UNIVERSITY OF ALBERTA

Capstone Project - 709Report

Submission on

"Analyzing LTE traffic requirement for User, control and management Plane in the LTE backhaul Networks"

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Abstract

With the new LTE network concepts which constitute a rapid progress toward the All-IP concept, enables high data rate for both up-link and down-link at cell site. It will stringent the requirement in terms of capacity and traffic dimensioning because there will be there will be more and more users packed in each cell site. Thus, a well-organized planning and design will be required for these networks to provide various IP-Based crucial services such as Voice over IP and Rich communication services (RCS). As we have diversity of access technologies in the network, the traffic dimensioning and planning aspects become very important.

Traffic analysis and dimensioning is an important part for a mobile network planning process. In this report we will analyze cell site data and traffic types and how these values are calculated. Based on LTE-Backhaul network we will differentiate various traffic types existed in the core network.

Main objective of this report to provide analysis of various traffic types and their requirements in the LTE network. We will calculate the capacity requirement of each link from radio part to EPC network. More specifically, we will work on set of equations which are used to generate a traffic profile with considering many realistic and pre calculated parameters. Some of the calculations will be based on theoretical approach with considering ideal conditions of network and these will be used to dimensioning capacity requirement in each link of network. We will also calculate the EPS traffic and based on that we will analyze how many network elements we needed.

In last we will implement all of these calculations for a geographical region using various topologies and analyze how much bandwidth and capacity required to design such a network.

Acknowledgment

On the very beginning of this project report, I am writing this note to express my thanks to the people whose direction and supervision made it possible. Working on this project had a big impact on me and I have learned lot of things not only on technical level, but also on a personal level.

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1. Introduction to Mobile Network

Telecommunication is a Greek term defines Communication at a distance between transmitter and receiver using any transmission medium. Near to ending of the 19th century, wired telegraphy and telephony changed the scenario of communication. It all start with plain old telephony system (POTS)/Trunk system which only used for the voice purpose & also these services were not reachable and affordable to one and all. The system was further developed and improved in the following years. Then after, in the 20th century, another revolution took place, in which radio freed those same communications from the constraint of a wire. To overcome the limitation of bandwidth scarcity and to give coverage to larger sections, BELL lab launched the principle of Cellular concept that changed the overall perspective of Telecom.

In the early 1980 voice over the air (Radio Interface) services started, which was also known as 1G (First Generation). These systems were analog, based on FDMA technology, but it was not robust due to interference and every country had their own standards. To conquer this issue Second Generation (2G) of wireless technology was launched which was based on GSM. It provides better quality of Voice and improved spectral efficiency. It had new services like text messages and MMS.

Second Generation system were built mainly for voice services. Based on user requirements more improvement in technology took place. 2.5 G (GPRS) was introduced, which added data with voice service. Speed of data was very slow which just meet the basic requirements like email send/receive.

In Today's era mobile communication is not just voice it is more diverted towards data services. Mobile users demands for more services like Video on demand, live streaming, online games on high speed. Main goal of research and development was to provide high speed data. After that Edge (2.75 G), 3G were launched; with these evolutions the only aim was to provide high speed data to mobile users.

At present users are using Fourth Generation of wireless communication which provides high data rates with extended multimedia services. It is capable to provide speed 100Mbps with high QoS and Security. Within fraction of seconds you can download GB's of files.

1.1. Evolution of Mobile Technology:

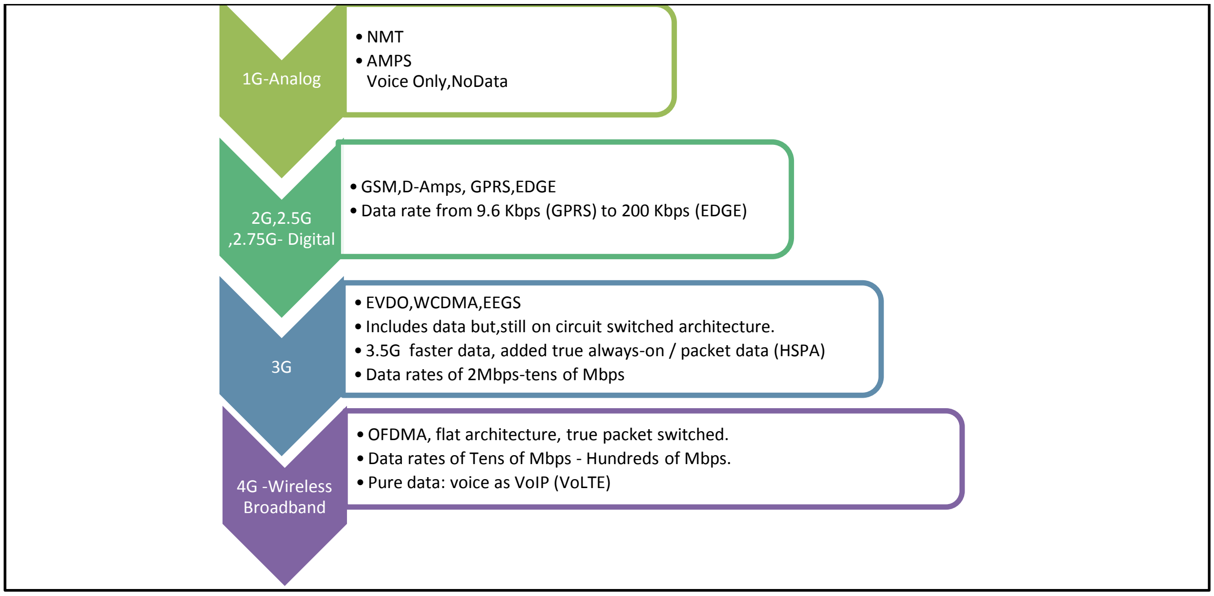


Figure 1: Evolution of mobile network

Over the years, Mobile communications have been encountering a gigantic consistent advance for as far back as decades, and a large number of individuals are utilizing different services provided by cellular networks each day. The expanding interest for data services puts weight on the network operators who need to put intensely in their system infrastructure and in planning tools that give a cost-productive system outline ready to meet every one of the clients' requests. The competitive market likewise requires network operators to give the services at sensible cost. For efficient Network, operators need to design best network by which they can fulfill all demands of the subscribers.

LTE is a framework with bigger transmission capacities (up to 20 MHz), low latency and Packet optimized radio access technology having peak data rates of 100 Mbps in downlink and 50 Mbps in the uplink . In LTE Radio access technology uses OFDM (Orthogonal frequency division multiplexing) which provides higher spectral efficiency and more robust against multipath fading, as compared to legacy technology such as CDMA (Code division multiple access). So as to offer the operators increased flexibility in network deployment, the LTE technology supports bandwidth scalability and both FDD and TDD duplexing techniques. LTE technology also supports both unicast and multicast traffic – in cell sizes from micro cells (small distance - hundreds of meters) up to large macro cells (>10 km in radius).

2. Objectives and Approach

The new LTE enables high data rates for both up-link and down-link at cell site eNodeB. As per the new 3GPP standards and specifications, it means more and more user are packed in each cell site with high speed data and has very stringent requirements in terms of bandwidth and traffic dimensioning.

It is a reality that traffic measurement plays a vital role in designing a network and measuring and maintains its performance. Before measurement it is necessary to understand the traffic flow and pattern in the network and identify with the various types of traffic carried on the each link of network. Also it is necessary to understand the various kinds of links and interfaces in which traffic is flowing. With the traffic analysis and measurement we can evaluate capacity of network, number of network nodes, network latency or delay, and other performance measurement parameters. Here term Traffic is defined as the, for a given period of time how much data is flowing through the links of network. But in LTE network traffic is divided into four parts based on delay sensitivity which are conversational class, streaming class, interactive class, and background class. We will discuss all of these in next topics.

Objective of our project is to analyze the LTE traffic requirement for User, control and management plane in the LTE backhaul Networks. In this we will analyze the cell site data and traffic types and how these are calculated. We will analyze the peak and average throughput of the network and based on that we will design a small network using various topologies.

2.1. Main Objectives are listed below:

- Introduction with LTE and Network Architecture
- LTE Interfaces and Traffic Types.
- Requirement of LTE Backhaul Network (QoS, GoS, Traffic Flows)
- eNodeB Traffic Management and distribution of Traffic for Backhaul Network.
- LTE – Advanced and their Impact on Backhaul
- eNodeB Traffic Pattern, Loading and Utilization.

- Backhaul Bandwidth, Capacity and Utilization Calculation.
- Link Dimensioning Principle for Backhaul
- LTE Backhaul Topologies
- Implementation of IP Backhaul Network for Regina City

3. Long Term Evolution of 3GPP (LTE)

The principle goals of LTE structure are to develop a framework that meets demands for high data rate, low latency and streamlining for packet-domain traffic. LTE system will be intended to have a peak data rate of 100 Mbps in Downlink and up to 50 Mbps in the uplink. With the below text we will describe the basic features of LTE system.

3.1. LTE Overview:

RAN Evolution workshop conducted in Toronto for the Evolution of 3G Mobile system in November 2004 by the 3GPP.More than 40 contributors to mobile business included Mobile Operators, Manufacturers and research institute participated to give their views on evolution of Universal Terrestrial Radio Access Network (UTRAN). In workshop high level requirements are identified to improve services with less user and operator costs. Main objectives are given below:

- Utilization of existing 2G and 3G spectrum along with the new LTE spectrum to increase the system capacity and reducing cost per bit.
- As discussed above main goal was to increase data rate as comparison to legacy technology and the goal was 100Mbps in uplink and over 50Mbps in downlink.
- To provide greater coverage along with the higher data rates.

3.2. Requirements for LTE

Requirement and targets for this technology are quite stringent; therefore, it took several years to develop the technology. In every evolution the main objective is to give further improve services as comparison to existing technology with reduces user/operator costs. Some of the key requirement and capability for long-term evolution are given below:

- Peak Data rate : DL- 100 Mbps and UL- 50Mbps.
- Bandwidth Scalability- Different bandwidth can be used depending upon the requirement and it save resources.
- Low latency – Latency should be low, for both user plane and control plane with a 5 MHz spectrum it should be below 5ms.
- In LTE only Packet switched domain support.
- Improved coverage with high data rate.
- Technology should be able to work with existing 2G and 3G systems, CSFB should be supported by the system.
- System should not be complex; Architecture should be simple as comparison to complex legacy system.
- Migration from existing system should be easier.

These are basics requirement for the LTE system and there are many more. But the key requirement for LTE to make a flawless transition from existing system. It can be achieved by reusing of the current spectrums, interoperability between current and upcoming system and reuse of current cell sites. With this operator can easily migrate from one system to other with less cost. To achieve this we need to adopt simplified system architecture, stringent limits on spectrum.

3.3. Multiple Access Techniques

The above discussed requirements were achieved with the choice of air interface technology used. After the all research conducted, keeping in mind all the requirements of spectrum, data rates, coverage and performance, it was concluded that orthogonal frequency-division multiplexing (OFDM) will be used as the multiple access technology in Downlink.
For the Uplink, single-carrier-based frequency division multiple access (FDMA) selected. The main cause to use this selection to reduce power consumption of the user device.

3.4. OFDMA for Down Link:

In downlink OFDMA with Cyclic Prefix (CP) chosen as transmission scheme due to simplicity of the receiver. OFDM yields a frequency structure that partitions the data over various sub-carriers. The spacing between two sub-carriers is settled at 15 kHz. A resource block (littlest unit in time and frequency) is characterized to comprise of 12 sub-carriers in frequency and 14 constant symbols in time. This make one resource block to traverse 180 KHz and 1ms in frequency and time respectively. These sub-frames are also having the minimum transmission time interval (TTI). Short TTI also achieve the goal of low latency.

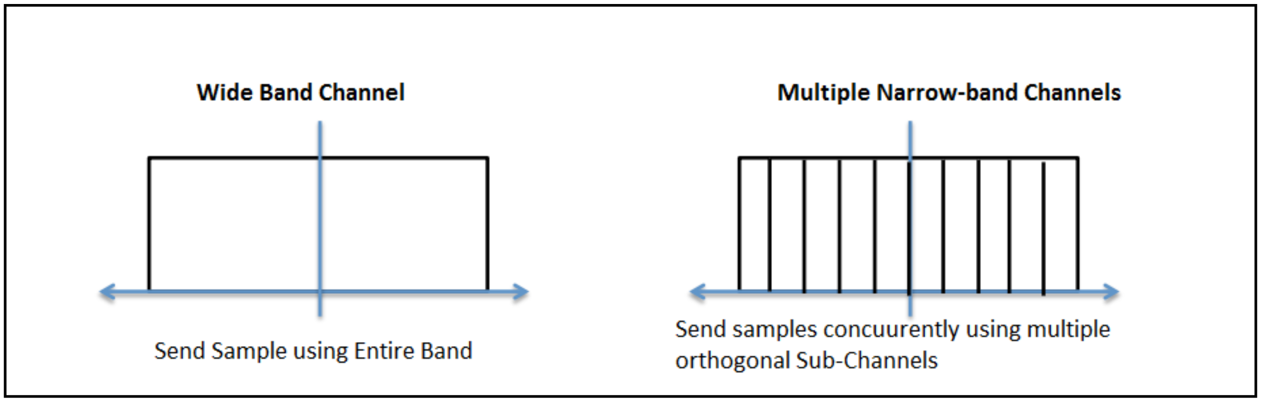
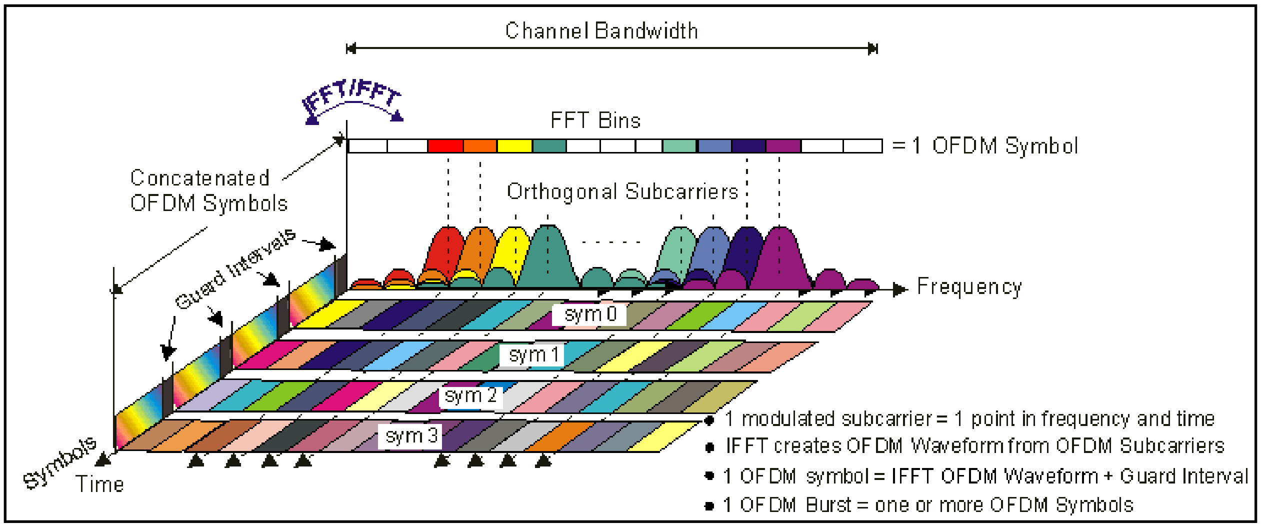


Figure 2 – Sampling example for Wide-Band and Narrow Band

In channel bandwidth flexibility is provided by allowing five different bandwidth options to choose as per the requirement. These five options are 1.25,3,5,10 and 20 MHz. As stated above subcarrier spacing is fixed for all possible bw at 15 KHz. With the sub-carrier spacing of 15 KHz, symbol time is 66.68 µsec. To get rid of Inter symbol Interference, a guard interval is used which is inserted between two consecutive symbols. Guard interval is filled with the CP.



Source-http://rfmw.em.keysight.com/wireless/helpfiles/89600b/webhelp/subsystems/wlan-ofdm/content/ofdm_basicprinciplesoverview.htm

Figure 3 – OFDMA Representation for Channel Bandwidth

We know the spacing of sub-carriers is fixed; the transmission bandwidth is varied based on changing the number of sub-carriers. Based on the cyclic prefix each sub-frame consists of 6 or 7 OFDM symbols.. DL Physical layer parameters are summarized in the table below.

Downlink Frame Structure of LTE is given below. One radio frame has different sub-frames which carry PDSCH, PDSCCH and PBCH. Whereas PDSCH and PDSCCH are present in each sub-frame. But, PBCH is only present in particular sub-frames that contain the System Information. SFN represents the frame time reference.

Radio frame is of 10ms long and have 20 slots of length 0.5ms, which are numbered as 0 to 19. In frequency division duplexing 10 frames are available for downlink transmission whereas 10 sub-frames are available for uplink in each 10 ms frame interval. UL and DL are separated in the frequency domain. Nut in case of Time division multiplexing a sub-frame is either allocated to downlink or uplink transmission. Whereas Sub-frame 0 and 5 are always allocated for DL.

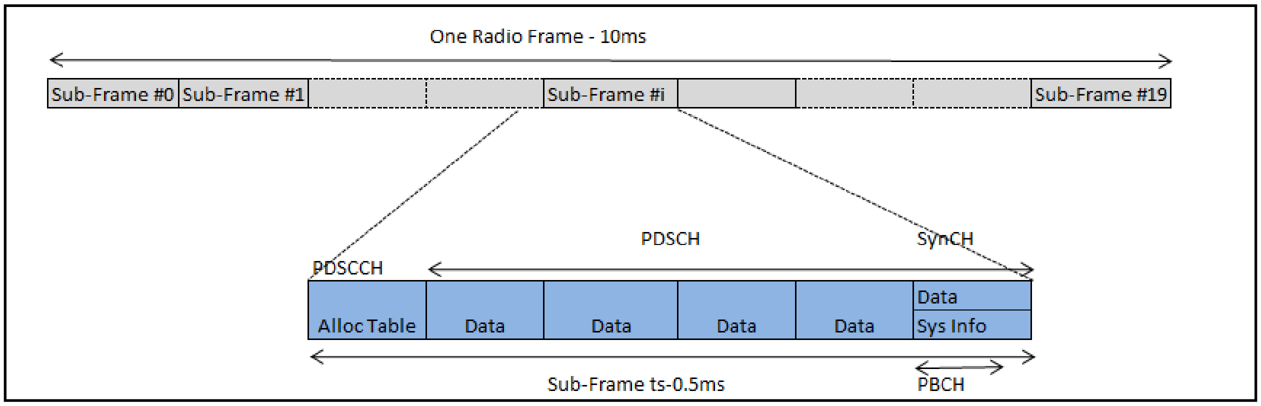


Figure 4 - Downlink Frame Structure

3.5. SC-FDMA for UP Link

For the Uplink Single carrier – Frequency Division Multiplexing transmission is used. Cyclic Prefix is used to attain UL inter-user orthogonality and which will enable the efficient equalization in frequency domain on the receiver side. Uplink frame is given below. Frame has two parts short blocks SB and six long blocks LB in each sub frame. Purpose of Short block is to do coherent demodulation or for control data transmission or sometime both of these purposes. LB is used for Control and Data transmission.

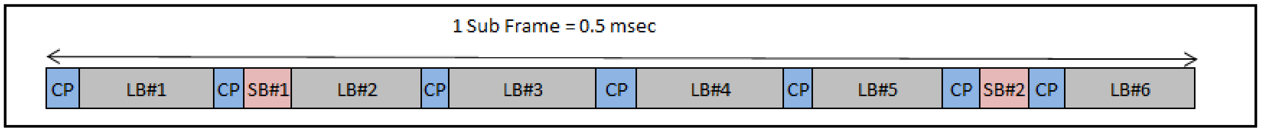


Figure 5 - UL Frame structure for LTE

3.6. Bandwidth Scalability

LTE technology usually operates on the 2 GHz band, with the extended 2.6 GHz and at some point on the 900 MHz bands. As per the requirement of LTE discussed above, we use different Bandwidth as per the requirement. In order to offer flexible utilization of the bandwidth, we can use different carrier bandwidths, which range from 1.25 MHz to 20 MHz (1.25 MHz, 2.5 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz). But for all of these different bandwidth the sub-carrier spacing remains the same which is 15 KHz, only the number of subcarrier will change.

Case Study: *It is found that, in practical scenarios these bandwidths are used based on their operations. As discussed above we have 900, 2100 and 2600 band, Usually operator used 1.5 or 3 MHz bandwidth on 900 bands, because we know 900 band has more coverage than 2100. This is used for coverage. 900 bands can overshoot at maximum distance, so smaller band with 3 MHz used for control operations. Instead of dropping calls max user can latch on the site. Whereas 2100 band user for the data plane with the bigger bandwidth such as 10 MHz or 20 MHz, which can provide maximum throughput to the user with better quality of signals.*

Major Sources –

- LTE Backhaul Planning and Optimzation by Esa Markus Metsälä and Juha T.T. Salmelin
- LTE Traffic Generation and Evolved Packet Core (EPC) Network Planning by Dima Dababneh
- Dimensioning of LTE Network Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface by Abdul Basit

4. Network Architecture:

As discussed above, to achieve all goals for LTE it has some requirement which is: Packet switched domain only, Low latency and reduced cost. All of these requirements are characterized by the LTE architecture. To achieve this objective and to reduce complexities present in the legacy network, LTE must be designed in such a way that it contains fewer nodes. This is an important point because it will affect the whole network, with the smaller number of nodes reduces overall amount of protocol-related processing, complexity, number of interfaces and cost of testing. It also provide into simplicity of optimizing radio interface protocols. This can be achieved by merging some control protocols and with using shorter signaling sequences which can provides rapid session setups.

Evolution of Radio access in Universal Mobile Telecommunications System (UMTS) in LTE is known as Evolved UTRAN (E-UTRAN), on the other hand development of the non-radio part including the Evolved Packet Core (EPC) network is known as the System Architecture Evolution (SAE). Both EPC and E-Utran known as EPS (Evolved Packet system).

E-Utran consists of two parts which are given below:

- eNodeB (Enhanced Node B)
- aGW (access Gateway)

ENodeB is the basic access network device which covering a single cell or installed on one site based on the requirement. Its function is to provide the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the User Equipment . In LTE we don’t have concept of BSC but two eNodeBs are connected with each other with X2 interface. In LTE architecture eNodeB is designed to give a better level of intelligence to decrease the overhead due to which task of Radio Resource Management are provided by eNodeB such as Radio Admission Control, Connection Mobility Control, Radio Bearer Control, Dynamic allocation of resources to User equipment in both uplink and downlink. ENodeB also provide security services by encrypting user data stream and also provides routing of data towards S-GW. It also has a capability for scheduling and transmission of paging and BCCH messages.

aGW is the second networking device in E-UTRAN which is one stage above eNodeB. An aGW can be connected to more than one eNodeBs depending upon the network design.

4.1. E-UTRAN Interfaces

We know one objective of LTE architecture is to remove the complexity by simplifying and reducing the number of interfaces between E-UTRAN and EPC. Interfaces between various network elements are S1 (eNodeB – S-GW) and X2 (inter eNodeB). S1 interface subdivided into two types:

· S1-C: Interface between eNodeB and MME (Control Information).

· S1-U: Interface between eNodeB and S-GW (User Information).

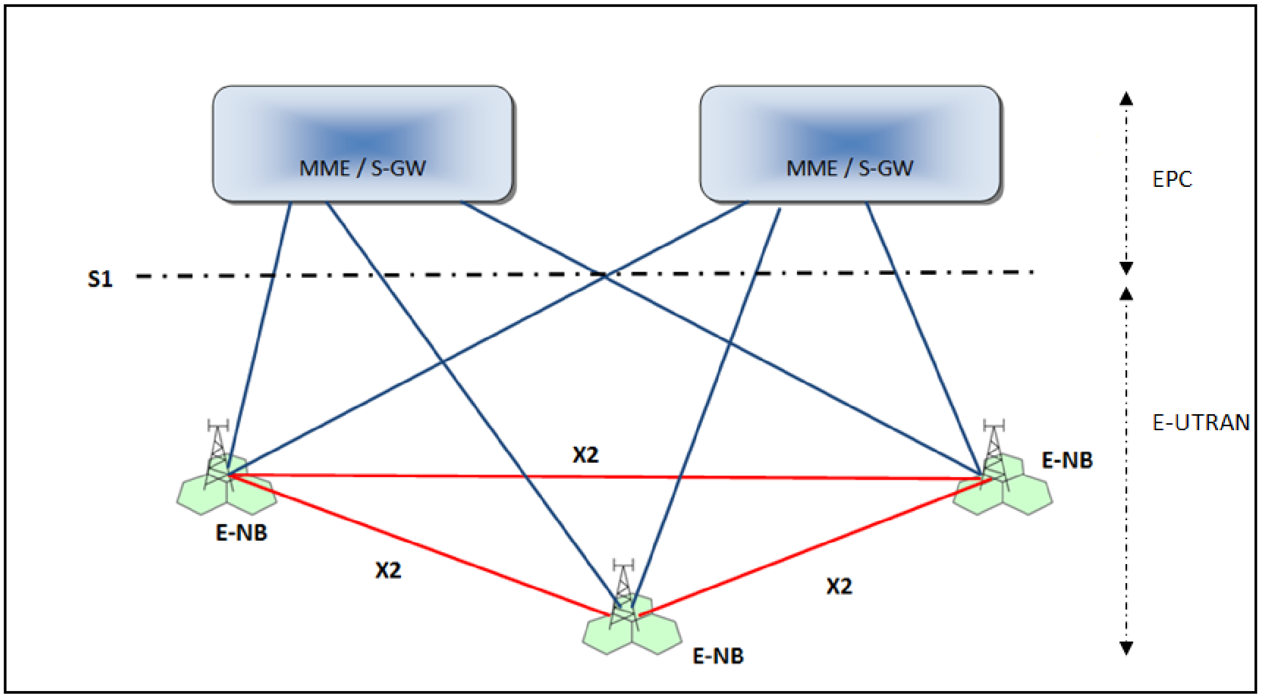


Figure 6- LTE Interfaces

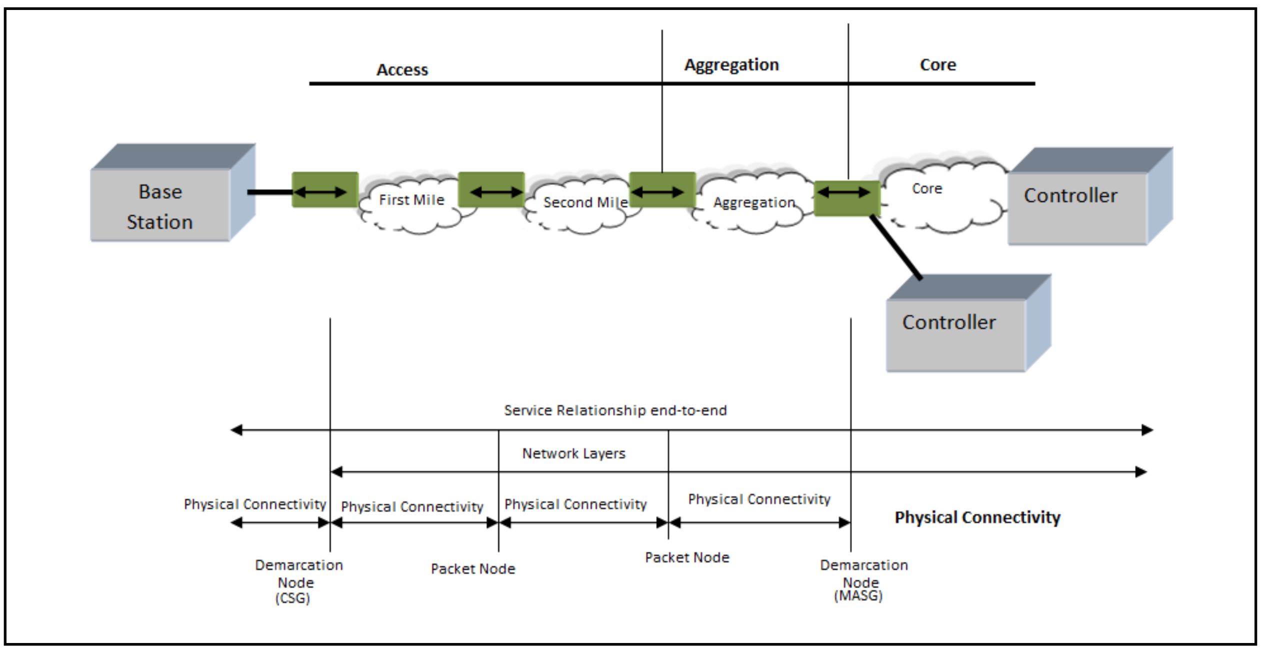
For the S1 Interface, access point for E-UTRAN is eNodeB and access point for EPC is either control plane MME or User Plane S-GW. S1 interface support both control plane and user plane information and it has many function such as initial context setup, mobility functions and UE context management. It also supports signaling functions of User Equipment. It also provide mobility functions for the handover, it can be Intra-LTE handover or Inter-3GPP (CSFB) handover.

As there is no concept of BSC two eNodeB are connected with the X2 interface. It supports the signal information exchange between any two eNodeBs. Logically it is point to point link, it mean we can create X2 link even eNodeBs are not physically connected. X-2 also provides the interconnection between equipments of different vendors and offers continuation in service via S1 link.

4.2. LTE Core Network and its and it's Component:

Backhaul Network is a crucial part of any telecommunication network which connects the RAN part to the core network. Backhaul network provide a medium which connect the eNodeB to their relevant network element present in the core. Network element will be part of EPC including MME and S/P-GW.

Any network consists of three parts: Core, Aggregation and access. Access part provides connectivity to eNodeB, which is mostly having tree or chain topologies. But also some times fiber and copper cable is also used. Aggregation network is normally located in place of RNCs and BSCs. In the ore network all the network controller elements are connected with each other, which in most of the cases are IP/MPLS routed network.



Source- -https://www.ngmn.org/uploads/media/NGMN_Whitepaper_Guideline_for_LTE_Backhaul_Traffic_Estimation.pdf

Figure 7 : Network Representation

4.3. Core Network:

Core network of LTE is composed of different pieces of equipment so the architecture of the core network is a little bit more complex. Some of the network elements details are given below:

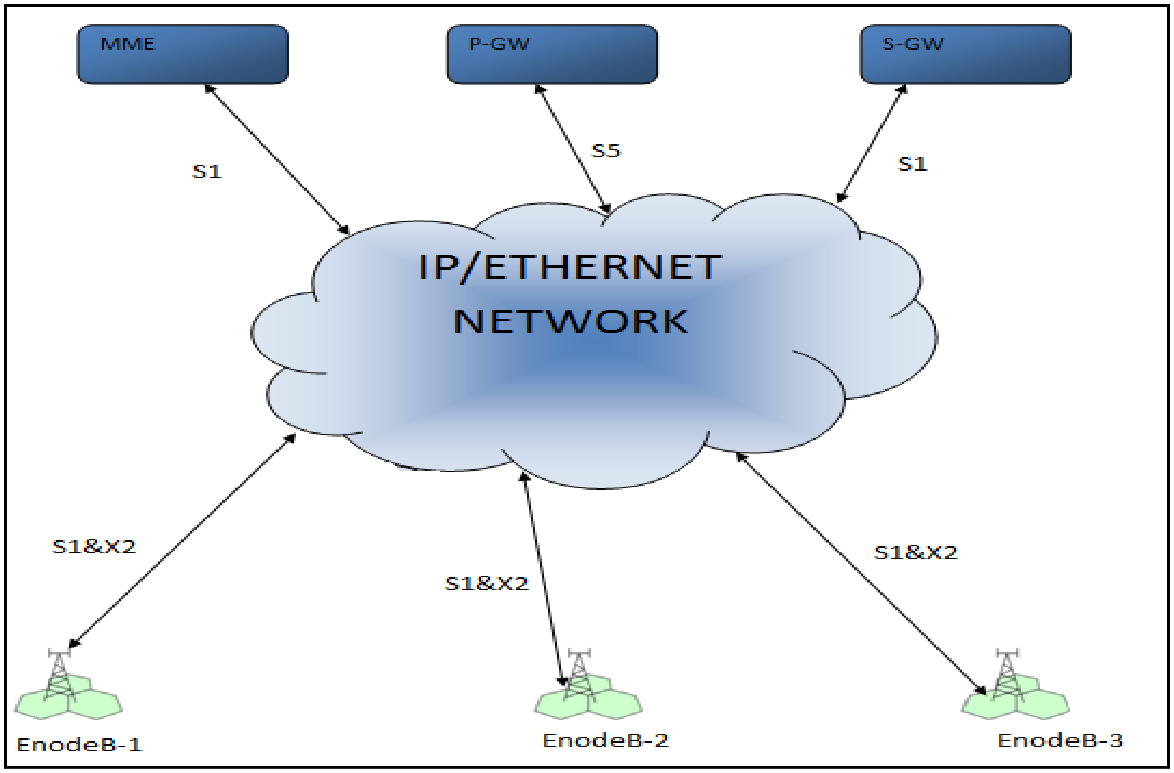


Figure 8 -Core IP network representation

4.3.1. **Serving Gateway (S-GW):** This network element deals with the user plane traffic. They basically transport the IP data traffic from Mobile equipment to external network. This is the interconnection point between radio access network and EPC. It acts like a local mobility anchor, during handover when UE moves between eNodeBs it holds data. When UE is in idle condition it keeps information about bearers and when MME is starting paging for subscriber's bearer reestablishment it act like a buffer for the downlink data. It also collects data for charging such as traffic on the link whether received or sent by the subscriber. In case of internetworking with other 3GPP (CSFB) technology it acts as a mobility anchor. It is logically connected with other network elements.

4.3.2. **Packet Data Network Gateway (P-GW):** It connects the EPC with the external IP network. Main task for this element is to assign and distribute the IP addresses to the subscribers. On the based on PCRF rules it is enforcing Quality of service and flow based charging. It has responsibility to distribute and classify all IP packets in downstream into different QoS classes and bearers based on TFT (Traffic flow templates). This network element is also known as default gateway because it has capability to do packet filtering and lawful interception which analyze the signaling data.

4.3.3. **Mobility Management Entity (MME):** This control node deals with the Control plane traffic between user equipment and core network. This network element plays a key role for setting and maintain the EPS bearers. Its major tasks including registering User Equipment, controlling mobility function between subscriber and core network, and creating & maintain the IP connectivity. Link between eNodeB and MME is known as S1-MME. MME is also logically connected with other network elements to perform other necessary tasks.

4.3.4. **Home Subscriber Server (HSS):** Basically, Home Subscriber Server is a database that contains subscriber related information. It keeps the dynamic data to keep track of the MME to which subscribers are connected. It also contains information for subscribers SAE subscription such as QoS profile, Limitations for roaming or extra data requested by subscriber. HSS also plays a vital role for the authentication process, which computes security keys and authentication vectors.

4.3.5. **Policy Control and Charging Rules Function (PCRF):** This network element is connected with the P-GW and main task for this element is to control the functionalities of Policy Control and Charging Enforcement Function. It also provide Qos authorization which have QCI (QoS Class Identifiers) and bit rates, as per the subscription of user it defines the PCEF treatment for certain data flows.

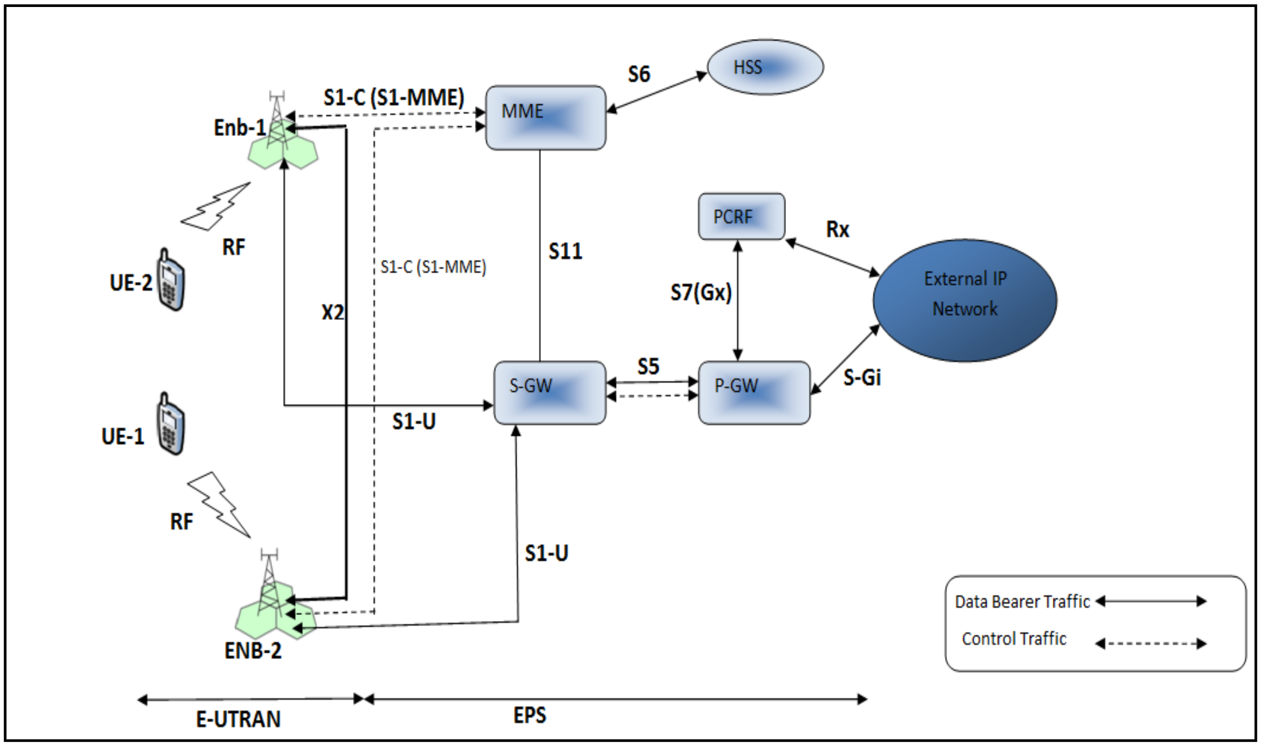


Figure 9– IP Traffic and interfaces of network

As shown in above figure, for user plane traffic the S1-U interface connects the eNodeB and the S-GW (for bearers' tunneling, inter-eNodeB handover), also for the control plane processes and signaling messages traffic the S1-C) connects the eNodeB with the MME. Link S-11 connects the MME to the S-GW, link S5 connects the S-GW to the P-GW and link S-6 connects the MME with the HSS. Link S7 connects PCRF with P-GW and S-Gi connects P-GW with the external network.

4.4. LTE Traffic Types:

In any communication network, we have two major Planes, User Planes used for transport User Traffic and Control Plane used for Signaling traffic. Although we have different kinds of user and control planes (C-planes) have to be transported across the LTE backhaul network.

From these we have most significant are the user traffic S1 user plane (U-plane), which has to be transported from eNodeB to S-GW and P-GW (or combined SP-GW), and the control traffic S1 C-plane between eNodeB and MME. As well we have the management traffic which includes all the data needed for FCAPS (fault, configuration, accounting, performance, security) support of the network elements and the X2 traffic which have user and control plane between neighboring eNodeBs has to be considered. The special role of the synchronization plane can be realized in various ways.

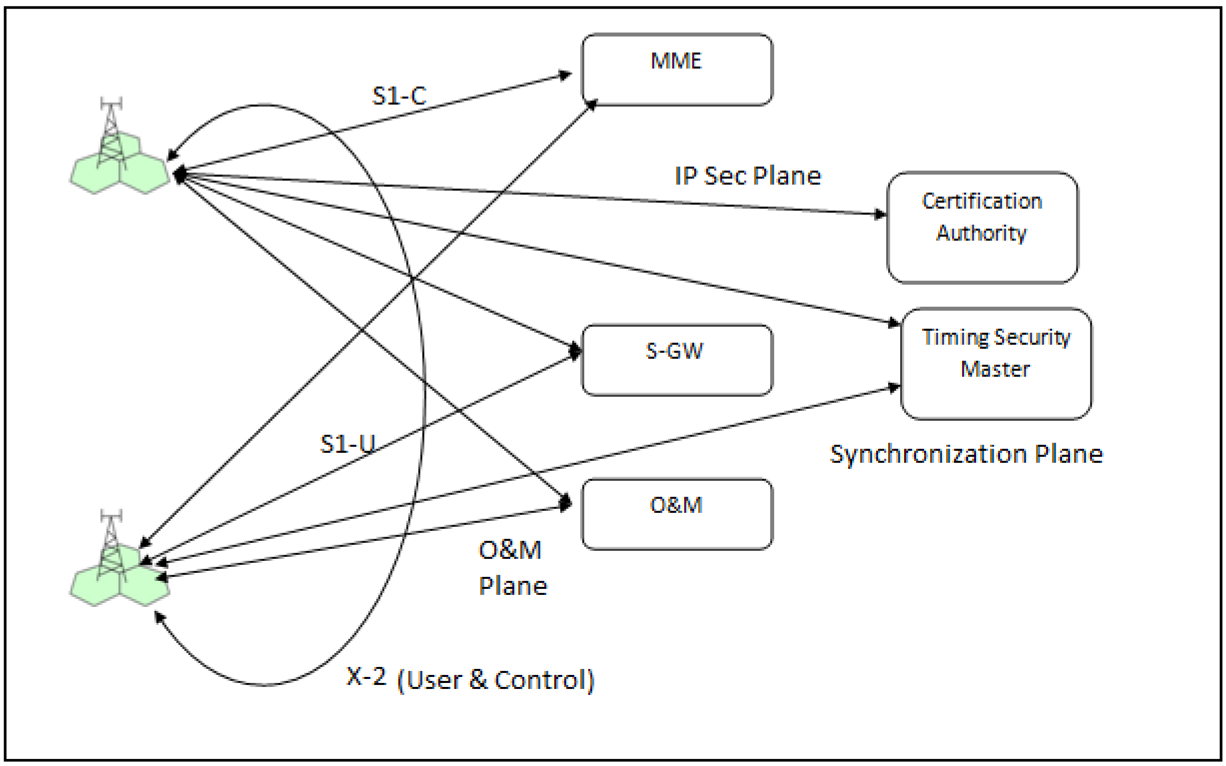


Figure 10 – Core Traffic Types

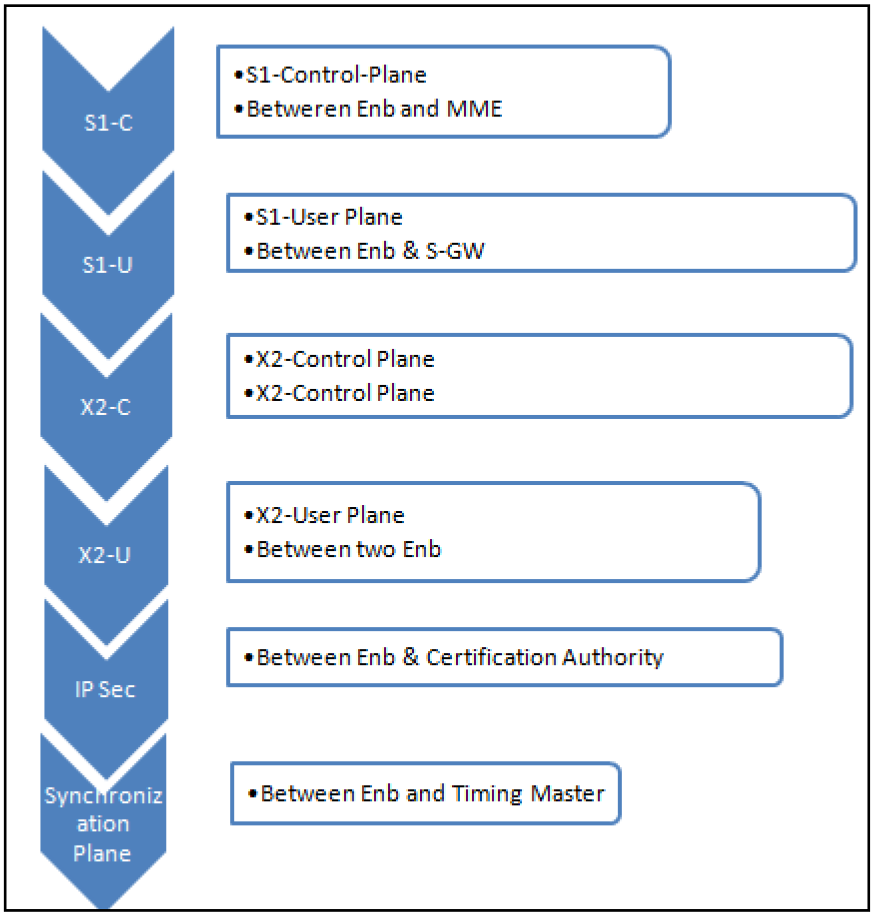


Figure 11 –Flow chart of the Traffic

4.4.1. **S1 Interface (S1-C and S1-U)**

This the main interface of LTE architecture that separate E-UTRAN and EPC. The S1 interface further divided into two parts:

C-plane (Control): S1-C is the interface between eNodeB and MME for signaling and control messages.
U-plane (User): S1-U is the interface between eNodeB and S-GW for User data traffic.

The protocols over radio and S1 interfaces are sub-divided into two parts and those interfaces that linked together give this E-RAB service:

- User plane protocols - These protocols implement the actual E-RAB service which carry the user data through the access stratum.

- Control plane protocols - These protocols used for controlling the E-RABs and the connection between the subscriber and the EPC network from different aspects (including requesting the service, controlling different transmission resources, inter or intra handover etc.).

4.4.2. S1 – MME (on Control-Plane) Traffic

The S1-MME plane carries the signaling traffic which is used to transfer control information between the eNodeB and MME using S1-AP protocol TS36.413 (3GPP, 2015b). Which is used for S1 bearer management, for the transport of network application server (NAS) signaling messages between the subscriber (UE) and MME and also provides mobility and security handling.

- Signaling of the radio network (layer) over S1 consists of the S1 Application Part (S1-AP over the Transport Layer is present on IP transport, having SCTP on top of IP.)
- This protocol provides technique to handle all events between the EPC and E-UTRAN.
- It also has a capability to send message transparently between EPC and subscriber without processing of E-UTRAN.

In the S-1 interface the S1-AP protocol is used for following purposes:

- It provides a set of general E-UTRAN procedures from the core network such as paging information as defined by the notice from SAP.
- It separates each subscriber on the protocol level for mobile specific signaling management
- As defined in the dedicated SAP it can transfer of transparent non-access signaling.
- It can ask for various types of E-RABs from the dedicated SAP.
- It also executes the mobility function.

4.4.3. S1-U (on U-P) Traffic:

The S1-U plane is used to transport user data (S1-User traffic) between the eNodeB and the S-GW. It uses a general packet radio service tunneling protocol user (GTP-U) for this task. Every S1 bearer consists of a couple of GTP-U tunnels in which one for the uplink [UL] and one for the downlink [DL]. The eNodeB in EUTRAN provide mapping between radio bearer

IDs (RBID) and GTP-U tunnel endpoints. The GTP-U protocol is defined in TS29.060 (3GPP, 2015a).

- This plane provides the non guaranteed delivery of user plane PDUs between the eNodeB and the S-GW.

- Similar to S1-Control plane transport network layer is built on IP transport and in this GTP-U is used on top of UDP/IP to carry the PDUs between the eNodeB and the Serving-GW.

GTP-tunneling protocols support the following tasks:

- It indicates the SAE Access Bearer in the target node from which packet belongs to.
- It also provides minimum packet losses due to mobility.
- It has a capability for Packet loss detection.
- It can provide Error handling mechanism.
- It also supports MBMS functions.

4.4.4. X2 Interface (X2-C and X2-U) Traffic:

Traffic generated from X2 Interface is known as X2- traffic. It is the interface between two eNodeBs. X2 interface subdivided into two parts:

- Control-plane (Control): X2-C is the C-plane interface between eNodeBs.
- User-plane (User): X2-U is the U-plane interface between eNodeBs

The X2 interface provides following facilities:

- It provides inter-connection of eNodeBs supplied by different vendors.
- It also provides continuation of services between eNodeBs of the E-UTRAN services offered via the S1 interface.

4.4.5. X2- Control Plane Traffic:

The X2-C-plane traffic contains signaling information between two neighboring eNodeBs using the X2-application protocol (X2-AP) TS36.423 (3GPP, 2015c). This signaling information is used for inter or intra handovers and inter-cell radio resource management (RRM) signaling. Connection of X2-AP is established when neighbor relations are formed, i.e. while integrating a new eNodeB neighbors are added by manual operation or by the operation and maintenance (O&M) intervention, or by automatic neighbor relations. Before X2-AP setup, another protocol Stream Control Transmission Protocol (SCTP) connection is initialized with the usual SCTP four-way handshake. X2 data streams (messages) and the radio network signaling are separated from the data transport resource and traffic handling.

4.4.6.X2-U: (on U-P) Traffic:

The X2-U-plane traffic contains the forwarding user data between the source eNodeB and target eNodeB during inter-eNodeB handovers. It is mainly used for the handovers. For this task a GTP-U tunnel is established across the X2 link between the source eNodeB and the target eNodeB.

- Protocols for the X2-User Plane interface is almost similar to the S1-UP protocol stack.
- Similar to S1-Control plane and S1-UP transport network layer is built on IP transport and in this GTP-U is used on top of UDP/IP to carry the PDUs between the eNodeB and the Serving-GW.

For X2 traffic the X2-User plane interface give a tunneling of end user packets between the two connecting eNodeBs. Similar to other data planes the tunneling protocols provide the following functions:

- It indicates the SAE Access Bearer in the target node from which packet belongs to.
- It also provide minimum packet losses due to mobility

4.4.7. Management Plane

In this Plane, it is responsible to interchange all the information which is shared between eNodeB and O&M system. As it is clear from its name, it carries the management plane traffic which have all the necessary data which is needed to manage and monitor the status of the all the network elements and equipments in the system. The performance data is used for the planning process. In the process of collecting data maximum data is collected from the inputs of all nodes to observe the performance and after that it provides suggestion for further planning if required. While collecting data a stable connection is required to avoid unnecessary site visits and to assure continuous counter values collections.

4.4.8. Synchronization Plane Traffic:

In any network Synchronization is important to make sure proper functionality of nodes, in our cases with the synchronization we are assuring proper functionality of eNodeBs. Different radio technologies have different sync needs. Freq Sync has to be distinguished from time and phase synchronization.

In the case of Frequency synchronization we use the physical method such as SDH (Synchronous digital hierarchy) or Precision Time Protocol based protocol which is used to transfer information about frequency over the core network. In the other way instead of using backhaul network we can use GNSS (global navigation satellite system) solutions.

4.4.9. Security Control Plane:

Secured communication is required in any network. To set up a secured communications with Internet Protocol Security architecture (IPSec) tunnels it need more control protocols. It uses the public key infrastructure (PKI) architecture system which is fetching data from a certification authority (CA). In this method all the Protocols which are used is all based on Certificate Management Protocol (CMP) or Simple Certificate Enrollment Protocol (SCEP).

4.4.10. Main Traffic Types in LTE Backhaul:

In User plane, traffic carries the user data which are encapsulated using GTP-U tunneling protocols. In User plane traffic we have S1-U and X2-U both uses GTP-U. All the Bearers for User-Plane at S1 and X2 Interfaces are controlled by the Control Plane which are signaling traffic. In control plane we have traffic for S1-C and X2-C interface which sends their signaling packets using S1-AP protocol. Both User plane and control plane are protected by IPsec protocols. As discussed above synchronization can wither do by backhaul with PTP or we can use Global satellite mean. After the synchronization these packets are delivered to the eNodeB.

To manage the eNodeB a remote connection is established and Network management traffic (O&M) used to monitor the nodes. This traffic is cryptographically protected. As per the need and logs requirement we used different protocols for the troubleshooting purpose.

Major Sources

- LTE Backhaul Planning and Optimization by Esa Markus Metsälä and Juha T.T. Salmelin
- Mobile Backhaul by Esa Markus Metsälä and Juha T.T. Salmelin
- A White Paper by the NGMN AllianceLTE Backhauling Deployment Scenarios
- http://welcometodannysblogger.blogspot.ca/2009/05/lte-interfaces-s1-and-x2-in-u-planec.html

5. Quality of Service and User's Traffic Priorities:

Quality of Service (QoS) in LTE plays a vital role in network planning & design when deploying technology for data & voice services. Quality of Service is used to provide the better user experience to some Premium subscribers who always want to have best user experience of Internet & Applications on LTE device. These premium subscribers want high bandwidth (high data rate) and better network experience by paying more money. But here not only users but some services itself need priority handling in LTE network such as voice call. There are some users which are using LTE services for some critical tasks as well (VOIP calls, 911 – Emergency, Hospital operations, Bank transactions and many more). LTE was designed to provide high data rate and applications demand with consistent connection and low cost of deployment. To achieve this goal QoS service is used. Advanced LTE uses QoS which defines priorities in time of congestion to certain services or customers.

In LTE network Quality of Service (QoS) is implemented between CPE and P-Gateway and which is applied to a set of bearers. Here bearer is basically a virtual concept which is a set of configuration to provide special treatment to certain traffic. Such as VOIP packets are always prioritized by network as compared to web browsing traffic.

Mechanism of QoS is very simple. To make sure that bearer traffic is properly handled in LTE networks, a procedure is required to categorize the different types of bearers into various classes, in which every class contains proper QoS parameters for that traffic type. This whole procedure is known as QCI (QoS Class Identifier).

Mechanism for QoS:

As discussed above QoS is a class-based, in which each bearer type is assigned with one QoS class identifier by the network. QCI is a scalar entity which is used eNodeB (access network) as a reference to node specific indicators that manage packet forwarding treatment. QCI is also mapped to network layer parameters for backhaul nodes by preconfigured QCI to DSCP mapping. There are 13 QCI values which are standardized by the 3GPP in term of traffic treatment. Packets scheduling priority, delay budget and error loss rate is associated with this QCI value. These things are already configured in nodes parameters so that they can assure services mapped to a particular QCI receive the same level of Quality of service in case of roaming or multi-vendors environment.

5.1. Bearers:

LTE Bearers are just a virtual concept in network. It categorizes how the subscriber traffic is treated when it flows crossways the network. Network has to treat some traffic in a particular way and treat others as normal traffic. In this some of the transported traffic should be provided guaranteed bit rate while other can face low transfer rate. In other words, it is a network parameter which defines traffic specific treatment. For example User A will always get downloading speed at least 512 Kbps on his LTE device on other hand in case of User B there is no guaranteed bit rate he will face very bad download speed at certain times.

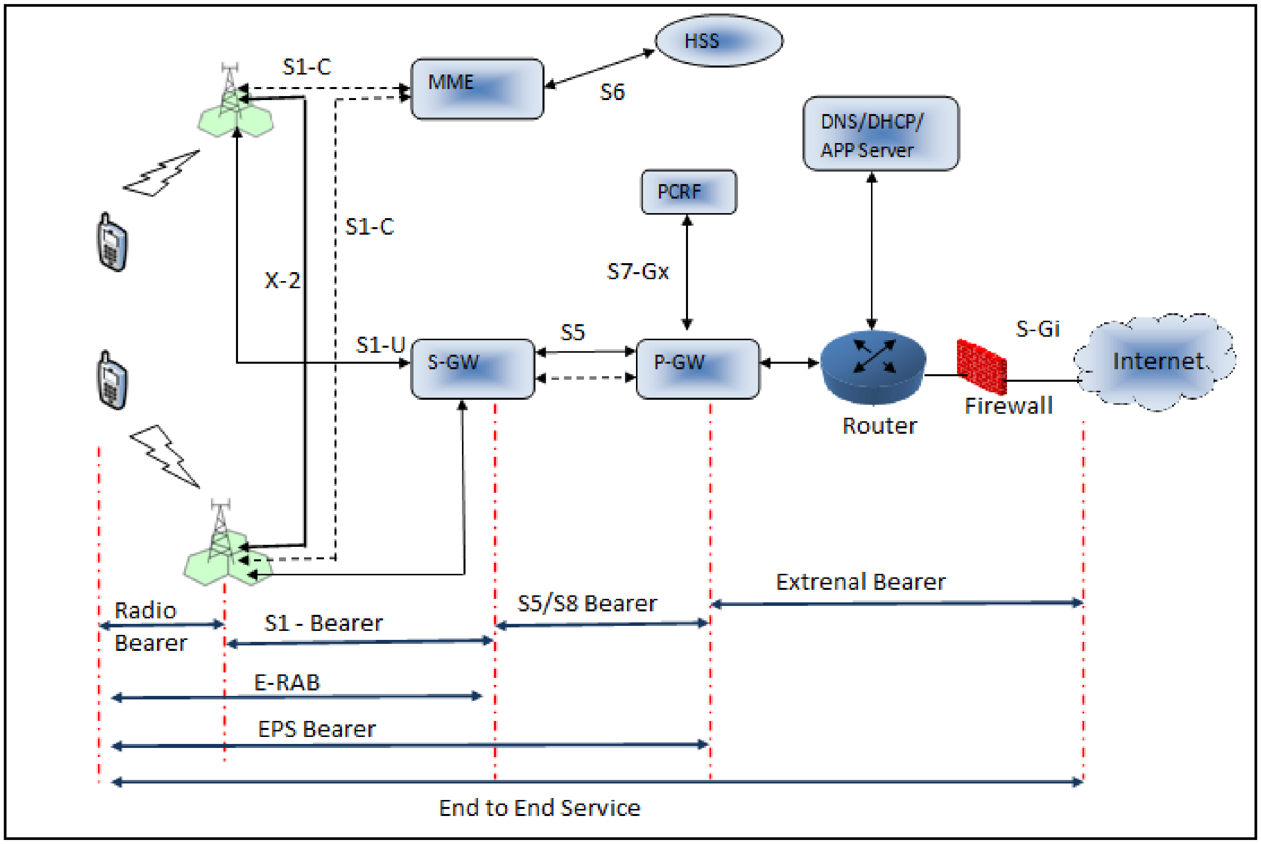


Figure 12: LTE Network Bearer Representation

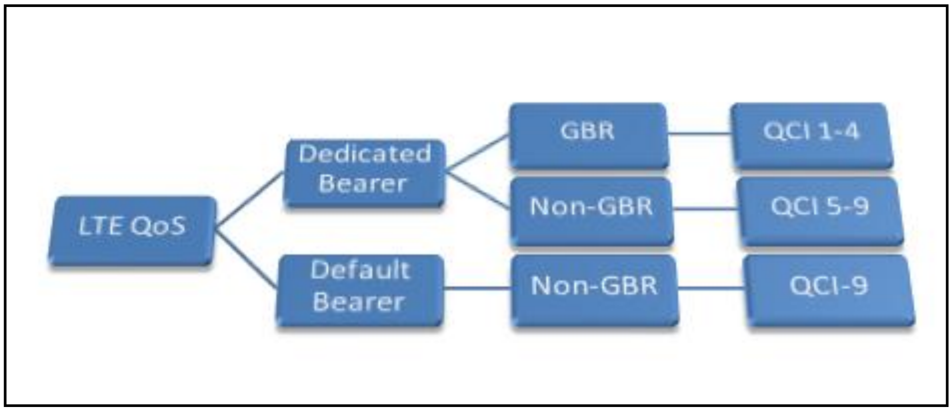


Figure 13: Bearer Types

5.1.1. Default Bearer:

Every time when LTE user latches with the network for the first time, it will automatically get assigned with default bearer which remains as long as User Equipment is connected with network. It is best effort service. Every default bearer comes along with an IP address. Any User device can have additional default bearers at same time. In that case every default bearer will have a different IP address. If look QCI table QCI value 5 to 9 (Non- GBR) can be assigned to these default bearer. It always has Non- Guaranteed Bit Rate.

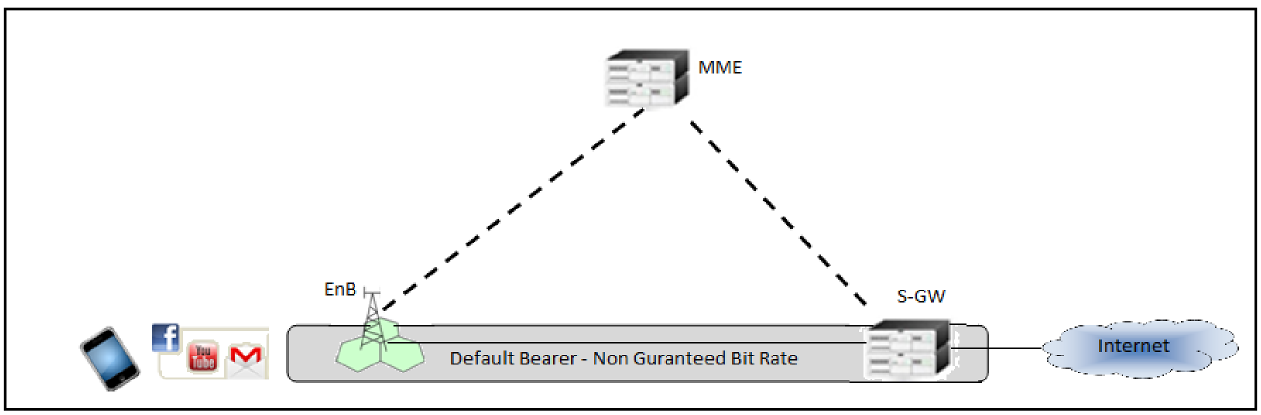


Figure 14:Default Bearer

5.1.2. Dedicated Bearer

Dedicated bearer is assigned on top of the default bearers. To make it simple, it provides a logical tunnel to one or more particular type of traffic such as VOIP or Video. Dedicated bearer does not need any separate IP address because it is linked with the already established Default bearer, if we need any other Dedicated bearer it will first chose Default bearer then it will linked with that bearer. Dedicated bearer is subdivided into two parts which GBR or non-GBR. Services like Voice over LTE we have to provide better user experience in that case dedicated bearer is handy. These bearer uses TFT (Traffic flow template) to give special treatment to traffics.

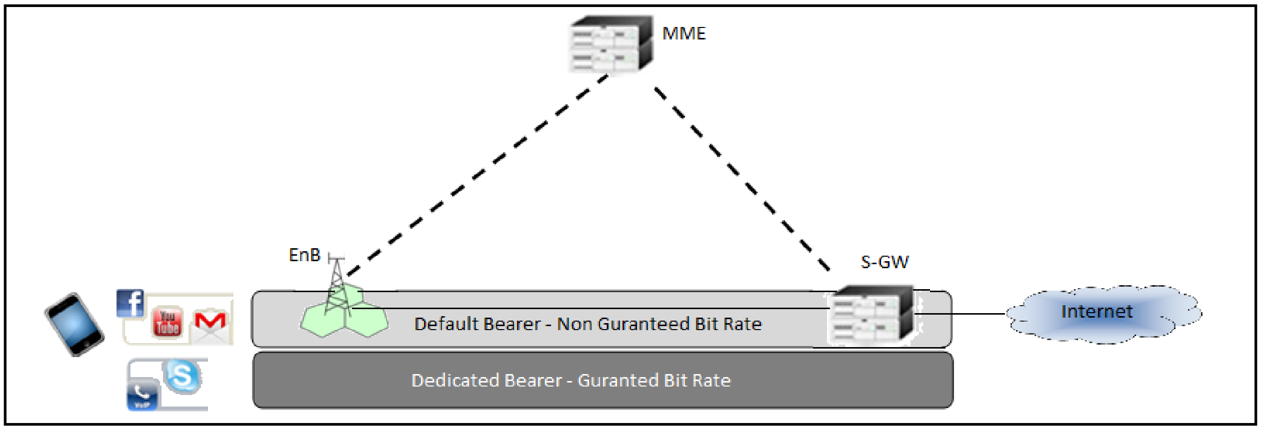


Figure 15: Dedicated Bearer

Case Study: When we are using Voice over LTE services at that time it has two default bearer and one dedicated bearer.

Default bearer 1 is used for signaling information (sip signaling) related to IMS network. Which is using QCI value - 5. Dedicated bearer is used for Voice over LTE and VoIP traffic. It has high priority and it uses QCI value-1 and this dedicated bearer is linked with the default bearer 1. On the other hand Default bearer 2 is used for all other Smartphone applications traffic such as video, chat, email, and browser etc, this traffic does not need that much priority.

Source- Quality of Service (QoS) in LTE technology [BEC Technologies] & https://en.wikipedia.org/wiki/Quality_of_service

As discussed above dedicated bearer is further subdivided into two parts which are Non-GBR and GBR types.

5.1.3. **Guaranteed Bit Rate (GBR)** – This is minimum guaranteed bit rate for each EPS bearer. GBRs are defined separately for uplink (UL) and downlink (DL). Value for a GBR QoS parameter is already determined and it is linked to the bearer.

When we assigned the value to particular bearer after that traffic will be assigned to that bearer, but at the time of congestion packet loss will not occur on the services that are using that GBR bearer. This process is started on the network end i.e. access base station at the time of activation or admission of control processes and this will be executed when bearer is established.

Guaranteed bit rate bearers are formed on basis of demand, because if we use this system as usual in systems it will block the network resources by reserving them by assigning priorities. In LTE network in case of insufficient resources it will implement service blocking rather than giving a downgrade services. They prefer user experience, in which network carriers block a service request instead of giving all services with degraded quality and performance. Relevant to this scenario priority services like Voice services will be remained up while data traffic or other low priority traffic will be discontinued in case of congestion or an emergency.

5.1.4. **Non-Guaranteed Bit Rate (Non-GBR)** – In this type there is no requirement of minimum guaranteed bit rate for each EPS bearer. Low priority services are assigned with this type. All internet services which are utilizing a non-GBR bearer is prone to heavy traffic related packet losses. It does not obstruct any network specific traffic or network resources. This type can established in the both default or dedicated bearer and it can stay connected for a long period of time. Any service should be GBR or NON-GBR is depends on operator’s traffic load versus dimensioned capacity. GBR and Non-GBR is assigned based on following QCI values:

QCI	Bearer Type	Priority	Packet Delay	Packet Error Loss	Example Services
1	GBR	2	100 ms	10^{-2}	Conversational Voice
2		4	150 ms	10^{-3}	Conversational Video
3		3	50 ms	10^{-3}	Online Gaming-Real Time Gaming
4		5	300 ms	10^{-6}	Video Streaming,Non-Conversational Video (Buffered Streaming)
65		0.7	75 ms	10^{-2}	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		2	100 ms	10^{-2}	Non-Mission-Critical user plane Push To Talk voice
5	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6		6	300 ms	10^{-6}	Video (Buffered Streaming) TCP-Based services e.g. www, email, chat, ftp, p2p
7		7	100 ms	10^{-3}	Voice, Video (Live Streaming), Interactive Gaming
8		8	300 ms	10^{-6}	Video (Buffered Streaming) TCP-Based services e.g., www, email, chat, ftp, p2p
9		9	300 ms	10^{-6}	Video (Buffered Streaming) TCP-Based services e.g. www, email, chat, ftp, p2p. Typically used as default bearer
69		0.5	60 ms	10^{-6}	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70		5.5	200 ms	10^{-6}	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)

Source-https://en.wikipedia.org/wiki/QoS_Class_Identifier

Figure 16 :QoS Classes and associated traffic

As per the 3GPP Standard TS23.203 description of some of the component of above table is given below:

- For Packet Delay Budget: Here PDB stands for packet delivery delay from User Equipment to P-GW with at level of 98%. To calculate the packet delay budget which implies to the radio interface will be calculated by subtracting delay of 20 ms[delay between the radio base station to PCRF] from given PDB. We have consider this as a average delay, if PCRF is close to base station then delay will be 10 ms if PCRF is far then delay will be around 50ms.

5.2. Quality of Service Requirement in LTE backhaul:

We know that most of the backhaul traffic have user plane data and have a lesser extent signaling traffic, X2 traffic, Operation and Maintenance (OAM) traffic and possibly traffic for Synchronization over IP (SoIP).

QoS requirements plays vital role while planning for backhaul bandwidth. If the amount of traffic transported over the LTE backhaul exceeds the available transport capacity for an extended period of time, then packets will be lost. In that case we are providing some priority and queues in the network, in case of Queues in the backhaul network nodes it have ability to absorb temporary bursts of excessive traffic, but it can create packet delays. Two most important QoS parameters for traffic over LTE backhaul are: Packet Loss and Packet Delay, which we already discussed above.

While designing network it is recommended to keep backhaul QoS requirement of LTE is more stringent than legacy networks. As per analysis some of the requirements are given below:

Type	Servicer Type	Latency	Jitter	Packet Error Loss Rate
S1 interface	Excellent	<= 5 ms	<= 2 ms	<= 0.0001%
	Recommended	<= 10 ms	<= 4 ms	<= 0.001%
	Satisfactory	<= 20 ms	<= 8 ms	<= 0.5%
X2 interface	Excellent	<= 10 ms	<= 4 ms	<= 0.0001%
	Recommended	<= 20 ms	<= 7 ms	<= 0.001%
	Satisfactory	<= 40 ms	<= 10 ms	<= 0.5%

Figure 17: Latency, Jitter and Error Loss for Core Traffic

Major Sources-

- Quality of Service (QoS) in LTE by BEC Technologies
- LTE BACKHAUL REQUIREMENTS: A REALITY CHECK By: Peter Croy, Sr. Network Architect, Aviat Networks
- http://www.simpletechpost.com/2013/01/quality-of-service-qos-in-lte.html

6. Traffic flows:

Traffic flow is considered as a major part for calculating and dimensioning the backhaul bandwidth, In brief we can say there is two kind of traffic flows Elastic traffic flow and Inelastic Traffic flow.

6.1. **Inelastic flows**: In this flow it requires a fixed data rate and bandwidth during the whole lifetime of the flows. To assure the Quality of Service requirements for this flow, the whole required bandwidth must be allocated on the link. Perfect example of the inelastic flows is voice.

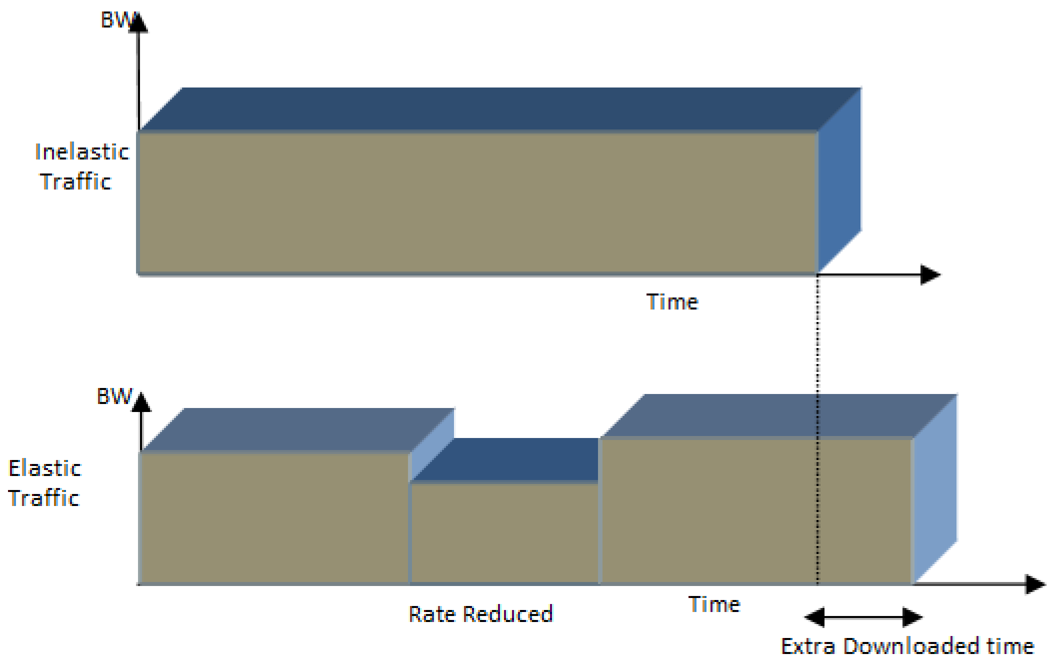


Figure 18: Traffic flows

6.2. **Elastic flows:** In this flow it can reduce their bandwidth and data rate demands if congestion occurs in network, but in that case length of the flows will then increase. Perfect example of a service with elastic flow is non guaranteed bit rate data transport.

6.3. QoS for Traffic Flows:

There are different ways to guarantee QoS requirements for these kinds of flows:

1. In case of inelastic flow CAC function is used. For this flows a Connection Admission Control (CAC) function issued to make a decision if we have enough bandwidth available in our resource to make sure that each new connection can get its required bandwidth. If any case it is not available, the connection will be rejected. Bearers of Inelastic flow will be referred to as Guaranteed Bit Rate (GBR).
2. In case of elastic flows, we use congestion detection mechanism and which is used in such a way by which sending rates for flows can be reduced at congestion. Bearers of Elastic will be referred to as non GBR.

7. Grade of Services (GoS)

In any telecommunication network, and specially in tele-traffic engineering, by two factor we can specify the quality of voice service: one is grade of service (GoS) and other is quality of service (QoS).

The Grade of Service (GoS) is a term which measures the availability of the transport services in the transport network. This parameter is always referenced with the busy hour time when the traffic intensity is the high.

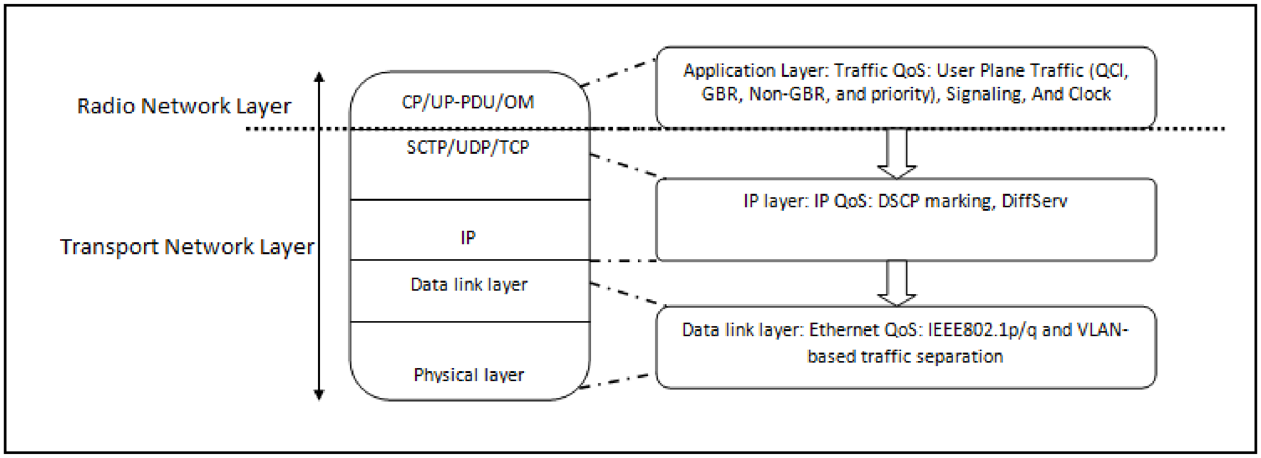
1. In case of non-GBR bearers the Grade of Services – Grade of Services is achieved by the average throughput of the flow which is the amount of data transferred divided by the total length of the flow.
2. In case of GBR bearers, the Grade of Services - Grade of Services is the blocking probability which is the probability that how much flow is rejected by the CAC function. As per the *“3GPP QoS-based scheduling framework for LTE”*

Major Sources-

- *3GPP QoS-based scheduling framework for LTE*
- *Ericsson Documents*

8. Enode-B Traffic Management and Congestion Control

Traffic differentiae are the first task and it follows the layers to describe traffic. As given in the below diagram EnodeB is basically divided into two parts which are Radio Network Layer and Transport Network Layer. In the Radio network layer, it is receiving user traffic and control traffic and it is categorize the traffic and assigning QCI values as per the needs and requirement. After that in the Transport network layer it is assigning Diffserv and DSCP marking in the IP layer because we know LTE backhaul is all IP based. In the Data link layer it again differentiates traffic based on Vlan-ID's.

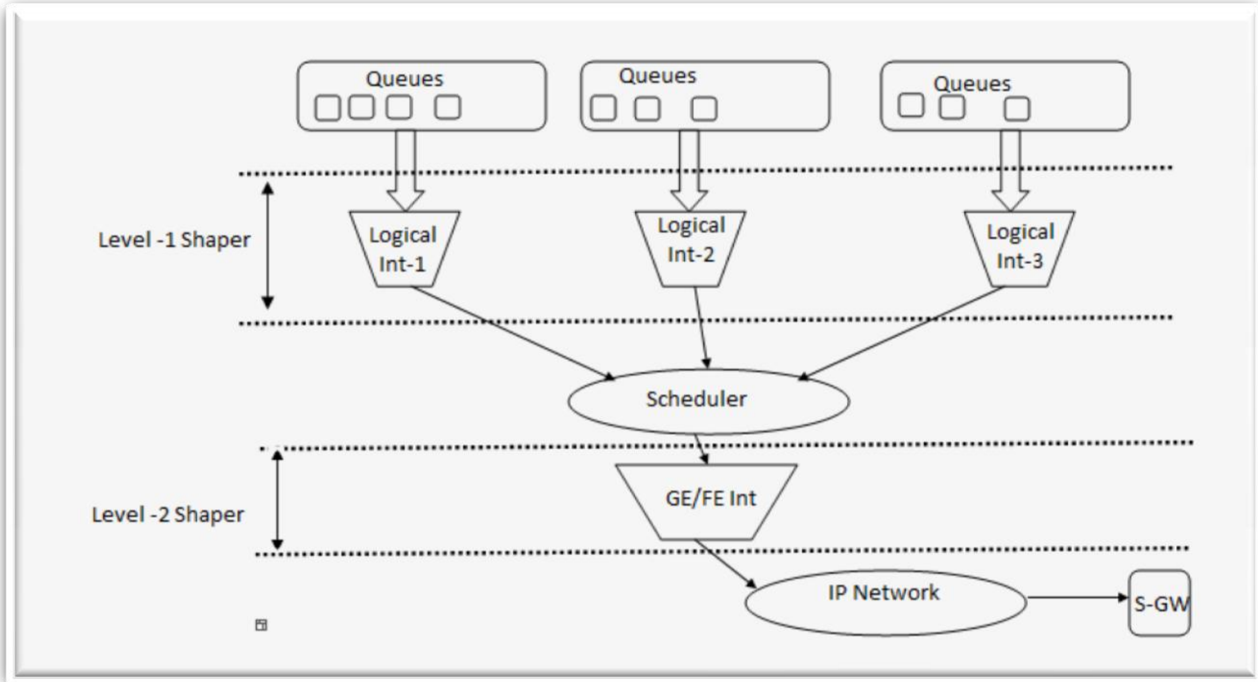


Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

Figure 19: Protocols in EnodeB

8.1. eNodeB Two Level Traffic Shaping

EnodeB has two level traffic shaping option Level 1 and Level 2. After assigning QCI values and PBH values queues are created inside the eNodeB and these are assigned to the logical Interface of eNodeB. IP interface board in eNodeB provides 6 priority queues for different traffic classes. To share the eNodeB resources operator can use different logical port identified by different IPs.

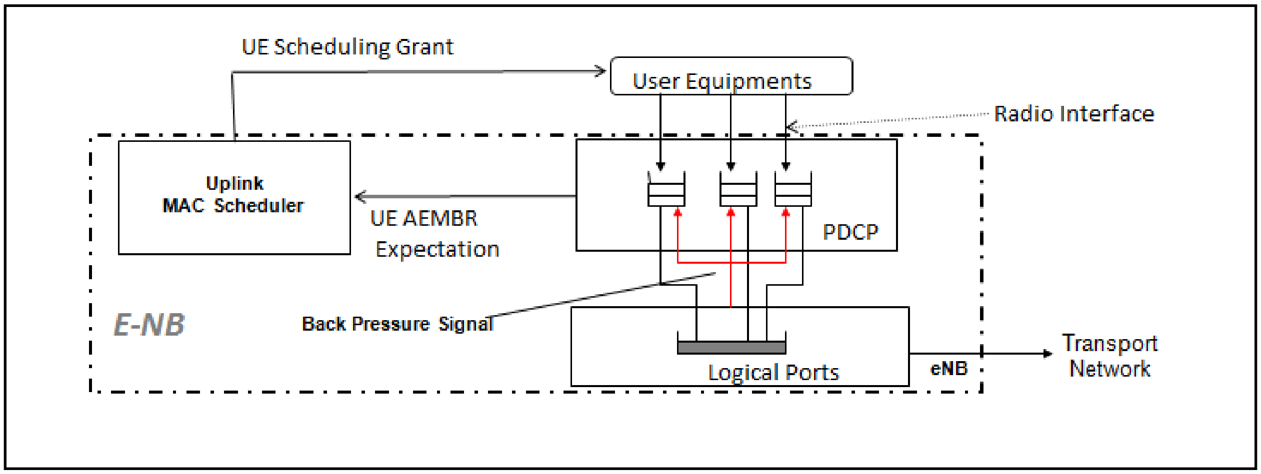


Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

Figure 20: Traffic Control Algorithm

8.2. Back Pressure Control in eNodeb in Case of Congestion:

When the backhaul bandwidth is limited due to congestion in that case logic port buffer and PDCP buffer would be in congestion and in that if UE is still sending new packets then the overflowing packet would be simply dropped. In the case of transport congestion, flow controller in eNodeB it inform MAC scheduler to decrease the Uplink packet rate to avoid wasting network resources and this can save UE's battery power. UP link Mac scheduler is responsible to control traffic in case of PDCP buffer congestion.



Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

Figure 21: Backpressure Control Algorithm

8.3. Distributing EnodeB Traffic in Backhaul:

As discussed above we have different traffic which goes to backhaul network such as User Plane, Control Plane, Management Plane and Synchronization Plane traffic. In the LTE backhaul network terminology we use IP based network. Most of the eNodeBs have a flexible way to bind eNodeB applications traffic (S1/X2 U-plane, S1/X2 C-plane, M-plane, Synch-plane) arbitrarily to either

- eNodeB interface physical address or
- eNodeB virtual (loopback) address

This type of flexibility allows eNodeB to be configured according to the transport services offered by the backhaul network, along with this we also need to provide traffic separation (e.g. Signaling plane from U/C-plane traffic) mechanism as needed.
IP address to eNodeB interface can be assigned by the following way:

- Either eNodeB have one or more physical interface(s)
-or eNodeB have more than one logical interface(s).

Here physical interface represents the physical Ethernet port on eNodeB , on the other hand logical interface can be provided by a VLAN termination. Each interfaces either physical or logical (VLANs) belong to different IP sub networks. Which have ability to differentiate the different traffic, means User plane traffic assigned to one interface and Control Plane traffic assigned to other interface or Vlan.

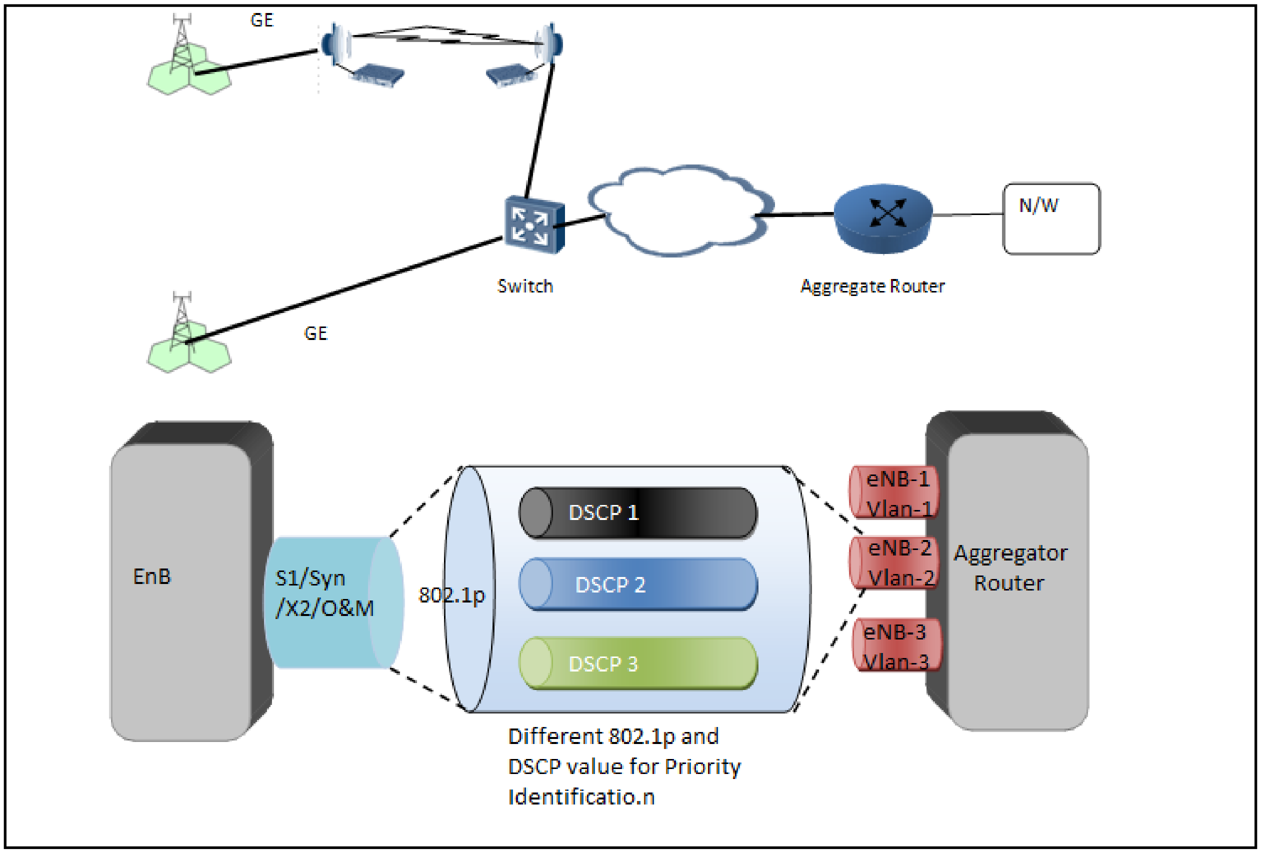
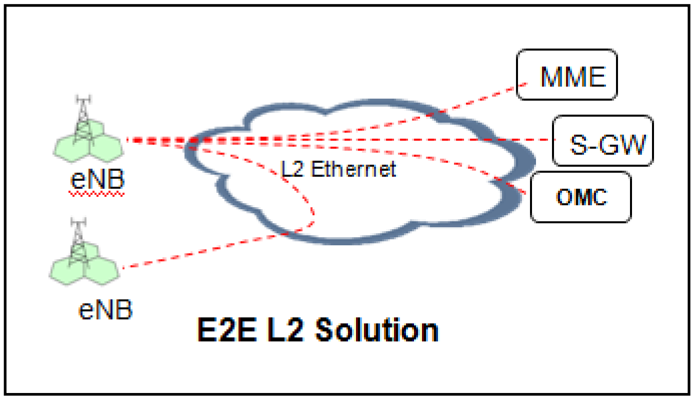


Figure 22: Traffic Alignment to Core network

As given in the above diagram each traffic is sub divided in logical way and it is transported to the backhaul network. Traffic such as S1-U,S1-C and X-2 are divided into logical interfaces. All of this traffic belongs to different sub network. These sub networks will belong to corresponding network entity. Such as S1-C traffic goes to MME and S1-U traffic goes to S-GW. There are many other ways to distribute traffic in the backhaul network. Furthermore, traffic of each eNodeB is identified at Aggregator router by some more Vlan addresses. If traffic comes from backend Aggregator router based on Vlan forwards the traffic to that particular eNodeB. By this way it is very easy to identify traffic in the backhaul. In most of the scenarios these configurations in the eNodeB are created by the internal routing procedures.

There are four types of solutions used to connect eNodeB to backhaul network.

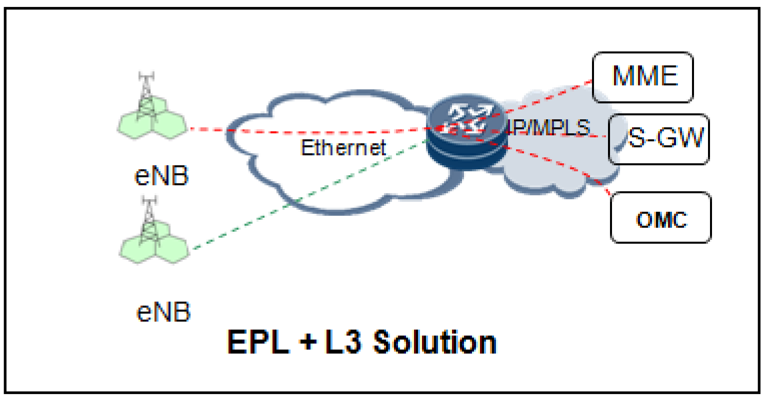
8.4. E2E – Layer 2 Solution



- In this scenario all network elements (eNodeBs, S-GW, MME, etc) will be in same broadcast domain. When one element will send packet other will receive this.
- To transport different traffic various L2 VPNs need to create.
- It is very Complex and not preferred in LTE network.

Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

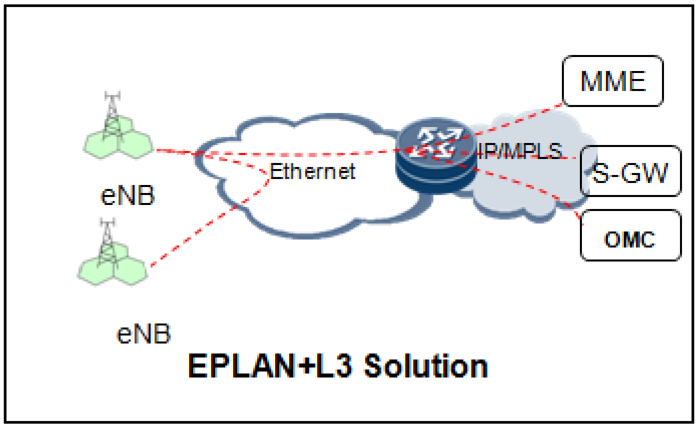
8.5. EPL + Layer 3 Solution



- Vlan is created for eNodeB. Vlan Tags and priorities are used to differentiate the traffic
- According to IP address traffic is mapped into L3VPN in MPLS The eNodeBs are configured in different subnet. MPLS priorities are used to identify traffic.
- All traffic is forwarded to IP/MPLS network including X2 Traffic.

Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

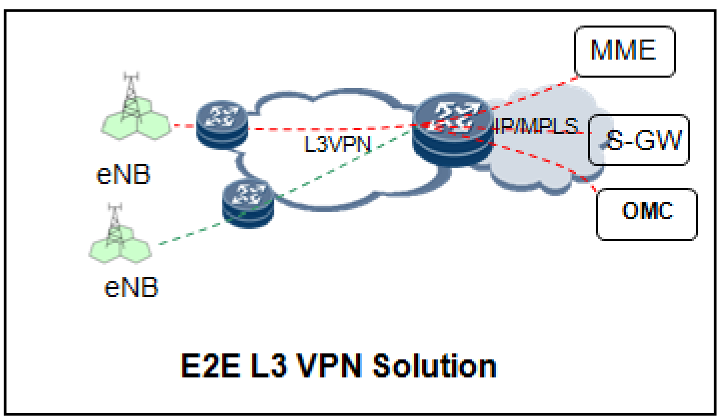
8.6. EPLAN + L3 Solution



- Some of the eNodeBs are configured with the vlans and they are using Vlan priorities to identify the traffic. Some will co configured with IP/MPLS and traffic will be identified by L3VPN priorities.
- If X2 traffic will be in the same network it will switched on the Ethernet network according to the VLAN priorities and MAC address. X2 traffic in the other subnet will go to IP/MPLS network.

Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

8.7. E2E - Layer 3 VPN Solution



- In this all network is on Layer 3 and different traffic is move to various VPNs. Traffic will be prioritize by the DSCP.
- Each eNodeB have different sub network and X2 traffic will go to aggregate routers.

Source – Huawei LTE Transport Solution Workshop (2010.10.06)v2

Major Source– Huawei LTE Transport Solution Workshop (2010.10.06)v2

9. Backhaul requirements for LTE Backhaul (SLAs) Summary:

This is the main part of designing any network. There are some of the requirement which are defined in LTE standards. Details of these requirements are given below:

LTE Performance Requirement	Description	Requirement
Peak data rate	Peak data rate by LTE system considered in ideal conditions, it means by not considering RF and antenna configuration parameter.	For 20 MHZ spectrum -DL:100 Mbps, UL: 50 Mbps.
Mobility support	Network should be able to provide mobility across whole network for both high and low speed and also maintain performance of services.	For low speed between 0 and 15 km/h and up to 500 km/h.
Signaling latency	Transition time between two state i.e from ideal to active state.	From ideal to active-100 ms
Transport (User plane) latency	Time take data IP packet to travel from source to destination.	should be less than 5 ms
Control plane capacity	Active user supported by system.	For 5 MHZ it should be more than 200 users.
Coverage	It is basically using and reusing sites and spectrum frequencies to support User Equipment.	Should be 5-100 km with slight degradation after 30 km
Spectrum flexibility	Ability to support spectrum of different size.	1.25, 2.5, 5, 10, 15,& 20MHz
Backhaul Capacity	Backhaul capacity need to high to support peak rates.	
QoS	It is essential to distribute limited resource between different traffic classes.	CoS separation (scheduling), shaping, policing
Availability	Availability requirement for backhaul network is derived from availability requirement of service.	It should not be less than 99.95%
Security	It is critical to prevent the user data from any attack as we don't have any RNC anymore and data is encrypted from eNodeB.	IP sec Tunnel.

10. LTE- ADVANCED AND THEIR IMPACT ON BACKHAUL:

As per 3GPP standards LTE-Advanced has been further develop LTE to complete the requirement of International Telecommunication Union for mobile communications. With LTE-A it enhance some of the features of LTE and some of the features are given below:

- Increased Peak Data rate
- Increased number of Simultaneous users
- High Spectral Efficiency
- Improved coverage at cell Edges.
- Greater Availability.

For LTE-A new technologies and features need to enable such as Carrier Aggregation , MIMO, Coordinated Multi-
Point, Inband Relaying , heterogeneous networks and many more. Description of some of the technology and their impact is explained below:

10.1. Carrier Aggregation:

This is technology is for Release 8 Compatible devices. It allows up to five component carriers being combined each having a bandwidth spectrum range from 1.4 MHz to 20 Mhz, which provides a maximum of 100 MHz aggregated bandwidth which result with the high spectrum efficiency and peak data rates as comparison to single allocation. Carrier Aggregation can imply to intra band which means carrier belong to same operating frequency band or inter-band which means devices working in different frequency bands. We know CA will improve single user throughput but its capability depends on number of users present in a cell. If the users number will be less then scheduling function over multiple carriers can provide maximum throughput gain, because available radio resources can be allocated to the users. If we have high number of users will provide less gain.

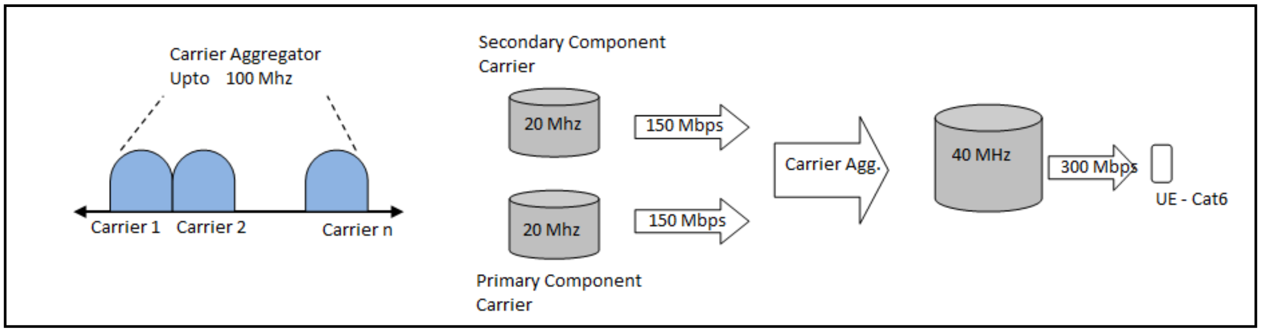


Figure 23: Carrier Aggregation

Carrier Aggregation Impacts on Backhaul Transport:

If we are improving average cell throughput by providing maximum gain to user with CA both in uplink and downlink, which actually means needing a higher backhaul bandwidth. But CA approach does not affect the synchronization and delay requirement of Backhaul.

10.2. Multiple Input Multiple Output (MIMO):

MIMO is technology which is used to enhance the peak data rate when two or more (2,4,8) parallel data streams are transmitted by sender and received by user with the help of multiple antennas by using the same resources in both frequency and time. It is clear peak data rates always depends on the number of antennas on the Transmitter and receiver side, bandwidth used and radio conditions. With the MIMO we can achieve 25% average Downlink cell throughput gain.

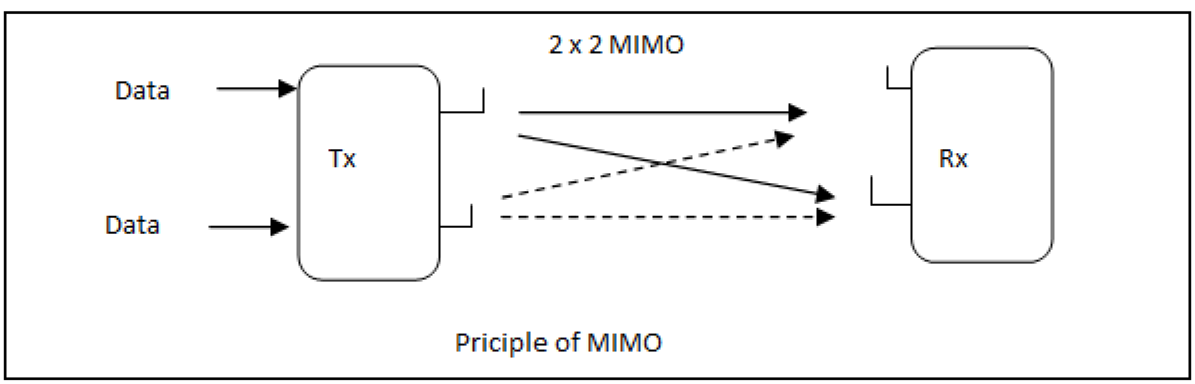


Figure 24: MIMO

Multiple Inputs Multiple Output Impacts on Backhaul Transport:

Its impact is same as CA. If we are improving average cell throughput (DL) and higher peak rates it will affect the required backhaul capacity.

10.3. Coordinated Multi‐Point (CoMP)

CoMP is used to improve the cell edge performance which means providing a higher throughput with fewer out of coverage users. In this technology numbers of Transmit points will provide coordinated transmission in DL and same happen in UL in which receive points provide coordinated reception.

Major Source

- LTE Backhaul Planning and Optimzation by Esa Markus Metsälä and Juha T.T. Salmelin
- Mobile Backhaul by Esa Markus Metsälä and Juha T.T. Salmelin

11. ENodeB Traffic Pattern and Throughput Calculations:

As we have large Bandwidth available in LTE, so we can achieve high cell peak rates in LTE. For example if take 20 MHz bandwidth we can achieve 150 Mbps Downlink [64 QAM with 2x2 MIMO] and 75 Mbps [64 QAM single stream]. But this can be possible if we consider ideal conditions like very close to the Base Station and without interference from other cells. Of the same importance is the cell average capacity. LTE provides higher spectral efficiency than other similar systems. Simulations show 1.75 and 0.75 b/s/Hz/cell.

11.1. Throughput Calculation:

In any mobile network User Equipments (UEs) are served by one of many cells in the coverage area, it means it can latch to multiple cells. LTE macro base station usually controls three cells, Micro and Pico Base station consist of one cell and some highly dense eNodeB controls up to six cells.

Based on radio conditions LTE transceivers use ‘adaptive modulation and coding’ to adjust their data rate. For calculating throughput spectral efficiency plays a vital role. Spectral efficiency or Spectrum efficiency defined by how much information rate that can be transmitted over a given bandwidth in a specific communication system. It is measured in bits per second per Hz (bits/s/Hz).Practically, it is a term which measure how efficiently a limited frequency spectrum is utilized by the physical layer protocol. When the US will be close to cell and there is no interference in that case more information can be carried without error for each unit of spectrum.

When the Radio conditions will be good and, 64 QAM modulation technique will be used and which can send 6 bits/s/Hz, but it requires high SINR. In poor signal conditions near the cell edge during busy hour having more interference, where QPSK will be used, it has ability of 2bits/s/Hz

In LTE RAN each cell in the network can reuse the entire bandwidth of the spectrum block owned by the operator. Most of the Bandwidth is shared amongst the served UEs to carry their data. So, if there will be more users, then share will be divided accordingly which mean smaller share will be assigned.

UE throughput is calculated by the product of spectral efficiency and assigned share of the Cell's spectrum.

UE Throughput (bits/s) = Spectral Efficiency (bits/s/Hz) x Assigned Share of Bandwidth (Hz)

Since the total bandwidth of cell cannot be changed, so cell throughput is product of total bandwidth and average spectral efficiency of UEs served by that cell.

Cell Throughput = Total Bandwidth x Avg. Spectral Efficiency of UEs.

Peak Downlink data rate can also be calculated by other way. Data rate depends upon the channel Bandwidth, as high as channel bandwidth more subcarrier can be used.
Let us consider we have a Channel Bandwidth of 5 MHz which have 300 subcarriers for delivering then data symbols. If we have good radio conditions with High SINR, it allows 64 QAM, which means that each subcarrier carries 6 bits. Total Bits on all subcarriers for a duration of a symbol is 300 x 6 = 1800bits. LTE symbol duration is 71.4 micro seconds. Each symbol contains 1800 bits then data rate will be

1800 / 71 µsec = 25.2Mbps

Channel Bandwidth	5 Mhz	10 Mhz	20 Mhz
Number of PRB's per Time Slot	25	50	100
Subcarriers per LTE sumbol	300	600	1200
Modulation Technique - bits per Subcarriers	64 QAM -6	64 QAM -6	64 QAM -6
Data Rate [Mbps]	25.2	50.4	100.8

Figure 25: Modulation Techniques for various bands

Cell throughput varies as we use different Channel Bandwidth based on traffic requirement and it will change the throughput for the cell.

11.2. Traffic Pattern during Busy and Quiet times:

In Busy hour of the day each cell of eNodeB in mobile network has a capability to serve many UEs at same time. All users are served are on the basis of resource allocation done by the MAC scheduler used in eNodeB. Resource allocation for user in LTE is done at data at Physical Resource block level. When we take example of 5 MHz Cell, in that we have 25 PRBs present for scheduling process. At that time Scheduler will decide how many PRBs are required for each user.

When we have multiple user, In that case UEs have different spectral efficiencies at that time, which depends upon the quality of radio link as discussed above. As there are many UEs, so it is unlikely that they will be having all good or bad spectral efficiency. Accordingly each UE's throughput varies which is based on the amount of spectrum resources assigned to them and quality of radio link. If we consider spectral efficiency of all UE's then eNodeB spectral efficiency will be positioned somewhere in the middle.

User Equipment		Spectral Efficiency
UE1	64 QAM - 6 bits per symbol	6
UE2	16 QAM - 4 bits per symbol	4
UE3	QPSK - 2 bits per symbol	2
UE4	64 QAM - 6 bits per symbol	6
UE5	QPSK - 2 bits per symbol	2
UE6	16 QAM - 4 bits per symbol	4
UE7	QPSK - 2 bits per symbol	2
UE8	16 QAM - 4 bits per symbol	4
UE9	64 QAM - 6 bits per symbol	6
UE10	16 QAM - 4 bits per symbol	4

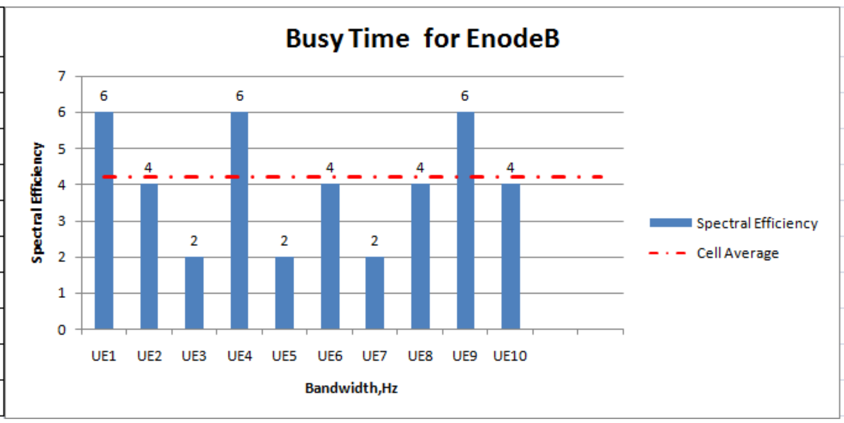


Figure 26: Busy Hour for 10 eNodeB

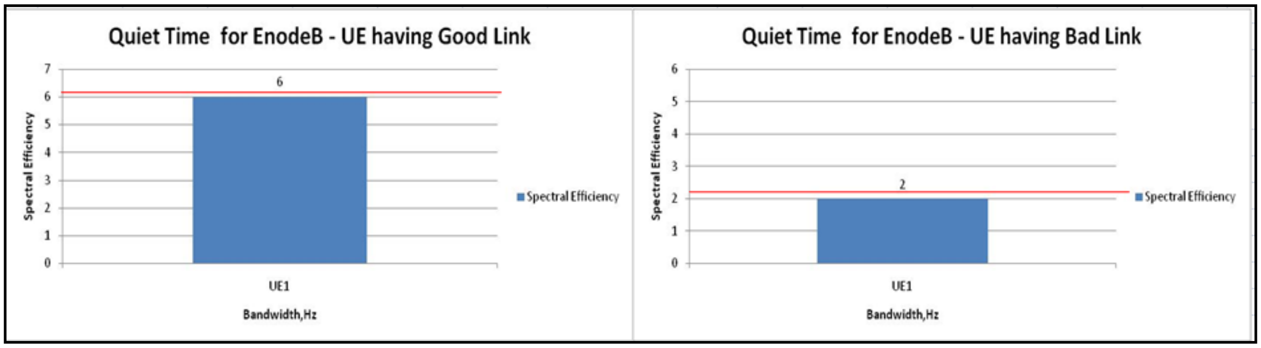


Figure 27: Quiet time EnodeBcompariosn

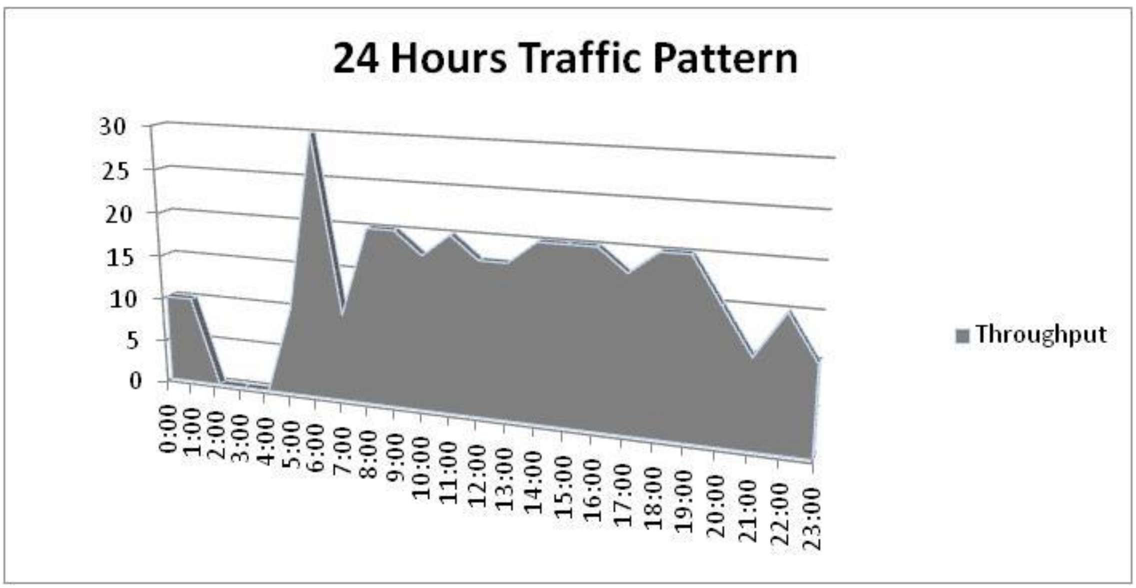


Figure 28: Traffic Pattern for eNodeB

In quiet times, there will be less UE, maybe one UE served by the cell. In that case cell spectrum efficiency will be entirely depend upon that UE and there will be variations for that. Because that UE can have either very good radio link or very poor radio link. When UE have a good radio link then it can utilize the entire cell's spectrum to itself in which highest UE and cell throughput occur. This will represent the peak data rate. When UE will be in bad radio link then accordingly cell throughput will be very less.

11.3. Impact on Backhaul in Peak Hours:

Traffic generated from each cells are aggregated at the ENodeB level then it flows towards the Backhaul Network. In Backhaul most of the traffic is User data traffic as comparison to signaling traffic. All the links in backhaul are pre calculated for their capacities, which means they have limited resources for each site. Each site has to share their resources among the associated cells. In the Peak Hours or Busy hours the traffic will be increased in the cell sites and these packed cells will move towards the Backhaul. But we have no flexible options in backhaul by which it can change dynamically their resources. If peak data will flow from the backhaul there will be always a case of congestion in the network.

Let us take an example, there is a water tank which is connected with many sources of water, from each source to water tank there are small pipes. These pipes connect sources of water with the water tank; here the size of water pipe is already calculated. There will be a big pipe of big source and small pipe of small source. If there will be no proper planning, than in case of high pressure from water source can burst the pipes, in our case burst is congestion.

To avoid congestion proper planning is required for the peak hours, in most of the cases network planner plan the network according to peak hours. We can also use topologies in the network, by which we can share the load between sites by traffic engineering concept. Backhaul capacity is directly related to traffic of any cell.

Major Source –
NGMN_Whitepaper_Guideline_for_LTE_Backhaul_Traffic_Estimation

12. Cell Types:

There are different Cell types in LTE network and which cells are used it depends upon the traffic intensity and operators requirement. There are four types Pico, Femto, Micro and Macro. Pico and Femto cells are known as small cells. Small cells are those radio nodes which operate on low power and having a diameter range of few meters. On the other hand Micro and Pico cells have range up to 20 miles. Brief description of these cells is given below:

Femto Cells: These are the smallest cell which is basically used to improve coverage within a small area such as home office or a deadzone in any building. These cells can bear only small number of users as compare to other cells and on these cells only few calls at same time can took place.

Pico Cells: These are bigger than femto cell and capable to offer more capacities and coverage area range from 100 to 250 yards. These are deployed in indoors area to improve poor coverage, which is usually used inside the buildings or retail office.

Micro Cells: They have a better coverage area than others, these cells are either used in those areas having less traffic intensity with a smaller frequency spectrum or it is used as a temporary purpose in those areas where we have traffic for a limited period of time such as any sporting event.

Macro Cells: These are normal cells and having a coverage area up to 20 miles, mostly some of the smaller cells are connected with these cells. Again spectrum is allocated according to traffic requirement, such as in Urban area we will use 20 MHz and in Rural we will use 10 or 5 MHz.

12.1. Backhaul for Small Cells:

There are many cells as discussed above and planning for all of these cells is almost same. But there are two planning problems which need to be separated which are physical and logical planning. After the physical connectivity then we need to implement the logical part. All base stations are planned according to certain address scheme and routing/switching technologies. Any small change can impact the whole network. For these small cells physical part can easily resolved because most of the sites are connected with fiber or copper to big sites. Small sites are cheaper than macro cell and revenue for small cell is also less than others, so we cannot implement backhaul planning approaches to small cell which we are using for Macro cells. So additional approaches are required for this.

Major Source -
LTE Backhaul Planning and Optimzation by Esa Markus Metsälä and Juha T.T. Salmelin

13. IP Backhaul Traffic Analysis and Capacity Calculation

Backhaul traffic is the traffic generated by eNodeB which goes back to the core part. It contains eNodeB user traffic and control traffic. For each eNodeB backhaul traffic is the combination of all cells served by that eNodeB.
LTE technology has new RAN and backhaul network domain as compare to its legacy technologies. LTE standards defining bodies such as 3GPP extrapolate requirements for the core network considering the ideal RAN interface capabilities. With this thing it leads to embellished results and it is inadequate way
to plan backhaul networks.

Backhaul traffic is mainly consist of user data, for the calculation we will consider the user data and after that we can adds other components such as overheads and signaling.

For dimensioning we will follow basic tasks which are given below:

- Calculation of Last-mile bandwidth dimensioning for one eNodeB.
- Calculation of Aggregate bandwidth dimensioning of n eNodeB.

13.1. LTE Backhaul Capacity Requirement and Calculations:

Dimensioning of the transport in mobile network is very essential to make sure that the expected quality is achieved for end-users (UE) without unnecessary transmission costs for the operator. Tasks in dimensioning the transport network follow the radio network dimensioning activity as well as the capacity licensing activity, so the activities are interdependent.

In the above topics we have discussed how to calculate the theoretical cell level throughput in ideal conditions. Every cell uses assigned bandwidth channel for transmit and receive the user traffic. 3GPP defined 1.5,3,5,10 and 20 MHz channels and Traffic size is directly proportional to the bandwidth channel. We have spectral efficiencies according to radio conditions and as per defined standards our objective for downlink is [5-6 bits/Hz using 64 QAM modulation] and for uplink is [2.5-3 bits/Hz using QPSK modulation] for radio channel. For the calculation of peak rate in radio part, we have to check how an LTE eNodeB maximizes the available channel bandwidth. The main parameter is SINR for idle condition it should be high and it will decide signal quality received by the user equipment. When UE will be near to base station the signal quality will be good and peak rate will also be high at that time.

LTE have three modulation techniques 64QAM, 16QAM and QPSK and based on this spectral efficiency will be decided as discussed above. Peak rate is only achieved by the 64QAM and this is only possible when UE will be very close to cell centre under idle conditions and at that time peak rate will be 100%. When we have 16QAM modulation technique it will give the 66% of peak rate and with the QPSK we have 33% of the peak rate.

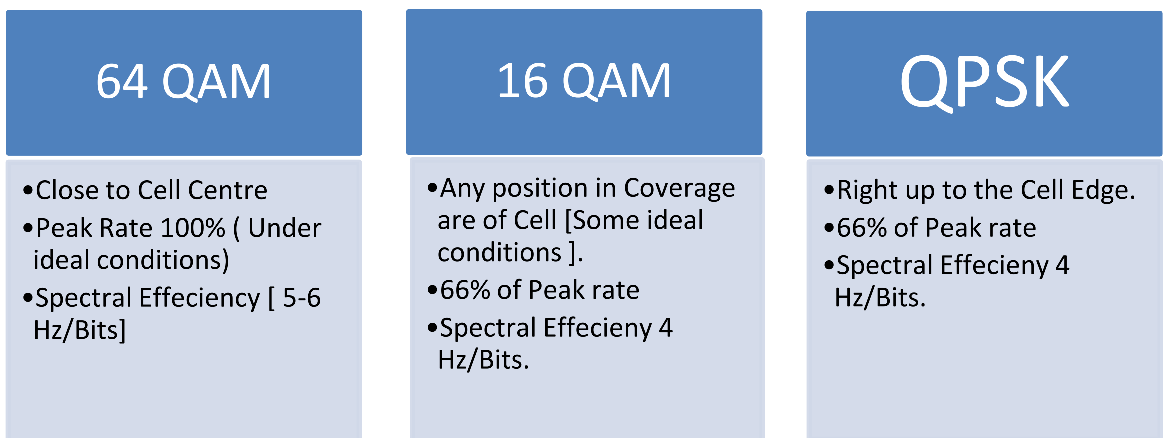


Figure 29: Modulation Techniques

When we considering the LTE peak rate we are considering the entire channel bandwidth used by single LTE user and it include the overhead of layer 1 and layer 2 (Error correction, MAC control etc.).
In actual scenario multiple users will share the radio resources of each cell, which will result the lower peak rate as well as average throughput per user.

Let us take a example of 10 MHz channel bandwidth, if we consider the ideal condition and its spectral efficiency is 5bits/Hz then its theoretical peak rate will be 50Mbps.
For 16 QAM throughput will be 66% of peak data rate and after removing layer 1 and layer 2 header peak data rate will be as follow

= Theoretical Peak data rate x 66% (16 QAM) x 85% (removing L1 and L2 header)

= 50 x 0.66 x 0.85 = 28.05Mbps

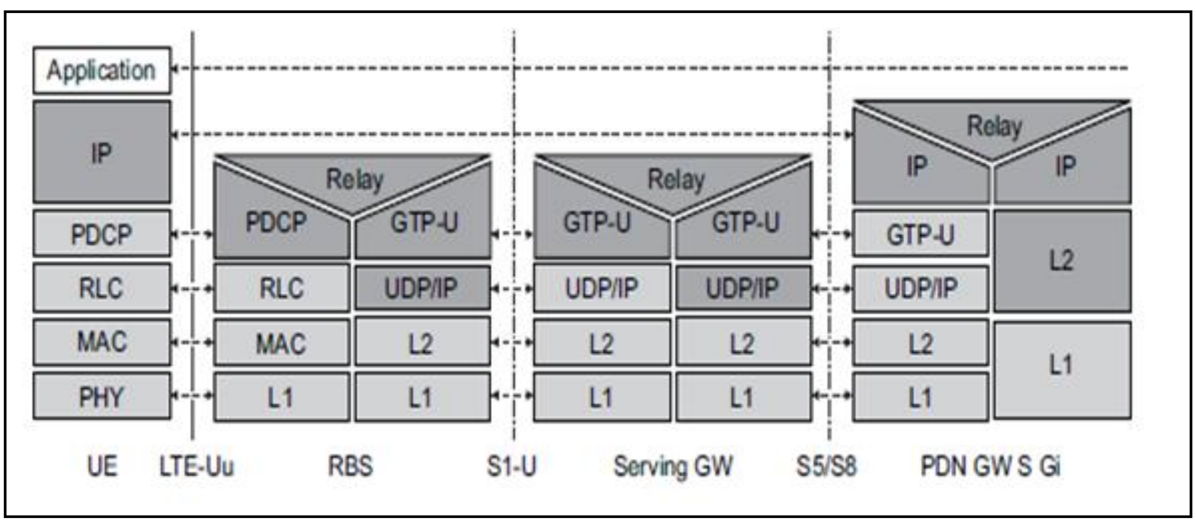
Using above formula calculation for each modulation is given below.

Channel Bandwidth	64 QAM - Very Close [Mbps]	16 QAM - Medium [Mbps]	QPSK - FAR from cell site [Mbps]
5 MHz	25.5	16.83	8.41
10 MHz	51	33.66	16.83
20 MHz	102	67.32	33.66

13.2. Transport Overhead Calculation:

As already discussed in above topics we have different interfaces which have their own functionality which helps out to flow traffic. Backhaul network has two major interface S1 and X2, S1 is further subdivided into logical IP interface with User data plane (S1-U) and control plane (S1-C) traffic which connects with MME.

S1 – User Plane protocol Stack



Source- http://www.cse.unt.edu/~rdantu/FALL_2013_WIRELESS_NETWORKS/LTE_Alcatel_White_Paper.pdf

Figure 30: S1-U Protocol Stack

- Transport overhead must be considered when dimensioning the mobile backhaul.
- The relatively small bandwidth required for OAM data leads to the assumption that the bandwidth required for the Mul interface is excluded from the calculations.

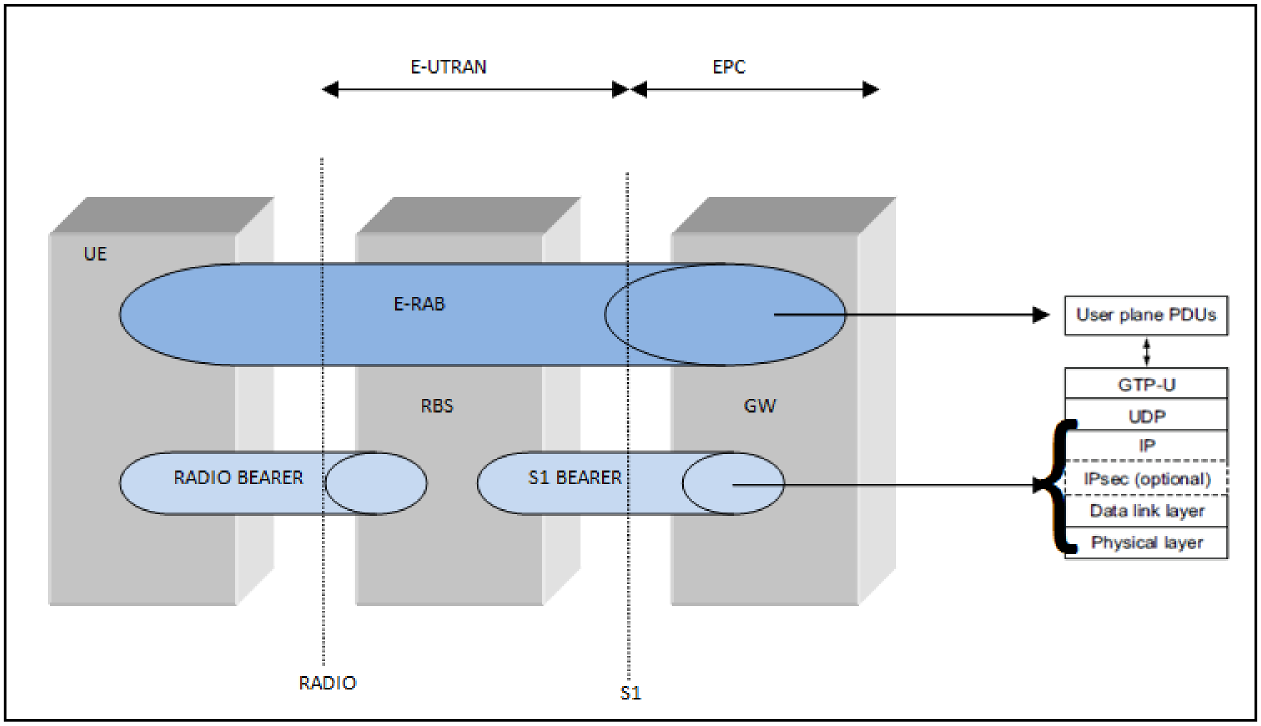


Figure 31: Bearer association with Protocols

13.3. For IPv4 User Plane Data:

Protocol Overhead	Octets with Ipsec without,preamble,start of fram delimiter and inter frame gap	Octets with Ipsec with preamble,start of fram delimiter and inter frame gap	Octets without Ipsec without,preamble,start of fram delimiter and inter frame gap	Octets without Ipsec with preamble,start of fram delimiter and inter frame gap
GTP-U Header	8	8	8	8
UDP Header	8	8	8	8
IP Header	20	20	20	20
Ipsec Header	73	73	-	-
Total GTP- U/UDP/IP Overhead	109	109	36	36
Ethernet Overhead (IEEE 802.1Q)	22	22	22	22
Preamble+interframe	0	20	0	20
Total Overhead	131	151	58	78
Average Payload Size (Uplink and Downlink)	700	700	700	700
Protocol Overhead factor(Average Pauload Size + Total Overhead / Average Payload size)	1.19	1.22	1.08	1.11
Transmission Efficiency	0.95	0.95	0.95	0.95
Total transport overhead factor	1.25	1.28	1.14	1.17

Source- http://www.cse.unt.edu/~rdantu/FALL_2013_WIRELESS_NETWORKS/LTE_Alcatel_White_Paper.pdf

We will calculate the Payload Peak Throughput per cell and Peak Throughput per cell (without overhead) based on the air interface. For the calculation we have to consider following parameters for the calculation.

- MIMO – Whether it support MIMO support or not
- Num of sub-carriers, - As per LTE standard number of sub carriers are 12
- Num of sub-frame symbols, - As per LTE standard number of sub frame symbol is 14
- Resource Block, - Number of resource block, which change with the spectrum and it is defined in below table.
- Modulation mode: - For peak rate 16 QAM for UL- 4 and for Down link 64 QAM – 6
- Code rate - As per standard for UL - 3/4 and for DL- 5/6
- TTL -1000ms
- Overhead of air interface – It is overhead calculation for L1 and L2 and for UL – and for DL it is 0.85.

For the calculation we will use following formula.

Payload Peak Throughput Per Cell (with Overhead)＝MIMO X Over-head X sub-carriers X 1 sub-frame symbols X Resource Block X Spectral-eff (Mod) X code rate X 1ms sub-frame

Peak Throughput per cell (Mbps) ＝MIMO X sub-carriers X 1 sub-frame symbols X Resource Block X Spectral-eff (Mod) X code rate X 1ms sub-frame

Bandwidth (MHz)	UL/DL	MIMO	Number of Resource Block	Spectral Efficiency based on Modulation.	Code Rate	Peak Throughput per cell (Mbps)	Payload Peak Throughput Per Cell (Mbps)
20	Downlink	2	100	6	0.83	167.33	142.23
	Uplink	1		4	0.75	50.40	41.83
10	Downlink	2	50	6	0.83	83.66	71.11
	Uplink	1		4	0.75	25.20	20.92
5	Downlink	2	25	6	0.83	41.83	35.56
	Uplink	1		4	0.75	12.60	10.46
3	Downlink	2	15	6	0.83	25.10	21.33
	Uplink	1		4	0.75	7.56	6.27
1.5	Downlink	2	6	6	0.83	10.04	8.53
	Uplink	1		4	0.75	3.02	2.51

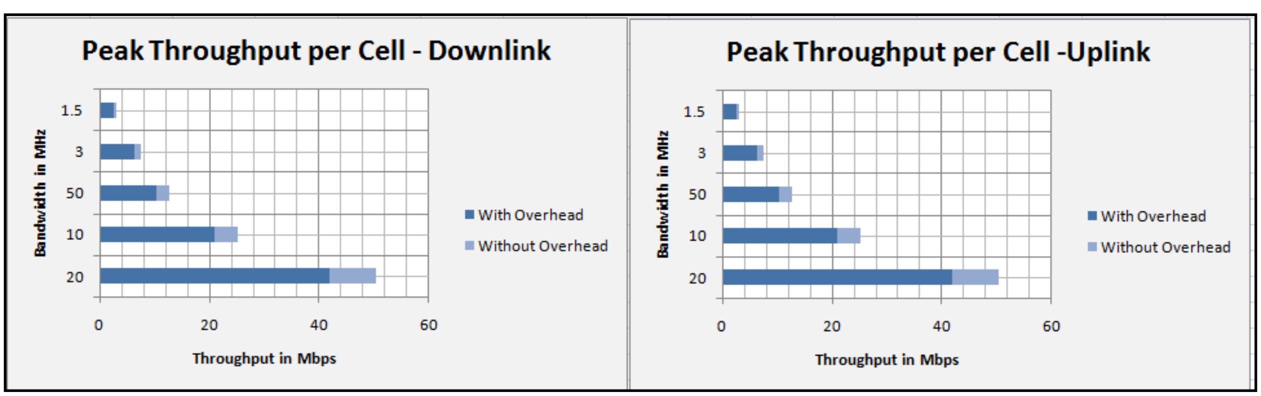


Figure 32: Graphical representation of Peak Throughput

13.4. Engineering Estimation of bandwidth calculation for EnodeB :

The value calculated for Cell peak is theoretical value, as we know in actual scenario this value is always less and we will calculate average value for each cell based on actual peak value which we also called as Engineering estimation. For engineering Estimation we will multiply above value with the experience factor which is based on UMTS engineering experience [As per LTE transport workshop].
We also know that as per the traffic density we implement different sites with different bandwidth without wasting any resources. In each bandwidth we even cannot implement MIMO, so for different sites calculation is given below.

These traffic calculations are derived from the following formula:

Engineering Peak Throughput per eNodeB = Payload Peak Throughput per cell x 0.6 (experience factor) x 3

Engineering Average Throughput per eNodeB = Engineering Peak Throughput / 0.33 (experience factor) x3

Description	UL/DL	Payload Peak Throughput Per Cell (Mbps)	Payload Peak Throughput Per EnodeB (Mbps)	Engineering Peak Throughput per EnodeB (Mbps)	Engineering Average Throughput per EnodeB (Mbps)
20 Mhz,3 Sectors, 2x2 MIMO	Downlink	142.23	426.69	281.61	93.87
	Uplink	41.83	125.50	82.83	27.61
10 Mhz,3 Sectors,No MIMO	Downlink	35.56	106.67	70.40	23.47
	Uplink	20.92	62.75	41.41	13.80
5 Mhz,3 Sectors,No MIMO	Downlink	17.78	53.34	35.20	11.73
	Uplink	10.46	31.37	20.71	6.90
3 Mhz,3 Sectors,No MIMO	Downlink	10.67	32.00	21.12	7.04
	Uplink	6.27	18.82	12.42	4.14
1.5 Mhz,3 Sectors,No MIMO	Downlink	4.27	12.80	8.45	2.82
	Uplink	2.51	7.53	4.97	1.66

But as discussed above different sites will be considered as per different traffic density, for different types of cells calculation is given below.

Site Type as per Traffic Density	Description	UL/DL	Payload Peak Throughput Per Cell (Mbps)	Payload Peak Throughput Per EnodeB (Mbps)	Engineering Peak Throughput per EnodeB (Mbps)	Engineering Average Throughput per EnodeB (Mbps)
Macro	20 Mhz,3 Sectors,2 x 2 MIMO in DL	Downlink	142.23	426.69	281.61	93.87
		Uplink	41.83	125.50	82.83	27.61
Sub-Urban Macro	10 Mhz,3 Sectors,No MIMO	Downlink	35.56	106.67	70.40	23.47
		Uplink	20.92	62.75	41.41	13.80
Rural Macro	5 Mhz,3 Sectors,No MIMO	Downlink	17.78	53.34	35.20	11.73
		Uplink	10.46	31.37	20.71	6.90
In Buliding Pico 1-cell	20 Mhz,1 Sectors,2 x 2 MIMO in DL	Downlink	142.23	142.23	93.87	31.29
		Uplink	41.83	41.83	27.61	9.20
In Bulilding Femto -1Cell	20 Mhz,1 Sectors,2 x 2 MIMO in DL	Downlink	142.23	142.23	93.87	31.29
		Uplink	41.83	41.83	27.61	9.20

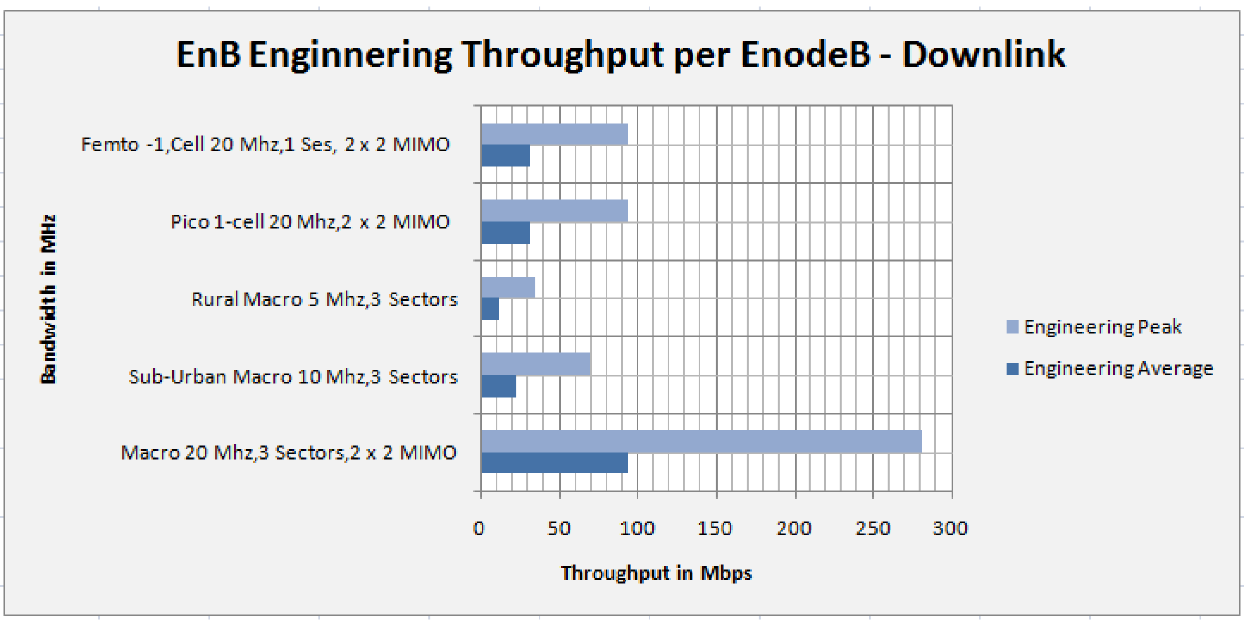


Figure 33: Graphical representation of Engineering Throughput for various Cells.

13.5. Actual Throughput for Backhaul including Transport Overhead:

This is the input which we got from air interface including all User plane data with its header.
We can get the average and peak throughput of the backhaul bandwidth as given in the above tables. When ENodeB got the upstream from subscriber, it will remove the overhead of air interface such as MAC overhead on air interface and it will replace it with user IP packet. ENodeB will encapsulate IP packet with GTP protocol stack, and it will send further to Backhaul.

So for this we have to consider the backhaul overhead factor which is 1.48 *[“As per the LTE Transport Solution Workshop (2010.10.06)v2 “*] including all types of packets in backhaul with their distribution levels. So for the calculation the Backhaul bandwidth for user data we will multiply the peak and average bandwidth with factor 1.48. If we take reference of [“*NGMN Whitepaper LTE Backhauling Deployment Scenario”*] the transport overhead factor will be 1.39 [X2 Overhead -4% Transport Overhead – 10% and IPSec Overhead - 25%]. Complete calculation is given below.

Backhaul Peak Throughput = Engg. Peak Throughput on air X 1.48 [Weighing factor for various packets]

Backhaul Average Throughput = Engg. Avg Throughput on air X 1.48 [Weighing factor for various packets]

Site Type as per Traffic Density	Description	UL/DL	Engineering Peak Throughput per EnodeB (Mbps)	Engineering Average Throughput per EnodeB (Mbps)	Backhaul Peak throughput (Mbps)	Backhaul Average Throughput (Mbps)
Macro	20 Mhz,3 Sectors,2 x 2 MIMO in DL	Downlink	281.61	93.87	**416.79**	**138.93**
		Uplink	82.83	27.61	**122.58**	**40.86**
Sub-Urban Macro	10 Mhz,3 Sectors,No MIMO	Downlink	70.40	23.47	**104.20**	**34.73**
		Uplink	41.41	13.80	**61.29**	**20.43**
Rural Macro	5 Mhz,3 Sectors,No MIMO	Downlink	35.20	11.73	**52.10**	**17.37**
		Uplink	20.71	6.90	**30.65**	**10.22**
In Buliding Pico 1-cell	20 Mhz,1 Sectors,2 x 2 MIMO in DL	Downlink	93.87	31.29	**138.93**	**46.31**
		Uplink	27.61	9.20	**40.86**	**13.62**
In Bulilding Femto -1Cell	20 Mhz,1 Sectors,2 x 2 MIMO in DL	Downlink	93.87	31.29	**138.93**	**46.31**
		Uplink	27.61	9.20	**40.86**	**13.62**

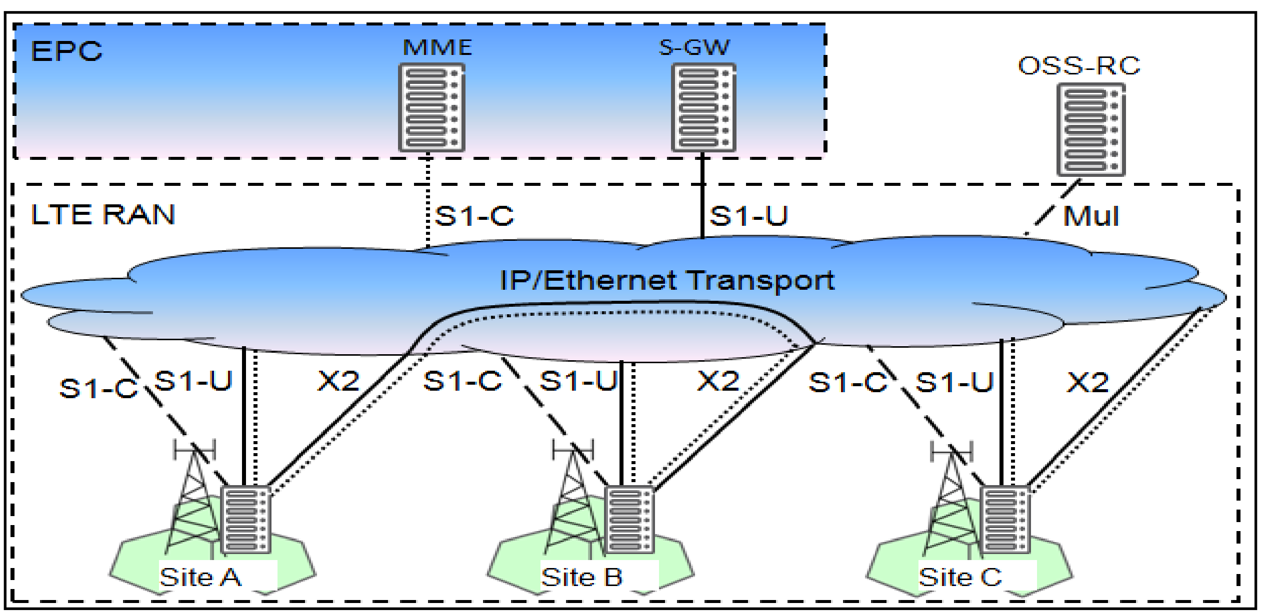


Figure 34: EPC Traffic Flow Representation

13.6. Traffic calculation and dimensioning Activity based on Predicted load:

For dimensioning process we need to start with eNodeB which includes the following steps:

As discussed above we have to determine all the transport requirements to select appropriate transport dimensioning strategy. Then we have to calculate the bandwidth required for the last mile to the eNodeB [Air Interface]. There are two methods one is system method and other is traffic model method. Then next step is to Calculate the bandwidth required for aggregated traffic higher up in the mobile backhaul. This can be achieved by the system method, the traffic model method or by using a combination of both of these methods on different aggregation levels.

Note – It is very important to consider that all the contribution which are required for a backhaul network dimensioning process are based on predicted traffic load at initial level. When we will implement the network then other traffic will be considered and traffic loads will apply. At initial point typically it is important to start with low traffic load during service introduction but after service uptake it's necessary to monitor the load of the network and be ready to tune the transport capacity when required to avoid congestion. It will be based on fine tuning and Optimization of the network.

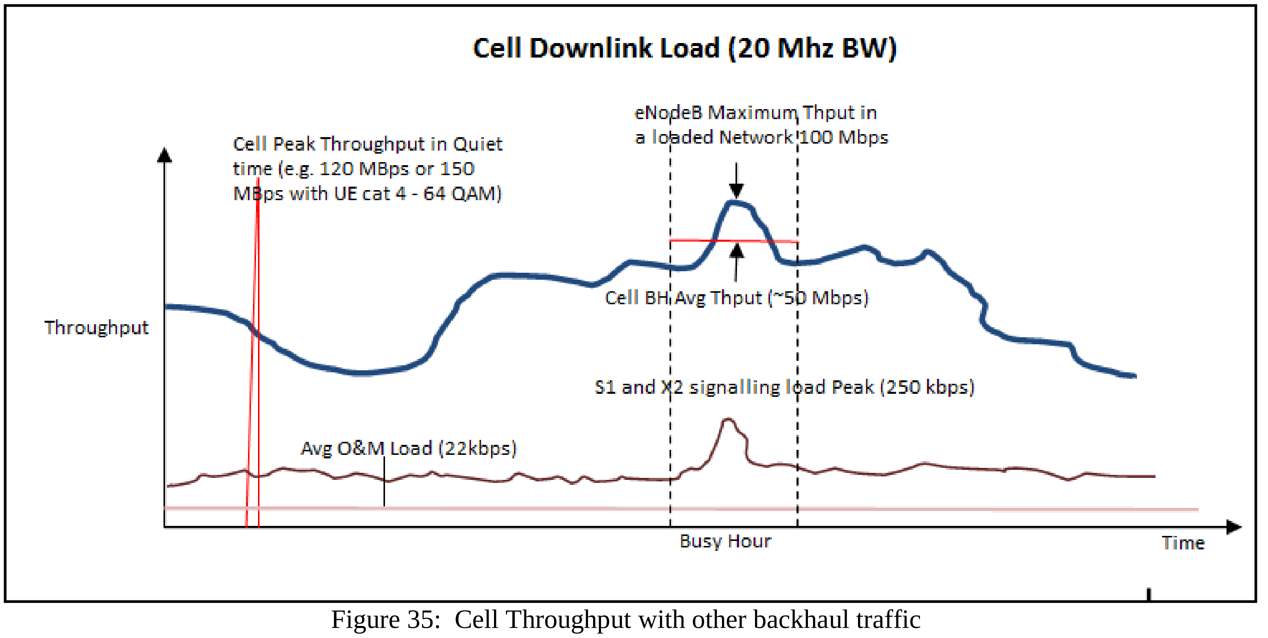


Figure 35: Cell Throughput with other backhaul traffic

All the calculation in above line diagram is considered in ideal conditions and these all are theoretical values. When we are getting Cell Peak loading in quite time it can be due to Hardware, license or UE limited. As per NGMN If we take example of User Equipment category 4 [2x2, 20 MHz, cat4 (150 Mbps] then we can have achieved peak rate of 150 Mbps with 20 MHz channel bandwidth using 64 QAM modulation technique.

When we are calculating eNodeB Maximum Throughput in a fully loaded network then it is calculated based on the utmost traffic values averaged over all cells in eNodeB of highly loaded network. As per the calculation done above and simulation done by Ericsson's tool we observed rate will be 35 Mbps [~33.33]for 20 MHz channel bandwidth. We know most of the eNodeB has three cells then maximum throughput in loaded network will be just about 100 Mbps.

Usually Busy Hour Average Throughput of a cell is calculated from the number of users in the cell and the sum of data that they transfer in the period of busy hour. If we didn't get this supply from the Radio Network Dimensioning tool then in that case we can be assumed the average throughput will be 50% of the Cell Maximum Throughput in a fully loaded network. For an eNodeB which have three cells and 20 MHz bandwidth in the eNodeB the it's Busy Hour Average Throughput will near about 50 Mbps.

In above diagram we are considering the Target Average Rate of 2 Mbps which is used in dimensioning calculations to include a small margin above the average throughput for a single user entering the cell.

For S1 and X2 signaling load of 250 kbps in busy hour for an eNodeB is considered for dimensioning purposes. Average O&M or Mul load of 22 kbps for an eNodeB is considered. Synchronization load of 1 Kbps is considered so for dimension purpose we will not consider this load.

Major Sources-

- LTE Transport Solution Workshop (2010.10.06)v2 by Huawei
- NGMN_Whitepaper_Guideline_for_LTE_Backhaul_Traffic_Estimation
- A White Paper by the NGMN AllianceLTE Backhauling Deployment Scenarios

14. LTE Backhaul Link Dimensioning Principle

For the actual traffic flow in backhaul we need to consider the Dimensioning process of LTE as well. This is used to dimension the backhaul components. In LTE access transport networks includes a number of aggregation points or routers between the eNodeB and EPC, sometime these Aggregator router have a ENodeB itself. These are illustrated as A1, A2 and A3. All of the assumptions in this are based on Ericsson LTE documents.

First part is known as first mile, which is a dimensioning link between the eNodeB and first aggregation router point A1 and this part is based on Cell Peak Throughput in an unloaded network.

As discussed above we can use two different approaches for the LTE Backhaul from the first aggregator to the EPC network. First is the Traffic Model method which optimizes link capacity and cost but with this model we are always at the risk of congestion. On the hand we use the System method which does not require a Traffic Model and it will give the best RAN performance but we always are at the risk of over dimensioning network and this will cause wastage of the resources. The choice of these method used will always depend on the accuracy of the traffic model and cost of transmission and will use accordingly.

In between of the first and second aggregator A1 and A2, it is recommended by Ericsson design principle to use the System Method which uses the Cell Maximum Throughput in a loaded Network.

In between of the second and third aggregator A2 and A3, it is recommended by Ericsson design principle to use the Traffic Model Method which uses the Cell Busy Hour Average Throughput, S1 and X2 signaling load Peak, Average Mul Load (Dimensioning Purpose) and Target Average, but we always have a risk of congestion.

But the bandwidth requirement between the last aggregator point A3 and the EPC network will be the sum of all the A2 to A3 bandwidth necessities when the eNodeB Busy Hour Average Throughput is taken from the Traffic Model. As we are getting the eNodeB Busy Hour Average Throughput from the eNodeB Maximum Throughput in a loaded Network this thing can be reduced by a Busy Hour Displacement Factor of 0.8 to consider the fact that not all cells will have the same Busy Hour in network.

As discussed above all of these dimensioning calculations must include Transport Network Overhead.

Last Mile	Air Interface	Cell Peak Throughput in an unloaded Network
Backhaul	A1 to A2	eNodeB Maximum Throughput in a loaded Network
	A2 to A3	eNodeB BH Average Throughput S1 and X2 signalling Peak and Average Mul Load
	A3 to EPC	nA2 X 0.8 (BH Displacement Factor)

14.1. Description of Network Using Tree Model

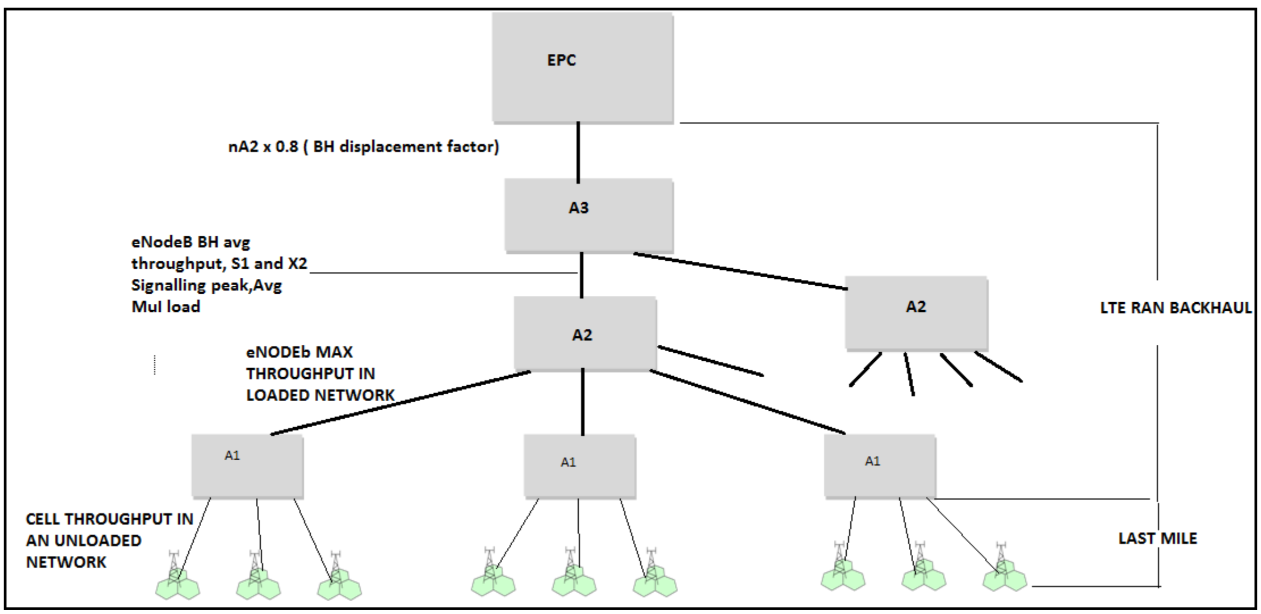


Figure 36: Tree Model

14.2. Capacity Requirement and Link Dimensioning using Traffic Model:

Here the Traffic Model Link Dimensioning method described here assumes a system bandwidth of 20 MHz and a Transport Network overhead of 1.17 which is calculated above for an any operator build transport network using IPv4 without IPSec. Here in this example the eNodeB Busy Hour Average Throughput of 30 Mbps [With no MIMO] is considered from the above discussed Traffic Model.

The capacity required at first point which is for the last mile is considered as Cell Peak

Throughput in an unloaded Network (CPT) which is multiplied by the Transport Network Overhead (TNO) giving a requirement of 176 Mbps.

Last Mile Capacity requirement = Cell Peak Throughput in Unloaded network x Transport Overhead

= 150 X 1.17 = 176 Mbps

Next step is link between A1 and A2 and the capacity requirement for this link is the maximum of the sum of the eNodeBBusy Hour Average Throughput (EBT) got from the Traffic Model, S1 and X2 signalling Peak (SLP) and Average Mul Load (AML) for all the sites which come under the A1 aggregator (nA1) plus the target rate [~ 2Mbps] or the Cell Peak Throughput in an unloaded Network (CPT) multiplied by the Transport Network Overhead (TNO). With the calculations in this example we get a requirement of 357 Mbps. We need to establish a link at least of these values.

Capacity requirement of Link between A1 and A2 = Max [((EBT + SLP + AML) X nA2) +TAR]XTNO

= [((30+0.250+0.022) X 10)+2] X 1.17
= 357.7 Mbps

After that we need to calculate the capacity requirement between link A2 and A3 which is calculated by the maximum of the sum of the eNodeBBusy Hour Average Throughput (EBT) taken from the Traffic Model, S1 and X2 signalling load Peak (SLP) and Average Mul Load (AML) for all the eNodeB which comes under the A2 aggregator (nA2) plus the target rate [~ 2Mbps] or the Cell Peak Throughput in an unloaded Network (CPT) multiplied by the Transport Network Overhead (TNO). With the calculations in this example we get a requirement of 3.54 Gbps. We need to establish a link at least of these values.

Capacity requirement of Link between A2 and A3 = Max[((EBT + SLP + AML) X nA2) +TAR]XTNO

= [((30+0.250+0.022)X100)+2]X1.17
= 3.54 Gbps

Last step is the calculation between A3 aggregator and EPC network ,since the eNodeB Busy Hour Average Throughput (EBT) is taken from the traffic model the capacity required between A3 and the EPC is the sum of all capacity requirements which we calculated above between A2 and A3. With the calculations in this example we get a requirement of 7.08 Gbps.

Capacity requirement of Link between A3 and EPC = Sum of all A2

= 3.54 + 3.54

= 7.08 Gbps

CPT= Cell Peak Throughput in an unloaded Network (e.g. 150 Mbps)
EMT= eNodeB Maximum Throughput in a loaded Network (~ 100 Mbps)
EBT= eNodeB Busy Hour Average Throughput (30 Mbps)–*Traffic Model*
n= eNodeBs under each aggregator (nA1= 10, nA2=100, nA3= 200)
TAR= Target Average Rate (~ 2 Mbps)
SLP= S1 & X2 signaling load Peak (250 kbps)
TNO= Transport Network Overhead (1.17)
AML= Average Mul Load (22 kbps)

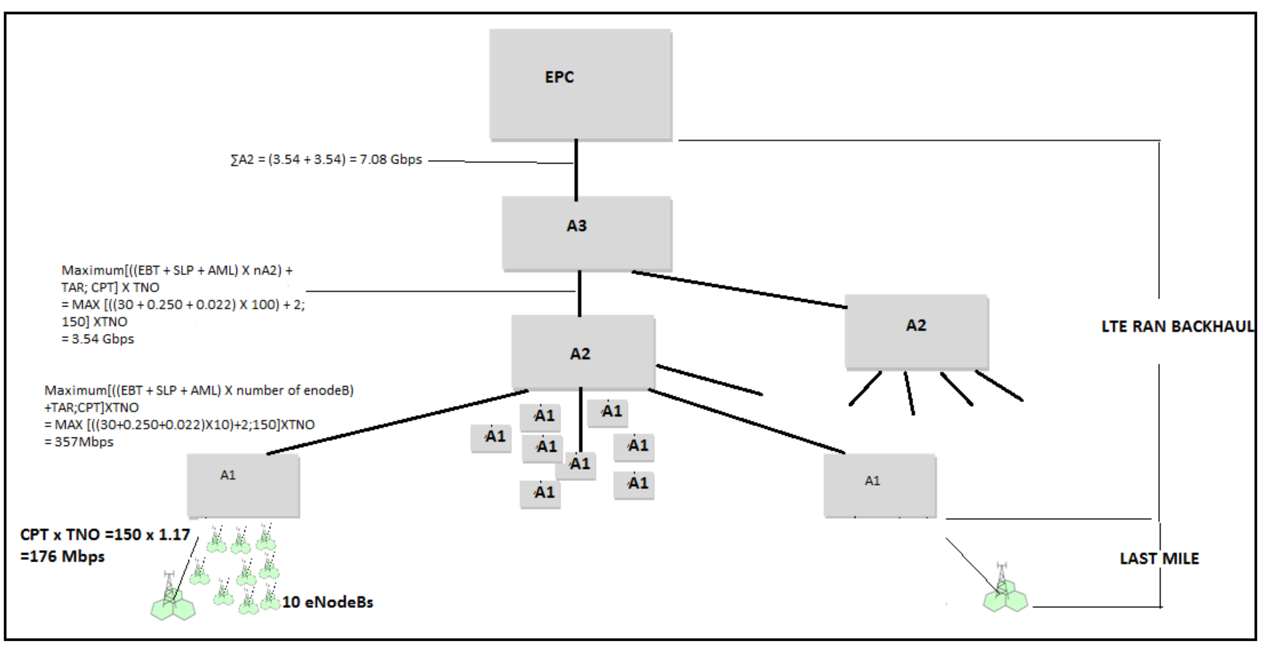


Figure 36: Traffic Model

14.3. Capacity Requirement and System Model Link Dimensioning Model:

Other way for dimensioning is the System Method Link Dimensioning model and example of this model described below by assuming a system bandwidth of 20 MHz with Transport Network overhead of 1.7 (which is calculated above) for an operator build transport network using IPv4 without IPSec. In this dimensioning modeling example we will consider the eNodeB Busy Hour Average Throughput value of 50 Mbps which is not taken from the Traffic Model but is assumed to be 50% of the eNodeB Maximum Throughput in LTE loaded Network.

The capacity required at first point which is for the last mile is considered as Cell Peak Throughput in an unloaded Network (CPT) which is multiplied by the Transport Network Overhead (TNO) giving a requirement of 176 Mbps.

Last Mile Capacity requirement = Cell Peak Throughput in Unloaded network X Transport Overhead

= 150 X 1.17 = 176 Mbps

Next step is link between A1 and A2 and the capacity requirement is calculated by different way. Calculation is done by multiplying eNodeB Maximum Throughput in a loaded Network (EMT) with the Transport Network Overhead (TNO) and the number of eNodeB which comes under the A1 aggregator (nA1) and result of calculation is giving a requirement of 1.17 Gbps.

Capacity requirement of Link between A1 and A2 = EMT X TNO X nA1

= 100 X 1.17 X 10
= 1.17 Gbps

After that we need to calculate the capacity requirement between link A2 and A3 which is calculated by following way. We know the eNodeB Busy Hour Average Throughput (EBT) is not taken from the Traffic Model and then the capacity requirement between A2 and A3 is simply the eNodeB Busy Hour Average Throughput (EBT) multiplied by Transport Network Overhead (TNO) and the number of eNodeBs which comes under the A2 aggregator (nA2) which gives a requirement of 5.85 Gbps.

Capacity requirement of Link between A2 and A3 = EBT X TNO X nA2

= 50 X 1.17 X 100
= 5.85 Gbps

Last step is the calculation between A3 aggregator and EPC network, We know the eNodeBBusy Hour Average Throughput (EBT) is not taken from the Traffic Model and then the capacity requirement between A3 and the EPC is the sum of all capacity requirements between A2 and A3 multiplied by the Busy Hour Displacement Factor of 0.8. In this example calculation will give us a result of 9.36 Gbps.

Capacity requirement of Link between A3 and EPC = Sum of all A2 x 0.8

= (5.85 + 5.85) x 0.8

= 9.36 Gbps

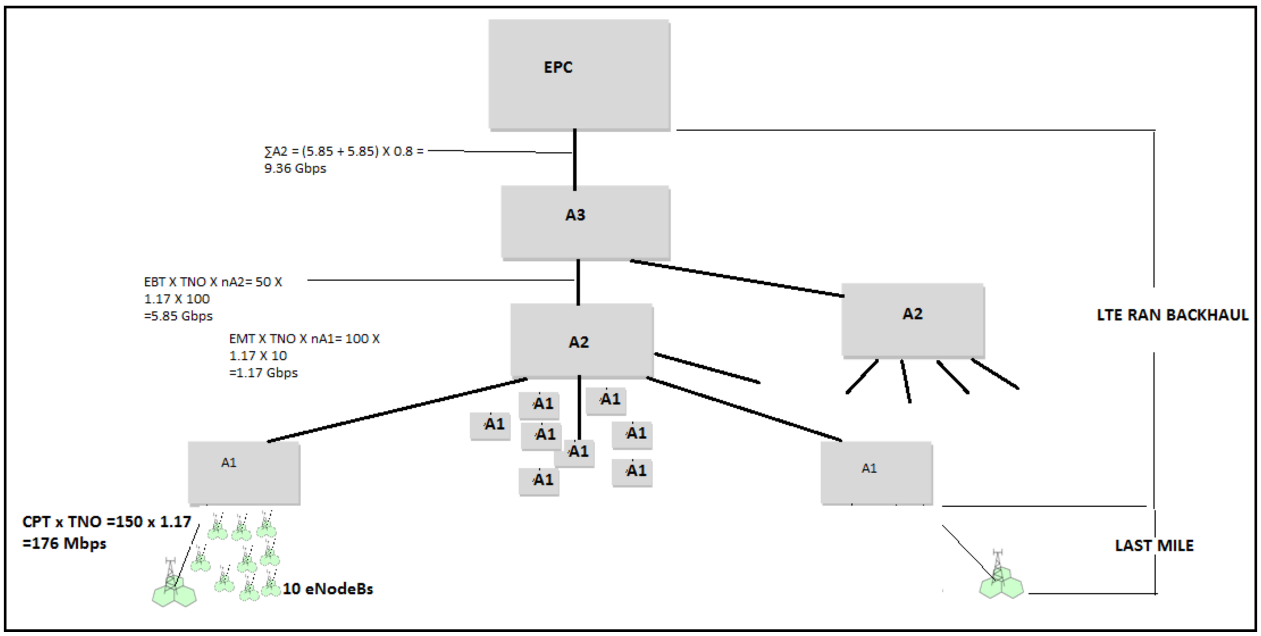


Figure 37: System Model

15. EPS Traffic Calculation:

In this section we will calculate the traffic in EPS part. In order to be able to provide realistic traffic, we will always consider the busy hour traffic .In addition to that, there are certain important traffic parameters that need to be considered. Arranging a best network that depends on practical traffic parameters is not a simple assignment, and to have the capacity to build up a device that considers sensible activity there are certain important traffic parameters that should need to be considered while calculation:

- **Number of subscribers:** Total numbers of users which are covered by a given eNodeB represented by this parameter.

- **Number of attached subscribers (ASUB) in Busy Hour (BH):** BH is consider as busiest 60 minutes of time, in which we the total traffic is the maximum throughput of the day. This parameter corresponds to the total number of LTE users that have assigned IP and were able to have a successful link with the P-GW along with a successfully established default bearer.

- **Busy Hour Data Session Attempt (BHDSA):** This parameter represents the number of data sessions attempted in a busy hour, and it is one of the most important methods to estimate the capacity of the network.

- **Busy Hour Voice Session Attempt (BHVSA):** This parameter represents the number of voice sessions attempted in a busy hour.

- **Bandwidth required for bearer sessions (BW):** This parameter represents the amount of throughput required for the users' services.

- **Simultaneous Evolved Packet System Bearer (SEPSB):** This parameter represents the number of EPS bearer sessions occurring simultaneously in a busy hour. The EPSB is an established end-to-end connection between the UE and the P-GW to provide the users with the different services they required.

In this method, the subscribers' traffic profile is provided by the operator or service provider, which varies depending on various plans provided for Data and Voice by the mobile operators. To compute the eNodeB traffic profile we are using Table 2 in which some of the values are referenced and some of the values are considered based on knowledge and logic. It is important to consider these values can be changed according to specific requirement of mobile networks.

As discussed two main values that affect the dimensioning process are presented in Table 1, which are average downlink rate which was taken to represent a single direction (eNodeB – UE) [Which is already explained in above topics] and monthly usage or data traffic per subscriber in a month. Let us take a example in which Telus Canada (2012) states that the existing 4G LTE enable users to access network with speed up to 75 Mbps with an expected average of 12-15 Mbps, other hand BELL network states they offer speed of 150 Mbps with average speed 18-40 Mbps. If we talk about data usage per user, Fido states per subscriber it starts from 100 MB up to 5GB, Telus provides data usage that goes up to 5GB.

Subscriber traffic profile	
Average rate	Monthly usage
25Mbps	2GB per month per subscriber

Table 1

Planning parameters	
Adaptive multiple rate	12.2 kbps
Mean session time (MST)	180 s
Handover ratio (HO)	0.4
IP overhead percentage (IPov) 50 %	50%
Dense area attached subscriber ratio (ASR)	0.9
Active BH EPSB ratio (BR)	0.5
Average EPSB session duration (BSD)	900 s
Retransmission factor	0.25
S1U utilization factor (S1UF)	0.8
Working days per month (WD)	22
Working days traffic ratio (WDR)	0.9
Busy hour traffic ratio (BHR)	0.15
Voice Activity Factor (VAF)	0.5
Burstiness (B)	0.25

Table 2

Note: Table 2 Planning parameters values are referenced from various resources of internet which are given below and it is mostly referred from *[“Data and Control Plane Traffic Modeling for LTE Networks - Dima Dababneh1- Carleton Univ”]*

A mobile network is designed in such a way that it is capable to provide different services to all of it subscribers and it is capable to handle the highest amount of traffic during busy hour. In order to have a realistic amount of traffic, different traffic types such as web browsing, file downloads, e-mail, messaging, conversation voice, conversation video, gaming, and streaming is taken into consideration.

Now with this method we will calculate the busy hour usage, that will be calculated by the below equation, in which we will consider the value of k that is equal to

k = 1024 x 1024 x 1024 x 8 [Converting monthly usage of GB into bits]

In equation working day traffic ratio shows a percentage of the amount of traffic that occurs during working days, and busy hour traffic ratio is similar to a percentage of the amount of traffic that occurs for the duration of a busy hour. Average BH usage is measured for a subscriber in bits/ busy hour taking

The average busy hour usage per subscriber is calculated using Equation 3.1 in which k is a constant that is equal to 1024*1024*1024*8 and is used to convert the monthly usage of GB provided in Table 3.1 to bits. Working days traffic ratio represents a percentage of the amount of traffic that occurs during working days, and busy hour traffic ratio resembles a percentage of the amount of traffic that occurs during a busy hour. Average BH usage is measured for a subscriber in bits/ busy hour taking into consideration that Busy hour will be the busiest hour in which traffic will be maximum as comparison to whole day.

$$\textbf{BH Usage} = \frac{\textbf{monthlyusage} * \textbf{k} * \textbf{workingdaytrafficratio} * \textbf{busyhourtrafficratio}}{\textbf{workingdayspermonth}}$$

$$\frac{\mathbf{2x1024x1024x1024x8x0.9x0.15}}{\mathbf{22}}$$

= 105.217 Mbph

=105421924.53 bits per hour per subscriber

In the LTE network Voice is supported by various techniques, such as Voice over LTE and CSFB - Circuit Switched Fallback [Using legacy technologies] IP multimedia services was first priority when LTE was launched, but it was not predictable and it causes some issues while supporting Voice over LTE. Due to which CSFB used, which is a service which provide voice services on LTE network by using legacy techniques such as GSM, CDMA or UMTS. If we consider VoLTE, there are many factors that control the voice bandwidth, such as CODER – DECODER and sample period, IP header, Transmission medium. Using AMR codec's it increases the voice capacity and it uses multiple voice encoding rates ranging from 4.75 to 12.2 kbps. For example, when we use Adaptive Multi rate 12.2 kbps codec rate caused a data rate of 30 kbps on top of IP.

Now we will calculate the **average throughput of the S1U interface per subscriber**. We know S1 – U is the interface between eNodeB and the S-GW, which carries user plane data [Various types of data, and Voice sessions with different data rates.] When traffic flows from S1 U interface traffic is bursty, and due to which we will include burstiness factor for the calculation. Burstiness is a demonstration of a group of packets with smaller gaps among other packets being handled before or after, and it usually has a value between 0 and 1. When the value get close to 0 traffic become more bursty.

We need to include Handover Ratio [HO] in calculation because we know S-GW is considered a mobility commentator for inter- eNodeB handovers. We also know some of the application also needs retransmission in case of failure, so RTF (Retransmission Factor) is also included in Calculations. Here we using k as constant which have value of 3600 which is used to ensure dealing with S1UBW of rate in bps [because in last calculation we calculate traffic for whole busy hour] In calculation we considered two other main parts which are VAF (Voice Activity Factor) to ensure calculating the period in which voice is active and other time intervals where other data applications are being handled. Apart of it voice data constant is used which represents the sum of data that needs the AMR codec for transmission, and since data is transmitted over IP, IP overhead will also be considered for the calculation.

S1 UBW = ((1 – VAF)(BH Usage / k) + (VAF * AMR * Voice data constant)) * (1 + HO ratio) * (1 +RTF) *(1+ IP Overhead) * (1+ Burstiness)

S1 UBW = ((1 – 0.5)(105421924.53 [bits per Hour] / 3600) + (0.5 * 12.2 * 1024 [bps])) * (1 + 0.4) * (1 +0.25) *(1+ 0.5) * (1+ 0.25)

= 35137.93 (bps per user)

Now we will calculate the number of session attempts during the busy hour (BHSA). BHSA is calculated for each subscriber by multiplying the busy hour traffic intensity, which shows the amount of usage per user in busy hour, by 3600 and dividing it by mean session attempts for all users. This calculation will represent the max number of busy hour session attempts for all subscribers. Unit for BHSA is expressed in number of sessions per busy hour.

$$\textbf{BHSA} = \frac{\textbf{attachedsubscribers} * \textbf{trafficintensity} * \textbf{3600}}{\textbf{meansessiontime}\ (\textbf{seconds})}$$

It is fact that we have two types of attempts one is Voice and Data; so we need to calculate two seprate equation for BHVSA and BHDSA. Voice traffic Intensity is equal to 20 and the data traffic intensity on an average will be 1.52 as per [*A Novel Traffic Capacity Planning Methodology for LTE Radio Network Dimensioning - J. Gu, Y. Ruan, X. Chen, C. Wang,]*,

Let us assume we have a small eNodeB **and capable to handle users = 1125**

$$\textbf{BHVSA} = \frac{\textbf{attachedsubscribers} * \textbf{Voicetrafficintensity} * \textbf{3600}}{\textbf{meansessiontime}\ (\textbf{seconds})}$$

$$\textbf{BHDSA} = \frac{\textbf{attachedsubscribers} * \textbf{Datatrafficintensity} * \textbf{3600}}{\textbf{meansessiontime}\ (\textbf{seconds})}$$

BHVSA = (1013 *20*3600)/180 = 405000

BHDSA = (1013 *1.52*3600)/180 = 30780

To calculate the **number of attached subscribers** for any eNodeB, we will multiply the total number of users by the attached subscriber ratio for dense area as per the Table 2. We have assumed the attached subscriber ratio otherwise it depends upon the geographical region, whether that particular area is crowded or has less population.

Attached subscriber = Total number of Subscriber x attached subscriber ratio

Attached subscribers = 1125 * 0.90 = 1013

LTE has a very good concept that a subscriber has a ability to have more than one concurrently bearer session, and one of the benefit of this feature is that a subscriber can connect to a PDN for Internet services and simultaneously connect for Video streaming or Gaming Services or to another PDN. Now we will calculate **the total number of simultaneous EPS dedicated bearer sessions handled by the S1U interface**. We will calculate this by multiplying the number of attached users by the average interval of each data bearer session and the active BH EPSB ratio which correspond to the percentage of active sessions and it is usually managed by the network operator. Now we will divide this again by 3600 to make sure we will get the value in a busy hour.

$$\textbf{eNodeB Simultaneous EPSB} = \frac{\text{Number of attached subscribers} * \text{Average EPSB session duration (sec)} * \text{active BH EPSB ratio}}{3600\ (\text{sec})}$$

eNodeB Simultaneous EPSB =(1013 * 900 * 0.5)/3600 = 127

Now we have to calculate the throughput of the S1 User interface, before that calculation we need to calculate Fair usage Policy (FUP), which is a method to manage the ability to access the provided services by operator, and it is apply to only those users who exhaust their assigned quotas and get limited access speed until the end of users billing cycle. With this services which require high bandwidth such as online gaming and video streaming will be affected; however application which uses low throughput such as web browsing, emails and other services will not be highly affected because they do not need much speed to download. For example if LTE uses will be exceeded for any user then operator will switch the user from LTE to 3G UMTS or 1x EVDO network. If we consider 15% [A = 0.15] of attached subscribers depleted their shares and had to use additional FUP data with size of 2 GB, for that purpose we will calculate the **FUP throughput.** To calculate this we need to multiply the number of subscriber using the FUP feature by the number of excess data per subscriber. We will use k as constant which is used to convert Gbps to bps k = 1024*1024*1024*8.

$$\textbf{FUPBW} = \frac{A*AttachedSubscribers*Amountofextradata*k*workingdaystrafficratio*busyhourtrafficratio}{workingdayspermonth*3600}$$

We know some of the subscriber need to use some Top UP features on top of its current plan. It is a important factor that add to total throughput of the network. Usually many users who will be out of their quotas, and their downloading speed will goes down and to access the high speed theu have to buy some extra data plan. Let us take an example, if a subscriber pays $25 for 2GB data in a month, and the total number of subscriber who use the Top up feature is 20% [B= 0.2]of total number of attached users. Top up BW is a outcome of the number of subscriber using the Top UP feature by excess data per user. Constant value k converts data from Gb to bps [1024*1024*1024*8], the rest of the values will be same as above.

$$\textbf{TOPUPBW} = \frac{B*AttachedSubscribers*Amountofextradata*k*workingdaystrafficratio*busyhourtrafficratio}{workingdayspermonth*3600}$$

Now we will calculate the **total amount of Bandwidth being carried by S1 – User Interface.** As per the fact **utilization is resulted by dividing the traffic load (bps) by the capacity (bps);** where capacity is the highest amount of load sustained by the network. Where S1U total bandwidth is a result of adding up the FUPBW and the TOPUPBW to the total number of the simultaneous EPS bearers multiplied by the average S1U throughput and the output of the summing up is divided by the interface consumption which must have to be always less than 0.85 [85 % of utilization]. To get the total bandwidth in Mbps, we need to divide the output by 1M.

$$\textbf{S1- User Total BW} = \frac{(eNBSimultEPSB*S1UBW) + FUPBW + TOPUPBW}{S1Uinterfaceutilization*1000000}$$

15.1. Traffic profile generation and Simulation results of each formula With Excel Spreadsheets:

We will analyze each formula discussed above and calculate the values. Traffic records taken into consideration is of different types such as Voice, Web Browsing and Applications based on the delay sensitivity traffic classification which are conversational, streaming, interactive, and background classes. In this example we have consider 14 different eNodeB from which first 10 eNodeB will be of smaller size and have less capabilities can handle subscriber below 5000 and other eNodeB can handle subscriber more than 10000. We have considered each type to describe how the other parameters are directly related to the number of subscriber. The term number of subscriber which are handled by eNodeB is depends on the capability and performance of eNodeB (e.g. memory, hardware, CPU, etc.). It totally depends upon the network operators deploying traffic model, how much the requirement based on need and equipment they have.

In below table first column is for eNodeB represent different eNodeB of different traffic type. Second column has total number of subscriber served by each eNodeB (all whether they are active or idle), doe small scale it is below 5000 and for large scale it is more than 10000. Next column represent Attached subscribers which is percentage of users who have a successful connection with the PGW. Next two columns represent busy hour session attempt for both Voice and Data. Sixth column have number of simultaneous sessions of dedicated EPS bearer. Seventh column have BW in Megabits per second (Mbps). The peak data rate for LTE differ from 5–75 Mbps on uplink and 10–300 Mbps on downlink, and the effective bandwidth is always less.

eNodeB	Number of Users	Attached Subscriber Calculation	BHVSA	BHDSA	EPSB	BW in Mbps	Busy Hour Usage per Subscriber in bph
1	1125	1013	405000	30780	127	29.65	105421924.5
2	1254	1129	451440	34309	141	33.05	105421924.5
3	1342	1208	483120	36717	151	35.37	105421924.5
4	1452	1307	522720	39727	163	38.27	105421924.5
5	1587	1428	571320	43420	179	41.83	105421924.5
6	1024	922	368640	28017	115	26.99	105421924.5
7	2658	2392	956880	72723	299	70.05	105421924.5
8	3655	3290	1315800	100001	411	96.33	105421924.5
9	4485	4037	1614600	122710	505	118.20	105421924.5
10	3956	3560	1424160	108236	445	104.26	105421924.5
11	10025	9023	3609000	274284	1128	264.21	105421924.5
12	11256	10130	4052160	307964	1266	296.66	105421924.5
13	13542	12188	4875120	370509	1523	356.91	105421924.5
14	15214	13693	5477040	416255	1712	400.97	105421924.5

It can be concluded from the above table, the amount of traffic is proportional to the number of users for each eNodeB. As per table the eNodeB that has a high number of users has a high number of attached subscribers, BHDSA & BHVSA, simultaneous bearers and high amount of BW.

15.2. Control Plane [Signaling] Calculation:

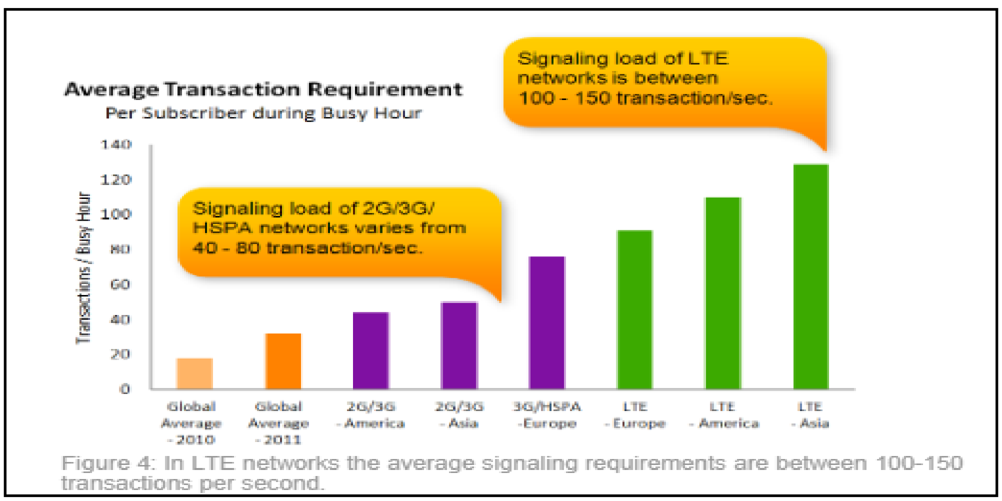
With the growth in the mobile network with, service providers face a storm of signaling traffic that make threats to engulf conventional backhaul networks. As users increases more and more dynamic on social networks and operates a growing number of applications at the same time generating a huge volumes of signaling traffic from their smart phones when they interacting with the mobile network. This will rise in the data traffic. As per the NSN 50%

faster growth can be observe in data traffic over next few years. Smartphone is the only factor behind increase in signaling traffic.

15.3. Drivers for the Signaling traffic:

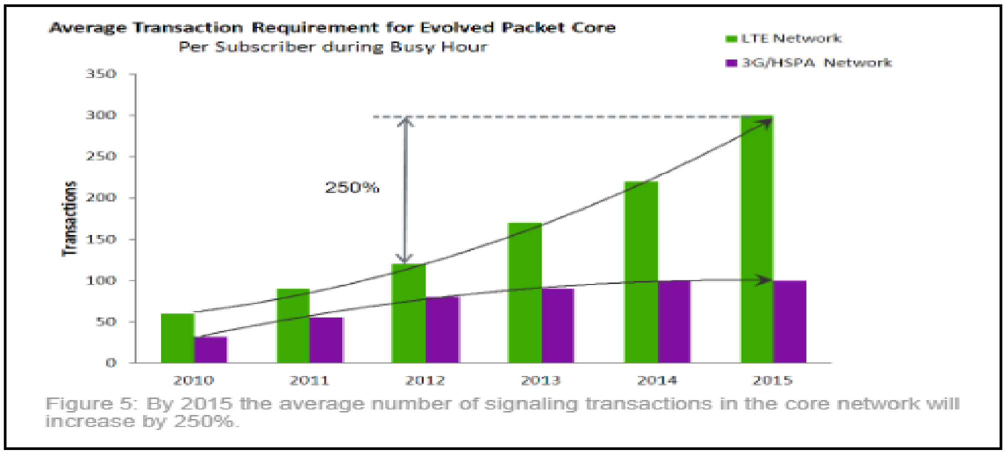
Service providers are more and more relying on service awareness to deliver a enhanced experience for Smartphone users. When it will be combined with differentiated charging, it will increase signaling by 30%. When we use VOLTE it requires scalable signaling capacity and differentiated real time service experience, which increases the signaling traffic.

In legacy network such as 3G networks, we use the Radio Network Controller (RNC) between the base station and core network elements, which effectively used as a shielding for the core backhaul network from the mass of signaling produced by the RAN for mobility management. But in LTE it uses a simple architecture that eliminates the RNC. In Backhaul it is connected directly to the LTE base stations, it must handle every signaling traffic .Now the average signaling requirement per subscriber is up to 42% higher with LTE as compare to 3G. So signaling becomes a critical consideration when dimensioning packet core networks.



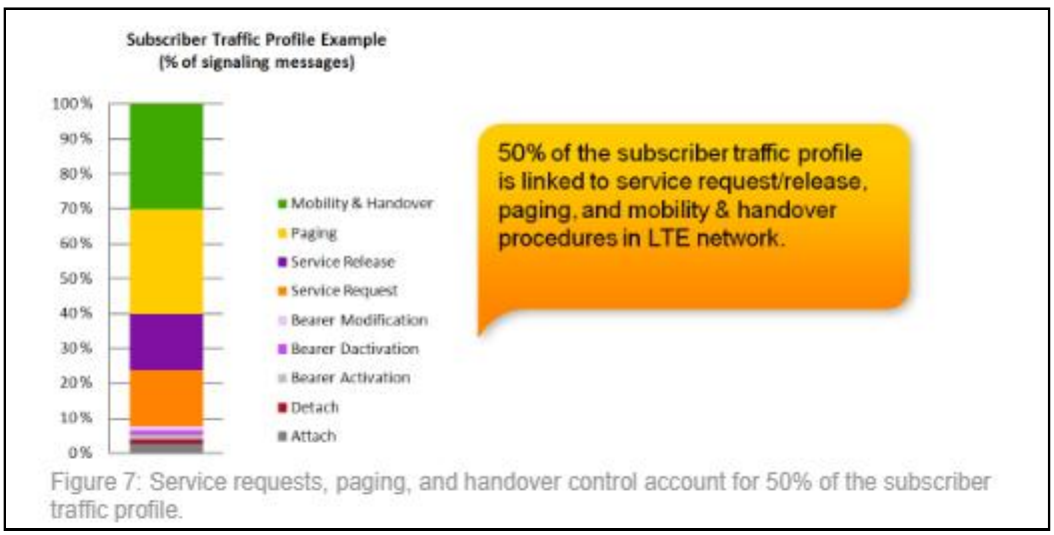
Source - Nokia Siemens Networks, "Signaling is growing 50% faster than data traffic", White paper, 2012.]

Figure 37: Comparison of HSPA with LTE network



Source - Nokia Siemens Networks, "Signaling is growing 50% faster than data traffic", White paper, 2012.]

Figure 38: Per subscriber traffic profile for Signaling



[Source - Nokia Siemens Networks, "Signaling is growing 50% faster than data traffic", White paper, 2012.]

Figure 39: Per subscriber traffic profile for Signaling

For the calculation of control plane, all the signaling and control traffic moves from the S1-Control plane interface as discussed above and it creates load to the network. Control operations such as EPS bearer establishment and management, attachment and detachment and authentication requests and responses As we know the eNodeB is directly connected with the MME, MME has a gigantic load of transaction per seconds with both HSS and S-GW. Each elements has its own functionality and various processes so signaling is based on equipment itself, based on that it has a different amount of signaling because it need a different amount of transactions per seconds for each of its operations. However the amount of signaling also varies depending upon the vendors specifications and model of the element. We will calculate the amount of signaling for HSS and rest of the element such as MME,P-GW,S-GW and PCRF. But the transaction per second is not exact it always depends upon the type of element, provider, vendors and model along with the parameters. For HSS signaling for the HSS it is calculated by multiplying number of users with the number of transactions per second. For the calculation of signaling for the each element by multiplying number of bearer during a busy hour by the number of transactions per second per bearer.

Signaling for HSS = Number of Users * Transaction per seconds per subscriber

Signaling Core Element (Signaling load per element) = Number of bearer during a busy hour (EPSB) * number of transactions per second per bearer.

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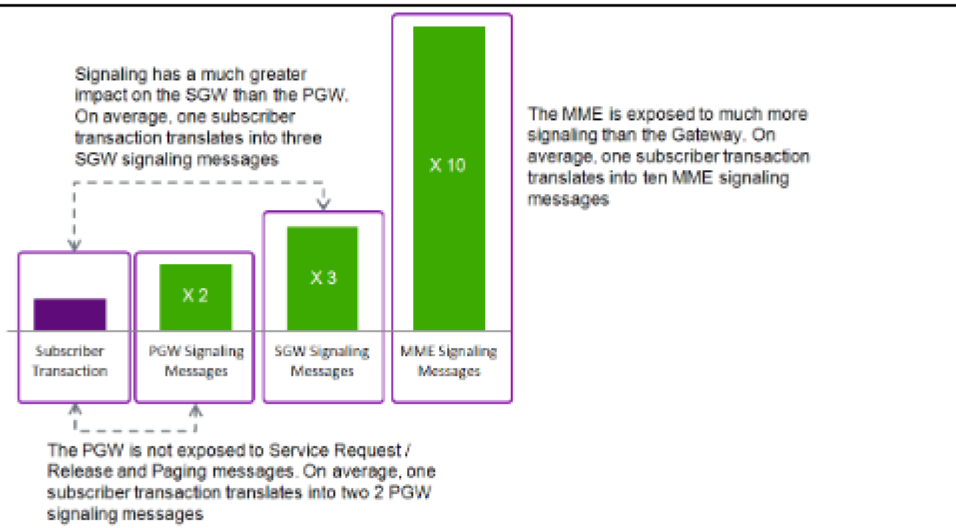


Figure 8: Transactions comprise a different number of messages depending on the network element. For example, one transaction is comparable to 10 messages in the MME, but only 3 messages in the SGW.

[Source - Nokia Siemens Networks, "Signaling is growing 50% faster than data traffic", White paper, 2012.]

As per the Nokia Siemens Network's White paper MME can handles 9.3 transactions per second per bearer since it can handle around 290,000 messages per seconds. For the Packet Gateway it can handle 63,000 messages per second with leading 2 transactions per bearer. S-GW can handle 94,000 messages per second with leading to 3 transactions per bearer. P-GW doesn't have to deal with service request, release and paging message, so that's why S-GW is higher than P-GW.

15.4. Calculations and Issues for the Control Plane

When we ready with the traffic profile of every eNodeB, after that we have to plan the rest of the network (i.e evolved packet core) such that it will be capable to load generated by all the users.
For this let us assume the above used 14 eNodeB from above table are randomly located on a 10km x 10km geographical area. We will assume these all 14 eNodeB are connected to single MME and SGW. MME has also a connection with SGW. As per the architecture SGW is connected to PGW and PGW is connected to PCRF.

Now traffic profile which calculated above from each eNodeB along with their capacities of the various elements is the most important thing that controls the number and types of core network elements need to installed in a network. Similarly, the number of links among the elements also varies as per the traffic parameters from all the eNodeB and the network core elements.

In fact, every element in core network has a maximum capacity that it can't exceed, and in order to plan a efficient network, capacity limitations of each element need to be taken into consideration.
Important factor of looking into capacity constraints of core elements that it helps to identify the type and the needed number of network elements.
Usually, there are four types of capacity constraints **throughput, transaction, subscriber and bearers.**
Whereas Throughput is the maximum amount of data load that any node can handle, and it is measured as a data plane constraint, whereas **transactions** are signaling messages which are related to the control plane. **Subscribers** stand for the number of users that can be handled by a node, and we know there are various types of subscribers that can be handled by any node such as Active user or Idle User (no ongoing media session), or activated vs. configured subscribers which are not yet activated. However bearer is a data connection and which have two types default bearer and dedicated bearers. For any attached users dedicated bearer is mandatory whereas dedicated bearer is set up based on requirement.

For MME the number of transactions (or signaling) as well as the number of users that are attached to MME or in MME's temporary subscriber database is a big capacity issue. MME is also limited by the BHSA and EPSB as well as amount of BW.

Whereas HSS is a database for users data and it is related with the control plane in particular. The interface between MME and HSS is related to control plane only. HSS have only two concerns, one is number of transactions and other is number of subscribers.

SGW act as a mobility anchor for the traffic being carried on different eNodeB [distributing like a router] and it also forwards packet between eNodeB and the Packet Gateway. SGW is focused on data plane only, and it's biggest constrain is throughput.

P-GW has a biggest limitation for throughput and number of subscribers because service providers are supposed to be able to accommodate a big number of users. If we talk about transactions, PGW is affected by three control operations which are setup/teardown bearers, Quality of service negotiation with PCRF and inter SGW mobility.

Capacity Constraints affecting LTE components				
Core Element	**Throughput (User Plane)**	**Transactions (Control Plane)**	**Subscribers**	**Bearers**
MME	✗	✓	✓	✗
HSS	✗	✓	✓	✗
S-GW	✓	✓	✗	✓
P-GW	✓	✗	✗	✓

Now, We will analyze signaling load per authentication element [HSS], which also refers to the signaling load per HSS. First column represent number of eNodeB and next column is Number of subscriber. Next column is SLAE and which is expressed as transactions per second (tps). As discussed above Signaling for HSS or signaling load per authentication element is calculated by multiplying the number of users by the number of transactions per subscriber per second which is equal to 6.2 as per the [Nokia Siemens white Paper]. Similarly as the other table SLAE is directly proportional to user. As user increases SLAE also increases.

Signaling Load per Authentication Element		
eNodeB	**Number of Users**	**SLAE (tps)**
1	1125	6975
2	1254	7775
3	1342	8320
4	1452	9002
5	1587	9839
6	1024	6349
7	11256	69787
8	13542	83960
9	15214	94327

Now we will calculate the signaling load per core. First column represent number of eNodeB and next column is Number of EPSB which is considered as main factor. Signaling load per core element is calculated by multiplying the number of EPSB with the number of transaction per bearer per second. Number of transaction per bearer always depends upon the core element. As per the NSN Whitepaper for MME the number of transaction per bearer per second is equal to 9.3 and for S-GW it is 3, and number of transaction per bearer per second for P-GW and PCRF is 2. Calculation is given below for each element.

Signaling Load per Core Element					
eNodeB	**EPSB**	**Signaling load for MME**	**Signaling load for S-GW**	**Signaling load for P-GW**	**Signaling load for PCRF**
1	127	1177	380	253	2354
2	141	1312	423	282	2624
3	151	1404	453	302	2808
4	163	1519	490	327	3038
5	179	1660	536	357	3321
6	115	1071	346	230	2143
7	299	2781	897	598	5562
8	411	3824	1234	822	7648
9	505	4692	1514	1009	9385
10	445	4139	1335	890	8278
11	1128	10489	3383	2256	20977
12	1266	11777	3799	2533	23553

13	1523	14168	4570	3047	28337
14	1712	15918	5135	3423	31835

15.5. Analysis of User Plane & Data Plane and Network Capacity specifications:

For the LTE network processed proper network planning plays a vital role. It is important process that has a various parameters with different requirements such as capacity a cost. A proper network is achieved by generating a various possible topologies with various elements that are located in various locations, and then selecting topology that achieve the goal for a perfect network.

Now we will analyze different features for every core elements as well as the links and the interfaces connecting them with each other. It is a fact that for all elements, there is a limitation of capacity that cannot be violated; in case if we have traffic handled by the network is more than its capacity, then at that moment we need to maximize the capacity either by using more equipment or by choosing equipment with higher capacities.

In the telecom world there are many LTE/EPC technology vendors such as Ericsson, Huawei, Alcatel-Lucent, Cisco Systems, Motorola, Nokia-Siemens, etc. We are assuming some facts in these calculations and maybe some of the features are not absolute due to the fact that they vary among different vendors, and different types and models.

We will analyze the MME types first as given in below. We will assume two types, which are compared according to their features that affect most to the MME. In this Type B can support more idle and active subscribers than type A and it is also capable to provides more throughput as well as high BHSA and EPSB capacities. So, as cost will also increase as the feature will increase in the equipment, so B will be more costly than A.

All of the Specifications provided by various network vendors and referred from [“ *LTE Traffic Generation and Evolved Packet Core (EPC) Network Planning – Dina Dibbaneah*”]

Features of the MME		
	Type A	**Type B**
Subscribers	15,000,000	20,000,000
Attached Subscribers	13,500,000	18,000,000
Throughput (Gbps)	55	75
BHSA	405,000,000	540,000,000
EPSB	15,000,000	20,000,000

We will analyze the **S-GW**&**P-GW** types as given in below. We will assume two types, which are compared according to their features that affect most to the S-GW. In this Type B can support more attached subscribers than type A and it is also capable to provide more throughput as well as high BHSA and EPSB capacities. It can also support more EPSB and BHSA.

Features of the S-GW		
	Type A	**Type B**
EPSB	3,150,000	4,200,000
Attached Subscribers	13,500,000	18,000,000
Throughput (Gbps)	55	75
BHSA	405,000,000	540,000,000

Features of the P-GW		
	Type A	**Type B**
EPSB	3,150,000	4,200,000
Attached Subscribers	13,500,000	18,000,000
Throughput	55	75
BHSA	405,000,000	540,000,000

PCRF is basically a piece of software that needs to be installed on big servers such as Linux or Solaris servers. We can say it is a combination of both hardware and software. The software requirement depends on the total number of Active Sessions (AcS) that can be supported by the PCRF. With that we need a database which is directly proportional to the number of CPUs. In this Type B can support more attached subscribers than type A and it is also capable to provide more throughput as well as high BHSA and EPSB capacities.

Features of the PCRF		
	Type A	**Type B**
EPSB	3,150,000	4,200,000
Attached Subscribers	13,500,000	18,000,000
Throughput (Gbps)	25	55

15.6. Signaling Capacity for Core elements:

Signaling in LTE network is a complex job; we cannot calculate it directly since it mostly depends on the equipment itself along with the data traffic distressing it **or we can say control plane is directly proportional to user plane**. Now we will find out the signaling capacity for core elements. We know it is measured in expressions of transactions per second, and this value is intended by multiplying the number of bearers in a busy hour [EPSB] with the number of transactions per second per bearer [As per NSN White Paper].

Elements	**Transaction per sec per bearer**	**Signaling Capacity (Transaction per sec)**	
		Type A	**Type B**
MME	9.2	139,500,000	186,000,000
S-GW	3	9,450,000	12,600,000
P-GW	2	6,300,000	8,400,000
PCRF	2	6,300,000	8,400,000

Signaling Measurement for HSS:

Calculation for measurement of the HSS signaling is quite same as above discussed equations. Signaling capacity is expressed in transaction per seconds, and it is result of multiplying the number of subscriber with the transaction per second per subscriber. HSS transactions per second per subscribers are 6.2 as per NSN.

	Type A	Type B
Subscribers	15,000,000	20,000,000
Signaling (tps)	93,000,000	124,000,000

If we take example of our last 14 eNodeB which are connected to one MME for the purpose of control and management and also connected to S-GW for accessing the P-GW to use its services.

If we talk about the term traffic flow, each link carries specific type of traffic flows having some features. However, the traffic flow must be conserved among the link at specific point. For explaining the scenario we will take example of that 14 eNodeB . For the S1- User plane data it is from eNodeB to S-GW, the BW traffic flow and conservation are given below.

Bandwidth Flow Conservation in S1-U Interface		
eNodeB	**Traffic Entering the S-GW (Mbps)**	**Traffic exiting the S-GW(Mbps)**
1	29.65	1912.75
2	33.05	
3	35.37	
4	38.27	
5	41.83	
6	26.99	
7	70.05	
8	96.33	
9	118.20	
10	104.26	
11	264.21	
12	296.66	
13	356.91	
14	400.97	

Number of subscriber and busy hour session attempts flow conservation is given below table. Normally, the traffic flow depends on the topology of network, the number of core elements and the capacity of each equipment.

Flow Conservation for Subscriber's number			Busy hour session attempt conversation		Attached subscriber flow conversation		Flow conversation for EPS bearers	
eNodeB	**Traffic Entering MME**	**Traffic Exiting MME**	**Traffic Entering MME**	**Traffic Exiting MME**	**Traffic Entering MME**	**Traffic Exiting MME**	**Traffic Entering MME**	**Traffic Exiting MME**
1	1125	72575	435780	28112652	1013	65318	127	8165
2	1254		485749		1129		141	
3	1342		519837		1208		151	
4	1452		562447		1307		163	
5	1587		614740		1428		179	
6	1024		396657		922		115	
7	2658		1029603		2392		299	
8	3655		1415801		3290		411	
9	4485		1737310		4037		505	
10	3956		1532396		3560		445	
11	10025		3883284		9023		1128	
12	11256		4360124		10130		1266	
13	13542		5245629		12188		1523	
14	15214		5893295		13693		1712	

Whereas signaling does not need to be conserved among the interfaces because it depends on the core equipment itself, and it differs from one element to another.

IMPROVING LTE THROUGHPUT AND SERVICE QUALITY

With the increase in radio capacity will improve user data throughput and user experience. But we know we cannot easily increase licensed LTE radio channel size, the other way is to deploy more LTE cell sites to coverage smaller radio areas. A lot of smaller cells, e.g. Pico cells, can supplement three-sector macro cells.

We know in Pico cells can host less concurrent user handsets, but on the other hand it provides better radio signal quality and throughput rates to each subscriber. But this thing require separate devoted backhaul networks to high user demand environments like stadiums, business parks, conference centers or other public areas.

With the deployment of these smaller cells within the existing coverage area of macro cells also increases radio interference and increases handovers. For this Advanced LTE radio network investigation and plan adaptation is requisite to diminish side effects of deploying many small radio cells to enhance LTE throughput and User necessities.

Major Sources-

- Data and Control Plane Traffic Modelling for LTE Networksby Dima Dababneh, Marc St-Hilaire
- Traffic Model for Long Term Evolution Networks by Dima Dababneh, Marc St-Hilaire
- LTE Traffic Generation and Evolved Packet Core (EPC) Network Planning by Dima Dababneh
- Nokia Siemens Networks, "Signaling is growing 50% faster than data traffic", White paper, 2012

16. TOPOLOGIES FOR LTE BACKHAUL

The requirement for novel high-speed cellular data services has caused network designer to re-evaluate backhaul capacity requirements. The planning practice must take difficult network topology considerations into account. Link capacity alone is not sufficient for a flourishing LTE backhaul network. Many other factors need to be measured while designing the backhaul network.

Details for some of the topologies are given below:

16.1. DAISY CHAINS

This topology is also known as the linear topology which have a two-way link between one Cell Site and the next cell site. Though, this is expensive for a network, because each cell site (except for the Cell at each end) needs two receivers and two transmitters. But by modifying this technology, connecting two sites at end makes a ring topology.

Current 2G/3G backhaul networks for TDM circuits have often depended on daisy-chained links to carry the individual circuits. But for Ethernet packet networks which connect every cell sites to
each other and with the core network, in that case daisy chains topologies are not a good option, because traffic needs to pass links numerous times to provide the preferred connectivity. In this case it is very difficult to add new cell sites because it creates the chains longer and make worse associated problems.

Issues: If any of site goes down the sites next to the down site will be also down, there will be no backup in that case.

16.2. HUB & SPOKE

In the In Hub & Spoke or Site-to-Site network topology, one physical cell site act as Hub (Example, Macro Cell), while other physical cell sites act like spokes (Pico or Micro Cell). All the Spoke cell sites are connected to each other via Hub site. All the communication in this topology goes from the HUB site always.

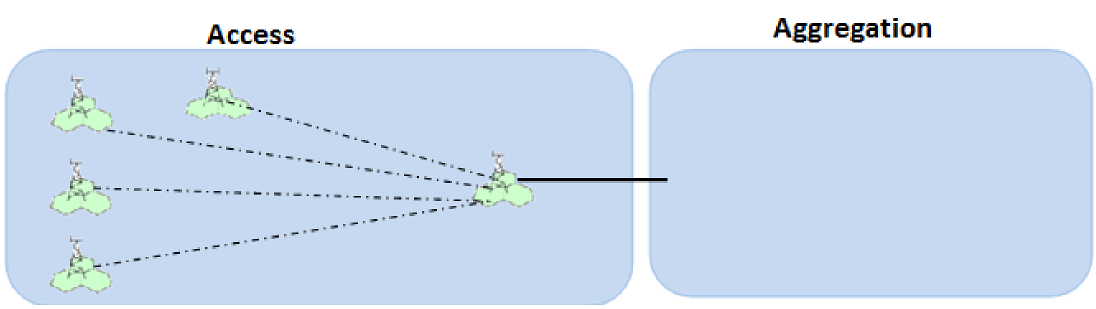


Figure 40: HUB & Spoke Topology

Pros:

There are some good points using this topology which are given below:

- In this topology, Individual links scattering out from a single hub site is improving the connectivity and capacity requirements of LTE as compared to daisy chains.

- Backhaul is based on IP,If we have N Nodes in a network, to connect all nodes only N-1 routes are necessary; that will reduces the complexity of a network,

- If we have less number of routes it leads to more efficient use of insufficient transportation resources. User can experience better throughput.

- IN this case Spokes [eNodeB] are simpler, and as per the network requirement new spokes can be connected quickly.

Cons: But still the overall packet transfer capacity is still concentrated on the hub site, but with this network accessibility and upgradeability factors are better. This model is centralized [dependant on HUB] and day-to-day operations may be relatively inflexible. Any Changes at the hub site could have unexpected consequences across the whole network. In these, packets scheduling is more complex for the network operator. Network resources need to be utilized very carefully to avoid starving the hub because resources are insufficient. To keep HUB operating efficiently careful traffic analysis and precise timing is required. The hub can be a bottleneck to the network. All of the traffic will flows through the HUB, Total transportation capacity of the network is limited by the hub's capacity. If any delays arise at the hub (e.g., weather, Terrain) site it can result delays across the entire network. The entire packets routed through the Hub before reaching at, then it probably requiring a much longer expedition than a direct point-to-point links.

16.3. TREE/TIERED NETWORKS

A tree topology is a unique type of network structure in which many connected eNodeB are arranged like the branches of a tree. It split the network into multiple, smaller hub and branch sites which will result in more flexible traffic routing and capacity distribution. ENodeB -to-eNodeB connections (such as LTE X 2 interfaces) are much shorter and link upgrades increase and it grant capacity exactly where needed. With this topology we have very few numbers of hops from the core edge to the cell site, which result in strict low packet delay and latency requirements of LTE.

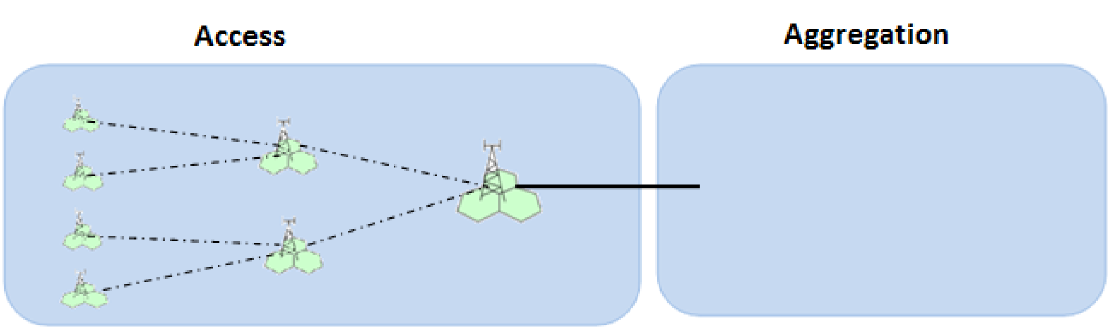


Figure 41: Tree Topology

Advantages of tree topology:

- It is more scalable, because leaf nodes can easily add more nodes in the hierarchical chain. We can easily add nodes as per the Network requirement.
- If any of nodes get damaged, other hierarchical networks will not be affected. Each node will be independent from other nodes in other hierarchy.
- It is very easy for Network Optimizer to maintain and fault finding.
- All traffic will be distributed; there will be less delay in the network and less chances of congestion.

Disadvantages of tree topology:

- Lot of resources required such as cabling, microwave or other links.
- Lot of maintenance required for these topologies.
- If any failure occurred at backbone it will affect the whole network.

16.4. Ring Topology:

It is a network topology in which each nodes connects to exactly two other nodes in the network, which form a single pathway for signals through each node, which forms a ring.

Ring topology supports the best of all networking features in terms of capacity, accessibility and upgradeability. This topology has a feature of fast link failure detection and recovery to make sure carrier-class transport operation.

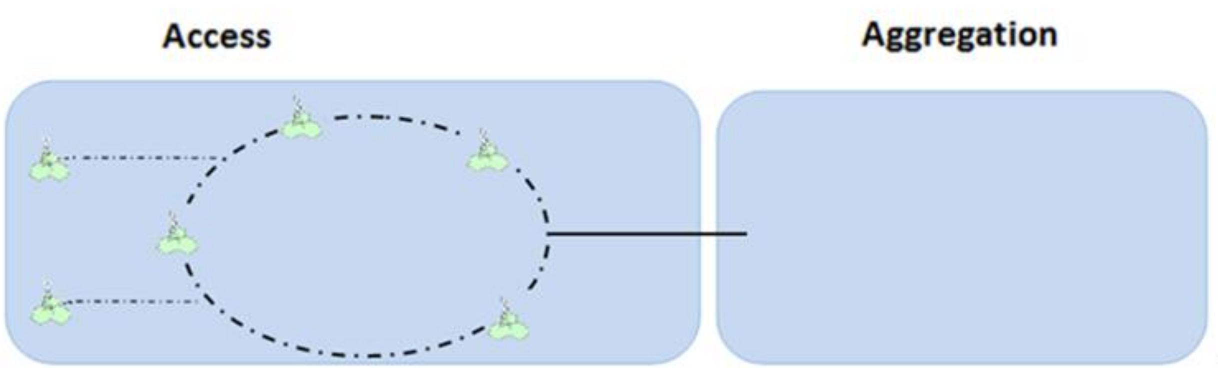


Figure 42: Ring Topology

Advantages:

- This is very orderly topology network in which every device has access to the token and the opportunity to transmit.
- In the case of heavy traffic load it performs better than other topologies.
- It does not need a central node to manage the connectivity between the sites.
- If we need to add and install new site it is quite simple as we need to only remove only two connections between two devices, because it has a point to point link between two nodes.
- As it has Point to point line between two nodes it make easier to identify and isolate faults.
- It has naturally built the dual uplink connectivity to the nearest aggregation point.

Disadvantages:

- In this topology one issue with any site can create problems for the entire network. But this issue can be resolved by using a dual ring topology or a switch that closes off the break.
- In this latency is directly proportional to number of nodes used in the network.
- In this topology link bandwidth is shared on all links between devices.
- Introduces aggregate BW from neighboring node hence limiting the number of cell sites can be part of the ring.

16.5. Mesh & Combination Network:

Mesh topology is of two types, full Mesh and Partial Mesh. In this topology each node is connected with each other and in Partial mesh some nodes are connected to all other but other nodes are connected to those only in which it is communicating. In case of telecom, some pico or micro cells are connected with the macro cell, all of the communication is based on Macro site or we can say they are sub part of Macro site. In more detail it is explained in the below diagram:

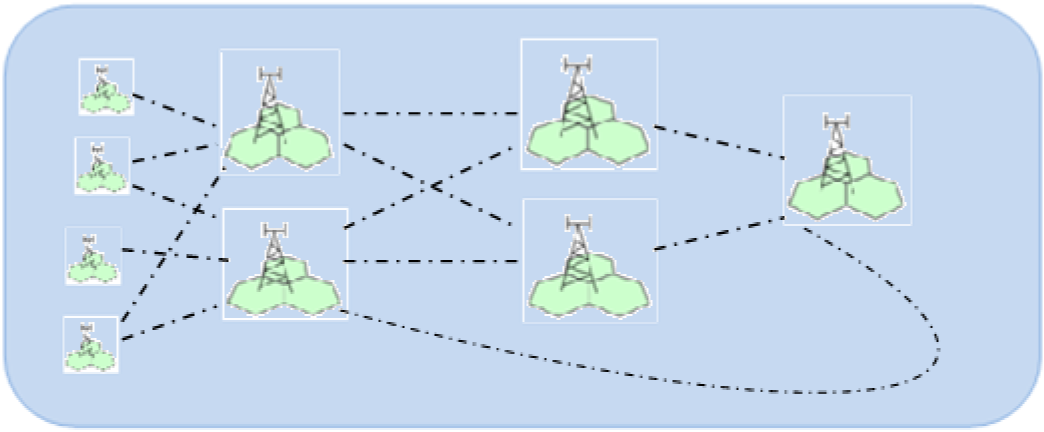


Figure 43: Mesh Topology

But in any telecom network, network planner cannot rely on one topologies, they have to use combination of topology as per the requirement of the network. All of these things are based on capacity and user requirement.

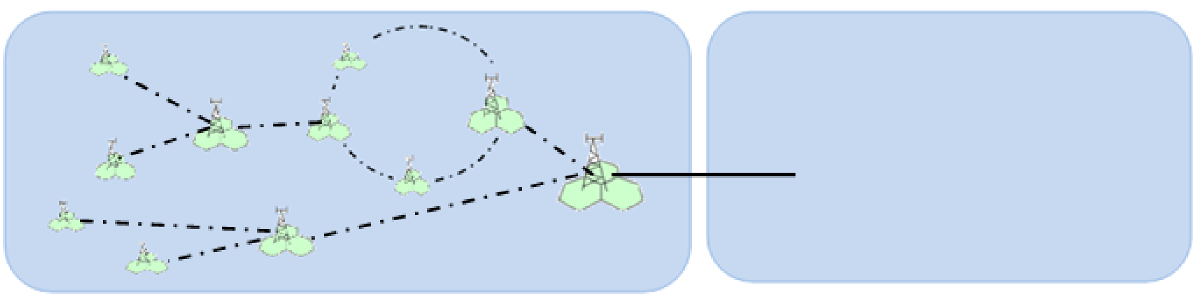


Figure 44: Combination Network

16.6. Summary for the Network Topologies:

In the legacy backhaul network most of the network operators uses hub-spoke or ring access architecture, and some of them were taking advantage of IP/Ethernet's flexibility to begin planning partial mesh topologies. While designing a network it is common practice in hub-spoke topologies to string together a number of spokes into a serial line of cell sites, mainly when we are using microwave. In radio access networks, carrier Ethernet technology using MEF services can run

on many topologies, including parallel links or partial mesh to allow diversity, along with the usual approaches such as an access ring. In mobile backhaul network any of the hub-spoke, ring, and mesh topologies can be used using the key advantage of Ethernet, which is flexible enoughto build any of them.
When we are using capacity is main factor and the capacities needed at a cell site on hub-spoke, serial, ring, or mesh configuration all depend on the site's position in topology; the hub site must carry the accumulated traffic of the further sites and its own. Most of the microwave sites falls in the spokes category.

In the aggregation/metro network part, all topology is simpler (a few rings or in some cases mesh) and mostly used fiber instead of Microwave. In the aggregation sites resiliency is , where traffic from hundreds of sites gets aggregated. With the Carrier Ethernet it allows a common data plane across access and aggregation/metro networks.

17. Implementation of Calculation on Geographical Region:

We have already discussed the calculation of Bandwidth, Capacity and utilization requirements in the above equations. We will try to implement all of the discussed calculation in a geographical region and try to explain how traffic is distributed among all the sites. In this part we will try to explain in which area which type of site is required, what is the capacity requirement of that site and how much capacity required connecting a site with the backhaul network. We will describe this section by dividing it into some parts.

17.1. Geographical Region - Regina:

In the below picture it is a representation of any geographical region having LTE sites, In first picture we can see there are lot of sites in this geographical region. This is the part of planning process in which we decide where we required site and how much spectrum a site needed it all depends upon the traffic intensity of that area. This geographical region can have one EPC core elements or it can share multiple core elements which all depend upon planning and optimization process. In the planning process, geographical area is always at first priority, it means we cannot plant site only with the traffic intensity we have to take care of the terrain and weather conditions of that area.

Which is clear from the below diagram we have less sites near the water bodies.

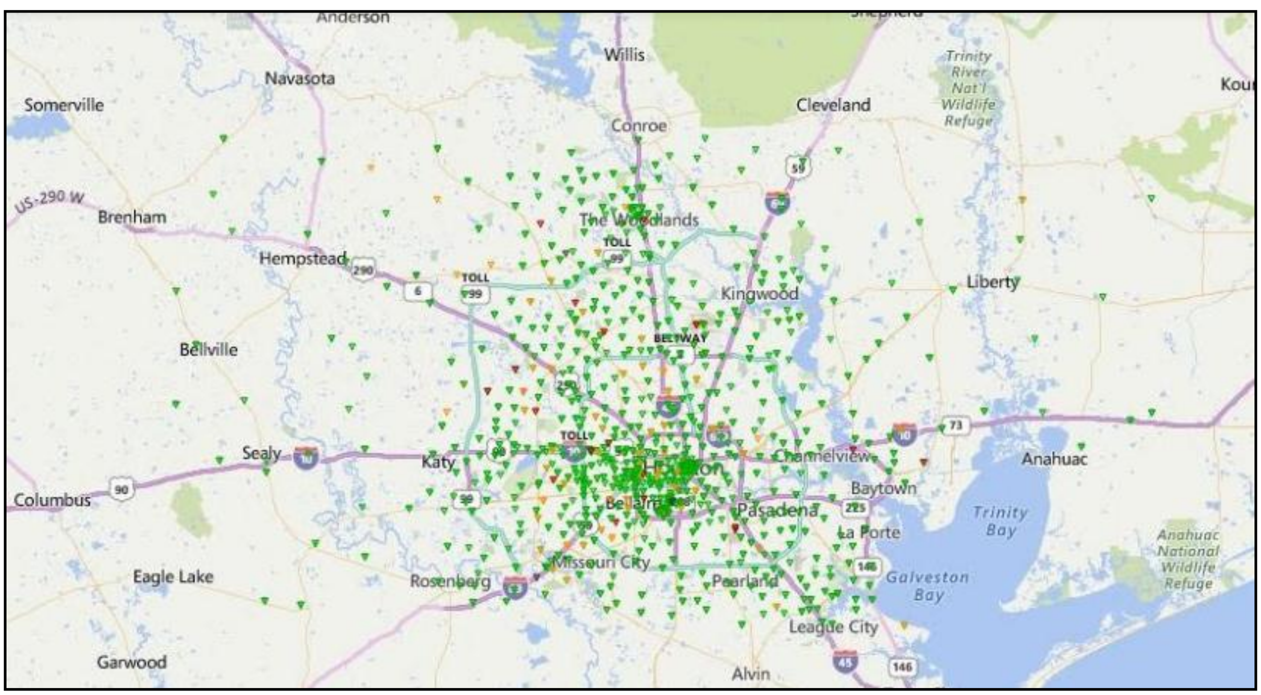


Figure 45: Geographical View of any region having multiple sites

Below diagram is a small representation of a big area or in telecom term we can say it is a combination of 2 or 3 clusters. If we look in this diagram each eNodeB is having three cells and it is very important to notice the azimuth of the site [Direction of Cell site], we cannot implement cells with any direction. Standard azimuths of any eNodeB having three cells are [0 degree, 120 Degree, 240 Degree] but this is a hypothetical thing we cannot implement directly this thing. It all depends upon the traffic intensity and sites requirement if we randomly set the azimuths of a sites it will start overshooting instead of providing proper coverage.

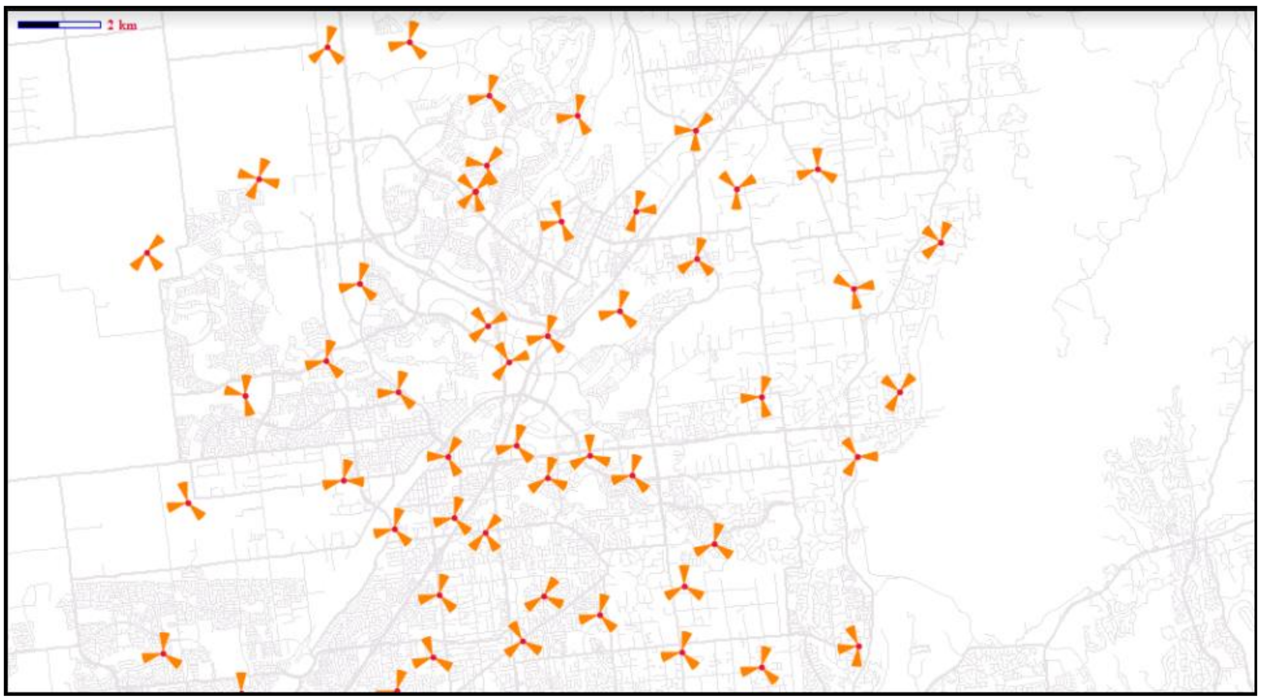


Figure 46: Geographical View of any region having multiple sites with Azimuths

17.2. Traffic Representation for Regina and Planning:

In the following figure we have taken the example of Regina City in Saskatchewan, CA. We are dividing the Regina city hypothetically otherwise there are many planning and optimization tool to divide any area. By dividing this region we will plant the enodeb according to traffic intensity. In Macro Sites area we know there will be a busy part and there will be a lot of user at every point so we will provide more resources to those area as discussed above we provide 20 MHz spectrum and this Macro area will be further subdivided for In building solution such as Pico and femto cell, we haven't described those part in our

diagram. For sub macro sites we have those sites which have less traffic as comparison to Macro sites and if look in the figure all the macro area is covered by the sub-macro area.
Third part is Rural macro sites, these sites always have less traffic, these sites are plants either near the Highways or in Rural area, These sites can shoot at long distance to cover maximum area, in most of the cases Operator always prefer lower bands such as 800 MHz or 900 MHz because they can shoot at long distance.
These Rural sites are mostly connected with the Fiber link instead of putting a physical Fiber or other link, which can save resources. These Rural sites are mostly connected with a part of topology to the big sites.
By planning any network in this way can save lot of resources and we can easily implement this.

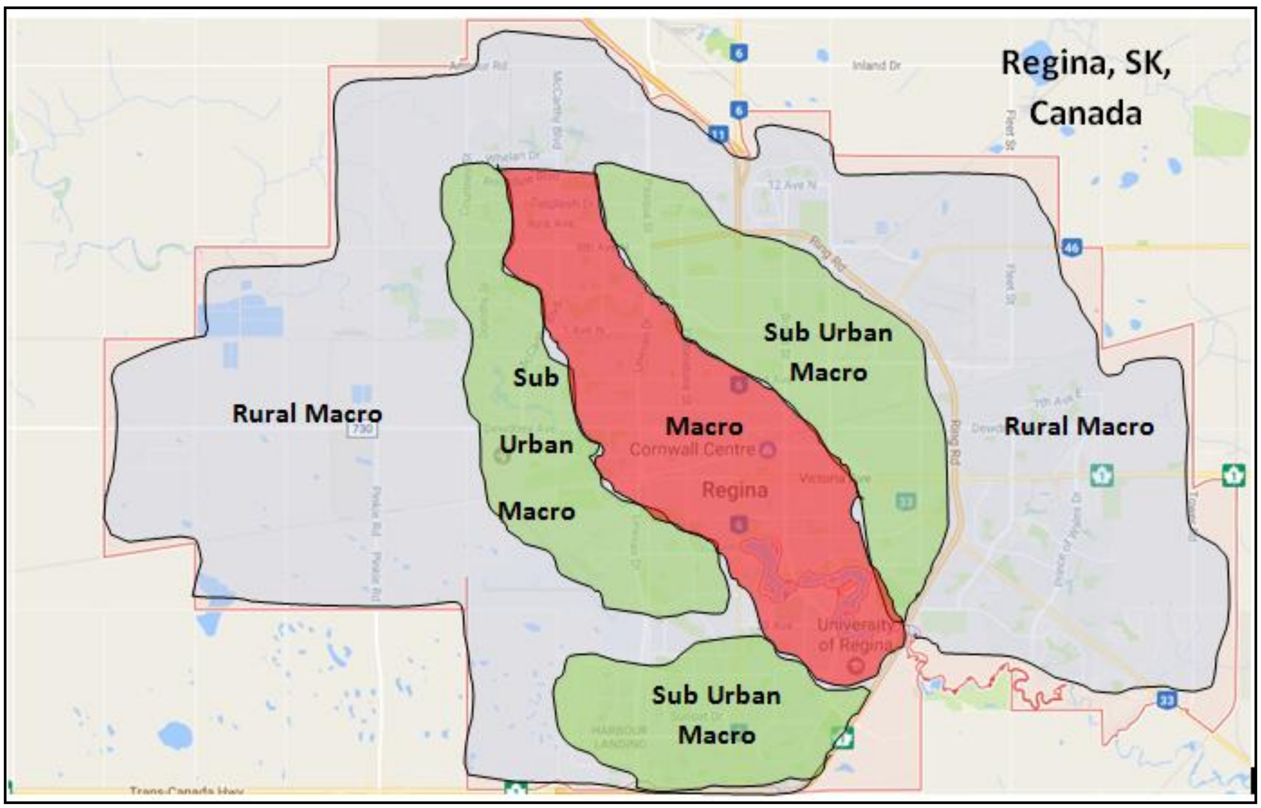


Figure 46: Regina – Divided into three parts

Blue Shaded Area – Rural Macro

Green Shaded Area – Sub-Urban Macro

Red Shaded Area - Macro

17.3. Theoretical Capacity Requirement for Regina region:

As we already explained in above diagram the Regina region with its sub category based on traffic intensity. We hypothetically assume some sites in Regina region and we planted those sites on the Google Map which is give in the below diagram. These all sites are connected with the core network by mean of various topologies. As we cannot attach each site with the core network directly so we used topologies to connect these sites. Some of these sites have high capacity which can bear traffic load of other sites which is clearly mentioned in the below diagram. For connecting these sites, for Rural sites we use Microwave link because mostly these sites are at a long distances. With this we saved our resources and costs.

We used Ring, Tree and Hub- Spoke topologies at different points as required and these are combination of all the topologies. We have divided sites between three part R# which are Rural Sites , SU # which are sub urban sites and M# which are Macro sites and some of the macro sites are directly connected with the core network.

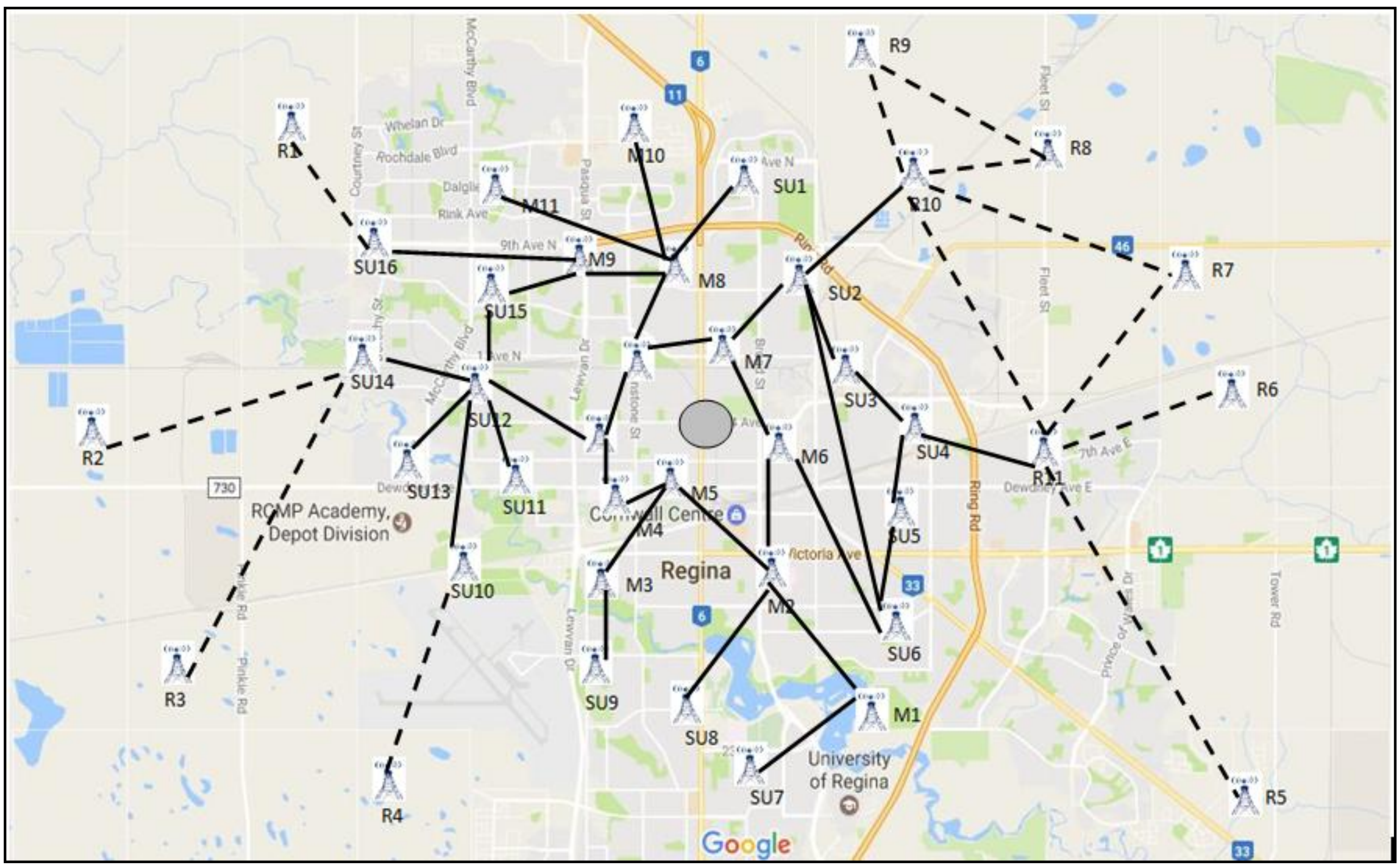


Figure 47: Regina – Traffic Calculation

Site Type	Description	Notation	Capacity Req	
Macro	20 Mhz,3 Sectors,2 x 2 MIMO in DL	M#	417 Mbps	Used for Downtown area
Sub Urban Macro	10 Mhz,3 Sectors, No MIMO	SU#	105 Mbps	Used for Sub Urban Area
Rural	5 Mhz,3 Sectors, No MIMO	R#	52 Mbps	Used for Rural Area
Femto	20 Mhz,1 Sectors,2 x 2 MIMO in DL	F#	139 Mbps	Not Used In this network

After planting all ENodeB we have connected these with the different links. As we have already calculated the Backhaul Capacity requirement of these sites in above calculations so we have used these directly over here. But we haven't used any femto cells because we are generating capacity requirement with a hypothetical approach.

Calculation for this is very simple, each site is connected with the other, For example Rural 1 is connected with the SU 16 the link capacity requirement between Rural and SU 1 is 52 Mbps. When Su1 is connected with the macro site then link capacity will be Rural + Sub-Urban which is 157 Mbps. Just by following this concept we have made a theoretical planning for whole town. But we cannot implement this on any network because lot of other factor and optimization need to be consider for a perfect network.

We have used topologies so the main benefit using it we have a redundant path for every site, if one site will be down the traffic flow will go to the other link just by following some basic concept of Traffic engineering. After the all calculation when each site is connecting with the core network it require a ~2 Gbps of link capacity. But this is just a theoretical approach we will try to find some other aspects in next diagrams.

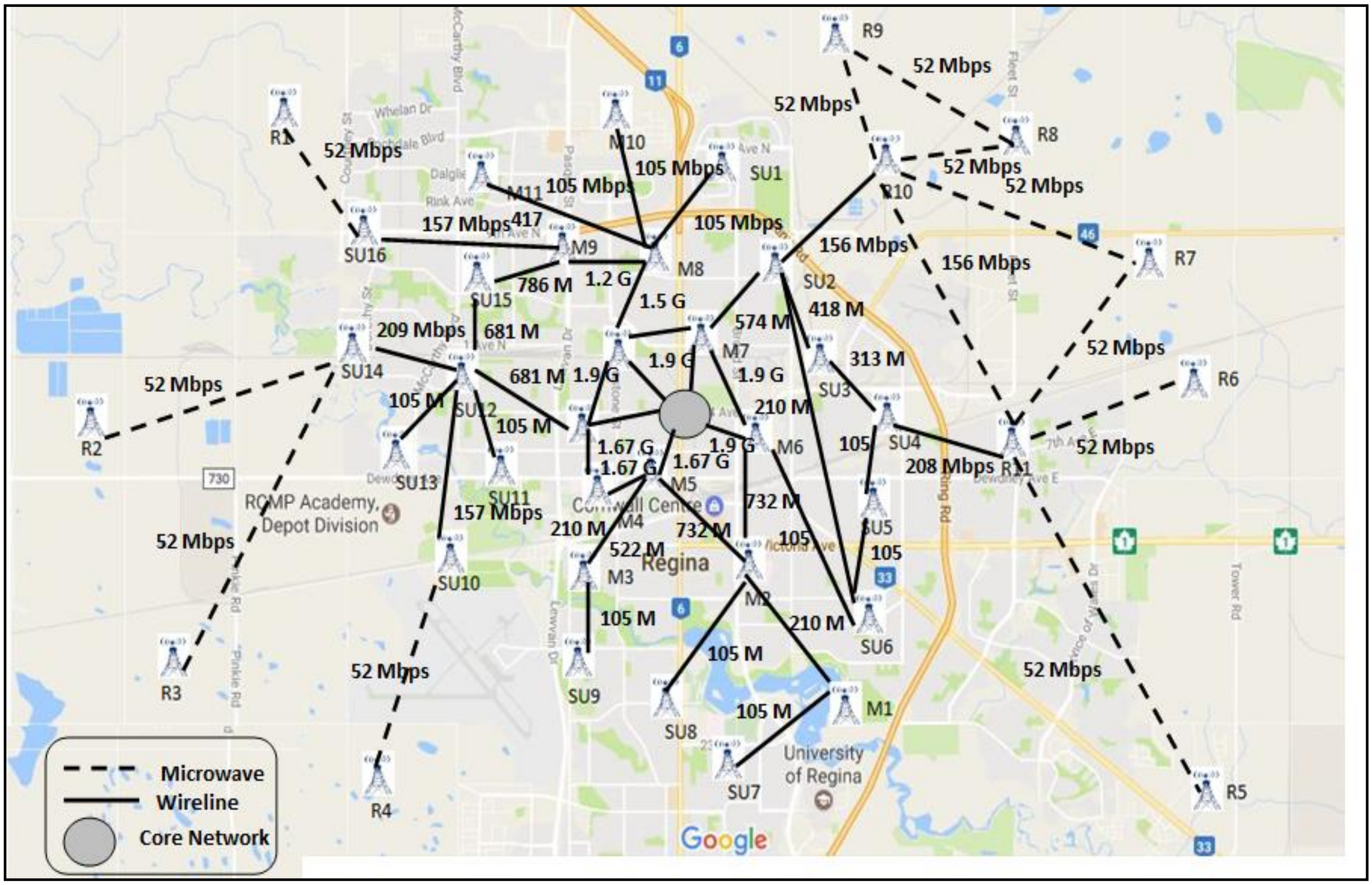


Figure 48: Regina – Traffic Calculation

17.4. Traffic Capacity Requirement for Aggregator in Regina Region:

The above explained method is a theoretical approach, we cannot directly connect the sites with the core using topologies, and we have to need some aggregator points in the network, which forwards the traffic towards the network. It is already discussed above aggregator is just a point where traffic comes from various nodes and moves towards the core network. In the example discussed above we have placed three type of aggregator points A1,A2 and A3.

We are just going to apply that approach in our Regina City. We have divided Regina city in many sub areas, in telecom term we also called these area as Clusters. These clusters having different number of sites and these are connected with the aggregator and aggregation of these sites and cluster will go to next level and it will connect with next aggregator.

In this example we have not explaining only Regina region, we are assuming all the traffic which comes from small town near the city will aggregate at same core network, because as discussed above Core network have much capacity to bear these loads. Different types of transport mediums are used to connect these sites.

Here again it is just a hypothetical approach, because we need different types of topologies and optimization while designing this type of network. In this a group of sites will connect with the Aggregator A1 and multiple Aggregator A1 will connect with the A2, usually two or three A2 will connect to the A3, and then A3 will be connected with the EPC.

We will calculate the capacity requirement of these links which connects different Aggregator with each other. We will use two types of methods Traffic model and System model to calculate the capacity requirement which we already explained in above topics.

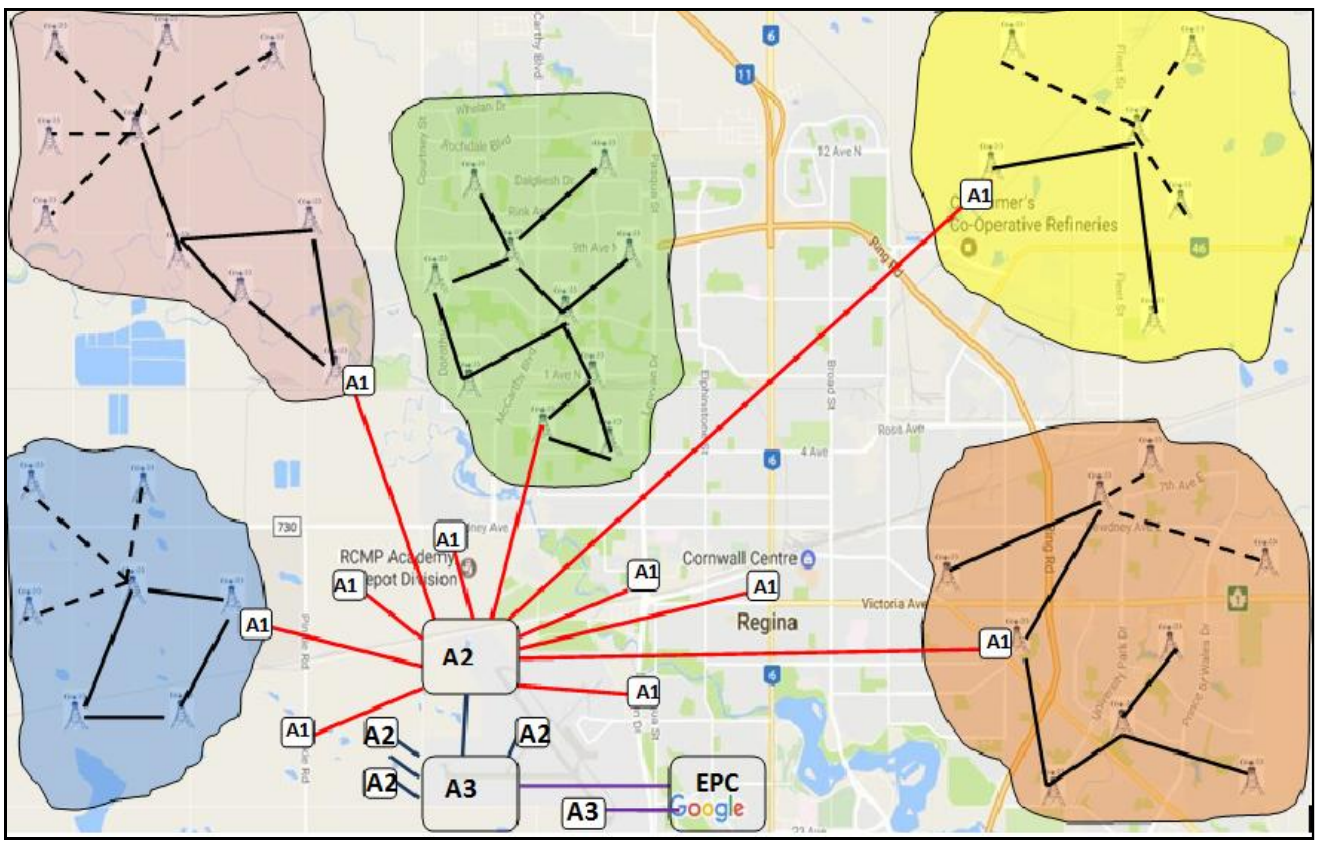


Figure 49: Regina – Traffic Calculation- Cluster Wise

Representation of Regina with Various Clusters

17.5. Traffic Model:

As we have already explained this model, we will take a quick review and try to implement the calculation on these links. We assume a system bandwidth of 20 MHz and a Transport Network overhead of 1.17. ENodeB Busy Hour Average Throughput of 30 Mbps [With no MIMO] is considered from the above discussed Traffic Model.
The capacity required at first point from each site towards the Aggregator A1 Calculated by Cell Peak Throughput in an unloaded Network (CPT) which is multiplied by the Transport Network Overhead (TNO) giving a requirement of 176 Mbps for each site.

= 150 X 1.17 = 176 Mbps

Now A1 and A2 and the capacity requirement for this link is calculated with the formula **[((EBT + SLP + AML) X nA2) +TAR]XTNO.** Here eNodeBBusy Hour Average Throughput (EBT) got from the Traffic Model, S1 and X2 signalling Peak (SLP) and Average Mul Load (AML) for all the sites which come under the A1 aggregator (nA1) plus the target rate [~ 2Mbps] multiplied by the Transport Network Overhead (TNO). The calculation will vary according to number of sites as it is clear from below diagram.

For 10 Site = [((30+0.250+0.022)X10)+2] X 1.17
= 357.7 Mbps

For 6 Site in a cluster = 215 Mbps

For 7 Site in a Cluster = 250 Mbps

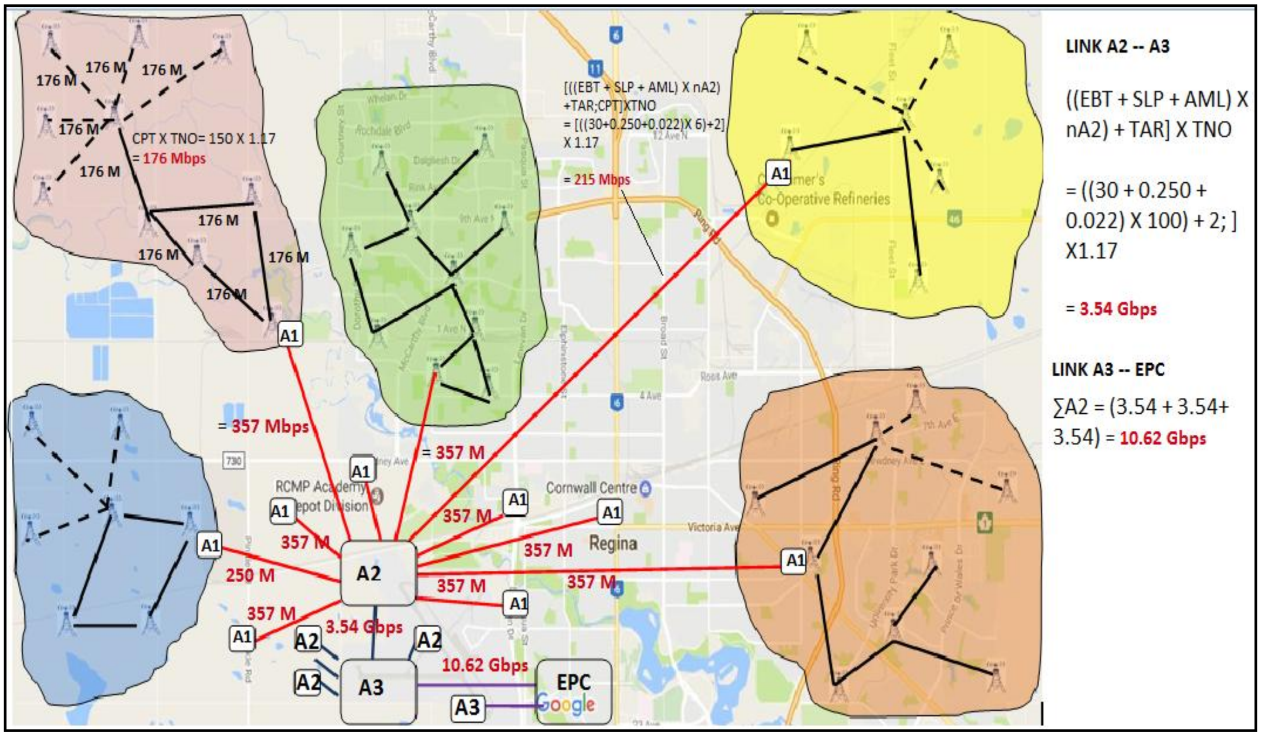


Figure 50: Regina – Traffic Calculation- Cluster Wise

Now Calculation between A2 and A3 [Here A2 is a combination of different small town and cities] which is calculated by formula **[((EBT + SLP + AML) X nA2) +TAR]XTNO** .With the calculations in this example we get a requirement of 3.54 Gbps.

Capacity requirement of Link between A2 and A3 = Max[((EBT + SLP + AML) X nA2) +TAR]XTNO

= [((30+0.250+0.022)X100)+2]X1.17
= 3.54 Gbps

Now between A3 aggregator and EPC network , it is calculated by formula **Sum of all A2**With the calculations in this example we get a requirement of 10.62 Gbps.

Capacity requirement of Link between A3 and EPC = Sum of all A2

= 3.54 + 3.54+3.54

= 10.62 Gbps

17.6. System Model:

Other way for dimensioning is the System Method Link Dimensioning model and this method is also discussed above. Last mile calculation is same as the above, we have to calculate the requirement of other links.

Last Mile Capacity requirement = = 150 X 1.17 = 176 Mbps

Now requirement between A1 and A2 link is calculated by formula **EMT X TNO X nA1** and result of calculation is giving a requirement of 1.17 Gbps.

Capacity requirement of Link between A1 and A2 = EMT X TNO X nA1

= 100 X 1.17 X 10
= 1.17 Gbps

For 6 Site in a cluster = 702 Mbps

For 7 Site in a cluster = 819 Mbps

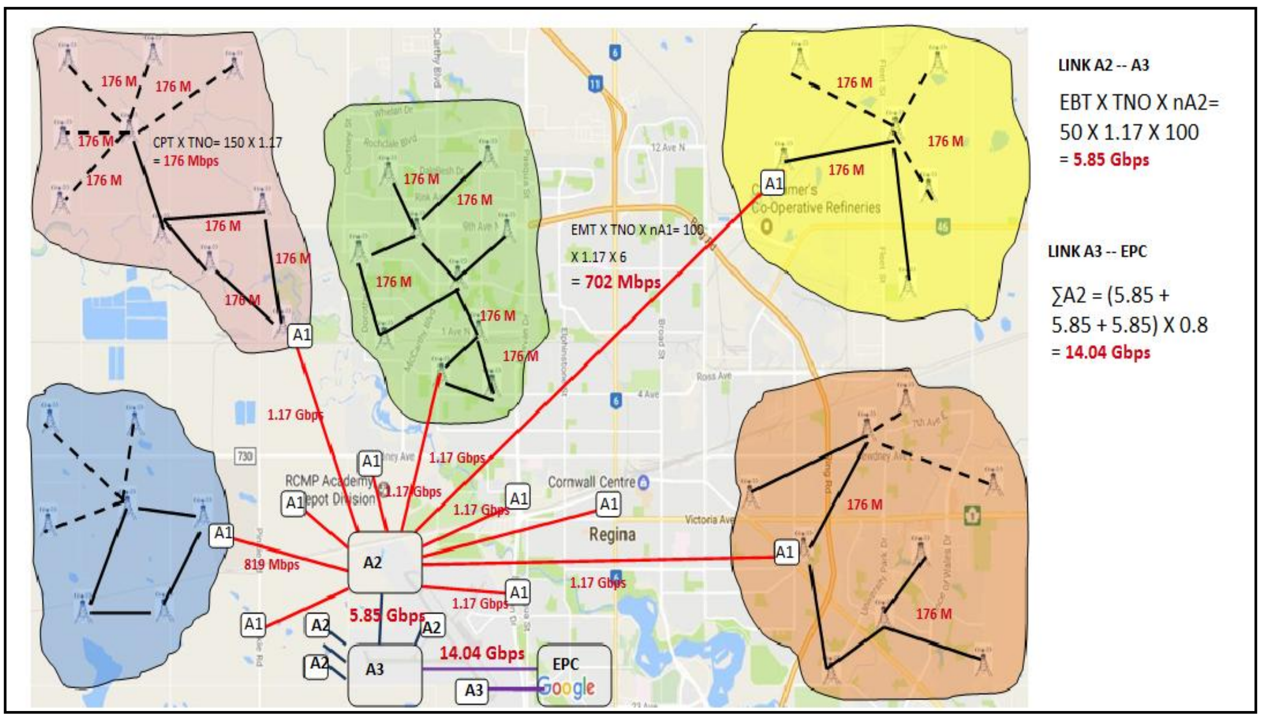


Figure 51: Regina – Traffic Calculation- Cluster Wise

Now the calculation between After link A2 and A3 is calculated by formula **EBT X TNO X nA2** and which gives a requirement of 5.85 Gbps.

Capacity requirement of Link between A2 and A3 = EBT X TNO X nA2

= 50 X 1.17 X 100
= 5.85 Gbps

Last step is the calculation between A3 aggregator and EPC network, which is calculated with formula **Sum of all A2 x 0.8 and here 0.8 is** Busy Hour Displacement Factor. In this calculation we will get a result of 14.04 Gbps.

Capacity requirement of Link between A3 and EPC = Sum of all A2 x 0.8

= (5.85 + 5.85 + 5.85) x 0.8

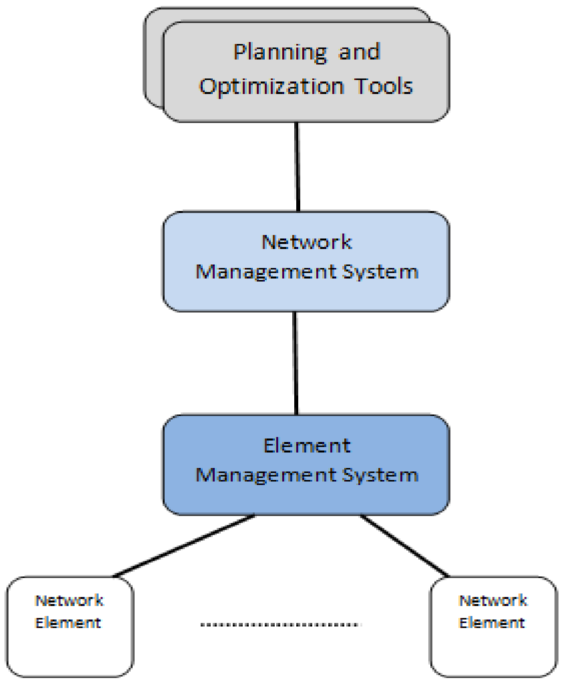
= 14.04 Gbps

18. Network Management:

After the calculation of Traffic and designing the network according to capacity required of various links it is necessary to manage the network. At the initial point of design, all the design activities are done with hypothetical approach, actual requirement is observed when the network will be live. At that point proper management and optimization is required for the network.

Network management of backhaul network is required because day by day capacity requirement is increasing and network complexity is also one factor. In network management we have Element management system (EMS) and actual network management system (NMS). It all comes under OSS (Operation Support system). This system includes all those equipment and software's which required for any network to maintain its network. Operation and Maintenance is also part of this which gathers all information from network which is required for the Network management such as KPI's counters. Network management includes all the group performing activities such as planning, configuring, optimization, troubleshooting and monitoring the network. Network Management systems have a central point which collects all the information about the network and perform optimization task either manually or automatically.

All of the optimization configuration is maintained by the NMS at any centralized location where any optimizer can easily change network element configuration or parameters remotely when required. In the whole process collected information includes network topologies and updated configurations, troubleshooting and isolation of the faults.



High Level Network Management Architecture

Some of the main task of Network Management is system is given below:

- **Fault Management** – Detect Fault in the network and give a notification.
- **Performance Management**–Analyze the performance of network by collecting KPI's and comparing with the threshold values.
- **Configuration Management** – Monitor and control network configurations
- **Optimization** – Provide optimization to network configurations and settings.
- **Self-Organizing Network** – It will detect fault and optimize without intervention of NMS.

These are some task by which we gen get a perfect network.

19. Summary

Objective of our project was to analyze the traffic requirement for User, control and management plane in the LTE backhaul network. To describe this we have started with LTE network architecture and we have reviewed the basics of LTE which was required for the description of Traffic Calculation. We have also discussed the LTE requirements which play a vital role for dimensioning the network.

After that we have described the LTE interfaces and Traffic types and discussed the LTE Backhaul requirement such as QoS, GoS and Traffic Flow which is required to prioritize and manage the traffic flow inside the network. Traffic management is also a important part of a network which is described in next section with ENodeB traffic Management topic which also cover how traffic is distributed in the backhaul network and which IP technologies we can use in Backend to manage the traffic, which Includes E-Line, E-Lan types.

LTE features has been improved with the introduction of LTE Advanced and this topics cover all the new features of LTE including Carrier Aggregation, MIMO, CoMP and all of these features are used in current network design process to provide enhance services to the users.

After that we have started with the calculation part of the Traffic in the network. Which we have started from the Radio interface by calculating Theoretical Peak Throughput and Utilization of the ENodeB, we have also covered the Traffic Pattern for whole day including busy hour of a day. We have also calculated the Throughput including transport headers and other Backhaul Traffic including Signaling traffic.

After the each calculation we have found the capacity requirement of each links between aggregators and which goes toward the EPC network. We have used Traffic Model and Link Model for the calculation. We have calculated every traffic types in EPC with various formulas and with that we have found the capacity of each network element in backhaul network and for how many users we need how many network elements.

In the last we have put all the findings in a map; we have designed a network for Regina region with various methods which we already discussed. With the Hypothetical assumption we have designed a network.

20. Conclusion:

In this project we have learned about various traffic types in User, Control and Management plane such as S1-U,S1-C,X2-U,X2-C, O&M, IPSec and their functionality in the LTE network. For the traffic analysis we have calculated traffic for Last Mile for ENodeB and we have analyzed loading, Capacity and traffic pattern for each cell. We observed the behavior of each cell with different frequency spectrum and calculated the peak and average throughput which was used for the backhaul dimensioning process.

We have analyzed peak and average throughput of each ENodeB with and without transport overhead and we have considered each aspect to calculate this value. As we have different type of Sites such as Macro, Sub-Urban Macro, Pico; we have calculated traffic for each site by assuming various bandwidths, which we have used further while designing the network. As a network is not directly connected with the core network, to save the cost and resources we are using various topologies inside a network and to connect these topologies with each other we used various aggregator in between of network before the EPC. It is necessary to calculate the capacity requirement between each link of aggregators, so that we can make a efficient network without wastage of any resource. We know for designing a perfect network we required optimization and lot of study of the network area, but in our project we are designing network with the hypothetical approach. Link dimensioning is necessary as we cannot provide link of any size, which will waste a lot of resources.

EPS traffic also plays an important role in the LTE network, with the help of various research papers and guidance of the experts we have calculated the traffic for the EPS using various parameters and formulas. For that we have used pre calculated values. After the calculation we have observed network elements in the core network are directly proportional to the number of users. As number of users increase in the network we need more network elements. All of the calculation for each network element is discussed in this papers. Analysis of each component we have performed in this paper.

With the help of expert guidance and hypothetical approach we have designed a network for the Regina City. In that we have created a network with the theoretical values and tried to find how much bandwidth is required for the backhaul links. We also used traffic and system model to design the network.

In whole project we have worked in the traffic analysis and backhaul capacity and planning requirement.

References:

[1] Referred from the contents and material provided y Mr. JunedNoonari -Fujitsu,US

[2] TusharKanti Das - Specialist - Ericcson India Pvt Ltd.

[3] VedParakash Sharma - Specialist - Ericcson India Pvt Ltd.

[4] Rajesh Kumar - Solution Architect - Nokia Siemens Network, India

[5] Sachin Sharma - Engineer - Shaw,Canada

[6] Syed Rizvi - Manager Ericsson India Pvt Ltd

Referred Books and Research papers.

[7] LTE Backhaul Planning and Optimzation by Esa Markus Metsälä and Juha T.T. Salmelin

[8] Mobile Backhaul by Esa Markus Metsälä and Juha T.T. Salmelin

[9] A White Paper by the NGMN AllianceLTE Backhauling Deployment Scenarios

[10] NGMN_Whitepaper_Guideline_for_LTE_Backhaul_Traffic_Estimation

[11] Data and Control Plane Traffic Modelling for LTE Networksby Dima Dababneh, Marc St-Hilaire

[12] Traffic Model for Long Term Evolution Networks by Dima Dababneh, Marc St-Hilaire

[13] LTE Traffic Generation and Evolved Packet Core (EPC) Network Planning by Dima Dababneh

[14] Understanding the Super-sized traffic of the Super Bowl by Jeffrey Erman, K.K. Ramakrishnan

[15] Understanding Mobile Traffic Patterns of Large Scale Cellular Towers in Urban Environment by Huandong Wang1, Fengli Xu1, Yong Li

[16] LTE BACKHAUL REQUIREMENTS: A REALITY CHECK By: Peter Croy, Sr. Network Architect, Aviat Networks

[17] LTE Design and Deployment Strategies by ZeljkoSavic

[18] Quality of Service (QoS) in LTE by BEC Technologies

[19] Co-Transmission Solution Workshop (2010.08.25) by Huawei

[20] X2 Interface Networking Solution Workshop (2010.08.25) by Huawei

[21] LTE Transport Solution Workshop (2010.10.06)v2 by Huawei

[22] Quality of Service in LTE Wireless Backhaul Applications with VortiQa Software for Service

Provider Equipment by Bharat Mota

[23] Intelligent Traffic Enforcement for LTE backhaul by YasirZaki∗, ThusharaWeerawardane

[24] Dimensioning of the LTE S1 Interface by X. Li, U. Toseef, T. Weerawardane

[25] Signaling is growing 50% faster than data traffic by Nokia Siemens

[26] LTE Network Throughput Estimation by Alexander Babkin, Alexey Pylenok

[27] Infonetics-Research-Whitepaper-Using-Carrier-Ethernet-to-Backhaul-LTE By Michael Howard

[28] LTE Dimensioning Guideline- Nokia Siemens

[29] Dimensioning of LTE Network Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface by Abdul Basit

Referred Internet and Websites

[30] https://en.wikipedia.org/wiki/Spectral_efficiency

[31] https://pdfs.semanticscholar.org/87ed/2c90661d1645722b278cbd06587d4960239e.pdf

[32] http://www.omnisecu.com/basic-networking/site-to-site-wan-network-topologies-hub-and-spoke-topology.php

[33] https://answers.yahoo.com/question/index?qid=20061219041807AAoNaaH

[34] https://fossbytes.com/tree-topology-advantage-disadvantage/

[35] https://en.wikipedia.org/wiki/Ring_network

[36] https://www.csie.ntu.edu.tw/~hsinmu/courses/_media/wn_11fall/ofdm_new.pdf

[37] http://www.dragonwaveinc.com/solutions/mobile-backhaul\

[38] http://www.3gpp.org/technologies/keywords-acronyms/100-the-evolved-packet-core

[39] https://en.wikipedia.org/wiki/System_Architecture_Evolution

[40] http://www.bectechnologies.net/main/newsletter_images/QoS.pdf

[41] http://www.simpletechpost.com/2012/05/default-bearer-dedicated-bearer-what.html

[42] http://www.simpletechpost.com/2013/01/quality-of-service-qos-in-lte.html

[43] https://en.wikipedia.org/wiki/Grade_of_service

[44] http://welcometodannysblogger.blogspot.ca/2009/05/lte-interfaces-s1-and-x2-in-u-planec.html

[45] https://www.wikipedia.org/

[46] https://www.google.ca

[47] https://www.youtube.com/

[48] http://www.tmcnet.com/voip/departments/articles/306439-mobile-backhaul-networks-next-generation.htm

[49] http://visual.ly/evolution-telecommunication

[50] http://wikipedia.com

[51] http://www.tutorialspoint.com/umts/umts_history_of_mobile_communication.htm
[52] http://www.winlab.rutgers.edu/~narayan/Course/Wireless_Revolution/vts%20article.pdf
[53] http://go.radisys.com/rs/radisys/images/paper-lte-eutran.pdf
[54] http://www.ciscopress.com/articles/article.asp?p=1156957
[55] https://www.cmg.org/wp-content/uploads/2013/04/m_97_3.pdf
[56] http://www.oscilloquartz.com/file/press_release/022-29_Synch%20Distribution_final.pdf