Master of Science In Internetworking

MINT 709

Comprehensive Access Technology Solution for the City of Calgary

By

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1. Introduction

In this project we have carried out comprehensive research, study and paper modeling to build access network and services for the City of Calgary. The proposed design is based on focusing and offering access solution with many network technologies on both inclusive of Wired and Wireless access.

The project constitutes of three phases. In the first phase we focused on the architecture of the network with a probable solution for access part. Research and analyzes have been done on both wired and wireless solutions such as 4G/LTE/LTE-A/5G/Microwave/Fiber/GPON/EPON. The consideration is derived based on criteria such as – Terrain type, population density, customer category and types, penetration of users, internet and smartphones, available technologies in hand and its viability and other similar factors.

In the Second phase, we have analyzed how the solution impacts to fulfill the specific requirement and characteristics like throughput, data rate (uplink / downlink), range (indoor / outdoor), spectral efficiency, quality, latency, operational frequency based on the review of given access technologies. Best possible KPIs are discussed as per the proposed design and requirement of the market dynamics.

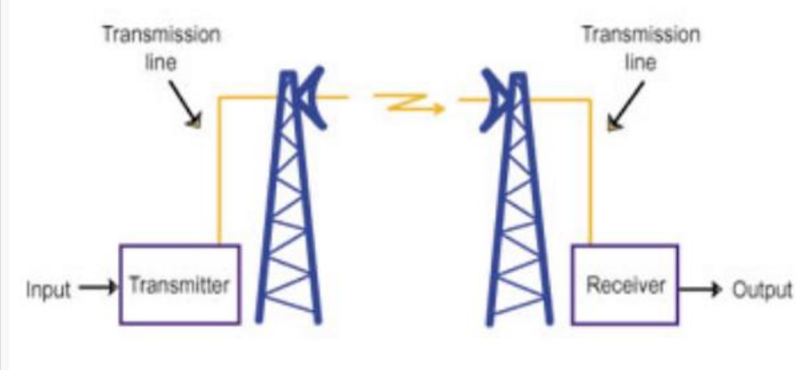
In the third phase, we analyzed the pros and cons of the given solution. The section address the critical technical challenges and identify the most relevant options. Challenges are assessed in the introduction and coexistence of these standards (including coexistence with the existing legacy ones (if)), development and details of the probable migration scenario. This section also covers the future plans and path of the network for seamless network upgrade.

2. Access Technologies

2.1 Wireless Access Technologies

2.1.1 Microwave

Microwave transmission is a line-of-sight wireless communications system that uses radio waves in the microwave frequency range to transmit & receive voice, video, and data information between two fixed locations on the earth, which can be from just a few feet or meters to several miles or kilometers apart.



A simplified rendering of a microwave link. A microwave link is a communications system that uses a beam of radio waves in the microwave frequency range to transmit information between two fixed locations on the earth.

Source: https://ethw.org/Microwave_Link_Networks

Microwave are widely used in communication industries as they can be directed in narrow beams from conveniently sized antenna because their small wavelength & point-to-point communications property. Because of this property nearby microwave equipment are allowed to use the same frequencies without interfering with each other, as lower frequency radio waves do. The high frequency of microwaves has the advantage of carrying large information. The microwave bandwidth is 30 times than that of all the rest of the radio spectrum below it.

The higher part of radio electromagnetic spectrum above 30 GHz frequencies and below 100 GHz, are called “millimeter waves”. As their wavelengths can be conveniently determined in millimeters ranging from 10 mm down to 3.0 mm. Radio waves are usually strongly attenuated by the Earthly atmosphere and particles, especially during wet weather within this range

Microwave radio transmission is mainly used in satellite communications, and in deep space radio communications. Other parts of the microwave radio band are used for radars, sensor systems, radio navigation systems, and radio astronomy.

MW Components:

A simple microwave link includes four major elements:

A. Transmitter
B. Receiver
C. Transmission lines and
D. Antennas.

A. Transmitter: Two fundamental tasks of transmitter are- generating microwave energy at the required frequency and power level, and modulating it with the input signal to convey information properly. Modulation is done by varying some characteristic of the energy in response to the transmitter's input.

B. Receiver: At the receiver side, information from the microwave signal is extracted and then demodulated. Demodulation technique separates the information from the microwave energy that carries it and made available in its original form. As signal loses much of its strength while it travels, the receiver must be capable of detecting very small amounts of microwave energy.

C. Transmission lines: Transmission lines carry the signal from the transmitter to the antenna end and at the receiving end of the link, from the antenna to the receiver. It conducts current from one point to another. At microwave frequencies signal is weakened. Coaxial cables, hollow pipes called waveguides are used as medium for MW.

D. Antenna: MW consists of two antennas –one at transmission end and one at receiver end. Transmitting antenna emits the microwave signal from the transmission line into free space. At the receiver end, receiving antenna pointed toward the transmitting station collects the signal energy and feeds it into the transmission line for further processing by the receiver.

Another vital element of the microwave link is the path taken by the signal through the earth's atmosphere. A clear line of sight is very crucial for the microwave link's success. Man made obstacle along with natural obstacles might block the signal. Undesirable reflections, absorbing and scattering microwave energy can weaken a marginally strong signal. These can be overcome by tall antenna structures. All these must be taken into account while designing link.

Planning of Microwave Links

Following parameters need to be considered while designing MW links:

- Distance (km/miles) and capacity (Mbps) between terminals
- Availability of Line of Sight (LOS) between end terminals
- Towers or masts if required to achieve clear LOS
- Frequency of operations, availability, licensing cost specific to region/country
- Terrain properties, e.g. water, cliffs, forests, snow;
- Interference management of link receiver. Fading, dispersion & multipath distortion
- Availability, cost and size of equipment

Microwave Frequency Bands

Microwave frequency bands are often divided into three categories:

- Ultrahigh frequency (UHF) (0.3-3 GHz);
- Super high frequency (SHF) (3-30 GHz);
- Extremely high frequency (EHF) (30-300 GHz).

Higher MW frequencies are used for shorter links and regions with lower rain fade. Conversely, Lower frequencies are used for longer links, and regions with higher rain fade.

Uses of Microwave Links

- As Backbone carrier and “Last Mile” Communication for cellular system
- For Internet Service Providers’ (ISPs) and Wireless ISPs (WISPs) backbone system
- In communications between satellites and base stations
- Indoor communication-Corporate Networks for Building to Building and campus sites
- Telecommunications, to link remote and regional telephone exchanges to larger (main) exchanges by avoiding the need for copper/optical fiber lines.
- Broadcast Television with HD-SDI and SMPTE standards

MW Advantages:

- No requirements of cables
- No in between equipment are required between terminals. Easy to install.
- Multiple channels available
- Wide bandwidth or broadband. Higher Capacity.

MW Disadvantages:

- Require Line-of-sight. Can be disrupted with the presence of obstacle- building blocks, trees etc.
- Expensive equipment - Towers, Antenna
- Prone to attenuation due to atmospheric conditions.

2.1.2 Wi-Fi

The popular wireless networking technology Wi-Fi stands for "wireless fidelity". It uses radio waves to provide connectivity over short distances by emitting frequencies between 2.4GHz - 5GHz, based on the amount of data on the network. Nowadays Wi-Fi is a popular choice for home and business network as it enables local area networks (LANs) to operate without cables and wiring. Once configured in devices like laptops, smartphones, tablet computers, and electronic gaming consoles, it can provide wireless broadband Internet access. Wi-Fi allows devices to connect to the Internet when they are near areas having Wi-Fi access, called "hot spots." Hot spots are very common nowadays; many public places such as cafes, airports, hotels, bookstores, shopping malls, and coffee shops are offering Wi-Fi access.

WIFI Technology

Source: https://www.elprocus.com/how-does-wifi-work/

Working Principle:

Wi-Fi network uses radio waves to transmit information across a network like mobile phones. All that is required is a wireless adapter that will translate data sent through a radio signal. This same signal is transmitted, via an antenna, to a router. Once decoded, the data is sent to the Internet. In the same way when data is received from the internet, it will pass through the router to be coded into a radio signal and is received by the computer's wireless adapter.

Under the IEEE Wi-Fi standards, the available frequency bands are divided in several separate channels. For each channels, Wi-Fi uses a “spread spectrum” technique. Spread spectrum breaks the signal into pieces and transmitted over multiple frequencies. It allows signal to be transmitted at a lower power per frequency and also enables multiple devices to use the same Wi-Fi transmitter. Wi-Fi___33 signals are prone to multipath interference, while traveling short distance the signal can reflect off walls, furniture, and other obstacles. therefore Wi-Fi uses channels that are far apart.

Wi-Fi Frequencies

Depending on amount of data to be sent, a wireless network transmits at a frequency level of 2.4 GHz or 5GHz. The 2.4 GHz band of Wi-Fi signal occupies five channels. Any two channels differ by five or more do not overlap such as 2 and 7. The channels 1, 6, and 11 are the only non-overlapping channels and therefore are not accurate. These are the only group of non-overlapping channels in North America and the United Kingdom. Channels 1, 5, 9, and 13 for 802.11g and 802.11n is used in Europe and Japan.

Below are four major types of WI-FI technologies available currently-

- Wi-Fi-802.11a
- Wi-Fi-802.11b
- Wi-Fi-802.11g
- Wi-Fi-802.11n

The 802.11a transmits data at 5GHz frequency band. One of a series of wireless technology is 802.11a. It defines the structure and format of the radio signals sent out by WI-FI networking routers and antennas. The Orthogonal Frequency-Division Multiplexing (OFDM) is used here. It enhances reception by splitting the radio signals into smaller signals before reaching the router. A maximum of 54 megabits of data per second can be transmitted here.

The 802.11b transmits data at 2.4GHz frequency band. It is a relatively slow in speed. A maximum of 11 megabits of data per second can be transmitted here.

The 802.11g transmits data at 2.4GHz. It also uses OFDM coding. Hence can transmit a maximum of 54 megabits of data per second.

The 802.11n can transmit a maximum of 140 megabits of data per second. It transmits data at frequency level of 5GHz. This is more advanced technology.

Interference

In Wi-Fi connections Internet speed can be lowered or disrupted by having other devices in the same area. Wi-Fi protocols are designed in such a way that it can share channels reasonably fairly, and can work with little to no disruption generally. However, many 2.4 GHz 802.11b and 802.11g access-points use the same channel on initial startup by default, thus contributing to congestion on certain channels. Wi-Fi pollution, or an excessive number of access points in an area creates few problems like - preventing access, interfere with other devices' use of other access points, decreased signal-to-noise ratio (SNR) between access points. In addition interference can happen due to overlapping channels in the 802.11g/b spectrum. In high-density areas such as office buildings with many Wi-Fi access points or large apartment complexes, these issues can become a problem.

Additionally, 2.4 GHz band is used by few other devices such as microwave ovens, ISM band devices, security cameras, video senders, cordless phones, ZigBee devices, Bluetooth devices, baby monitors and, in some countries, amateur radio, all of which can generate significant additional interference. It is also an issue when large area needs to be covered.

Range and speed

Operational range of Wi-Fi depends on factors such as radio power output, frequency band, receiver sensitivity, antenna gain and antenna type as well as the modulation technique. In addition, propagation characteristics of the signals can have a big impact as well. At longer distances, speed is usually reduced because of greater signal absorption.

Network security & methods to secure

One of the main concerns of wireless network security is its simplified access to the network compared to traditional wired networks such as Ethernet. With wired networking, one must either break through an external firewall or gain access to a building. One merely needs to be within the range of the Wi-Fi network to access Wi-Fi. With inadequate or no encryption security of the wireless network is reduced. Attackers' first gain access to Wi-Fi network router and then can initiate a DNS spoofing attack against any other user of the network by forging a response before the queried DNS server has a chance to reply.

One frequent method to deter unauthorized users is to hide the access point's name by disabling the SSID broadcast. It is effective against the casual user but ineffective as a security method because the SSID is broadcast in the clear in response to a client SSID query.
Another measure is to only allow devices with known MAC addresses to access the network. Spoofing an authorized address enables determined eavesdroppers to join the network.

Another measure can be Wired Equivalent Privacy (WEP) encryption. It was designed to protect against casual snooping but it is no longer considered secure. 'Wi-Fi Protected Access (WPA) was specifically designed to work with older equipment usually through a firmware upgrade. The more secure WPA2 using Advanced Encryption Standard was introduced in 2004 and is supported by most new Wi-Fi devices'.

Wi-Fi Applications:

Business applications
Home applications
Mobile applications

Computerized applications
Automotive segment
Web surfing
Video conference

Wi-Fi Advantages:

Mobility. Wireless devices can be moved from one place to another place
Wireless technology. We can connect internet wirelessly.
Thus can reduce the cost of wires.
Wi-Fi setup and configuration is easier compared to cabling process
We can also connect internet via hot spots

Wi-Fi Disadvantages:

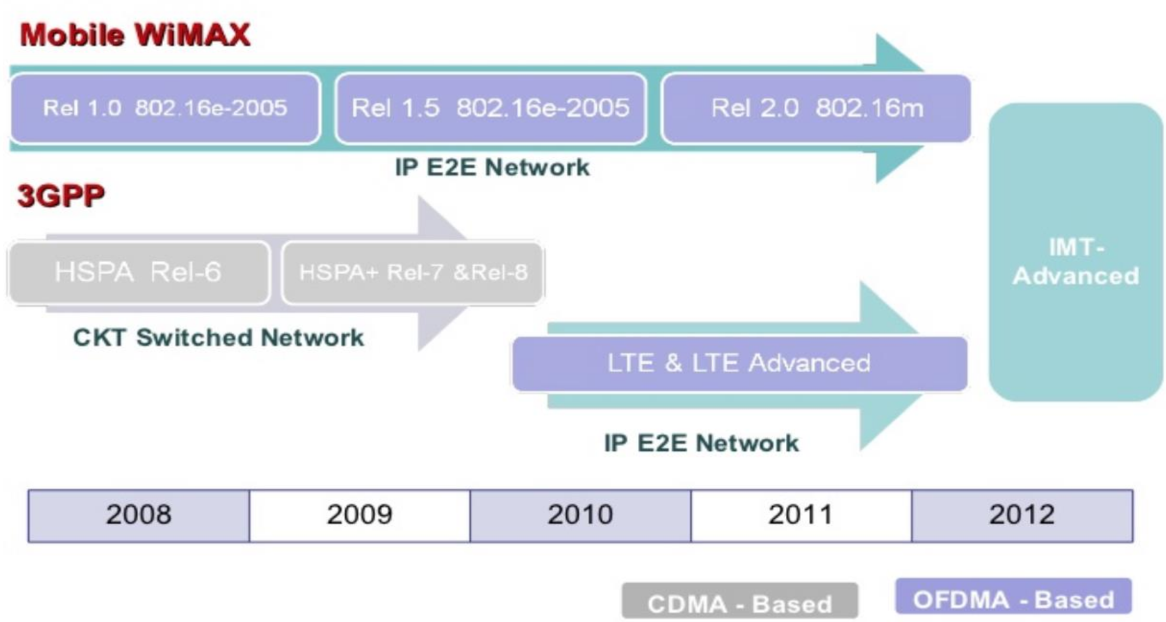
Wi-Fi radiates energy that can harm the human health
Throughput limitation. There are some limits to transfer the data.
Data transfer over long distance is a not possible
Wi-Fi can be expensive compared to the wired connection

2.1.3 LTE (Long-Term Evolution)

LTE Evolution

LTE stands for Long-Term Evolution. It is a standard for high-speed wireless communication for cellular services, evolved from GSM/EDGE and UMTS/HSPA technologies. The standard is developed by the 3rd Generation Partnership Project known as 3GPP. LTE is mainly designed to increase the capacity and throughput of cellular data networks using new DSP (digital signal processing) techniques and modulation. A further goal was to simplify the architecture and evolve to an IP-based system by significantly reducing transfer latency compared to 3G architecture. LTE must be operated on a separate radio spectrum from 2G or 3G as its wireless interface is incompatible with 2G /3G networks.

4G Technologies



Source: https://www.slideshare.net/hamdani2/lte-long-term-evolution?next_slideshow=1

	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE
Max downlink speed bps	384 k	14 M	28 M	100M
Max uplink speed bps	128 k	5.7 M	11 M	50 M
Latency round trip time approx.	150 ms	100 ms	50ms (max)	~10 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8
Approx. years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA

Source: https://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/3g-lte-basics.php

LTE Overview:

- LTE enhances the spectral efficiency of cellular networks and brings up to 50 times performance improvement.
- With LTE, network can achieve 300Mbps peak downlink and 75 Mbps peak uplink under ideal network conditions.
- LTE supports high data rates for the services such as voice over IP (VOIP), video conferencing, streaming multimedia, gaming etc.
- LTE uses both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) mode and supports flexible carrier bandwidths, from 1.4 MHz up to 20 MHz both in FDD and TDD.
- Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink, Single-carrier FDMA for the uplink to conserve power.
- LTE supports (MIMO) Multiple Input Multiple Output transmissions, allowing Base station to transmit several data streams over the same carrier simultaneously.

- All interfaces are IP based in LTE- Interfaces between network nodes including the backhaul connection to the radio base stations.

- Quality of Service (QoS) in LTE ensures the requirement of voice calls for a constant delay and bandwidth.

- LTE supports hand-over and roaming to existing GSM/EDGE/UMTS systems utilizing both existing 2G and 3G spectrum and new spectrum.

Basic Parameters:

Basic parameters of the LTE:

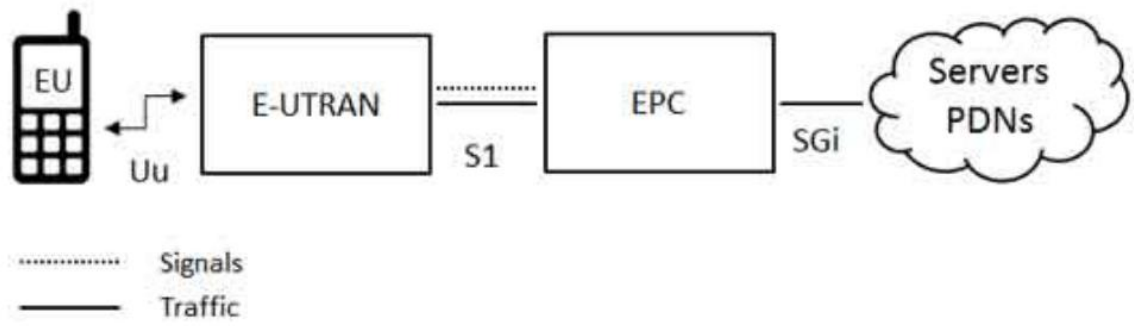
Frequency Range	UMTS FDD bands and UMTS TDD bands					
Channel bandwidth, 1 Resource Block=180 kHz	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
	6 Resource Blocks	15 Resource Blocks	25 Resource Blocks	50 Resource Blocks	75 Resource Blocks	100 Resource Blocks
Modulation Schemes	Downlink: QPSK, 16QAM, 64QAM Uplink: QPSK, 16QAM, 64QAM (optional for handset)					
Multiple Access	Downlink: OFDMA (Orthogonal Frequency Division Multiple Access) Uplink: SC-FDMA (Single Carrier Frequency Division Multiple Access)					
MIMO technology	Downlink: Wide choice of MIMO configuration options for transmit diversity, spatial multiplexing, and cyclic delay diversity (max. 4 antennas at base station and handset) Uplink: Multi user collaborative MIMO					
Peak Data Rate	Downlink: 150 Mbps (UE category 4, 2x2 MIMO, 20 MHz) 300 Mbps (UE category 5, 4x4 MIMO, 20 MHz) Uplink: 75 Mbps (20 MHz)					

Source: slideshare

LTE System Architecture:

The basic architecture contains the following network elements-

1. The User Equipment (UE).
2. LTE E-UTRAN (Evolved Universal Terrestrial Radio)
3. LTE Evolved Packet Core (EPC)



Source: https://www.tutorialspoint.com/lte/lte_network_architecture.htm

The User Equipment (UE)

The mobile equipment comprised of the following important modules:

Mobile Termination (MT): MT handles all the communication functions.

Terminal Equipment (TE): TE terminates the data streams.

Universal Integrated Circuit Card (UICC): Also known as the SIM card for LTE equipment. It runs an application named Universal Subscriber Identity Module (USIM).

A USIM is similar to stores 3G SIM card. It stores user-specific data - about the user's phone number, home network identity and security keys etc.

The E-UTRAN (The Access Network)

LTE E-UTRAN (Evolved Universal Terrestrial Radio) handles the radio communications between EPC (core) & consists of base stations, called eNodeB or eNB. Each eNB is connected with the EPC through S1 interface and with adjacent base stations through X2 interface. This is used mainly for signaling and packet forwarding during handover.

In LTE, E-UTRAN is responsible for complete radio resource management. When UE powered is on, eNB performs the Radio Resource Management i.e. radio bearer control, allocation of uplink and downlink to UE, radio admission control etc. When UE sends packet to eNB, IP header is compressed by eNB and data stream is encrypted. It is also in charge for adding a GTP-U header to the payload and sending it to the SGW. The control plane has to be established before the data is actually transmitted. The eNB chooses MME using MME selection function. The QoS along with other functionalities including scheduling and transmission of paging messages, bearer level rate enforcement and broadcast messages are taken care by eNB.

LTE Evolved Packet Core (EPC)

The major components of EPC are

- MME
- SGW
- PGW
- HSS and
- PCRF

Mobility Management Entity (MME):
The MME is responsible for all the control plane operations and is a control entity. All the NAS signaling terminates in MME (originating at UE). MME is also responsible for tracking area list management, selection of PGW/SGW and other MME during handovers, SGSN (Serving GPRS Support Node) selection during LTE to inter RAN (2G/3G) handovers .The UE is also authenticated by MME. Bearer management functions is also done at MME.

Serving Gateway (SGW):
The serving gateway (S-GW) forwards data between the base station and the PDN gateway and acts as a router. At a particular time, for each UE there is a single Serving GW associated with EPS. It acts as the mobility anchor during inter-eNodeB handovers and between LTE and other 3GPP technologies. SGW terminates the downlink data path and triggers paging when downlink data is received by UE in case idle state UEs. Serving gateway node terminates the interface towards EUTRAN.

PDN Gateway (PGW):
The Packet Data Network (PDN) Gateway (P-GW) communicates with the outside world using SGi interface and is responsible for all the IP packet based operations such as policy enforcement, packet filtering & screening, Transport level packet marking in uplink and downlink, UE IP address allocation, accounting UL and DL rate enforcement etc. For accessing multiple PDNs, a UE may be simultaneously connected with more than one PGW. QoS for bearers is determined here by contacting PCRF. PGW is the node that terminates SGi interface towards the PDN.

Home Subscriber Server (HSS):
The HSS is a central database that contains information about all the network operator's subscribers. Mobility management, session and call establishment support, subscriber authentication and authorization are the responsibilities of HSS. Authentication center (AUC) can be integrated here, which generates the vectors for authentication and security

keys. It contains information about the current PDNs as well as dynamic information like identity of the MME to which the user is currently attached or registered.

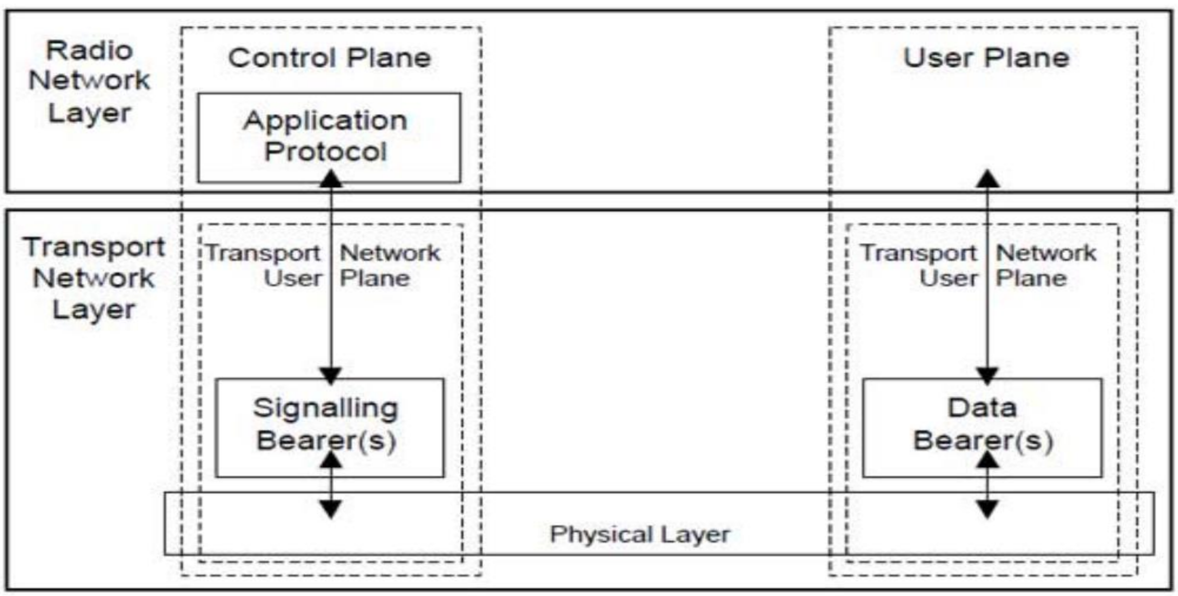
Policy Control and Charging Rules Function (PCRF):

PCRF supports service data flow detection, policy enforcement and flow-based charging in the Policy Control Enforcement Function (PCEF), which resides in the P-GW. The PCRF does the QoS authorization (QoS class identifier [QCI] and bit rates). It allows new generation service provider to better control their services and align their revenue with their resources by offering a comprehensive solution.

LTE Radio Protocol Architecture:

The radio protocol architecture of LTE can be divided into

- Control plane architecture and
- User plane architecture

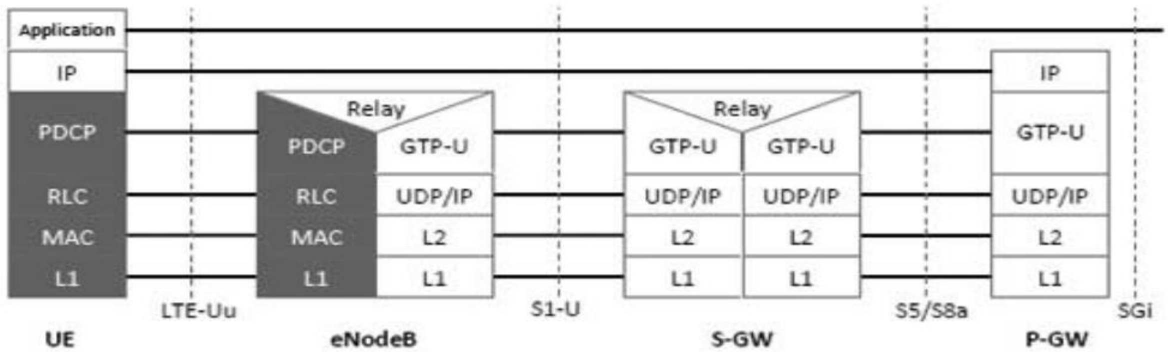


Source : https://www.tutorialspoint.com/lte/lte_radio_protocol_architecture.htm

At user plane, data packets created by application are processed by IP. While in the control plane, signaling is done by the radio resource control (RRC) protocol, exchanged between the base station and UE. On both cases prior to passing the physical layer, the information is processed by the packet data convergence protocol (PDCP), the radio link control (RLC) protocol and the medium access control (MAC) protocol.

User Plane

On the user plane, specific EPC protocol encapsulates the packets and tunneled between the eNB and P-GW. Depending on the interface, different tunneling protocols are used here. GPRS Tunneling Protocol (GTP) is used on the S1 interface between the eNB and S-GW and on the S5/S8 interface between the P-GW and S-GW.



Source: https://www.tutorialspoint.com/lte/lte_radio_protocol_architecture.htm

User plane in LTE UE consists of following upper layers-
NAS
PDCP(Packet Data Convergence Protocol)
RLC (Radio link control)
MAC
PHY and
RF.

Functions of each layer is given below-

NAS: Packet filtering in UL.

PDCP: It performs the transfer of User plane and control plane data. In the uplink it manages sequence number addition, integrity protection, handover data handling, and ciphering and header compression. In the downlink it performs sequence delivery, integrity validation, duplicate packet detection, and deciphering and header decompression.

RLC: Transfer of upper layer Protocol Data Units (PDUs) in one of three modes: Acknowledged Mode (AM), Unacknowledged Mode (UM) and Transparent Mode (TM). In the uplink it does buffer status report, segmentation and concatenation, error connection through ARQ (for AM mode). In the downlink it manages re-ordering, assembly and ARQ (for AM mode).

MAC: MAC layer facilitates the radio resource allocation service and the data transfer service to the upper layer. In the uplink it performs channel mapping, handling UL grant and DL assignment, multiplexing, random access procedure, logical channel priority and HARQ. In the downlink it does channel mapping, DRX, Handling control elements, HARQ and de-multiplexing.

PHY:

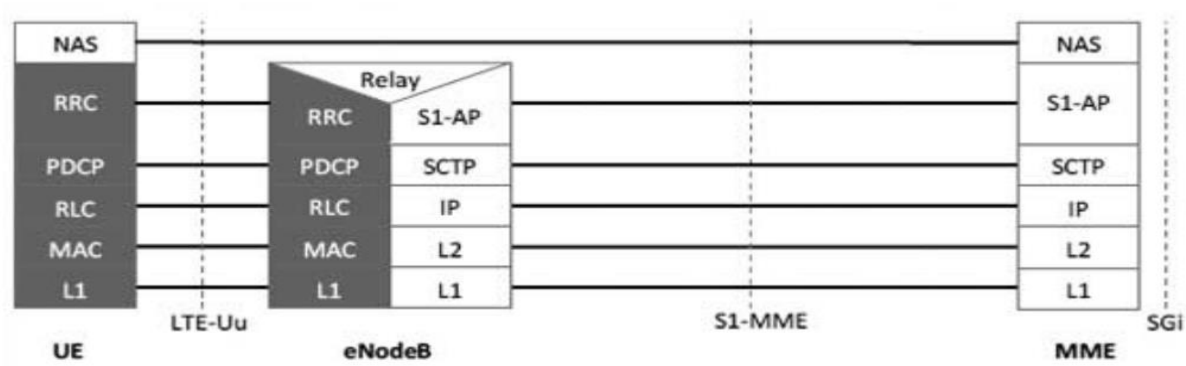
- Scrambling/descrambling
- Modulation/de-modulation
- Resource element mapping/de mapping
- HARQ
- MIMO
- Measurement
- CRC attachment
- Coding block

RF:

- Radio Transmission and Reception

Control Plane

The control plane protocol stack between the UE and MME is shown below.



Source: https://www.tutorialspoint.com/lte/lte_radio_protocol_architecture.htm

The grey portion indicates the access stratum (AS) protocols. The lower layers perform the similar functions like user plane but without header compression function.

Control plane in LTE UE consists of

- Upper Layers
- NAS
- RRC
- PHY and
- RF

Functions of each layer are given below-

Upper layer: Provide interface between upper layer and lower layers (NAS).

NAS: It performs Mobility Management, Session Management, Bearer Management, Paging Control and Security Management.

RRC: It is responsible for Paging control, Configuration Management, Connection Management, Security Management, Broadcast, Measurement configuration, Measurement Reporting, Cell selection and reselection and Mobility Management

PHY and RF: functions are same as mentioned above.

LTE RRC states-IDLE/Connected

RRC has two states IDLE and RRC CONNECTED.

In RRC IDLE state,

- UE camps on a cell after a cell selection or reselection process. Here radio link quality, cell status and radio access technology are considered. EPC knows UE and has IP address but it is not known in E-UTRAN/eNB.
- User equipment receives broadcast/multicast data, monitors a paging channel for detecting incoming calls, performs neighbor cell measurements and acquires system information.

In the RRC CONNECTED state,

- To enable the E-UTRAN to select the most suitable cell for the UE, here UE provides the E-UTRAN with downlink channel quality and neighbor cell information. It includes the Radio Link Control (RRC) protocol. In this case, UE is known in EPC and E-UTRAN/eNB.

LTE Frame Structure:

TDD and FDD are two topologies where critical resources -time & frequency are shared among cellular subscribers or terminals. LTE supports both TDD & FDD. The major differences between LTE-TDD and LTE-FDD are - LTE-TDD uses a single frequency. It doesn't require paired spectrum as transmission and reception occurs in the same channel. Whereas LTE-FDD uses paired frequencies to upload and download data by segregating data in time domain and using guard band. The ratio of uploads and downloads can be dynamically adjusted as per requirement. Besides, LTE-TDD and LTE-FDD uses different frequency bands. LTE-TDD works better at higher frequencies whereas LTE-FDD works better at lower frequencies.

LTE-TDD Band

TDD LTE BANDS & FREQUENCIES		
LTE BAND NUMBER	ALLOCATION (MHZ)	WIDTH OF BAND (MHZ)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 - 2620	50
39	1880 - 1920	40
40	2300 - 2400	100
41	2496 - 2690	194
42	3400 - 3600	200
43	3600 - 3800	200
44	703 - 803	100

LTE-FDD Band

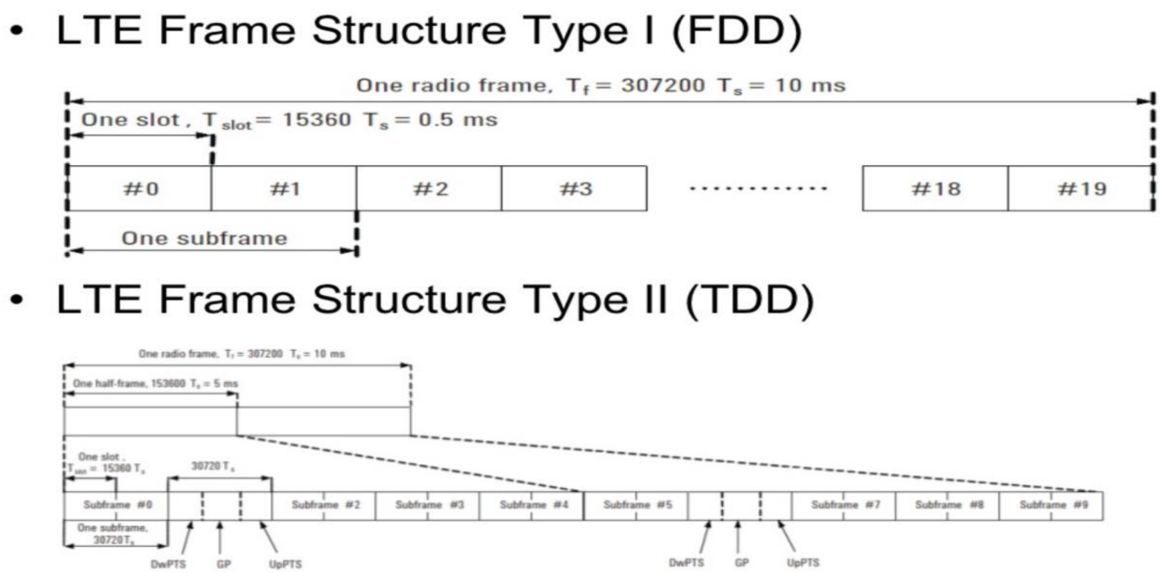
FDD LTE BANDS & FREQUENCIES					
LTE BAND NUMBER	UPLINK (MHZ)	DOWNLINK (MHZ)	WIDTH OF BAND (MHZ)	DUPLEX SPACING (MHZ)	BAND GAP (MHZ)
1	1920 – 1980	2110 - 2170	60	190	130
2	1850 – 1910	1930 - 1990	60	80	20
3	1710 – 1785	1805 -1880	75	95	20
4	1710 – 1755	2110 - 2155	45	400	355

5	824 – 849	869 - 894	25	45	20
6	830 – 840	875 - 885	10	35	25
7	2500 – 2570	2620 - 2690	70	120	50
8	880 – 915	925 - 960	35	45	10
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95	60
10	1710 – 1770	2110 - 2170	60	400	340
11	1427.9 - 1452.9	1475.9 - 1500.9	20	48	28
12	698 – 716	728 - 746	18	30	12
13	777 – 787	746 - 756	10	-31	41
14	788 – 798	758 - 768	10	-30	40
15	1900 – 1920	2600 - 2620	20	700	680
16	2010 – 2025	2585 - 2600	15	575	560
17	704 – 716	734 - 746	12	30	18
18	815 – 830	860 - 875	15	45	30
19	830 – 845	875 - 890	15	45	30
20	832 – 862	791 - 821	30	-41	71
21	1447.9 - 1462.9	1495.5 - 1510.9	15	48	33
22	3410 – 3500	3510 - 3600	90	100	10
23	2000 – 2020	2180 - 2200	20	180	160
24	1625.5 - 1660.5	1525 - 1559	34	-101.5	135.5
25	1850 – 1915	1930 - 1995	65	80	15
26	814 – 849	859 - 894	30 / 40		10
27	807 – 824	852 - 869	17	45	28
28	703 – 748	758 - 803	45	55	10
29	n/a	717 - 728	11		
30	2305 – 2315	2350 - 2360	10	45	35
31	452.5 - 457.5	462.5 - 467.5	5	10	5

Source: https://www.radio-electronics.com/

There are two types of LTE frame structure-

Type 1: For the LTE FDD mode systems - Overall length of 10 ms and split into 20 individual slots. Each LTE Sub frames consist of two slots. Hence in total ten LTE sub frames within a frame.



Source: slide share

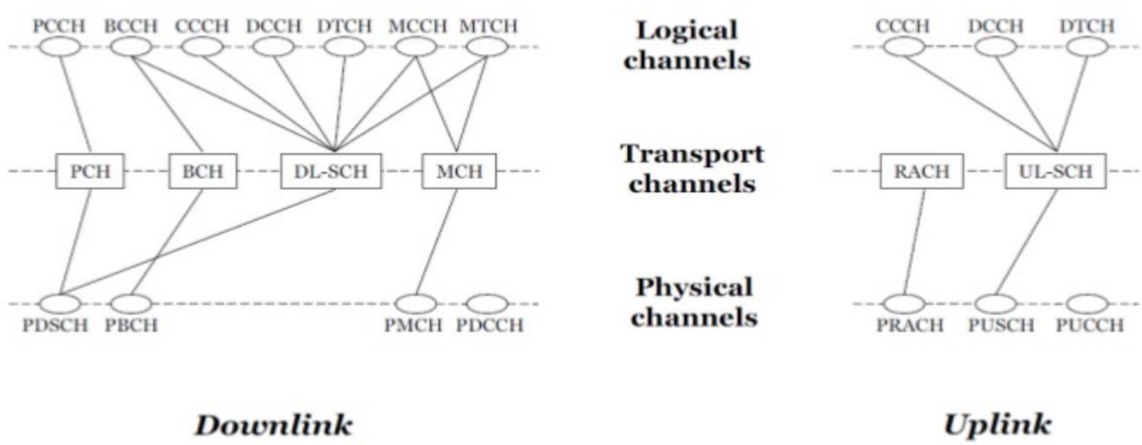
Type 2: For the LTE TDD systems- The 10 ms frame consists of two half frames, each 5 ms long. The half-frames are further split into five sub frames, each 1ms long.

The sub-frames may be divided into standard sub-frames and special sub-frames. The special sub frames consist of three fields;

DwPTS - Downlink Pilot Time Slot
GP - Guard Period
UpPTS - Uplink Pilot Time Slot.

LTE Communication Channels- Physical, Logical & Transport Channels

There are three types of channels in LTE (logical channel, transport channel and physical channels) where the lower layers provide services to the upper layers.



Source : slide-share

Physical Channels

Physical DL Channels	Physical UL Channels
Physical broadcast channel (PBCH)	Physical uplink control channel (PUCCH)
Physical control format indicator channel (PCFICH)	Physical uplink shared channel (PUSCH)
Physical downlink control channel (PDCCH)	Physical random access channel (PRACH)
Physical downlink shared channel (PDSCH)	
Physical multicast channel (PMCH)	
Physical Hybrid ARQ Indicator Channel (PHICH)	

Downlink Physical Channels:

a. PBCH: Carries Cell specific information

b. PDSCH: Transmit L1 transport data information. On PDSCH, supported modulation formats are QPSK, 16QAM and 64QAM.

c. PMCH: This channel defines the physical layer structure to carry Multimedia Broadcast and Multicast Services (MBMS)

d. PHICH: Carries Hybrid ARQ (HARQ) ACK/NACK for UL transfer.

e. PDCCH: Carries information about control channel regarding scheduling of PDSCH, UL grant, carries DCIs, Indication for paging, carries HARQ ACK/NACK

f. PCFICH: Used to signal CFI (control format indicator).Defines number of PDCCH OFDMA symbol per sub-frame (1, 2,or 3)

Uplink Physical Channels:

a. PRACH: Use for Initial access.
b. PUSCH: Carries the L1 UL transport data along with control information.
c. PUCCH: Carries control information

Transport Channels

Transport DL Channels	Transport UL Channels
Broadcast Channel (BCH)	Uplink Shared Channel (UL-SCH)
Downlink Shared Channel (DL-SCH)	Random Access Channel(s) (RACH)
Paging Channel (PCH)	
Multicast Channel (MCH)	

Downlink Transport Channels:
a. PCH: Paging
b. BCH: MIB, Mapping into BCCH
c. DL-SCH: SIB, data transfer
d. MCH: Transmitting MCCH information to set up multicast transmissions

Uplink Transport Channels:
a. RACH: Initial access to the network
b. UL-SCH: UL data transfer

Logical Channels

Logical Control Channels	Logical Traffic Channels
Broadcast Control Channel (BCCH)	Dedicated Traffic Channel (DTCH)
Paging Control Channel (PCCH)	Multicast Traffic Channel (MTCH)
Common Control Channel (CCCH)	
Multicast Control Channel (MCCH)	
Dedicated Control Channel (DCCH)	

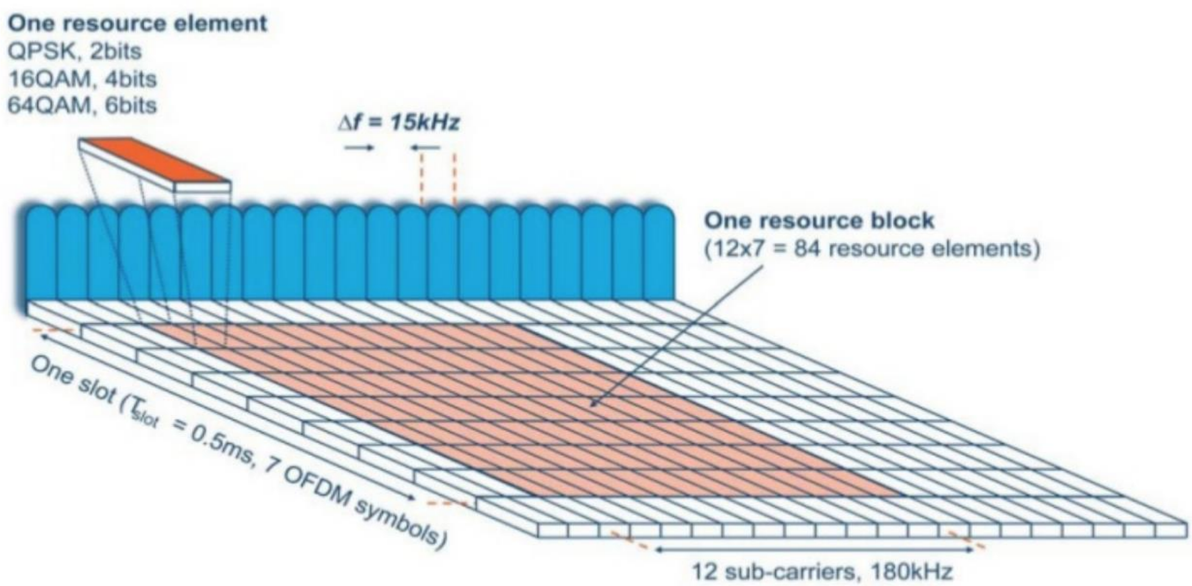
Downlink Logical Channels:
a. PCCH: Paging subscriber (UE)
b. BCCH: Broadcasting MIBs/SIBs
c. CCCH: Common to multiple UE's
d. DCCH: Transmit dedicated control information for a specific UE
e. DTCH: Dedicated Traffic for a particular UE
f. MCCH: Transmit information for Multicast reception
g. MTCH: Transmit Multicast data

LTE OFDMA Technology

OFDMA (Orthogonal Frequency Division Multiplexing):

One of the key reasons for using OFDM as a modulation format within LTE is its robustness in the face of multipath fading and interference. Another significant parameter associated is the choice of bandwidth in LTE.

In OFDM, symbols are grouped into resource blocks of a total size of 180 kHz in the frequency domain and 0.5ms in the time domain. 'Each 1ms Transmission Time Interval (TTI) consists of two slots (Tslot)'. Each user is allocated a number of resource blocks (RB) in the time-frequency grid. Higher bit rate can be achieved by getting more resource blocks and using higher the modulation scheme.



Source : https://www.slideshare.net

LTE subcarriers are spaced 15 kHz apart from each other as subcarriers spacing is 15 kHz. To maintain orthogonal characteristics, this gives a symbol rate of 1 / 15 kHz = of 66.7 µs where each subcarrier can carry data at a maximum rate of 15 kbps. For 20 MHz bandwidth network, a rate of 18 Mbps can be achieved. And by using 64QAM, data rate of 108 Mbps can be obtained.

SC-FDMA Technology

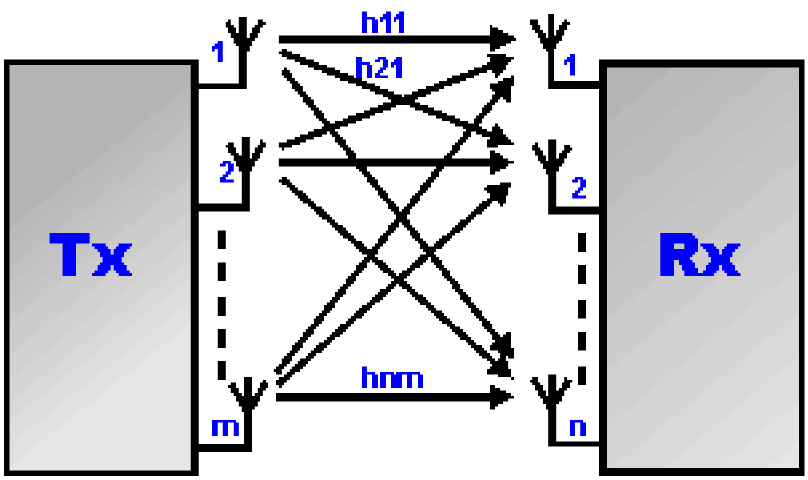
In OFDM, Peak to Average Power Ratio (PAPR) is very high. To compensate this LTE uses Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink.

In Mobile communication, it is still necessary to ensure that the mobiles use as little battery power as possible. Using RF power amplifier while transmitting, this can be significantly affected by the form of radio frequency modulation and signal format. Signals that have a high peak to average ratio and require linear amplification cannot use RF power amplifiers efficiently. As a result it is necessary to employ a constant power level while operating. As OFDM has a high peak to average ratio, it is a problem for mobile phones (though not a problem for the base station). As a result, LTE uses SC-FDMA - Single Carrier Frequency Division Multiplex in Uplink. This offers low peak to average ratio offered by single-carrier systems with flexible subcarrier frequency allocation and multipath interference resilience similar to OFDM. A low PAPR also improves coverage as well as cell-edge performance.

LTE Features:

MIMO (multiple-input and multiple-output):

The basic concept of MIMO is to multiply the capacity of a radio link using multiple transmit and receive antennas to exploit the advantage of multipath propagation. Rather than creating interference, these paths can be used in a constructive way.



General Outline of MIMO system

Source: https://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/lte-mimo.php

In MIMO more than one antenna are used both on transmitter and receiver side. It uses the processing power available at either end. They improve the data throughput available on a given channel with its defined bandwidth by utilizing different paths exist between the two entities. In MIMO, multiple data streams are set up on the same channel, thereby increasing the capacity of a channel.

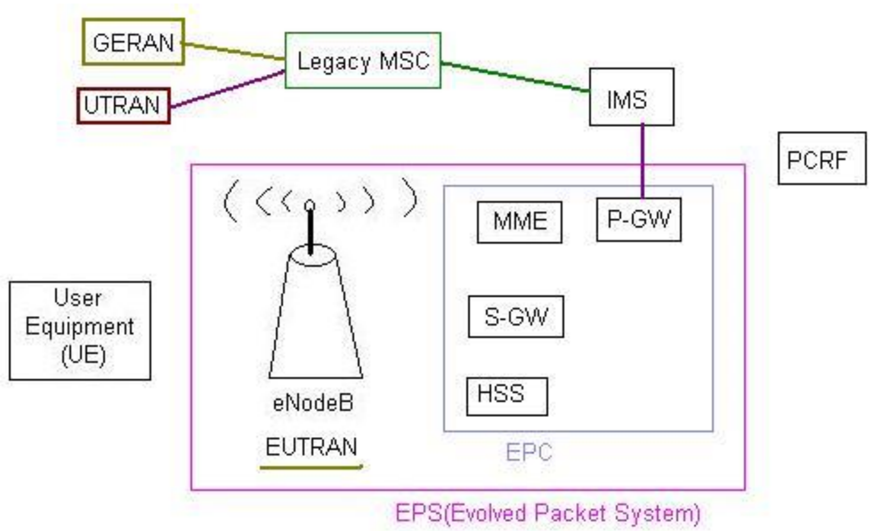
Following several modes of MIMO can be implemented in LTE- Single antenna, Transmit diversity, Open loop spatial multiplexing, Close loop spatial multiplexing, Closed loop with pre-coding, Multi-User MIMO, MU-MIMO and Beam-forming:

VoLTE (Voice over Long-Term Evolution)**:**

VoLTE is an IP Multimedia Subsystem (IMS) based high-speed wireless communication service for mobile phones and data terminals. It comprises of specific profiles for control and media planes for voice service on LTE where voice can be delivered as data flows within the LTE data bearer. Meaning no circuit-switched dependency with up to three times more voice and data capacity than 3G UMTS and up to six times more than 2G GSM.

In LTE two options are available -

1. VoLTE using VOIP through IMS - As shown in the figure, EUTRAN comprised of more than one eNB, MME, S-GW, HSS and P-GW. LTE supports voice call using VOIP using IMS. For VOIP to VOIP call, it will remain within LTE network using VOIP protocols. But for VOIP to CS call (GSM/WCDMA), IMS with the help of application servers and legacy MSC transfers will transfer call from PS to CS network.



Source: http://www.rfwireless-world.com/Terminology/VoLTE-Voice-Over-LTE.html

2. VoLTE using CSFB, SRVCC (Single Radio Voice Call Continuity) – It occurs during handover from LTE network to legacy networks (GSM/WCDMA).It takes into account the measurement report. For this UE should support SRVCC. Meaning UE will be connected with single radio at a time and hence one single RAT (either LTE or GSM or WCDMA). Therefore battery life becomes longer here with UE capable of SRVCC.

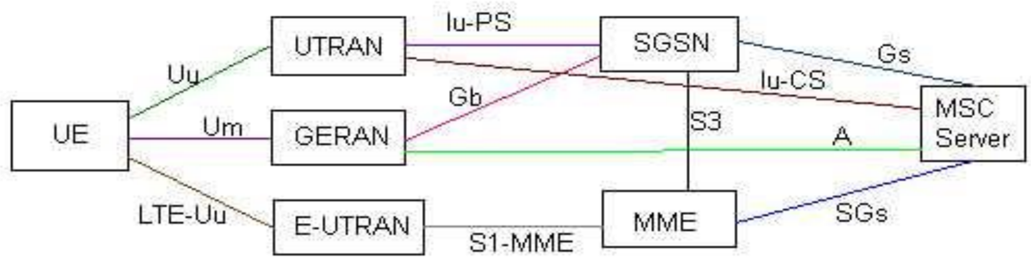


Fig.1 VoLTE using Legacy fall back(CS),using SRVCC

Source: https://www.slideshare.net/hamdani2/lte-long-term-evolution?next_slideshow=1

2.1.4. LTE Advanced

Introduction:

LTE Advanced is the next major step of the Long Term Evolution (LTE) standard focusing on higher bit rate in a cost efficient way. LTE-A provides around three times higher throughput compared to LTE.

LTE Advanced is expected to provide higher capacity, enhanced user experience, and more efficient resource allocation. It facilitates this by combining a bunch of technologies, many of which have been around for some years, so this is not an entirely new system.

	3G	WiMax	HSPA+	LTE	LTE Advanced
Peak rate	3 Mbps	128 Mbps	168 Mbps	300 Mbps	1 Gbps
Download rate (actual)	0.5 – 1.5 Mbps	2 – 6 Mbps	1 – 10 Mbps	10 – 100 Mbps	100 – 300 Mbps
Upload rate (actual)	0.2 – 0.5 Mbps	1 – 2 Mbps	0.5 – 4.5 Mbps	5 – 50 Mbps	10 – 70 Mbps

Source: https://www.digitaltrends.com/mobile/what-is-lte-advanced-and-why-should-you-care/

As per 3GPP, major highlights of LTE-A are

- Increased peak data rate with DL speed 3 Gbps & UL 1.5 Gbps
- Offers higher spectral efficiency, from a maximum of 16bps/Hz in R8 to 30 bps/Hz in R10
- Improved performance at cell edges
- Increased number of simultaneously active users

Carrier Aggregation (CA), enhanced use of multi-antenna techniques and support for Relay Nodes (RN) are the main new functionalities introduced in LTE-Advanced.

Carrier Aggregation facilitates higher throughput because as it allows to download data from multiple sources simultaneously. Rather than connecting to the best signal, smartphone chooses to combine multiple signals. Selecting different frequencies are also possible. Up to five of these “component carriers,” each up to 20MHz of bandwidth can be combined. Therefore creating a maximum aggregated bandwidth of 100MHz.

MIMO (Multiple Input Multiple Output) increases the overall data rate by transmitting two or more different data streams using two or more different antennas. Hence, higher spectral efficiency can be achieved by leveraging more radio links through more antennas.

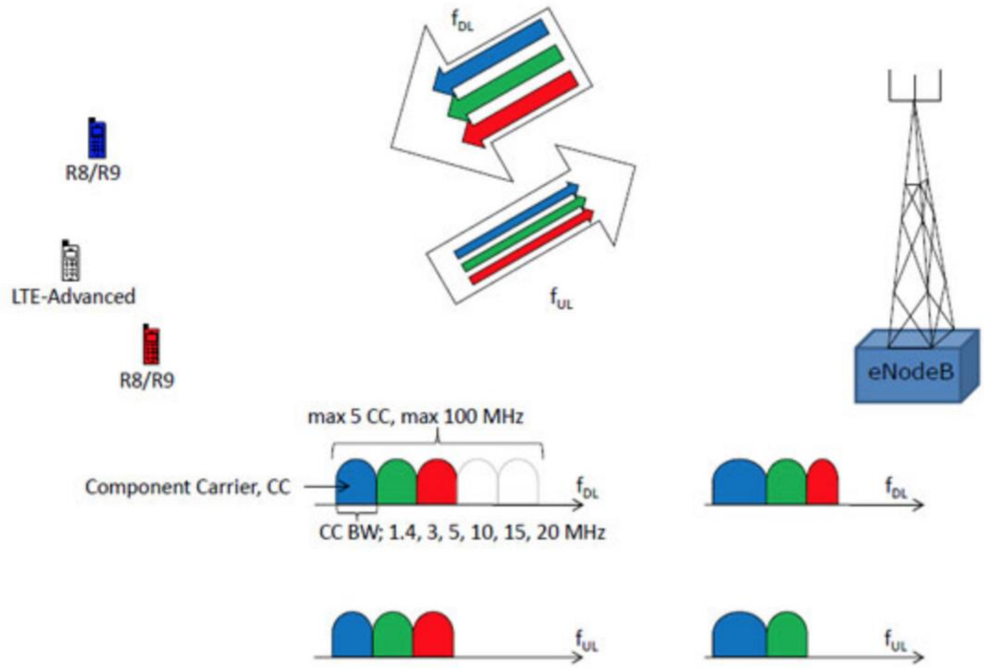
As per 3GPP, “The Relay Nodes are low power base stations that will provide enhanced coverage and capacity at cell edges, and hot-spot areas and it can also be used to connect to remote areas without fiber connection”. Relay Nodes (RNs). Increased the possibility for efficient heterogeneous network planning – i.e. a mix of large and small cells – in LTE-A. The Relay Node is connected to the Donor eNB (DeNB), via radio interface Un - the modified version of the E-UTRAN air interface Uu. Therefore the radio resources in the Donor cell are shared between UEs served directly by the DeNB and the Relay Nodes.

Details of Major Features LTE-A

Carrier Aggregation

Capacity can be increased easily by adding more bandwidth. As it is crucial to keep backward compatibility with R8 and R9 mobiles -in LTE-Advanced the increase in bandwidth is provided through aggregation of R8/R9 carriers. FDD and TDD in both cases carrier aggregation can be used.

Each aggregated carrier is known as component carrier. The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz. Up to five components carriers can be aggregated. Therefore the maximum bandwidth is 100 MHz. In DL and UL , the number of aggregated carriers can be different. It is never seen that number of UL component carriers is never larger than the number of DL component carriers. The individual component carriers can also be of different bandwidths, see below figure.

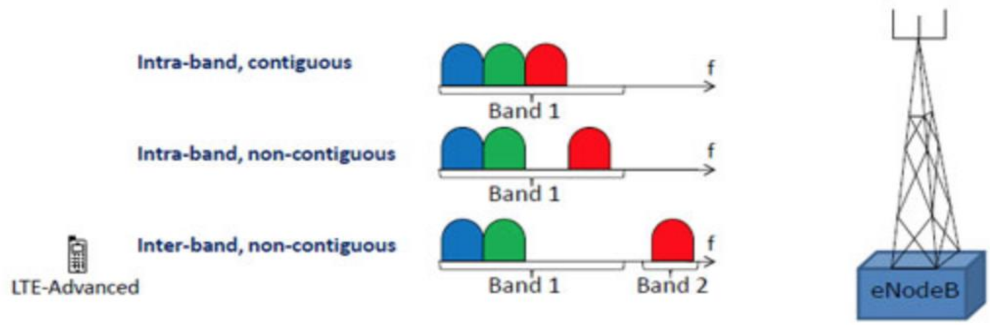


Source: 3GPP

As per 3GPP - “Carrier Aggregation – FDD the R10 UE can be allocated resources DL and UL on up to five Component Carriers (CC). The R8/R9 UEs can be allocated resources on any ONE of the CCs. The CCs can be of different bandwidths”.

Different carrier aggregation configurations like combinations of E-UTRA operating band and the number of component carriers are introduced in steps for backward compatibility. There are two component carriers in the DL and only one in the UL in R10 and two component carriers DL and one or two component carriers in the UL in R11 when carrier aggregation is used.

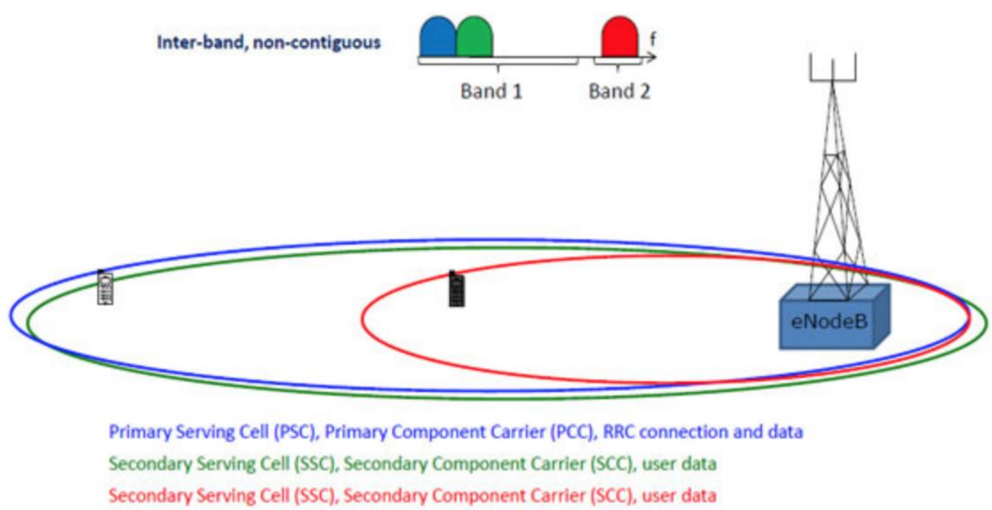
The straightforward way to arrange aggregation is to use intra-band contiguous carriers within the same operating frequency band (as defined for LTE). This cannot be done always due to frequency allocation scenarios. For non-contiguous allocation it could either be intra-band separated by a frequency gap, or inter-band where the component carriers belong to different operating frequency bands.



Source: 3GPP - Carrier Aggregation – Intra- and inter-band alternatives.

When using carrier aggregation there are a number of serving cells, one for each component carrier. The serving cells coverage may vary – due to e.g. component carrier frequencies. Primary serving cell handles RRC connection served by the Primary component carrier. Whereas secondary component carrier serves the Secondary serving cells.

In the below figure, carrier aggregation on all three component carriers is only possible for the UE closer to the cell. White user equipment is not within the coverage area of the red component carrier.

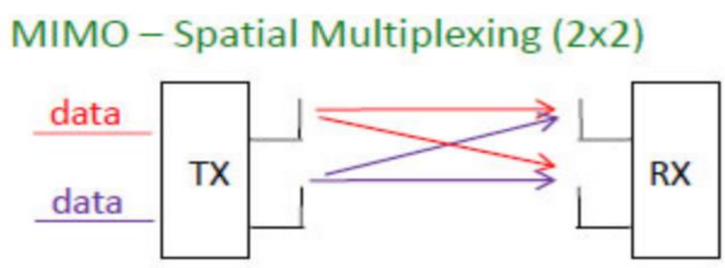


Source: 3GPP
"Carrier Aggregation; Serving Cells. Each Component Carrier corresponds to a serving cell. The different serving cell may have different coverage."

Mainly the physical layer and MAC protocol are influenced by carrier aggregation provided RRC must be able to make decisions about addition/removal of secondary CC and RLC buffer must be larger.

MIMO, Multiple Input Multiple Output – or spatial multiplexing

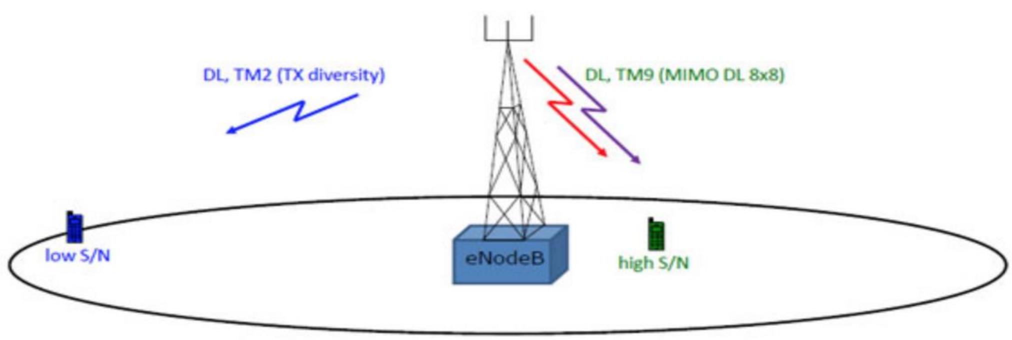
MIMO uses two (or more) different antennas to transmit two (or more) different data streams - using the same resources in both frequency and time, separated by different reference signals - to be received by two or more antennas. Thus increase the overall throughput. Here one or two transport blocks are sent per TTI.



Source : 3GPP

Introduction of 8x8 MIMO in the DL and 4x4 in the UL is the major change in LTE-Advanced compared to LTE.

For low S/N, multi-antenna techniques MIMO is used to improve the S/N by means of TX-diversity different from MIMO used in high S/N scenario.



Source : 3GPP

A number of different Transmission Modes (TM) has been defined in order to adjust the type of multi-antenna transmission scheme. The UE is informed through RRC signaling regarding the mode of transmission. There are nine different transmission modes in downlink. Among them TM1-7 were introduced in R8, TM8 in R9 and TM9 in R10. UL have TM1 and TM2. TM1 was introduced in R8 and TM2 in R10.

As per 3GPP, different transmission modes differs by

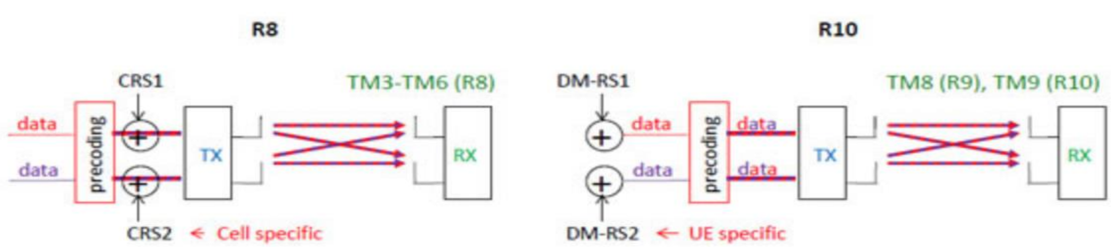
- Number of layers, streams, or rank
- Antenna ports used
- Type of reference signal, Cell-specific Reference Signal (CRS) or Demodulation Reference Signal (DM-RS), introduced in R10.
- Pre-coding type

TM9 supports 8x8 MIMO in DL, and TM2 supports 4x4 MIMO in UL. Introducing these required UE to support this as well. In R10 introduced three UE category. Category 6, 7 and 8. Among them category 8 supports the maximum number of CC and 8x8 spatial multiplexing.

Pre-coding is used for mapping the modulation symbols onto the different antennas in multi-antenna techniques. Pre-coding type depends on the multi-antenna technique as well as number of layers and the number of antenna ports. Its goal is to achieve the best possible data reception at the receiver end.

To handle fading, reference signals will be sent together with the data. Receiver will demodulate of the received signal at their end.

In R8 after pre-coding reference signal is added one CRS (Cell-specific Reference Signal) per antenna. UE estimates how the radio channel influenced the signal by analyzing received CRS. UE demodulate the received signal and regenerate the information sent by using this along with information about the used code-book based pre-coding.

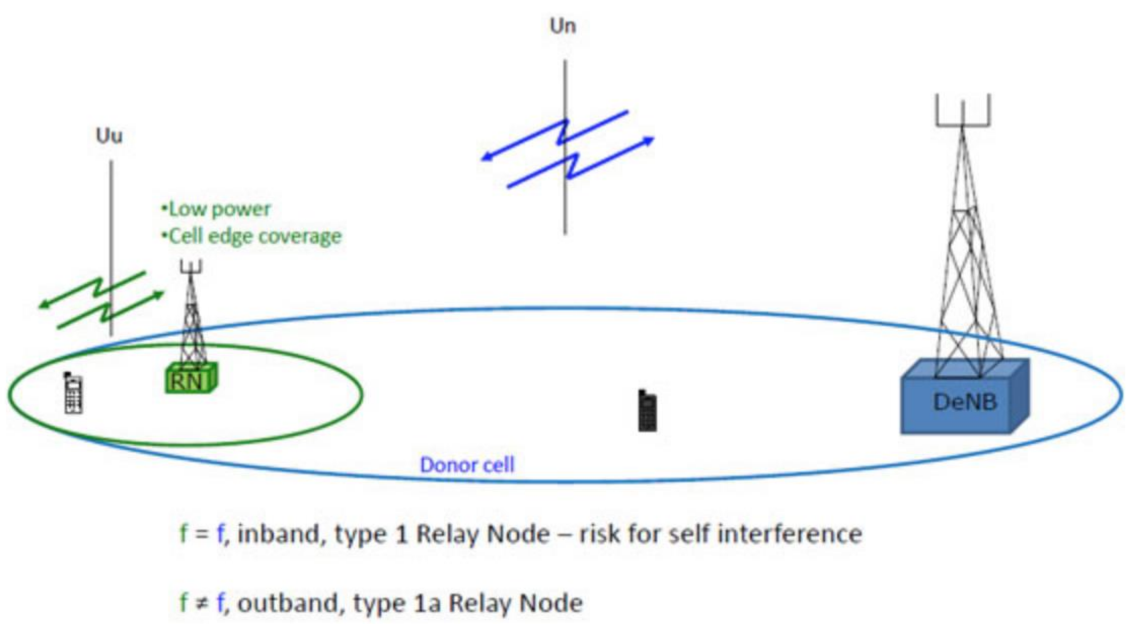


Source: 3GPP

DM-RSs (Demodulation Reference Signals) are added before pre-coding to the different data streams in R10. Knowledge about the reference signal gives information about the combined influence of radio channel and pre-coding. Receiver doesn't need any pre-knowledge about the pre-coder. This is known as non-codebook based pre-coding.

Relay Nodes

In LTE-Advanced, efficient heterogeneous network planning possibilities are increased with the introduction of Relay Nodes (RNs). The Relay Nodes are low power eNodeBs providing enhanced coverage and capacity at cell edges and hot-spot areas. Fiber connections are not required to connect these to remote areas. The Relay Node is connected to the Donor eNB (DeNB) via a radio interface, Un. Un is a modified version of the E-UTRAN air interface Uu. Therefore radio resources of Donor cells are shared between UEs provided directly by the DeNB and the Relay Nodes. In relay Node, when the Uu and Un use same frequencies it is known as a Type 1 RN, when using different frequencies it is referred to as Type 1a RN Uu. There is a high risk for self-interference in Type 1n RN as receiving on Uu and transmitting on Un use the same time (or vice versa). It can be minimized by time sharing between Uu and Un, or using different locations for the transmitter and receiver. MME selection is done in DeNB.

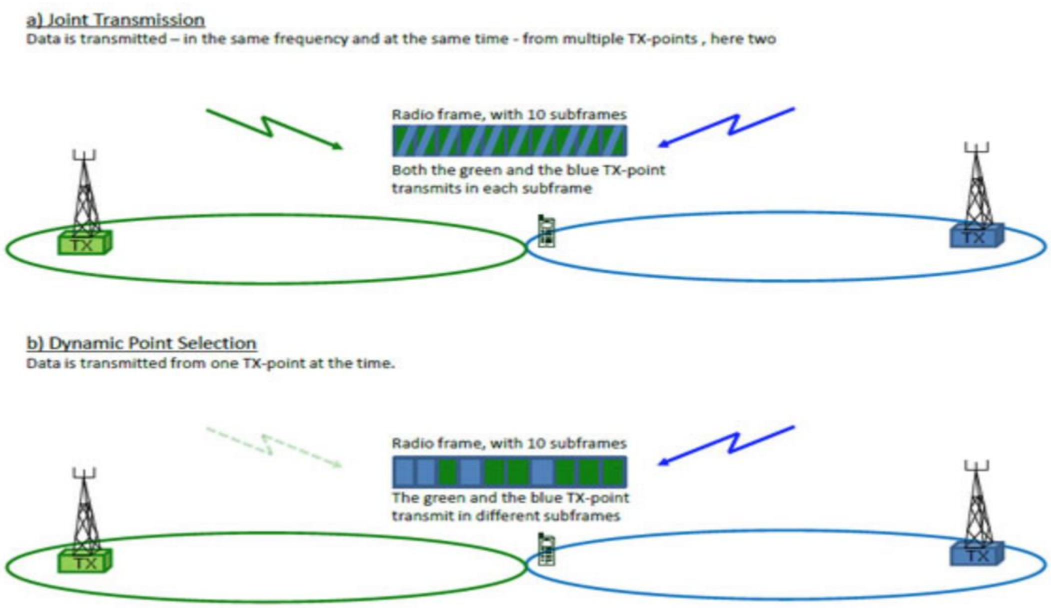


Source: 3GPP

Coordinated Multi Point operation (CoMP) – R11

As a part of evolution, a new feature like Coordinated Multi Point (CoMP) is introduced in LTE-advanced in R11.

The main goal of introducing CoMP is to enhance network performance at cell edges. As per 3GPP "In CoMP a number of TX (transmit) points provide coordinated transmission in the DL, and a number of RX (receive) points provide coordinated reception in the UL". A TX/RX-point comprising of a set of co-located TX/RX antennas is there to provide coverage in the same sector. The set of TX/RX-points can either be co-sited or at different locations. For coverage purpose in different sectors, they can be on the different or same eNBs. There are several ways for CoMP. It can be done for both homogenous networks as well as heterogeneous networks.



Source : 3GPP

As per 3GPP above figure DL CoMP

a)" Joint Transmission; two TX-points transmit to one UE in the same radio resource,

b) Dynamic Point Selection; two TX points are ready to transmit, but only one will be scheduled in each sub frame."

2.1.5 5G

Introduction:

5G is the fifth generation wireless mobile communications succeeding 4G (LTE/WiMAX), 3G (UMTS) and 2G (GSM) systems. It supports various frequency bands including above 6 GHz (mm-wave bands), below 6 GHz and below 1 GHz.5G performance aims at high data rate, minimum latency, lowering cost, higher system capacity, energy saving and massive device connectivity. Beyond just throughput improvements, it is expected to facilitate a massive IoT ecosystem where networks can serve billions of connected devices, with the right trade-offs between speed, cost and latency.

Roadmap:

"The first phase of 5G specifications in Release-15 will be completed by March 2019, to accommodate early commercial deployment. The second phase in Release-16 will be completed by March 2020, for submission to the ITU as a candidate IMT-2020 technology. "

5G technology features or advantages:

- User experienced data rates up to 1 Gbps downlink and 500 Mbps uplink for indoor hotspot environments
- Latency targets are as low as 0, 5 ms for tactile interaction.
- For indoor hotspots, capacity targets can be as high as 15 Tbps/km2 with 250 000 users/km2
- 1,000x bandwidth per unit area.
- Feasibility to connect up to 100 devices.
- About 90% reduction in network energy usage.
- Low battery consumption.
- More secure
- Better QoS (Quality of Service)
- Worldwide coverage/Wi-Fi zone.

5G Capabilities:

As per IMT-2020 5G, following eight parameters are key capabilities for 5G –

Capability	Description	5G target	Usage scenario
Peak data rate	Maximum achievable data rate	20 Gbit/s	eMBB
User experienced data rate	Achievable data rate across coverage area	1 Gbit/s	eMBB
Latency	Radio network contribution to packet travel time	1 ms	URLLC
Mobility	Maximum speed for handoff and QoS requirements	500 km/h	eMBB/URLLC
Connection density	Total number of devices per unit area	$10^6/km^2$	MMTC
Energy efficiency	Data sent/received per unit energy consumption (by device or network)	Equal to 4G	eMBB
Spectrum efficiency	Throughput per unit wireless bandwidth and per network cell	3-4x 4G	eMBB
Area traffic capacity	Total traffic across coverage area	10 $(Mbit/s)/m^2$	eMBB

Source : WiKi

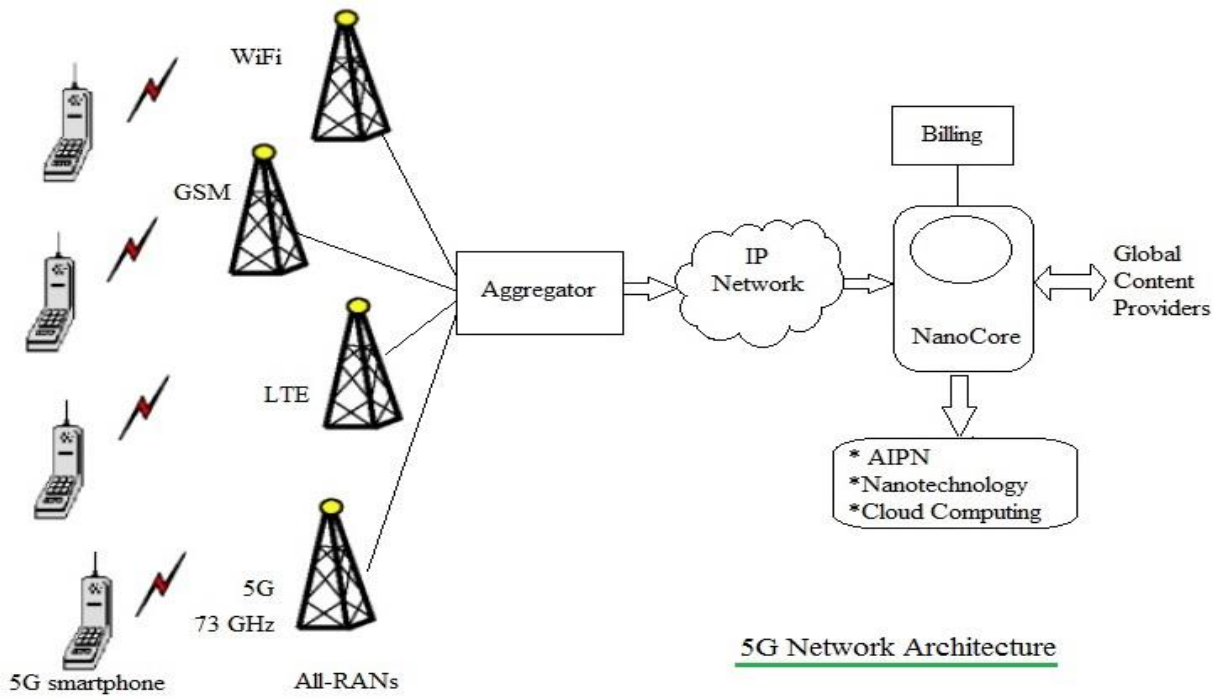
5G Frequency Bands:

Band	Uplink (MHz)	Downlink (MHz)	Duplex mode
n1	1920 – 1980	2110 – 2170	FDD
n2	1850 – 1910	1930 – 1990	FDD
n3	1710 – 1785	1805 – 1880	FDD
n5	824 – 849	869 – 894	FDD
n7	2500 – 2570	2620 – 2690	FDD
n8	880 – 915	925 – 960	FDD
n12	699 – 716	729 – 746	FDD
n20	832 – 862	791 – 821	FDD
n25	1850 – 1915	1930 – 1995	FDD
n28	703 – 748	758 – 803	FDD
n34	2010 – 2025		TDD
n38	2570 – 2620		TDD
n39	1880 – 1920		TDD
n40	2300 – 2400		TDD
n41	2496 – 2690		TDD
n50	1432 – 1517		TDD
n51	1427 – 1432		TDD
n66	1710 – 1780	2110 – 2200	FDD
n70	1695 – 1710	1995 – 2020	FDD
n71	663 – 698	617 – 652	FDD
n74	1427 – 1470	1475 – 1518	FDD
n75	N/A	1432 – 1517	SDL[A 3]
n76	N/A	1427 – 1432	SDL[A 3]
n77	3300 – 4200	N/A	TDD
n78	3300 – 3800	N/A	TDD
n79	4400 – 5000	N/A	TDD
n80	1710 – 1785	N/A	SUL
n81	880 – 915	N/A	SUL
n82	832 – 862	N/A	SUL
n83	703 – 748	N/A	SUL
n84	1920 – 1980	N/A	SUL
n86	1710 – 1780	N/A	SUL

Source : Wiki

5G Probable Network Architecture:

The generic 5G network architecture consists of all RANs, nano-core, aggregator, IP network, billing, global content provider etc**.**



Source: http://www.rfwireless-world.com/Tutorials/5G-network-architecture.html

As per basic 5G architecture, network uses flat IP concept. Hence supporting different RANs (Radio Access Networks) with same single Nanocore for communication. 5G RAN supports all the existing services - LTE, LTE-advanced, WiMAX, WI-Fi___33, UMTS, GSM, GPRS/EDGE, CDMA2000, EV-DO, CDMA One, IS-95 etc.

Flat IP architecture identify devices using symbolic names. Whereas in hierarchical architecture normal IP addresses are used. In this architecture by reducing the number of network elements in data path lower the operational cost as well as latency. It makes easier for all the RANs to utilize a single core.

The All IP network is a platform for interaction of converging three technologies – Nano Technology, Flat IP and Cloud computing.
5G aggregator's task is to aggregate all the RAN traffics and route it to gateway. Hence eliminating interconnecting charges and complexities. It is located at BSC/RNC place. 5G UEs accommodates different radio interfaces for each RAT. It will also reduce the network entities for end-to-end connection and thus reducing latency significantly.

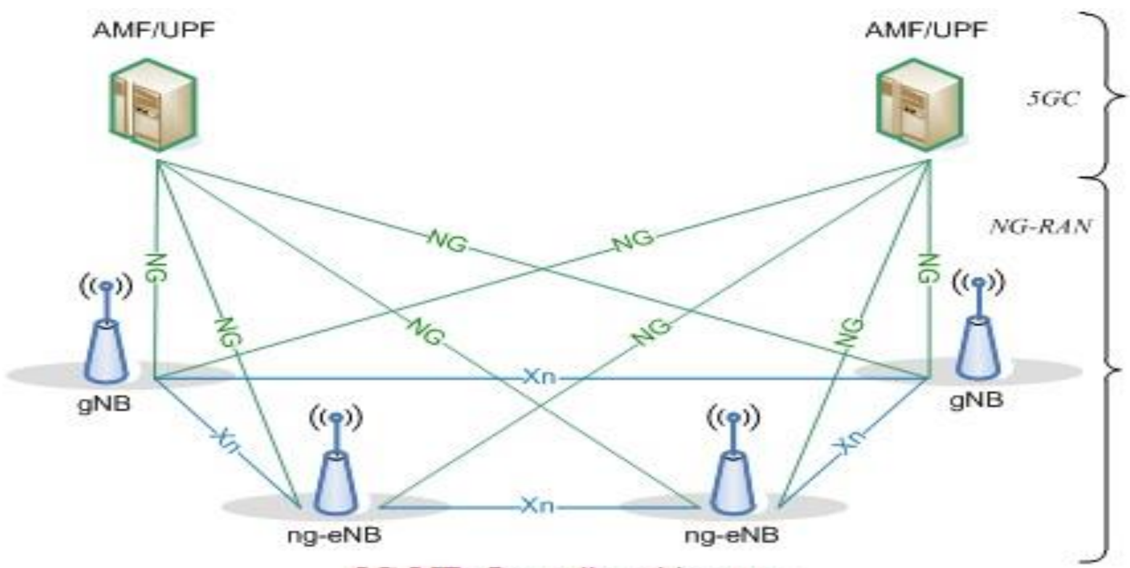
5G nano core consists of nanotechnology, all IP architecture, cloud computing. It is convergence point for the other technologies.

Cloud computing is a technology that uses internet and central remote server to maintain all the data and applications of the subscribers. . It facilitates subscriber to obtain much more real time application. It allows users to use applications without any installation. Consumer’s access files from any computer across the globe using internet.

Global content service providers support Search engine, public portal & private portal, education, government, transportation, banking & medical services and many more.

5G NR (New Radio) Architecture:

The probable 5G NR overall architecture is shown below as per the 3GPP TS 38.300 specification.

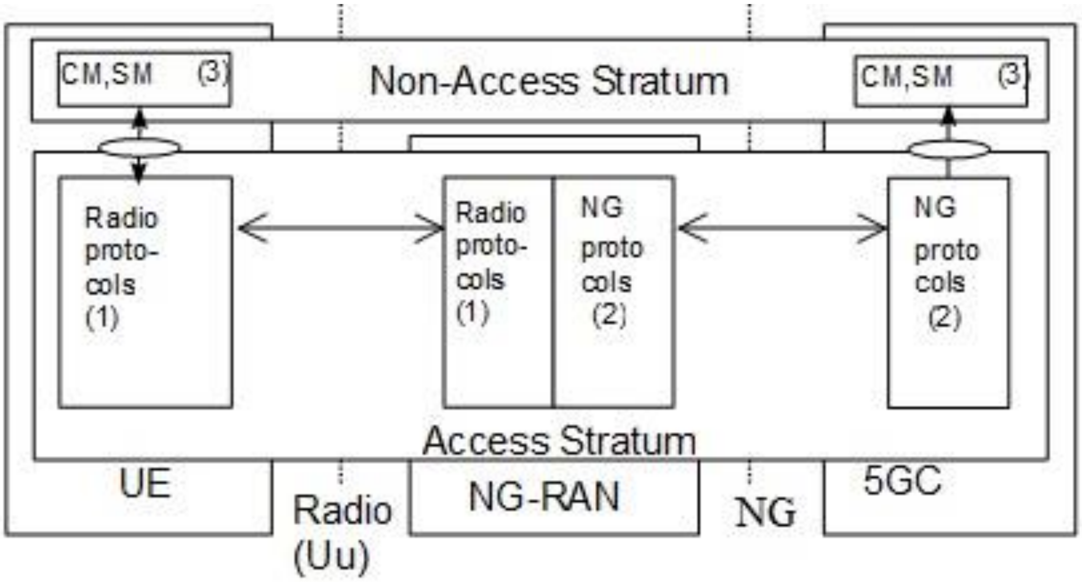


5G NR Overall architecture

Source: RFwireless world

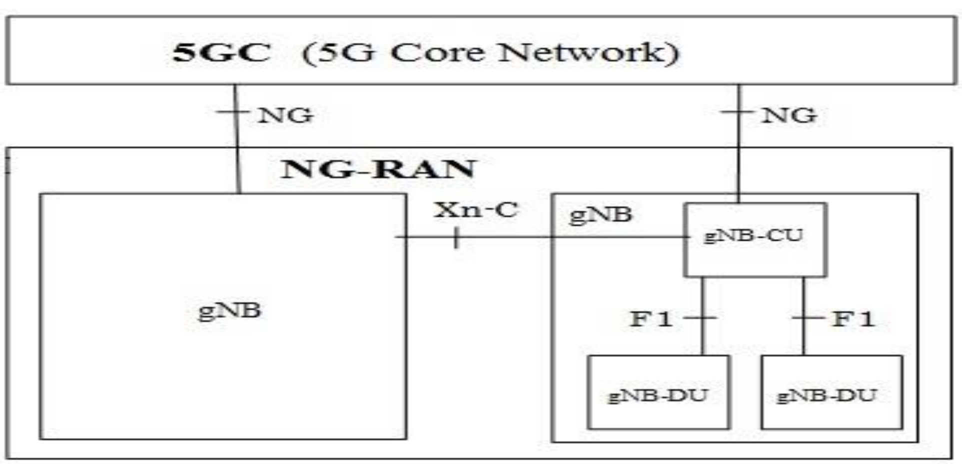
As shown in the figure, terminations of NR (New Radio) user plane and control plane protocol towards the UE are done at gNB. It is connected to 5GC via NG interface. On the other hand, terminations of user plane and control plane protocol towards the UE are done at ng-eNB node for E-UTRA (i.e. LTE). It is also connected to the 5GC via the NG interface.

UPF stands for User Plane Function and AMF stands for Access and Mobility Management Function.



Source: RFwireless world

Uu is the interface between UE & NG-RAN and NG is the interface between NG-RAB and 5GC (5G core). User plane protocol carries user data through the access stratum implementing actual PDU Session service. Control plane protocols manage PDU Sessions connecting UE and the network from various aspects inclusive requesting the service, handover, controlling different transmission resources etc. It also includes the mechanism for transparent transfer of NAS messages.



NG-RAN Architecture

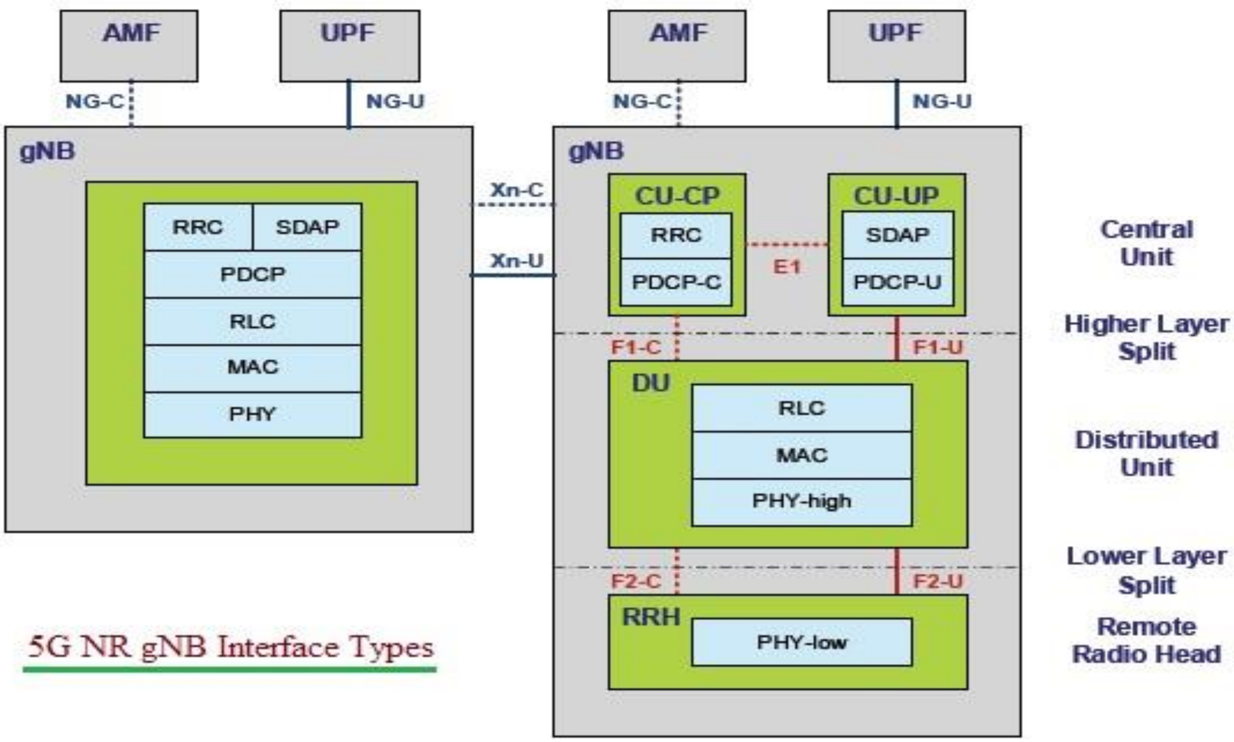
Source: RFwireless world

The NG-RAN consists of a set of gNBs connected to the 5G Core via the NG interface. It can support FDD mode, TDD mode or dual mode operation. gNBs are interconnected through the Xn interface. A gNB includes a gNB-CU and one or more gNB-DU(s). A gNB-DU and a gNB-CU is connected via F1 interface. All these interfaces (NG, Xn and F1) are logical interface.

5GC offers many functions including network slicing to serve vivid subscriber requirements. It incorporate distributed cloud, NFV (Network functions virtualization) and SDN (Software Defined Networking). 5G Core Network is highly flexible, modular and scalable.

5G NR Network Interfaces

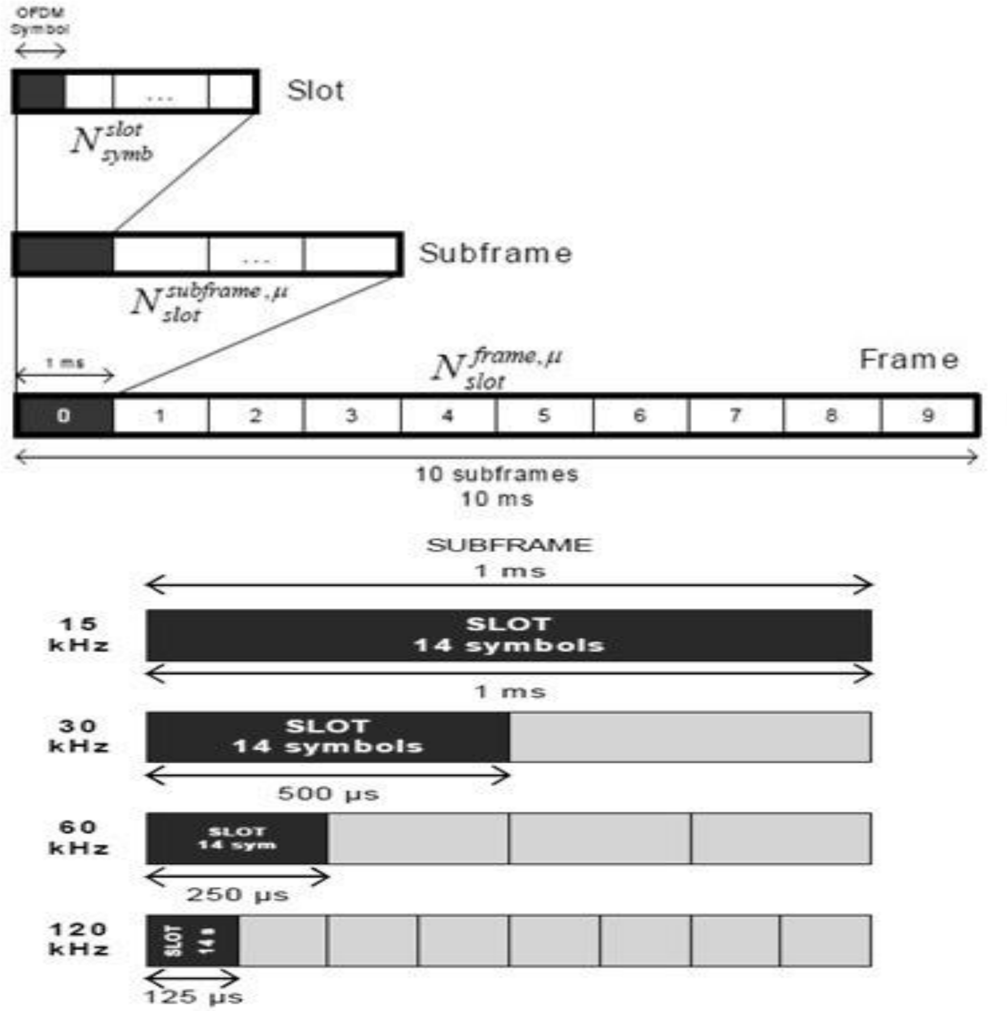
5G NR network interfaces include Xn interface (between base stations), NG interface (between 5GC and base station), E1 interface (between a gNB-CU-CP and a gNB-CU-UP), and F1 interface (between gNB-CU and gNB-DU)
and F2 interface.



Source: RFwireless world

5G NR Frame Structure:

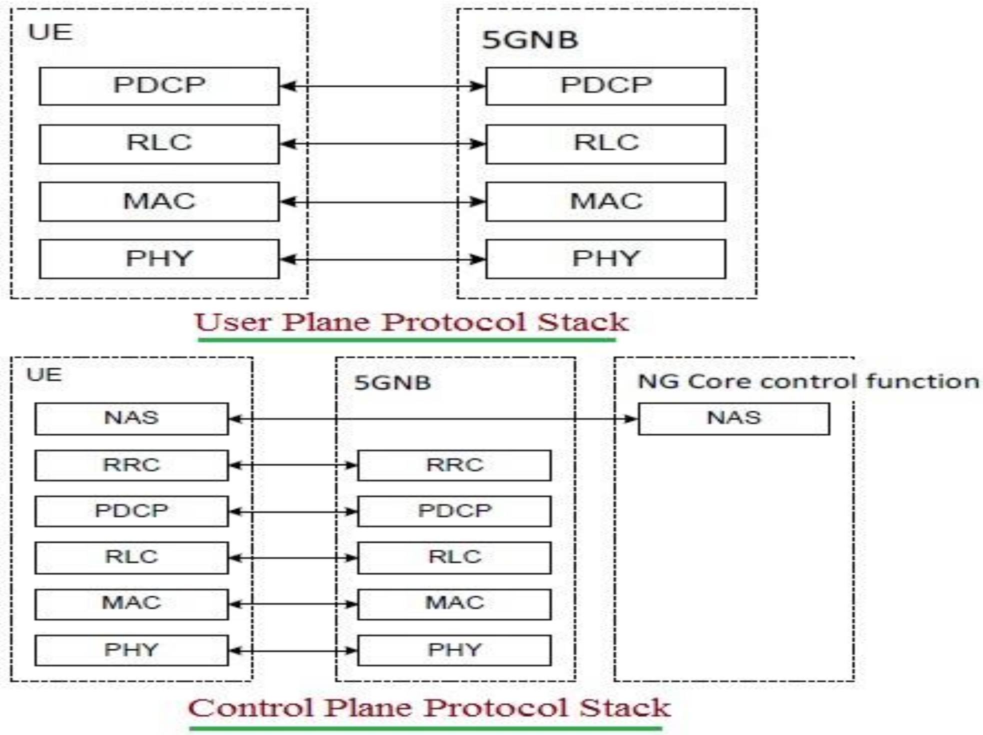
5G NR Supports two frequency ranges FR1 (Sub 6GHz) and FR2 (millimeter wave range: 24.25 - 52.6 GHz).



Source: http://www.rfwireless-world.com/5G/

Here the duration of frame is 10 ms consisting 10 sub-frames of 1ms duration each. Each sub-frame can have 2µ slots typically consisting of 14 OFDM symbols each.

5G NR Radio Protocol Architecture:



Source: http://www.rfwireless-world.com/5G/

5G Layer 1 - 5G PHYSICAL Layer

- Error detection on the transport channel
- FEC encoding/decoding of the transport channel
- Modulation and demodulation of physical channels
- Frequency and time synchronization
- Hybrid ARQ

5G Layer 2 - 5G MAC, RLC, PDCP Layer

- Random access procedure
- Multiplexing/de-multiplexing of 5G-MAC SDUs
- Scheduling information reporting
- Error correction through HARQ
- Mapping between logical channels and transport channels

Following are the functions of RLC sub-layer-
- Transfer of upper layer PDUs
- Error Correction through ARQ (only for AM data transfer)

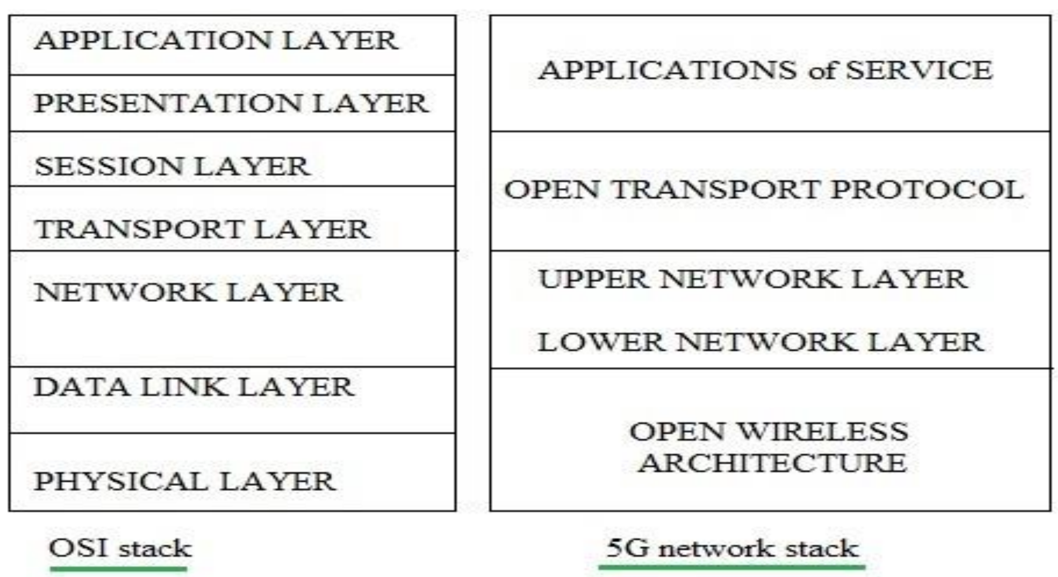
• Protocol error detection (only for AM data transfer)
• Segmentation (only for UM and AM data transfer) & re-segmentation (only for AM data transfer)

Following are the functions of PDCP sub-layer -
• Transfer of user data & control plane data
• Sequence delivery of upper layer PDUs
• Duplicate detection of lower layer SDUs
• Retransmission of 5G-PDCP SDUs
• Ciphering and deciphering

5G Layer 3 - 5G RRC Layer

- Broadcasting of system information to NAS and AS.
- Establishment and release of RRC connection.
- Mobility functions along with cell addition and cell release
- NAS direct message transfer to/from NAS from/to UE
- UE measurement reporting, control of UE reporting

5G Protocol Stack:



Source: http://www.rfwireless-world.com/Tutorials/5G-network-architecture.html

5G protocol stack consists of OWA layer, network layer, Open transport layer and application layer.

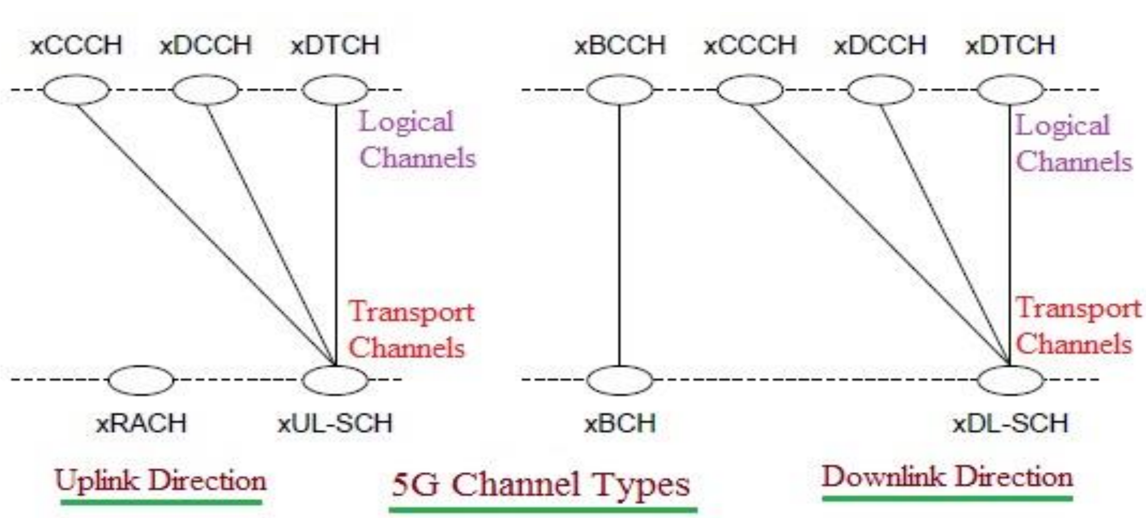
OWA Layer (Open Wireless Architecture layer): It performs the function of physical layer and data link layer of OSI stack.

Network Layer: It splits into lower and upper network layers. It is responsible to route data from source IP device to the destination IP device/system.

Open Transport Layer: It functions both as transport layer and session layer.

Application Layer: It is responsible for proper formatting of data. It performs encryption and decryption. It provides intelligent QoS for different networks. For a given service, it selects the best wireless connection.

5G Channel Types:



Source : http://www.rfwireless-world.com/5G/

5G Control Channels: xBCCH, xCCCH and xDCCH
5G TRAFFIC Channel: XDTCH
5G Transport Channels: xBCH, xDL-SCH, xRACH, xUL-SCH.

Challenges:

5G technology is still under process and researches for its development are going on. Few major challenges are -

1. 5G will utilize millimeter wave, which makes it unsuitable to penetrate against barriers. Its propagation distance will be small. Meaning more towers will be needed to make the technology fully functional. The throughput that 5G is claiming might be difficult to achieve. Another factor here would be the transmitting power.

2. There still remain doubts regarding the way it will handle critical security and privacy concerns. If the common data hacks issues are not dealt properly, then people might be wary of adopting this technology.

3. As it is approaching towards D2D communication, complex data transmission protocols required to implement D2D communication and making the technology available in devices is a big challenge for 5G.

4. The mass adoption of 5G might need to deal with its hefty expense. The initial subscription plans as well as regular up gradation are likely to be more expensive than the currently available technologies.

2.2 Wired Access Technologies

2.2.1 DSL

Digital subscriber line belongs to a group of technologies used to transmit digital high-bandwidth data such as multimedia and video, over telephone lines for homes and businesses competes. Along with cable Internet, DSL is one of the most popular ways in providing high-speed internet service. DSL provides dedicated, point-to-point, public network access. This connection is typically between a customer premises and the network service provider central office. Hence known as a last-mile technology.

DSL separates Internet frequencies from telephone, enabling users to be online and use the phone simultaneously since DSL uses higher frequency bands for data. High-frequency interference are filter-out to enable simultaneous use of the voice and DSL services at customer end.

Telephones are connected to the telephone exchange via a local loop, which was originally designed for the transmission of speech. This supports voice band ranging from 300 to 3400 Hertz. However because of the conversion of analog to digital operation for long-distance trunks, DSL took the lead to pass data through the local loop.

DSL bit rate typically ranges from 256 kbit/s to over 100 Mbit/s in downstream direction. Bit rates of 1 Gbit/s have been achieved. Rate mainly depends on technology, line conditions, and implementation of service.

In order to access the Internet using DSL, a DSL modem is connected to either a router or a computer. The DSL modem is connected to a phone line. The location of modem shouldn't be too far from the user because of attenuation, loss of data. DSL line uses a complicated modulation scheme to fit data onto copper wires.

DSL service can be categorized as

a. ADSL - Asymmetrical Digital Subscriber Line
b. SDSL - Symmetric Digital Subscriber Line

Most types of DSL service are asymmetric

Asymmetric DSL
Asymmetric DSL offers more bandwidth for downstream than upstream data flow. Typically subscribers require more throughput on downstream rather than upstream. By reducing the amount of bandwidth available on upstream, service providers can use bandwidth more efficiently.

Asymmetric DSL technology is popular residential DSL service as users typically download much more data than they send. Common forms of ADSL include the following:

ADSL (Asymmetrical Digital Subscriber Line): Offers download speed of up to 8 Mbps and an upload speed of 384 Kbps. It supports telephone service and data transmission simultaneously.

ADSL 2+: Is a newer version of ADSL. It provides downstream rate of up to 20 Mbps and upstream rate of up to 850 Kbps.

ADSL Lite or G.Lite: Offers slower speeds of up to 1 Mbps download and 512 Kbps upload speed.

R-ADSL (Rate-Adaptive Digital Subscriber Line): Provides the same transmission rates as ADSL. Modem can adjust the transmission speed here.

VDSL (Very High Bit-Rate Digital Subscriber Line): Over a single copper wire it offers downstream rates of up to 52 Mbps and upstream rates of up to 2.3 Mbps. It is the fastest DSL service.

Symmetric DSL
Symmetric DSL (SDSL) splits the upstream and downstream frequencies evenly providing equal bandwidth for both uploads and downloads. It is popular for simultaneous voice and video communications and for business where high speed in both directions is a requirement.

Forms of symmetric DSL include:

SDSL (Symmetric Digital Subscriber Line) offers speed up to 1.54 Mbps both in upstream and downstream transmission.

SHDSL (Symmetrical High-Speed Digital Subscriber Line) is approved by the International Telecommunications Union. It is the same technology as SDSL.

HSDL (High Bit-Rate Digital Subscriber Line) offers data rates up to 2.048 Mbps but required multiple phone lines. Now being obsolete for this.

Pros

- More widely accessible than fiber and cable internet
- Usually more affordable compared with fiber optic or satellite internet service.

Cons

- Usually slower than fiber and cable internet
- Upload speeds are much lower than download

2.2.2 Cable

Cable Internet Access is a high-speed data transmission technology typically over the coaxial cable, which uses the same infrastructure as a cable television. It is a form of broadband Internet, shortly known as cable internet.

In cable internet, few channels are used for upstream transmission and other channels for downstream transmission. As coaxial cable used by cable TV possesses larger bandwidth than telephone lines, extremely fast access to the internet can be achieved. Cable Internet access provides last mile access to subscriber end from the Internet service provider. Cable TV networks and telecommunications networks are the two most widely used forms of residential Internet access.

For Broadband cable Internet access, a cable modem is required at the customer's premises. And at a cable operator facility, a cable modem termination system (CMTS) is needed typically a cable television head end. Coaxial cable or a Hybrid Fiber Coaxial (HFC) plant is required for connecting these two ends. Cable Internet systems can typically operate well where the distance is up to 160 kilometers (99 mi). For larger HFC network, CMTS can be grouped into hubs for efficient management.

For Downstream, bit rates up to 1 Gbit/s can be achieved. Upstream traffic, ranges from 384 kbit/s to more than 20 Mbit/s. One downstream channel can maintain hundreds of cable modems. As the system grows, the CMTS can be grouped into hub CMTSs for efficient management and upgraded with more downstream and upstream ports.

Data over Cable Service Interface Specification (DOCSIS) is a telecommunications standard used to offer Internet access via a cable modem. It defines a standard to modem manufacturers and network service providers to work together in an anticipated way. Evolution of DOCSIS is given below-

BROADBAND GENERATION	DOCSIS 1.0	DOCSIS 1.1	DOCSIS 2.0	DOCSIS 3.0	DOCSIS 3.1
HIGHLIGHTS	Initial cable broadband technology	Added voice over IP service	Higher upstream speed	Greatly enhanced capacity	Capacity and efficiency progression
DOWNSTREAM CAPACITY	40 Mbps	40 Mbps	40 Mbps	1 Gbps	10 Gbps
UPSTREAM CAPACITY	10 Mbps	10 Mbps	30 Mbps	100 Mbps	1-2 Gbps
PRODUCTION DATE	1997	2001	2002	2008	2016

Cable Broadband Technology Evolution, 1990s to Present

Source: https://www.cablelabs.com/insights/cable-broadband-technology-gigabit-evolution/

Upload and download rates can be restricted by Data over Cable Service Interface Specification (DOCSIS) cable modem. Limits can be restricted using the Trivial File Transfer Protocol by setting configuration file in the modem during initial connection. Full access to the bandwidth can be gained by overriding the BW cap known as uncapping process.

In most broadband technologies like FTTX, Satellite Internet, or WiMAX, subscribers share the available bandwidth. Whereas some technologies like Cable Internet and PON share the access network. There are other technologies that share their core also. This facilitates network operator to take advantage of statistical multiplexing to distribute bandwidth fairly at an acceptable price. Since it is a shared technology, network operator has to provide enough bandwidth for a particular neighborhood. Otherwise when everyone tries to access the Internet at the same time, your download service could be saturated and speed could slow to a crawl. Operators have been using bandwidth cap, or other bandwidth throttling technique to limit download speed during peak times. However, to ensure end user service even during peak-usage times, the operator has to monitor usage patterns and scale the network appropriately.

PROS

- Faster than DSL.
- More reliable than DSL service.

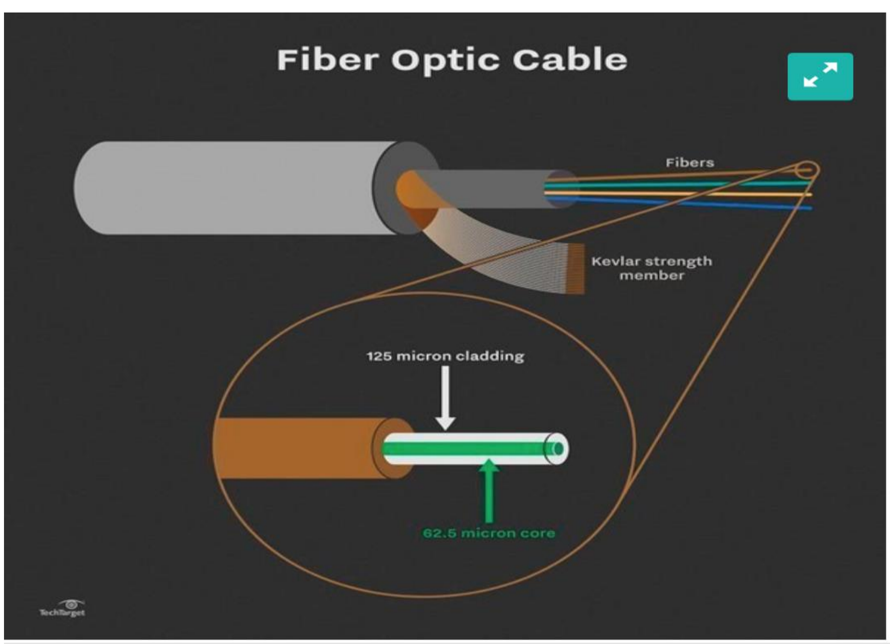
CONS

- More expensive than DSL.
- Availability issue - may not be available everywhere

2.2.3 Fiber

Fiber optics, or optical fiber, refers to the medium and the technology of transmitting information from one place to another by sending pulses of light through a glass or plastic strand or fiber. Here an electromagnetic carrier wave is modulated to carry information. At receiving end the light pulses in converted into binary values.

Fiber optic cables provide the fastest data transfer rates and are also less susceptible to noise and interference compared to copper wires or telephone lines which makes them suitable for long-distance communications and high-demand applications. However, fiber optic cables require more protective shielding as they are more fragile than their metallic counterparts.



Source: https://searchtelecom.techtarget.com/definition/optical-fiber

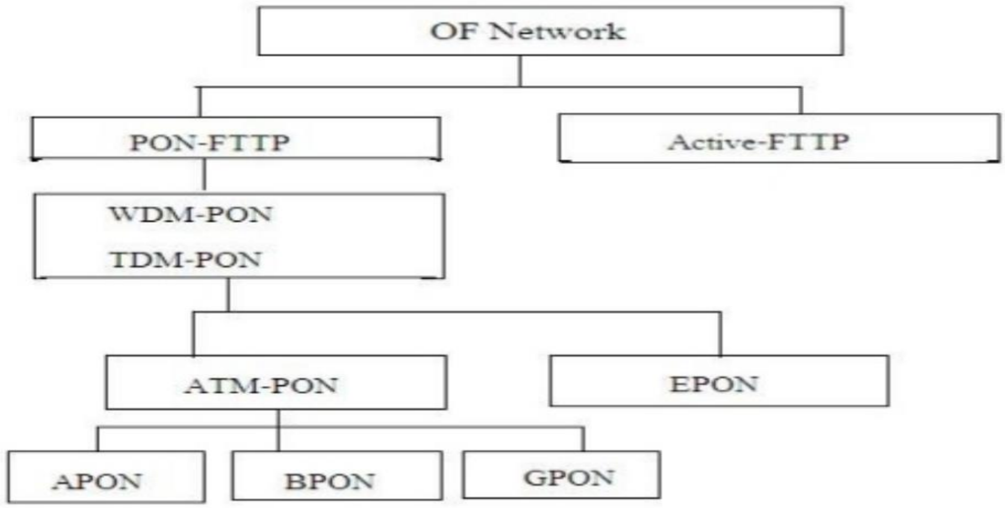
An optical fiber cable consists of a core, cladding, and a protective outer coating named buffer to guide the light along the core through cladding by using total internal reflection method. The core and the cladding are usually made of high-quality silica glass or plastic as well. Fusion splicing and mechanical splicing are used to connect two optical fibers.

Optical fibers are of two types- multi-mode optical fibers and single-mode optical fibers. A multi-mode optical fiber has a larger core greater than 50 micrometers. It requires less precision, cheaper transmitters and receivers. Multi-mode fibers are usually more expensive and exhibit higher attenuation as it contains higher dopant. A multi-mode fiber might limit the bandwidth and length of the link as it introduces multimode distortion. On the other hand, single-mode fiber has smaller (<10 micrometers) core and requires more expensive components and interconnection methods. But it allows much longer, higher-performance links.

For fiber-to-the-home broadband connections, two important types of systems are available - active optical networks and passive optical networks. Each has its own advantages and disadvantages and offers ways to separate data and route it to the proper place.

An active optical system uses electrically powered switching equipment to manage signal distribution and direct signals to specific users. It could be a router or a switch aggregator. Here incoming and outgoing signals are directed towards proper place by opening and closing switch in various ways. In AON a subscribers usually have a dedicated fiber running to their premises.

In a passive optical network, there is no electrically powered switching equipment. Instead it uses optical splitters to separate and collect optical signals. PON shares fiber optic strands for portions of the network. Only source and receiving ends need powered equipment. It implements point-to-multipoint architecture. PON are often referred to as the "last mile" between an ISP and customer. Also known as fiber to the home (FTTH) networks.



Source: https://www.slideshare.net/manishhit1/manish-passive-optic-network?qid=f6d65727-c68b-407b-85be-89aa11bfd3e1&v=&b=&from_search=9

Pros

- Gigabit speed .Higher throughput compared to DSL or cable.
- Fast upload rates
- Reliable service

Cons

- Expensive
- Limited availability

- **GPON**

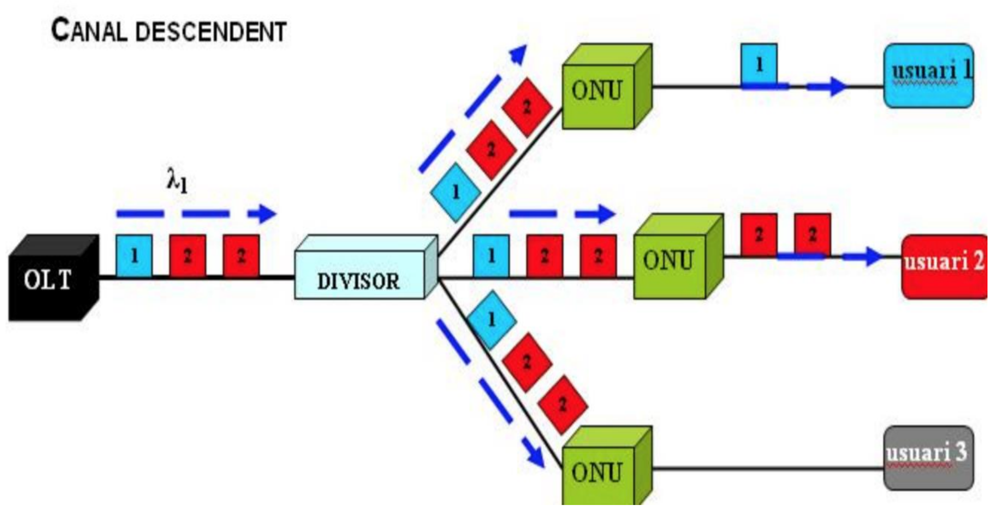
Gigabit Passive Optical Networks (GPON) is a point-to-multipoint access mechanism providing network Internet access at very high speed. It can serve multiple homes and small businesses by enabling one single feeding fiber from the provider's central by using passive splitters in the fiber distribution network.

A GPON network usually transports Ethernet frames but also theoretically capable of carrying ATM loads. The GPON standard succeeds in 2003/2004 as the eventual successor to BPON (ITU G.983.x standards) enabling it to reach peak useful rates close to 1 Gbit / s in each direction of transmission as well as a data rate of 2.5 Gbps in downstream and a data rate of 1.25 Gbps in upstream divided by the split ratio to each customer.

GPON uses optical wavelength division multiplexing (WDM) to use single fiber for both downstream and upstream data. Single mode bi-directional optical fiber supports a wavelength of 1310 nm for the uplink and 1490 nm for the downlink in sharing environment.

In GPON system an optical coupler (passive) is used to distribute the signal from the OLT (optical line termination) to several ONU- optical network units serving several subscribers using passive optical distribution network. For 2.488 Gbits/s downstream at ONU, time division multiple access (TDMA) is used to allocate a specific timeslot to each user. Here the bandwidth is divided so each user gets a fraction of it, depending on service provider's requirement. The upstream rate is shared with other ONUs in a TDMA scheme and thus less than the maximum. The distance and time delay of each subscriber is defined by OLT. Then with the help of software timeslots are allotted to upstream data for each user.

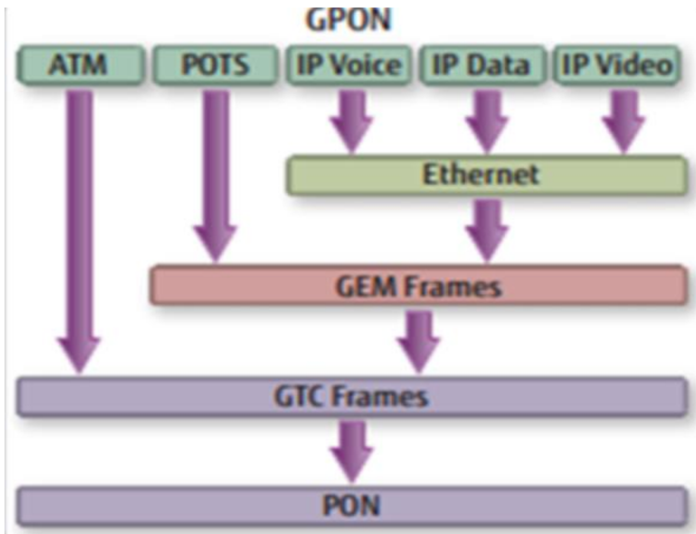
Typically split of a single fiber is 1:32 or 1:64 are used meaning each fiber can serve up to 32 or 64 subscribers. Some system can accommodate up to split ratios of 1:128.



GPON network, downstream flows to 3 subscribers.
Source : Wiki

In a GPON network, two options available for the physical range (max. physical distance between the OLT and the subscriber termination units (ONU / ONT): 10 km and 20 km. The maximum distance depends on the attenuation of the optical signal and type of laser diode used in the ONU. Attenuation is mainly related to the division rate of the line and to the number & types of splitters used.

In GPON encapsulation is done in two steps. First, TDM and Ethernet frames are wrapped into GEM (GPON Encapsulation Mode) frames. It has a GFP-like format. Secondly, ATM and GEM frames are both encapsulated into GTC (GPON Transmission Convergence) frames. GEM frame is used to provide a frame-oriented service, as an alternative to ATM to accommodate Ethernet and TDM frames. All traffic is mapped across the GPON network using a variant of SONET/SDH GFP with GEM. GEM can facilitate native transport of voice, video, and data without an added ATM or IP encapsulation layer.



Source :http://www.fiber-optic-solutions.com/epon-vs-gpon-a-practical-comparison.html

The latest version of GPON is a 10-Gigabit GPON called XGPON, or 10G-PON. XGPON serves the purpose of high demand for video and over the top (OTT) TV services that has increased over the years. XGPON can serve a rate up to 10 Gbits/s (9.95328) downstream and 2.5 Gbits/s (2.48832) upstream. Allowing different WDM wavelengths of 1577 nm downstream and 1270 nm upstream enables GPON to coexist on the same fiber with standard GPON. Optical split is 1:128, and use the same data format as GPON. The supporting maximum range is still 20 km. XGPON is not yet widely implemented but it is paving an upgrade path for future service providers and customers.

The higher the number of subscribers or consumers sharing a fiber of a GPON network the more it becomes cost-effective to operators. "However, a high splitting rate involves splitting the optical signal over multiple fibers (using a splitter) and the need for more power to compensate for downlink- sharing mitigation between multiple subscribers (ONU) and to take into account the physical scope". As multiple users use the network simultaneously, high division rate results in a lower throughput for each subscriber. Currently division rates of up to 1/64 for the physical layer are in use. But it is anticipated that a value of 1/128 can be achieved in future as well.

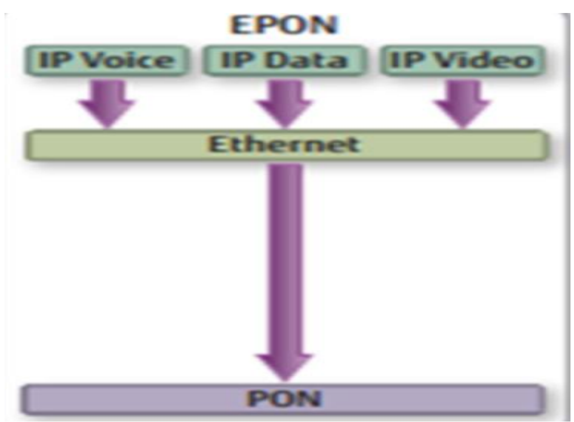
As in GPON network fiber is shared between multiple users, it requires security mechanisms to prevent users from easily decoding data sent by the OLT to other subscribers through data encryption or invading as other UN / ONT units / terminations or other users than themselves.

- **EPON**

Ethernet Passive Optical Network (EPON) is a passive access technology that provides a low-cost method of deploying optical access line between carrier office (CO) and customer site through single optical fiber and is considered as the best candidate for next-generation access network.

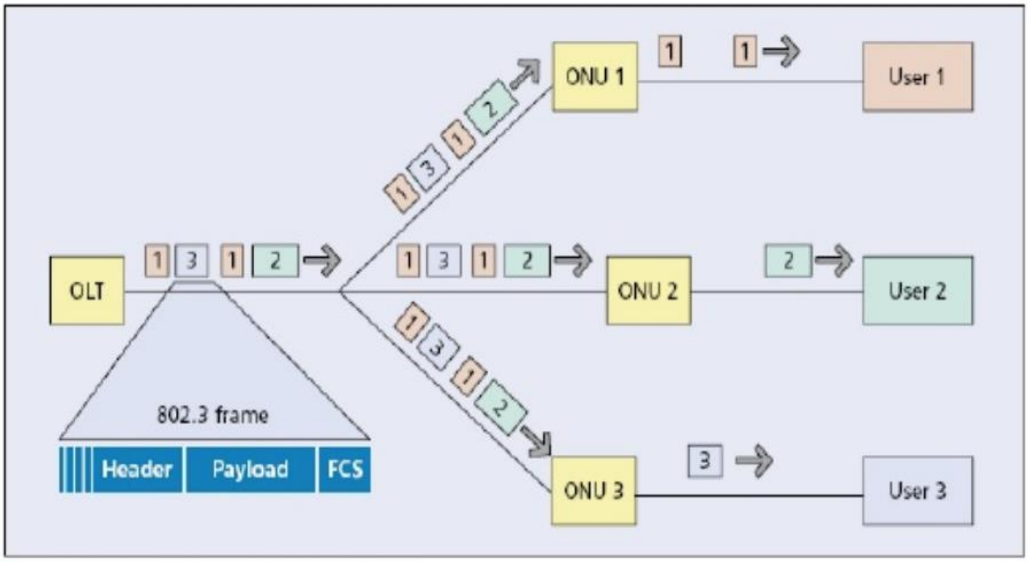
The Institute of Electrical and Electronic Engineers (IEEE) ratified EPON as the IEEE standard 802.3. EPON 802.3ah set a similar passive network with a range of up to 20 km. Like GPON, it also uses WDM with the same optical frequencies and TDMA. EPON has fixed raw downlink and uplink data rate of 1.25Gbps, using 8b / 10b line coding, and the actual rate of 1Gbps. Here the upper and lower rows of data streams are transmitted in different frequency bands- the downstream 1490nm, upstream 1310nm, 1550nm are optional for CATV.

EPON is fully compatible with other Ethernet standards. Hence no conversion or encapsulation is required while getting connected to Ethernet-based networks on either end. In EPON, data transmission occurs in variable length packet with a payload of up to 1518 bytes according to the IEEE 802.3 protocol for Ethernet.



Source: http://www.fiber-optic-solutions.com/epon-vs-gpon-a-practical-comparison.html

A typical EPON system consists of OLT, ONU and ODN. OLT can be considered as L2 switch or L3 routing switch. In downstream, OLT provides passive optical network (ODN) optical interface whereas in upstream, it provides GE optical or electrical interface. OLT also supports E1 and OC3 interfaces in order to provide multi-service access to achieve the traditional voice access or circuit relay service. A single optical fiber is used between the OLT and ONU to provide symmetric 1.25Gbps bandwidth.



Downstream traffic of EPON
Source : https://www.slideshare.net/networksguy/ethernet-passive-optical-network-epon-building-a-next?qid=380cffb6-208d-4670-b61a-7ac6ef43bb7d&v=&b=&from_search=1

Downlink data stream using broadcast, OLT will push 802.3 Ethernet frame format data flow through unicast replication towards all the way at the ONU. Upstream data streams use time division multiple access (TDMA) technology. ONU upstream data streams are allocated as per priority in different time slots.

In EPON, complex and expensive ATM and SONET elements are eliminated thereby lowering costs to subscribers. At present, EPON equipment costs are approximately 10 percent of that of GPON equipment. EPON equipment is rapidly becoming cost-competitive with VDSL. Another advantage of EPON lies in its strong coverage in the 1:32 split ratio covering up 20km and at 1:64 up to 30M or more can be covered.

There is also a 10-Gbit/s Ethernet version ratified as IEEE standard 802.3av in 2009. In 10G-PON, usable bandwidth is 10 Gbit/s out of a raw bandwidth of 10.3125 Gbit/s. It supports two configurations: symmetric- operating at 10 Gbit/s data rate in both directions and asymmetric - operating at 10 Gbit/s in the downstream direction and 1 Gbit/s in the upstream direction. The 10-Gbit/s versions use different optical wavelengths - 1575 to 1580 nm downstream and 1260 to 1280 nm upstream. Hence it can be wavelength multiplexed on the same fiber as a standard 1-Gbit/s system.

Variable-length packets in EPON suits better to IP traffic compared fixed-length. This in comparison to other systems can significantly reduce 10G-EPON's overhead. Typical 10G-EPON overhead is approximately 7.42% whereas for GPON overhead is 13.22%. This high data-to-overhead ratio enables high utilization with low-cost optical components.

10G-EPON uses 64B/66B line coding. Thus overhead is just 3.125% for encoding compared to 25% encoding overhead of 1G-EPON as it uses 8b/10b encoding.
The 10G-EPON standard is backward compatible as it defines a new physical layer. It keeps the MAC, MAC Control and all the layers above unchanged to the greatest extent possible. This also makes it backward compatible of network management system (NMS), administrations, PON-layer operations, and maintenance (OAM) system, DBA and scheduling, and so on.

	GPON	EPON
Standard	ITU-T G.984	ITU G.983
Protocol	GPON encapsulated Mode(GEM) supports: Ethernet TDM ATM	ATM
Speed	2.5 Gbps Downstream 1.2 Gbps upstream	1.25 Gbps Symmetric
Maximum Split ratio	64 users	64 users

Source : http://www.fiber-optic-solutions.com/epon-vs-gpon-a-practical-comparison.html

3. Pilot City Calgary

3.1 Calgary Overview

Calgary is the largest city in the Canadian Province of Alberta and is Canada's third-largest municipality. It is Alberta's populous city with around 1.2 million population in metropolitan areas.

This diverse and prosperous city is located at the confluence of the Bow River and the Elbow River in the southern Alberta. It is about 80 km away from the front ranges of the Canadian Rockies, sits more than 1km above of sea levels in the areas of foothills and prairies. It is semi arid with brown landscape. Calgary's latitude – 51 degrees north results in long days in summer and long nights in winter.

Calgary experiences dry humid continental climate with long, cold snowy winter and short, warm to hot summers. Close to Rocky Mountains, it is among the sunniest in Canada however, with an average of 332.9 days every year. The average temperature in January is −8.9 °C and 16.2 °C in July. Calgary has a very distinctive characteristics known as 'The Chinook' a warm, moist wind from the Pacific Ocean that may raise the temperature by as much as 15 degrees in a few hours in uncomfortably cold winters days.

Calgary is framed by fresh air, parks and pathways, open spaces, mountains and rivers including activities in the area of energy, educational & financial services, transportation and logistics, technology, aerospace, manufacturing, health and wellness, film and television, retail, and tourism sectors. Its economy revolves around oil industry, estimated to be second next to Saudi Arabia.

3.2 Geography

With an area of 848 km2 (327 sq. mi) Calgary is situated in a transition zone between the Rocky Mountain Foothills and the Prairies.

For Project context, geography of Calgary can be divided into three parts –

- Rivers,
- Centre City & Downtown and
- Dwelling Communities.

Source: Wiki

River:

Two rivers- The Bow and The Elbow - run through the city. The Bow River flows from the west to the south. The Elbow River flows northwards from the south. Then it converges with the Bow River at Fort Calgary near downtown. The main topographical feature of the city is formed by The Bow River valley. Smaller streams —Nose Creek and Fish Creek — flow through the city into the Bow resulting a creation of valleys and bluffs. The placement of railways is impacted by spatial growth patterns. The main business section is framed between main line of the Canadian Pacific Railway and the Bow River.

Downtown & Centre City:

Downtown of Calgary is about 1,042.4 m (3,420 ft.) above sea level. Numerous skyscrapers are framed in Calgary Downtown. Amongst few unique structures-Calgary Tower and the Saddledome are distinct. Office buildings tend to concentrate within the commercial core. Whereas residential towers occur most frequently within south of downtown and the Downtown West End and the Beltline. These iconographic buildings of the cities reflect the booms and busts, and help to recognize the various phases of development that have shaped the image of downtown.

At least 14 office towers are 150 m (490 ft.) (usually around 40 floors) or higher. The tallest is Brookfield Place is one of the tallest office tower in Canada. The Bow is the second tallest building in Calgary built in 2012. Calgary's Bankers Hall Towers are the tallest twin towers in Canada.

The downtown region consists of five neighborhoods:

a. Eau Claire (including the Festival District)
b. The Downtown West End
c. The Downtown Commercial Core
d. Chinatown and
e. The Downtown East Village

The commercial core is divided into a several districts comprising the Stephen Avenue Retail Core, the Entertainment District, the Arts District and the Government District.

Dwelling Communities:

As of 2013, Calgary has 198 neighborhoods referred to as "communities" by the City of Calgary, and 41 industrial areas.
The inner city of Calgary is surrounded by suburban communities of various densities. The city is immediately surrounded by two municipal districts – the Municipal District of

Foothills No. 31 to the south and Rocky View County to the north, west and east. Peripheral cities beyond the city within the Calgary Region include: North - the City of Airdrie; East- the City of Chestermere, the Town of Strathmore and the Hamlet of Langdon; South - the towns of Okotoks and High River; northwest- the Town of Cochrane. To west and northwest many rural subdivisions are located within the Elbow Valley, Springbank and Bearspaw areas. To southwest there is the Tsuu T'ina Nation Indian Reserve No. 145 borders.

Calgary's densest neighborhood is the Beltline. The area comprise of number of communities such as Victoria Crossing, Connaught, and a portion of the Rivers District. Focus is given in planning and rejuvenation initiatives to increase the density and liveliness of Calgary's center. Inglewood is one of the city's oldest residential neighborhoods, located east of downtown Calgary. Adjacent to downtown are the first of the inner-city communities including Hounsfield Heights/Briar Hill, Crescent Heights, Hillhurst/Sunnyside (including Kensington BRZ), Bridgeland, Mount Royal, Renfrew, Scarboro, Sunalta, Ramsay , Mission, and Inglewood and Albert Park/Radisson Heights directly to the east. The inner city is surrounded by neighborhoods such as Rosedale and Mount Pleasant to the north - relatively dense and established neighborhood;" Parkdale , Bowness and Glendale to the west; Park Hill, Bankview, Altadore, South Calgary (including Marda Loop), and Killarney to the south; and Forest Lawn/International Avenue to the east. Suburban communities including Evergreen, Somerset, Auburn Bay Country Hills, Sundance, Riverbend, and McKenzie Towne are lying beyond these and separated mostly from one another by highways. In all, city consists of over 180 distinct neighborhoods.

City of Calgary is divided into four geographic quadrants generally described as

a. Northwest Calgary – west is the combination of Centre Street/Harvest Hills Boulevard and north is a combination of the Bow River, Sarcee Trail and Highway 1 (Trans-Canada Highway)

b. Northeast Calgary – east is a combination of Centre Street//Harvest Hills Boulevard and north is a combination of the Bow River, a Canadian Pacific rail line, Centre Avenue and Memorial Drive

c. Southwest Calgary – south is a combination of the Bow River, Sarcee Trail and Highway 1 (Trans-Canada Highway) and west is a combination of Centre Street, a Canadian Pacific rail line, Macleod Trail and Sheriff King Street

d. Southeast Calgary – south is a combination of the Bow River, a Canadian Pacific rail line, Centre Avenue and Memorial Drive and east is a combination of Centre Street, a Canadian Pacific rail line, Macleod Trail and Sheriff King Street

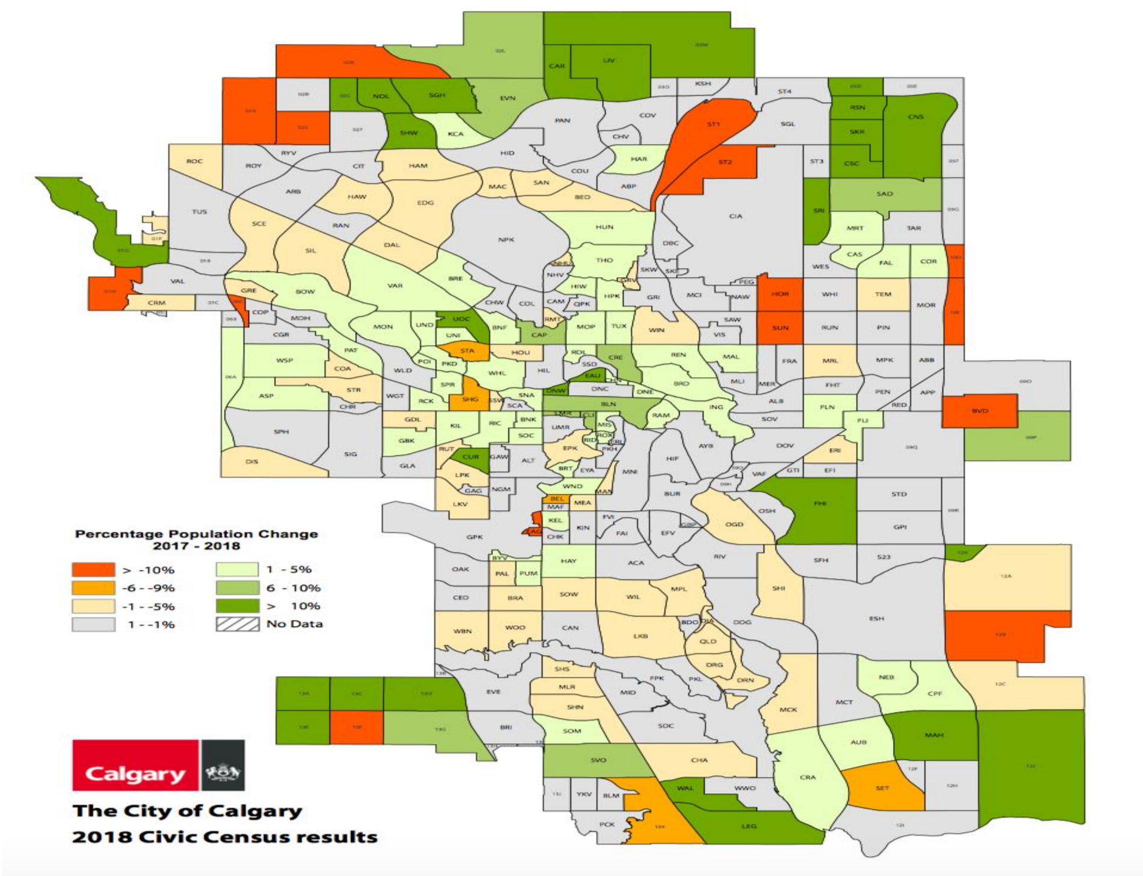
Several of Calgary's neighborhoods were initially separate municipalities but as the city grew these were annexed. These include Bowness, Montgomery, and Forest Lawn.

Completed in July 2007 , the most recent annexation of lands from Rocky View County – "the city annexed Shepard, a former hamlet, and placed its boundaries adjacent to the Hamlet of Balzac and City of Chestermere, and very close to the City of Airdrie".

Dense vegetation occurs naturally only in the river valleys, on some north-facing slopes, and within Fish Creek Provincial Park because of dry climate of Calgary.

3.3 Demographics

According to its 2017 municipal census, the population of the City of Calgary is 1,246,337 and 1,235,171 in 2016. A change of 0.9% is observed from 2016 to 2017. It had a population density of 1,501.1/km2 (3,887.7/sq. mi) in 2016 in a land area of 825.56 km2 (318.75 sq. mi).



Source: www.calgary.ca/

As per 2016 Census of Population conducted by Statistics Canada, a population of 1,239,220 living in 466,725 in City area, with a growth of 13% from its 2011 population of 1,096,833. Among the three cities in Canada that saw their population grow by more than 100,000 people between 2011 and 2016 Calgary was ranked 1st. Followed by Edmonton at 120,345 people and Toronto at 116,511 people, Calgary saw a population growth of 142,387 people during this time.

In the 2011 Census, City of Calgary had a population of 1,096,833 living in 423,417 of its 445,848 total dwellings, which was 988,812 in 2006 – an increase of 10.9% during this time. In 2011 it had a population density of 1,329.0/km2 (3,442.2/sq. mi) in a land area of 825.29 km2 (318.65 sq. mi). In 2011, 49.9% was male and 50.1% was female. Persons aged 65 and older made up 9.95% and those of aged 14 years and under made up 17.9% of the population. The median age was 36.4 years.

The Calgary census metropolitan area (CMA) is the largest in Alberta and the fifth-largest CMA in Canada. The CMA has grown almost 13% in past five years from 2006 to 2011. 42% was added by International migration. Growth is mainly observed in the peripheral areas, including communities like Aspen Woods, Copperfield, Skyview Ranch and Cranston. As per 2011 Census, CMA had a population of 1,214,839 compared to its 2006 population of 1,079,310. Calgary ranked 1st among all CMAs in Canada between 2006 and 2011 for a growth of 12.6% over these year. In 2011, the Calgary CMA had a population density of 237.9/km2 (616.0/sq. mi) with a land area of 5,107.55 km2 (1,972.04 sq. mi). As of Statistics Canada's latest estimate - CMA population of the Calgary, as of July 1, 2013, is 1,364,827. If we consider an hour commuting distance then the population of the city is 1,511,755.

Calgary comprise of multicultural & multi-religion society where Christians make up 54.9% of the population, Muslims (5.2%), Sikhs (2.6%) and Buddhists (2.1%) and 32.3% have no religious affiliation.

3.4 Drivers of Market

Alberta leads the nation in terms of access to internet with 86% having household internet and seems the major adopters of latest wireless technology along with services. As per Canada 's Survey of Household Spending 2015 report, 93.4% Albertans are subscribed to wireless mobile services which ranks it top amongst all provinces. Calgary, the largest city of Alberta seems one the major contributor here. Calgary shows the sign of being the embracer of latest cutting edge technologies.

Key Drivers of LTE-A can be divided into 3 major segments:

Technical

The most dominating factors that are projected to drive the Calgary market are increased need for higher data-rates and greater spectral efficiency .LTE & LTE-A are the till date widely used latest cellular technologies in the mobile broadband market. LTE-A significantly improves spectral efficiency by increasing the performance of cellular networks to downlink throughput of up to 100 Mbps and reducing latency. The continuous proliferation of smartphones increased the data consumed by average human. Moreover, this era of sophisticated gadgets made the features of a computer handy through tablets, smartphones and mobile data cards. As a consequence it has pushed the adoption of mobile broadband service across the globe. With LTE and LTE-Advance the end users get benefitted from enhanced bandwidth and superior performance combined with advanced applications and features like video streaming, video calls, and many other real-time functioning features. In LTE –A standard data rates and performance is improved by using features like, carrier aggregation, interference management, improved antenna technique like beam forming, MIMO. All these rising factors put pressure on current infrastructure to move towards LTE and LTE-A solutions. In one hand ,the accelerated adoption of in-expensive smart devices such as smartphone, tablets and laptops and on the other hand - on going demand for better connectivity for enhancing customer experience are expected to be some of the driving factors for the deployment of LTE-A.

Another driver is the growth of VoLTE Services for Long-Term Evolution market. VoLTE does not require the need for different voice channel as it uses the same channel as data calls, which helps the use of the spectrum more efficiently.

Implementing LTE/LTE-A in the public sectors like in defense and security is further driving the market exponentially. For high-speed communication at times of emergencies like fire, police and ambulance, LTE &LTE-A are the best-suited solutions to feed this need. Furthermore, changing customer preferences and rising demand for high-speed mobile broadband has created a huge potential in the market like Calgary.

Business

Demand for higher data rates and better spectral efficiency has ignited the need for use of LTE services in business sectors. Many businesses have been growing focusing in the need for data owing to digitization in almost every aspect of business. Telecom giants are putting enormous investments in new wireless technologies and are looking for better applications to provide pay offs. They are creating opportunities to enable innovative new small and medium business models. A large number of businesses are managing IT systems depending on the infrastructure of this high traffic carrying capable backbone of telecom industry. Nowadays businesses are moving towards deploying of BOYD (bring your own device) devices at work to ease the hassles of work for the employees. Facilitating this trend need better data connectivity and speed, which can only be achieved by deploying cutting edge technology, like LTE or LTE-A services.

Financial

LTE and LTE-A are likely to create opportunities in emerging economies. The key elements to bolster the market development in the near future are- Infrastructural advances in information technology, consumer demand for broadband and cost-effective services. Moreover, LTE enabled devices create plethora of opportunities for telecom companies to have a dominating market share and in turn likely to contribute to the regional as well as global economy.

3.5 User Penetrations

Canada belongs to one of the most connected countries in the world with 89.94% having internet access. Its internet penetration ranks Canada 22nd globally (in 2016). It ranks second in Internet penetration, behind the United Kingdom among its G8 counterparts.
(https://en.wikipedia.org/wiki/List_of_countries_by_number_of_Internet_users)

Among the highest income quartile, around 95% of Canadians are connected to the Internet, whereas it is 62 % for the lowest income quartile.

"Internet access varies by province. As per Statistics Canada's Canadian Internet Use Survey in 2012, British Columbia and Alberta lead the nation in household Internet access with 86%, followed by Ontario at 84%. Household access is lowest in Quebec (78 %) and the east coast (Prince Edward Island, 78 %; New Brunswick, 77 %)".

100 % of Canadians that live in urban areas have broadband access. It is 85% for rural areas.

In terms of wireless connection, today, more than 30 million Canadians are wirelessly connected which is around 81% of the total population. As per recent CRTC, more Canadian households have mobile phones than landlines. 27.5% Canadian households are subscribed exclusively to wireless services reached as per report in 2015.

And most impressively, Canadians are also high adopters of the latest wireless products. According to Cisco, 83% of Canadian mobile subscribers use smartphones ranking Canada as first amongst the G7.

Consumption of mobile data including all kinds of apps and streaming content increased by 41% between 2015 and 2016 alone. As per forecasts, this trend will continue and reach 500% from 2016 to 2021, which amounts to a compound annual growth rate of 38% according to Cisco.

As per CRTC 2017 report, household expenditures on Internet services and wireless services increased by 9.63% and 5.54%, respectively, over the previous year in 2015. While over the same period, expenditures on wireline telephone services and broadcasting distribution services decreased by 9.5% and 3.3% respectively.

Expenditures on internet service represent the largest and in fact is the fastest growing expenditure category for households. From 2011 to 2015, expenditures on Internet services increased by 7.7% per year on an average.

In 2015, Canadian households spent an average of $218.42 per month for their communications services. It is $3.67 (or 1.7%) higher from 2014. Canadian spent the following in 2015 - wireless services ($87.25), BDU services ($54.50), Internet services ($46.50) and wireline telephone services ($30.17).

In 2016, revenues from telecommunications services represented approximately 73% of all communications service revenues. This represents that mobile wireless service is accounted for nearly half of all telecommunications service revenues.

Wire line and Mobile wireless services subscribers per 100 households, by province, 2015

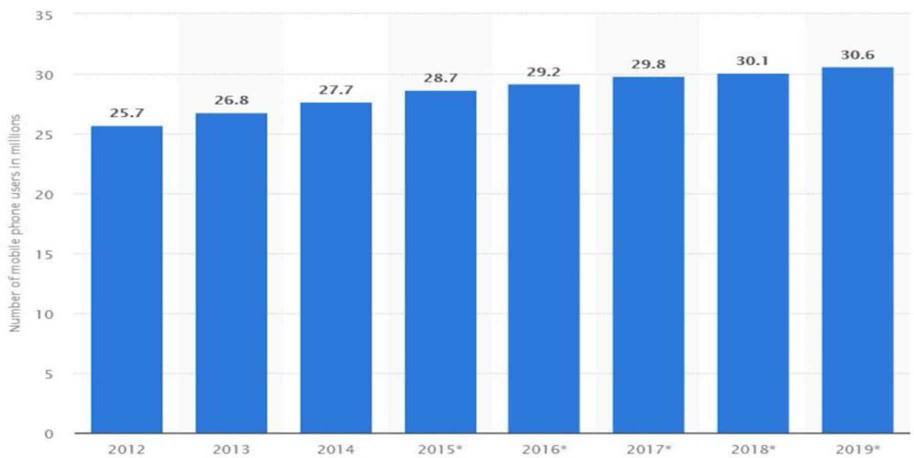
Province	Wireline	Mobile wireless	Wireline and/or mobile wireless	Wireline only	Mobile wireless only	Only wireline or wireless
British Columbia	70.7	88.5	98.9	10.4	28.2	38.6
Alberta	65.2	93.4	99.8	6.4	34.7	41.1
Saskatchewan	68.7	91.1	99.4	8.4	30.8	39.1
Manitoba	76.1	85.1	99.0	13.9	22.9	36.8
Ontario	69.1	88.1	99.5	11.4	30.4	41.8
Quebec	77.0	79.0	99.2	20.2	22.2	42.4
New Brunswick	84.1	82.8	98.5	15.7	14.4	30.1
Nova Scotia	75.0	83.2	99.2	16.0	24.2	40.2
Prince Edward Island	77.3	83.8	98.8	15.0	21.5	36.5
Newfoundland and Labrador	83.6	86.4	99.1	12.7	15.5	28.3
All of Canada	71.9	86.1	99.3	13.2	27.5	40.7

Source: Statistics Canada's Survey of Household Spending

As per table above, Alberta ranks highest in the list for Mobile wireless services with 93.4% which makes it as one of the topmost contestant for embracing new wireless technology. Moreover, Alberta plays an important role in the rise of mobile-wireless-only households.

3.6 Mobile & Internet Penetrations

Number of Mobile Phone users in Canada from 2012 to 2019 (in millions)



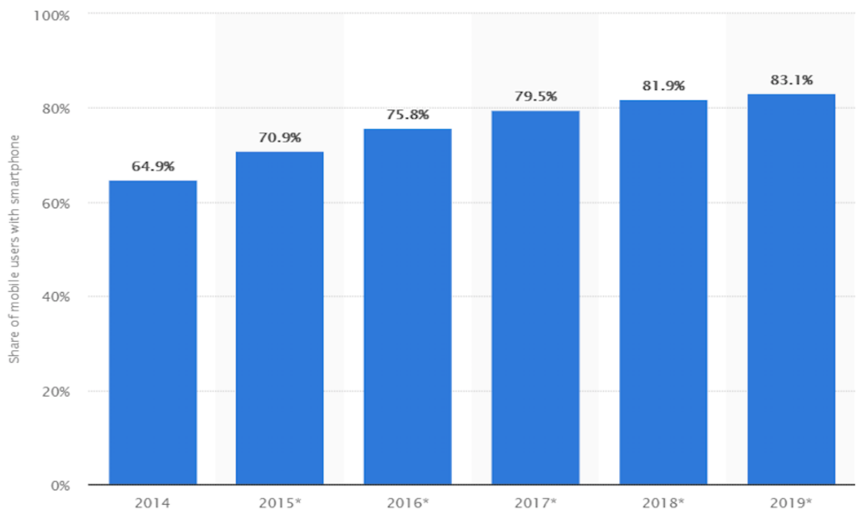
Source: https://www.statista.com

"Mobile phone users are defined as individuals who can use a mobile device to transfer data or make a call." As per statistics (source Statista), it is projected that Number of Mobile Phone users in Canada will reach 30.6 million in 2019, and over nine billion worldwide. Growth rate is around 19.1% from 2012 to 2019. This huge number of mobile subscribers in Canada indicates that it is a very good platform for the billion-dollar mobile communications market.

As per recode, last year mobile industry produced more than $3.3 trillion in revenue. That reflects to more than $400 per average human - man, woman and child on earth.

In 2016, the number of unique mobile subscribers was four billion worldwide. Out of these four billion subscribers, around 28 million resided in Canada. Bell Canada is in leading position in terms of mobile subscribers in Canada.

Share of Mobile Phone Users that use a Smartphone In Canada from 2014 to 2019

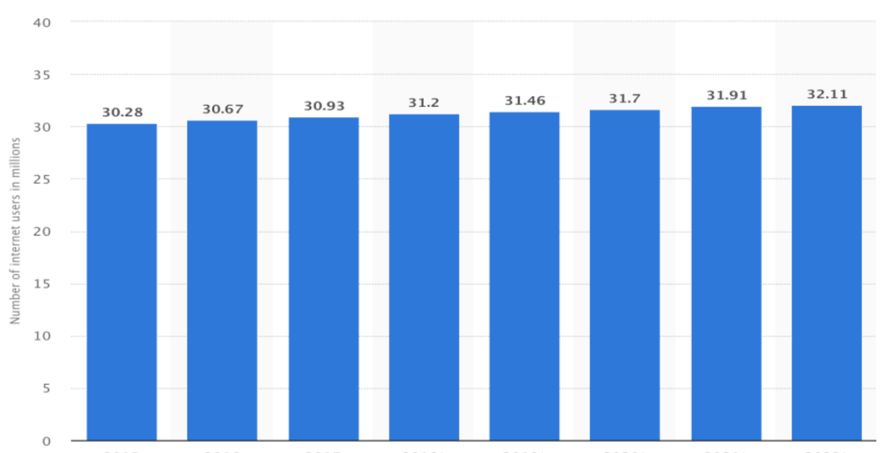


Source: https://www.statista.com

Canada is one of the leading countries regarding the share of mobile phone subscriber who have a smartphone. In 2014, 64.9% of mobile subscriber had smartphones. This is expected to reach 83.1% by 2019. Only Japan and South Korea are leading ahead with a higher smartphone penetration rate amongst mobile subscribers. As Alberta ranks top in the list for Mobile wireless services, we expect the similar ratio in Calgary as well which is the largest city of Alberta.

In 2016, 87 percent of Canadians owned cell phones (cell phones, smartphones, and tablets).

Number of Internet Users in Canada from 2015 to 2022 (in millions)

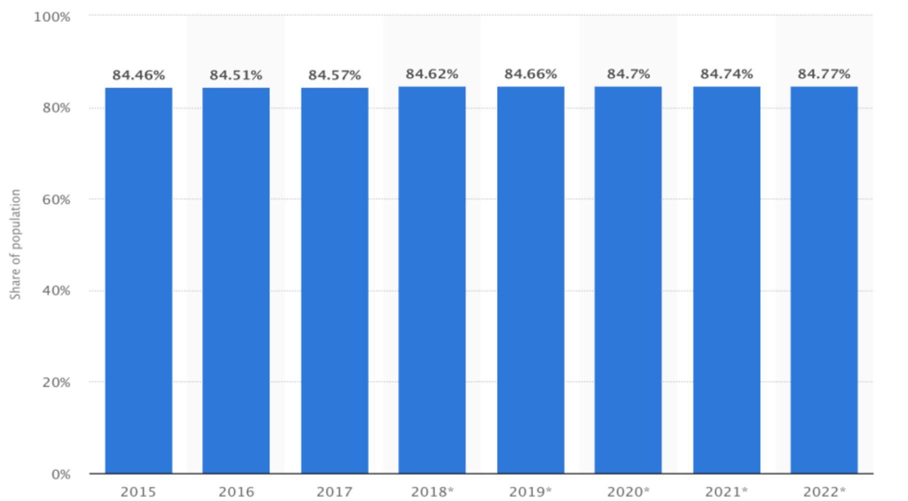


Source: https://www.statista.com

This statistic shows the number of internet users in Canada from 2015 to 2022. This is the total internet user in Canada. In 2017, internet users in Canada was 30.9 million. This statistics is projected to grow to 32.1 million in 2022. In global context, Canadians are the second heaviest users of the Internet, averaging 41.3 hours/month online.

For different activities, Canadians tend to use different Internet-connected devices. On portable devices like laptops, tablets and smartphones social media is the topmost activity.

Internet usage Penetration in Canada from 2015 to 2022



Source: https://www.statista.com

Internet usage penetration is quite high in Canada. In 2017, penetration was 84.57 percent and is about to reach 84.77 percent by 2022. And mobile phone is one of the major contributors here.

Mobile Phone Internet usage penetration in Canada from 2015 to 2022

Source: https://www.statista.com

In 2017, 66.74 percent of total population used internet on mobile phone. And it is forecasted to grow by 76.82% in 2022.

In 2016, Mobile usage in Canada was 30 million which is one of the highest in the world with the country's total number of mobile subscribers. As of January 2017, mobile phones generated around 29 percent of online traffic in Canada. The number of mobile phone internet users stood at 22.8 million in 2016 and is projected to reach to about 28.6 million by 2021. Based on subscriber count in 2016, Rogers Wireless, Bell Canada, and TELUS Mobility were the three largest mobile service providers in Canada.

Among internet users in Canada, watching online videos is the most popular mobile device activity as per report. Amongst the young users- sending and receiving emails and text messages, taking photos and recording videos, surfing the internet and were among the most popular mobile phone activities. As per survey in 2017, around 55 percent of Canadians accessed email on a weekly basis through a smartphone device. Furthermore, more than 20 million Canadians use mobile phone for gaming purposes and the number of phone messaging app users was projected to be at around 17.3 million as of 2017. Facebook was the leading smartphone app in Canada. Facebook by far is the most popular social media website in Canada having the largest share of mobile visits.

3.7 Restrains on Market

LTE- the next generation mobile network promises significant benefits over the current 3G/4G technology such as higher spectral efficiency, faster speeds lower latencies and lower cost of data transmission. However, as with any new technology, several challenges lie ahead for global operators in deploying 4G LTE networks.

1) Fragmentation of LTE Spectrum Bands

One of the biggest challenges faced by operators is the range of spectrum bands to support. Mains are 700MHz, 800MHz, 1800MHz and 2600MHz frequency bands.

A lower spectrum band (e.g. 1800MHz) facilitates better indoor signal strength and covers further compared to one of a higher spectrum band (e.g. 2600MHz). However, the higher spectrum bands are more suitable for densely populated areas because of their larger bandwidth.

Lower the frequency lower will be the penetration loss. Lower bands are more affordable to build and signals travel higher distances, whereas for higher frequency spectrums a way more base stations will require to cover a similar distance. Therefore besides the obvious fact of having limited availability of these spectrum bands, this seems another possible reason why different telecom companies around the world use different frequency bands.

2) Building a New or Converged Network

Another challenge is how operators build up new network and how to make different generations of technologies work together for converged network. For both scenarios, the process is highly cost intensive and complex as well. The transition to 4G network demands totally new radio access technology and core network up gradation. On the other side, maintaining existing 2G/3G networks alongside the new 4G network results additional load on telecom industry.

3) Return on Investment (ROI) on 4G LTE

Not only migrating to LTE or upgrading of existing mobile networks will incur high costs but it is also expected to disrupt the traditional business models of voice calls and SMS pattern.

With higher throughput, it is projected that users will be more inclined to use services and apps such as Messenger, Skype, VoLte, Whatsapp, Viber and many more for communication. Telkom Operators would be at the losing end if subscribers turn to Messengers or Skype for making voice calls overseas or started using similar online messaging applications for SMS .This change in consumer's usage pattern will throw a challenge to telecom giants to make profit from investments in 4G networks.

4) Tiered Data Plans

To justify the investments in the new 4G networks, operators might need to adjust their data price models. Either, mobile service providers can charge higher prices for their LTE offerings compared to the existing plans and maintain a higher quality of service to justify the higher premiums. Or they can break away from the traditional one-size-fits-all approach to "pay-for-what-you-use" models, where subscribers are charged based on their usage behaviors. Or they can adopt a value-based pricing model where users can pay a premium for a better experience. But these are tough model to implement.

6) True 4G Global Roaming - Fiction more than Reality

Lacking harmonization of LTE spectrum bands across different countries might make it impossible to support LTE global roaming.

To use a LTE device for data roaming, device needs to support at least 15 bands. Supporting so many bands on a device is really a challenge from an engineering perspective. Therefore, it might lead 3G data roaming still be the dominant.

7) Data Management

It is projected that in future network traffic would be dominated by video, games and other high volume multimedia contents. All these will require new ways to maximize the consumer experience and optimize networks to prevent saturation. For telcos, to handle such huge data, increasing network capacity is a major challenge. All these challenges must be efficiently addressed and on time to augment the increasing demand for video applications in cellular and wireless network.

4. Calgary Access Network Model

4.1 LTE-Advanced for City of Calgary

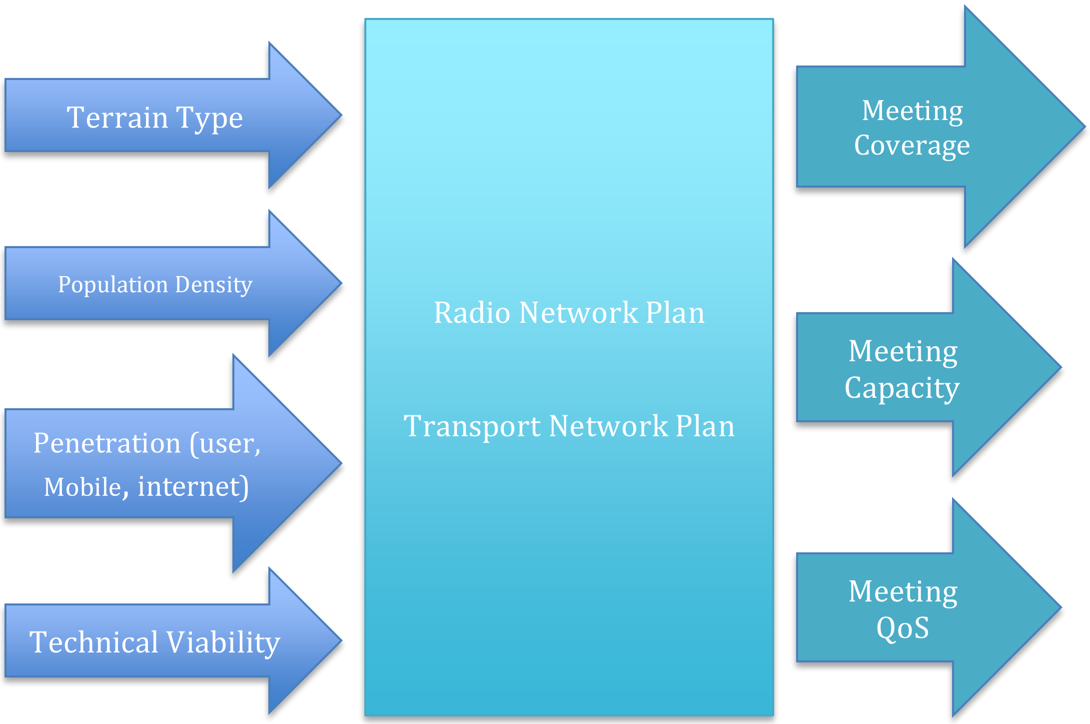
One of the most critical tasks in network design is the optimal planning of cellular networks aiming to meets the needs of the subscriber and service providers. Besides, competitive regulatory framework, monopolies in market combined with the high cost of equipment are similarly important factors while deploying cutting edge wireless technology.

Calgary is a metropolitan city with population density of 1,501.1/km2 in a land area of 825.56 km2 [2016] that is gradually increasing with a growth rate of around 1%. Moreover, Alberta belongs to one of the most connected province with around 93% households having wireless mobile connections. And it is the leading nation in terms of access to internet as well with 86% having internet in households. 'In 2015, Canadian households spent an average of $218.42 per month for their communications services'. All these factors seem applicable for Calgary as well which in turn made it one of the topmost adopters of the latest wireless technology. **Taking all these into account, in this paper we are going to propose LTE-A for city of Calgary.**

While choosing the ultimate design for Calgary we have taken into consideration of the following criterions ---

- Terrain type (Dense urban, Urban, Sub-Urban, Rural, Highways)
- Population Density
- User & Mobile Penetration and growth
- Technical viability

4.2 Access Network Model



Network elements in LTE-A networks can be grouped into two categories-

1. Access Network that consists of radio transmission subsystem and the transport network; both are strongly interconnected. Handle all radio & transport related functionalities.
2. Core Network (CN) - responsible for switching and routing calls and data connections to external network.

In this paper we will be discussing the access network only.

4.3 Calgary Access Network Planning:

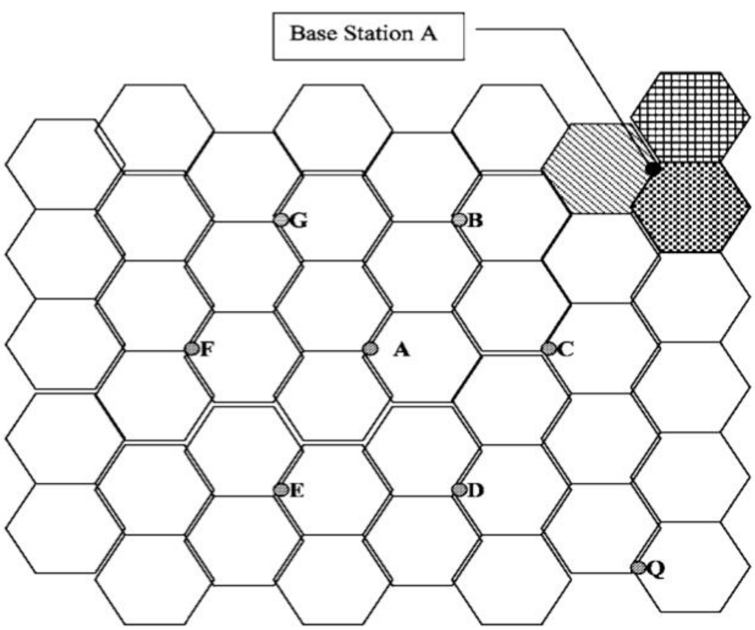
Access network consists of

- Radio Network Planning
- Transport Network Planning

Radio Network Planning:

For designing radio network, the primary & foremost endeavor consists of planning of the eNBs ensuring full coverage to the service area with respect to current as well as projected traffic requirements, available capabilities, and the desired Quality of services together with link budget parameters like propagation model, penetration loss, fading margin, interference margin.

The city of Calgary is rectangular in shape. For planning context, the rectangular geographical area will be sub divided in grids covered by multiple hexagonal cells.



Source : Cellular Network Design Site Selection and Frequency Planning By AMITAVA DUTTA and VERNON HSU

Cellular planning systems proceeds in stages. Each succeeding stage deals with their own design parameters and corresponding issues. The initial phase would be the nominal plan.

It consists of physical parameters of the eNodeB based on traffic characteristics within the geographic area to be covered. This incorporates

- Latitude & longitude of the Base Station(eNB)
- Antenna height, azimuth & tilt, type -omni/directional
- Type of cells - macro/micro/nano /pico and crresponding radius
- Frequency allocation

One of the subsequent activities include preparing of link budget. This comprise of propagation model, penetration loss, fading margin, interference margin. Topography of the surrounding area needs to be precised also.This is done by selecting appropriate propagation models , geographic databases and using industry standard tools. Precising propagation model helps to determine antenna parameters more accurately.

Radio propagation models can be categorized into outdoor and indoor propagation models. Different factors are involved for each of these propagation models.

For Calgary, following propagation models are to be applicable for different terrain types. Here we have followed **Huawei definition**.

I. Free Space Model

Free space indicates an ideal medium of space which is even and isotropic.
In this medium no reflection, refraction, absorption or scattering occurs. Propagation losses occur only by the energy spread of electromagnetic waves. In this case, the base station and the terminal communicates through LOS . The propagation losses in the free space model are as follows:

$PL = 32.4 + 20\log(d) + 20\log(f)$
Where, d indicates the distance between the terminal and the base station in km.
f indicates the carrier frequency in MHz.

II. Cost231-Hata Model

Cost231-Hata model can be applicable in macro cells as the propagation model. The application range is as follows:
Frequency band: 1500 MHz to 2000 MHz
Base station height: 30 meters to 200 meters. The base station must be higher than the surrounding buildings.
Terminal antenna height: 1 meter to 10 meters
Distance between the transmitter and receiver: 1 km to 20 km

The Cost231-Hata model can be expressed by the following formula:

Total = L -a (Hss) +Cm

L= 46.3 + 33.9 × lg(f) - 13.82 × lg(H_BS) + (44.9 - 6.55 × lg(H_BS)) × lg(d)

Where, f indicates the working frequency of the system in MHz.
H_BS indicates the height of the base station antenna in meter.
Hss indicates the height of the terminal antenna in meter.
d indicates the distance between the terminal and the base station inkm.
a(hss) indicates the terminal gain function. This function is related to the antenna height and working frequency of the terminal and the environment.
The value of Cm depends on the terrain type. The values of Cm in the standard Cost231-Hata are as follows:
In large cities:
Cm = 3 (as defined in Urban - large city in the related protocol)
In medium-sized cities:
Cm = 0 (as defined in Urban – small city in the related protocol)
In suburban areas:
Cm = -2(log(f/28))2- 5.4dB (as defined in Urban – Suburban in the related protocol)
In rural open areas:
Cm= -4.78 × (lg(f))2+ 18.33 × lg(f) -40.94 (As defined in Rural (open) – desert in the related protocol)
In highways:
Cm= -4.78 × (lg(f))2+ 18.33 × lg(f) -35.94 (As defined in Rural (quasi-open) – countryside where the terminal is unobstructed for 100 meters in the front in the related protocol)
Since some of the LTE band have exceeded the band range of the standard Cost 231-Hata model, that is, 150 MHz to 2000 MHz. Therefore, the standard Cost231-Hata model must be updated during implementation.

III. Standard Propagation Model (SPM)

The standard propagation model is a model suitable for frequency band in range of the 150MHz~3500MHz over long distance (1Km<d<20Km) and is very adapted to GSM900/1800, UMTS, CDMA2000, WiMAX and LTE technologies. This model takes into account the terrain profile, diffraction mechanisms, clutter classes and effective antenna heights for calculating path loss.
The model is based on the following formula:
L_SPM =K 1+K 2 log (d)+K 3log (HTxeff)+K4DiffractionLoss+K 5 log (d)log(HTxeff)+K 6HRxeff +Kcluttetf(clutter)
Where:
K1Constant offset (dB)
K2Multiplying factor for log(d)
dDistance between the receiver and the transmitter (m)
K3Multiplying factor for log(HTxeff)
HTxeff Effective height of the transmitter antenna(m)
K4Multiplying factor for diffraction calculation, K4 has to be a positive number

Diffraction lossLosses due to diffraction over an obstructed path(dB)
K5Multiplying factor for log(d)log(HTxeff)
K6Multiplying factor for HRxeff
HRxeff Mobile antenna height (m)
KClutterMultiplying factor for f(clutter)
f(clutter)Average of weighted losses due to clutter

IV. Okumura-Hata Model

The Okumura-Hata model is the most widely used propagation model for predicting the behavior of propagation of radio frequency in built up areas. This model is the upgraded version of Okumura model and developed further incorporting the effects of diffraction, reflection and scattering caused by city structures. The model is ideal for using in cities with many urban structures but not many highrise blocks. The following assumptions apply to the use of Okumura Hata model.
Frequency: 150 MHz to 1500 MHz
Mobile Station Antenna Height: between 1 m and 10 m
Base station Antenna Height: between 30 m and 200 m
Link distance: between 1 km and 20 km.The traditional Okumura Hata model formula is shown below:

Hata Model for Urban Areas is formulated as:

$$L_U = 69.55 + 26.16 \log f - 13.82 \log h_B - C_H + [44.9 - 6.55 \log h_B] \log d$$

For small or medium sized city,

$$C_H = 0.8 + (1.1 \log f - 0.7) h_M - 1.56 \log f$$

and for large cities,

$$C_H = \begin{cases} 8.29 (\log(1.54 h_M))^2 - 1.1 & \text{, if } 150 \le f \le 200 \\ 3.2 (\log(11.75 h_M))^2 - 4.97 & \text{, if } 200 < f \le 1500 \end{cases}$$

Where,

L_U = Path loss in Urban Areas. Unit: decibel (dB)

h_B = Height of base station Antenna. Unit: meter (m)

h_M = Height of mobile station Antenna. Unit: meter (m)

f = Frequency of Transmission. Unit: megahertz (MHz).

C_H = Antenna height correction factor

d = Distance between the base and mobile stations. Unit: kilometer (km).

Source : Huawei

V. ITU Indoor Model

The IEEE documents provide a propagation loss model in the indoor base station environment based on the Cost231 model. The expression of this model is as follows:

$$PL = L_{FS} + L_c + \sum k_{wi} L_{wi} + n^{((n+2)/(n+1)-b)} * L_f$$

Source: Huawei

Where,
LFS indicates the propagation losses in free space.
Lc indicates the constant loss.
kwi indicates the number of walls in type i penetration.
N indicates the number of penetrated floors.
Lwi indicates the loss brought by penetration through walls in i mode.
Lf indicates the loss of neighboring floors.
B indicates the experience parameter.

Next stage of radio network planning is detailed planning. It includes neighbor cell configuration, PCI (Physical Cell Identifiers) & TA (tracking area) planning and other logical parameter configuration.

While planning , base station cost structure, available spectrum bandwidth and demand must be taken into consideration. But a discussion of the available spectrum and its allocation mechanism is outside the scope of this paper Incorporating market parameters such as calling rates, internet cost per unit , prices of mobile units and number of alternate service providers are also crucial. This demand estimate is considered as input to be translated into radio capacity.

Transport Network Planning:

Two major options that we have in hands for designing transport network for Calgary are -

- Microwave
- Fiber

Calgary market is driven by the explosive growth of internet along with the increasing demand for bandwidth for video, game and data traffic, voice. It leads the demand of Calgary towards fiber optic network mostly. Wherever laying cable is not technically viable, option will be directed towards microwave.

Designing fiber optic network includes determining the type of communication system needs to be carried over the network, the transport equipment required, the terrain type including geographic layout of premises, campus, outside plant (OSP, etc.), and the fiber network over which it will operate. Interfacing to other networks connected over copper cabling or wireless is also a part of the design.

Subsequent consideration goes to the requirements for permissions and inspections. Once this is done, we have to consider component selection, installation practices, testing & troubleshooting. Taking account of cost is also an important factor in design.

Loss budget analysis is very crucial for calculation and verification of operating characteristics of a fiber. It is used to measure the loss of a cable. A link loss budget takes into account the length of the link, type of fiber, wavelengths, and any other components loss in the link along with attenuation and bandwidth.

Cable route plan depends heavily on maps comprising of basic data on the local geology, locations of road, buildings, underground and aerial utilities, and much more. Detailed maps use GIS (Geographic Information Systems) data to create the routes of cable plants during the design phase. But this is beyond the scope of this paper.

If fiber is not technically viable for a particular site, we have to focus on microwave transmission. For MW, initial survey should take into account the field input data such as terrain type, obstacle; LOS (line of site) report, frequency planning, Antenna type and size and interference.

4.4 Calgary area wise planning model

From planning context, the city of Calgary can be structured into following terrain type. Here we have used **Huawei definition** for area type & corresponding penetration loss:

Terrain Type	Description
Dense-Urban	In this scenario, buildings are densely distributed, and the average building height exceeds 30 m. In certain areas, buildings are distributed in order. The distance buildings are distributed in order. The distance between buildings is narrow and is not fixed. The average distance between buildings is 10 m to 20 m. Most streets those are not main avenues are narrow. These areas are densely populated.

Urban Area	In this scenario, the average building height is about 20 m. The average distance between buildings is similar to the average building height. Such areas contain a certain amount of open spaces and greenery.
Sub-Urban Area	In this scenario, the average building height is about 10 m. Buildings are scattered and the average distance between buildings is 30 to 50 m. The streets are wide. Such areas may contain many open spaces and much greenery.
Rural Area	In this scenario, buildings are scarce. The average building height is about 5 m. Such areas are likely to contain vast open spaces, fields, greenery, and roads.

Terrain Type	**Penetration Loss**
Densely populated urban area	18 - 25 dB
Common urban area	15 - 18 dB
Suburban area	10 - 12 dB
Rural area	6 - 8 dB

City Center

This is the major part of the city consists of an array of modern skyscrapers, office towers, historic sandstone buildings and residential units. Around 160,000 people work here. It falls in the category of highly dense urban. Penetration loss would be greater than 20 db. Demand for traffic (data & voice) is pretty high. For this area our proposal would be a cell radius of 300m or less. The height of the antenna should be in between 21-27 meter. High capacity Wi-Fi would be another requirement. For transport, high capacity fiber will be used.

Major Activity Center & Community Activity Center

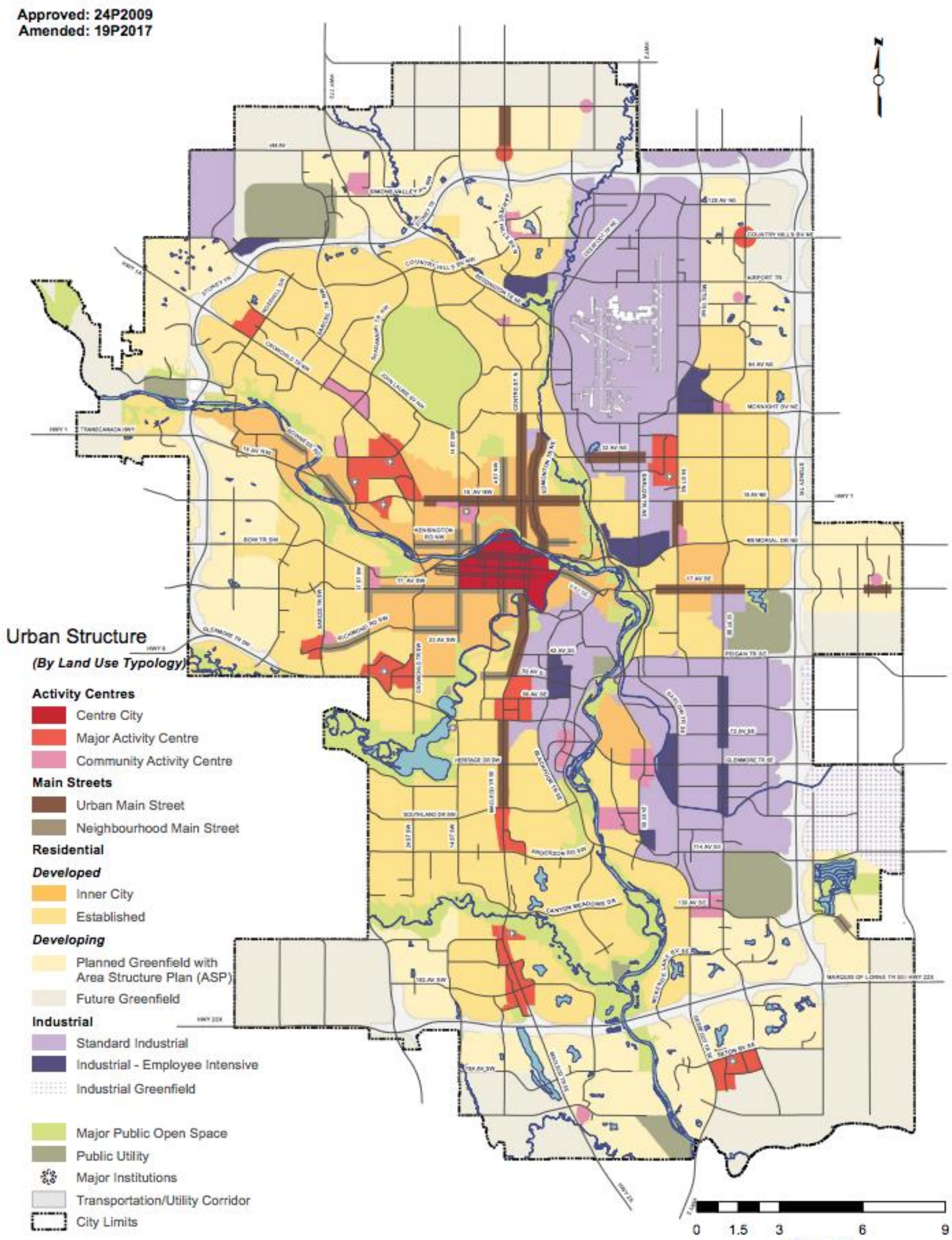
It consists of major institutions and activity centers. It belongs to the dense & highly dense urban. Penetration loss would be in the range of 18-20 dB. Demand for traffic (data & voice) is pretty high. High capacity Wi-Fi would be a major requirement for indoor area. For this area our proposal would be a macro cell having radius of 350m or higher. The height of the antenna should be in between 24-27 meter. For transport, high capacity fiber will be used. If not viable we can think of microwave transmission.

Inner City & Established Area

This area comprises of residential units and open spaces. It falls in the category of urban structure. Projected penetration loss would be in the range of 15-20 dB. For this area our proposal would be a macro cell having radius of 500m or higher. Antenna with height of 21-27 meter should be good. For transport, high capacity fiber will be used. Wherever not viable we can think of microwave transmission also especially where laying fiber is not feasible.

Standard Industrial & industrial (Employee Intensive)

This area industrial zone comprise of open spaces. It is the combination of urban & sub - urban structure. Projected penetration loss would be in the range of 12-18 dB. For this area our proposal would be a macro cell having radius of 700m or higher. Antenna with height of 24-27 meter should be good. The demand of traffic won't be that much high here. For transport either fiber or microwave can be deployed depending on viability.



Source: http://www.calgary.ca/PDA/pd/Documents/municipal-development-plan/mdp-maps.pdf?noredirect=1

Planned & Future Greenfield

This area comprises of a certain amount of open spaces and greenery. It should belong to suburban or rural structure. Projected penetration loss would be in the range of 8-12 dB. For this area our proposal would be a macro cell with site-to-site distance of 700m or higher. Antenna with height of 24-27 meter should be good. The demand of traffic won't be that much high here. For transport either fiber or microwave can be deployed depending on viability.

Urban & Neighborhood Main Street

For streets, our recommendation would be directional antenna to cover all speed range vehicles. This area should consists both macro and micro cell to avoid coverage whole. Penetration loss will vary as per surrounding area. Antenna with height of 24-27 meter should be good. For transport, high capacity fiber will be used. Wherever not viable we can think of microwave transmission also especially where laying fiber is not feasible.

Others

It comprises of open spaces where the loss would be minimum. We would classify this as rural area. The proposed site-to-site distance would be greater than 900m. Antenna height of 24 meter more is preferred. We can deploy fiber or microwave as per feasibility as the requirement of traffic would be minimal here.

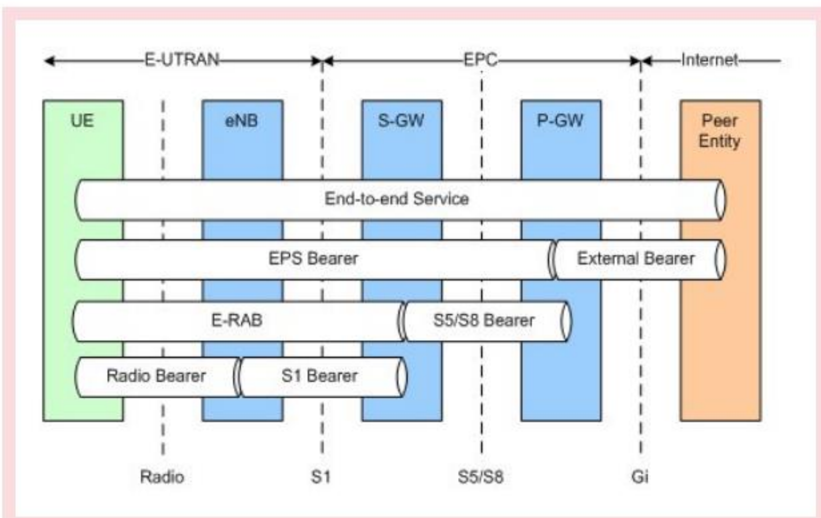
5. LTE Key Performance Indicator (KPI) Analyses

Key Performance Indicators (KPIs) sometimes referred to as "key success indicators (KSI)". These are a set of quantifiable events, parameters and measurements used to monitor and compare performance in terms of meeting mobile network's strategic and operational goals. KPIs can vary between management, marketing, operations and network depending on their priorities, perspectives or performance criteria...

KPIs can be used for the following tasks:

• To monitor and optimize the network performance for providing better subscriber experience by better utilization of available network resources

• To detect and trace unacceptable performance related issues in the cellular network quickly. This enables the operator to take immediate actions to maintain the quality of the existing network.

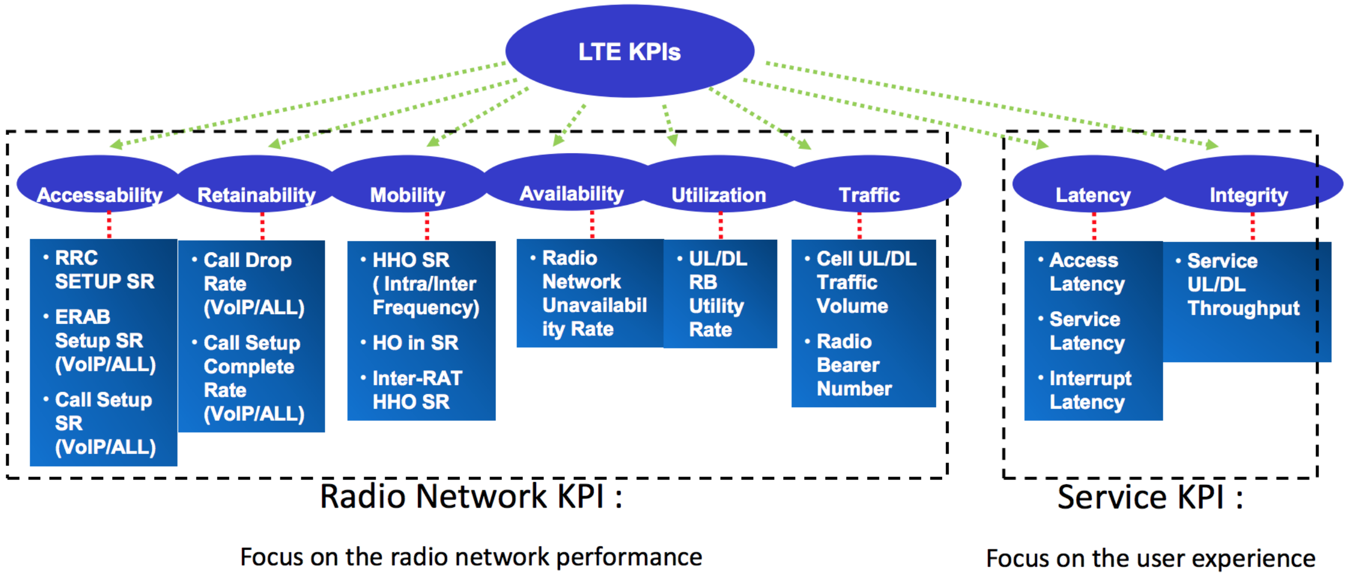


Source: https://ytd2525.wordpress.com/2012/08/09/lte-kpis-key-performance-indicators/

KPI can be categorized into following subcategories:

• Accessibility
• Retain-ability
• Integrity
• Availability
• Mobility

Following table summarizes major RAN (Radio Access Network) KPIs for LTE network -



Source:https://www.slideshare.net/RayKhastur/kpi-in-lte-radio-network-huawei-based?qid=5769759a-c2bb-4dcf-a7b9-6bbda9c52627&v=&b=&from_search

KPIs for LTE RAN (Radio Access Network)	
LTE KPI	**INDICATORS**
Accessibility	RRC setup success rate
	ERAB setup success rate
	Call Setup Success Rate
Retain-ability	Call drop rate
	Service Call drop rate
Mobility	Intra-Frequency Handover Out Success Rate
	Inter-Frequency Handover Out Success Rate
	Inter-RAT Handover Out Success Rate (LTE to WCDMA)
Integrity	E-UTRAN IP Throughput
	IP Throughput in DL
	E-UTRAN IP Latency
Availability	E-UTRAN Cell Availability
	Partial cell availability (node restarts excluded)
Utilization	Mean Active Dedicated EPS Bearer Utilization

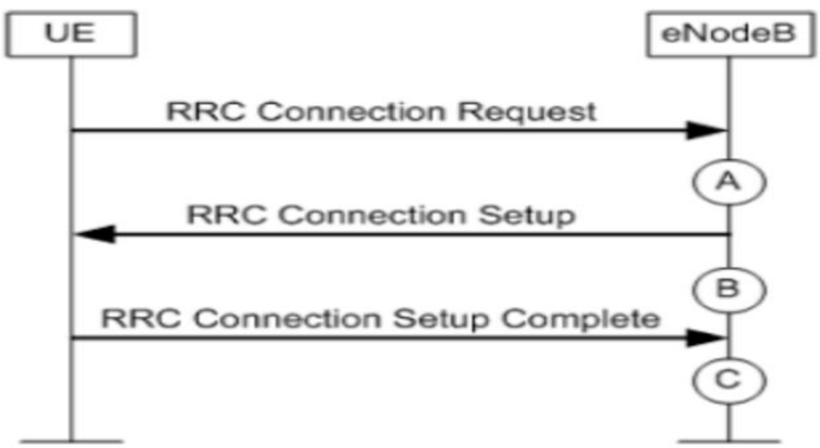
5.1 Accessibility

RRC Setup Success Rate (Service):

The RRC setup is measured based on eNB counter when the eNB received the RRC connection request from UE. Number of RRC connection attempt is calculated by the eNB at point A, and the number of successful RRC connection at point C.

This procedure is trigged by different reasons: emergency, high Priority Access, MT (mobile terminal) -Access, mo (mobile originating)-Signaling, mo-Data etc.

For service related causes in a cell or cluster, the illustration is



KPI Name	RRC Setup Success Rate (Service)
Measurement Scope	Cell or radio network
Formula	$RRCS\_SR_{service} = \frac{RRCConnectionSuccess_{service}}{RRCConnectionAttempt_{service}} \times 100\%$

https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

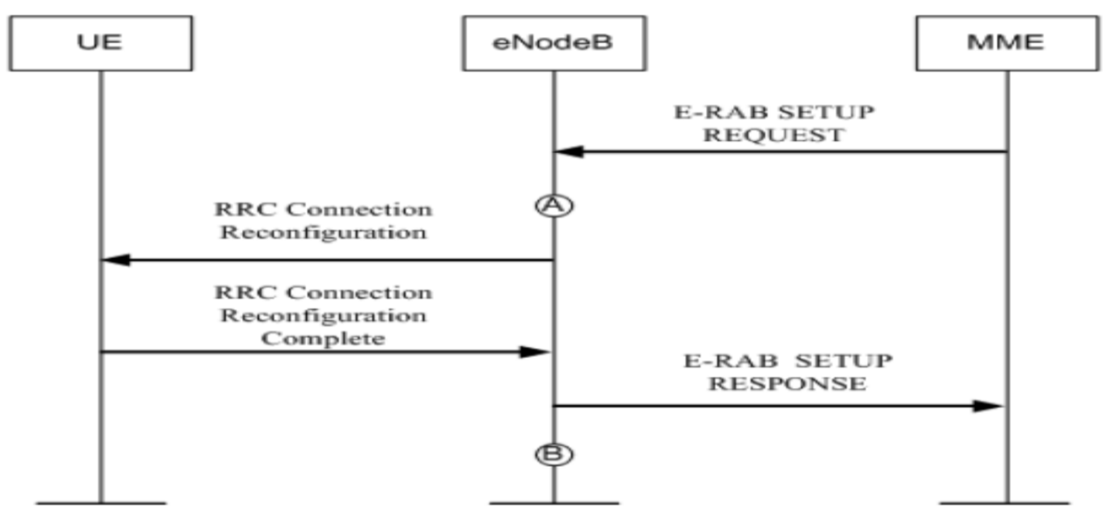
RRC Setup Success Rate (Signal)

RRC setup success rate for signaling defines the RRC setup success rate with signal related causes (mobile originated signaling) in a cell or cluster.

$$RRC\_SSR_{\text{Signal}} = \frac{RRC\_ConnectionSuccess_{Signal}}{RRC\_ConnectionAttempt_{Signal}} \times 100\%$$

ERAB Setup Success Rate (All)

ERAB setup success rate is evaluated based on ERAB connection setup attempt at point A and successful ERAB setup at point B. It shows the probability of success ERAB to access all services in a radio network. It is illustrated in following way:



KPI Name	E-RAB Setup Success Rate (All)
Measurement Scope	Cell or radio network
Formula	$ERABS\_SR = \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

Call Setup Success Rate

Call Setup Success Rate is calculated by multiplying the RRC setup success rate KPI, S1 signaling connection success rate KPI and ERAB success rate. It indicates the probability of success for all service on a radio network. It is defined in the following way

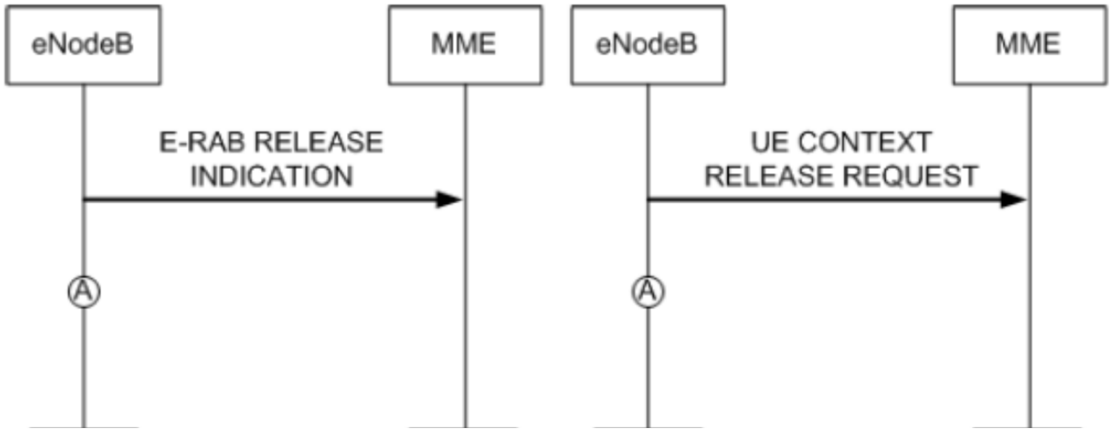
KPI Name	Call Setup Success Rate
Measurement Scope	Cell or radio network
Formula	$CSSR = \frac{RRCConnectionSuccess_{service}}{RRCConnectionAttempt_{service}} \times \frac{S1SIGConnectionEstablishSuccess}{S1SIGConnectionEstablishAttempt} \times \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

5.2 Retain-ability

Call Drop Rate

Call Drop Rate can be used to evaluate the call drop rate of all services in a cluster or cell. Call drop happens when ERAB release is not normal or 'when eNB initiates active ERAB release process by E-RAB Release Indication or UE Context Release Request message for abnormal reasons'. The causes other than - Normal Release, Detach, User Inactivity, UE Not Available for PS Service, CS fallback triggered or Inter-RAT redirection.



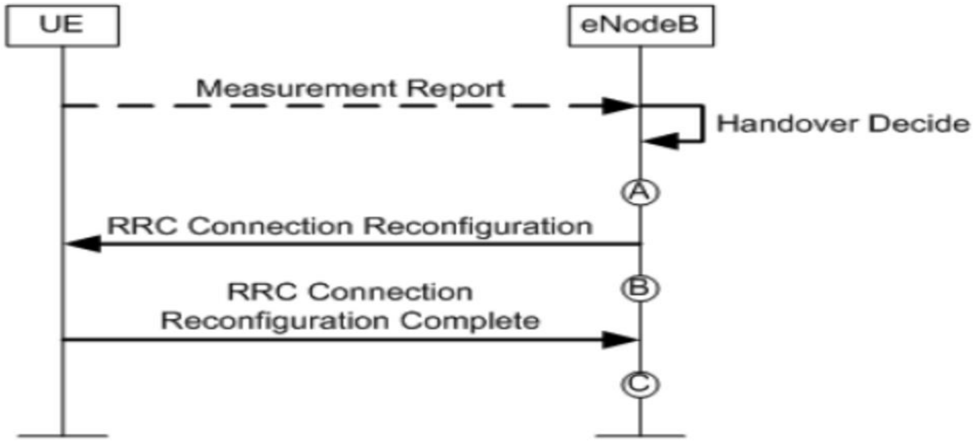
KPI Name	Service Drop Rate (All)
Measurement Scope	Cell or radio network
Formula	$Service\_CDR = \frac{ERABAbnormalRelease}{ERABRelease} \times 100\%$

https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

5.3 Mobility

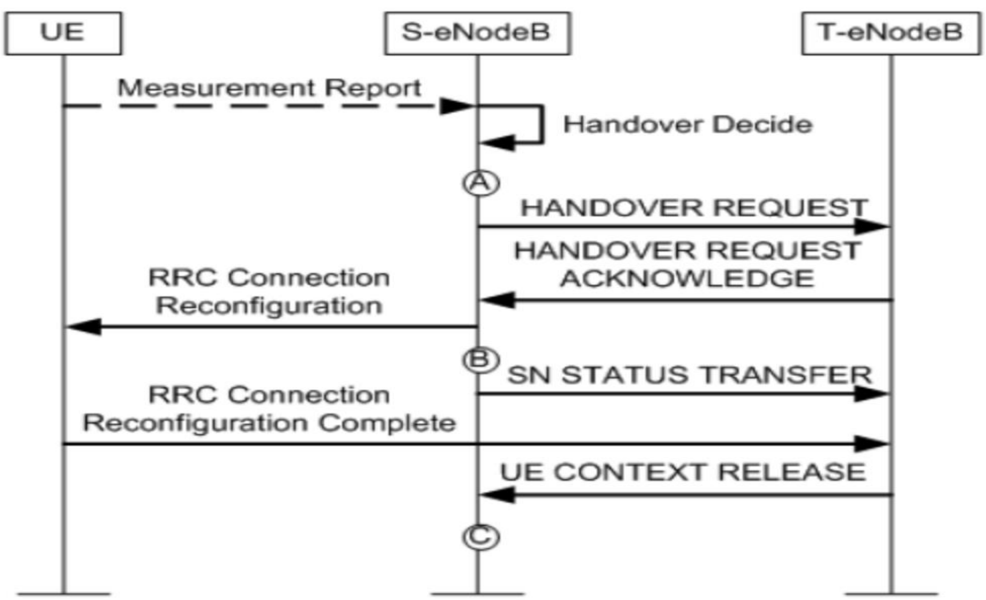
Intra-Frequency Handover Out Success Rate

It evaluates the intra-frequency handover out success rate in a cell or cluster. It is the handover success rate of local cell or radio network to the intra-frequency neighboring cell or radio network. Intra-frequency HO indicates single cell eNB or different eNB.
Intra-frequency HO scenario is shown below:



https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

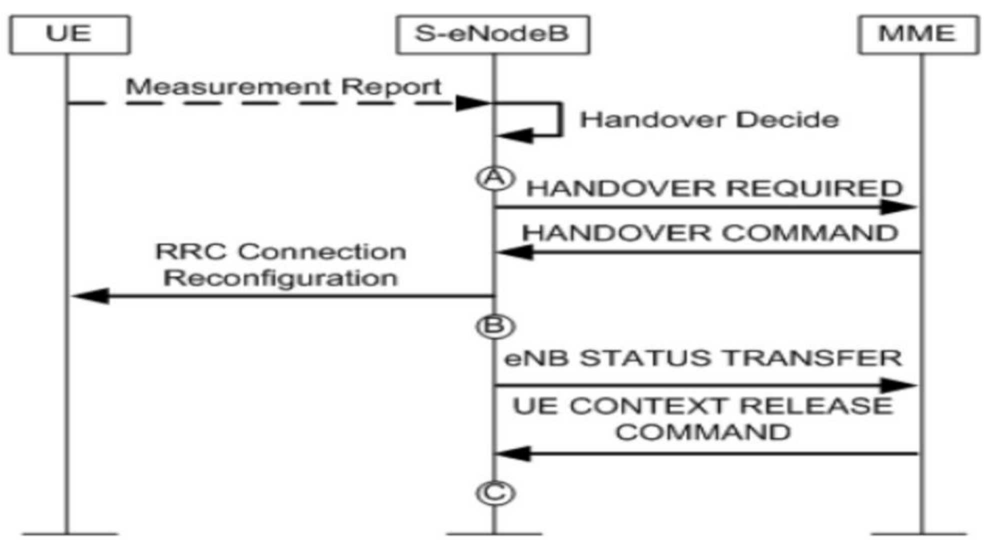
At point B, no attempt HO calculations occur. When eNB sending RRC connection reconfiguration message to the UE, handover will occur. eNB counts the number of HO attempt at the source cell. HO success is calculated at point C when eNB receive RRC connection reconfiguration message complete from UE.
Below is a scenario intra-frequency handovers inter eNB:



https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

At point B, handover attempt occurs when the source eNB (S-eNodeB) transmits RRC connection reconfiguration message to the UE. It decided to conduct inter eNB HO. Here the source and the target cell work have same frequency. The number of handover attempt is calculated at the source cell. The number of successful HO occurs at point C. During HO, success is measured in the source cell. This happens when S-eNB received a UE context release message from the T-eNB or the UE context release command from the MME, which indicates that the UE-eNB has successfully attach at the T-eNB.

The following figure illustrates intra frequency B HO - inter eNB:

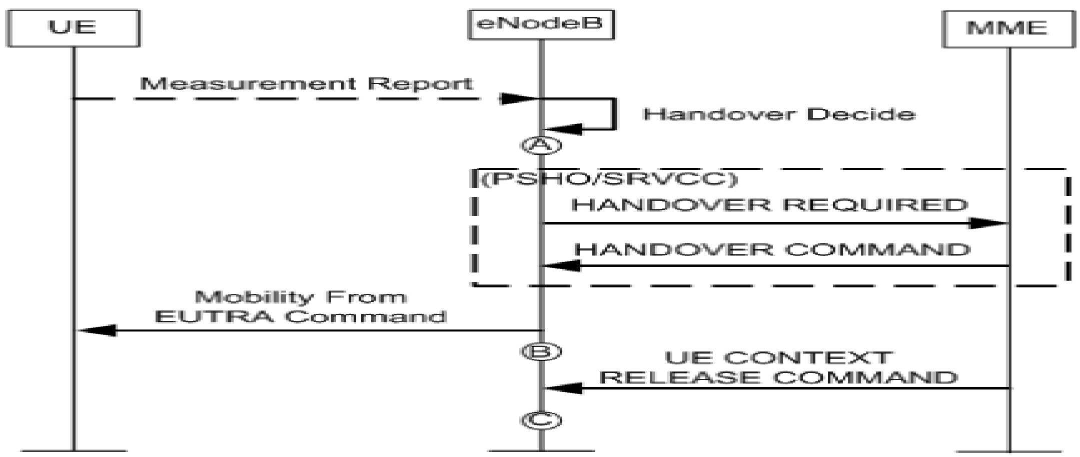


KPI Name	Intra-Frequency Handover Out Success Rate
Measurement Scope	Cell or radio network
Formula	$IntraFreqHOOut\_SR = \frac{IntraFreqHOOutSuccess}{IntraFreqHOOutAttempt} \times 100\%$

https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

Inter-RAT Handover Out Success Rate (LTE to other Technology)

Inter RAT Handover Out Success rate shows the success rate of HO from LTE radio network to a cell with different technology. Below is the scenario out inter RAT handover success rate:



KPI Name	Inter-RAT Handover Out Success Rate (LTE to WCDMA)
Measurement Scope	Cell or radio network
Formula	$IRATHO\_L2W\_SR = \frac{IRATHO\_L2W\_Success}{IRATHO\_L2W\_Attempt} \times 100\%$

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

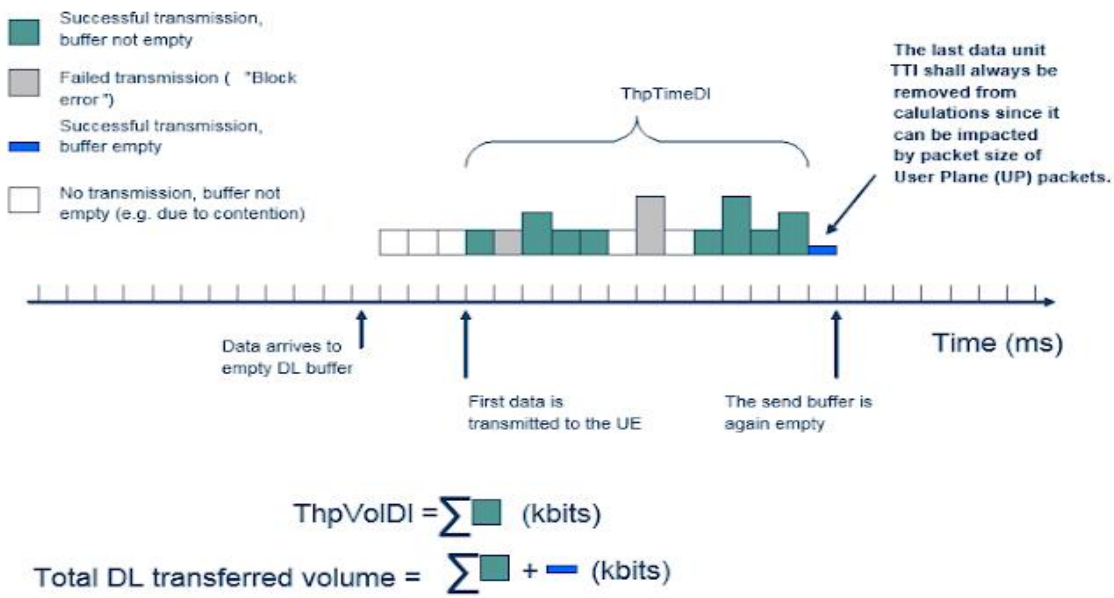
5.4 Integrity

E-UTRAN IP Throughput

It shows how E-UTRAN impacts the end-user service quality. It is the payload data volume on IP level per elapsed time unit over Uu interface. IP Throughput for a single QCI is given by:

$$Downlink \quad Thp_{QCI=x} = DRB.IPThpDl_{QCI=x}$$

$$Uplink \quad Thp_{QCI=x} = DRB.IPThpUl_{QCI=x}$$

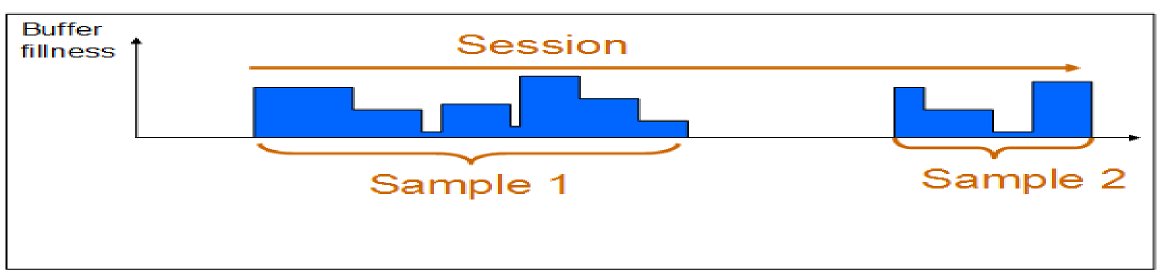


IP Throughput in DL = ThpVolDl / ThpTimeDl (kbits/s)

Here an idle gap between incoming data is not included in the measurements. Each burst of data is considered as one sample.

ThpVolDl = volume on IP level

ThpTimeDl = the time elapsed on Uu for transmission of the volume included in ThpVolDl.

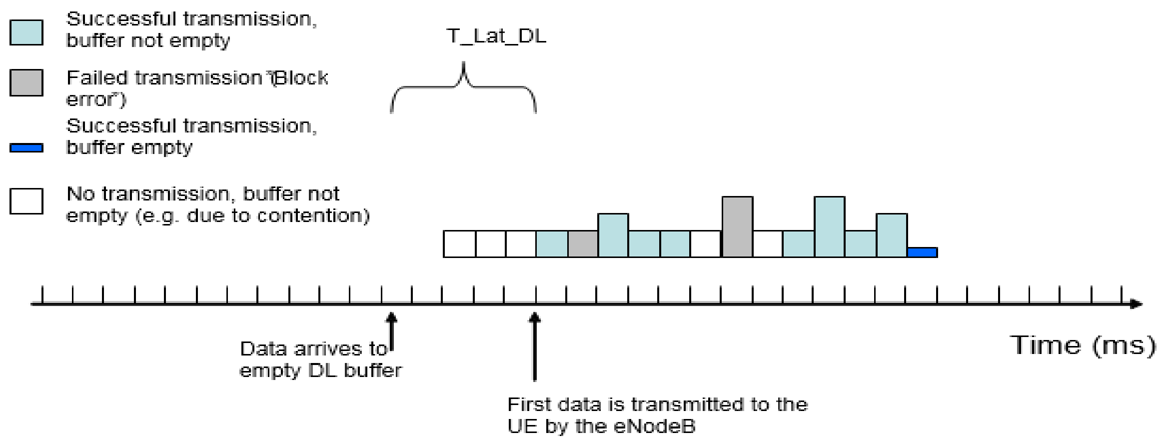


$$IP\ Throughput\ DL = \sum_{Samples} ThpVolDl \Big/ \sum_{Samples} ThpTimeDl$$

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

E-UTRAN IP Latency

It shows how E-UTRAN impacts on the delay experienced by an end-user. It is the time from reception of IP packet to transmission of first packet over the Uu interface. To measure the delay for a certain packet size the IP Throughput can be used together with IP Latency.



$$Latency\_DL = \sum T\_Lat\_DL(s) \,/\, \#\,samples$$

T_Lat =time between reception of IP packet and the time when the eNB transmits the first block to Uu.

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

5.5 Availability

UTRAN Cell Availability

E-UTRAN Cell Availability shows the percentage of time that the cell is considered available.

$$Availability = \frac{\text{Time that cell is available}}{\text{Measurement Time}} * 100\ [\%]$$

A cell is considered available when the eNB can provide E-RAB service.

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

5.6 Utilization

Mean Active Dedicated EPS Bearer Utilization

It is the ratio of the mean number of active dedicated EPS bearer to the maximum number of active dedicated EPS bearers provided by EPC network. It helps to evaluate utilization performance of EPC network.
This can be obtained by dividing the mean number of active mode dedicated EPS bearers by the system capacity.

$$MADEBU = \frac{SM.MeanNbrActDedicatedBearer}{Capacity} * 100\%$$

Source: https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

It indicates system capacity is not enough if the value of this KPI is very high. Then it needs to be increased.

6. LTE-A Advantages, Challenges & Roadmap

6.1 Advantages

LTE-A is an end-to-end internet protocol architecture. It provides dedicated packet switched operations. Here the service providers have the advantage to offer data access to a wide variety of devices. Along with data it supports voice as well. The voice can be transmitted using voice over LTE protocols (i.e. VOIP). It is more reliable and more flexible. It is easier to standardize.

LTE-A network provides three times faster speed than LTE and 10-12 times faster than the 3G network. As connection with network gets released faster after each connection it decreases traffic load on network. It supports quality service when streaming videos, watching online videos, video calling, playing online music, watching online TV & the others streaming stuffs and broadband services. It doesn’t throttle and thus provides more stable connection. The younger generation can stream the music, videos and movies at a much faster speed than ever before and can easily share the information online.

LTE-A supports few cutting edge features like MIMO, Carrier Aggregation, Beam-forming which helps it to achieve higher data rate and lower interference. Using OFDMA in the downlink facilitates channel resources utilization effectively. This helps to increases total user capacity. On the other hand, using SC-FDMA in the uplink uses low power during transmissions and hence enhancing battery life on user side. Because of its improved architecture, handoff is smooth from one area to the other. This results smooth data streaming without any interruption during on-going data transfer.

6.2 Challenges

The existing mobile phones (3G) cannot be used to access LTE-A network features. The subscribers need to have LTE supported devices. This will incur cost to the LTE-A consumer. LTE-A network offer higher data prices for the consumers. It consumes the data very quickly .It consumes a lot of battery when in use as this uses many antennas & transmitters.

LTE network needs complex hardware. New equipment & antennas are required to be installed to make it operational. Hence requires highly skilled engineers and technicians to maintain and manage the system. On the other hand, 4G mobile technology is still fairly new. Therefore it will most likely have its initial glitches & bugs that might not be rectified all on a sudden. It might make the user a bit annoyed.

6.3 Future Roadmap

The 3GPP standards show the roadmap from LTE through LTE Advanced to 5G, led by operators and vendors together of the cellular industry. LTE Advanced not only push LTE capabilities closer towards 5G , at the same time it will also become an major part of the 5G network, providing many services including connected cars, drones and the Internet of Things (IoT) essential to experience 5G.

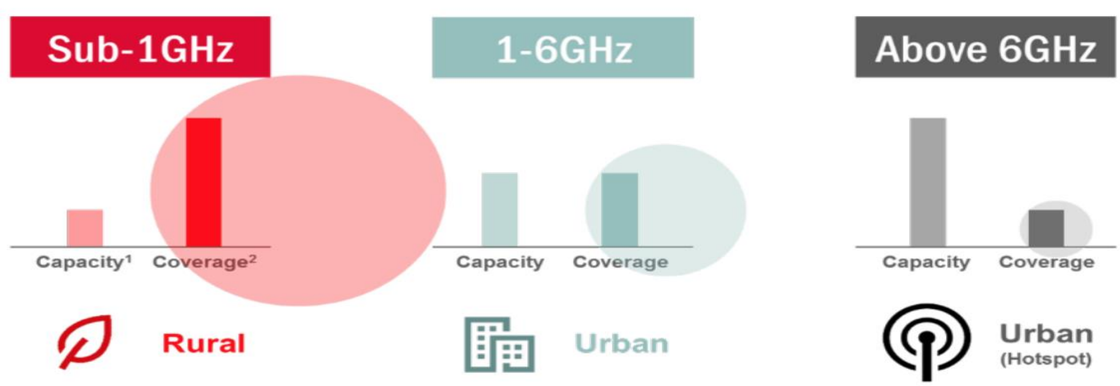
The fifth generation (5G) technology is expected to transform the role that cellular technology used to play in the society previously by facilitating hyper connected society - where not only are all people will be connected to the network whenever needed, but also virtually creating the society where everything connected through IoT. Hence 5G will create new experience like smart cities, smart agriculture, logistics and public safety agencies.

In terms of spectrum bands, 5G can be sub-divided in three macro categories:

- 1GHz
- 1-6GHz and
- Above 6GHz.

Sub-1GHz bands are suitable for IoT services. It can be used to extend mobile broadband coverage from urban to suburban and rural areas as propagation properties of this sub category helps to provide coverage to very large areas creating deep in-building penetration.
The sub category 1-6GHz bands offer a reasonable mixture of capacity and coverage for 5G services. As there already exists a reasonable amount of mobile broadband spectrum with this range, hence it can be used for initial 5G deployments.
Sub category 6GHz above provide significant capacity and can be allocated to mobile communications enabling enhanced mobile broadband applications. This high spectrum bands reduce coverage size of each cell significantly and increase the susceptibility to blocking.
This variety of spectrum shows that there are many options for introducing 5G depending upon the requirements. Service providers must consider the feasibility of different options before deploying. It should meet the intended initial use cases and interoperability of their choice enabling effective delivery of use cases while supporting global interoperability.

Capacity and coverage considerations of spectrum categories



Source: https://www.gsma.com/futurenetworks/wpcontent/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

Though 3GPP defined both a new 5G core network (5GC) and a new radio access technology called 5G “New Radio” (NR) for 5G network, there are ways to integrate elements of different generations in different configuration with 5G – one is SA (standalone) and other is NSA (non-standalone). In SA only one radio access technology is used either 5G NR or the evolved LTE (Long Term Evolution) radio cells. Core networks are operated on standalone basis. In NSA NR radio cells and LTE radio cells are combined using dual-connectivity providing radio access and the core network either by EPC (Evolved Packet Core) or by 5GC.

Three variations of SA & NSA are being defined in 3GPP:

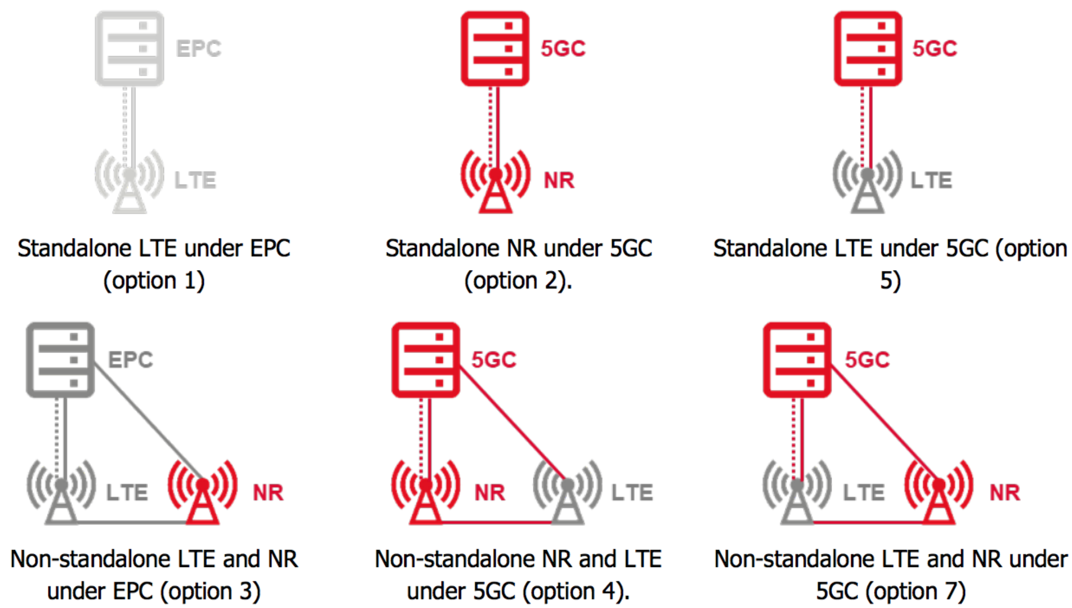
For SA options are –

- Option 1 using EPC and LTE eNB access (i.e. as per current 4G LTE networks);
- Option 2 using 5GC and NR gNB access
- Option 5 using 5GC and LTE ng-eNB access

Options for NSA are-

- Option 3 using EPC and an LTE eNB acting as master and NR en-gNB acting as Secondary;
- Option 4 using 5GC and an NR gNB acting as master and LTE ng-eNB acting as Secondary;
- Option 7 using 5GC and an LTE ng-eNB acting as master and an NR gNB acting as secondary .

Overview of SA and NSA Options



Source: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

There are therefore several possible "paths" service providers can follow to first introduce 5G and then migrate to the target network. Here we are assuming that the operator:

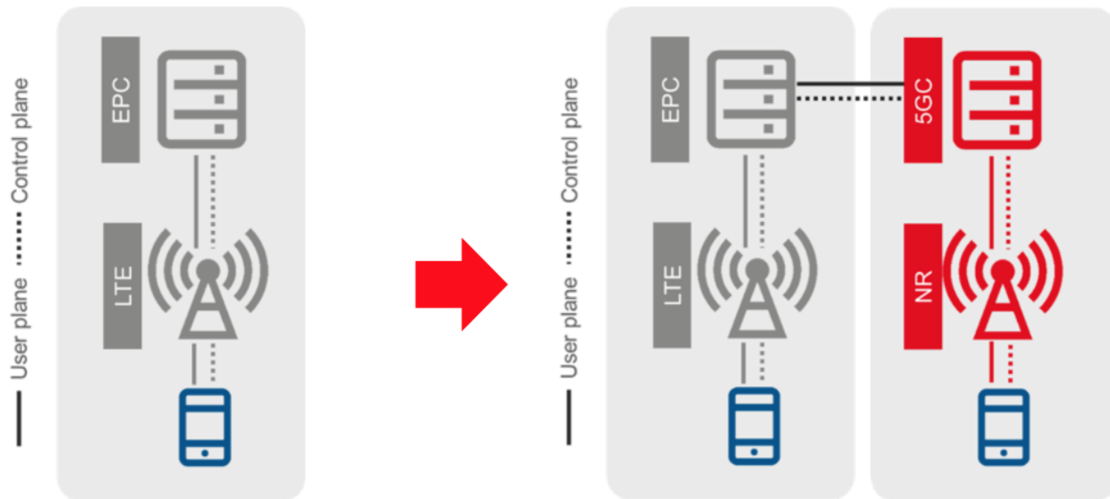
- has deployed a full LTE system having an existing EPC and LTE access
- has plans to upgrade in mid- or long-term to 5GS.

EPS to SA Option #2

In this scenario the operator migrates directly from EPS (Option 1) to the standalone Option 2. It supports inter-RAT mobility mechanisms to move between 4G LTE under EPC coverage and 5G NR under 5GC coverage.

Here SA architecture can take full benefit of 5G end-to end network capabilities supported by NR and 5GC. It supports customized service, new features- including service-based architecture and ensure customized superior user experience. It is a long-term network architecture with both the newly defined radio and core system.

EPS to SA Option #2



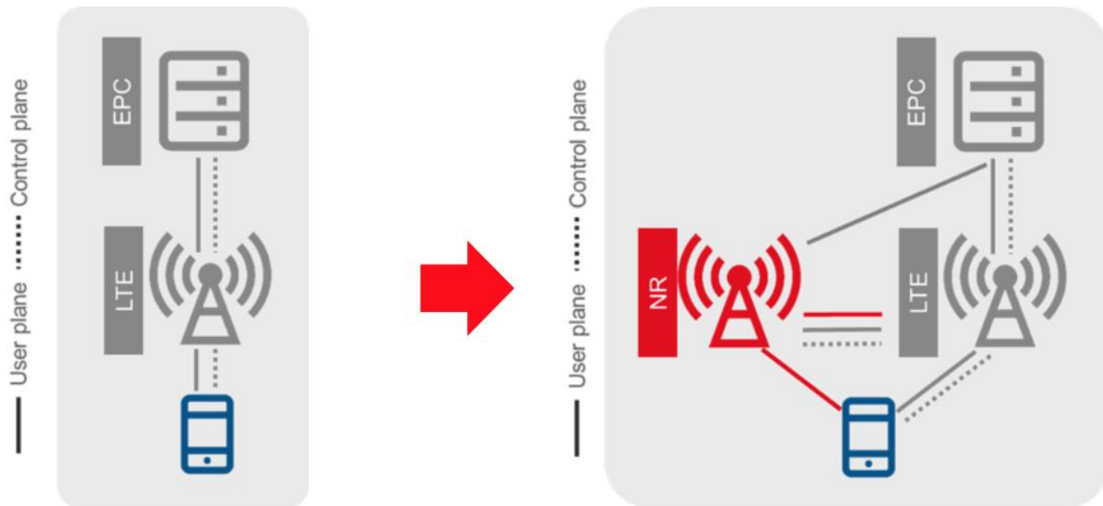
Source: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

As Dual-connectivity is not required for this option (Option #2), workload and cost for upgrading existing LTE is relatively low, only minor modifications needed to support interworking with 5G.

EPS to NSA Option #3

In this scenario, migration is done from EPS (Option 1) to non-standalone Option 3 with the extended EUTRAN capable to use dual connectivity to combine NR radio access and LTE.

It only needs the development of specifications of NR as non-standalone access as part of E-UTRAN connected to EPC. Specification of the full 5G network is not required here.

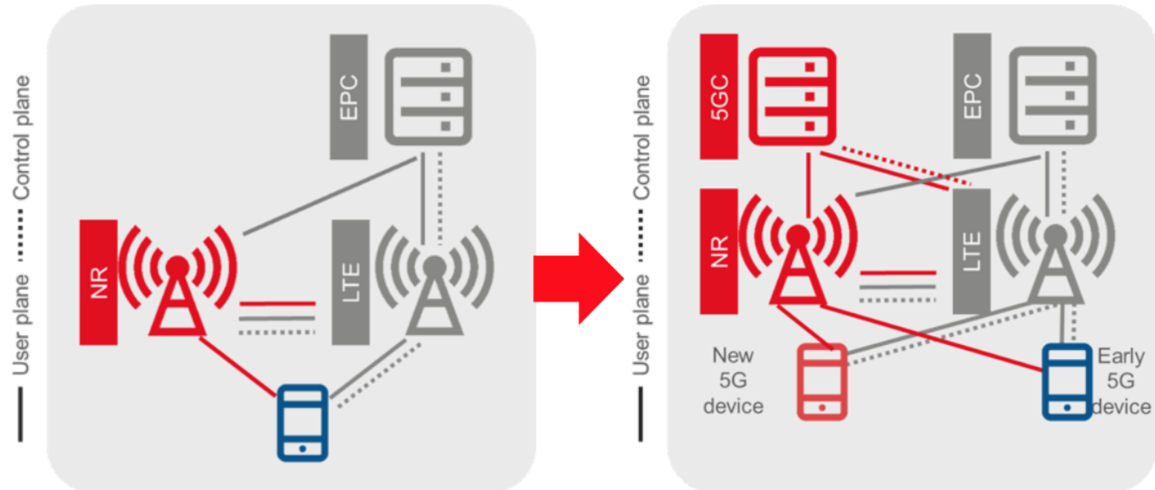


Source: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

It allows flexibility of deployment using the same or different vendors for LTE and NR where there is a requirement for capacity. This option can be used in longer term.
There is a bottleneck of limiting the performance of the EPC capabilities that could otherwise be extracted from NR. Data speed of 5G connected users is projected to increase via NR and LTE in dual-connectivity. But here we have to consider of adopting of additional features to resolve the challenge.
NSA Option #3 requires NSA NR en-gNB in E-UTRAN and new features on LTE eNB to support EN-DC procedures. Therefore it has impacts on E-UTRAN. NSA Option #3 has impact on UE as well along with limited impact on EPC and HSS depending on operators' choice. From the point of view of the device, the device will be able to communicate with the core network using the same EPC procedures used by currently available devices .It could be either under only LTE or under both LTE and NR radio coverage.

NSA Option #3 to NSA Option #7 and SA Option #5

This scenario defines the migration from non-standalone Option 3 to non-standalone Option 7 and standalone Option 5 with RAN connectivity to 5GC along with EPC connection.

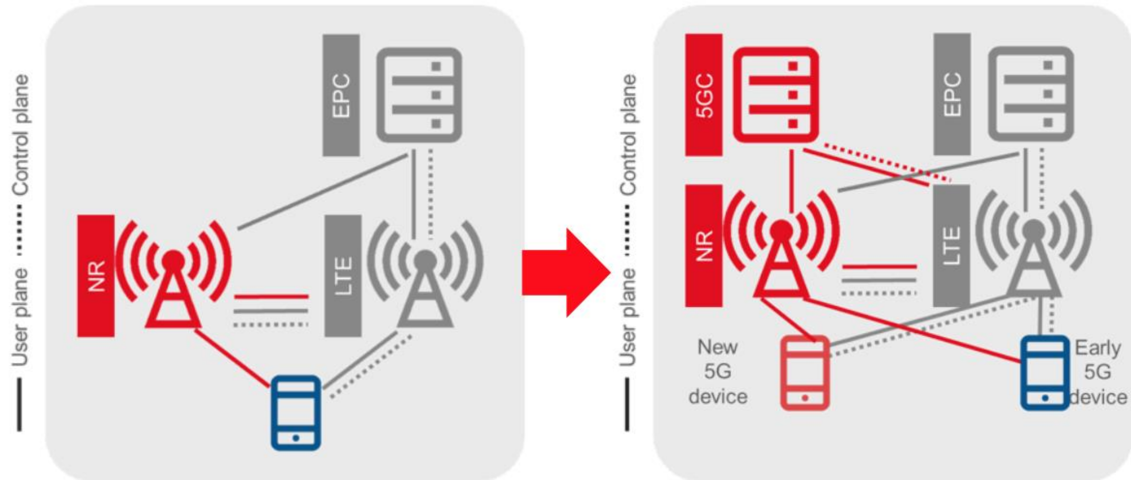


Source: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

In NSA Option #3 the network couldn't take the advantages of 5GC. Here full advantage of 5G end-to-end network capabilities can be delivered to the subscribers.
This migration path requires devices to support the new protocol stack to access this core network. This is problematic for early 5G devices supporting only NSA Option #3 that only have an EPC protocol stack along legacy 4G-only devices. Mobile operators are likely to maintain Option #3 after the introduction of Options #7/5. LTE RAN & eNBs need to be upgraded to connect to 5GC. Tight interworking is needed between LTE and NR. This path allows providers to selectively deploy NR only where required.

NSA Option #3 to NSA Option #3 and SA Option #2

This scenario depicts the migration from non-standalone Option 3 to standalone Option 2 with inter-RAT mobility mechanisms to enable devices between 5G NSA LTE plus NR under EPC coverage along with 5G NR under 5GC coverage.



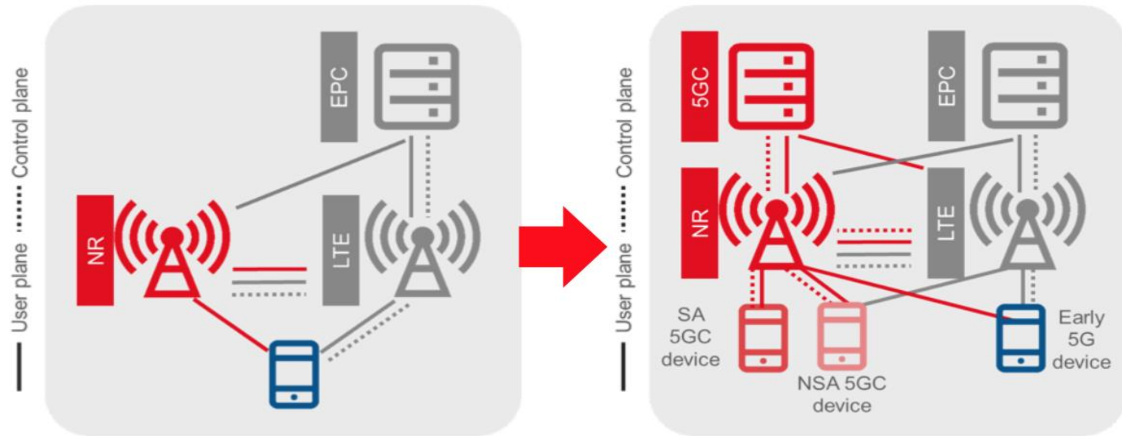
Source: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

In NSA Option #3 the network couldn't take the advantages of 5GC. Here full advantage of 5G end-to-end network capabilities can be delivered to the subscribers. This path enables service providers to address all use cases on clean slate 5GS network. However, migration of initial use cases served by EPC to 5GC should be under consideration.
As here tight interworking between radio level 4G and 5G doesn't exist, this works best when NR has been deployed to support wide-area coverage. This transition needs a change of core network architecture and QoS model and hence should not be used too frequently. Early 5G devices supporting only NSA Option #3 with capability of communicating only with EPC, will be able to utilize their 5G radio capabilities in the target context provided the gNB is able to support both option #2 and #3 devices simultaneously.

Option #2 needs deployment of 5GC and up-gradation of NR gNB to support both NSA and SA (option #2) simultaneously.

NSA Option #3 to NSA Option #4 and SA Option #2

This scenario depicts the migration from non-standalone Option 3 to non-standalone Option 4 and standalone Option 2 with RAN connectivity to 5GC along with EPC connection.



Source: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

In this scenario, unlike in NSA Option #3, the 5GC core network replaces the EPC in serving 5G use cases. If EPC is replaced completely then legacy 4G UEs will no longer be served. Here users take full benefit of 5G end-to end network capabilities. However, the service providers need to think of migration of initial use cases served by EPC to 5GC.

Here operators will keep maintaining the EPC for long term as early 5G devices supporting only NSA Option #3 and only able to connect to EPC. In addition, LTE RAN requires up gradation to connect to 5GC. Here it needs more LTE base stations (eNB) and needs to be upgraded to interwork with NR. Tight interworking between LTE and NR is required for this path. It gives operators the advantage to continue to selectively deploy NR only where there is demand. More NR gNB deployment is needed as NR acts as is the master node where LTE is the secondary node. In this scenario, it is possible to continue to cover wide area by LTE and supplement it with selective NR deployment based on demand.

Option 3 to option #4/2 requires up gradation of NR gNB to support 5GS session, mobility, QoS management and 5GC RAN-core interfaces along with LTE eNB up gradation to support 5GC RAN-Core user plane interface.

Conclusion

The primary objective of this project was to design an access model for a city with the technology that suits it most to fulfill the coverage, capacity and quality requirement. In this project we took Calgary as our pilot city, which is one of the topmost adopters of the latest wireless technology and our proposal was to deploy LTE-advanced there.

For design purpose we divided the city in seven major parts - City Center, Major Activity Center & Community Activity Center, Inner City & Established Area, Standard Industrial & industrial (Employee Intensive), Planned & Future Greenfield, Urban & Neighborhood Main Street & Others. The radius of the cell and antenna height varied considering factors like geography, demography, penetration of end user & consumer devices and the viability of the technology. For transport part we have considered mainly fiber optic and microwave depending on its feasibility.

As we are approaching towards 5G, a roadmap with few options is discussed for smooth merging and adaptation both for standalone and non-standalone case.

Glossary

Term	Description
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
4G	4th Generation
5G	5th Generation
5GC	5G Core
ADSL	Asymmetrical Digital Subscriber Line
AM	Acknowledged Mode
AMF	Access and Mobility Management Function
ARIB	Association of Radio Industries and Businesses
ARQ	Automatic Repeat-reQuest
AS	Access stratum
ATIS	Alliance for Telecommunication Industry Solutions
ATM	Asynchronous Transfer Mode
AWS	Advanced Wireless Services
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
CAPEX	Capital Expenditure
CATV	Cable Television
CC	Component Carrier
CCCH	Common Control Channel
CCSA	China Communications Standards Association
CDMA	Code Division Multiple Access
CDMA2000	Code Division Multiple Access 2000
CMTS	Cable modem termination system
CO	Carrier Office
CoMP	Coordinated Multi Point operation
CRC	Cyclic redundancy check
CRS	Cell-specific Reference Signal
CRTC	Canadian Radio-television and Telecommunications Commission
CSFB	Circuit Switched Fall Back
D2D	Device-to-device
DAB	Digital Audio Broadcast
DCCH	Dedicated Control Channel
DeNB	Donor eNB
DL-SCH	Downlink Shared Channel
DM-RS	Demodulation Reference Signal
DNS	Domain Name Servers

Term	Description
DOCSIS	Data Over Cable Service Interface Specification
DRX	Discontinuous Reception
DSL	Digital Subscriber Line
DSP	Digital signal processing
DTCH	Dedicated Traffic Channel
DVB	Digital Video Broadcast
DwPTS -	Downlink Pilot Time Slot
E-UTRAN	Evolved Universal Terrestrial Radio
EDGE	Enhanced Data rates for GSM Evolution
eHSPA	Evolved High Speed Packet Access
eNB	Evolved Node B
EPC	LTE Evolved Packet Core
EPON	Ethernet Passive Optical Network
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FWT	Fixed Wireless Terminal
G7	Group of Seven
Gbps	Gigabit per second
GEM	GPON Encapsulation Mode
GFP	Generic Framing Procedure
gNB	g node B (next generation)
GP	Guard Period
GPON	Gigabit Passive Optical Networks
GSM	Global System for Mobile communication
GTC	GPON Transmission Convergence
GTP	GPRS Tunneling Protocol
HD-SDI	High-definition serial digital interface
HFC	Hybrid Fiber Coaxial
HSDL	High Bit-Rate Digital Subscriber Line
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IEEE	Institute of Electrical and Electronics Engineers
IMSI	International mobile subscriber identity
IMT-2020	International Mobile Telecommunications -2020
IP	Internet Protocol
IPTV	Internet Protocol Television
ISM	Industrial, scientific and medical
ISP	Internet service provider
ITU	International Telecommunication Union

Term	Description
LAN	Local Area Network
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MAC	Medium access control
MBMS	Multimedia Broadcast Multicast Service
Mbps	Megabit per second
MCCH	Multicast Control Channel
MCH	Multicast Channel
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MT	Mobile Termination
MTCH	Multicast Traffic Channel
MW	Microwave
NAS	Non-access stratum
NG	Next generation
ng-eNB	Next generation eNodeB
NG-RAB	Next generation Radio Access Bearer
NG-RAN	Next generation radio access network
NGMN	Next Generation Mobile Networks
NMS	Network management system
NR	New Radio
OAM	Operations, and maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OLT	Optical line termination
ONU	Optical network units time division multiple access
OPEX	Operational Expenditure
OWA	Open Wireless Architecture layer
PAPR	Peak to Average Power Ratio
PAPR	Peak to Average Power Ratio
PBCH	Physical broadcast channel
PCCH	Paging Control Channel
PCFICH	Physical control format indicator channel
PCH	Paging Channel
PCI	Peripheral Component Interconnect
PCRF	Policy and Charging Rules Function
PCRF	Policing and Charging Rules Function
PDCCH	Physical downlink control channel
PDCP	Packet Data Convergence Protocol.
PDSCH	Physical downlink shared channel
PDSN	Packet Data Serving Node

Term	Description
PDU	Protocol Data Units
PGW	Packet Data Network Gateway
PHICH	Physical Hybrid ARQ Indicator Channel
PMCH	Physical multicast channel
PRACH	Physical random access channel
PS	Packet Switched
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QCI	QoS Class Identifier
QoS	Quality of Service
R-ADSL	Rate-Adaptive Digital Subscriber Line
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Radio Bearer
RLC	Radio link control
RN	Relay Nodes
RRC	Radio Resource Control
S-eNodeB	Source eNodeB
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDH	Synchronous digital hierarchy
SDSL	Symmetric Digital Subscriber Line
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SHDSL	Symmetrical High-Speed Digital Subscriber Line
SNR	Signal-to-noise ratio
SONET	Synchronous optical networking
SRVCC	Single Carrier Frequency Division Multiple Access
SSID	Service set identifier
T-eNodeB	Target eNodeB
TDD	Time Division Duplex
TDM	Time-division multiplexing
TDMA	Time-division multiple access
TE	Terminal Equipment
TM	Transmission Mode
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee
TTI	Transmission Time Interval
UE	User Equipment

Term	Description
UICC	Universal Integrated Circuit Card
UL-SCH	Uplink Shared Channel
UMTS	Universal Mobile Telecommunications System
UPF	User Plane Function
UpPTS	Uplink Pilot Time Slot.
USIM	Universal Subscriber Identity Module
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
VDSL	Very High Bit-Rate Digital Subscriber Line
VOIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WDM	Wavelength division multiplexing
WEP	Wired Equivalent Privacy
Wifi	Wireless fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPA	Wi-Fi Protected Access
WPA2	Wi-Fi Protected Access 2

References

https://en.wikipedia.org/wiki/Calgary

http://www.calgary.ca/SitePages/cocis/default.aspx

https://www.livingin-canada.com/living-in-calgary-alberta.html

https://www.prepareforcanada.com/choosing-a-city/calgary/living-in-calgary-alberta/#.W6UhLBJKjEY

https://www.thecanadianencyclopedia.ca/en/article/calgary

http://worldpopulationreview.com/world-cities/calgary-population/

https://en.wikipedia.org/wiki/List_of_neighbourhoods_in_Calgary

https://en.wikipedia.org/wiki/Microwave_transmission

https://ethw.org/Microwave_Link_Networks

https://www.cablefree.net/wirelesstechnology/microwave/

https://www.sqa.org.uk/e-learning/NetTechDC01CCD/page_44.htm

https://www.britannica.com/technology/Wi-Fi

https://www.elprocus.com/how-does-wifi-work/

https://en.wikipedia.org/wiki/Wi-Fi

http://freewimaxinfo.com/wifi-technology.html

https://ccm.net/faq/298-what-is-wifi-and-how-does-it-work

https://en.wikipedia.org/wiki/LTE_(telecommunication)

https://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/3g-lte-basics.php

https://www.tutorialspoint.com/lte/index.htm

https://www.slideshare.net/hamdani2/lte-long-term-evolution?next_slideshow=1

http://www.rfwireless-world.com/Tutorials/LTE-tutorial.html

https://ltebasics.wordpress.com/2013/05/29/lte-downlink-physical-layer-channels/

https://en.wikipedia.org/wiki/LTE_Advanced

http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced

https://www.digitaltrends.com/mobile/what-is-lte-advanced-and-why-should-you-care/

https://www.tutorialspoint.com/5g/5g_advancement.htm

http://www.rfwireless-world.com/5G/

http://www.3gpp.org/news-events/3gpp-news/1831-sa1_5g

https://en.wikipedia.org/wiki/5G

https://www.gemalto.com/mobile/inspired/5G

https://www.rfpage.com/category/5g/

https://www.cnet.com/how-to/the-5g-revolution-is-coming-heres-everything-you-need-to-know/

https://dzone.com/articles/5g-is-coming-an-overview-of-the-advantages-amp-cha

https://en.wikipedia.org/wiki/Digital_subscriber_line

https://techterms.com/definition/dsl

https://www.lifewire.com/different-types-of-dsl-technology-817522

https://www.cisco.com/c/en_uk/solutions/routing-switching/dsl.html

https://en.wikipedia.org/wiki/Cable_Internet_access

https://www.cablelabs.com/insights/cable-broadband-technology-gigabit-evolution/

https://www.webopedia.com/DidYouKnow/Internet/cable_vs_dsl.asp

https://help.teksavvy.com/hc/en-us/articles/200315040-DSL-vs-Cable-Internet

https://www.reviews.org/internet-service/cable-internet-work/

https://www.usr.com/education/broadband/what-cable-internet-access/

https://en.wikipedia.org/wiki/Optical_fiber_cable

https://en.wikipedia.org/wiki/Fiber-optic_communication

https://searchtelecom.techtarget.com/definition/optical-fiber

http://www.bb-elec.com/Learning-Center/All-White-Papers/Fiber/Fiber-Optic-Technology.aspx

https://www.electronicdesign.com/what-s-difference-between/what-s-difference-between-epon-and-gpon-optical-fiber-networks

https://en.wikipedia.org/wiki/Passive_optical_network

http://www.fiber-optic-solutions.com/epon-vs-gpon-a-practical-comparison.html

https://computer.howstuffworks.com/fiber-to-the-home2.htm

https://www.highspeedinternet.com/resources/what-is-the-difference-between-satellite-dsl-cable-and-fiber-internet/

https://www.nerdwallet.com/blog/utilities/understanding-difference-dsl-cable-fiberoptic-internet-service/

https://www.fastmetrics.com/blog/internet-services/dsl-vs-cable-vs-fiber/

https://www.attinternetservice.com/resources/fiber-vs-dsl/

http://www.fiber-optic-solutions.com/epon-vs-gpon-a-practical-comparison.html

https://www.cozlink.com/dac-aoc-a272-2470-2471/article-73742.html

https://www.eetimes.com/document.asp?doc_id=1272066

https://www.fiberoptictel.com/apon-bpon-epon-gpon-and-wdm-pon-brief-talk/

https://www.linkedin.com/pulse/what-gigabit-passive-optical-networks-gpon-sayed-qaisar-shah/

https://www.slideshare.net/manishhit1/manish-passive-optic-network?qid=f6d65727-c68b-407b-85be-89aa11bfd3e1&v=&b=&from_search=9

https://fr.wikipedia.org/wiki/GPON

https://www.slideshare.net/networksguy/ethernet-passive-optical-network-epon-building-a-next?qid=380cffb6-208d-4670-b61a-7ac6ef43bb7d&v=&b=&from_search=1

https://en.wikipedia.org/wiki/10G-EPON

https://www.quora.com/What-are-the-differences-between-GPON-and-EPON

https://www.sciencedirect.com/science/article/pii/S0030402618304571

https://www.optcore.net/gpon-vs-epon-difference/

http://www.fiber-optic-transceiver-module.com/epon-based-on-ethernet-access-technology.html

https://www.researchgate.net/figure/Urban-structure-map-of-Calgary_fig2_323616930

http://everydaytourist.ca/2018/2018/9/8/suburban-sprawl-birthdeath-differential-managing-growth

http://www.calgary.ca/PDA/pd/Documents/municipal-development-plan/mdp-maps.pdf?noredirect=1

https://www.alliedmarketresearch.com/long-term-evolution-LTE-market

https://www.mordorintelligence.com/industry-reports/long-term-evolution-lte-market-growth

https://www.futuremarketinsights.com/reports/lte-and-lte-advance-market

http://www.digitaljournal.com/pr/3859717

https://www.apacciooutlook.com/news/growing-demand-for-high-network-speed-to-drive-lte-market-states-research-and-markets-nwid-2810.html

journal homepage: www.elsevier.com/locate/cities

‘The influence of the built environment on household vehicle travel by the urban typology in Calgary, Canada’

https://crtc.gc.ca/eng/publications/reports/policymonitoring/2017/cmr5.htm

https://cira.ca/factbook/2014/the-canadian-internet.html

https://www.cwta.ca/blog/2018/06/05/state-of-the-canadian-wireless-industry-2018/

https://www.cwta.ca/facts-figures/

https://en.wikipedia.org/wiki/List_of_countries_by_number_of_Internet_users

https://www.statista.com/topics/3529/mobile-usage-in-canada/

https://www.prnewswire.com/news-releases/8-billion-lte-advanced-pro-market---global-forecast-to-2023---research-and-markets-300737809.html

https://pdfs.semanticscholar.org/5ee5/12154ea58fda78322b86083f1c08372ce23f.pdf

https://ieeexplore.ieee.org/document/6585408

https://www.hardwarezone.com.sg/feature-challenges-faced-operators-4g-lte-deployment

Cellular Network Design Site Selection and Frequency Planning By AMITAVA DUTTA and VERNON HSU

CELL PLANNING OF 4G CELLULAR NETWORKS: ALGORITHMIC TECHNIQUES AND RESULTS by David Amzallag*, Michael Livschitz † , Joseph (Seffi) Naor*, Danny Raz*

Radio Planning of Energy-Efficient Cellular Networks by Silvia Boiardi, Antonio Capone

AN INTEGRATED APPROACH TO CELLULAR NETWORK PLANNING by K. Tutschku, N. Gerlich, and P. Tran-Gia

http://www.academia.edu/10319245/Long_Term_Evolution_LTE_Radio_Access_Network_Planning_Guide_Long_Term_Evolution_LTE_Radio_Access_Network_Planning_Guide

http://www.thefoa.org/tech/ref/basic/design.html

http://www.4gunwired.com/key-preformance-indicator-kpi-analyses.php

http://www.rfwireless-world.com/Terminology/what-is-KPI.html

https://ourtechplanet.com/lte-kpi-optimization-deep-dive-rrc-success-rate/

https://telecom-hyb.blogspot.com/2016/12/4g-optimization-and-kpi-analysis.html

https://www.slideshare.net/RayKhastur/kpi-in-lte-radio-network-huawei-based

file:///Users/user/Downloads/209261635-huawei-lte-kpi-ref-150429104255-conversion-gate01.pdf

https://www.online-sciences.com/technology/4g-technology-uses-features-advantages-and-disadvantages/

http://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-LTE.html

https://www.lifewire.com/4g-mobile-networks-pros-and-the-cons-2373260

https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

https://www.rcrwireless.com/20180419/5g/the-roadmap-to-5g

https://www.riverpublishers.com/journal/journal_articles/RP_Journal_2245-800X_611.pdf

https://www.4g-lte.net/lte/lte-advanced-pro-to-5g-roadmap/