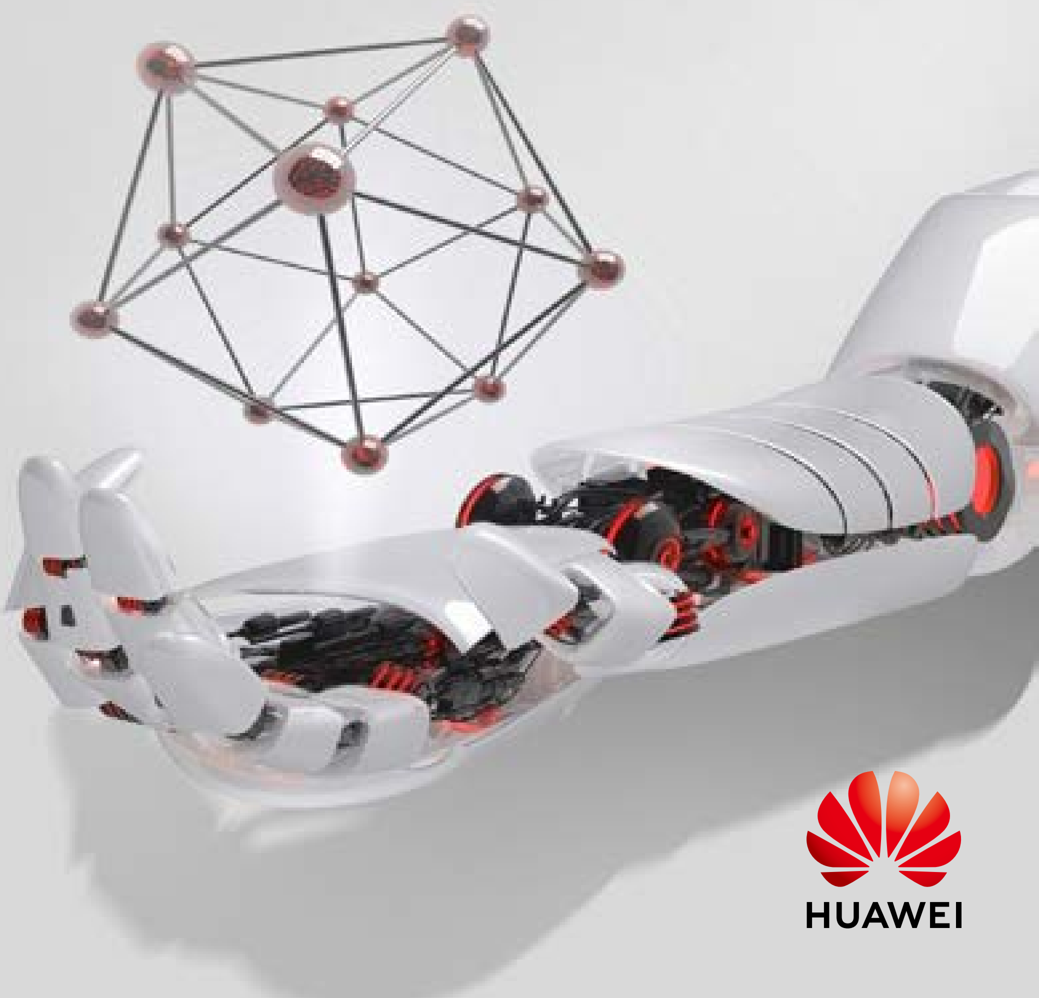
LTE Evolution to Build All Business Foundation

Feb,2019



HUAWEI

Executive Summary

LTE has completely changed the landscape of mobile broadband and everyone's daily life, brought huge revenues to most mobile operators. However operators are now concerning about how to boost the network capacity and enhance user experience, how to enable new business for new revenue growth, and how to improve the investment efficiency. In recent years, LTE standards and industry are evolving not only to overtake all 2G and 3G services, but also to enable all business as the foundation of the next decade. This white paper presents an overview of how shall we redefine LTE towards the 2020s to address the challenges regarding use experience and network capacity and bring sustainable revenues.

Executive Summary

5GC	5G Core
AAU	Active Antenna Unit
AI	Artificial Intelligence
BS	Base Station (or Basestation)
BW	Bandwidth
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CP	Control Plane
CPE	Customer-premises equipment
CQI	Channel Quality Indicator
CRS	Cell-specific reference signal
CSFB	Circuit Switch Fallback
CSI	Channel State Information
CSI-RS	Channel State Information Reference Signal
DL	Downlink
DMRS	Demodulation Reference Signal
E2E	End-to-End
eMTC	Enhanced Machine Type Communications
EN-DC	E-UTRAN/NR Dual Connectivity
E-UTRAN	Evolved Universal Terrestrial Access Network
FBB	Fixed Broadband
FDD	Frequency Division Duplex
GSM	Global System for Mobile Communications
GSMA	Global System for Mobile Communications Association
HetNet	Heterogeneous Network
HSPA	High Speed Packet Access
ICIC	Inter-Cell Interference Coordination
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITS	Intelligent Transportation System
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
LAA	Licensed Assisted Access
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-V	LTE-Vehicle
MBMS	Multimedia Broadcast Multicast Services
MIMO	Multiple-Input Multiple-Output
MTC	Machine Type Communications
MU-MIMO	Multi-User MIMO
NB-IoT	Narrowband Internet of Things
NE-DC	NR/E-UTRAN Dual Connectivity
NG-RAN	Next Generation Radio Access Network
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operating Expense
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
RAT	Radio Access Technology
RS	Reference Signal
RTT	Round-Trip Time
SIB	System Information Block
SINR	Signal to Interference plus Noise Ratio
SRVCC	Single Radio Voice Call Continuity
SRS	Sounding Reference Signal
TCO	Total Cost of Ownership
TDD	Time Division Duplex
TM	Transmission Mode
TTI	Transmission Time Interval
TTM	Time To Market
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra-Reliable Low-Latency Communication
V2X	Vehicle to Anything
VoLTE	Voice over LTE
WBB	Wireless Broadband

1. LTE: New Evolution, New Growth Opportunities

1.1. LTE Standards Are Evolving towards the 2020s

The introduction and increasing use of mobile devices (e.g., smart phones and tablets) and various mobile applications have dramatically changed mobile communications systems and upgraded the cellular technologies from one generation to another. As the dominant 4G technology, LTE, also known as Evolved Universal Terrestrial Access Network (E-UTRAN), was developed by 3GPP starting in 2004 to meet the requirements of diverse mobile applications. LTE is a release-based technology family. In every one to two years, a new release of various key features is specified to meet the requirements of emerging use cases, to support technologies from latest researches, and to address practical issues seen in real deployments. In the past decade, the LTE family has grown to include LTE, LTE-Advanced, LTE-Advanced Pro and now its further evolution towards satisfying IMT-2020 (a.k.a. 5G) requirements and use cases. On one hand, LTE standards are evolving to ensure ubiquitous evolved mobile broadband (eMBB) experience in terms of latency, coverage, and throughput. On the other hand, LTE standards continue to develop to enable business expansion into vertical markets, e.g., IoT, V2X, unmanned aerial vehicles (UAVs), and industry automation by means of ultra-reliable low-latency communication (URLLC). In addition, LTE is evolving to support the operation of other RATs by means of technologies such as E-UTRAN/NR Dual Connectivity (EN-DC).

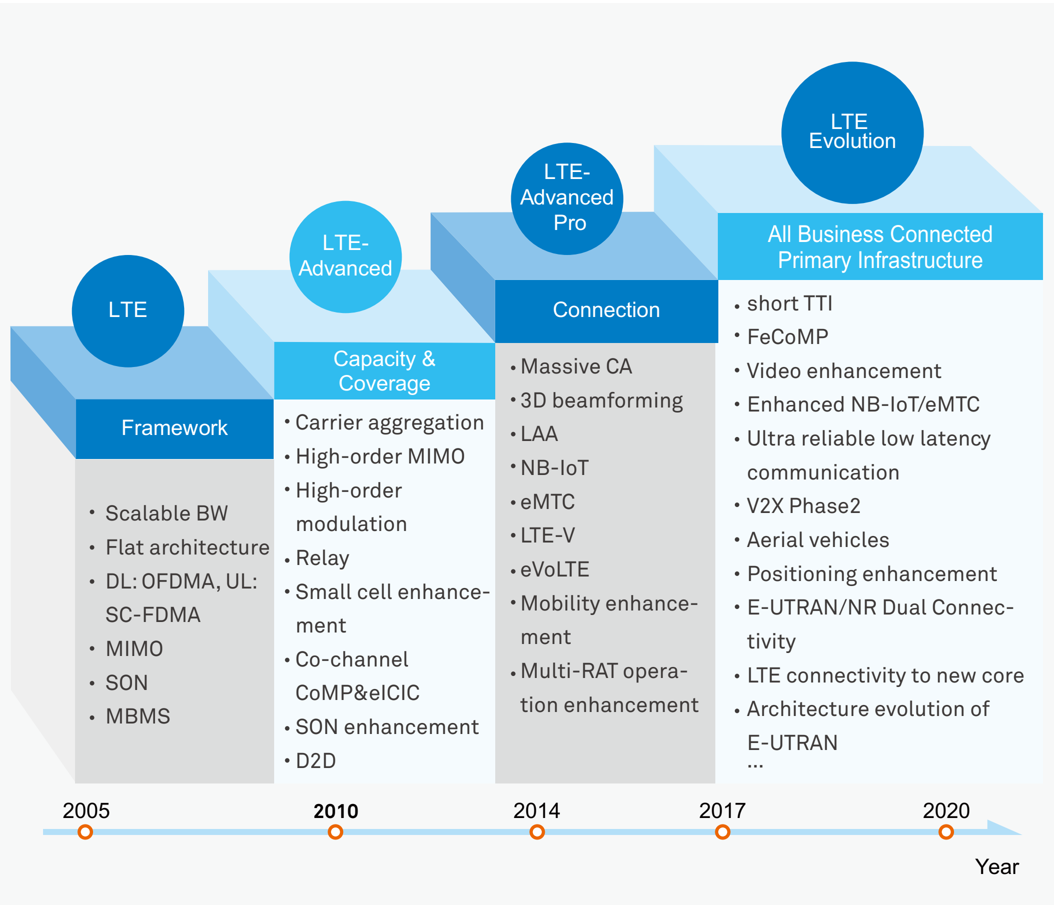


Figure 1. Key features of LTE and its evolution

Thanks to its technology advancement and well established ecosystem, LTE is the fastest developing mobile communications system ever. More than 700 LTE networks have been deployed for commercial use, serving 3.2 billion users (78% of the global population) and contributing to 66% of the operators' revenues on average. With its all business capabilities from voice to data and IoT, it is no surprise that LTE will gradually replace 2G and 3G as the foundation for the next decade in the 5G era.

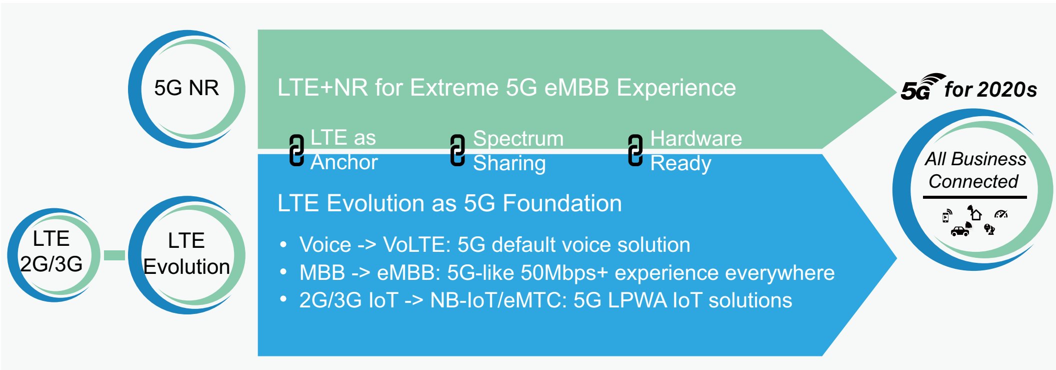


Figure 2 LTE evolution towards the 2020s

1.2. New Growth Opportunities and Requirements

From ubiquitous coverage to traffic capacity, the past decades have witnessed tremendous business growth driven by LTE. Nevertheless, operators are also looking for new growth opportunities, which raise new requirements for LTE evolution.

- **Demographic Dividend Requires Better 4G Coverage.**

  Mobile networks have been providing the demographic dividend across the world by voice and data services. More than 10 years ago, 2G/3G voice surpassed the landline voice, and the voice duration in service packages is almost unlimited in many markets. In recent years, 3G/4G data is a more and more essential part of modern daily life boosted by all kinds of smart devices, especially the smartphones. However, the **4G LTE coverage** is still not as good as that of 2G and 3G, which causes users to fall back to the 2G or 3G networks and significant user experience deterioration. According to Huawei analysis, an average of 18% of the mobile data traffic falls back to 2G and 3G.

- **Traffic Dividend Needs to Boost Network Capacity.**

  In some developed MBB countries, operators are getting more revenues by encouraging users to consume more traffic. Unlimited data packages are becoming popular in many high-competition markets. According to Analysis Mason, the global average smartphone data traffic per user per month (DOU) has reached 2.7 GB, and this figure will increase over the next few years at a compound annual growth rate (CAGR) of 50%. In some markets, the CAGR even doubles or triples. With the increasing number of subscribers and exponential traffic growth, how to **boost network capacity** with limited spectrum is a common concern in most markets.

- **Better User Experience and New Services Will Provide New Growth Opportunities.**

  Beyond the traffic capacity, leading operators are also looking for new growth opportunities to differentiate from their competitors. Monetizing **better experience and new services** is a popular approach to reinstate growth. According to P3 test report, the user experienced data rate of developed MBB markets is around 20 Mbps, which could be even lower at busy hour or in some developing MBB markets like India. With the rollout of new services such as ultra-HD video, fixed wireless access (FWA), and mobile gaming, users are expecting much better experience.

- **Improve Investment Efficiency on the Doorstep of 5G.**

  To provide more capacity and better experience, operators need to install more radio boxes, construct more sites, and buy more spectrums. Consequently, on the doorstep of 5G, how to **increase investment efficiency** is another major concerns of mobile operators.

The investment can be categorized as Capital Expenditure (CAPEX) and Operating Expense (OPEX):

- CAPEX is the cost for hardware infrastructure, spectrum, and site construction include mast, transmission, power supply and so on.
- OPEX is typically 3–4 times of CAPEX and includes the cost for network operation, marketing & subsidiary, customer care, interconnection & roaming, and administration.

From the network perspective, the investment in hardware, spectrum, and network operation shall be more efficient and future proof.

2. Redefining LTE towards the 2020s

How shall we redefine LTE and meet the business requirements in coverage, capacity, experience, and investment efficiency?

2.1. Zero Fallback

Zero fallback refers to the expansion of the foundation LTE network coverage so that it is equivalent to or better than 2G and 3G. All voice, data & IoT services will be served by LTE without any fallback to 2G or 3G. The OPEX of an operator that has deployed 2G, 3G, and LTE networks generally accounts for more than 60% of the total cost of ownership (TCO). It should be noted that the network operation cost will also increase by about 10% for each new radio band and RAT. After 5G is put into commercial use, the OPEX will be even higher. To improve operational efficiency, 2G and 3G networks shall be gradually phased out.

- In the 5G era, VoLTE shall be the most ubiquitous and preferred voice solution without further fallback to 2G or 3G.
- Subscribers using legacy 2G and 3G technologies can migrate to LTE to enjoy better experience.
- NB-IoT and eMTC are future proof technologies. In March 2018, 3GPP clarified that "(5G) LPWA use cases will continue to be addressed by evolving LTE-M(eMTC) and NB-IoT". The NB-IoT and eMTC ecosystem is also growing very fast. Within just 2 years, the NB-IoT module price has reached about 3 USD, which is similar to that of a 2G M2M module.

Dozens of operators, such as AT&T in the US, Vodafone in Australia, and TELUS/Bell in Canada, have shut down their 2G networks. Many other operators plan to shut down their 2G networks around 2020 to 2025.

2.2. Zero Wait

LTE evolution, as the foundation in the next decade, shall provide much more superior experience than the current LTE network to satisfy new business requirements. According to the study of Google, content load time will significantly impact the bounce rate, which is the percentage of visitors who come to your site and leave after only viewing one page. Zero wait will minimize service loss by providing popular services, such as HD video, web browsing, and mobile gaming, at the lowest possible latency Zero wait may also enable the network to provide new services such as cloud VR and smart manufacturing.

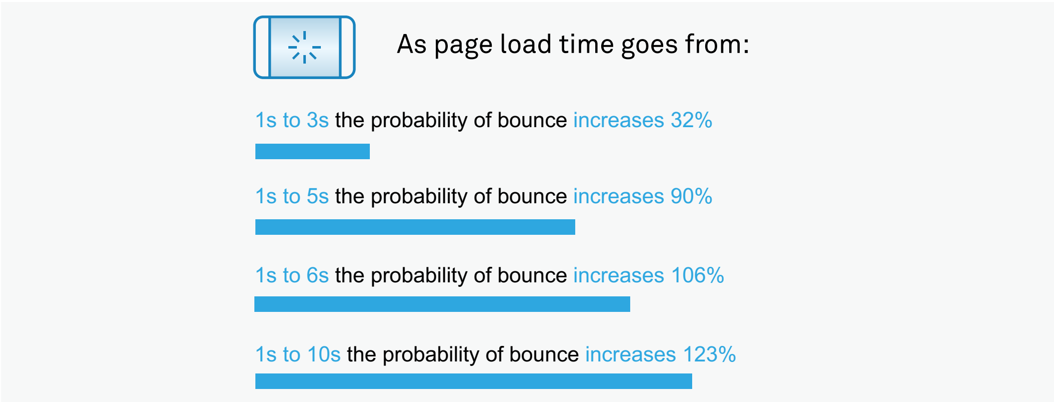


Figure 3 Google study on page load time vs service bounce rate

Data rate and **latency** are two major dimensions to evaluate such zero wait experience.

- In some fierce-competition markets, unlimited packages are becoming more and more popular. User experience will be a key differentiation for operator marketing and business. For example, in Finland and Thailand, operators have launched speed-based packages.

  Currently, the user experienced data rate of major operators around the world is around 20 Mbps. A recommended benchmark for such "Zero wait" experience should be around 50 Mbps anytime anywhere, which is fast enough for most popular services. Compared with the current 20 Mbps data rate, the recommended benchmark has a narrower gap with the 5G user experience requirement (100 Mbps).

- There are more than 2 billion mobile gaming users worldwide, with an annual growth of 12%. This is a huge potential market since low latency experience is a key benchmark in many real-time games and many players are willing to pay for such experience. A new business model has emerged in China: operators and OTTs cooperated to sell game acceleration packages.

  According to Huawei and OTT game research, a 50-ms latency can provide decent mobile gaming experience, requiring a 10–20 ms latency over the air interface. In the near future, more time-critical business like LTE-V2X and smart manufacturing will demand even lower latency experience with a typical air interface latency to be below 10 ms.

2.3. Smooth Evolution

Firstly, **LTE evolution is one crucial component of 5G target network**. In the past, the evolution of mobile communications technologies was a process of replacing old-generation technologies with new ones. After 3G emerged, 2G standards stopped evolving. But how shall we picture the target network and its evolution in the 5G era? According to the standards and industry opinions, the target network will be LTE Evolution + 5G NR, where LTE will evolve in parallel with 5G NR over a long period of time in terms of standards, industries, and ecosystems. Gradually taking over 2G and 3G, being all-business foundation network in the 5G era, **LTE will serve as the NSA anchor and coverage complement to 5G NR.**

Secondly, **hardware should apply the most state-of-art technologies and be ready for 5G NR**. Such hardware should include base stations, antennas, site infrastructure. The new infrastructure should support wide-band or multiple bands, which not only makes it easier to upgrade to NR, but also greatly simplifies the site structure and reduces the OPEX.

Spectrum is another important asset of mobile operators. Its value shall be maximized between multiple RATs. **Operators shall be able to flexibly allocate the spectrum between different RATs according to E2E business and terminal readiness.**

Another 5G key innovation is AI-powered operation, which will greatly reduce the OPEX. It is firstly introduced into LTE because big data can be acquired from the widely-deployed LTE commercial networks and 5G technologies like massive MIMO are already used in LTE.

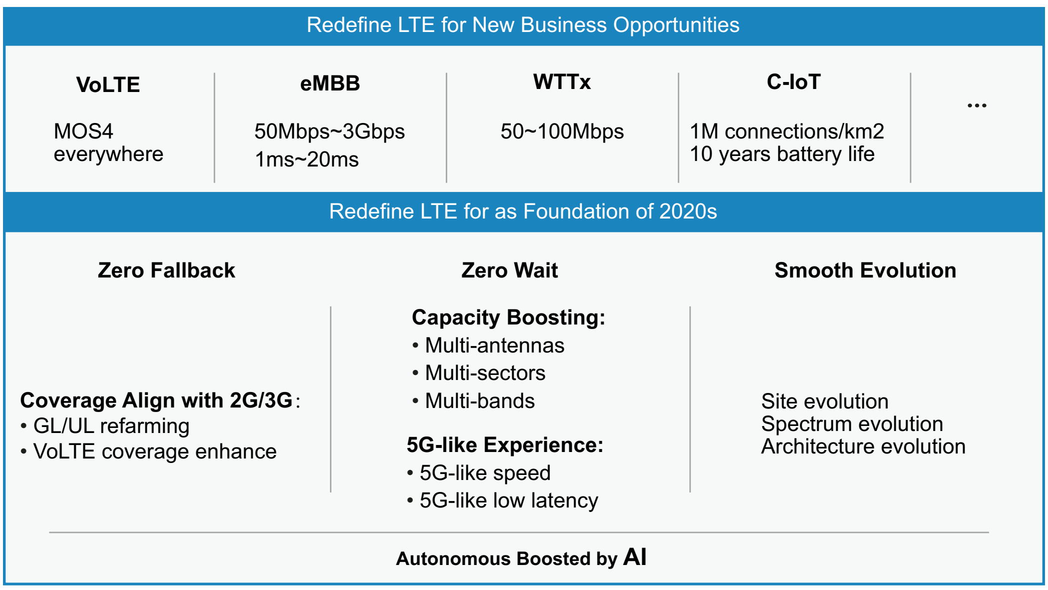


Figure 4 Technologies supporting LTE evolution towards the 2020s

3. Key Technologies for LTE Evolution

LTE standards and solutions need continuous evolution to help operators cope with the challenges of coverage, capacity, user experience, new services, and the requirements of 5G-oriented evolution. 3GPP specifications R15 frozen in June 2018 determined that LTE and NR should complement each other and evolve together. This chapter describes key LTE evolution technologies in terms of coverage, capacity, user experience, interworking with NR/NG Core, site evolution, and new services.

3.1. Coverage

Currently, around 18% of the total data traffic falls back to 2G or 3G globally, failing to achieve the zero fallback target. The main reasons are as follows:

1. There is still a gap between LTE coverage and 2G or 3G coverage. According to the report from GSMA intelligence, LTE covers 75% of the global population in 2018, lagging far behind the 2G or 3G coverage for the global population, which exceeds 90%.

2. The VoLTE service provisioning rate or VoLTE coverage is insufficient. As a result, voice services of 4G subscribers fall back to 2G or 3G through CS Fallback (CSFB) or single radio voice call continuity (SRVCC). Consequently, data also falls back to 2G or 3G for a short period of time.

This section describes the main technologies used for improving LTE network coverage and VoLTE coverage.

3.1.1. Dynamic Spectrum Sharing

Currently, refarming part of the 2G and 3G spectrums for LTE deployment is the most effective way to expand LTE coverage and achieve zero fallback. However, most networks still have 2G and 3G subscribers. Especially in 2G networks, lots of 2G IoT devices are deployed and are difficult to transfer to other RATs. Therefore, 2G and 4G or 3G and 4G need to coexist on certain spectrums for a period of time.

Dynamic spectrum sharing can dynamically allocate spectrums based on traffic requirements. When there is light traffic on the GSM (or UMTS) network, more spectrum resources are automatically allocated to the LTE network. This improves spectrum utilization (up to 44% with GSM and LTE spectrum sharing and 52% with UMTS and LTE spectrum sharing), while ensuring the service quality of GSM (or UMTS). This helps operators fully utilize the limited GSM (UMTS) spectrums to quickly achieve full LTE coverage.

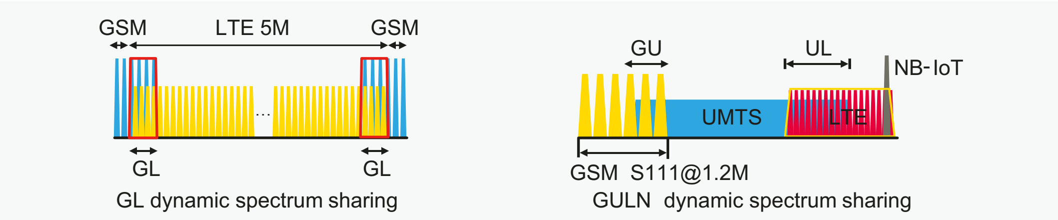


Figure 5 GSM-LTE and UMTS-LTE spectrum sharing

By the end of 2018, 100 operators have deployed the dynamic spectrum sharing solution. This number is expected to reach 200 in 2019. Bharti Airtel in India uses the dynamic spectrum sharing technology to deploy LTE, GSM, and UMTS on the 900 MHz band. This greatly improves the LTE network coverage and mobile user experience, and enables high-speed Internet access and HD voice services indoors. LTE network traffic also increases by 20%.

3.1.2. VoLTE

The VoLTE industry has been quite mature. According to a GSMA report, 180 operators have launched VoLTE services in their networks. A total of 1982 terminal models are VoLTE-capable, and some VoLTE feature phones are sold at a price of lower than 20 USD. This accelerates the migration of 2G and 3G subscribers to 4G networks. At the same time, the VoLTE technology is continuously evolving to provide a better voice experience for subscribers.

TTI bundling: TTI bundling enables a data block to be transmitted in four consecutive TTIs. Different hybrid automatic repeat request (HARQ) redundancy versions of the same data block are transmitted in different TTIs. TTI bundling reduces the number of retransmissions and makes full use of HARQ combining gains to enhance VoLTE coverage. For UEs under weak coverage, the uplink packet loss rate decreases by 5%–20% and the coverage gain is about 1 dB.

In compliance with 3GPP R12, the following enhancements are introduced to TTI bundling to further decrease the packet loss rate by up to 10%:

- The resource allocation size is no longer limited to three PRBs, enabling more flexible resource allocation for TTI bundling.
- The number of HARQ processes is reduced from four to three, and the new HARQ feedback time sequence is supported.

VoLTE voice rate control: Depending on the rates supported by a UE, the voice rate of the UE can be adjusted between the high voice rate mode and the low voice rate mode. In this way, the UE can use a lower voice coding rate (such as 12.65 kbps and 6.6 kbps) at the cell edge for transmission, improving the uplink voice coverage by 0.5–1 dB.

Voice rate adjustment can be triggered based on the uplink quality, load, and SINR. This enables VoLTE voice rate control to take effect in different scenarios, improving VoLTE coverage. VoLTE voice rate control also includes EVS rate control. Enhanced voice services (EVS) using high voice rates such as 24.4 kbps or 13.2 kbps can be adjusted to use low voice rates such as 13.2 kbps or 9.6 kbps, respectively.

VoLTE CoMP: VoLTE CoMP converts inter-cell interference into useful information by coordinating multiple cells based on the channel status and data information shared between the cells. VoLTE CoMP breaks through the limitation of single-cell transmission on spectral efficiency and enhances VoLTE coverage by up to 2 dB.

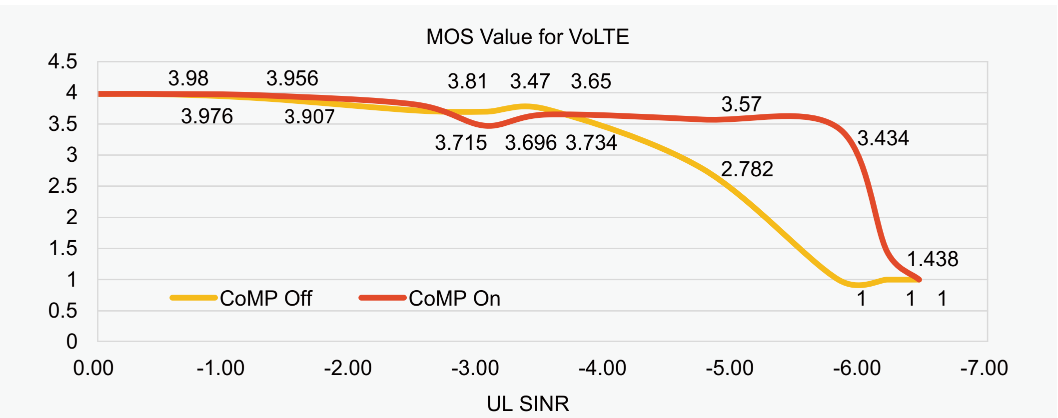


Figure 6 VoLTE coverage enhancement by VoLTE CoMP

In addition, in Rel-14, eVoLTE coverage enhancement (CE) technologies are introduced which reuse the existing CE technologies in eMTC CE mode A as much as possible. The main coverage enhancement techniques defined in eVoLTE or eMTC are described as follows:

- RAN-assisted codec adaptation
- Relaxing the air interface delay budget
- Multi-subframe frequency hopping
- Asynchronous HARQ
- Flexible repetition

3.1.3. Coverage Enhancement Technologies

Low band deployment is a major approach to wide coverage guarantee, especially in rural areas. To further improve coverage, it is recommended that low-band 4T4R or 2T4R modules be used, which provide approximately 3 dB higher coverage gains than 2T2R modules.

For operators that cannot deploy LTE at low bands, 1800-MHz high-power RF modules and high-gain antennas are an alternative means to provide wide coverage in rural areas. A 20-dBi high-gain antenna offers a gain of 4 dB, as compared with a 16-dBi common antenna. A high-power RF module provides a 6 dB downlink coverage gain. In the uplink, related algorithms can be optimized to improve the receiver sensitivity and provide a 6 dB coverage gain. In this way, the coverage is almost the same as that of the GSM 900 MHz band.

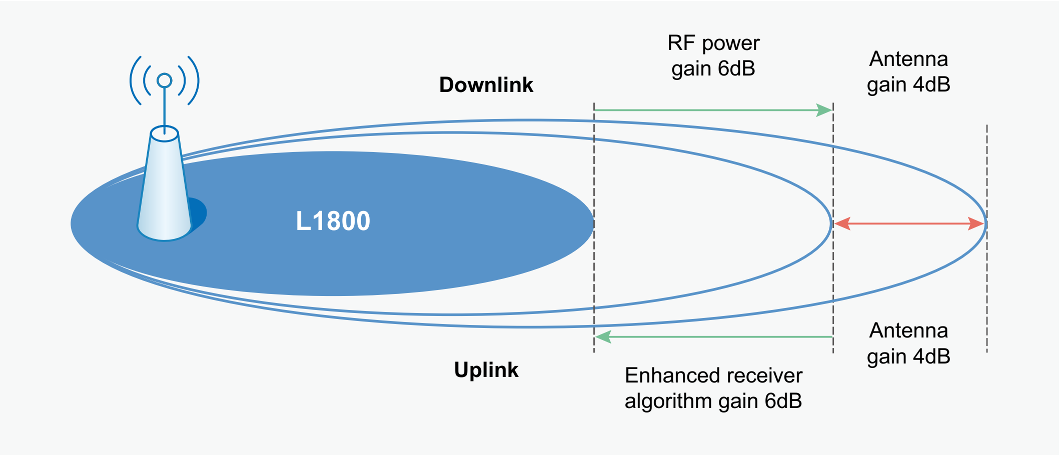


Figure 7 Enhancements of L1800M coverage

3.2. Capacity

User experience of operators' networks is declining gradually as the traffic increases year by year. To achieve the zero wait experience goal, network capacity improvement is the first choice. The technologies for capacity improvement during the LTE evolution include multiple antennas, multiple sectors, and multiple carriers.

3.2.1. Multi-Antenna Technology

4-antenna technology has been introduced since the initial stage of LTE development. 4x4 MIMO supports simultaneous transmission of up to four data streams, almost doubling the peak rate of 2x2 MIMO. Base on the field test result in following figure, we can see that, DL 4x4 MIMO can enjoy nearly 80% gain at all RSRP scenarios.

Even if UEs have only two antennas, which means only a maximum of two data streams can be transferred to this UE, 4x2 MIMO can still achieve a much higher average throughput than 2x2 MIMO. This is because a 4-antenna eNodeB obtains more accurate channel measurement results and feedback, and produces more spatial diversity gains.

Impressed by the capacity gain and experience gain, there are already around 180 4T4R networks deployed globally up to now.

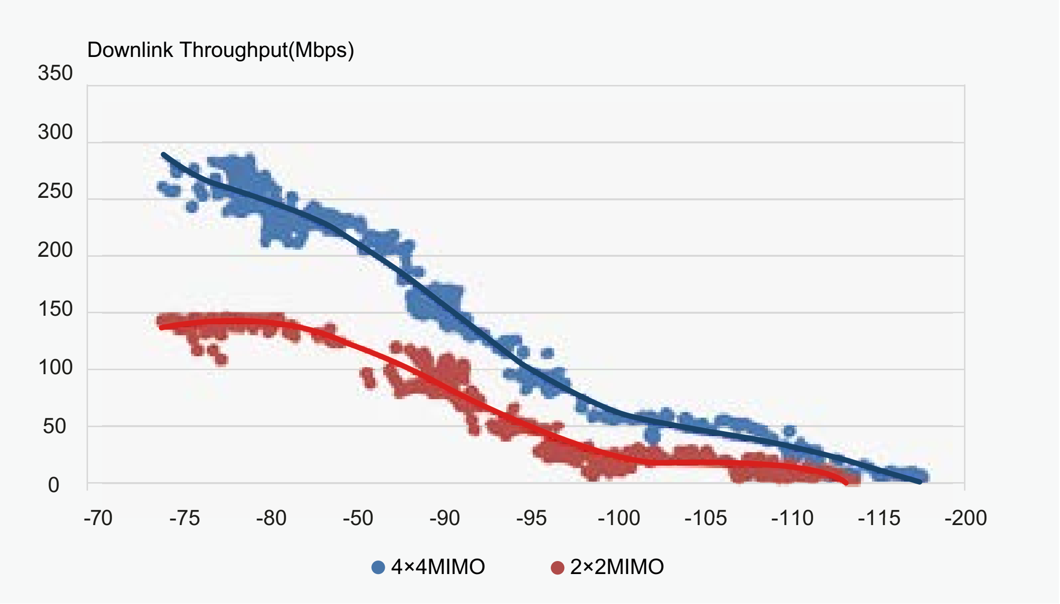


Figure 8 Enhancements of spectral efficiency of FDD MIMO

In TDD, 8T8R gradually becomes the mainstream deployment mode for 4G and a basic configuration for 5G. Since 2011, 8T8R has been used as a mandatory requirement of LTE TDD network construction in China.

As the unlimited data plan becomes more and more globally popular, higher order of MIMO solutions, e.g., Massive MIMO, are deployed to boost the cell average and edge performance.

FDD massive MIMO uses the beamforming technology to split one massive MIMO cell into multiple 4T4R cells. The AI technology is adopted to adaptively adjust the beams based on UE distribution. This balances traffic between different beams and maximizes the air interface resource multiplexing gains. With traditional TM4 UEs, FDD massive MIMO provides approximately three-fold capacity gains. As the penetration rate of TM9 UEs increases, the eNodeB can adopt the sector split solution of FDD massive MIMO for TM4 UEs and dynamic beamforming for TM9 UEs to further increase the capacity gains of FDD massive MIMO and the experienced data rate of TM9 UEs.

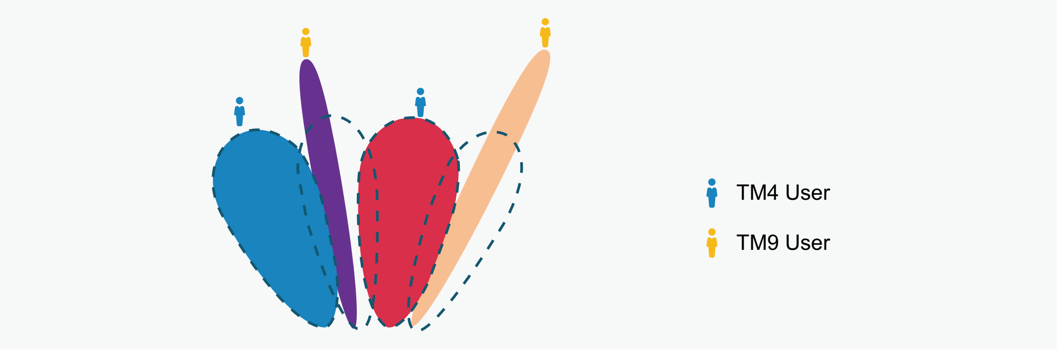


Figure 9 TM4 and TM9 hybrid transmission

In 2018, FDD massive MIMO started to be commercial deployed and helped operators build an ultimate capacity layer. In Thailand, 3.7-fold capacity gain is achieved in contrast to previous 4T4R cells in the heavy traffic areas of Bangkok.

For TDD massive MIMO, the channel state information can be obtained thanks to the reciprocity of wireless channels between downlink and uplink transmissions. Therefore, dynamic beamforming can directly be applied to existing UEs to enable MU-MIMO in TDD massive MIMO, providing 3-5 times of capacity gains. The AI technology is introduced to allow the dynamic selection of an optimal coverage parameter combination from nearly 300 options in different UE distribution scenarios.

Meanwhile, Protocols related to TDD massive MIMO also continue to evolve，In LTE Rel-13~Rel-16, SRS capacity and coverage enhancement, such as the introduction of more than one SRS OFDM symbols, rather than the last symbol of a normal and special sub-frame, were specified, which could provide at most 6 times capacity improvement for the typical TDD Configuration 2 compared to Rel-12. In addition, the code multiplexing comb=4, SRS antenna switching for 1T4R and 2T4R were also introduced to further enhance the SRS performance, and therefore improve the higher spectral efficiency for TDD massive MIMO significantly.

TDD Massive MIMO has always been welcomed since 2016. About 40,000 massive MIMO modules have been commercially deployed in over 50 LTE networks, including the heavy-traffic countries and areas like China, Japan, Philippines, West Europe, and India. More than 5 times of gain have been observed in some of the busiest cells, such as in stadiums.

3.2.2. Multi-Sector Technology

With the multi-sector technology, traditional three sectors of an eNodeB are split into six sectors to increase the available RB resource. This technology has been recognized as a key capacity expansion approach by global operators. Normally the capacity of a single eNodeB can be increased by 50%-70% without additional spectrum resources required.

There are two types of splitting: hard splitting and soft splitting.

Hard splitting uses multi-beam antennas. Within each antenna, the Butler matrix is used to map the RRU channels to beams. Some channels are mapped to the left beam, and the other channels are mapped to the right beam. In this way, the original cell is split into two independent cells.

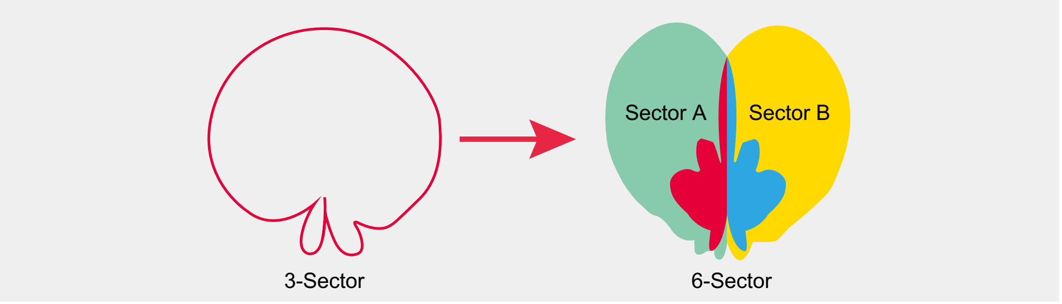


Figure 10 From 3-sector to multi-sector

Unlike using the Butler matrix in hard splitting, soft splitting uses flexible baseband weighting to implement beam mapping. Spatial multiplexing can be achieved by beam mapping without adding any hardware. In addition, joint scheduling between multiple beams and scenario-specific flexible beam combinations can further improve the spatial multiplexing efficiency.

The multi-sector technology has become one of the major solutions for operators with insufficient spectrum resources in densely populated areas. Currently, the sector splitting solution has been deployed for more than 60 networks in the world. In Thailand, operator deployed FDD 4T4R + 6 sectors (4T6S) solution in Bangkok dense urban area to achieve 90% capacity gain. In Jordan, operators deployed soft-split six-sector 8T8R TDD eNodeBs in the central urban areas, increasing the downlink traffic by 94%.

3.2.3. Multi-Carrier

3GPP defines a broad spectrum range for LTE: from sub-1 GHz to 6 GHz. Operators can improve network capacity by accelerating spectrum refarming and utilizing idle spectrums.

In TDD, there are still a large number of contiguous large-bandwidth spectrums available. For example, the 2.6 GHz TDD band of some operators in Europe has not yet been monetized. The licenses for the 2.3 and 2.6 GHz bands have not been granted in many countries in Asia Pacific and Africa. In addition, the 3.5 GHz band (C-Band) that some operators have acquired can be used for TDD LTE deployment to meet the current traffic growth demand before the 5G ecosystem is mature.

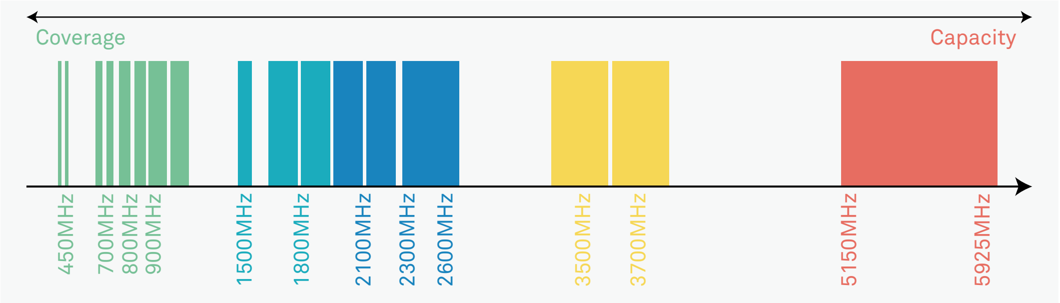


Figure 11 E-UTRAN operation bands

The number of unlicensed spectrums that have been assigned or currently planned to be assigned is comparable to or even more than the number of licensed spectrums. Licensed assisted access (LAA) is introduced with tight coordination with licensed LTE systems. Carrier aggregation (CA) mechanisms can be used, where the LAA carriers are operated as secondary cells (SCells) associated to and controlled by the existing licensed LTE primary cell (PCell). In this way, joint operation and flexible offload between licensed and unlicensed cells can be easily achieved, as shown in Figure 13.

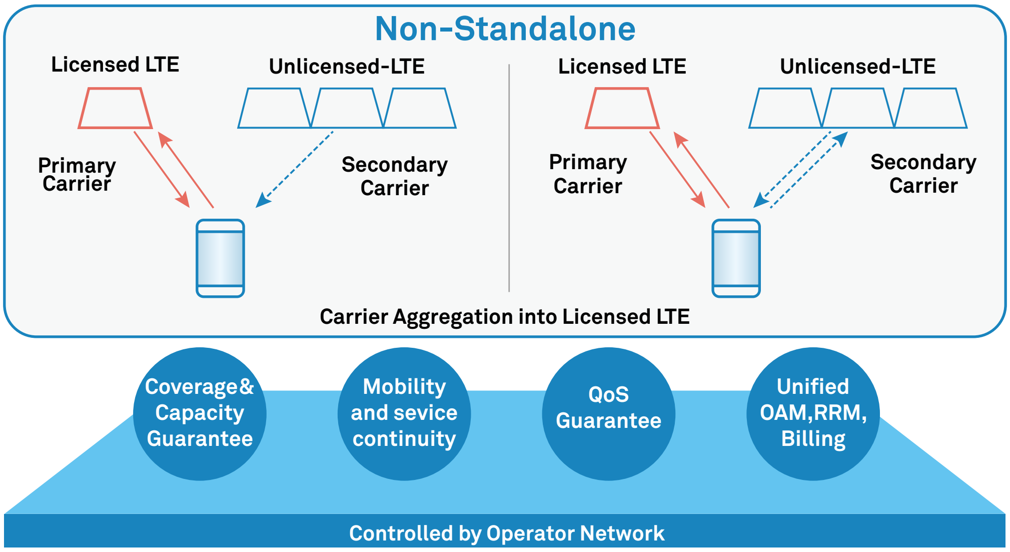


Figure 12 Illustration of licensed assisted access

In terms of the possible operating modes for the LAA SCell, the unlicensed spectrum can be operated as a DL-only cell or a DL+UL cell, regardless of the operating mode of PCell in the licensed spectrum.

3.3. User Experience

There are two ways to deliver a zero wait user experience. One is to increase the UE throughput to allow service data to be downloaded within a short time. The other is to reduce the round trip time (RTT) to shorten the interaction and response time between the UEs and the application servers. In LTE evolution, the technologies used for throughput improvement include CA and large-bandwidth technologies. The technology used for RTT reduction is short TTI.

3.3.1. Carrier Aggregation

CA has become one of the widely used LTE features for boosting data rates as larger amount of bandwidth can be utilized to increase the throughput of a UE. LTE has supported up to 32 aggregated carriers since 3GPP R13.

With the successful deployment of LTE networks, some challenges concerning the efficient use of E-UTRAN CA have emerged in the networks. The current CA framework can be further optimized to reduce the delay of SCell configuration and activation in order to improve the efficiency of radio resources. For instance, as the network needs to make sure that the UE has completed the activation and starts to schedule the UE only after receiving the valid CSI report, there is a non-negligible maximum delay about 34ms after eNodeB send activation message to UE. In this case, it is possible that the data available for transmission is already served by the PCell before a SCell is activated. To achieve fast SCell configuration and activation and reduce terminal power consumption, the following solutions are under development in R15:

- Enable UEs in idle mode to perform measurements so that SCells can be configured directly in connected mode. The eNodeB may instruct UEs in idle mode to perform measurements, the results of which can be used for fast configuration and activation of SCells when the UEs enter connected mode. If all optimizations have been introduced, the duration required for SCell configuration and activation can be reduced to a minimum of 95 ms.
- Introduce a new dormant state of SCells to activate SCells rapidly. During this new SCell state, a UE only performs CSI report without monitor the PDCCH of the SCell. Compare with legacy mechanism, SCell activation delay can be reduced from 34ms to 8ms.

3.3.2. Large-Bandwidth Technology

Large bandwidth is one of the key technologies of 5G NR. The large-bandwidth technology reduces the guard band and increases scheduling efficiency, improving user experience.

LTE can also use large-bandwidth technologies, including super horizontal band and super vertical band.

The super horizontal band leverages the orthogonality of subcarriers and uses the interference compensation and noise cancellation technologies to utilize the LTE guard band spectrum without increase any additional interference. This enables operators to have more available spectrums and increases the network capacity by 5%–8%.

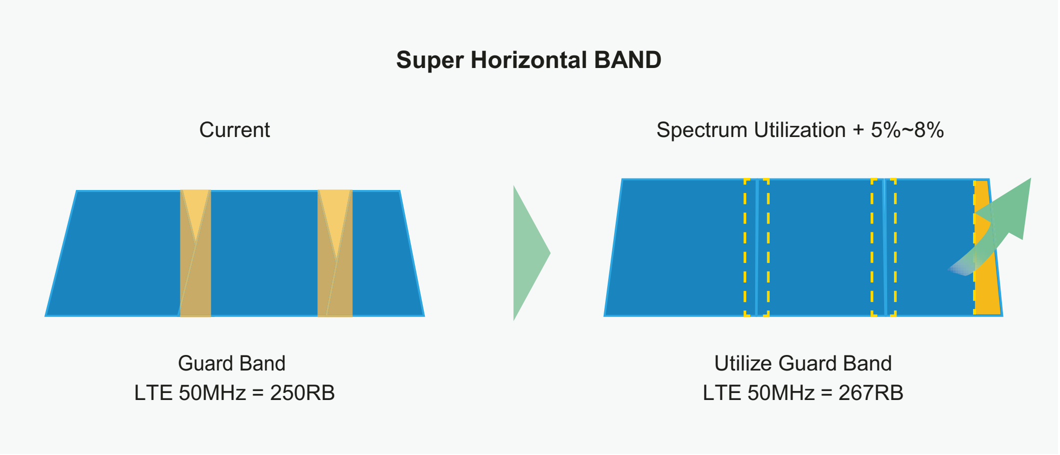


Figure 13 Super horizontal band

With the super vertical band, the artificial intelligence (AI) virtual grid technology is used to construct an inter-frequency information library. UE-level inter-frequency information and spectral efficiency can be predicted to perform rapid and accurate carrier selection. Secondary component carriers (SCCs) can be intelligently pre-scheduled based on the packet prediction model, and scheduling can be rapidly performed following an optimal scheduling path on the entire frequency. In this way, the effect of small-bandwidth multi-carrier scheduling is similar to that of large-bandwidth single-carrier scheduling. The CA activation rate increases, and the user experienced data rate improves by 20%–30%.

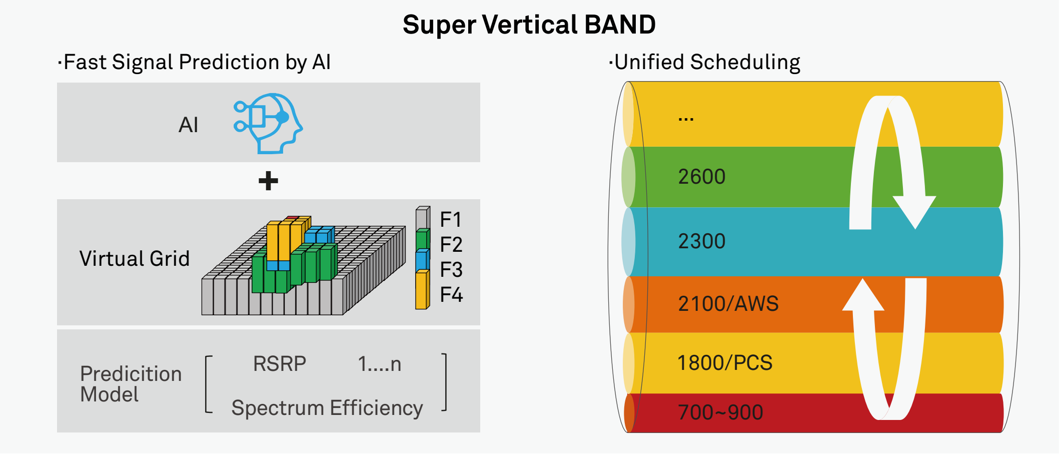


Figure 14 Super vertical band

3.3.3. Short TTI

Latency reduction improves user experience by significantly cutting down the response time. When responsiveness is ensured, real-time services become possible for commercial applications. Reduction in latency further facilitates automation and intelligence. For example, the precise control of a drone requires no more than a 20 ms end-to-end latency. Low latency opens the door for to large-scale commercialization of real-time mobile applications.

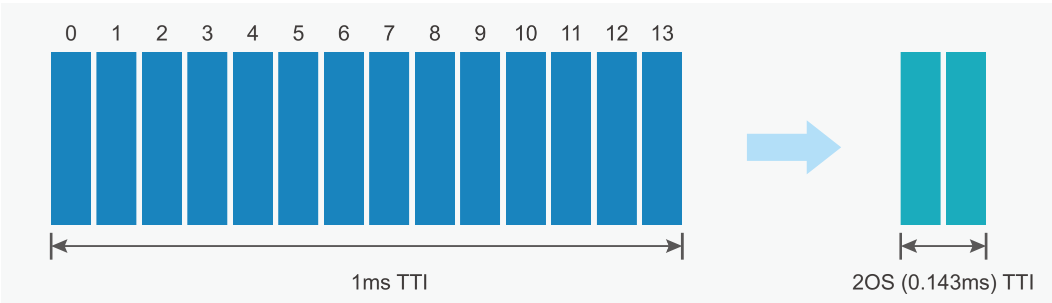


Figure 15 Illustration of a short TTI compared with a normal TTI

One important way to reduce air interface latency is to reduce the TTI length. This feature is named "short TTI". For example, 1 ms TTI (14 OFDM Symbols) of LTE can be divided into 0.143 ms (2 OFDM symbols). With 2-OS short TTI, the User Plane (UP) latency is reduced from 4.8 ms to about 0.8 ms. The RTT decreases from 8 ms to 2 ms.

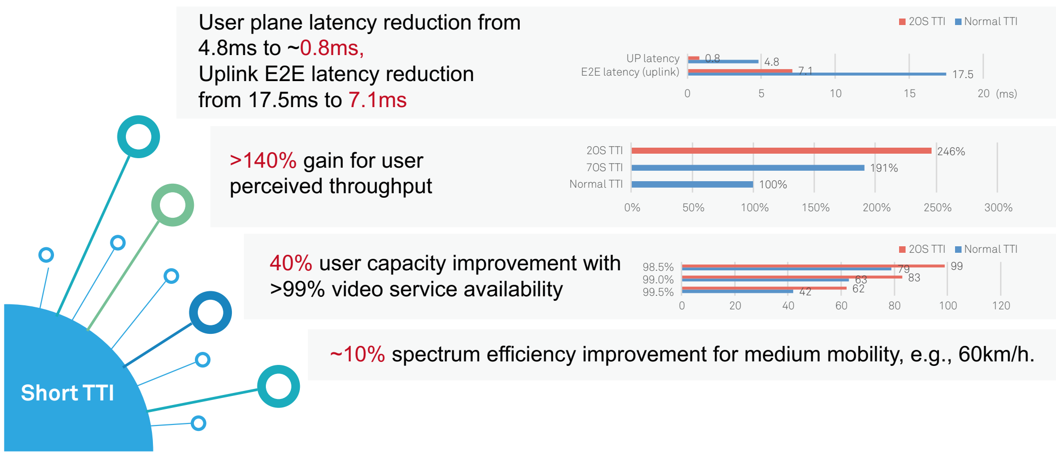


Figure 16 Performance gain analysis of short TTI

Short TTI not only reduces the latency, but also significantly increases the user perceived throughput for TCP-based traffic. The end-to-end TCP throughput is latency sensitive during the TCP slow start period. Low latency means quick data transmission and quick TCP-ACK feedback, which accelerates the increase of TCP window and improves the end-to-end TCP throughput.

In addition to gain in latency and TCP throughput, short TTI provides a lower outage ratio for some real-time services like video streaming. In this case, 2-OS short TTI supports 40% more UEs than 1-ms TTI with the same packet outage. Furthermore, short TTI enables fast CSI measurement and feedback to better track channel fading and interference fluctuation, which further increases the spectral efficiency. Short TTI also provides other benefits. For example, VoLTE capacity can be increased due to the finer transmission granularity.

3.4. Interworking with NR/NG Core

As shown in Figure 18, several network architecture options of the migration path were proposed during 5G study item in order to enable a smooth evolution towards 5G.

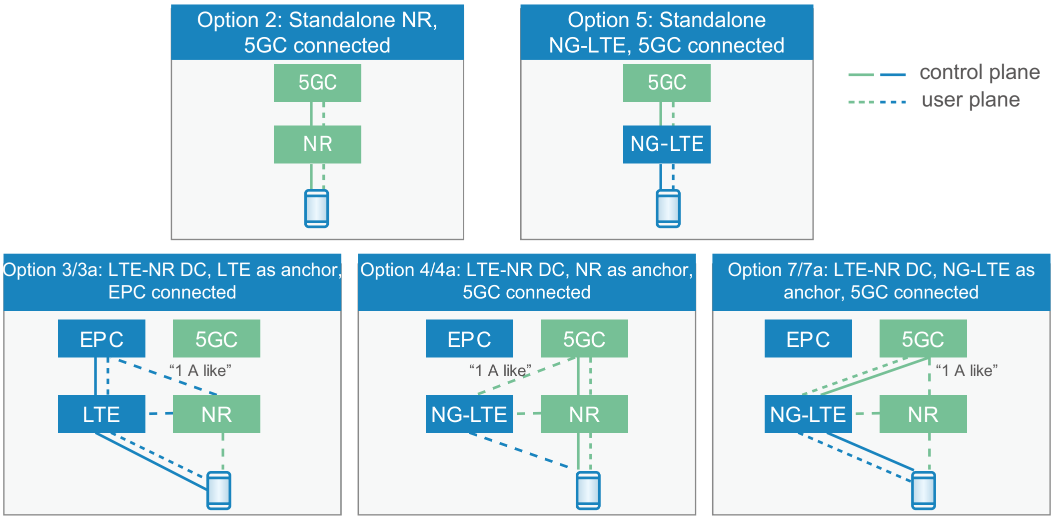


Figure 17 Illustration of 5G network architecture options

These options can be categorized as follows:

- Standalone NR connected to 5G new core (Option 2, no LTE involved)
- Standalone LTE connectivity to 5G new core (Option 5)
- LTE-NR DC (Options 3/4/7)
  - Option 3 series: LTE as an anchor (EN-DC)
  - Option 4 series: NR as an anchor (NE-DC)
  - Option 7 series: NG-LTE as an anchor (NG EN-DC)

In R15, Option 3 was standardized at the end of 2017, Option 2/5 was standardized by June 2018, and Options 7/4 are planned to be finished before March 2019.

3.4.1. LTE-NR DC

Considering operators' huge investment in LTE deployments, tight interworking between LTE and NR (i.e. E-UTRAN/NR DC) attracts lots of attention from operators and vendors. In 3GPP standard work Option3 series (i.e., EN-DC), LTE tight interworking with non-standalone NR under EPC, has been given a high priority in R15. Based on EN-DC, the existing EPC can be used to provide wide coverage, and the NR can be used to provide high throughput wherever it is available at the initial stage. In EN-DC, the LTE eNodeB connecting to the EPC acts as the master node and the NR gNodeB (i.e., en- gNB) acts as a secondary node (SN). The overall EN-DC architecture is illustrated in Figure 18.

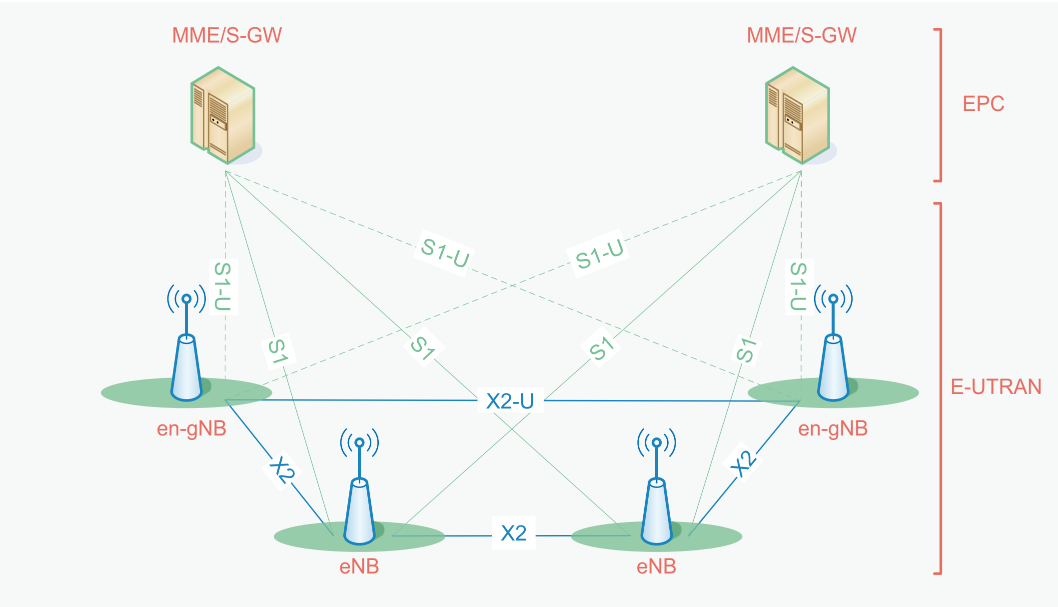


Figure 18 Overall architecture of EN-DC

With EN-DC operation, the en-gNB is able to establish a user plane connection with the LTE eNodeB and/or S-GW to provide NR AI (Air Interface) service to EN-DC-capable UEs under the control of the LTE eNodeB. Taking maximum benefit from the wide coverage of LTE and high throughput of NR, EN-DC is regarded as an efficient solution to improving user experience on both high data rate and high reliability.

3.4.2. LTE Connectivity to 5G New Core

During the evolution towards 5G, from operators' perspective, it is desirable to leverage the existing LTE coverage to provide continuous coverage nationwide, since the deployment of NR will gradually increase. By enabling Option 5, i.e. connecting LTE to 5GC, LTE coverage could be utilized to provide LTE UEs with new 5GC functions such as network slicing, QoS-flow based QoS framework, and 5GC security framework. On top of that, LTE connectivity to 5GC also enables tight interworking between NR and LTE under 5GC, as in Option 7 and Option 4, in order to leverage NR radio resources to boost the UE data rate.

The E-UTRA connected to the 5GC is supported as part of NG-RAN as shown in Figure 19, where the term "ng- eNB" refers to an LTE eNodeB connected to the 5GC, and the term "gNB" refers to an NR base station. The difference between the architecture of NG-RAN shown in Figure 19 and that of EN-DC shown in Figure 18 is that NG-RAN nodes (e.g gNB and ng-eNB) have complete NG interfaces including control plane and user plane connected to the 5GC, while EN-DC nodes (e.g. eNB and en-gNB) are connected to the EPC, and en-gNB functioning as an SN may only have the user plane of S1 interface.

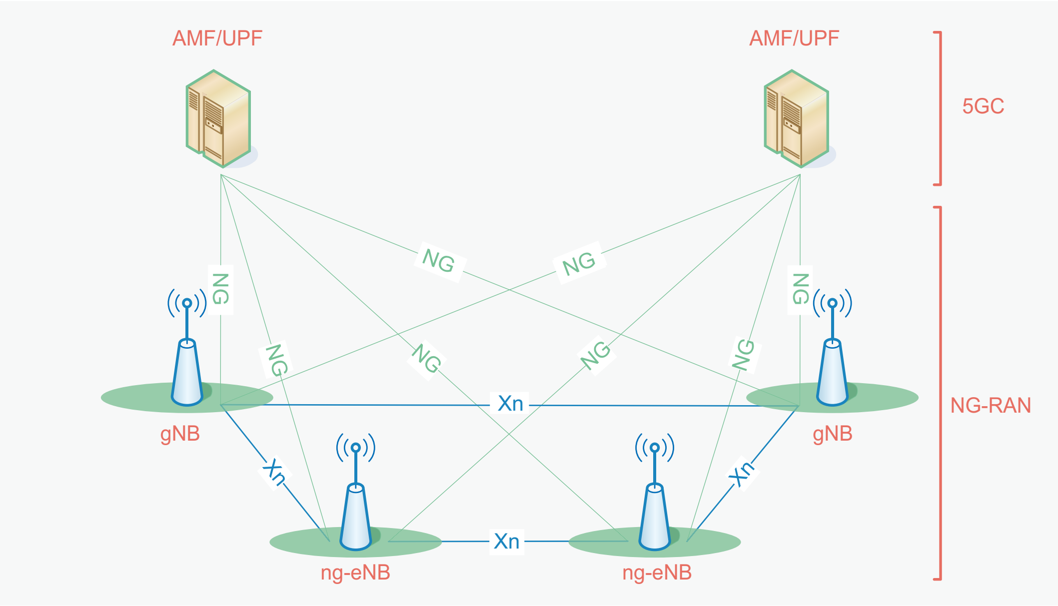


Figure 19 Overall architecture of NG-RAN

3.5. Site Evolution

5G commercial deployment is a foreseeable future. To save investment and shorten the time to market (TTM) of 5G, sites need to be ready in terms of antenna evolution capability, RF module simplification, and spectrum evolution capability.

3.5.1. 1+1 Antenna

The introduction of the 5G massive MIMO makes the space on the tower even scarcer, especially the space on poles. It is recommended that antennas of multiple RATs and bands be integrated to make room for future 5G deployment.

Generally, one sector is recommended to be configured with two antennas. One is a 5G massive MIMO antenna. The other is a Frequency Band below 3GHz (Sub3G) full-band passive antenna, supporting all frequency bands below 3 GHz, including LTE FDD 4T4R and TDD 8T8R. For six-sector sites operating on high bands, integrated antennas serving three sectors on low bands (700-900 MHz) and six sectors on high bands (1.8-2.6 GHz) can be used to incorporate all Sub3G passive ports.

For sites where LTE massive MIMO has been deployed that occupy one pole, the massive MIMO A+P module can be used to deploy C-Band NR massive MIMO and Sub3G passive antennas on another pole.

3.5.2. Wideband RF Module

Likewise, the increasing number of RF modules causes site space shortage and high lease costs. RF module reduction can make room for 5G deployment and reduce the operational expenditure (OPEX) of multi-network operation in the future.

Generally, a low-frequency wideband RF module can be used to simultaneously serve 2T4R cells on the bands of 700, 800, and 900 MHz. This reduces the number of RF modules, feeders, and couplers on the sites. The RF module used for L800 deployment and LTE deployment on the refarmed GSM 900 MHz band can also be used for NR700M deployment in the future.

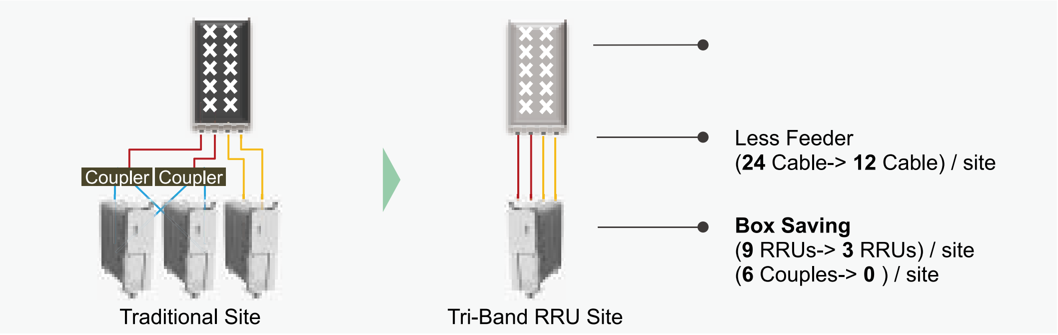


Figure 20 Overall architecture of NG-RAN

Similarly, a wideband RF module can be used to simultaneously serve 4T4R cells on the FDD bands of 1800 and 2100 MHz, or TDD bands of 2300 and 2600 MHz. This saves the number of boxes on the sites and improves the investment efficiency of the IF 4T4R.

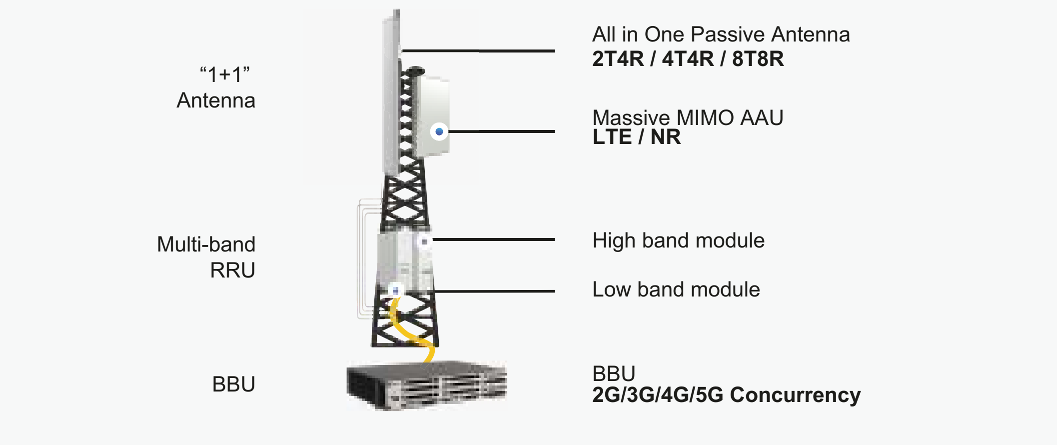


Figure 21 Overall architecture of NG-RAN

3.5.3. Hardware Ready for NR

The C-Band and TDD 2.6 GHz will be among the first batch of frequency bands for 5G NR deployment. However, in the early stage, some operators would consider deploying LTE on these bands to alleviate the capacity pressure of LTE networks. When 5G NR traffic increases in the future, these spectrums can be gradually refarmed to NR to offload NR traffic. In the long run, the FDD Sub3G band will also be gradually adjusted to serve NR, providing better coverage and capacity for 5G. Therefore, the LTE hardware modules, especially RF modules, should be capable of evolution to NR. This not only protects operators' investment, but also mitigates the engineering difficulty in NR deployment caused by on-tower hardware replacement.

Moreover, dynamic spectrum sharing between LTE and NR on the same module is also important. The spectrum resources allocated to LTE and NR can be dynamically adjusted based on their respective load. This increases the spectrum efficiency and achieves the smooth evolution to NR.

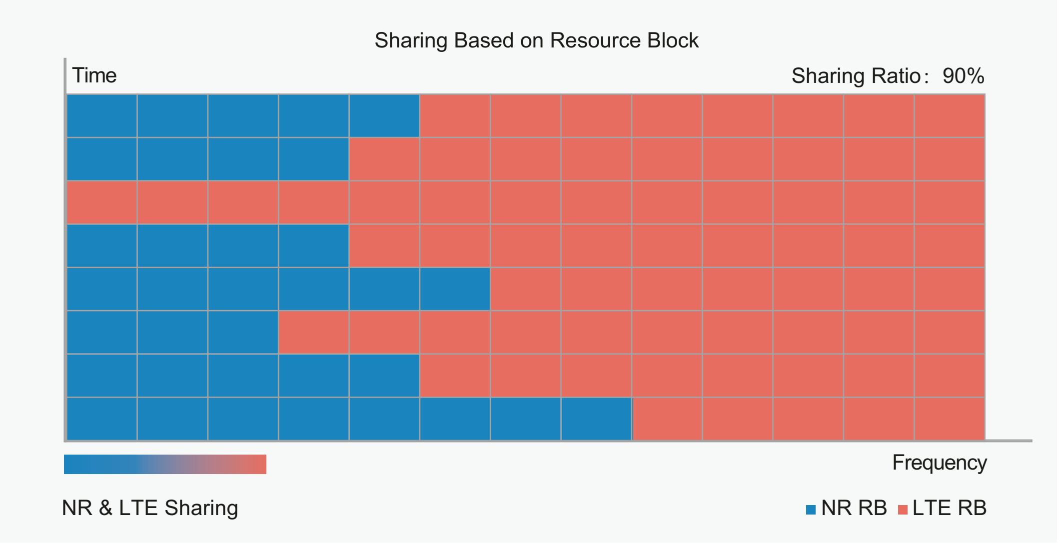


Figure 22 Sharing based on resource blocks

3.6. Business

At present, digital transformation is accelerating in traditional industries. All industries use communications technologies to carry out informatization and intelligent reform. To make the most of their networks and obtain new growth opportunities from the industry market, global leading operators are seizing this historical opportunity to transform from serving people-to-people communications to serving industry communications. LTE evolution enables the network to carry all ranges of services, meeting the connection requirements in Internet of Things (IoT), home broadband, vehicles, and other fields.

3.6.1. C-IoT

Since R13, vibrant, complementary Cellular IoT technologies of NB-IoT and LTE-M have been introduced to LTE to enable low-complexity and low-cost IoT devices (known as Cat-NB and Cat-M). They are competent for diverse IoT use cases and services, including the rapidly growing Low Power Wide Access (LPWA), which requires extended coverage, massive connectivity, and low UE power consumption. NB-IoT is targeting for a low data rate (about 100 kbps) while LTE-M has the capability for a medium data rate (Mbps level). Both technologies have their own application scenarios. The minimum bandwidth for deployment is 180 kHz for NB-IoT and 1.4 MHz for LTE-M.

Since its birth, C-IoT has received extensive attention from the industry. Currently, 67 NB-IoT networks have been put into commercial use, 25 LTE-M networks have been deployed, and more than 1 million sites have activated with NB-IoT or LTE-M.

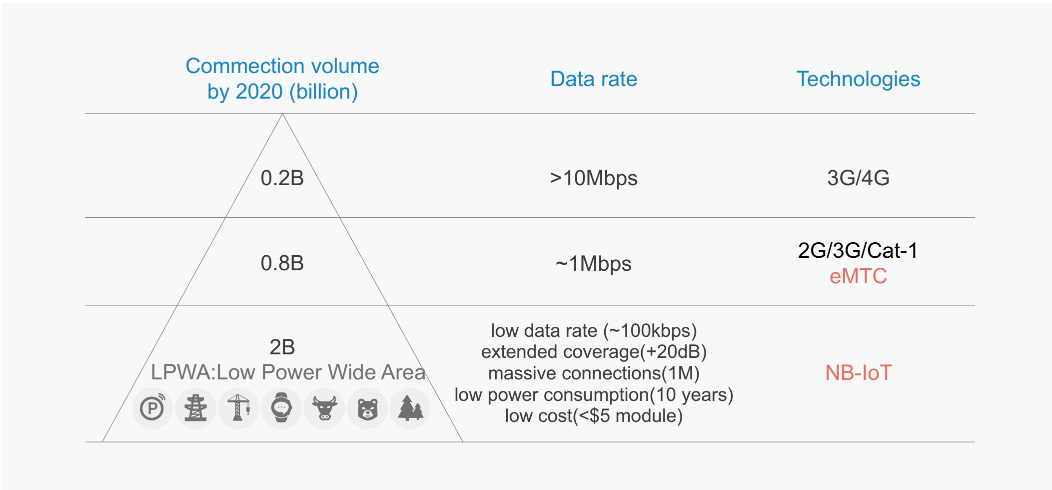


Figure 23 IoT markets and technologies

As IoT devices usually have a long lifecycle (many years after installation), the evolution of NB-IoT/LTE-M mainly focuses on two aspects without affecting the hardware:

- Enhancement of performance and functionality: e.g. positioning, multi-cast, further UE power saving, further latency reduction, TDD etc.
- Support for coexistence with 5G new radio and connectivity to 5G new core

Both NB-IoT and LTE-M support positioning and efficient OTA firmware update via multi-cast in R14. In R15, wake-up signal for paging is introduced to notify a UE whether there are paging messages in the subsequent paging occasions. It saves power for UEs that camp on the cell but are rarely paged. Also, early data transmission on the RACH enables UEs to complete data transmission in idle mode without setting up RRC connections for small data packets. This helps reduce the signaling overhead, latency, and UE power consumption.

Except for NB-IoT and LTE-M there is no new technology defined for 5G LPWA use cases. Moreover, NB-IoT and LTE-M can well coexist with 5G new radio. They also support connectivity to the 5G new core in R16. As part of 5G, they fulfill the mMTC requirements posed by low data rate services for low power consumption, wide area coverage, and massive connectivity. The ecosystem of NB-IoT/LTE-M is ready. It is expected that LTE cellular IoT will continue taking 5G IoT forward to the next stage.

3.6.2. WTTx

WTTx is an advanced wireless broadband access solution, which utilizes wireless technologies to tackle the last-mile problem. Such scenarios can benefit from a large-capacity wireless connection from a network node (e.g. LTE eNodeB) to a stationary intermediate device (which further communicates with end users via other links). The distinctive characteristics of such large-capacity wireless stationary links include much better channel conditions (e.g., more LoS and/or higher SNR), and no/low mobility. Note that the UEs in such scenarios are typically new types of devices (e.g. Customer-premises equipment) with less limitation on the cost, power, size, and processing capabilities. So it is feasible to introduce more advanced features to serve such large-capacity stationary wireless links and to enable more emerging applications.

WTTx has been considered as an essential way to improve national ICT index. Many countries such as France, Indonesia, and Sir Lanka have identified WTTx as an important technology for national broadband development. WTTx has been deployed by operators in some developed countries, such as Germany Vodafone, Japanese SoftBank, as well as by operators in many developing countries, such as South Africa Telkom, Sir Lanka Dialog, Philippine Globe, Peru Entel and so on. By the end of 2018, around 75 million households in total have been connected by WTTx.

To further improve the spectral efficiency, 1024QAM can be configured on the PDSCH for DL-1024QAM-capable UEs. New TBS and new MCS table corresponding to 1024QAM have been specified. The peak data rate can increase by about 20%. The DMRS overhead for TM9/10 can be reduced by using OCC4 for DL SU-MIMO rank 3 or 4. The DMRS overhead is reduced by 50% and the spectral efficiency is improved. In addition, new technologies such as 8x8 MIMO and uplink 256QAM are being deployed in networks.

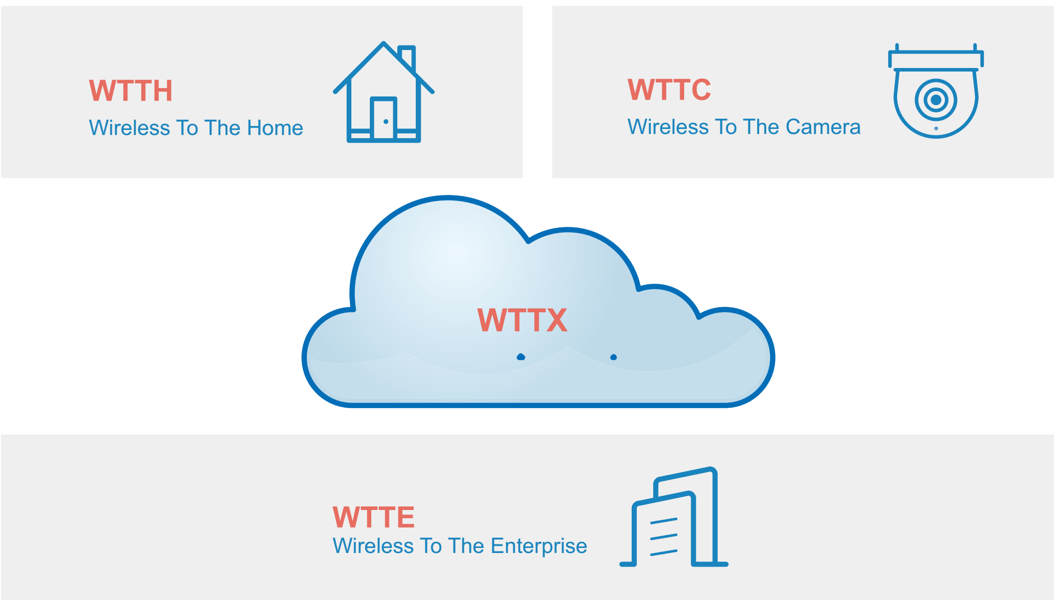


Figure 24 Scenarios of WTTx

3.6.3. LTE-V2X

The widely deployed LTE infrastructure network brings significant benefits to the deployment of Intelligent Transportation System (ITS) with various vehicles (e.g. automobiles, trains, drones, etc), which generally require ubiquitous coverage due to their movement nature. It is predicted that a rapid and vast growth in the ITS industry will bring new promising business opportunities for mobile network operators. In order to better support the ITS, specific enhancements on connected cars were developed by 3GPP.

The initial version of LTE-V2X standards was completed as part of R14, with the goal to support basic safety services (e.g. collision avoidance, traffic lights to vehicles, speed guidance, etc). LTE-V2X technology consists of the PC5 interface (direct link between vehicles, to support V2V/P/I) and Uu interface (via network, to support V2N/I). For V2X communications over the PC5 interface, additional DMRS symbols were added to handle high Doppler associated with speeds of up to 500 km/h and at high frequency (i.e. 5.9 GHz ITS spectrum). LTE-V2X enhanced the radio resource allocation mechanism to improve the system-level performance with a high vehicle density while meeting the stringent latency requirements of V2X. V2X communications over Uu interface can benefit from the highly reliable and low-latency Uu interface supported by LTE. If one V2X message needs to be delivered to multiple vehicles, the network can broadcast the V2X message by means of single-cell point-to-multipoint (SC-PTM) or eMBMS.

In R15, LTE-V2X continued the evolution with the goal to support more advanced V2X services (such as platooning, advanced driving, etc). R15 LTE-eV2X enhanced the performance of the PC5 interface with higher reliability (by means of transmit diversity), lower latency (by means of resource selection window reduction) and higher data rate (by means of carrier aggregation and 64QAM), while maintaining the backward compatibility with R14 LTE-V2X. It should be noted that NR-V2X to be specified in future releases will complement LTE-V2X for advanced V2X services and support the coexistence and interworking with LTE-V2X.

The LTE-V2X industry becomes mature. 5.9 GHz becomes the direct link spectrum of China, Europe, the United States, and other countries. Japan also begins to consider 5.9 GHz. In 2018, Huawei released an LTE-V2X E2E solution, including Road Side Unit (RSU), T-Box, cloud platform, and network. In Wuxi China, the world's largest LTE-V2X trial project has been deployed, spanning 240 intersections, covering most of the areas of the city (around 170 km^2), and serving over 10,000 vehicles with C-V2X devices.

4. LTE Evolution Ecosystem

The industry ecosystem related to LTE evolution is booming. This indicates that even if the 5G era has come, the industry is still optimistic about the performance improvement and profit growth brought by LTE evolution. In the dimensions of zero fallback and zero wait, terminals are gradually becoming mature. In the evolution dimension, as related protocols have been frozen and 5G terminals are coming to the market, chip and terminal vendors are expected to release the roadmap for supporting the evolution features soon.

4.1.1. Low Cost Terminals

The smooth phase out of 2G and 3G depends on low cost LTE terminals, especially cheap VoLTE-capable phones. There are a large number of low-value subscribers on the 2G and 3G networks, especially in the emerging markets. These subscribers require only voice services or a small amount of data. The launch of low cost LTE terminals will help accelerate the migration of these subscribers to the 4G network.

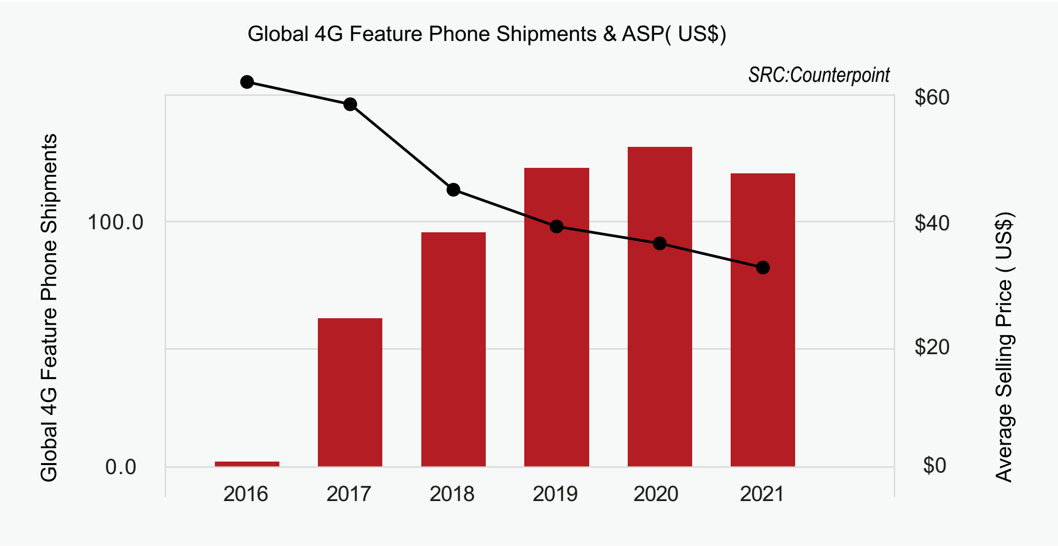


Figure 25 Global 4G feature phone shipments

According to the Counterpoint report, the average price of 4G feature phones in 2017 has been reduced to 50 USD, and is expected to decrease to 25 USD by 2021. In fact, the Indian market has already seen a VoLTE mobile phone worth of only 18.7 USD (1330 Rs).

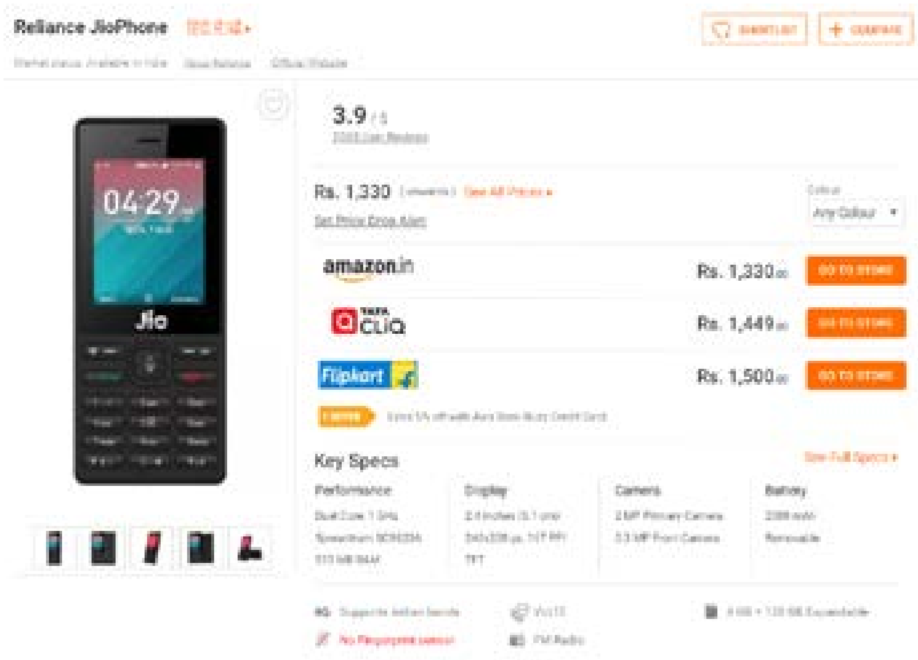


Figure 26 Affordable 4G feature phone in India market

IoT terminals have a long life cycle. As 2G networks will be shut down in the future, it is recommended that new IoT connections be provided on 4G NB-IoT networks. Now is the time for large-scale NB-IoT deployment. There are 14 chip vendors and more than 100 module vendors. Thanks to the large-scale procurement in the China market, the price of NB-IoT modules has dropped to 3.3 USD, the same price as that of GSM modules.

4.1.2. 4Rx Phone

Since 2016, the world has witnessed the accelerated deployment of 4T4R networks. Mainstream operators use 4T4R as the basic LTE configuration. In a 4T4R network, mobile phones supporting four antennas can greatly improve the experienced data rate. 4Rx has become one of the main considerations when consumers purchase mobile phones. Mainstream terminal chip vendors worldwide have released chips that support 4x4 MIMO. Apple, Huawei, Samsung, Sony, and LG have launched high-end smartphones supporting 4Rx. In recent years, Qualcomm's mid-range smartphone chips also started to support 4Rx. Different Chinese brands of mid-range 4Rx smart phones less than 3000 RMB have hit the market. 4Rx smartphones are quickly becoming affordable to the public. GSA statistics showed that more than 30 mobile phone models are capable of 4x4 MIMO 4Rx.

4.1.3. TM9

From standard point of view, TM9 is already defined as a mandatory feature that Cat-11 and above UEs need to support from Rel-15.

After several years of development, the TM9 industry has matured. Mainstream chip vendors, such as Qualcomm, HiSilicon, and MediaTek, have released TM9-capable smartphone chips. Currently, there are more than 20 models of smartphones equipped with TM9-capable chips. Subscribers can activate TM9 for their TM9-capable terminals by simply updating to the latest software released by terminal vendors. Since 2018, mainstream terminal vendors have activated TM9 by default. Currently, 15 new models from five mainstream terminal vendors have activated TM9 by default.

On the network side, operators have proactively carried out pilot TM9 commercial use, promoting the maturity of the TM9 terminal industry. Currently, 36 TM9 commercial networks have been deployed in 20 countries and regions, such as mainland China, Japan, Hong Kong, Thailand, Australia, Turkey, Kuwait, France, Russia, Canada, and South Africa. In North America, a number of operators are fully prepared and have specified the TM9 capability as a mandatory requirement for the procurement of terminals. This has helped to lay a foundation for massive MIMO deployment and LTE long-term evolution in the future ecosystem.

4.1.4. 8CC CA

8CC CA was introduced in 3GPP specifications R13. In R15, 8CC supports a peak throughput of over 3 Gbps. Currently, mainstream chip vendors have developed their 8CC CA chip roadmaps. The Exynos 9820 chip released by Samsung in November 2018 supports 8CC CA, providing a peak throughput of 2 Gbps. This chip will be used in Samsung Galaxy S10.

4.1.5. EVS

Enhanced voice services (EVS) is a new full-HD VoLTE codec. It was released by 3GPP in 2014. The EVS codec rate is 128 kbps (the common AMR-WB VoLTE codec rate is only 23.85 kbps). The voice definition is the same as that of a full-HD film. EVS has higher anti-jitter and anti-packet-loss capabilities. It ensures good voice quality in the case of cell edge and high-speed movement. In addition, under the same quality condition, the capacity of a network using EVS is twice or is even higher than that using a common voice codec.

According to GSA statistics, around 20 operators have enabled the EVS function on their LTE networks. Around 153 terminals have supported EVS, including mainstream terminal vendors such as Apple, Huawei, and Samsung.

4.1.6. sTTI

The short TTI technology was introduced in 3GPP R15, which was frozen in 2018 Q2. In November 2018, Huawei tested short TTI based on their commercial version at the global MBBF. The RTT over the air interface was as low as 2 ms. According to the roadmaps of mainstream chip vendors in the industry, terminal chips that support short TTI will be launched in 2020 Q3.

4.1.7. DC-Capable 5G Terminals

In option 3, 4, or 7 networks, UEs supporting dual connectivity (DC) can transmit data on both LTE and NR networks in the areas where the coverage overlaps. This enables a higher transmission rate and a shorter LTE-to-NR handover latency.

4.1.8. LTE UE to Access NG Core

After LTE terminals access the NG core, 5G slicing and flow-based QoS functions can be used on the LTE network to achieve service experience similar to that on 5G networks. If an LTE UE needs to access the NG core, it must support dual NAS protocol stacks of NG core and EPC.

4.1.9. 5G Terminal to Support LTE Evolution Features

The 5G terminal hardware has the capability of supporting LTE evolution features such as 4Rx, TM9, short TTI, and access to the NG core. If these features are activated in LTE mode, the LTE network capabilities can be maximized when 5G terminals leave the NR coverage area and fall back to the LTE network. In this way, the user experience gap between 5G and LTE can be reduced. The 5G AR, VR, CloudX, and other applications are easier to be used on the LTE network.

The popularization of a new technology requires the close collaboration among the terminals, networks, and chips. Only in this way, the value of the new technology can be maximized and a better user experience can be ensured. We call for open collaboration between industry terminal, chip, and network vendors to promote the E2E planning and activation of LTE evolution technologies and lay a foundation for the prosperity of the LTE evolution industry ecosystem.

5. Summary

In the upcoming decade, LTE networks will still be the major cash cow for operators. Traffic growth and full-service innovation will further push the enhancement of LTE network capabilities. LTE will become the main bearer of operators' mobile services.

With the advent of 5G, LTE enters a stage of connecting the old and new. The LTE in this new stage features zero fallback, zero wait, and evolution. The network capabilities will be reinforced to enable zero fallback and zero wait. LTE will gradually incorporate 2G and 3G, and become an all-business fundamental network. On the other hand, LTE will continue to evolve and develop to complement and co-exist with NR for a long period of time.

The standards, solutions, and ecosystems related to LTE evolution are ready. The LTE industry will embrace a golden decade.

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