/s in order to meet this requirement for cell edge users, if 25% PRB resources are allocated to a user during busy hours. Based on this, the following table lists the broadband experience rate and cell edge peak experience rate required for various home video services.

Resolution	Typical Bit Rate (YouTube)	Average Throughput	Cell Edge Throughput
4K	15 Mbit/s	25 Mbit/s	100 Mbit/s
2K	6 Mbit/s	10 Mbit/s	40 Mbit/s
1080p	3 Mbit/s	5 Mbit/s	20 Mbit/s
720p	1.5 Mbit/s	2.5 Mbit/s	10 Mbit/s
480p	700 kbit/s	1.2 Mbit/s	5 Mbit/s

Based on the required average throughput and cell edge throughput specific to video services, 4G FWA is recommended for SD/HD/FHD video services, which require an approximate 20 Mbit/s cell edge throughput. In addition, 5G FWA is recommended for FHD/4K video services, which require an approximate 50 Mbit/s to 100 Mbit/s cell edge throughput.

2.6. Summary

In the 5G era, services are more diversified and are driving the improvement of network bearer capabilities. As the foundation network, LTE needs to evolve in order to deliver larger capacity, higher throughput, and lower latency, satisfying the service experience requirements of 5G users.

3. Network Evolution Trends

Commercial use of 5G has begun, bringing with it the deployment of hardware, frequencies, and transmission resources directly related to 5G NR sites, in addition to the reconstruction of existing 2G/3G/4G networks. 5G network evolution trends can be summarized as follows:

LTE will replace GSM and UMTS as the foundation network for voice, data, and IoT, significantly improving service experience in the 5G era.

Operators are now witnessing the synchronous existence of 2G/3G/4G/5G networks, and multi-network operation leads to high OPEX. The spectral efficiency of VoLTE services is 5 to 20 times that of 2G voice services, while the spectral efficiency of 4G data services is 3 to 7 times that of 3G HSPA services. Migrating 2G/3G services to 4G networks improves user experience and enables operators to migrate the spectrum from 2G/3G networks to 4G networks, improving operation efficiency.

LTE+NR is the goal for future networks. Both modes, through long-term concurrent evolution, will provide improved experiences for 5G users.

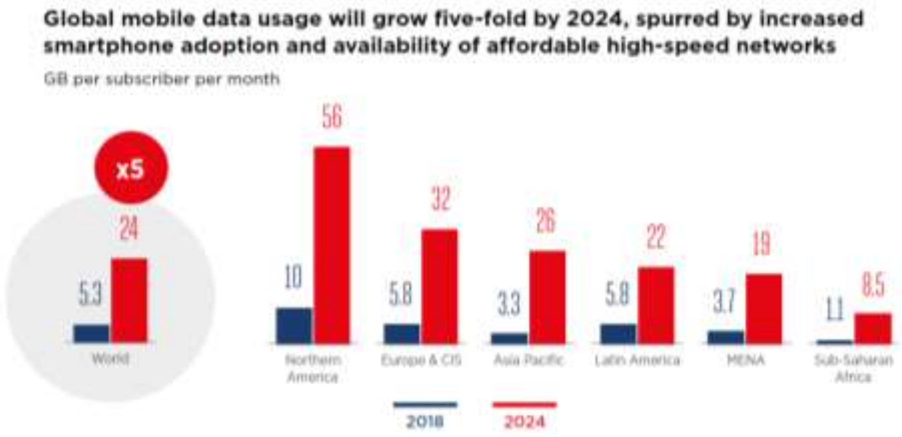
In June 2018, 3GPP Release 15 defined the relationship between LTE and NR, and defined multiple networking modes from option 3 to option 7. The close collaboration between LTE and NR will improve 5G user experience. In addition, the relationship between 4G and 5G has moved beyond that seen in the evolution from 2G to 3G, and from 3G to 4G. LTE will become one of the two key components of 5G era networks, with both complementing each other and evolving concurrently.

It will take time for 5G NR to achieve continuous coverage nationwide. Before we reach that point, LTE will guarantee positive 5G user experience. 5G high-speed applications such as VR and FHD video services will not be interrupted when users move out of NR coverage.

With ever increasing numbers of LTE users and rising traffic volumes, LTE will continue to be the main bearer of data traffic in the 5G era.

According to the Mobile Economy 2019 report released by GSMA intelligence, 4G accounts for 43% of connections in 2018, surpassing 2G as the major mobile access technology. Over the next few years, 4G user numbers will continue to increase, particularly in developing countries. By 2023, 4G connections will account for 60% globally. LTE will continue to perform as the main service bearer.

As user behaviour and habits change, data consumption volumes also increase sharply. In 2018, the average data of usage (DOU) of global users was 5.3 GB. In 2023, the number will increase by a factor of five, to 24 GB/Month. This will result in traffic surges and have a huge impact on LTE networks. To account for this, LTE network capacity needs to increase. Otherwise, network will become overloaded and the per capita air interface resource will decrease, leading to deteriorating user experience and failure to meet 5G service experience requirements.



Source: GSMA intelligence

4. 5G-oriented LTE Experience Improvement Technologies

4.1. LTE Evolution Overview

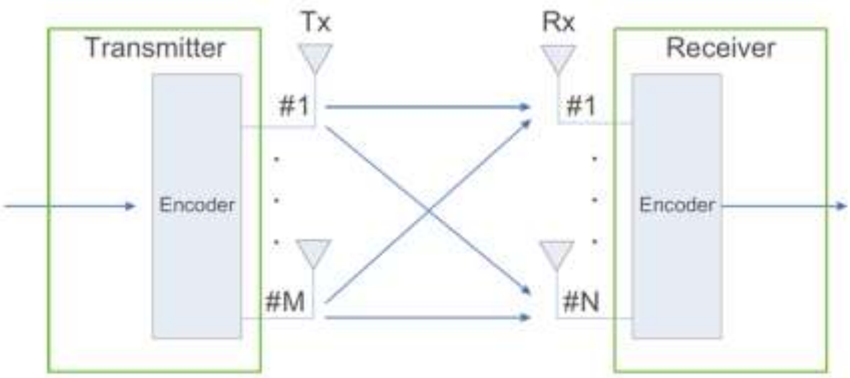
At the end of 2007, 3GPP Release 8 – the first LTE protocol – was introduced. Following over 10 years of evolution, the peak rate, capacity, and delay of LTE have vastly improved. In terms of peak rate, multi-carrier, multi-antenna, and high-order modulation technologies have been introduced to increase the peak throughput of a single UE from 150 Mbit/s of R8 to 3 Gbit/s. While in terms of delay, the Fast UL access, short TTI technologies have been introduced to reduce the loopback delay over the air interface from 20 ms to 2 ms. As a result, LTE is technically capable of carrying most services in the 5G era.

In June 2018, 3GPP Release 15 defined multiple networking modes from option 3 to option 7, as well as related processes of LTE-NR collaboration. Operators will accelerate network deployment by leveraging the coverage advantage of LTE networks, and provide improved user experience.

4.2. Capacity Expansion

4.2.1. Multi-Antenna Technology

Multi-antenna technology, also known as multiple-input multiple-output (MIMO), uses several transmit and receive antennas for improved spatial degree-of-freedom (DoF) and special signal processing technology for the transmitter and receiver. For a given amount of radio spectrum resources, MIMO maximizes the transmission reliability and spectral efficiency of radio links, increases capacity, expands coverage, and improves data rates.



MxN MIMO

In the early phase of LTE, 2x2 MIMO was the predominant technology. With the increase of network capacity and experience requirements, especially the popularization of four-antenna terminals, operators have begun to substantially deploy the four-antenna technologies. Currently, four-antenna technologies have been deployed on 180 networks worldwide.

In a 4T4R cell serving a terminal with four receive antennas, 4x4 MIMO supports simultaneous transmission of up to four channels of data streams, with the capacity approximately 1.8 times that of 2x2 MIMO. Even if the terminal has only two antennas, the 4T4R base station can obtain more accurate channel measurements and feedback, despite that simultaneous transmission of up to two channels of data streams is supported. Coupled with the space diversity gain, the 4x2 MIMO cell delivers a 1.3-fold capacity improvement over the 2x2 MIMO cell.

Massive MIMO is widely regarded as a key multi-antenna technology update, facilitating 4G evolution and 5G development. As a new site form, massive MIMO integrates more RF channels and antennas to implement 3D precise beamforming and MU-MIMO. This enables massive MIMO to offer improved coverage and larger capacity. Massive MIMO greatly improves the capacity and coverage capability of a single site, solves the pain points in spectrum sufficiency and site deployment, and significantly increases the single-user data rate to satisfy optimal user experience demands for various services.

Based on the spectrum type, massive MIMO falls into TDD massive MIMO and FDD massive MIMO.

There is channel reciprocity (similarity) between the uplink and downlink in TDD mode. The uplink sounding reference signal (SRS) can be measured to obtain the weight vector in the downlink. Based on the weight vector, the transmitter generates directional beams for carrying data. These beams are always directed towards the target terminal, with weak interference between terminals. Therefore, multiple terminals can transmit multiple channels of downlink data streams (MU-MIMO) using the same time-frequency resource, thereby obtaining three to five times of capacity gains (compared with 4T4R).

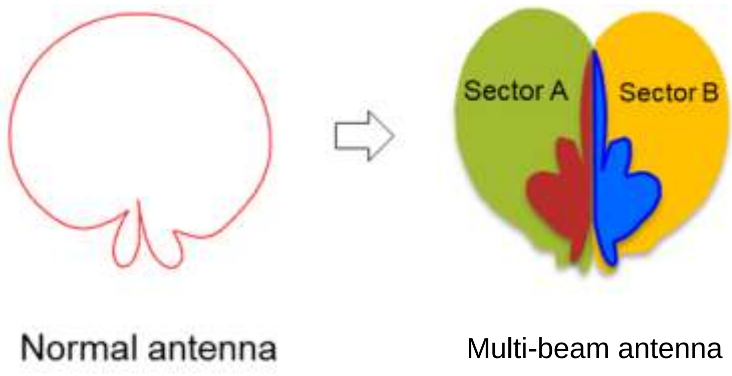
The uplink SRS channel capacity and channel measurement accuracy directly affect the precision of downlink channel estimation. In this case, the downlink capacity and user experience of massive MIMO can be affected. In 3GPP Release 15, four-antenna selective SRS transmission is introduced to send the SRS over four antennas of a terminal in turn. This improves the channel measurement precision and increases the downlink capacity by 8% to 20%. In 3GPP Release 16, the SRS channel capacity is expanded. SRSs can be transmitted on multiple OFDM symbols (previously, only the last symbol of a subframe can be used for transmission). This further improves the channel measurement precision and the downlink capacity of massive MIMO.

The FDD spectrum has a large frequency spacing between the uplink and downlink, and channels are not reciprocal. Therefore, the terminal needs to measure and report downlink channel characteristics by leveraging the TM9 technology, and enable beamforming by weighting. In the initial deployment phase of FDD massive MIMO, for TM4-capable terminals, a massive MIMO cell is split into four 4T4R cells through static splitting, to address the penetration insufficiency of TM9-capable terminals. Compared with 2T2R, massive MIMO enhances the capacity by three to five times. For TM9-capable terminals, user-level beamforming is enabled to improve user experience. As the penetration rate of TM9-capable terminals increases, the number of terminals paired for MU-MIMO using user-level beamforming in massive MIMO cells also increases, which further expands cell capacity.

Currently, FDD massive MIMO has been deployed on over 50 commercial networks worldwide. The shipment of TDD massive MIMO has reached 100K, covering over 50 commercial networks worldwide.

4.2.2. Multi-Sector Technology

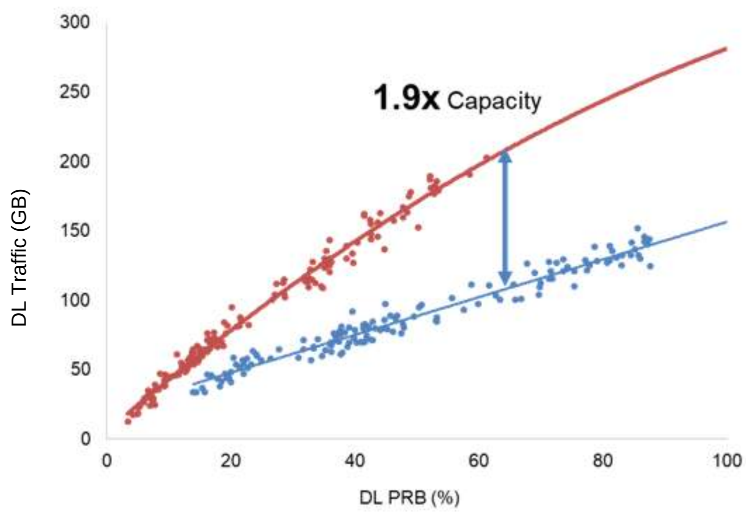
The multi-sector technology expands network capacity by utilizing the sector splitting technology, which differs from the traditional three-sector networking. This increases the available RB resources of the eNodeB without adding frequency spectrums. The 4T6S technology, commonly used on LTE networks, splits a site into six sectors (six 4T4R cells) with splitting antennas. The capacity of a single site can be increased by 50% to 70%.



Multi-beam antenna

5G terminals support NR beamforming. Compared with 4T6S, 8T3S provides better coverage and higher capacity gains for NR networks. The digital/analog antennas with eight transmit antennas are used to enable conversion between 4T6S and 8T3S (three 8T8R sectors). In the LTE phase, 4T6S can be used to increase capacity without relying on TM9-capable terminals. After future refarming to NR, the site type can be configured to 8T3S without hardware changes, while 8T8R dynamic beamforming helps obtain capacity and coverage gains.

The multi-sector technology has become a major solution for operators with insufficient spectrum resources in densely populated areas. Currently, the sector splitting solution has been deployed on more than 90 networks worldwide. In Thailand, the site capacity increased by 90% following the reconstruction from 2T3S to 4T6S.



4.2.3. Multi-Carrier Technology

Spectrum expansion can increase network capacity in a linear manner, which is crucial for operators in expanding network capacity. Currently, the LTE industry ecosystem is mature in each frequency band. Operators can fully utilize idle spectrums and migrate redundant spectrums released by GSM/UMTS to LTE, relieving the pressure caused by LTE traffic growth.

Frequency Band	Number of Terminal Models
1800 MHz band 3	10,327
2100 MHz band 1	8,557
2600 MHz band 7	9,061
900 MHz band 8	5,293
800 MHz band 20	6,049
2300 MHz (TDD band 40)	5,249
2600 MHz (TDD band 38 or 41)	5,212
3500 MHz (TDD C-band)	267

**Source: GSA*

The TDD spectrum has the advantage of continuous high bandwidth. It is also easier to enable spectrum efficiency improvement features, such as beamforming, due to reciprocity between the uplink and downlink, thereby obtaining larger capacity gains. The TDD spectrum is imperative for constructing the LTE capacity layer. However, as reported by GSA in August 2019, only 164 of 228 licensed operators have deployed TDD networks. In Europe, the 2.6 GHz TDD frequency band of some operators is yet to be commercially used, while many countries throughout Asia Pacific and Africa have not granted licenses for 2.3 GHz and 2.6 GHz frequency bands.

The 1800 MHz, 2100 MHz, and 2600 MHz frequency bands are golden capacity layers for FDD. The 1800 MHz frequency band is deployed worldwide. However, for the 2600 MHz FDD frequency band, site alignment rates with GSM/UMTS are below 20%. The 2100 MHz frequency band, mainly used for UMTS, is rarely used in LTE. With the traffic decrease on UMTS 2100 MHz, spectrum refarming to LTE can be performed.

With dynamic spectrum sharing between LTE and NR, 5G-dedicated frequency bands such as C-Band and band 41 can be used for LTE. In the early stages with light 5G traffic, the spectrum ROI can be significantly improved without affecting the 5G user experience.

4.3. User Rate Enhancement

4.3.1. Massive CA

CA, introduced in 3GPP Release 10, aggregates multiple contiguous or non-contiguous carriers to provide a wider bandwidth, which increases the data rate by folds. After CA is enabled, the RB resources of multiple carriers are scheduled in a unified manner. In this way, the idle RB resources of each carrier are effectively utilized, the load of each carrier is balanced, and the resource utilization is maximized.

In Release 13, LTE Massive CA supports 32CC at most. However, the number of actual aggregated carriers depends on the terminal capability and available spectrum resources of the operator. The Exynos 9820 chip released by Samsung in November 2018 supports 8CC CA, providing a peak rate of 2 Gbit/s. The Samsung Galaxy S10+ supports 6CC CA. The actual test rate of 6CC CA (four TDD carriers + two FDD carriers) on commercial networks in Australia exceeds 1.4 Gbit/s. As reported by GSA in February 2019, 26 operators worldwide have achieved the Gbit/s peak experience rate on commercial networks by leveraging the Massive CA, 4x4 MIMO, and 256 QAM technologies.

4.4. Low Latency

Low latency is another significant factor used for measuring user experience. A network with low latency not only improves the experience of traditional services, such as mobile games and videos, but also enables new services such as Cloud XR, industrial control, and Internet of Vehicles (IoV) in the 5G era, ensuring service continuity when 5G services fall back to 4G and presenting new opportunities for operators and vertical industries.

4.4.1. Optimized Scheduling

For latency-sensitive services, optimized scheduling reduces the latency even when common terminals are used.

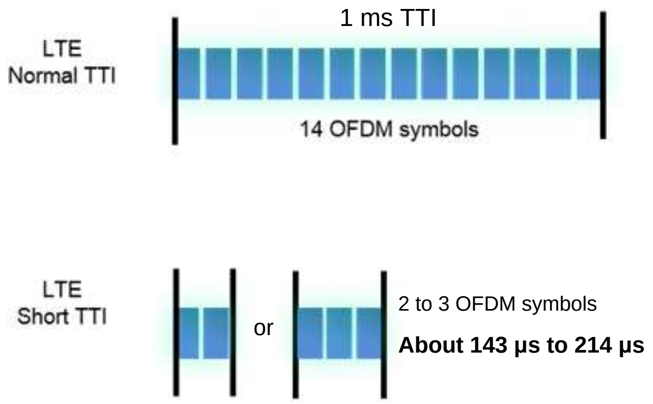
In heavy-load scenarios, the scheduling request priorities and the initial data volume scheduled, as requested for low-latency users, are increased. In addition, resources with shorter SRI periods are allocated to low-latency users. This method reduces the latency on SR-based scheduling and allows for more preallocation opportunities. In weak coverage scenarios, ROHC UDP is used to reduce the number of retransmission times and uplink RLC segments for terminals performing low-latency services. This method reduces the E2E latency. In addition, the base station precisely selects an MCS index for a terminal based on the terminal's data volume, which lowers the MCS index and reduces the number of uplink retransmissions for terminals performing low-latency services. In general, air interface latency optimization can be used in a variety of application scenarios to reduce average user latency by 5% to 30%.

4.4.2. Fast Uplink Access

For services sensitive to the uplink latency, the fast uplink access technology can effectively reduce the data loopback duration over the air interface. Generally, the air interface loopback latency for dynamic scheduling is about 20 ms. The fast uplink access technology, introduced in Release 14, supports short-period (1 ms to 5 ms) semi-persistent scheduling, which substantially shortens the scheduling period of uplink data. The air interface loopback latency for uplink data can be reduced to 8 ms, which improves user experience of latency-sensitive services in the uplink, including mobile games and remote control.

4.4.3. Short TTI

The 3GPP Release 15 introduces Short TTI to enhance the low latency capability of the LTE network. With this technology, the air interface subframe length is shortened from 1 ms (14 OFDM symbols) to 0.143 ms to 0.214 ms (2 or 3 OFDM symbols), and the air interface loopback latency is reduced from 20 ms to 2 ms. This reduces the transmission delay of small packets, shortens the TCP slow start process, improves MBB user experience, and enables low-latency services in the future.



4.5. Voice Quality Enhancement

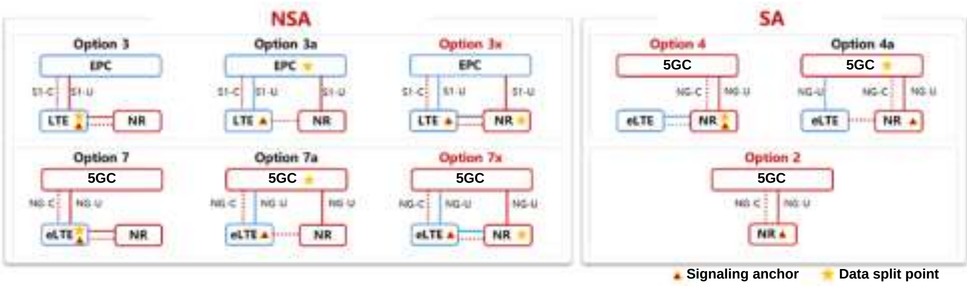
4.5.1. EVS

EVS is a new full HD VoLTE codec, which was released by 3GPP in September 2014. The EVS codec rate is 128 kbit/s (the common AMR-WB VoLTE codec rate is only 23.85 kbit/s), with the voice definition similar to that of a full HD film. EVS has higher anti-jitter and anti-packet-loss capabilities, ensuring good voice quality at the cell edge and during high-speed movement. In addition, under the same quality conditions, the capacity of a network utilizing EVS is twice or is even higher than that using a common voice codec. With user experience in mind, operators are deploying the EVS. According to GSA statistics, more than 20 operators around the world have enabled the EVS function on their LTE networks.

4.6. Interoperability with NR

Based on the LTE and NR networking structures, the 3GPP Release 15 defines Options 2, 3, 4, 5, and 7 as follows:

1. Option 2: The NR base station connects to the 5GC. In this networking mode, interconnection with LTE is not involved. So it is not described in this document.
2. Option 5: The LTE base station connects to the 5GC.
3. Options 3, 4, and 7: LTE-NR DC
   - Option 3 series: The LTE base station serves as the anchor (EN-DC).
   - Option 4 series: The NR base station serves as the anchor (NE-DC).
   - Option 7 series: The eLTE base station serves as the anchor (NG EN-DC).



4.6.1. LTE-NR DC

DC indicates that the terminal sets up wireless connections with two base stations at the same time. After connections are set up, the terminal can transmit data through the Master Node (MN) and the Secondary Node (SN) concurrently.

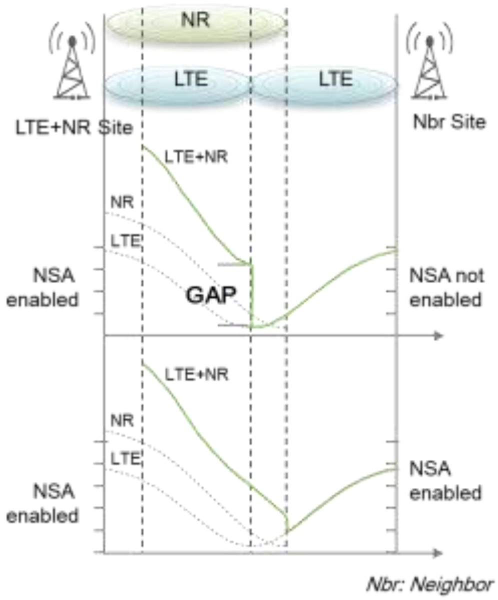
- EN-DC: LTE+NR DC. The LTE base station serves as the MN.
- NE-DC: NR+LTE DC. The NR base station accesses the 5GC and serves as the MN.
- NG-ENDC: DC of the NG-LTE+NR. The eLTE base station accesses the 5GC and serves as the MN.

With the wide coverage of LTE networks, DC enables the quick deployment of 5G NR networks and improves the 5G user experience. The DC functions can be summarized as follows:

1. The 5G user rate is the sum of user-plane data rates of LTE and NR connections. This helps improve 5G user experience. In particular, operators with disadvantages in the NR spectrum bandwidth may achieve optimal 5G experiences with superior LTE experience.
2. In the early stages of NR deployment, contiguous NR network coverage is not formed but the LTE base station provides continuous coverage. When a 5G user leaves the NR coverage area, inter-RAT handovers from the NR network to the LTE network can be avoided, ensuring user experience continuity.

In actual deployment, overlapping coverage may occur between the NR base station and the neighbouring LTE base station. Therefore, DC must be enabled for both the LTE base station, which shares the same site with the NR base station, and the neighbouring LTE base station. Otherwise, user experience can be greatly affected once 5G terminals perform 4G site handovers.

Inter site DC to Achieve Smooth Experience



The first countries to roll out commercial 5G networks, such as South Korea and the UK, have begun LTE-NR DC deployment on a large scale.

4.6.2. LTE Connectivity to 5GC

After the upgrade from LTE, eLTE can connect to the 5GC to use 5G core network functions, such as network slicing, QoS architecture based on the QoS flow, and 5GC security framework. This helps enable low-latency applications in the E2E manner. After the LTE base station connects to the 5GC, the NR and LTE base stations interwork closely in the architecture such as Option 4 or Option 7, and the DC function can be enabled for 5G users to obtain a higher experience rate.

5. Network and Terminal Requirements for Smooth 5G to 4G Experiences

The 5G-oriented experience evolution technologies require the support of both networks and terminals. If the network and terminal capabilities do not match, the network's potential cannot be unleashed and the terminal experience cannot be fully utilized. On the network side, the preceding evolution technologies are ready for commercial use as terminal-related capabilities mature. However, industry attention is still required, especially for 4G/5G dual-mode terminals, whose communications capabilities on LTE networks require experience evolution technologies, such as 4Rx, TM9, SRS Antenna Switching, Short TTI, Fast Uplink Access, Massive CA, EVS, and LTE Connectivity to 5GC. This bridges the gap between 4G and 5G experience after a fallback.

5.1. 4Rx

Four-antenna mobile phones achieve higher experience rates, which has now become a key selling point. Mainstream terminal chip vendors worldwide have released chips supporting 4x4 MIMO. Apple, Huawei, Samsung, Sony, and LG have all launched high-end smartphones supporting 4Rx. In recent years, some mid-range smartphone chips have also included support for 4Rx, including models from various Chinese brands such as Xiaomi, usually priced at less than 3000 RMB. As a result, 4Rx smartphones are quickly becoming affordable to the public. GSA statistics confirm that up to 60 mobile phone models are now capable of 4x4 MIMO 4Rx.

5.2. TM9

Mainstream chip vendors, such as Qualcomm, HiSilicon, and MediaTek, have launched TM9 terminal chips. Since 2018, TM9 has been activated by default on 20 new terminal models, covering five mainstream vendors.

In the future, TM9 needs to be popularized among high-end, mid-range, and low-end terminals. In practice, some operators in North America and China have started to prepare for the TM9 ecosystem, as it becomes mandatory during terminal procurement, laying a foundation for future massive MIMO deployment and LTE long-term evolution.

5.3. SRS Antenna Switching

Currently, four-antenna selective SRS transmission is supported by some CPEs, rather than mobile phones. Some chip vendors are planning to support SRS Antenna Switching in 4G/5G dual-mode chips.

5.4. Short TTI

While no chips currently support short TTI, mainstream chip vendors plan to launch terminal chips supporting short TTI during the third quarter of 2020.

Short TTI, significant to 4G/5G dual-mode terminals, is a prerequisite for low-latency applications to fall back from 5G to 4G.

5.5. Fast Uplink Access

A small number of terminals in the market support Fast Uplink Access.

5.6. Massive CA

According to GSA statistics, more than 160 terminal models support the 1 Gbit/s data rate, while 8 LTE terminal models support 5CC CA or higher capabilities.

For 4G/5G dual-mode terminals, it is imperative to support CA higher than 4CC during LTE communications. In NR base station coverage areas, 5G terminals can obtain a good user experience based on the high bandwidth of NR networks. After the fallback to 4G, terminals can achieve CA higher than 4CC, which helps maintain the high bandwidth advantage and avoids sharp user experience deterioration.

5.7. EVS

The EVS industry has matured. According to GSA statistics, 169 smartphone models now support EVS, including mainstream terminal vendors such as Apple, Huawei, and Samsung.

5.8. DC

2019 is the first year of commercial use for 5G terminals. The DC terminal industry is still in its infancy, with DC being supported by six terminal models. It is recommended that DC become a standard configuration for terminals to aggregate LTE and NR spectrum resources on the network, and enables a smooth user experience in the edge of NR cell.

5.9. LTE Connectivity to 5GC

Currently, no terminal supports LTE Connectivity to 5GC. Chip and terminal vendors are encouraged to integrate the LTE Connectivity to 5GC in order to provide a 5G-like low-latency experience in LTE coverage areas.

5.10. FWA CPE

According to GSA statistics, there are currently over 2700 CPE/Router terminal models. Of these, more than 2500 models are CAT6 or lower, with over 60 being CAT12 or higher. 4x4 MIMO and 256QAM have become basic configurations of medium- and high-end CPEs. Some high-end CPEs, supporting 8x8 MIMO and CAT19, have already gone to market.

4G/5G FWA terminals include indoor and outdoor CPEs. As the FHD/4K video eco-system matures, and to compete with fixed bandwidth fiber to the home (FTTH) experience, the mainstream service experience of 4G/5G FWA will enter a phase delivering 1 Gbit/s peak rate and 50–100 Mbit/s average rate. Based on requirements for smooth 4G-to-5G service experience, the following table lists the recommended technical specifications of 4G FWA CPE.

No.	Item	Specifications
1	Category	CAT16 or higher, peak rate > 1 Gbit/s
2	MIMO	4Rx, 4x4 MIMO mandatory 8Rx, 8x8 MIMO preferred
3	Transmission mode	TM9 mandatory
4	High order modulation	256QAM or 64QAM
5	CA	4CC CA mandatory T+F CA optional
6	SRS	SRS antenna selection

6. Summary

In the 5G era, MBB applications raise service experience standards and present challenges to LTE network capacity and experience. As LTE technologies evolve, the capacity, throughput, and latency experience a more than ten-fold improvement, making LTE technologies an integral part of 5G NSA network architecture.

To accelerate the implementation of new technologies, it is recommended that the entire industry focus on experience evolution technologies, perform interworking verification on networks and terminals, and promote terminals to follow the evolution of protocols, so to lay a solid foundation for network-wide application in the 5G era.

GSMA HEAD OFFICE
Floor 2
The Walbrook Building
25 Walbrook
London
EC4N 8AF
United Kingdom
www.gsma.com