LTE Standards Evolution towards an All Business Connected Primary Infrastructure

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Contents

Executive Summary

According to GSA report, 651 commercial LTE networks (LTE/LTE-Advanced/LTE-Advanced Pro) have been launched since the debut of LTE in 2009. It is a clear trend that LTE is becoming the primary mobile access technology in terms of number of deployed networks, number of subscriptions, variety of services and applicable spectrum. From Rel-15 and onwards, LTE standards are evolving to a next step aiming to further improve LTE capability towards an all business connected primary infrastructure. The improvement includes capability for ubiquitous user experience, capability for all business connection and capability for multiple Radio Access Technology (RAT) support and easy operation. This white paper presents an overview of technologies under development in Rel-15 and technologies considered for later releases.

List of Commonly Used Abbreviations

5GC	5G Core
5GS	5G System
AAU	Active Antenna Unit
BS	Base Station (or Basestation)
BW	Bandwidth
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CP	Control Plane
CPE	Customer-premises equipment
CQI	Channel Quality Indicator
CRS	Common Reference Signal
CSI	Channel State Information
CSI-RS	Channel State Information Reference Signal
CSMA	Carrier Sense Multiple Access
D2D	Device-to-Device
DL	Downlink
DMRS	Demodulation Reference Signal
E2E	End-to-End
eICIC	Enhanced Inter-Cell Interference Coordination
eMTC	Enhanced Machine Type Communications
EN-DC	E-UTRAN/NR Dual Connectivity
ESN	Emergency Services Network
E-UTRAN	Evolved Universal Terrestrial Access Network
FBB	Fixed Broadband
FDD	Frequency Division Duplex
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
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
LAA	Licensed Assisted Access
LPN	Low-Power Node
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-V	LTE-Vehicle
MBMS	Multimedia Broadcast Multicast Services
MDT	Minimization of Driving Test
MIMO	Multiple-Input Multiple-Output
MSA	Multi-Stream Aggregation
MTC	Machine Type Communications
MU-MIMO	Multi-User MIMO
NB-IoT	Narrowband Internet of Things
OFDMA	Orthogonal Frequency Division Multiple Access
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PoC	Proof of Concept
PRACH	Physical Random Access Channel
RAT	Radio Access Technology
RS	Reference Signal
SIB	System Information Block
SINR	Signal to Interference plus Noise Ratio
SRS	Sounding Reference Signal
TCO	Total Cost of Ownership
TDD	Time Division Duplex
TM	Transmission Mode
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
URLLC	Ultra-Reliable Low-Latency Communication
V2I	Vehicle-to-Infrastructure
V2X	Vehicle to Anything
VoLTE	Voice over LTE
WBB	Wireless Broadband

1. LTE, LTE-Advanced, LTE-Advanced Pro, and All Business Connected LTE

The introduction and increasing use of mobile devices (e.g., smart phones and tablets) and various mobile applications have dramatically changed the landscape of mobile communication systems and driven the development of cellular technologies from one generation to another, as shown in Figure 1. As the dominant 4G technology, LTE (Long Term Evolution), also known as E-UTRAN (Evolved Universal Terrestrial Access Network), 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, 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. In IMT-2020, in addition to enhanced mobile broadband (eMBB) type of use cases mainly for people-to-people communication, machine based use cases (including both people-to-machine and machine-to-machine communications) are becoming another key driver.

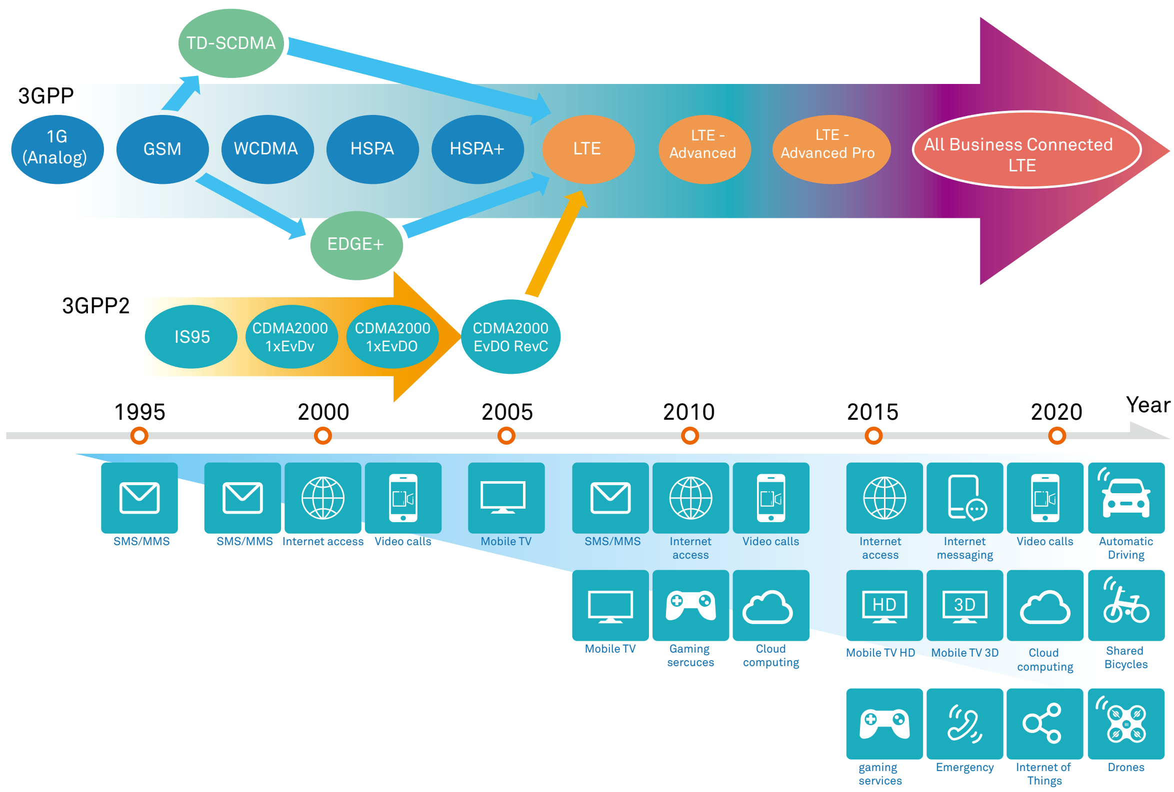

Figure 1 Timeline of cellular communications, including LTE and its further evolutions

In Figure 2, the key features of each major phase in LTE are presented, together with their design targets. Release 8 is the first and foundational release of LTE, where many fundamental features such as waveform, multiple access, modulation and coding schemes, and multi-antenna based transmission schemes are defined to meet the performance requirements. Further enhancements of LTE were introduced since Release 10 (a.k.a., LTE-Advanced), including CA (carrier aggregation), CoMP (coordinated multi-point), more advanced MIMO (multiple-input multiple-output) technologies and relay. The introduction of LTE-Advanced significantly improved the capability of LTE in order to fulfill all the requirements of IMT-Advanced and to be qualified as a 4G technology. It is worth mentioning that for LTE, backward compatibility is a very important design principle, which ensures that the introduction of new features has no negative impact on the legacy users and enables operators to smoothly upgrade their networks. In 2015, 3GPP approved a new LTE marker, i.e., LTE-Advanced Pro, which is used for the specifications of Releases 13 and 14. In Releases 13 and 14, the performance of MBB service was further improved through more advanced CA, MIMO and LAA (licensed assisted access) technologies. Furthermore, use cases and requirements of vertical services were taken into account. NB-IoT (narrowband internet of things) was introduced to enable the LPWA (low power wide area) machine type communications (MTC), and eMTC was introduced to improve the medium-to-high data rate applications. Other vertical services including Vehicle to Vehicle/ Vehicle to Anything (V2V/V2X) and enhanced MBMS (multimedia broadcast multicast services) were also supported.

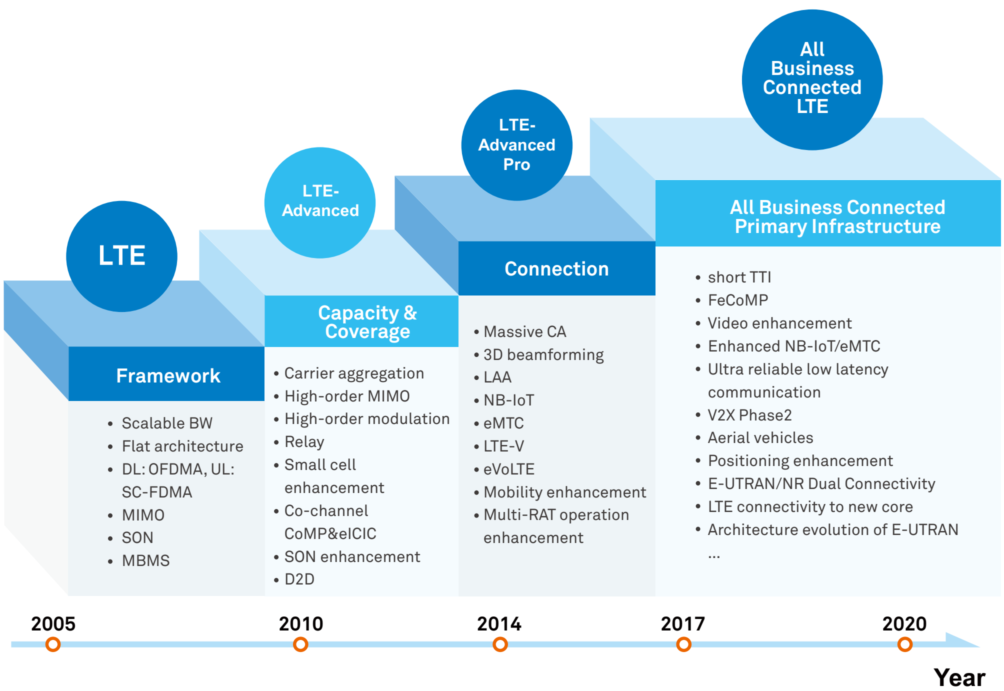

Figure 2 Key features of LTE and its evolution

Thanks to its technology advancement and well established ecosystem, LTE is the fastest developing mobile communications system technology ever. According to GSA report[1], there are 651 commercial LTE networks (LTE/LTE-Advanced/LTE-Advanced Pro) by January 2018. LTE subscriptions reached 2.43 billion globally by end of 2017Q3 and account for 32% of global mobile subscriptions as shown in GSMA intelligence database. It is expected that LTE will overtake GSM to be the most subscribed mobile technology in 2018. As shown in Figure 3, LTE supports a wide range of frequencies from sub-1GHz, e.g., 450MHz, to around 6GHz, e.g., 5.9GHz. The spectrum can be used for multiple services such as MBB, IoT, and vehicle communication services. The wide range of spectrum makes it quite flexible for operators to deploy LTE networks and launch new services quickly.

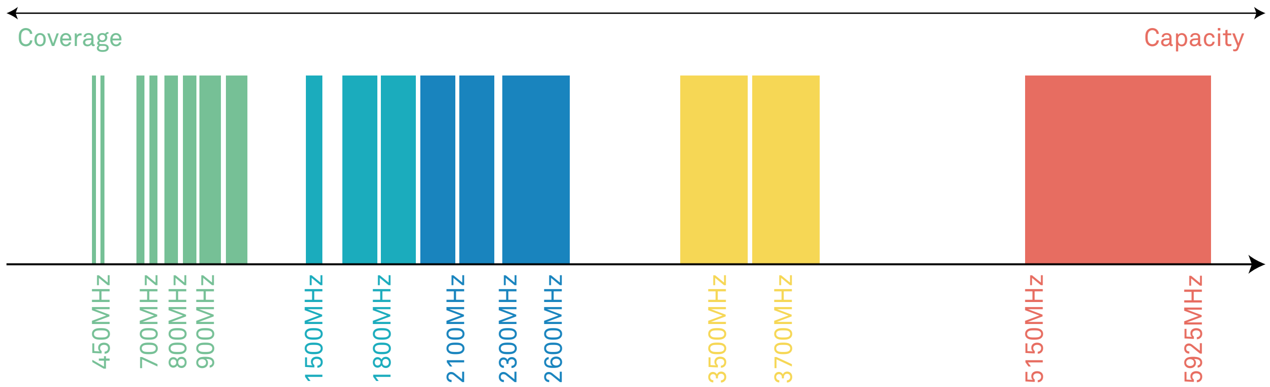

Figure 3 E-UTRA operating bands

It is a clear trend that LTE is becoming the primary mobile access technology in terms of number of deployed networks, number of subscriptions, variety of services, and applicable spectrum. From Rel-15 and onwards, LTE standard is evolving to a next step aiming to further improve the capability of LTE as an all business connected primary infrastructure as shown in Figure 4. To be more specific, on one hand, LTE standard is evolving to ensure ubiquitous user experience in terms of latency, coverage and throughput; on the hand LTE standard continues to develop to enable business expansion into vertical market, 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, e.g., E-UTRAN/NR Dual Connectivity (EN-DC) and to facilitate operation of the network by means of, e.g., enhancement in minimization of driving tests. In the following sections of this white paper, enabling technologies from different aspects will be provided.

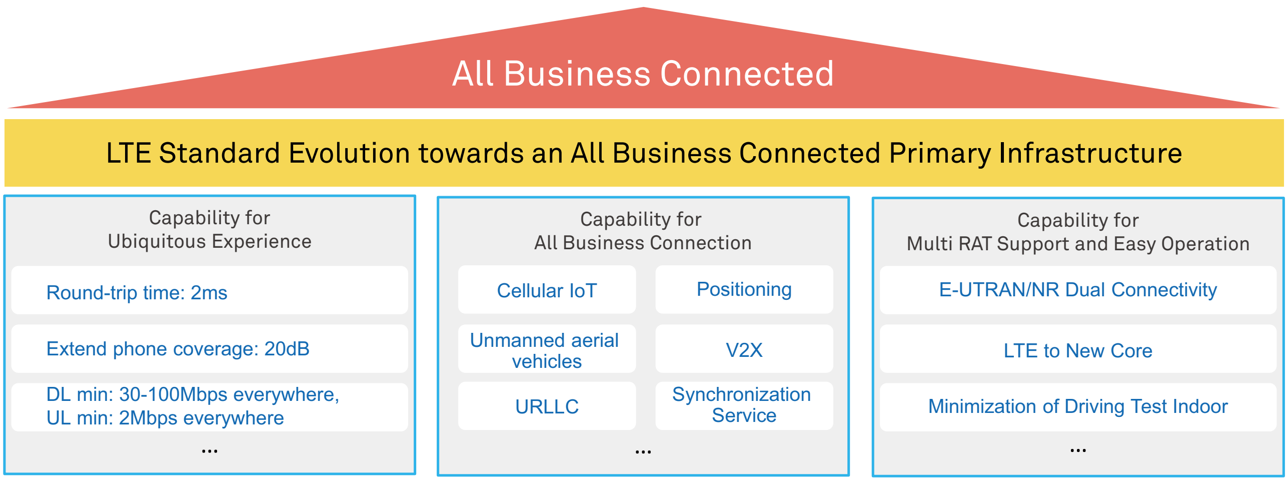

Figure 4 LTE as the primary infrastructure for an all business connected world

2. Capability for ubiquitous experience: always available, always satisfying

As the primary infrastructure of ICT to serve an all business connected society, LTE networks aim to provide good experience for the end users anywhere in the network. Considering the diverse applications and various deployment scenarios, satisfying user experience everywhere all the time becomes quite challenging. For example, voice and video have gradually become the basic services in LTE networks resulting in high requirements in terms of throughput, latency, jitter, and coverage. Other new services such as wireless broadband, Virtual Reality (VR) and Augmented Reality (AR), demand very high capacity to provide immersive experience.

LTE has specified various features to enable competitive solutions to provide outstanding quality of services. More specifically, short TTI will significantly reduce the E2E latency and then bring significant improvement of user data rate especially for small packets. Cell edge performance and coverage enhancements are important to help end users receive ubiquitous experience. MIMO as a powerful technology to boost the spectrum efficiency has been studied, specified, and further enhanced in LTE for several releases. The quality of video and voice is also an important topic in LTE with enhancements on both coverage and service continuity. In addition, the performance in specific environments or scenarios, e.g., in high speed trains, is also taken into account. The detailed technologies and their rationality, performance, and future work are presented as follows.

2.1 Short TTI

Latency reduction improves the 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 20ms end-to-end latency. Low latency opens the door for large scale commercialization of real-time mobile applications.

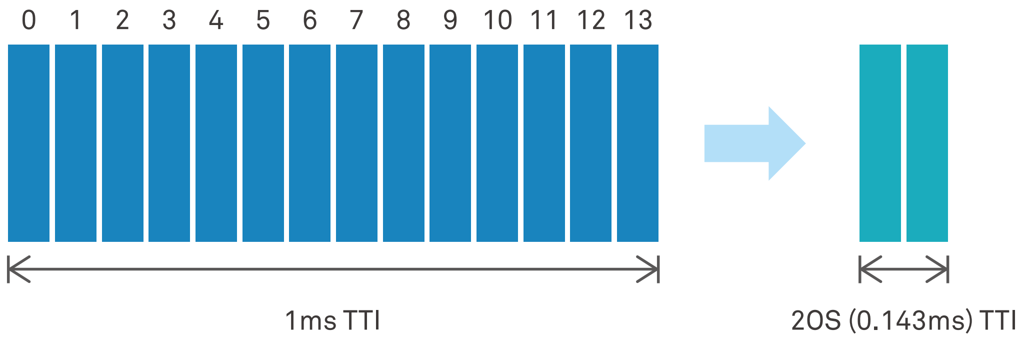

Figure 5 Illustration of short TTI compared with normal TTI

One important way to reduce air interface latency is to reduce the TTI length, named “short TTI”. For example, 1 ms TTI (14 OFDM Symbols) of LTE can be reduced to 0.143ms (2 OFDM Symbols). With 2OS short TTI, the User Plane (UP) latency is greatly reduced from 4.8ms to about 0.8ms. Round-trip time is greatly reduced from 8ms to 2ms.

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

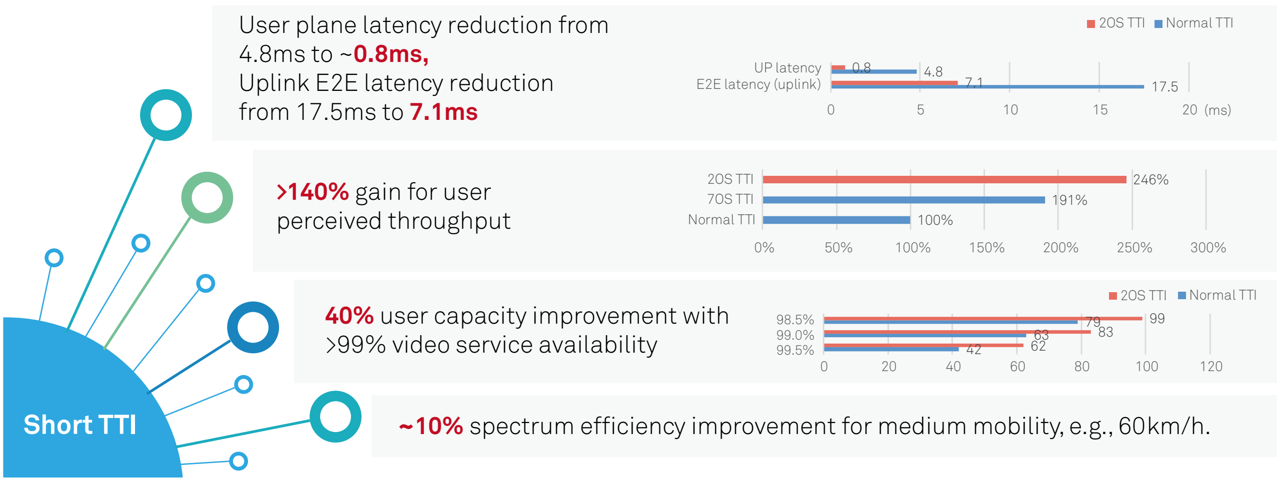

Figure 6 Benefit analysis of short TTI

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

2.2 Mobility enhancement and Control Plane (CP) latency reduction

Short TTI reduces latency when a UE is within a cell. In order to realize good experience anywhere for delay sensitive services, e.g. real time gaming, mobility performance should be guaranteed to avoid poor experience during handover. In addition, large handover interruption time will trigger TCP congestion avoidance mechanism such that the user perceived throughput will be reduced dramatically. LTE based mobility mechanism before Release 14 is built on the requirements of service continuity and lossless handover (with data forwarding between source and target eNBs), thus its average interruption time is about 50ms. In Release 14, the interruption time is further reduced by RACH-less handover and make-before-break technology. The interruption time is slightly reduced, but still cannot meet the IMT-2020 requirement of 0ms interruption time. To better resolve issues above, it is expected to further consider mobility enhancement mechanism in LTE Rel-15/Rel-16.

Figure 7 illustrates the basic procedure to achieve 0ms interruption when dual-connectivity based mechanism is adopted in handover case:

1. A new cell (cell2) that belongs to the target eNB is first added as "SCell" when UE moves towards cell edge,
2. PCell and SCell exchange roles
3. The previous source eNB is released when the UE leaves the coverage of the previous source eNB

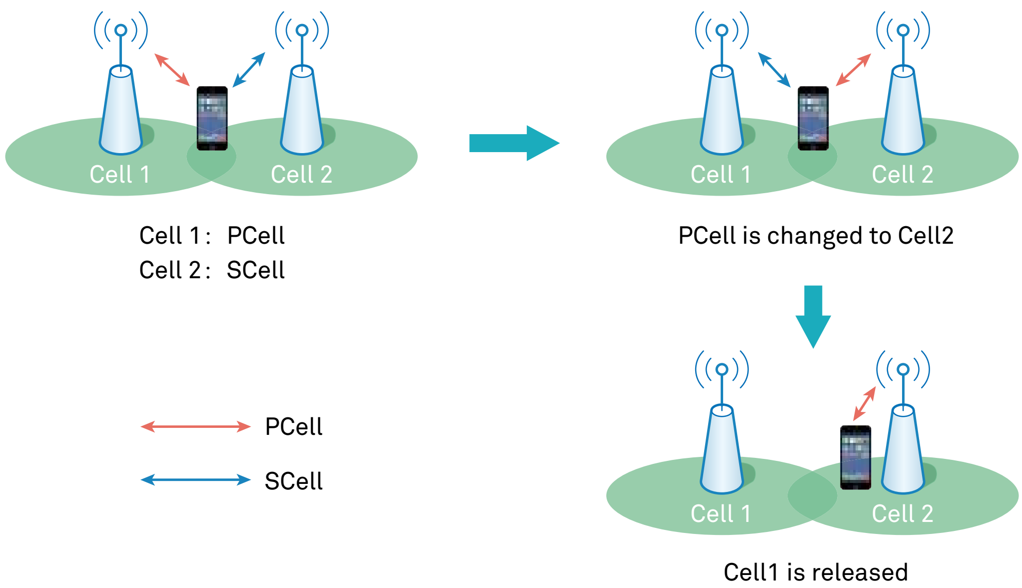

Figure 7 Dual-connectivity based handover

To achieve dual-connectivity based handover, UE needs to perform simultaneous reception from two nodes and synchronous network is required for intra-frequency handover scenarios.

Control plane latency, the transition time from idle mode to connected mode, is related to user experience especially for small packages. For LTE-Advanced systems, the control plane latency is 50 ms. The control plane latency for IMT-2020 refers to the transition time from a most "battery efficient" state (e.g. Idle state) to the start of continuous data transfer (e.g. Active state) and the requirement is 20ms. In LTE Rel-14, RRC resume procedure was introduced and control plane latency can be reduced to about 31.5ms, where the processing delay at both UE and eNB sides takes a large fraction of the total amount of RRC state transition latency.

It is expected that reducing UE/eNB processing time may lead to control plane latency of less than 20ms which depends on implementation of UE and eNB. In LTE Rel-15, short TTI is adopted in physical control channel and physical data channel. Applying short TTI to physical random access channel (PRACH) will speed up the RRC resume procedure and reduce control plane latency further.

2.3 Coverage enhancement

There are two aspects for coverage enhancement. One is coverage enhancement for traditional LTE eMBB services by means of high power UE and CoMP, and the other is to use coverage extension technologies like eMTC to provide ultra long-range data and voice services.

HPUE (High power UE) brings significant benefits in terms of cell coverage and cell edge user throughput that are needed for TDD networks with relatively high carrier frequency. Currently Band 38, Band 40, Band 41 and Band 42 can support HPUE. In addition, coordinated multi-point (CoMP) transmission is specified to improve the cell-edge as well as the system performance to achieve coverage enhancement and higher data rates.

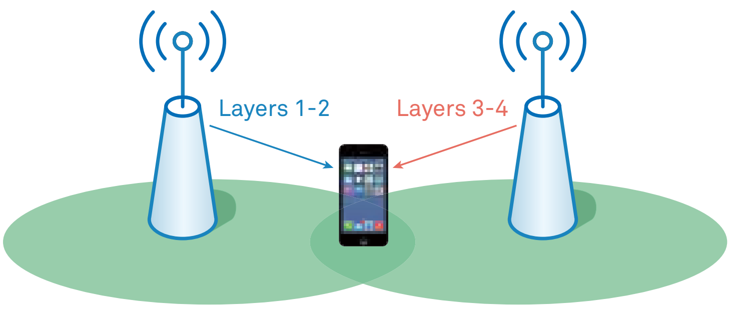

Figure 8 FeCoMP transmission

As shown in Figure 8, with more receiving antennas at the UE side, UEs can support up to four data streams, where non-coherent joint transmission (NCJT) could be enabled with different MIMO layers transmitted from different transmission points (TPs). Such transmissions can enhance the coverage performance by increasing the possibility of a high rank transmission from different TPs. In Rel-15, multiple quasi-co-location (QCL) with QCL type C, Demodulation Reference Signal (DMRS) grouping and enhanced CSI measurement and reporting are specified to support NCJT which can achieve about 26% gain for cell average performance and 13% gain for cell edge UEs.

Ultra long-range communication scenarios are defined to allow for the provision of services for very large areas with low density of users. The key characteristics of this scenario are Macro cells with very large area coverage supporting basic data and voice services, but with low to moderate user throughput and low user density. The aim is to support a minimum user throughput of 1Mbps on DL and 100 kbps on UL and to provide the related services for a density up to 2 users/km^2. For voice, a maximum of 400 ms E2E latency is required. Once coverage extension solution is implemented in a smart phone, a smart phone can be made to keep at least the ability the send/receive SMS and low-data-rate services. The main application will be allow services like emergency/SOS message, authentication token, payment credential checks, even in locations where there is no regular LTE coverage. Such coverage extension is under discussion in 3GPP, and it is proposed to set a 20 dB coverage extension target to the existing LTE baseline.

2.4 MIMO

As the main technology to improve spectrum efficiency to meet the ever increasing demand of data services over mobile networks, MIMO technology has been studied and enhanced in several LTE releases. In general, the main target of MIMO in standard is to make accurate channel state and interference information available at the transmitter with relatively low overhead in terms of both reference signals and feedback control channels, especially when the antenna numbers at the transmitter and receiver grow large.

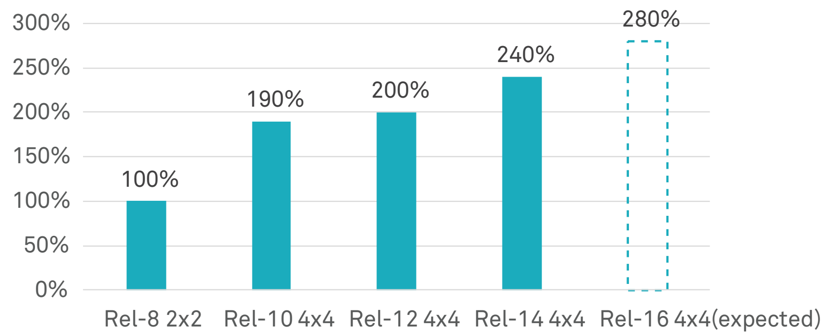

Figure 9 Enhancement on FDD spectrum efficiency in each release

FDD Network with 4T4R RF modules was already widely deployed around the world. For 4T4R, high resolution codebook and the related CSI reporting mechanism lead to continuous spectrum efficiency improvement, as shown in Figure 9. It is expected that with more accurate CSI measurement and inter-user interference measurement, nearly 3 times spectrum efficiency can be achieved compared with 2T2R in Rel-8.

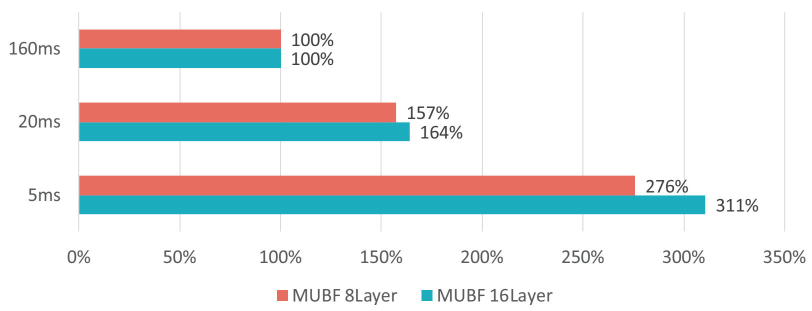

Figure 10. TDD massive MIMO (multi-user beamforming) performance with different SRS periodicity

To support massive MIMO in FDD and TDD bands with an increasing number of antennas, a number of techniques to substantially increase spectrum efficiency and cell edge user experience were also specified. For instance, CSI-RS and codebooks were enhanced to support up to 32 ports 2D antenna to achieve large beamforming gains and hence much higher throughputs at both cell center and cell edge. Moreover, a large number of antennas facilitate parallel data transmissions in spatial domain to different users (Multi-User MIMO). High resolution codebook for user to report more accurate channel state information and CDM4 based DMRS with up to 8 orthogonal or near-orthogonal DMRS ports for MU-MMIO transmission were specified in LTE.

Massive MIMO can be more efficient for TDD networks as it can take advantage of channel reciprocity between downlink and uplink. Using uplink sounding reference signal (SRS), the network can obtain the channel of each user and generate more accurate beams to offer better signal quality and provide more chances of transmitting multiple data streams for a single or multiple UEs. Latest LTE specification defines more resources for SRS transmission. For instance, up to 6 OFDM symbols in UpPTS can be assigned for SRS, and each OFDM symbol can support up to 48 wideband SRS transmissions. In addition, SRS switching between antennas and different carriers are also supported. With more SRS resources, higher spectral efficiency can be achieved as shown in Figure 10.

2.5 Wireless to the X (home/enterprise/camera, etc.)

WTTx is an advanced wireless broadband access solution, which utilizes wireless to tackle the last-mile problem. Such scenarios can benefit from a high capacity wireless connection, from a network node (e.g. LTE eNB) to a stationary intermediate device (which further communicates with end users via other links). The distinctive characteristics of such high 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 high capacity stationary wireless links and to enable more emerging applications.

Figure 11 Scenarios of WTTx

Diverse uplink dominated applications become more and more popular in existing networks, leading to a big challenge to the networks' uplink transmission capacities. The deployment areas for applications like video survillance of safe city may or may not be the areas with good link quality. However, the required data rate for such areas has to be guaranteed. Furthermore, taking into account the large number of cameras in the city, the total data rate requirement per cell in UL is also quite challenging.

The following enhancements are supported or under consideration to be supported in LTE for WTTx related applications:

- *1024QAM for PDSCH. Compared with 256QAM, 1024QAM could increase spectral efficiency. The target peak data rate for 1024QAM is 1Gbps for a UE with 4 layers per component carrier and two component carriers.*
- *DMRS overhead reduction. With stationary channels, channel estimation is less challenging and DMRS overhead can be reduced. Specifically, OCC4 is proposed to reduce overhead of DMRS for DL SU-MIMO rank 3/4 in TM 9/10.*
- *Better SU/MU MIMO performance for UL. Schemes for the high capacity UEs, such as codebook extension and non-codebook-based precoding, are under consideration.*
- *More accurate link adaption. With stationary channel case, more accurate channel information can be obtained for scheduling. Non-continuous resource allocation can also be supported for the frequency selective channels, which is under consideration.*
- *Network assisted interference cancelation is under consideration as well. With the stationary characteristics for channel and data traffic in WTTc scenarios, interference condition can be stable between interferers and victims. This can be used for interference cancellation, as well as the coordinated power control and scheduling mechanisms.*

2.6 Video/voice

Mobile video traffic has already accounted for 55 percent of total mobile data traffic in 2015, and it is foreseen that 75% of the world's mobile data traffic will be video by 2020. The long backhaul latency issue arises in cases where the distance between the RAN and the node hosting the application content is long or the number of routers on this route is large. In these cases long transportation latency may negatively impact user experience of video services.

Internet Content Delivery Network (CDN) provides acceleration for collaborating content providers by caching the content closer to the operator's network. UE provides assistance information for eNB to decide whether to accelerate the required content. Such mechanism is specified in Rel-15. Figure 12 gives an example on the local GW and remote GW. The UE can send the UE assistance information in the uplink packet, and eNB relays the assisted information in GTP-U header to the local GW. The local GW then routes the payload of packets with assistance information to local cache.

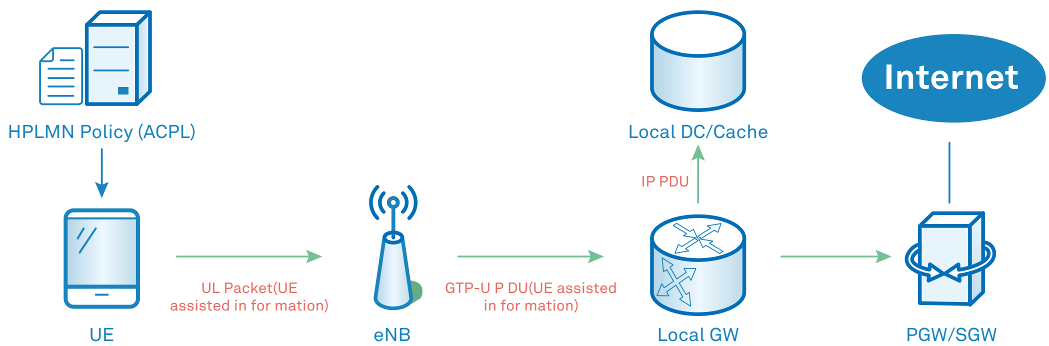

Figure 12 Example of UE assisted local caching above GW

VoLTE provides voice communication over LTE networks. Considering the increasingly fast migration from 2G/3G networks to LTE networks, it becomes extremely important that VoLTE can provide high quality voice service with good coverage. The main purpose of the eVoLTE coverage enhancement (CE) technologies is to largely reuse the existing CE technologies in eMTC CE mode A but without relying on eMTC "CE mode A" capability. In addition, enhancements such as the RAN-assisted codec adaptation, VoLTE/ViLTE signaling optimization and VoLTE quality/coverage further improves the quality of VoLTE.

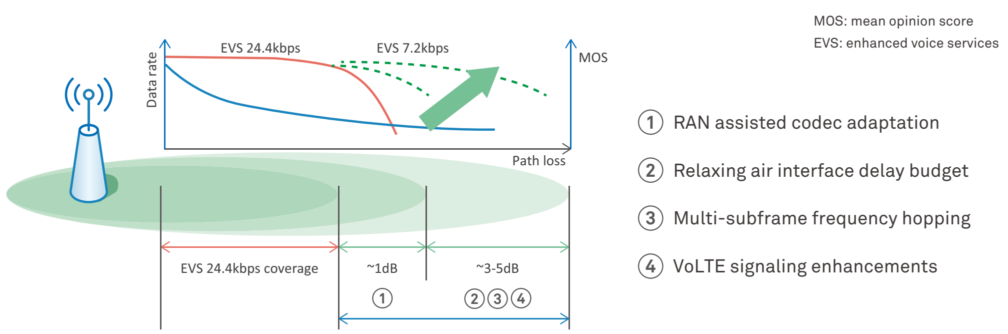

Figure 13 Enhancement of VoLTE

2.7 Enhanced CA utilization

Carrier Aggregation (CA) has become one of the widely-used LTE features for boosting data rates. Although CA was extended to 32 aggregated carriers, carrier aggregation and dual connectivity (DC) features are largely based on Rel-10 framework of CA. With the successful deployment of LTE networks, some challenges for the efficient use of E-UTRAN CA and DC have emerged in the networks. The current CA framework can be further optimized to reduce the delay in case of SCell configuration in order to improve the efficiency of radio resource and CA usage especially in small cell deployments.

As the network nedd to make sure that the UE has completed the activation and start to schedule the UE only after receiving the valid CSI report, there is a non-negligible delay about 24 ms to 34 ms in case of SCell activation. In dense small cell deployments, there is also substantial signaling overhead for each SCell as each of the SCell needs to be separately configured.

To resolve the above issues, the following solutions are under development in Rel-15:

- *Configure SCell directly in activated state. To shorten the activation procedure, a SCell can be configured directly in activated state. This also reduces the signaling overhead.*
- *Introduce a new SCell fast activation state. During this new SCell state only periodic CQI report based on CRS is performed, and UE does not need to monitor PDCCH of the SCell. In this case when an activation MAC CE is received by UE, it will take less time to finish the activation procedure.*
- *Define a temporary short period of the CQI reporting. When an activation command is received, a temporary CQI reporting with a short period can be performed to timely notify the network that it is ready to use the activated SCell.*

2.8 High speed enhancement

When users are moving at high speeds, e.g., in trains or vehicles on highways, it is quite challenging to maintain good user experience. LTE high speed enhancement technologies were specified in Rel-14 to address the related issues. It not only increases the successful rate of random access which improves the experience of accessing network by enhanced PRACH solution, but also increases the date rate by 12%~20% via UE enhancement in the deployed high speed network.

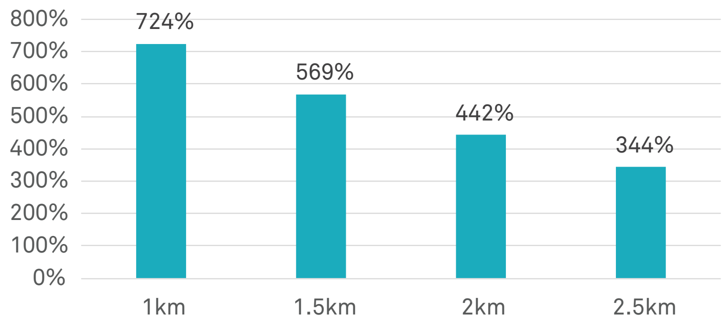

Figure 14 Preamble capacity gain with PRACH enhancement for different cell radius

The enhanced PRACH solution extends supportable Doppler shift from 1.25 kHz to 2.5 kHz via an improved restricted set. In addition, it also increases the preamble capacity greatly as show in the Figure 14. Meanwhile the enhanced preamble resource allocation scheme takes the co-existence of legacy and new UEs into account and can guarantee the random access performance of legacy UE in the very high speed scenario. The configured parameter with respect to the cell radius is also optimized to improve the utilization of root sequences.

The PRACH enhancement technology can support up to 500km/h in 2.6GHz carrier frequency or lower speed at higher carrier frequency and can be used in the scenario of high speed train and other very high speed scenarios. Extension to higher spectrum e.g. 3.5GHz for 500 km/h is to be considered in Rel-16.

In addition to PRACH, advanced UE transceivers can improve high speed performance, especially for single frequency network (SFN) scenario as shown in Figure 15. To specify advanced UE transceivers can be further considered to meet 500 km/h high speed train (HST) requirement in Rel-16.

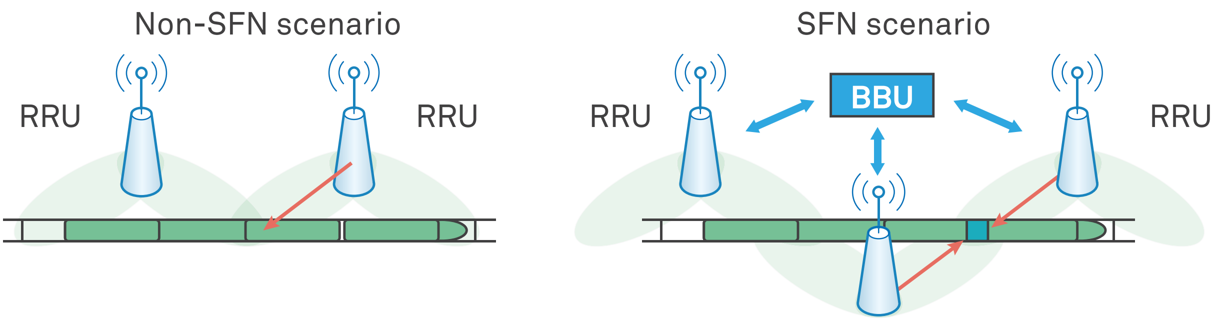

Figure 15 Deployment scenarios for high speed train communication

3. Capability for all business connection: boosting vertical markets

In addition to providing ubiquitous experience for mobile broadband services, many operators are expanding the business territory of their LTE networks to provide various new services. Some promising services are illustrated below:

3.1 Cellular IoT

Machine-to-Machine (M2M) communications with 2G/3G modules has been one of the successful growth factors for cellular network operators in recent years. When the number of machine-type-communication devices increase, the demand for cost reduction increases, which rapidly changes the shape of the M2M markets, especially changes the rapidly growing areas of LPWA.

Commection volume by 2020 (billion)	Data rate	Technologies
0.2B	>10Mbps	3G/4G
0.8B	~1Mbps	2G/3G/Cat-1 eMTC
2B *LPWA:Low Power Wide Area*	low data rate (~100kbps) extended coverage(+20dB) massive connections(1M) low power consumption(10 years) low cost(<$5 module)	NB-IoT

Figure 16 IoT markets and technologies

LTE started the study on this aspect called “cellular IoT” since year 2014. Now it has achieved vibrant complementary technologies including NB-IoT and eMTC to provide low cost and low power IoT device as well as IoT services for diverse use cases.

As one of the most important technology for cellular IoT, NB-IoT is based to a great extent on a non-backward compatible variant of LTE supporting a reduced set of functionality, which originally targeted dedicated design to address LPWA market by providing 20dB extended coverage, 1 million massive connections, $5 ultra low cost device module and 10 years long battery life. NB-IoT has the following key characteristics to address LPWA challenges and providing advantages of the cellular network:

- *The network has reduced minimum system bandwidth of 200 kHz, flexibility to support multi-carrier and 3 different operation modes (stand-alone, guard band and in-band deployment).*

- *Enable low cost UE with only 180 kHz RF bandwidth.*
- *Dedicated IoT cell decoupled with eMBB cell.*
- *Uplink single-tone transmission, which is designed to achieve low PAPR and beneficial for coverage enhancement and massive connections in power limited scenarios.*
- *Higher layer optimization for small package transmission, mandatory support of CP solution. introducing extended discontinuous reception (eDRX) and power saving mode (PSM) to save power consumption, simplified signaling overhead etc.*

In Rel-15, NB-IoT is being further enhanced to reduce power consumption and transmission latency, which includes:

- *Wake-up signal for efficient monitoring of paging to further save UE power consumption.*
- *Early data transmission during RACH enables early data transmission without setup RRC connection to further reduce latency and UE power consumption.*

eMTC is another LTE-based technology which provides low cost MTC device and 15dB coverage enhancement comparing to eMBB. It reuses the LTE eMBB cell and also has some optimization for small package transmission in higher layer. eMTC UE has wider bandwidth than NB-IoT and can provide higher peak data rate. NB-IoT is targeting low data rate (~0.1Mbps) service while eMTC has the capability for medium data rate (~1Mbps) service. NB-IoT and eMTC are complementary cellular IoT technologies for the rapidly growing IoT market.

NB-IoT ecosystem is already mature to fulfill LPWA requirements and as 5G IoT baseline it can fulfill the requirements of mMTC for low bit rate service on Low Power Consumption, Wide Area Coverage and Massive Connections aspects. Diverse applications emerge on market, e.g. metering, parking, shared bicycle and street light etc.

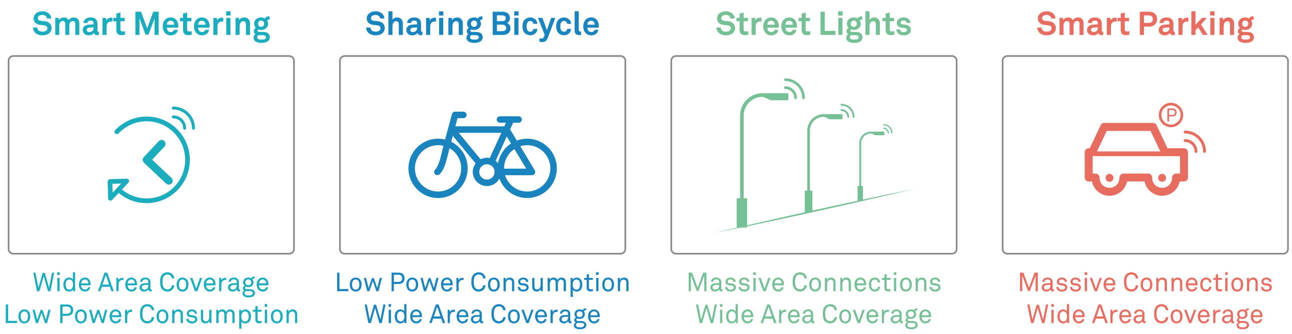

Figure 17 Diverse NB-IoT applications deployed

As IoT applications are usually deployed for many years, they cannot be replace easily, The design of coming system (e.g. new radio) is expected to support co-existence with NB-IoT and eMTC. Such kind of co-existence is expected to be standardized in Rel-16. In addition, it is expected that Celluar IoT will have further improvement in Rel-16 to address new use cases and new requirements, such as even higher data rate, mobility and positioning accuracy.

3.2 URLLC

Many services require higher reliability within low latency restriction, such as remote operation, drones, industrial automation, electricity distribution, intelligent transport systems, and so on. This type of communication has been taken as one of the key scenarios in ITU IMT-2020 requirements. As a candidate technology for ITU Submission, it is motivated to further enhance LTE system such that it can meet the key IMT-2020 requirements including the ones for URLLC.

Many URLLC services need to be accessible everywhere, for example electricity distribution. Some need to guarantee mobility, for example intelligent transport systems. LTE network can be a promising network for URLLC services due to its good coverage and good mobility capability.

For one transmission of a packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, a general URLLC reliability requirement is 99.999% for 32bytes with a user plane latency of 1ms, at a certain channel quality (e.g., coverage-edge).

Short TTI is the basic structure to meet the restricted latency requirement. Moreover, grant-free mechanism in uplink is necessary to omit the long interactive procedure in the current uplink grant-based transmission. Full diversity should be exploited in frequency, spatial, time, carriers (by carrier aggregation), and site (by dual connectivity) dimensions to ensure reliability within the delay bound. Repetition can be a basic solution and optimization is needed to improve the resource efficiency. HARQ mechanisms with fast scheduling, feedback and retransmission are also possible. Reliability depends on all involved physical channels. The performance of all related channels should be guaranteed to meet the final reliability requirement. At the same time, resource efficiency needs to be considered as an important metric, including the efficiency to multiplex with other eMBB services.There are also some further enhancements in user plane, e.g. accelerated SDU delivery, potential enhancement of ARQ mechanism and measurement, etc.

In addition to higher reliability and low latency restriction, time synchronization with high accuracy (e.g. us level) between UEs is required in many scenarios, such as factory automation, distribution network, programme making and special events (PMSE) and etc. In those scenarios, all the UE need be synchronized to a common time reference (e.g. GPS time) to achieve the synchronization between each other. It is motivated to further enhance LTE system to ensure UEs in such scenario are synchronized with a common time reference from LTE network.

In factory automation applications, UEs are required to act at an exact time instant. For example, the controller sends a command to an actuator to indicate when to move or stop. The controller should be synchronized with the actuator to ensure a common understanding of time. Otherwise, an unexpected move in the actuator may arise and cause possible financial damage and safety problem. For another use case with cooperation between UEs, all UEs should be synchronized to avoid any misalignment action. For some use cases, fake time information will cause serious problems in application, so reliable time information should be provided for them.

Before Rel-15, a common time reference (UTC and GPS) is provided in SIB16 by the eNB. However, the granularity of the time information in SIB16 is 10ms which can't meet the requirement . To support more applications which require accurate time synchronization, SIB16 can be extended with high granularity (e.g. us level) to enable high accuracy synchronization service. Furthermore, to ensure the time information is reliable and is not impacted by fake time from the jammer for the high security service, e.g., factory automation, Security mechanism for time information should be supported. In such case, the time information may be sent to UE via dedicated RRC signaling with integration protection. Furthermore, considering the charging policy, authorization for time synchronization can be supported.

3.3 V2X

The widely deployed LTE infrastructure network brings significant benefit to the deployment of Intelligent Transportation System (ITS) with various vehicles (e.g. automobiles, trains, drones, etc) which generally requires 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 opportunity for mobile network operators. In order to better support Intelligent Transportation System, specific enhancements on connected cars were developed by 3GPP.

The initial version of LTE-V2X standard was completed as part of Release 14, with the goal to support basic safety services (e.g. collision avoidance, traffic lights to vehicles and speed guidance etc). LTE-V2X technology consists of PC5 interface (direct link between vehicles, to support V2V/P/I) and Uu interface (via network, to support V2N/I). For V2X communication over PC5 interface, additional DMRS symbols were added to handle high Doppler associated with relative speeds of up to 500km/h and at high frequency (i.e. 5.9GHz ITS spectrum). LTE-V2X enhanced the radio resource allocation mechanism to improve the system-level performance with high vehicle density while meeting the stringent latency requirements of V2X. V2X communication over Uu interface can benefit from the high reliability and low latency Uu interface supported by LTE. If one V2X message needs to be delivered to multiple vehicles, network can broadcast the V2X message by means of single-cell point-to-multipoint (SC-PTM) or eMBMS.

In Release 15, LTE-V2X continued the evolution with the goal to support more advanced V2X services (such as platooning, advanced driving, etc). Release 15 LTE-eV2X enhanced the performance of 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 Release 14 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.

3.4 Unmanned Aerial Vehicle

The use cases of commercial drones are growing rapidly to include package delivery, search-and-rescue, monitoring of critical infrastructure, wildlife conservation, flying cameras, surveillance, and more. Many of these emerging use cases could benefit from connecting drones to the cellular network as a UE. LTE is well positioned to serve unmanned aerial vehicles. It is straightforward to provide connected drones service with existing LTE network, however, some key issues need to be resolved.

In the DL, as shown in Figure 18 below, the percentage of aerial UEs experiencing cell-edge like radio conditions (i.e., poor DL SINR) is much higher compared to terrestrial UEs. This is because aerial UEs, due to their high line-of-sight propagation probability, receive DL interference from a larger number of cells than a typical terrestrial UE does.

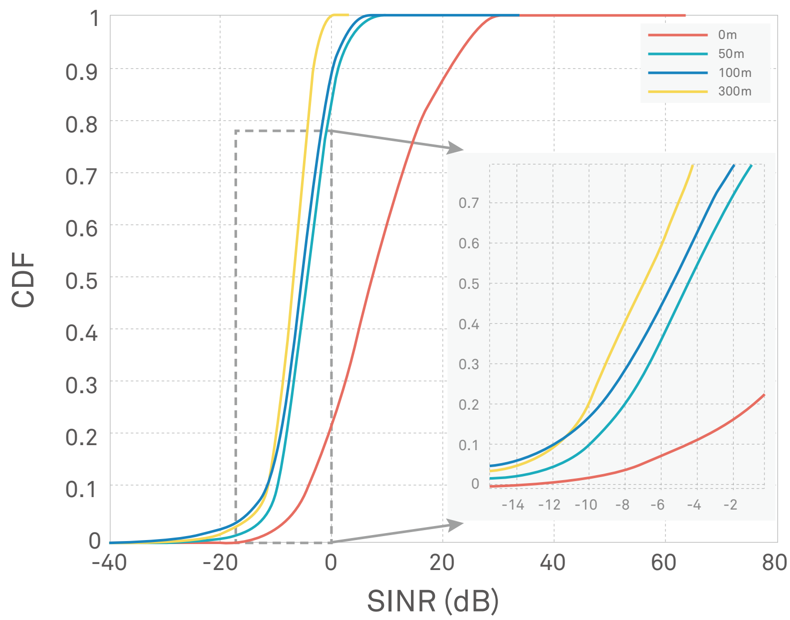

Figure 18: DL SINR performance for aerial UEs with different height above the ground

In the UL, the presence of aerial UEs increases the UL IoT of both aerial and terrestrial UEs. Since the aerial UEs experience line-of-sight propagation conditions to more cells with higher probability than terrestrial UEs, the aerial UEs cause more interference to more cells in the uplink than a typical terrestrial UE could.

To address some of the identified issues, enhancement in uplink power control and mobility is under development in Release 15. It is expected that there will be some further work to optimize drone application in Rel-16 by means of layered access via network coordination.

Layered access scheme is described below. As illustrated in Figure 19 multiple layers (e.g. drone layer and ground layer) are formed based on the existing deployment network. Drone layer and ground layer share the same spectrum with drones mount on drone SFN layer, smart phones mount on normal cell of ground layer, Drone RRM measurement based on SFN layer RSs.

Based on Layered access scheme, the severe DL and UL co-channel interference can be significantly reduced and in the meanwhile, it also can improve the handover performance including both handover rate and handover failure rate.

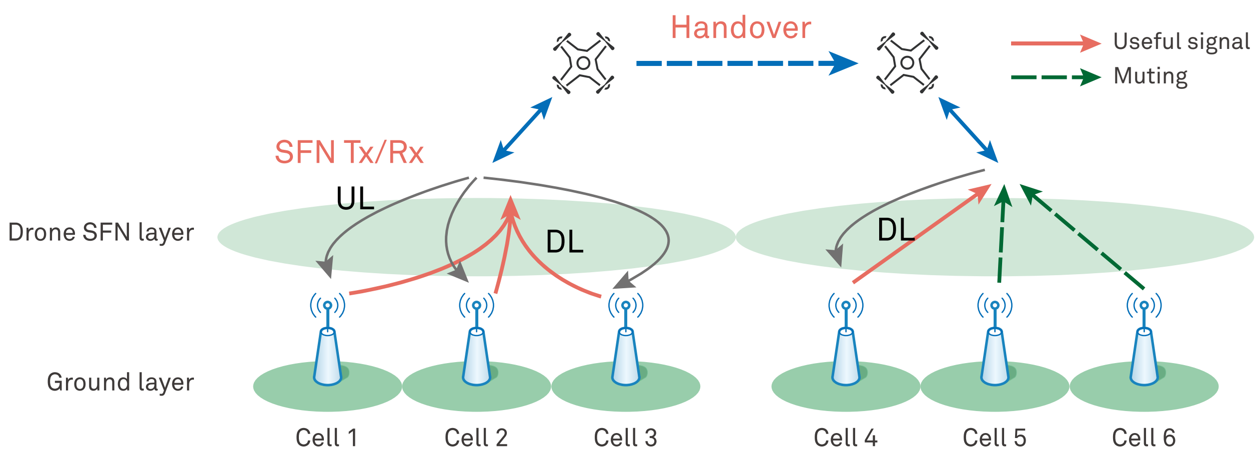

Figure 19 Illustration layered access for drones

For high speed train scenario with traditional network deployment, frequent handover will occur due to high velocity of train. The signal quality will fluctuate and be degraded and the radio link failure probability will be increased due to frequent handover and cell reselection. The technique of layered access scheme can also be extended to the high speed train case to reduce the handover frequency and improve the signal quality.

3.5 High precision positioning

UE positioning is recognized as an important feature for LTE networks due to its potential for massive commercial applications (for example intelligent transportation, entertainment, industry automation, robotics, remote operation, healthcare, smart parking, and so on).

Recent enhancements in GNSS technology include Real Time Kinematic (RTK) GNSS, which is a differential GNSS positioning technology which enables positioning accuracy improvement from meter level to decimeter or even centimeter level in the right conditions in real-time by exploiting the carrier phase of the GNSS signal rather than only the code phase.

As the number of UEs supporting network-assisted positioning increases, broadcasting of assistance data such as A-GNSS, RTK and UE-based OTDOA assistance information to the UEs helps to reduce signaling load.

4.Capability for multi RAT support and easy operation: smooth evolution and OPEX reduction

4.1 E-UTRAN/NR Dual Connectivity (EN-DC)

As shown in Figure 20, several network architecture options for migration path were proposed during 5G study item in order to enable a smooth evolution toward to 5G. In these options, Option 2 is standalone NR connected to 5G core (5GC), and Option 5 is standalone LTE connectivity to 5GC, Option 3/4/7 are LTE-NR DC, more specifically, Option3 series is EN-DC, Option 4 series is NE-DC, Option 7 series is NG EN-DC. In Release 15, Option 3 has been standardized at the end of 2017, and Option 2/5/7/4 are planned to be finished before June of 2018.

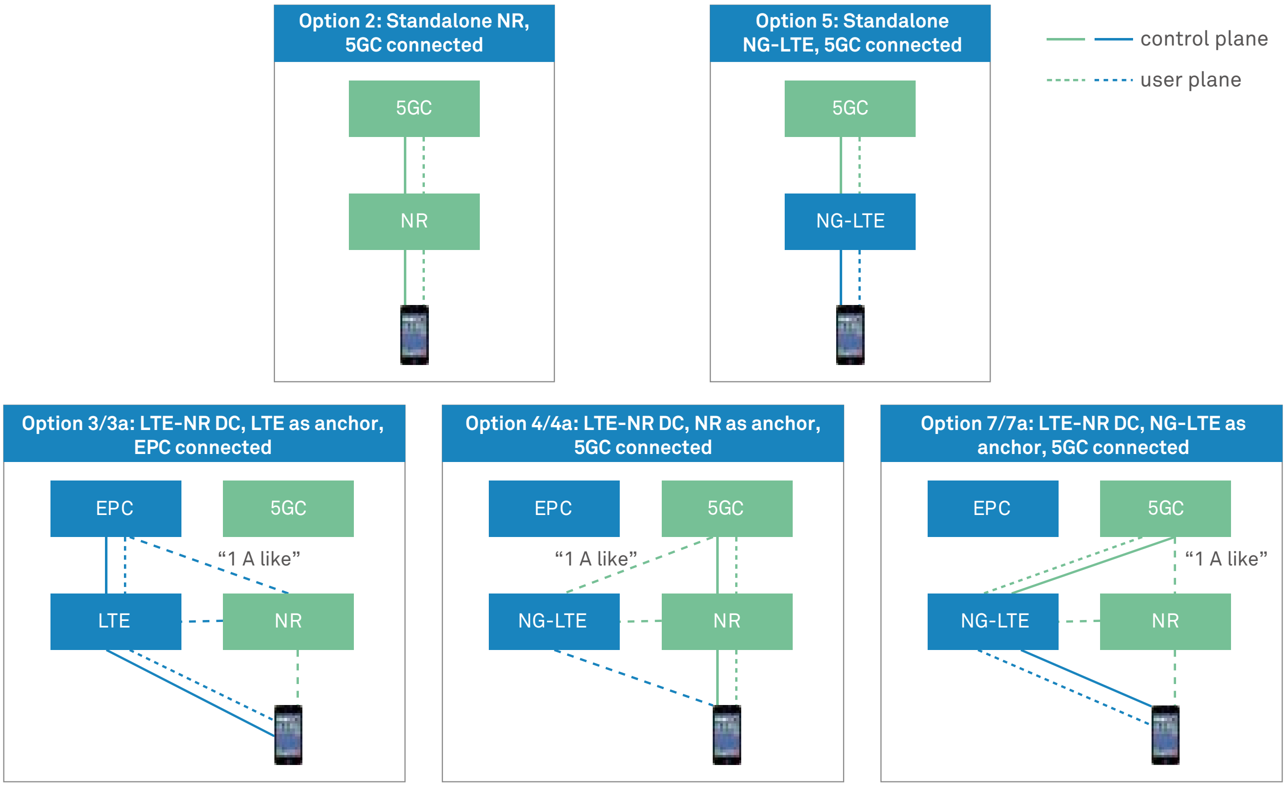

Figure 20 Options of 5G Network Architecture

Considering the huge investment of the operators on 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 high priority in Release 15. Based on EN-DC, the existing EPC connected LTE deployments 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 eNB connecting to the EPC acts as the master node and the NR gNB (i.e., en-gNB) acts as the secondary nodes (SN). The overall EN-DC architecture is illustrated in Figure 21 below.

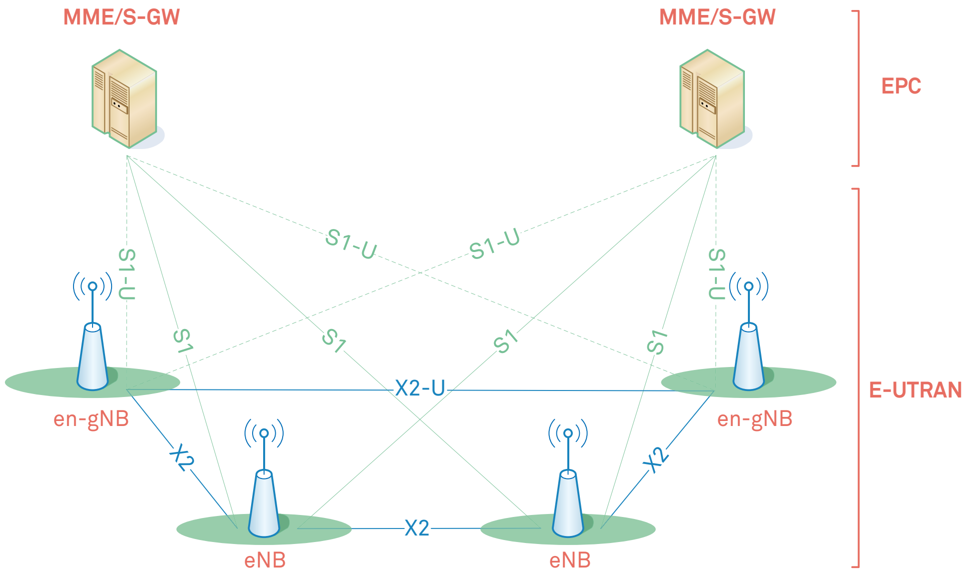

Figure 21. EN-DC overall architecture

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

4.2 LTE connectivity to 5GC

During evolution towards 5G, from operators' perspective, it is desirable to leverage the existing LTE coverage in order to provide a nationwide continuous coverage, 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 UE with 5GC new 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 Option 7 and Option 4, in order to leverage NR radio resource to boost UE data rate.

The E-UTRA connected to 5GC is supported as part of NG-RAN as shown in Figure 22, where the term "ng-eNB" is used for LTE eNB connected to 5GC, and the term “gNB” is used for NR base station. The differences between the architecture of NG-RAN shown in Figure 22 and that of EN-DC shown in Figure 21 is that NG-RAN nodes, e.g gNB and ng-eNB, have complete NG interface including control plane and user plane connected to 5GC, while EN-DC nodes, e.g. eNB and en-gNB, are connected to EPC, and en-gNB as SN may only have user plane of S1 interface.

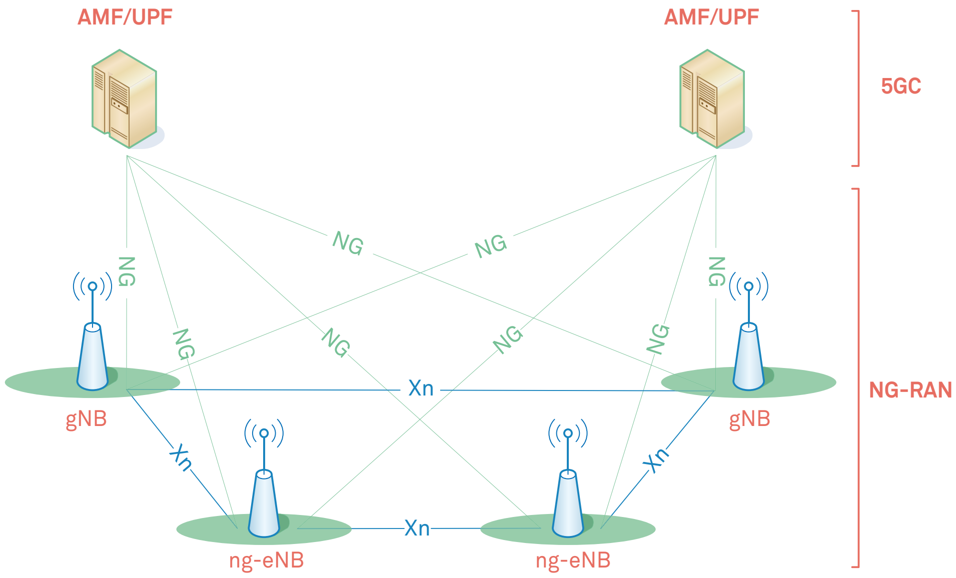

Figure 22 Overall Architecture of NG-RAN

The basic principle to standardize LTE connectivity to 5GC is trying to reuse the air interface of LTE and with minimum modifications on higher layer, e.g. PDCP. Since the QoS framework of 5GC is different from that of EPS, a new layer called Service Data Adaptation Protocol (SDAP) is defined for NG-RAN, i.e. NR and E-UTRA connected to 5GC. In addition, in order to avoid modification on legacy E-UTRA PDCP layer, the NR PDCP layer is agreed to apply for E-UTRA connected to 5GC. Thus, as shown in Figure 23, the radio protocol architecture of use plane for UE accessing 5GC via an ng-eNB, includes legacy E-UTRA PHY, MAC, RLC and NR PDCP, as well as SDAP; as shown in Figure 24, the radio protocol architecture of control plane includes legacy E-UTRA PHY, MAC, RLC, legacy E-UTRA PDCP (only used for SRB1), NR PDCP, and E-UTRA RRC layer, as well as 5G System (5GS) NAS layer.

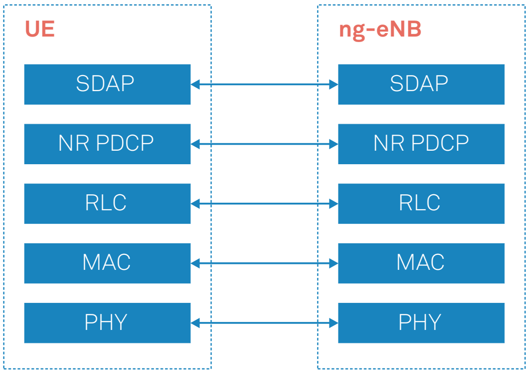

Figure 23 User Plane Protocol Stack

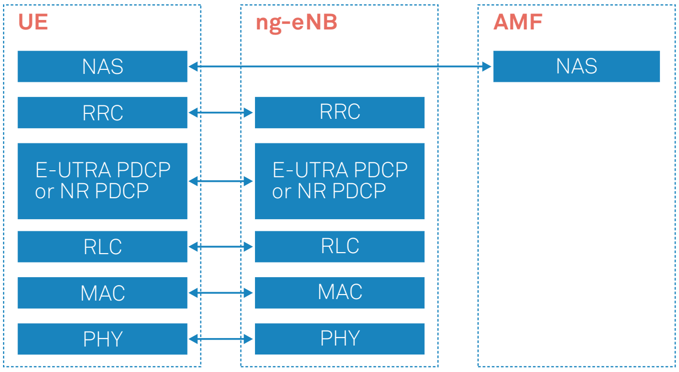

Figure 24 Control Plane Protocol Stack

The functions supported by E-UTRA connected to 5GC include 5GS NAS message transport, 5G security framework, Flow-based QoS, Network slicing, mobility management, and etc. The E-UTRA connected to 5GC can also be connected to EPC depends on network planning and deployment of operator, and in this case it also supports the same functions as in case of E-UTRA connected to EPC.

4.3 MDT

During LTE Release 10, minimization of driving test (MDT) was introduced. This feature can help operators on network management and performance optimization. In current LTE networks, more and more traffic are from indoor scenarios, and operators may deploy WLAN in order to increase network capacity and improve user experience. For WLAN (and also Bluetooth), it is mainly for network capacity and positioning purposes, but the legacy MDT mechanisms do not support collecting WLAN/Bluetooth measurements.

New measurements for WLAB/Bluetooth in MDT is being developed in Rel15, with such functions operators could get more accurate positioning information, and such information is a useful supplementary to legacy positioning information (e.g. GNSS). With accurate positioning information in MDT, operators can achieve more precise network planning, management and performance optimization.

4.4 New metrics for network planning and management

In current LTE networks, it uses the average physical resource block (PRB) utilization to characterize the network load, and uses the average user data rate (in hour) to evaluate the user experience. However, it sometimes results in "misjudgement" when using these evaluation metrics as sometimes hourly statistics may not represent real user experience. Therefore, how to evaluate network load more effectively to improve user experience and achieve accurate investments, has become an important issue.

Currently, it is under discussion in 3GPP to introduce smaller time granularity based metric collection solutions, and the use cases are to observe the network load and the user experience. The solutions are new evaluation methods based on user experience and network load. For the user experience based evaluations, it is to focus on analyzing the main busy hours of the network. Regarding the details, the industry generally considers the usage of “distribution” (second-level sample) to solve issues as mentioned above. The second-level granularity is considered because this granularity can be perceived by the user. With the second-level granularity distribution, the device can collect metrics every second, and the metrics are related to PRB utilization and user data rate.

The new metrics can better reflect the actual network load, and thus help operators on network planning, management and achieve precise investment.

5. LTE beyond Rel-15: 5G ready for IMT-2020

In early 2012, ITU-R launched a program to develop "IMT for 2020 and beyond", setting the stage for 5G research activities emerging around the world. In September 2015, ITU-R finalized the "Vision" of the 5G mobile communication system, including key capabilities to support three usage scenarios, i.e. eMBB, mMTC and URLLC. In the first half of 2017, the technical requirements of IMT-2020 including 13 key performance indicators and their detailed requirements for five test environments were approved, after that the relevant evaluation criteria and submission templates were agreed, based on which individual Standard development organizations (SDOs) can initiate the IMT-2020 proposal submission and evaluation work. The deadline of IMT-2020 proposal submission is June 2019, indicating that any technical proposals targeting for IMT-2020 should be stable and submitted by that time.

Previous sections showed that LTE and its further evolution towards an all business connected primary infrastructure is ready for IMT-2020 and future deployment. As shown in the Figure 25, Rel-15 satisfies the required performance of the eMBB use case except for the network energy efficiency and mobility. mMTC performance requirement in terms of connection density can be met by NB-IoT, while URLLC performance requirement can be achieved by the combination of short TTI and URLLC enhancement. After Rel-15, the evolution of LTE can further boost the performance of network, especially for the network energy efficiency and mobility. For network energy efficiency, service based access mechanism together with MBSFN subframe configuration can reduce the impact of always-on CRS, thus longer sleep duration and higher sleep ratio are expected. For mobility enhancement, advanced transceiver and improved reference signal design may be introduced to improve the robustness of link at high speed.

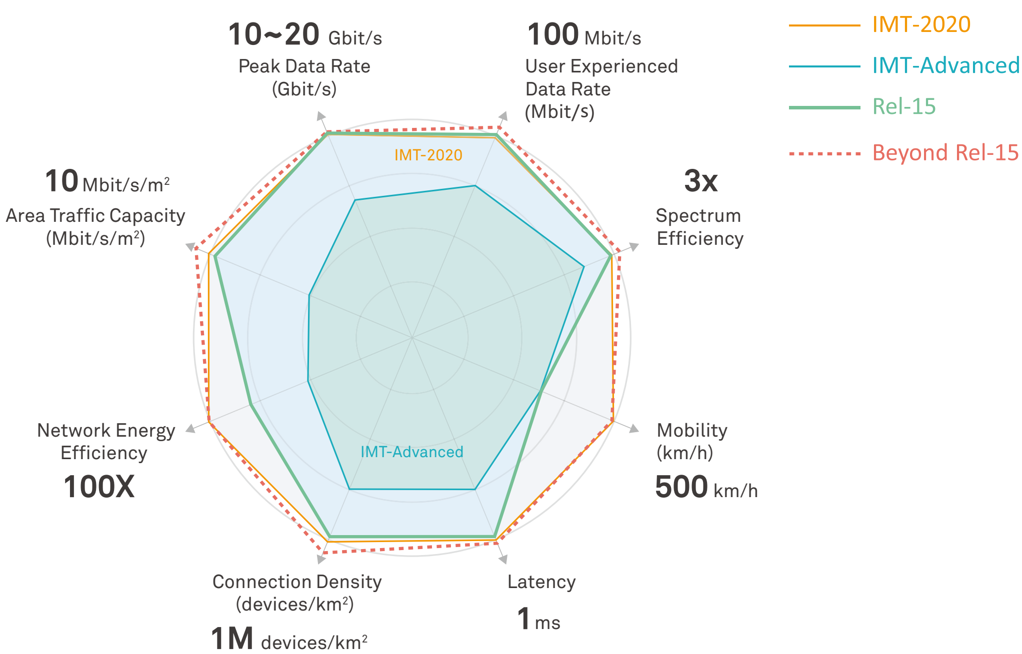

Figure 25 The capabiltiy figure of LTE and its evolution compared to IMT-2020 requirements (based on specification features and capabilities)

Note that the capabilities in Figure 25 are based on the specification features and the related capabilities, in practical deployment more realistic factors should be taken into account, e.g., the spectrum availability, hardware capabilities, cost, etc.

Regarding the timeline of IMT-2020 in ITU-R, 3GPP also proposed its own corresponding plan as shown in Figure 26. To be specific, from Rel-15 and onwards, 3GPP will propose NR and the evolution of LTE as the potential candidate technical proposals for IMT-2020. Note that in 3GPP RAN#77, it was agreed that a joint submission Set of Radio Interface technology (SRIT) including both NR and LTE evolution (each denoted as a component RIT) will be proposed to ITU-R, and in addition, a separate submission of NR can also be considered. It means that the majority of 3GPP stakeholders including vendors and operators share the same view that LTE and NR will complementarily meet the performance requirements of IMT-2020.

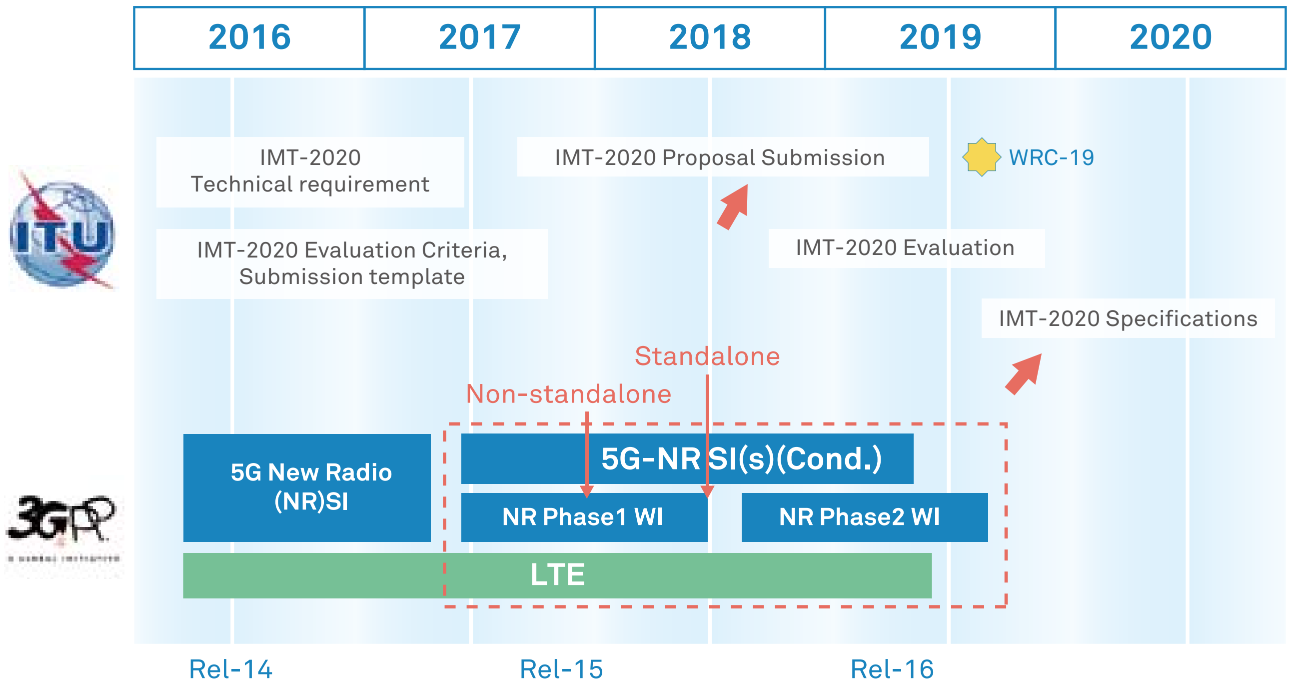

Figure 26 IMT-2020 activities of ITU-R and 3GPP

6. LTE market statistics, progress and outlook

According to GSMA's forecast[2], [3], a net 3.6 billion LTE users will be added between 2016 and 2025, and by 2025 LTE users will reach two thirds of the global mobile user base.

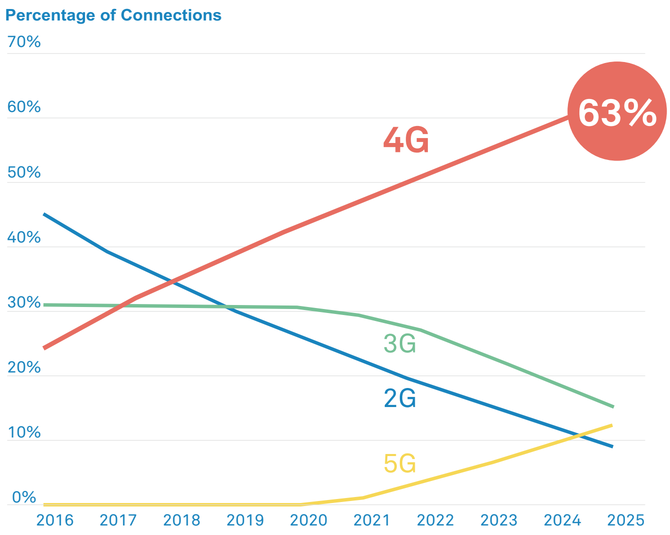

Figure 27 Trend of mobile network development

LTE network is regarded as the primary infrastructure in 5G Era, and multi-antenna technologies and carrier aggregation technologies in LTE network are continuously evolving to improve user experience towards xGbps. By now, a full set of multi-antenna RF products have been widely deployed in telecom market, including 4T4R, 8T8R, Massive MIMO (64T64R), etc.

4T4R: it is regarded as foundation of future network in 5G Era. The number of commercial networks equipped with 4T4R has been well over 100 by the end of 2017. From the shipment statistics in 2017, an obvious trend has been seen that more and more operators are planning to deploy 4T4R. It is reported that dual-band 4T4R will break into telecom market in 2018 assisting operators to incorporate multiple bands into one box and save the TCO.

8T8R: it can better meet the capacity demand in hotspot. TDD 8T8R has been mainstream radio unit in operators' TDD commercial networks, while FDD 8T8R AAU has become a new star in global market in 2017 with a twofold increase in capacity over legacy 2T2R for 2R UE. The capacity under FDD 8T8R AAU can further increase to three times with the evolution of MU-MIMO based on TM9. More than 20 operators finished PoC of FDD 8T8R AAU, some of which have announced commercial use. It is expected that the scale of FDD 8T8R AAU will highly increase in operators' networks in 2018, especially when more advanced 8T8R AAU products are coming forth, supporting sub-3G high and low bands all in one box.

Massive MIMO: it is universally regarded as the most important technology for super high spectrum efficiency, enabling LTE meet ITU-T's 5G requirements. The cell peak data rate can reach 1Gbps with only 20MHz TDD spectrum. Massive MIMO has always been embraced since 2016. About 20,000 Massive MIMO have been commercially deployed in over 40 LTE networks in 2017. It is estimated that the number of Massive MIMO deployed in 2018 will significantly increase, to approximately over 50,000 globally, including the traffic heavy countries and areas like China, Japan, Philippines, West Europe, India and etc.

Carrier Aggregation: LTE can support up to 32 Component carrier (CC) CA as specified in 3GPP R14. According to GSA database, there have been more than 1300 devices supporting CA. In October 2017, EE achieved 970Mbps in their commercial network with Huawei Mate 10 Pro smart phones which is about 10x of traditional LTE.

HetNet: There are rich portfolio of versatile LTE micro and small cell products in the market which have been flexibly deployed at poles, against walls, or above ceilings to enhance both outdoor and indoor coverage. They can perfectly be merged into the current network to increase both coverage and capacity.

As stated in previous sections many new services have been defined in the 3GPP standards, which enable the proliferation of new business in LTE commercial networks. In 2017, new services have sprang up while besides traditional mobile broadband service. Here are some inspiring market statistics:

VoLTE: So far there have been 131 operators launching VoLTE in 66 countries. More than 1400 types of VoLTE terminals have come out until the end of 2017. In 2017, India and Thailand announced 20 USD low-end VoLTE capable feature phones. 100 million of such phones will be shipped this year, which will boost the re-farming process from 2G/3G to LTE. It is right time to re-farm voice from 2G/3G to LTE to reduce significant OPEX by maintaining simpler networks rather than taking care of 2G/3G/4G/5G at the same time. In the mean while, such re-farming will also bring much higher spectrum efficiency in voice as well as data. With a mature ecosystem and excellent coverage of LTE networks, VoLTE will be the dominant voice solution in 5G era.

Video: Mobile video is the major driving force for the growth of data as well as revenue. Many operators have been promoting mobile video to increase subscribers' loyalty and stimulate data usage and revenue. By providing unlimited videos from the popular Netflix, Youtube, Amazon and etc, Vodafone Video Pass unlocks a whole new way to people's life at a price of £7. On the other hand, Deutsche Telekom offers "StreamOn" free of charge, providing video & music from more than 150 partners. This company has attracted 700,000 customers since "StreamOn" was launched in 2017 spring.

WTTx: Wireless broadband has been a popular business embraced by Vodafone, SoftBank, Telefonica, Orange and Singtel. "Wireless Broadband, an Important Ingredient of National Broadband", is a clear viewpoint from the ITU's report, "The State of Broadband 2017"[4]. "Wireless broadband combines advantages from traditional fixed wireless solutions (such as rapid and flexible deployment and low costs), with fixed broadband-class bandwidth and quality." More than 200 operators have utilized this technology to provide broadband service to around 50 million households globally. In 2017 the global wireless broadband connections have increased by 10M with 35% CAGR which is even higher than the global fiber connection. Regarded as one of the use cases in 5G initial stage, using LTE evolution to deploy WTTx will help operator seize higher ARPU family users, building E2E operation capabilities for new business before 5G comes.

NB-IoT: From connecting individuals to connecting things, IoT opens huge opportunities in new business. 2017 has been recognized as a milestone year for NB-IoT. 500K NB-IoT sites have been launched in 28 networks globally. More than 600 industry partners have been involved in the E2E ecosystem, bringing digital transformation to over 40 vertical industries as well as new revenue to mobile operators. For example, farmers can harvest more milk by collecting physical data through NB-IoT devices on each cow and performing more accurate management, which increases farmers' revenue by around $300 and brings $6 to operators per cow per year. And each base station can easily accommodate more than 10,000 cows. So it is no surprise that many operators have made ambitious IoT plans. In China for instance, operators plan to activate 1.5M NB-IoT base stations and have 600M NB-IoT connections by the end of 2020.

LTE-V: Billions of vehicles and transportation facilities to be connected are no doubt another huge markets. There are more than 1.3 billion vehicles globally, and there will be 80M new vehicles each year. Wireless will connect billions of vehicles, driver and passengers, license plates, sensors, roads, traffic signs and toll gates and change them into intelligent terminals. 3GPP have make such objective possible in LTE since R14. Recently all the stakeholders including vehicle manufactures, telecom industry, public safety, transportation, original and after-market device manufacturers were aggregated in China to form an open platform which standardized connection for traffic lights which are the most important node of V2I. Moreover, public traffic information and regulations are also open to the industry for more innovations. With all these efforts, LTE-V E2E commercial solutions will be accelerated from chipset, network to management platform in 2018, and expected ready for commercial launch by 2019.

7. Conclusion

As the world moves fast into the era of 5G mobile communication technologies, LTE network, with its decade long technical developments and globe-wise deployments, is positioning itself as the primary infrastructure to fulfill IMT-2020 requirements to provide connections to all business, everywhere. The advantages of LTE as an all business connected primary infrastructure include:

- *Extensive coverage provided by the existing and forthcoming deployments all around the world;*
- *Very high data rate of a Gigabit network enabled by its rich set of techniques such as full-dimension MIMO, massive carrier aggregation and abundant amount of applicable spectrums;*
- *Ubiquitous user experience to satisfy requirements of various services ranging from high reliability, low latency, ultra-long range, to high sustained data rate for video;*
- *Tailored and optimized air interfaces for some specific use cases and services including NB-IoT, eMTC, LTE-V2X, WTTx, and more coming;*
- *Core network ready, easy network management and full capability to support upcoming technologies such as NR and New Core.*

Overall, the diverse features defined in LTE enable operators to provide connection for all business with good experience for end users everywhere while taking advantage of the legacy assets including spectrum, sites and legacy subscriptions. The smooth evolution of LTE with backward compatibility together with the easy and smart operation make it possible for the operators to provide superior experiences with affordable cost so that the whole eco-system can be developed in a sustainable manner.

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