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4G

LTE-Advanced Pro

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Introduction

Background

- The main target of inventing the 4G LTE cellular system is to provide high data rates to mobile end users.
- 3GPP Release 10 through Release 12 are known as LTE-A in which additional improvements have been made such as NB-IoT and device-to-device communications.
- There can be an enhancement towards 5G from 3GPP Release 13 to onwards by making further improvements.

(contd...)

Background

- The main aim of enhanced cellular systems is to provide cost efficient services in order to support massive machine type connectivity and to provide lower latency and reliable communication that can be supported by industries such as automotive, eHealth and robots.

(contd...)

Introduction

- 3GPP release 13 and 14 are considered as LTE-A Pro which is also known as 4.5G, 4.5G Pro, 4.9G, Pre-5G, 5G Project.
- It is a successor of 4G LTE-A.
- Beyond 3 Gbps data rates are supported by this technology by using 32-carrier aggregation.
- The License Assisted Access concept is also introduced in it due to which licensed and unlicensed spectrum sharing becomes possible.

(contd...)

Introduction

- Various other new technologies will also be incorporated which are associated with 5G such as 256-QAM, Massive MIMO, LTE-Unlicensed and LTE IoT that will help this technology to support 5G.
- Both higher peak data rates per user and more capacity of the system will be supported by the enhanced mobile broadband (eMBB).
- To connect billions of devices in a cost-efficient way Massive machine type communications (mMTC) will be employed that also help the cellular network to not get overloaded.

(contd...)

Introduction

- This is also known as massive Internet of Things (mIoT).
- The new requirements from vertical industries such as automotive, eHealth and robotics are supported by the ultra-reliable low-latency communications (URLLC).
- There can be a transition in phase towards the coverage of 5G the components of the LTE-A Pro technology provided by 3GPP Releases 13 and 14.

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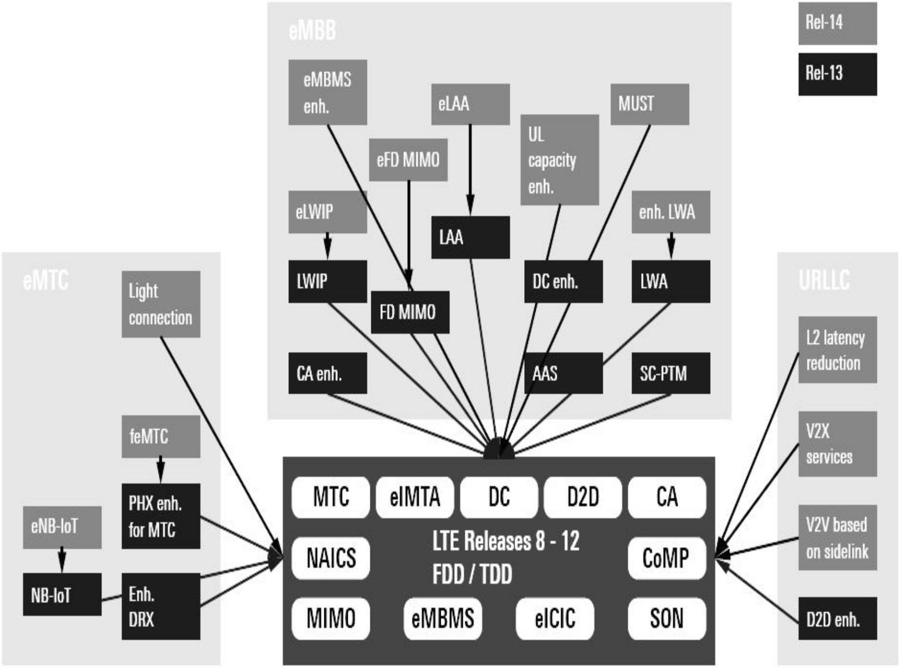
Introduction

- Figure shows the component dependencies of LTE-A Pro 3GPP Release 13/14 technology.



LTE-A Pro Features

- Higher data rates beyond 3GPP will be supported as it is enhanced version of LTE-A.
- Increased Bandwidth, increased efficiency and improved latency will be supported.
- Both licensed (400 MHz to 3.8 GHz) and unlicensed (5GHz) spectrum will be used so that upto 32 carriers of 20 MHz each can be supported.
- Backward compatibility with existing LTE and LTE Advanced devices.

(contd...)

LTE-A Pro Features

- Efficient use of spectrum with the increase of number of antenna paths as well as multi beam approach.
- A single radio cell can be served by using 16 to 64 antenna paths.
- Upto 200% increased network capacity.
- The battery life has increased to about 10 times as compared to LTE.

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LTE-A Pro Applications

- Used for mission critical public safety communications.
- Provides cost effective connectivity for IoT.
- Integration with 5G provides the way for programmable world.

(contd...)

Difference between LTE-A and LTE-A Pro

Specifications	LTE-A	LTE-A Pro
3GPP Standard Release	Release 10,11,12	Release 13 and beyond
Total carrier BW	100 MHz, 5 carriers of 20 MHz each	640 MHz, upto 32 carriers each of 20MHz bandwidth
Data Rates	1 Gbps	More than 3 Gbps
Latency	10 ms	Less than 2ms

(contd...)

Fundamentals

LTE-A Pro

- The latest version of LTE standard is LTE-A Pro which is also known as 4.5 G.
- It is an enhancement in LTE-A that can deliver significantly increased data speed, improved efficiency and capacity of the network.
- LTE-A Pro can be described as data superhighway that can achieve 1 Gbps data rate by using carrier aggregation, unlicensed band, 4x4 MIMO antenna scheme and 256 QAM increased modulation scheme.

(contd...)

Comparison between Different Standards

- 3GPP releases 13 (2016) and 14 (2017) are termed as LTE-A Pro standard.
- 3GPP releases 10 (2011), 11 (2012) and 12 (2014) are considered as LTE-A that has become highly available throughout the globe.
- There is a massive improvement in the devices of LTE-A over the LTE standard as it provides three times higher data speed and increased capacity.

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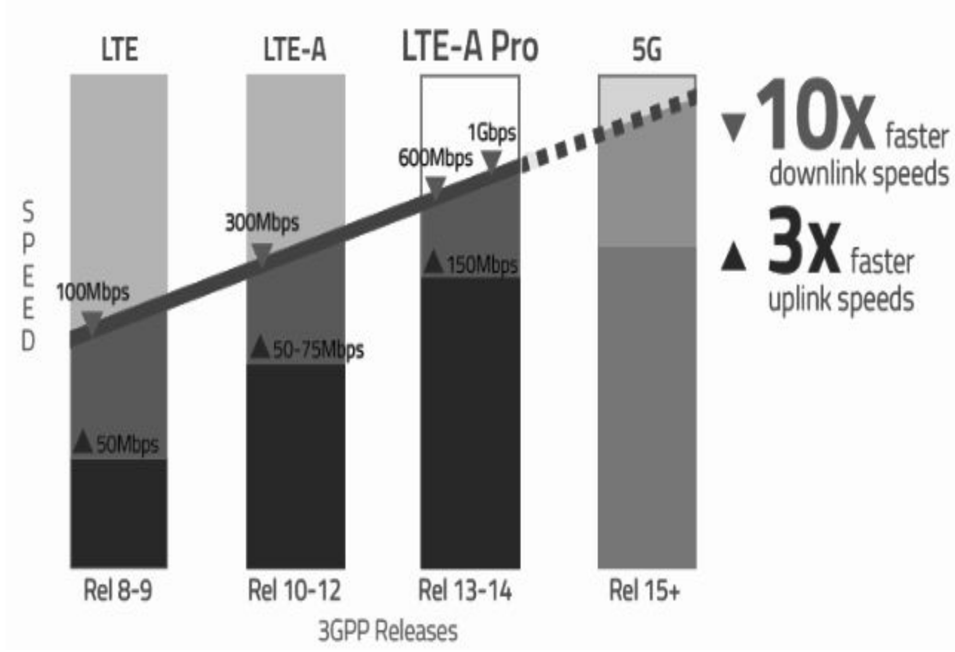
Comparison between Different Standards

- A download speed ten times faster and upload speed three times faster is provided by the LTE-A Pro standard with further enhanced efficiency and capacity.



Advanced Parameters

- Carrier aggregation
  - For 20 MHz bandwidth, carrier aggregation for upto 5 MHz is available in case of LTE-A
  - There can be a parallel transmission of combined frequencies that will deliver higher throughput.
  - Carrier aggregation of upto 32 carriers is used in LTE-A Pro each having a bandwidth of 100 MHz that can deliver an aggregated bandwidth of 640 MHz.

(contd...)

Advanced Parameters

- Network capacity and efficiency
  - The network capacity can be doubled in LTE-A Pro without employing any additional base station or spectrum.
  - Licensed Assist Access (LAA), enhanced LAA and LTE WiFi Aggregation (LWA) are supported by LTE-A Pro i.e. the data can be aggregated to provide additional bandwidth together from regular LTE bands, the 5GHz LTE-unlicensed spectrum and common WiFi networks.

(contd...)

Advanced Parameters

- The capacity can be increased by using the 4x4 MIMO antennas that allows simultaneous transmit and receive of multiple signals.
- More number of bits of data per symbol are carried by employing a 256 QAM modulation scheme that will also increase the throughput and the use of spectrum become better.

- LTE-A Pro provides longer battery life and a closer alignment is provided with 5G in order to provide improved network future-proofing.

(contd...)

Advanced Parameters

- Unlicensed spectrum
  - 5 GHz unlicensed spectrum will be used by the LTE-A Pro standard.
  - Frequencies from 400 MHz to 3.8 GHz are used by the primary carrier for its operation.
  - The unlicensed spectrum can be used by the carriers either standalone or aggregated with licensed spectrum.
  - This will allow expensive cellular resources to be used more effectively and subscribers are provided with increased speed.

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Applications of LTE-A Pro

- LTE-A Pro is ideally used for data-intensive, critical applications as faster data rates and improved network efficiency and capacity is offered by this network.
- Due to higher data rates, LTE-A Pro may be a better option for the future-proofing of the network.

(contd...)

The Rise of LTE-A Pro

Introduction

- 3GPP approved the new standard in October 2015, named as LTE-Advanced Pro, which is a successor of LTE-Advanced and LTE and denotes the next step towards the generation of 5G.
- 3GPP Release 13 and Release 14 define various specifications which are combinedly known as LTE-Advanced Pro.
- Various previous iterations are used to build LTE-A Pro so that the LTE platform can be improved and new use cases will be addressed.

(contd...)

Introduction

- The specifications for the 5G technology will be included in the 3GPP Release 15.

(contd...)

LTE

- In late 2008, there was an agreement of the specifications for the Long Term Evolution (LTE) access network.
- The NodeB 3G base stations were controlled by the radio network controller (RNC) in case of legacy 3G networks.
- The control functionality has been embedded in the evolved NodeB (eNodeB) base stations in case of LTE network and RNC will be removed from the network.

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LTE

- Hence, the quicker response times are allowed by this flatter, simple architecture.
- LTE aims to provide higher data rates as compared to that provided by legacy 3G.
- LTE-A is the further enhancement of LTE so that ITU requirements set for 4G can be completely fulfilled.
- Similarly, LTE-A Pro is the improvement of LTE-A and is evolution towards 5G.

(contd...)

Release 13 and Release 14

- 3GPP is the global organisation by which mobile technology standards specifications are consolidated and defined.
- After 3G, the focal point for mobile networks is 3GPP.
- The revision of specifications is measured in Releases and frozen refers the new features.
- When release is complete, it is ready for implementation.
- A number of releases are introduced by 3GPP and all the systems have made compatible with their predecessors as well as successors.

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Release 13 and Release 14

- The LTE-A technology has some additions in its features in the form of Release 13 and Release 14.
- In September 2012, R13 was begun and with 170 high level features and studies, it was frozen in March, 2016.
- In June 2016, the standardization of new narrowband radio technology known as NB-IOT was completed that can address the IoT market.
- In September 2014, the features and projects of R13 are used to build R14 by further enhancements and in June 2017, the work was frozen.

(contd...)

LTE-Advanced Pro

- The main aim of LTE-A Pro is to increase the data rates and the available bandwidth.
- A wide range of connected devices and platforms are brought by this network under a single standard.
- The capacity, performance, functionality and efficiency of LTE-A can be improved and optimized by deploying LTE-A Pro.
- Moreover, it will reduce the latency in order to provide the user with better experience.

(contd...)

LTE-Advanced Pro

- LTE-A Pro has been defined by the new attributes such as:
  - Data rates of 3 Gbps
  - Carrier bandwidth of 640 MHz
  - Latency of 2 msec.

(contd...)

LTE-Advanced Pro Fundamentals

- Large number of different technologies will be incorporated using LTE-A Pro.
- Faster data speeds are enabled by using carrier aggregation by increasing the available bandwidth with the use of more than one carrier.
- LTE-A key feature is carrier aggregation in which aggregation across FDD and TDD spectrum types has been supported.
- The number of different carriers will be increased by using the enhanced carrier aggregation upto 32.

(contd...)

LTE-Advanced Pro Fundamentals

- 3GPP introduced Licensed Assisted Access (LAA) to achieve this enhanced CA.
- LTE has an issue in spectrum availability whereas the availability of unlicensed 5 GHz frequency is used by Wifi networks.
- The simultaneous use of licensed and unlicensed spectrum bands are provided by using LAA so that the available spectrum can be efficiently used.

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LTE-Advanced Pro Fundamentals

- LTE and Wifi are aggregated by using LTE Wifi Aggregation (LWA).
- R14 uses enhanced LAA (eLAA) for aggregation of licensed and unlicensed spectrum in the uplink as well.
- In unlicensed spectrum, small cells are used ideally and there is a deployment as hotspots within coverage of macro cell.
- The growing demands of data transfer will meet by using these spectrums.

(contd...)

LTE-Advanced Pro Fundamentals

- Per-user throughput and mobility robustness will be significantly improved by using dual connectivity to aggregate small and macro cells in LTE-A Pro.
- Dynamic aggregation of uplink and downlink allow that varying traffic needs are adjusted by
  - Changing configuration of UL/DL on basis of traffic
  - Enabling traffic offloading in downlink

(contd...)

LTE-Advanced Pro Fundamentals

- The latency can be reduced more than tenfold due to the new FDD/TDD design.
- The future capacity demands are addressed by deploying two key technologies i.e. beamforming and MIMO.
- The main focus of beamforming is on the azimuth dimension prior to LTE-A at the ground level.

(contd...)

LTE-Advanced Pro Fundamentals

- Elevation beamforming becomes the point for investigation in LTE-A in which large buildings are targeted by the antenna array.
- FD-MIMO has been exploited by the LTE-A Pro in which both elevation and azimuth beamforming has been supported so that the capacity and coverage can be boosted.
- At the eNodeB, 8, 12 and 16-antenna elements are supported by R13 and upto 64-antenna ports are supported by R14.

(contd...)

LTE-Advanced Pro Features

- New devices and new services are introduced by LTE-A Pro to serve new industries and pave the way for IoT.
- The focus is on the development of new devices whose battery life is improved, cost can be reduced and coverage is extended.
- Many IoT applications need new category devices with low cost and low throughput.

(contd...)

LTE-Advanced Pro Features

- NB-IoT and LTE-M technologies are encompassed by LTE-A Pro in which low power devices are provided with the lower speed narrowband access.
- For M2M communication, LTE uses its variant LTE-M.
- For more powerful devices that need high throughput and low latency, high bandwidth networking is required.

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LTE-Advanced Pro Features

- Thousands of devices are discovered within a proximity of around 500m by enabling D2D technology so that proximity services can be facilitated.
- The main focus of proximity services is on public safety applications that started with LTE-A and continued into R13.
- The main aim of R13 is the multiplexing of regular devices with the reduced bandwidth MTC devices in the existing LTE networks.
- D2D and D2N relays for IoT and wearables are the areas of focus in R14.

(contd...)

LTE-Advanced Pro Features

- Defining the D2N relay architecture is the main aim of R14.
- The other important aspect of R13 was the use of LTE for emergency services and public safety which will be further continued in R14.
- V2X communications is another key aspect of R14 in which connection is made between vehicles and infrastructure, people or networks so that autonomous cars can be enabled.

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The Goals of LTE-A Pro (I)

Overview

- The popular technologies that are practically used nowadays are LTE and LTE-A which have more than 700 subscribers, more than 420 commercial networks and 450 Mbps data rate has been provided.
- The performance of these technologies can be improved by the further enhancements.
- More efficient mobile broadband services will be provided by the improved radio capabilities.

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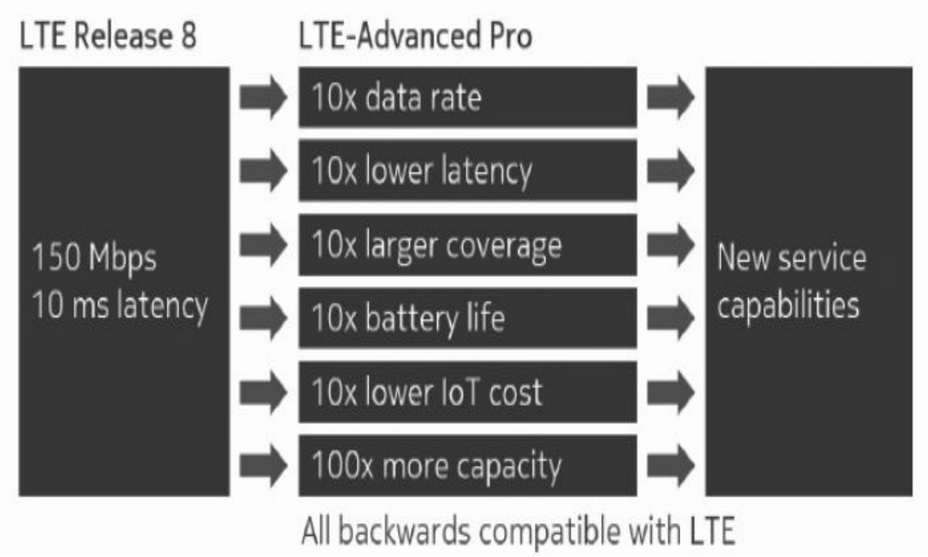
Overview

- Therefore, high quality will be provided and new set of services will be enabled on the top of LTE-A.
- 3GPP releases 13/14 define these features as shown in the figure.



Overview

- These releases are combinedly known as LTE-A Pro.
- The programmable world will be enabled by these developments for billions of connected IoT devices and public safety or critical communications.
- The data rates of users are raised to several Gbps by LTE-A Pro, latency has been reduced to few milliseconds, access has been given to unlicensed 5 GHz spectrum and efficiency of the network has been increased.

(contd...)

Overview

- Backward compatibility has been maintained with the existing LTE networks and devices.
- Similar technology components will be used by both LTE-A Pro and 5G so that radio capabilities will be enhanced.
- A new radio technology that is non-backward compatible is 5G which will operate below as well as above 6 GHz frequencies and higher data rates will be provided at lower latency.

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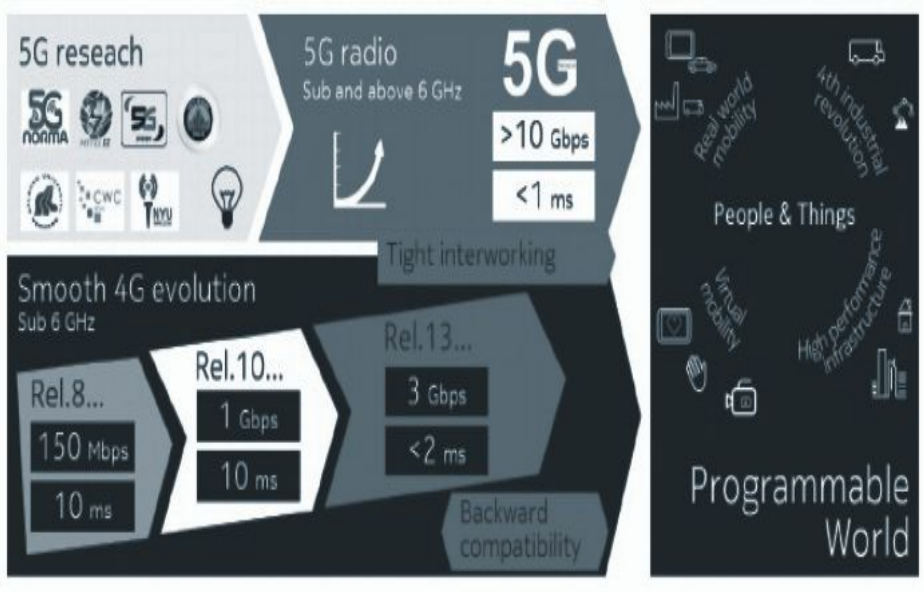
Overview

- LTE-A Pro will operate below 6 GHz and its development work is evolving along with that of 5G as shown in the figure.



Multi-Gbps data rates with carrier aggregation evolution

- The LTE has been originated with a peak data rates of 150 Mbps and bandwidth of 20 MHz.
- Carrier aggregation has been used in Release 10 of 3GPP so that the peak data rates were upgraded.
- A maximum capability of Release 10 of 3GPP is upto 5x20 MHz, that provides 1 Gbps with 2x2 MIMO and 64 QAM and 3.9 Gbps with 8x8 MIMO.

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Multi-Gbps data rates with carrier aggregation evolution

- More spectrum and more antennas can increase the data rates.
- The use of comparatively large antennas at base stations make the higher number of elements of antennas feasible.
- The challenge is the integration of further antennas into small devices.
- Hence, more spectrum is used to increase the data rates for them.
- The carrier aggregation has been enhanced to enable 32 carrier components to increase the data rates in Release 13.

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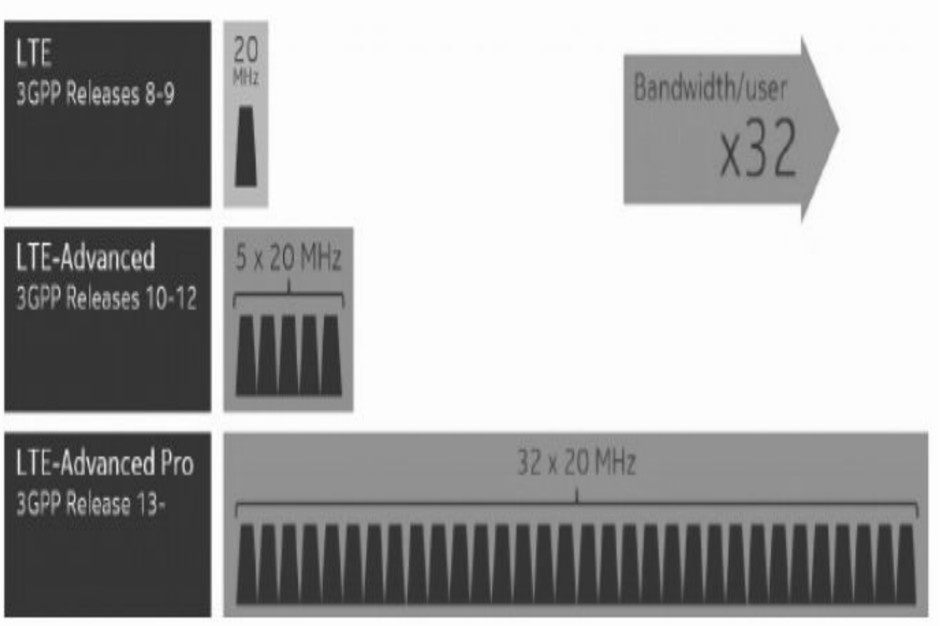
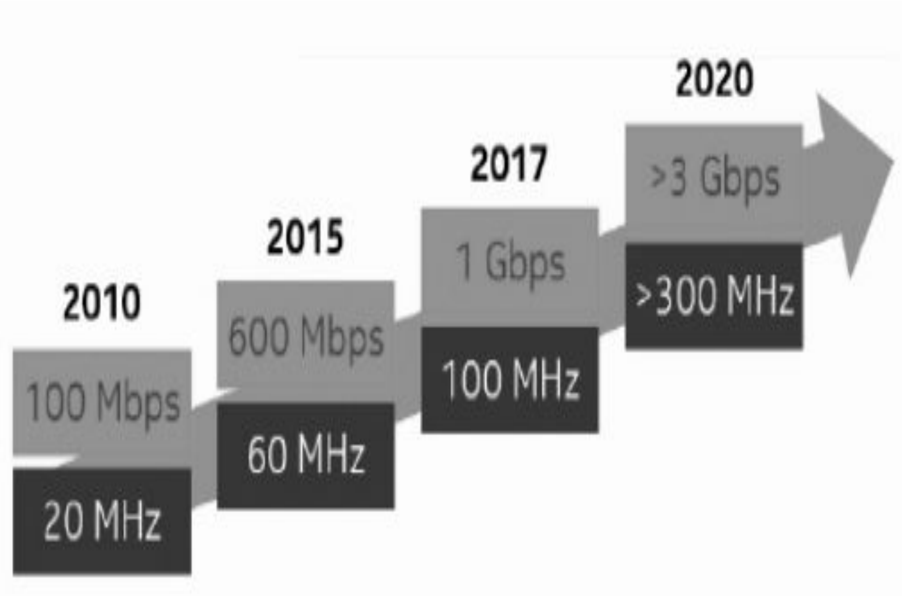
Multi-Gbps data rates with carrier aggregation evolution

- Figure shows the evolution of carrier aggregation in different LTE standards.



Multi-Gbps data rates with carrier aggregation evolution

- Figure shows the evolution in the peak data rates in different LTE standards.



Multi-Gbps data rates with carrier aggregation evolution

- When ten LTE carriers are aggregated, each of 20 MHz, a throughput of 4.1 Gbps was achieved.
- There can be a use of total bandwidth of 200 MHz.

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Using the 5 GHz Band

- The licensed spectrum between 450 and 3600 MHz is used to deploy the LTE networks.
- The capacity and peak data rates for LTE-A Pro will be improved with the use of unlicensed as well as licensed spectrum.
- The spectrum is available in plenty in the unlicensed 5 GHz band which is suitable for deployment of small cells.

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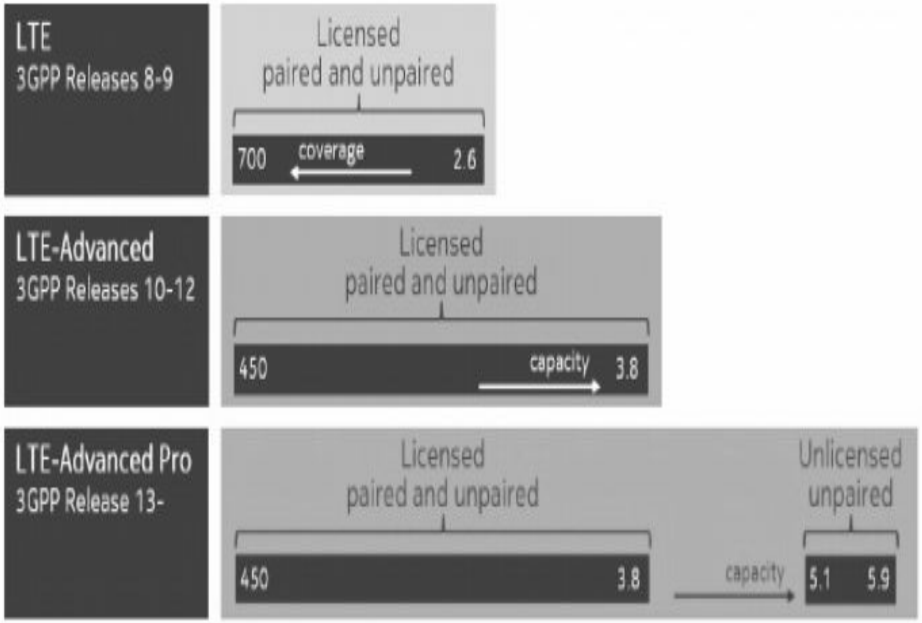
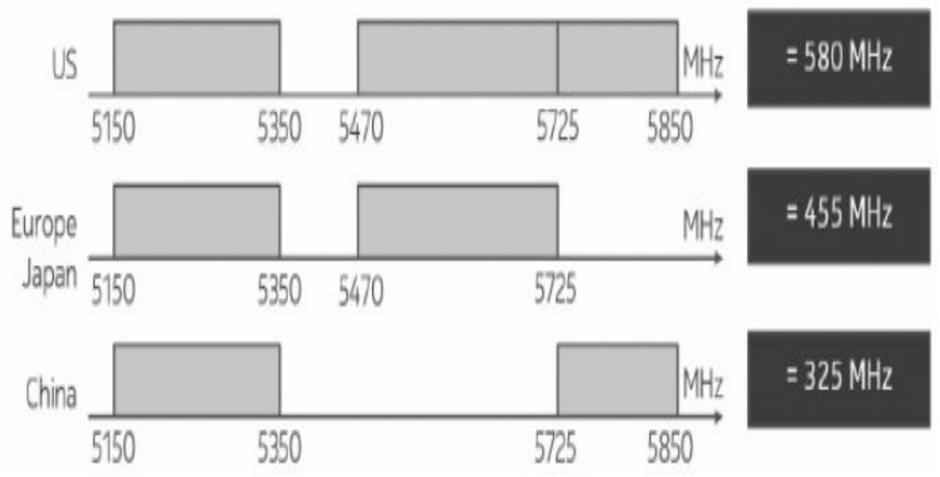
Using the 5 GHz Band

- Figure shows the evolution in the usage of LTE spectrum.



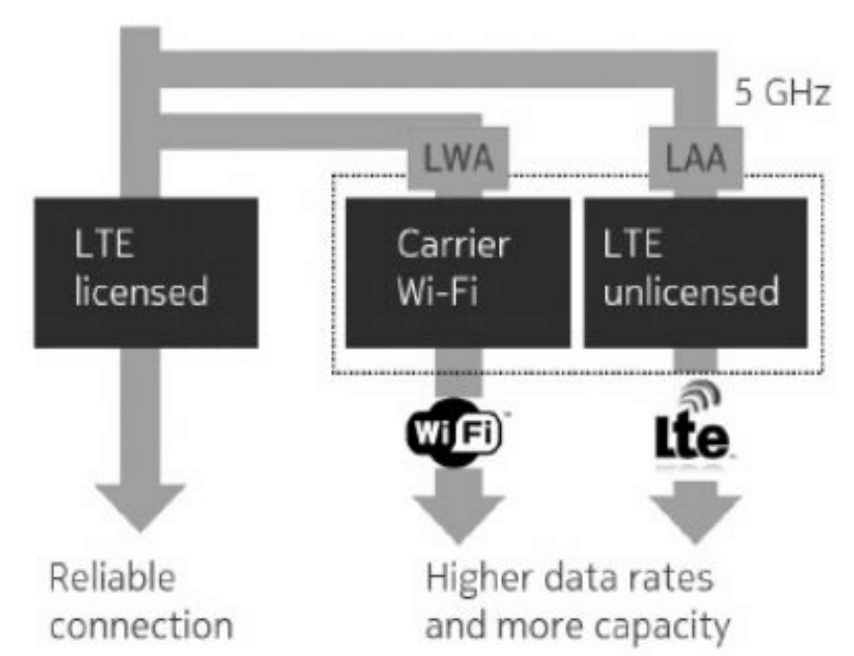
Using the 5 GHz Band

- Figure shows availability of spectrum in the 5 GHz band.



Using the 5 GHz Band

- Unlicensed band spectrum can be used by the LTE-A Pro through Licensed Assisted Access (LAA) or with the integration of Wi-fi via LTE Wifi Aggregation (LWA).
- Figure shows both the solutions.



Using the 5 GHz Band

- The licensed and unlicensed spectrum will be combined to use by LTE when LAA is employed by using carrier aggregation.
- To offload traffic, LAA is a highly efficient method as it can split the data traffic between licensed and unlicensed frequencies with millisecond resolution.
- The reliable connectivity, mobility, signalling and guaranteed data services can be provided by the licensed band.

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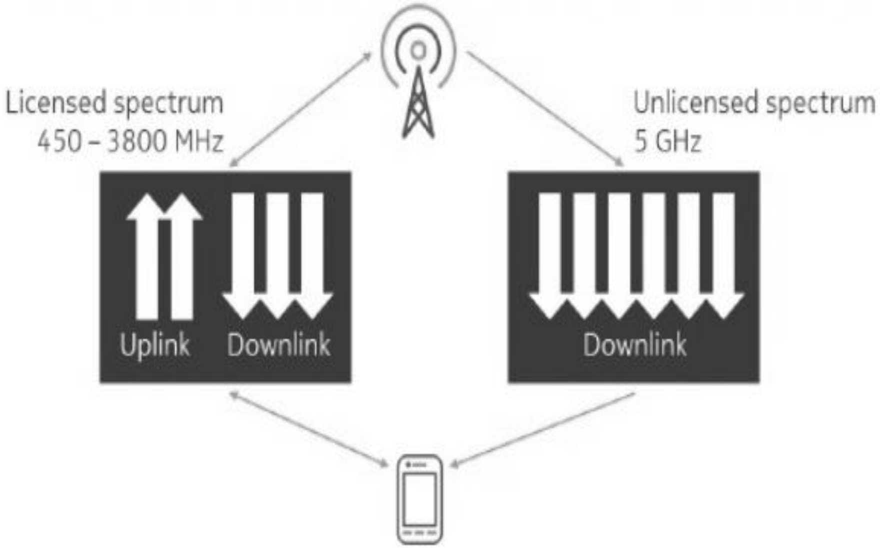
Using the 5 GHz Band

- The significant boost in data rates is provided by the unlicensed band.
- Dual connectivity and carrier aggregation based the technical solution is used to combine the licensed and unlicensed spectrum.



Using the 5 GHz Band

- LTE and Wifi transmissions are aggregated by the LTE-A Pro so that unlicensed band can be used efficiently.
- The application layer is used to implement LTE and Wifi interworking.
- There can be a splitting of data traffic between LTE and Wifi transmission, so both paths are used by the user device to receive data simultaneously.

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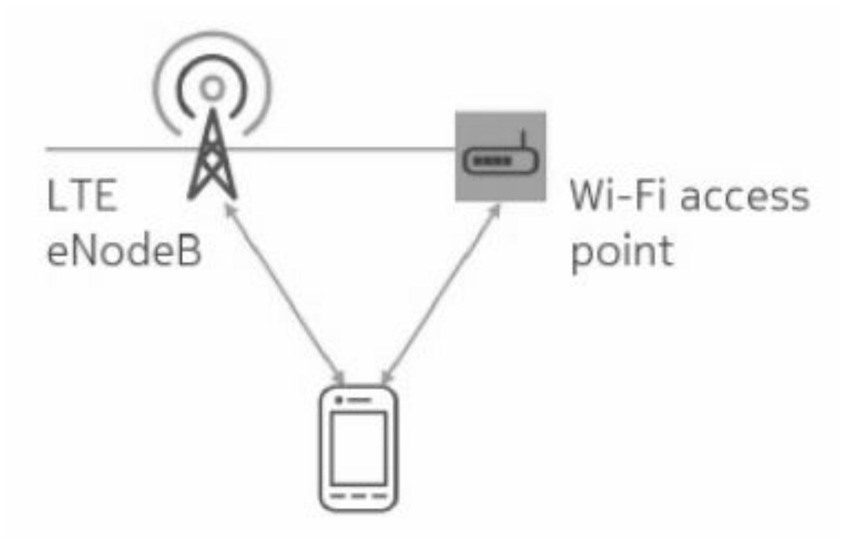
Using the 5 GHz Band

- Hence, the Wifi capacity can be fully utilised and LTE connection can be maintained to provide reliable mobility and connectivity.



The Goals of LTE-A Pro (II)

Enhanced Spectral Efficiency with Beamforming

- High spectral efficiency has been provided by the LTE.
- MIMO technology has been used to further boost the efficiency of the LTE standard that includes 4x2 MIMO, 8x2 MIMO and 4x4 MIMO.
- Three dimensional (3D) beamforming has been introduced in LTE-A Pro which is known as Full Dimensional MIMO (FD-MIMO).
- The high spectral efficiencies can be unlocked when the number of transceivers at the base station are increased.

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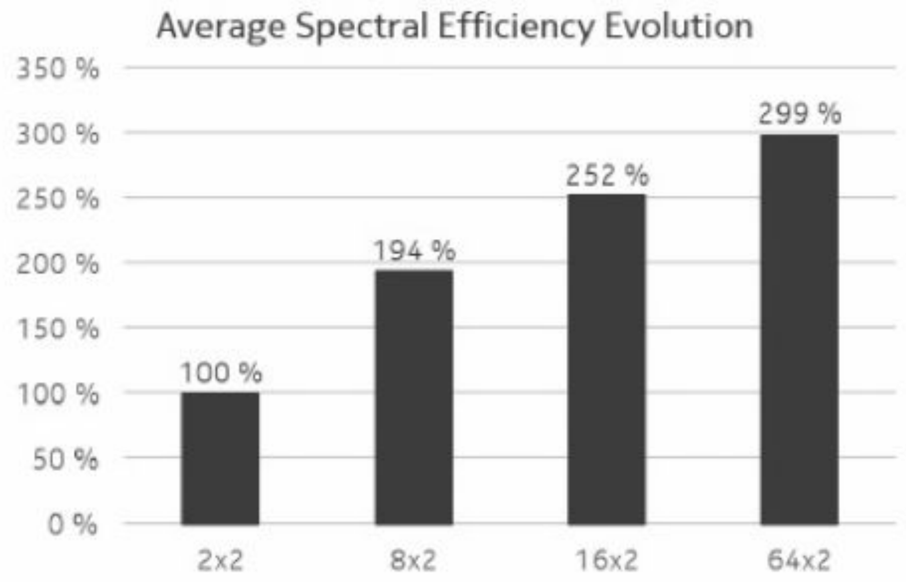
Enhanced Spectral Efficiency with Beamforming

- MIMO modes for upto 16 transceivers at the BS are specified by Release 13 and 64 by Release 14.
- Hence, for downlink, the efficiency gain can be improved as shown in the figure.



Enhanced Spectral Efficiency with Beamforming

- A 2.5-fold gain in spectral efficiency has been provided by 16x2 as compared to 2x2 whereas 3-fold gain is provided by 64x2.
- 64x2 provides 50% more gain as compared to 8x2.
- There are four columns of cross polarized antenna elements in 8x2, 16x2 and 64x2 configuration each with same physical dimensions whereas there is only one column in 2x2 configuration.
- The same total transmission power is provided by all the configurations.

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Enhanced Spectral Efficiency with Beamforming

- ❑ Number of receiving antennas are used to improve the uplink efficiency.
- ❑ The signals received in the form of CRAN from 4, 8 or more transceivers are aggregated to deploy this method.
- ❑ Active antenna arrays make it possible to deploy a large number of transceivers.
- ❑ The array is integrated with RF amplifiers, filters or digital processors along with passive radiating elements.

(contd...)

Enhanced Spectral Efficiency with Beamforming

- The radio moves closer to the radiating elements by using such active arrays effectively, that will reduce the feeder loss as well as the top-tower structure footprint.
- A single baseband processing unit is used to connect several distant antenna locations using an optical fiber or within a cloud RAN solution.

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Extreme Local Capacity with Ultra-dense Network

- High efficiency has been provided by the radio of LTE-A in the macro cellular layer.
- The increased local capacity has been provided by deploying the small cells.
- Dense urban areas deploy such high traffic hot spots.
- Greater efficiency can be brought by defining a number of enhancements by 3GPP for deployment of small cells coordinated with the existing macro layer.

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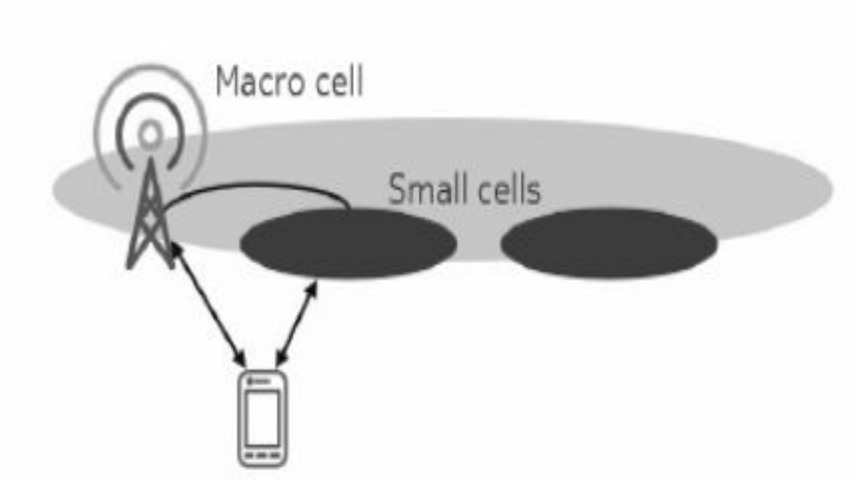
Extreme Local Capacity with Ultra-dense Network

- There can be an addition of Further enhanced Inter-Cell Interference Coordination (FeICIC) in Release 11 and dual connectivity in Release 12.



Extreme Local Capacity with Ultra-dense Network

- The user device receives simultaneous data from two different sites served by non-ideal backhaul by providing dual connectivity with inter-site carrier aggregation.
- The uplink transmission to two sites can be supported by Release 13 by enhancing the dual connectivity.
- Macro cells and number of small cells are consisted in the HetNets and this technique will become important for these networks.

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Extreme Local Capacity with Ultra-dense Network

- A number of benefits are brought for deployment of small cells by combining reliable mobility in the macro layer with the high capacity and enhanced data rates available from the small cells.
- The basis for LTE/5G and LTE/Wifi integration is provided by this dual connectivity.

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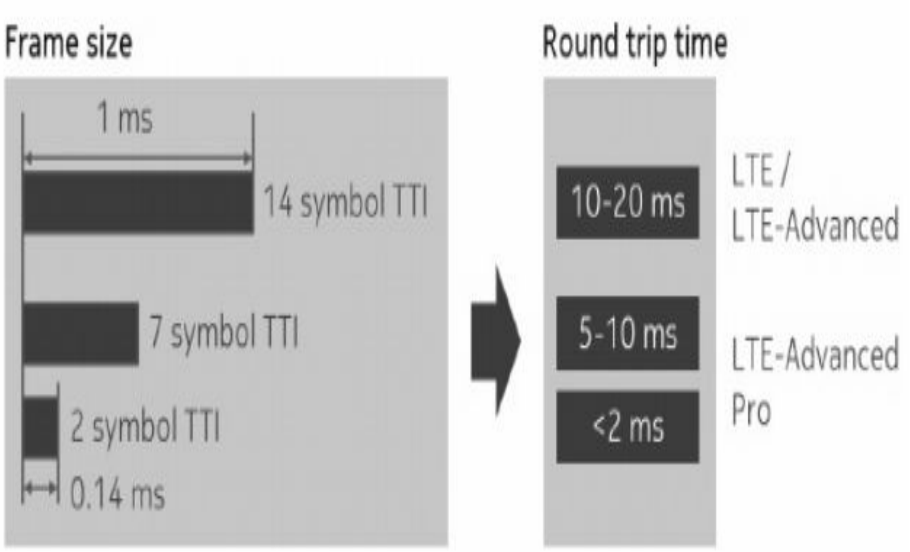
Millisecond Latency with Flexible Frame and Mobile Edge Computing

- The main aim of enhancing the cellular systems is reduction of latency and increase in bit-rates.
- The buffer requirements can be reduced at high data rates by lowering the latency.
- The latency problem can be tackled by LTE-A Pro with the frame length reduction and the physical layer control optimization of the air interface resources.

(contd...)

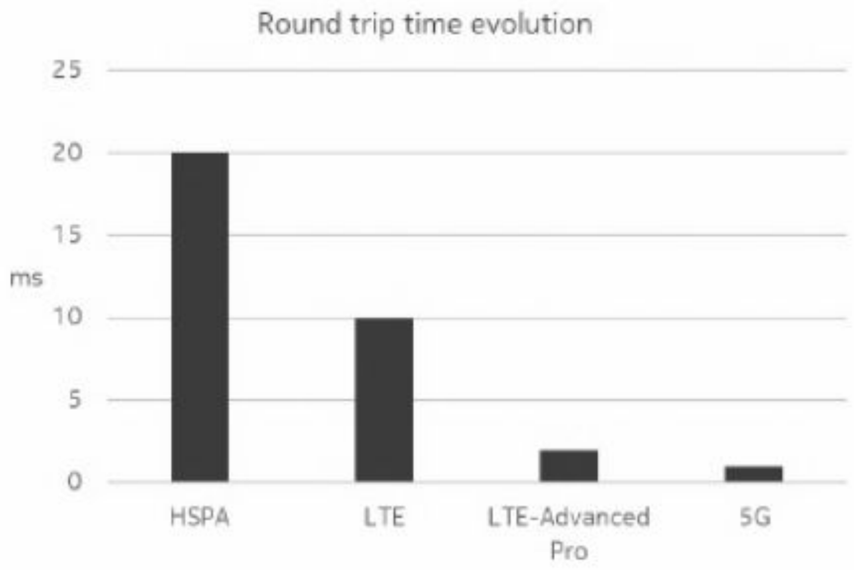
Millisecond Latency with Flexible Frame and Mobile Edge Computing

- The evolution of LTE frame structure and TTI are shown in the figure.
- The shorter TTI and delay in the air interface are directly proportional to each other.
- Reduce the number of symbols to shorten the TTI.



Millisecond Latency with Flexible Frame and Mobile Edge Computing

- A round trip time of 10-20 msec is produced by TTI of 1 msec used in LTE.
- A round trip time of less than 2 msec and one-way delay of less than 1 msec is provided by LTE-A Pro.
- Figure shows the evolution of round trip time.



Millisecond Latency with Flexible Frame and Mobile Edge Computing

- The time taken to allow transmission to the device and acknowledgement of received data causes latency in the physical layer.
- Hence, the latency can be shortened by the optimization of this time.
- A large part of fixed delay will be eliminated by the pre-allocating uplink grants.
- For voice services, semi-persistent scheduling uses this kind of technique.

(contd...)

Millisecond Latency with Flexible Frame and Mobile Edge Computing

- This can also be applied for other services in which the transmission of a small amount of data is performed in random fashion.
- There can be a reconsidering of the fixed latency occured due to the current synchronous ACK.
- In downlink, asynchronous ACK can also be employed in addition with potentially restricted data sizes.

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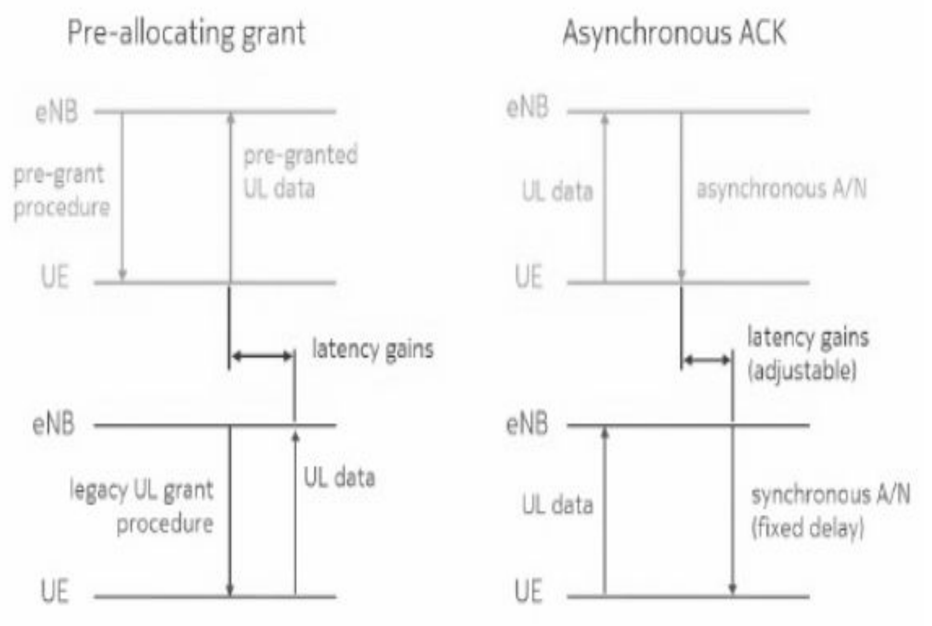
Millisecond Latency with Flexible Frame and Mobile Edge Computing

- Figure shows the uplink data procedures improvements.



Millisecond Latency with Flexible Frame and Mobile Edge Computing

- Mobile Edge Computing (MEC) is deployed to reduce end-to-end delay in content delivery.
- In this technique, the large amounts of localized data can be delivered to the user with lower delay without any burden to the core network.
- The benefits of MEC can be complemented by providing better radio interface in low-latency LTE-A Pro standard.

(contd...)

The Goals of LTE-A Pro (III)

Internet of Things (IoT)

- The interconnection and exchange of data between devices (machines or parts of machines including sensors and actuators) is referred to as IoT.
- There are tens of billions of IoT devices in the future connected world.
- The IoT can be served by LTE evolution by enhancing its ability by allowing coverage improvement, power consumption, cost and connectivity of the device.

(contd...)

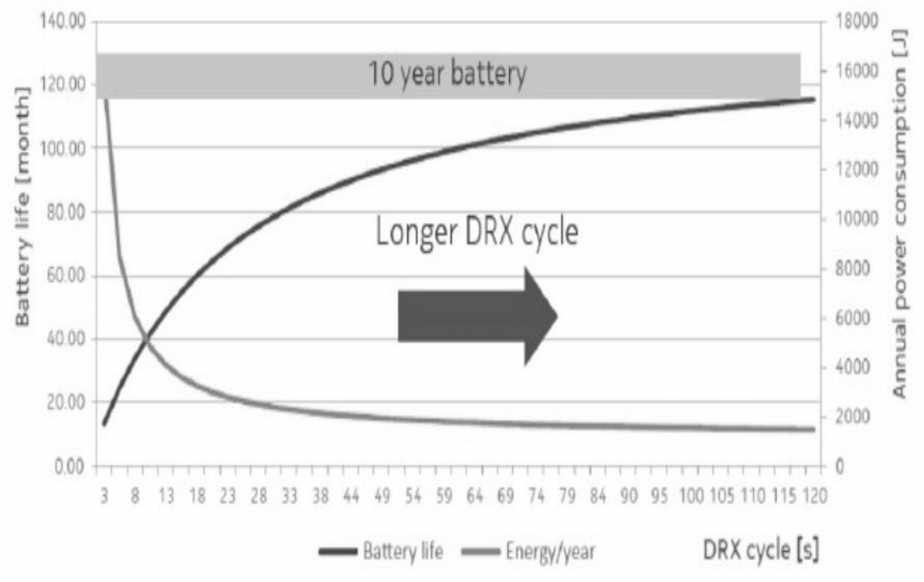
Internet of Things (IoT)

- The coverage for power-limited devices can be extended by IoT optimization in Release 13 by repetition and power spectral density, 164 dB boost in path loss, enable the operation of power-limited devices in cellars or indoor places.

(contd...)

Internet of Things (IoT)

- The introduction of Discontinuous Reception (DRx) cycles in Release 13 allows the improvement of battery consumption i.e. 2 AA batteries are used to allow upto 10 years battery life.



Internet of Things (IoT)

- Low cost device use has been supported by LTE that is enabled by reducing modem complexity and narrowing the operating bandwidth to upto 200 kHz.
- Moreover, the capacity of the networks can be improved by optimizing signaling and network so that a single network serves the tens of billions of devices.

(contd...)

Internet of Things (IoT)

- Figure shows the enhancements in IoT in LTE-A Pro.

	LTE-Advanced	NB-IoT
Coverage	140-145 dB	164 dB
Operation time with with two AA batteries	1 year	10 years
Device cost	Reference	-85%

Internet of Things (IoT)

- IoT devices are supported by the operators with LTE networks using category 1 devices from Release 8.
- Category 0 devices use upgraded network software that reduces the cost and power consumption in the devices in case of Release 12.
- Narrow-band 200 kHz IoT solution further reduces the cost in 3GPP Release 13.
- VoLTE prioritization uses QoS differentiation in data services for subscriber differentiation.

(contd...)

Internet of Things (IoT)

- Higher priority is also provided by applying QoS to IoT connectivity for critical IoT communication whereas there is a delay in the transmission of the lower priority packets.

(contd...)

Device to Device Communications

- The direct communication between two devices is also defined by 3GPP under D2D communications.
- There are several ways to use the D2D functionality, such as:
  - For V2V communications
  - For public safety
  - For social media
  - For advertisements

(contd...)

Device to Device Communications

- Cars have installed communication equipments that are used for diagnostics of remote cars including entertainment in car or fleet tracking.
- The automotive environment has transformed fundamentally by deploying vehicles with more integrated networking.
- The introduction of public safety system is the main aim of D2D.

(contd...)

Device to Device Communications

- Hence, the self-driving cars environment is provided, real time management of traffic is performed in cities and users are provided with the services related to car and traffic.
- Vehicular communications is also supported by LTE-A Pro so that coverage is provided for vehicle-to-infrastructure or vehicle-to-pedestrian communication, D2D communication can be enabled and low latencies will be supported.

(contd...)

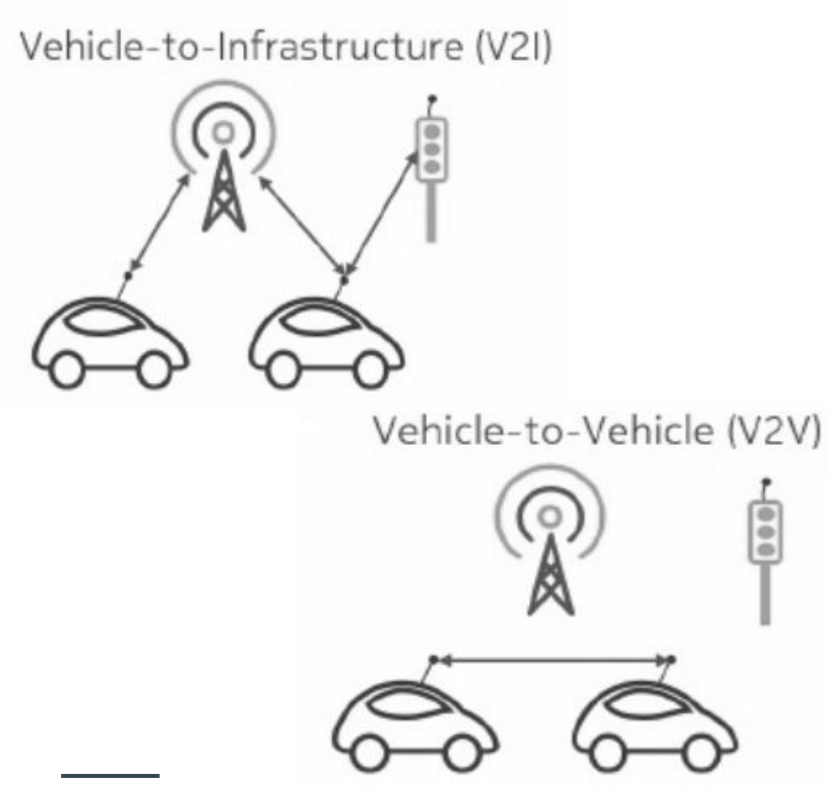
Device to Device Communications

- V2V communication has enabled public safety application as its main application that includes collision avoidance.
- The routing of V2V communication with the base station or by broadcasting of base stations or group-casting information to cars helps to accomplish the network for vehicular communication.
- Vehicular communications applications use LTE MEC solutions to retrieve dynamic map or to manage localized car traffic.

(contd...)

Device to Device Communications

- LTE radio has been used for smart traffic in vehicular communication as shown in the figure.



Cloud Radio Architecture for Network Scalability

- Various new functionalities are introduced through LTE-A Pro that allows these functionalities, extending from the core network to RAN, to move to the cloud.
- The service and savings introduction has been enabled by using the cloud approach in operating expenditure.
- The more challenging is the radio cloud due to requirement of very low latency at the radio processing and requirement of dedicated hardware at layer 1 processing for high efficiency.

(contd…)

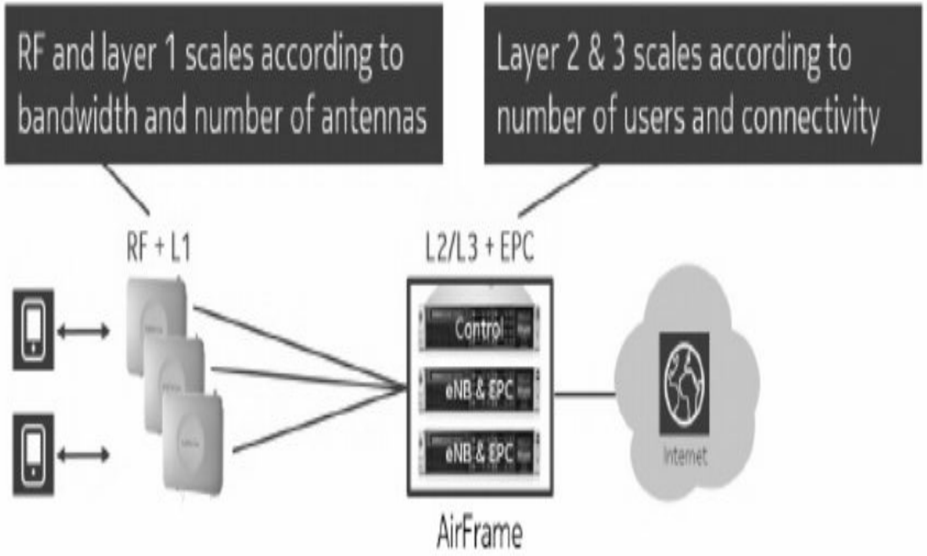
Cloud Radio Architecture for Network Scalability

- There can be an integration of low-latency layer 1 with the RF in the cloud radio solution.
- The location of layer 2/3 is within the cloud.
- The RF bandwidth and the number of antennas are used to determine the layer 1 processing and the number of users connected and the signaling requirements relates the layer 2/3 processing.

(contd...)

Cloud Radio Architecture for Network Scalability

- Greater flexibility has been provided by a cloud-based layer 2/3 that will increase the capacity of the network as there is an increase in the number of IoT objects.
- Figure shows cloud RAN.



Cloud Radio Architecture for Network Scalability

- The introduction of asynchronous Automatic Repeat Request (ARQ) retransmissions make deployment of radio cloud more flexible in case of LTE-A Pro.
- The flexibility of radio cloud deployment in the initial LTE standards is limited due to only synchronous ARQ support where fixed transmission delay is there.
- The latency flexibility becomes more in asynchronous ARQ.

(contd...)

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Licensed Assisted Access (LAA)

Introduction

- Advantage of CA has been taken by this feature of 3GPP Release 13.
- Any licensed 3GPP band is used to deploy the primary cell (PCell) which acts as an anchor cell in LAA.
- For downlink only operation, R13 uses secondary cell (SCell) that boost the data rates and are deployed in the 5 GHz ISM band.
- Up to four LAA SCells are deployed by R13 in this frequency band.

(contd...)

Introduction

- R13 introduced some additional features to enable this functionality, such as:
  - Frame structure type 3 and discontinuous transmission
  - Listen before talk
  - Measurement of signal quality of UE for carrier selection

(contd...)

Frame Structure Type 3

- The secondary cell operation of LAA uses frame structure type 3 with normal cyclic prefix only.
- For frame structure type 3, the duration for radio frame is 10 msec.
- For downlink transmission, there is an availability of all 10 subframes where one or more consecutive subframes are occupied for transmission starting at the first or second slot boundaries within the subframe.
- The implementation at the eNodeB become simple by limiting the flexibility to start a transmission only to slot boundaries.

(contd...)

Frame Structure Type 3

- There is a reuse of frame structure type 2 downlink pilot time slot (DwPTS)architecture.
- There is a signalling of the start position and the number of OFDM symbols of the current and next downlink subframe to the device in LAA SCell so that implementation on the UE end will be simplified.
- The downlink control information (DCI) format 1C in scrambling with the cell controlling radio network temporary identifier (CC-RNTI) is used to signal the number of occupied OFDM symbols in the last subframe of the transmission.

(contd...)

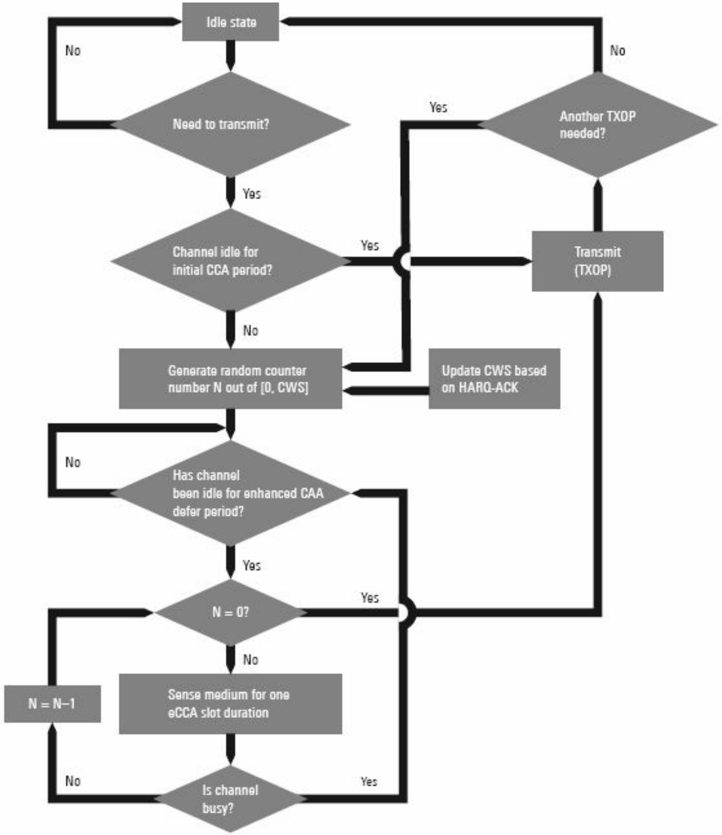
Listen Before Talk

- The listen before talk (LBT) principle is applied so that minimum channel occupancy time will be ensured.
- LAA adopted clear channel assessment (CCA) based category 4 LBT mechanism.
- A random backoff is used in LBT mechanisms described in category 4 with variable-sized contention window.

(contd...)

Listen Before Talk

- LAA LBT procedure for downlink is shown in this flowchart.
- CCA is applied by LAA in two steps:
  - An initial CCA
  - An enhanced CCA
- LAA applied CCA on the basis of energy detection (ED) over a defined time duration.



Listen Before Talk

- The detected energy should be below the threshold value.
- Wi-Fi ACK/NACK transmission can be protected by providing the defer time between access points and clients.
- The transmission is done by the transmitter for a limited amount of time if the channel is clear and this time is known as the maximum channel occupancy time.
- The “enhanced CCA” period is started if the channel is occupied by generating a random number from the contention window.

(contd...)

Discontinuous Transmission

- One part of the specification in some geographical regions for LAA operation is discontinuous transmission.
- After sensing the idle channel, the immediate transmission is performed by eNB on the LAA SCell for a maximum duration of 4 ms.

(contd...)

Discovery Reference Signal in LAA

- 3GPP Release 12 introduced the discovery reference signal (DRS) as an enhancement towards small cell operation.
- A small cell is allowed for transition from off state to on state very quickly by using DRS and a low duty cycle signal is transmitted for RRM.
- Any subframe can be used to transmit DRS in LAA within the discovery measurement timing configuration (DMTC) occasion.
- For transmission, there can be a use of only one subframe and only the first 12 OFDM symbols of this subframe.

(contd...)

Discovery Reference Signal in LAA

- PBCH is not transmitted.
- If PDSCH is scheduled in a particular subframe, only then it can be transmitted by embedding DRS with data.
- DRS can be transmitted through the radio frame and subframe depending on the parameters of RRC to which device is signaled.

(contd...)

Radio Resource Management in LAA

- It is very important for LAA to coexist with other technologies so the already congested frequencies/channels are accessed and used and avoiding the clients.
- The signal quality measurements such as reference signal received power (RSRP [dBm]) and reference signal received quality (RSRQ [dB]) are defined in LTE as RRM is critical.
- The key performance indicator for interference is RSSI on a given carrier.

(contd...)

Radio Resource Management in LAA

- DRS is needed to measure RSSI.
- Time information when measurement has been taken is included in RSSI measurement report of UE capable of LAA.
- A measurement period, a subframe offset and a measurement duration are used by higher layer to configure an RSSI measurement time configuration (RMTC).

(contd...)

Radio Resource Management in LAA

- The RSSIs are averaged by the device over the measurement duration and according to the periodicity, measurements are taken.
- The average RSSI as well as the channel occupancy (CO) is reported by the device.
- The load and interference situation is indicated by both measures on the given SCell of LAA.

(contd...)

eLAA Introduction

- 3GPP Release 14 defined the enhanced licensed assisted access (eLAA).
- The way in which the 5 GHz ISM band has been accessed by the UE for data transmission in the uplink direction is defined by eLAA.
- The first difference to LAA is scheduling of all uplink transmissions under the control of serving eNB.
- Hence, channel contention between devices is affected as it is required that LBT works in uplink direction also.

(contd...)

eLAA Introduction

- The second major difference is fulfilling the regulatory requirements when certain regions use 5 GHz ISM band.
- There is a scheduling of two clusters of resource blocks from each other by multi-cluster PUSCH in order to fulfill requirements of bandwidth.

(contd...)

Evolution to 5G

Introduction

- The future of mobile network development is dependent on the evolution of LTE-A Pro technology.
- There is a backward compatibility of this network on the frequencies of LTE networks and devices.
- While, 5G is non-backward compatible which is assumed to be available commercially in 2020 on a wide scale.
- It is expected that a much bigger impact has been brought by 5G to the global economy as compared to 3G or 4G.

(contd...)

Introduction

- The operators are migrated from circuit-switched to fully packet-switched network with the availability of 4G networks that improve the network capacity, data rate, and latency.
- The new business opportunities have been created with the invention of data-driven business model in the adjacent markets that include the Internet of Things (IoT), automotive, and many more.
- A close interworking is defined by 3GPP between LTE-A Pro and 5G e.g. dual connectivity.

(contd...)

Introduction

- There is a rise of new growth opportunities such as
  - Use of mobile broadband increases
  - New use cases will be derived by the smartphone devices
  - New types of high-quality streaming content
  - The new device types across industry grows in number that is vertically connected to internet.

(contd...)

Introduction

- The innovative technologies are developed by R&D in order to meet the faster, better mobile broadband services demands so that user experience can be enhanced and cost can be lowered.
- Only excellent LTE networks will provide high performance 5G networks.

(contd...)

New Business Models

- High speeds are offered more efficiently by the updated LTE networks and new use cases are enabled by them so that mobile service providers enter the new market.
- New advancements in LTE will continue even when 5G NR specifications will be defined in parallel.
- Release 14 and beyond continues to evolve as LTE-A Pro.

(contd...)

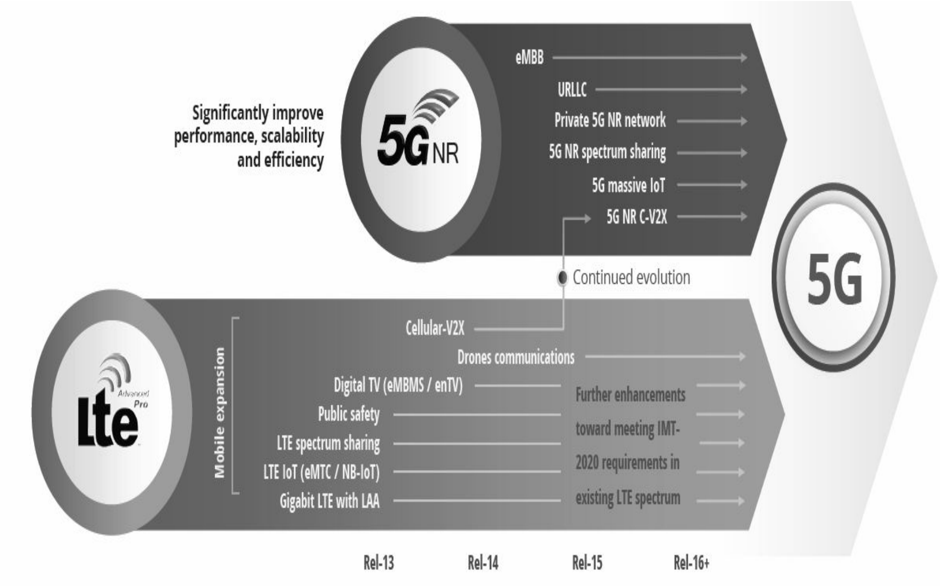
New Business Models

- There is an introduction of many new functionalities for mobile broadband including MIMO, 32-ports, 1024-QAM, eLAA, ULL.
- There is an introduction of C-V2X in Release 14 for expansion of LTE to new industry in order that LTE IoT capabilities and efficiencies can be enhanced.
- LTE-A Pro and 5G NR will be submitted in parallel so that the requirements of the International Telecommunication Union's (ITU) IMT-2020 5G can be fulfilled.

(contd...)

New Business Models

- Many essential services are provided by these LTE technologies for initiation of 5G technology.
- Figure shows the features of current LTE-A Pro that set the foundation for 5G.



GIGABIT LTE

- The Gigabit LTE provides enhanced speeds and network performance under all conditions throughout the cell.
- 300 Mbps or higher real-world speeds are provided by this.
- There are various benefits of Gigabit LTE i.e.
  - Approximately 1 sec is required to download a clip by devices compatible to Cat. 16.
  - Only 6 sec are taken by the devices compatible to Cat. 4 to download the file.

(contd…)

GIGABIT LTE

- The technologies required to achieve Gigabit LTE are:
  - 4x4 MIMO
  - 256 QAM
  - 3+ CA
- There is no need to acquire new spectrum or employing cell splitting or cell sectoring methods to support Gigabit LTE.

(contd…)

Connection to IoT

- The two complementary narrowband LTE technologies are introduced by Release 13 of 3GPP i.e.
  - Enhanced Machine-Type Communication (eMTC)
  - Narrowband IoT (NB-IoT)
- These are collectively known as LTE IoT.
- A downlink peak rate of ~1 Mbps is provided by eMTC or Cat-M1 over a 1.4 MHz channel.

(contd...)

Connection to IoT

- A downlink peak rate of ~100 kbps is provided by NB-IoT or Cat-NB1 over a 200 kHz channel.
- Better coverage and longer battery life is provided by the lower data rate of Cat-NB1.
- For a broader and more demanding set of applications, Cat-M1 is required that provides full mobility and Voice over LTE (VoLTE) support.
- Both Cat-M1 and NB-IoT pave the way for 5G massive IoT using which billions of devices will be connected to cellular networks.

(contd...)

Connection to IoT

- Both LTE and 5G core networks use the LTE IoT and compatibility with future networks will be provided.
- It is expected that in-band deployments of eMTC and NB-IoT will be supported by Release 16 with 5G NR.
- Hence, the efficiencies of cellular networks will be improved further by bringing these enhancements.

(contd...)

C-V2X Communication

- Automotive industry uses the concept of of Vehicle-to-Everything (V2X) communications to share safety-relevant data between vehicles so that obstacle detection, collision avoidance, and cooperative mobility can be supported.
- On-board ranging sensors are supported by C-V2X in Advanced Driver Assistance Systems (ADAS) and autonomous driving by providing Non-Line-of-Sight (NLOS) capabilities.

(contd...)

C-V2X Communication

- C-V2X is standardized by 3GPP in Release 14 in which current cellular (4G) network capabilities can be complemented and extended for the automotive sector.
- The licensed Intelligent Transportation System (ITS) band is used by it at 5.9 GHz and provides low-latency exchange of data between cars and a variety of end points such as V2I, V2N, and V2P.
- In 3GPP Release 15, there is an improvement in the standard that pave the way for 5G NR and is compatible with previous versions.

(contd...)

C-V2X Communication

- The longer range or higher reliability is offered by C-V2X and high-speed uses cases are also supported.
- C-V2X is further enhanced by subsequent releases of 3GPP.
- An evident strategic direction is there in C-V2X towards leveraging 5G NR and higher levels of predictability, sensors, and intent sharing for autonomous driving has been supported due to high data rates.
- A new business model has been implemented by using C-V2X with an existing network.

(contd...)

Private LTE Networks

- To provide connectivity to enterprise or industry, an alternative has been emerged in the form of Private LTE networks.
- Various key benefits are introduced by deploying private networks in LTE:
  - Carrier-Grade Features
  - Economies of Scale
  - Future-Proof
  - End-Market Appropriation

(contd...)

Private LTE Networks

- The private networks use the spectrum ranging from licensed spectrum , to shared spectrum.
- It can also be deployed in unlicensed frequencies by using MulteFire.
- Private network applications are supported by the introduction of new capabilities in the specifications of 5G.
- More flexible spectrum is supported by the 5G that includes licensed, unlicensed and shared spectrum.

(contd...)

Private LTE Networks

- Therefore, in the private network, the barrier of entry for the applications has been removed.
- A system approach has been introduced by the 3GPP to private networking that includes enterprise vertical automation, support of LAN over 5G NR.

(contd...)

Other Use Cases

- The next-generation digital Television (TV) i.e. LTE enhanced TV (enTV) will be delivered over cellular technology by which a standardized framework will be provided for broadcasters and content providers so that digital TV can be delivered to end users.
- The foundation for the evolution of the 5G broadcast can also be established by it that meets many requirements of the 5G broadcast.

(contd...)

Other Use Cases

- In Europe, for terrestrial TV delivery, enTV is a strong candidate that uses re-farmed 700 MHz spectrum.
- The appropriation of LTE network for drones, public safety, etc. are some of the other new use cases.

(contd...)