QoS Performance Evaluation of Video Conferencing over LTE

Md. Showket Hossen
Md. Neharul Islam

School of Computing
Blekinge Institute of Technology
371 79 Karlskrona
Sweden
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Contact Information:

Author (1):
Md. Showket Hossen
Address: Visättravagen 30, LGH 0704, 14150 Huddinge, Sweden
Email: showket.hossen@gmail.com

Author (2):
Md. Neharul Islam
Address: Kungsmarksvägen 61, LGH 1003, 371 44 Karlskrona, Sweden
Email: rummanmail@yahoo.com

Advisor:
Professor Adrian Popescu
Blekinge Institute of Technology
School of Computing
SE-371 79 Karlskrona, Sweden
Email: adrian.popescu@bth.se

Examiner:
Dr. Patrik Arlos
Blekinge Institute of Technology
School of Computing
SE-371 79 Karlskrona, Sweden
Email: patrik.arlos@bth.se

School of Computing
Blekinge Institute of Technology
371 79 Karlskrona
Sweden

Internet : www.bth.se/com
Phone : +46 455 38 50 00
Fax : +46 455 38 50 57
ABSTRACT

Mobile data usage has been on the rise in relation to the streaming media such as video conferencing and online multimedia gaming. As a result, Long-Term Evolution (LTE) has earned a rapid rise in popularity during the past few years. The aim of this master’s thesis is to analyze the quality of service (QoS) performance and its effects when video is streamed over a GBR (Guaranteed bit rate) and non-GBR bearers over LTE. Using OPNET (Optimized Network Engineering Tool), the performance can be simulated having Downlink (DL) and Uplink (UL) scenarios for video conferencing including web traffic. Further we also measured the performance of packet End-to-End (E2E) delay, packet loss and packet delay variation (PDV). This thesis work is an empirical work, which can be followed up by further research propositions.

Keywords: LTE, Real time application, Video, GBR, QoS.
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Md. Showket Hossen
Md. Neharul Islam
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<th>FULL FORM</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GPP</td>
<td>Third Generation Partnership Project</td>
</tr>
<tr>
<td>ARP</td>
<td>Allocation and Retention Priority</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier Transform</td>
</tr>
<tr>
<td>DL</td>
<td>Downlink</td>
</tr>
<tr>
<td>eNB/eNodeB</td>
<td>Evolved Node-B</td>
</tr>
<tr>
<td>EPC</td>
<td>Evolved Packet Core</td>
</tr>
<tr>
<td>EPS</td>
<td>Evolved Packet System</td>
</tr>
<tr>
<td>E-UTRAN</td>
<td>Evolved Universal Terrestrial Radio Access Network</td>
</tr>
<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
</tr>
<tr>
<td>FDMA</td>
<td>Frequency Division Multiple Access</td>
</tr>
<tr>
<td>GBR</td>
<td>Guaranteed Bit Rate</td>
</tr>
<tr>
<td>GERAN</td>
<td>GSM EDGE Radio Access Network</td>
</tr>
<tr>
<td>GP</td>
<td>Guard Period</td>
</tr>
<tr>
<td>HSPA</td>
<td>High Speed Packet Access</td>
</tr>
<tr>
<td>IDFT</td>
<td>Inverse Discrete Fourier Transform</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MBR</td>
<td>Maximum Bit Rate</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>MME</td>
<td>Mobility Management Entity</td>
</tr>
<tr>
<td>non-GBR</td>
<td>non-Guaranteed Bit Rate</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
</tr>
<tr>
<td>OFDMA</td>
<td>Orthogonal Frequency Division Multiple Access</td>
</tr>
<tr>
<td>OPNET</td>
<td>Optimized Network Engineering Tool</td>
</tr>
<tr>
<td>PAPR</td>
<td>Peak-to-Average Power Ratio</td>
</tr>
<tr>
<td>PCM</td>
<td>Pulse Code Modulation</td>
</tr>
<tr>
<td>PCRF</td>
<td>Policy and Charging Rules Function</td>
</tr>
<tr>
<td>PDCP</td>
<td>Packet Data Control Protocol</td>
</tr>
<tr>
<td>PDN-GW</td>
<td>Packet Data Network Gateway</td>
</tr>
<tr>
<td>PSTN</td>
<td>Public Switched Telephone Network</td>
</tr>
<tr>
<td>QCI</td>
<td>QoS Class Identifier</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RAN</td>
<td>Radio Access Network</td>
</tr>
<tr>
<td>RB</td>
<td>Resource Block</td>
</tr>
<tr>
<td>RLC</td>
<td>Radio Link Control</td>
</tr>
<tr>
<td>ROHC</td>
<td>Robust Header Compression</td>
</tr>
<tr>
<td>RRC</td>
<td>Radio Resource Control</td>
</tr>
<tr>
<td>RTP</td>
<td>Real-time Transport Protocol</td>
</tr>
<tr>
<td>SC-FDMA</td>
<td>Single Carrier-FDMA</td>
</tr>
<tr>
<td>SDFs</td>
<td>Service Data Flows</td>
</tr>
<tr>
<td>S-GW</td>
<td>Serving-Gateway</td>
</tr>
<tr>
<td>SID</td>
<td>Silence Description</td>
</tr>
<tr>
<td>SM</td>
<td>Spatial Multiplexing</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>TDD</td>
<td>Time Division Duplex</td>
</tr>
<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
</tr>
<tr>
<td>UE</td>
<td>User Terminal</td>
</tr>
<tr>
<td>UL</td>
<td>Uplink</td>
</tr>
<tr>
<td>UPTS</td>
<td>Uplink Pilot Timeslot</td>
</tr>
<tr>
<td>UTRA</td>
<td>Universal Terrestrial Radio Access</td>
</tr>
<tr>
<td>UTRAN</td>
<td>Universal Terrestrial Radio Access Network</td>
</tr>
<tr>
<td>VoIP</td>
<td>Voice over Internet Protocol</td>
</tr>
<tr>
<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
</tr>
</tbody>
</table>
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Chapter 1  INTRODUCTION

In this chapter, the overview of LTE, aims and objectives, research methodology, contributions and related work for this thesis and its outline are discussed.

1.1 Overview

Long Term Evolution (LTE) is a field of interest throughout the world due to the demand of using data in mobile devices in terms of streaming of media, for instance, internet TV, video conferencing, single or multiplayer online gaming as well as communicating through mobile video blogging. Long Term Evolution (LTE) [1] is promising radio access network technology standardized in Third Generation Partnership Project (3GPP) [2] in release 8. It is a system towards the 4G technology promising to be increased in data rates and more improved performance. Wireless networks are heading to their third phase. Where the first phase was concerned about voice traffic for voice calling, the second phase emphasized on data traffic. Now it is the period of video traffic in the third phase. As it will be more complex to manage, more efficient way of optimization is required to preclude saturation. Moreover, with the evolution of new technological devices like iPhone, there are plenty of powerful mobile devices. Those are capable to display high quality video contents. It is a pretty challenging task to do video communication through mobile broadband because of bandwidth limitation and demand of maintaining high reliability and quality [3]. Furthermore, it is mandatory to guarantee Quality of Service (QoS).

However, QoS implies traffic differentiation and using multiple bearers with configuration and priority optimization to provide pre-defined quality of service of different users, in LTE networks. Hence an evolved 3GPP QoS concept [4] has been developed. The key elements of the evolved QoS concept are network-initiated bearer establishment and network controlled simplified QoS profiles. These two key concepts of QoS based on QoS Class Identifiers (QCI) [5], which divides the packets in classes based on priority and associating QCI with Traffic Forwarding Policy (TFP). TFP defines a set of parameters for traffic forwarding through all the nodes in between source and the final user. For different traffics classified by QCI, different TFP is assigned which can guarantee the bandwidth wanted.

1.2 Aims and Objectives

The aims of this research are to analyze the performance of delivering video conferencing traffic over non-GBR and GBR bearers over LTE. Network performance measuring tool OPNET (Optimized Network Evaluation Tool) modeler 16.0 is used to develop simulation scenario of Downlink (DL) and Uplink (UL) for video conferencing including web traffic. The major objectives of the study are summarized as follows:

- Collection of qualitative and quantitative data to guide the analysis in suitable direction.
Chapter 1: INTRODUCTION

- Survey of existing literature and network design over LTE.
- Develop the simulation, model, evaluation and testing model.
- Creation of the simulation model for Video conferencing, FTP server and other, different network attribute of OPNET.
- Different constrains in LTE networks like packet delay variation, packet loss and end-to-end delays of video conferencing are discussed.
- Investigating different network simulation and network load and analyzing the simulation results.
- Validation of all simulation results.

1.3 Research Questions

The questions to be examined in this thesis paper are formulated as follows:

Q.1. What is the impact on the packet End-to-End (E2E) delay performance for video conferencing when Guaranteed Bit Rate (GBR) and Non-GBR bearers are established in LTE network under the congested circumstance?

Q.2. What is the impact on the Packet Delay Variation (PDV) performance for video conferencing when GBR and Non-GBR bearers are established in LTE network under the congested circumstance?

Q.3. What is the impact on the packet loss performance for video conferencing when GBR and Non-GBR bearers are established in LTE network under the congested circumstance?

1.4 Research Methodology

In order to determine the video quality in terms of QoS in LTE environment, Qualitative and Quantitative approaches had been taken for this thesis work suggested by John W. Creswell [6].

The main factors that influences QoS performance of video quality is identified in terms of packet delay variations, end-to-end delay, packet loss in LTE environment, by taking advantage from existing research and information based on well-known scholars, related articles and journals like IEEE Xplore, ACM, SCOPUS, Inspec, Google and Google Scholar. Following this, a detailed survey of existing literature related to the current area of research conducted. The essential data will be then collected for the assessment. Upon completion of literature review, certain experiments and simulations performed in order to provide the statistical data that have to be analyzed. Consequently, network modeling placed, which requires careful “deduction and validation” [7]. For the necessity of this study, the LTE network models designed on the workspace of the OPNET simulator with the help of different network entities, in which various experiments deploy to investigate the video quality in terms of packet delay variation, end-to-end delay, packet loss. Quantitative data such as packet loss, end-to-end delay, and packet delay variation collected by research. Finally in the validation, the part of experiment, the simulation results will discuss in different statistical plots and tables.
1.5 Contribution

This thesis paper analyzes performance of QoS metrics i.e. packet delay variation, packet loss and end-to-end delay for video conferencing in LTE networks as well as how well the LTE protocols reply under different network scenarios. Using OPNET modeler 16.0, we validate network models and analyze the results while video conferencing is going on with real-time applications under three different network scenarios.

1.6 Related Work

Different publications and contributions discussed the QoS evaluation over LTE. The authors of [8] described the LTE air-interface with three downlink (the link from the base station to the user equipment) video capacities. They described how the system outage criteria and quality of video can impact on air-interface video capacities. They also discussed different observations over quality with consideration of different cost assumption. In[9] the authors discussed the effects of various QoS. It is connected with scheduling strategies, which imposes over LTE mixed service performance. The authors of[10] presented a new scheduling algorithm for delivering wireless RT video in the case of downlink on LTE. Under delay constraint, they achieved best video quality. The authors in[11] (smoothing of video transmission rates) developed an approach which is called semi-optimal video smoothing approach. In LTE with Quality of Service environment, they managed to generate significant MPEG-4 and H.264 transmission rates.

1.7 Thesis Outline

In this thesis, background of LTE Technology, the basic coverage of the area is described. Network architecture of this study is given in chapter 3. In chapter 4, the simulation design and implementation are described whereas, simulation results and analysis are described in chapter 5. Chapter 6 concludes entire thesis work.
Chapter 2 LTE BACKGROUND

This section depicts an extension of the very general background that is given in Section 1.1. LTE, the modeled system of this thesis paper will be discussed in the first part of this section. Remaining part of this chapter we will describe most important protocols and terms of LTE. The desired information of this subject that is collected from external references will also provide.

2.1 Overview of 3GPP LTE

The next evolution of the Radio Access Network (RAN) is Long Term Evolution (LTE). This is also known as Evolved Universal Terrestrial Radio Access Network (eUTRAN). 3GPP LTE targets to support increase data rates and high efficiency, increased signal range with better user response time, interoperability with circuit-switched legacy networks compared to systems of today. LTE supports a wide range of bandwidth such as 1.4MHz, 3.0MHz, 5MHz, 10MHz, 15MHz and 20MHz bandwidths [12]. LTE uses Orthogonal Frequency Multiple Access (OFDMA) for downlink and uplink Single Carrier Frequency Division Multiple Access (SC-FDMA)[13]. LTE is specified to provide downlink peak rates over 150Mbps, RAN round trip time less than 30ms and three times higher spectral efficiency than High Speed Packet Access (HSPA) in 3GPP Release 6[14].

2.2 LTE Goals

As shown in Table 2.1. LTE is demonstrates to be a high data rate and low latency system as the key performance. FTP (File Transfer Protocol), video streaming, VoIP, online gaming, real time video, push-to-talk, push-to-view is expected to support different types of services including web browsing in E-UTRA. For transmission and reception both UE are expected to be 20MHz. This gives an opportunity to the service provider to make changes to the amount of available spectrum. The spectrum for extra capacity starts with the limited amount of spectrum for lower upfront cost and growth [12].
Table 2.1 LTE performance requirements [12].

<table>
<thead>
<tr>
<th>Measured</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet data rates</td>
<td>Downlink: 100 Mbps, Uplink: 50 Mbps For 20MHz spectrum</td>
</tr>
<tr>
<td>Mobility Supports</td>
<td>Up to 500 km/h but performed for low speeds from 0 to 15 km/h</td>
</tr>
<tr>
<td>Control plane latency (Transition time to active state)</td>
<td>Less than 100ms both in idle and active.</td>
</tr>
<tr>
<td>User plane latency</td>
<td>Less than 5ms</td>
</tr>
<tr>
<td>Control plane capability</td>
<td>More than 200 users per cell for 5MHz spectrum.</td>
</tr>
<tr>
<td>Cell size (Coverage)</td>
<td>5-100km with minor degradation following 30km.</td>
</tr>
<tr>
<td>Range flexibility</td>
<td>1.4, 3, 5, 10, 15 and 20MHz.</td>
</tr>
</tbody>
</table>

### 2.3 LTE Releases and Features

In this paper we will describe Long Term Evolution (LTE) and their important features as follows.

Table 2.2 Technical specifications published by the 3GPP group [15]

<table>
<thead>
<tr>
<th>Release</th>
<th>Specification</th>
<th>Date</th>
<th>Downlink Data Rate</th>
<th>Uplink Data Rate</th>
<th>Round Trip Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>WCDMA</td>
<td>March, 2000</td>
<td>384 kbps</td>
<td>128 kbps</td>
<td>150 ms</td>
</tr>
<tr>
<td>4</td>
<td>TD-SCDMA</td>
<td>March, 2001</td>
<td>384 kbps</td>
<td>128 kbps</td>
<td>150 ms</td>
</tr>
<tr>
<td>5</td>
<td>HSDPA</td>
<td>March to June, 2002</td>
<td>14 Mbps</td>
<td>5.7 Mbps</td>
<td>&lt;100ms</td>
</tr>
<tr>
<td>6</td>
<td>HSUPA</td>
<td>December, 2004 to March, 2005</td>
<td>14 Mbps</td>
<td>5.7 Mbps</td>
<td>&lt;100ms</td>
</tr>
<tr>
<td>7</td>
<td>HSPA</td>
<td>December, 2007</td>
<td>28 Mbps</td>
<td>11 Mbps</td>
<td>&lt; 50 ms</td>
</tr>
<tr>
<td>8</td>
<td>LTE</td>
<td>December, 2008</td>
<td>100 Mbps</td>
<td>50 Mbps</td>
<td>10 ms</td>
</tr>
<tr>
<td>10</td>
<td>LTE-Advanced</td>
<td>Published 2012</td>
<td>1 Gbps in a low mobility</td>
<td>375 Mbps</td>
<td>5ms</td>
</tr>
</tbody>
</table>

### 2.4 Key Features

Key features are needed to perform the best performance targets set for LTE.

In this subsection, we will briefly describe some key features with targets like coverage, capacity, data rate and delay [16].
2.4.1 Spectrum Flexibility

Radio spectrum for mobile communication is available for different frequency bands and sizes that appear as both paired and unpaired bands. Paired frequency involves uplink and downlink transmission that allow different frequency bands. Both uplink and downlink share the same frequency bands also are able to act jointly in several radio-access technologies, in the same spectrum bands. Spectrum flexibility in LTE can operate different frequency bands which operate can extend different frequency bandwidths and sizes. LTE supports average system bandwidths range from 1.4 MHz to 20MHz. LTE can operate paired and unpaired spectrum by transferring radio-access technology also supports Frequency-division duplex (FDD) and Time-division duplex (TDD) operation. FDD can be operated in full and half-duplex modes where terminals are connected. Half-duplex in FDD, the terminal distributes transmission, reception in frequency and time. It allows operating terminals with relax-filter requirements. It reduces terminal cost supporting both FDD and TDD modes of operation [16][17].

2.4.2 Multi-Antenna

Multi-antenna is an essential part of the LTE. Channel quality value for link adaption and scheduling that LTE designed to cater of this. LTE also supported multi-antenna system with transmit diversity and multi-flexing as well as Multiple input multiple output (MIMO). More than four antennas and beam forming multiple-antenna system depend on the scenarios. In Figure 2.1 four transmit antennas, LTE transmit diversity is depending on Space-Frequency Block Schemes (SFBC) complemented with Frequency-Switched Transmit diversity (FSTD) also can be applied to user transmission i.e. VoIP. Spatial multiplexing the multiple antennas used both the transmitter (base station) and the receiver (terminals) that require simultaneous transmission and parallel data stream over a single radio link. Benefits of increasing peak data rates that can manage over the radio link i.e. four transmit antennas (base station) and four receiver antennas at the same terminal side that can be transmitted up to four data stream parallel over the same radio link[17].
2.4.3 Power Control

With the purpose of enhancing system capacity by setting the transmission power levels, Power control also substantially inputs the exhaustion rate of power as well as coverage and quality. The power that is received by the control unit is essentially increased while ensuring minimum interference to the process [17].

2.4.3.1 Uplink Power Control

One of the mechanisms that LTE uses is Uplink Power Control (UPC). Received signals stability of the expect cell is controlled by the mechanism as well as ensuring control interference in connect cells. One of the principle characteristics of the mechanism is that fractional path-lose compensation which can be supported by eventually leads to less interference and power transmission to neighbor cells.

2.4.3.2 Downlink Power Control

Transmission bandwidth consists of transmission power located in the Downlink inter cell. The downlink coordination facilitates the relative narrow band transmission power indicator where a cell can transmit information to the neighboring cells. Dictated by these neighboring cells, which upon receiving
the indication can schedule its downlink transmission, it contributes to the overall reduction of the output of the spectrum. A reuse is possible on its fullest frequency in neighboring cells within the core part of the inter-cell interference coordination scheme in LTE [16][17].

2.5 Quality of Services (QoS)

One of the biggest challenges for the current IP based service is Quality of Service (QoS). As the rapid growth of multimedia application over Internet, it is required to maintain the QoS, which is ensuring the guaranteed service through Internet. For Example, Voice and Video services are bandwidth extensive, which requires less delay to maintain the QoS. It is not always possible to maintain the quality of all requirements.

Different mechanisms, models, schemes and policies are suggested by IETF (Internet Engineering Task Force) to maintain the demand of QoS. In this paper, we have used a scheduling algorithm, which prioritize the basis of user requirements. In this case, IP packets are prioritized on the basis of importance. This provides many bandwidths to more important traffic while delays those, which have less priority. Moreover, in some cases these less important traffics are ignored.

This trick is done by introducing Quality of Service Class Identifier (QCI) which divides packets in classes based on priority and associating QCI with Traffic Forwarding Policy (TFP). TFP defines a set of parameters for traffic forwarding through all the nodes in between source and the final user. For different traffics classified by QCI, different TFP is assigned which can guarantee the bandwidth wanted.

In most of the cases, the user defines the QoS by setting priority. The end user tells how the packets should be classified and associated with TFP. So users are getting service on demand[4].
Chapter 3 LTE ARCHITECTURE

This chapter describes an extension of the very general architecture of LTE. Section 3.1 and 3.2 describes LTE and its protocol architecture, while section 3.3 and 3.4 deals with MAC and physical layer. General discussion of OFDMA and SC-FDMA are described in section 3.5 and 3.6.

3.1 LTE Architecture

Long Term Evolution (LTE) grants solitary packet-switched services as it has designed for seamless and trouble-free Internet Protocol (IP) connectivity among user equipment (UE) and the packet data network (PDN). LTE includes the Universal Mobile Telecommunications Systems (UMTS) radio admission through the Evolved UTRAN (E-UTRAN). Whereas system Architecture Evolution (SAE) is evolution of the non-radio aspects, which encompasses the Evolved Packet Core (EPC) network and accompanied by the E-UTRAN. Hence, LTE and SAE embrace the Evolved Packet Systems (EPS).

EPS offers IP connectivity among UE and PDN for accessing the Internet and other running services, i.e. Voice over IP (VoIP) using the concept of EPS bearers, which also defines quality of service (QoS).

![Figure 3.1 EPS (LTE/SAE) Architecture [18].](image)

The EPS architecture comprised of the CN (EPC) and an E-UTRAN radio access network. Whereas, Core Network (CN) provides access to external packet IP networks and ensures privacy, security, QoS, mobility and terminal context management. Following figure demonstrates the network elements and the standardized interface comprising the overall network architecture [18][19].
3.1.1 Core Network

The core network is also known as EPC in SAE, where it establishes the bear-
ers for the overall control of the UE. There are three core logical nodes in EPC

- PDN Gateway (P-GW)
- Serving Gateway (S-GW)
- Mobility Management Entity (MME). Besides, EPS comprises with other
  logical nodes and functions, such as,
  - Home Subscriber Server (HSS) and
  - Policy Control and charging Rules Function (PCRF)

3.1.2 Access Network

eNodeBs comprise the access network of LTE, E-UTRAN, where eNodeBs are
connected through an interface identified as “x2” to each other. Whereas, eNo-
deBs are connected through the “s1” interface to the EPC, distinctively s1-
MME interface is accountable to connect MME and s1-U interface are accoun-
table to connect S-GW. Therefore, it is acknowledged by the “AS protocols” as
it runs between the eNodeBs and the UE [18].

Figure 3.2 Network Architecture[20].
Chapter 3: LTE ARCHITECTURE

Figure 3.3E-UTRAN Architecture [18].

- **UE**

For communication applications the UE (User Equipment) in which signal of the network to set up, maintain the network and remove the communication links to the end user needs. Most important is that the UE provides user interface to the end user [20].

3.2 Protocol Architecture

In this section we are going to describe different protocols layers and location of the functions in the LTE architecture. Figure 2.4 shows control plane and Figure 2.5 shows user plane protocol stacks [12].
3.2.1 NAS Layer

The Non Access Stratum (NAS) protocol runs between Mobility Management Entity (MME) and User Equipment (UE). In control purposes, the NAS is used for network attach, authentication, mobility management setting up of bearers. Messages from NAS have adjusted and stabilized and protected by the MME and UE.
3.2.2 RRC Layer

The Radio Resource Control (RRC) performs between the eNB and the UE. It also involves with control plane.

3.2.3 PDCP Layer

Packet Data Convergence Protocol (PDCP) layer works on both control plane and user plane. It is responsible in balancing both uplink and downlink as well[21].

3.2.3.1 PDCP Uplink

There are three types of uplink process model used to the LTE PDCP uplink [29]. In the first process, when PDCP receives IP packets from the upper layer it implements sequence numbers. The second process is responsible for the compressing or decompressing of the highest of the user plane IP packet by Robust Header Compression (ROHC) and the use of efficient interface bandwidth.

3.2.3.2 PDCP Downlink

In this process when PDCP receives the packet from lower layers, it checks the de-ciphering information from PDCP header and deletes it. After that it can cipher both user plane and control plan data, also find out the integrity of the control plane. At last for the upper layer to be delivered, the decompression of the header of the user plane packet is created to the sequence numbers [22].

3.2.4 RLC Layer

The RLC (Radio Link Control) layer is used to configure the vehicle traffic between the UE and eNodeB. There are three different types of reliability modes that RLC provides for data transport [12].

3.2.4.1 Transport Mode (TM)

The Transport Mode is a range between RLC SDUs to RLC PDUs. This mode controls some signalling e.g. broadcast system information and paging messages.

3.2.4.2 Unacknowledged Mode (UM)

The Unacknowledged Mode is used for the defensively holding traffic such as VoIP, point to multimedia known as Multimedia broadcast/Multimedia Service (MBMS). This mode performs distribution and continuity of RLC SDUs, detect duplicate and reordering of RLC PDUs, also remake of RLC SDUs.
3.2.4.3 Acknowledged Mode (AM)

The Acknowledged Mode supports delay and error in sensitive traffic which is non-real time i.e. web browsing. This mode provides bidirectional data where RLC can both transmit and receive data. The specialty of ARQ (Automatic Repeat Request) is that it can solve perfectly error packet of transmission of data. Some control plane is that, RRC messages also used in this mode. Beyond the information of the UM mode, the AM mode can operate transmission of the RLC PDUs, reselection of retransmit RLC PDUs[22].

3.3 MAC Layer

In The LTE protocol stack, the Medium Access Control (MAC) layer is part of the logical link layer in Figure 2.6 (layer 2). It is connected to the Radio Link Control (RLC) and the physical layer over the logical channel and transport channel. MAC layer sends MAC Packet Data Units (PDUs) to the physical layer same as it receives from the physical layer over transport channel and connection between RLC layer and logical channel through RLC Service Date Units (SDUs) [23][21].

![Figure 3.6 MAC Layer](24)
3.3.1 Logical Channel

The connection between MAC and RLC over different logical channels that perform data transfer service and specifies the kinds of data information that carried also the types of logical channels which includes both control channels (control plane data) and traffic channels (user plane data). In Figure 2.7, we are able to see the position between MAC and RLC through logical channel [21][22].

- **PCCH (Paging Control Channel)**
  Downlink channel is used to transfers paging informational also used this for paging when the network does not know the position cell of the UE.

- **BCCH (Broadcast Control Channel)**
  Downlink channel is used for broadcasting control information.

- **CCCH (Common Control Channel)**
  This channel is used for control transmitting information between UEs and the network, also is used for UEs without RRC connection to the network.

- **DCCH (Dedicated Control Channel)**
  It is a point to point bi-directional channel. It can broadcast control information between UE and the network which is used by UEs with RRC network connection.

- **DTCH (Dedicated Traffic Channel)**
  It is also a point to point channel that is assigned to one UE for transfer user information.

- **MCCH (Multicast Control Channel)**
  It is a point to point downlink channel that broadcast MBMS (Multimedia Broadcast and Multicast Service) control information to the UE from the network. UEs use this channel to receive MBMS.

- **MTCH (Multicast Traffic Channel)**
  It is also a point to point downlink channel that broadcast traffic data from the network to the UE. UEs also use this channel to receive MBMS [25].
3.3.2 Transport Channel

The connection between MAC and PHY over different transport channels that perform data transfer service and specifies how the information is carried to particular physical modulation that are fixed. Within the Figure 2.8, we are able to see the position between MAC and PHY over the transport channels [21][22].

- **PCH (Paging Channel)**
  Downlink channel and holds discontinuous feedback to enable UE power saving. This channel broadcasts total coverage area of the cell.

- **BCH (Broadcast Channel)**
  It is a fixed and pre-defined format downlink channel, also broadcasts total coverage area of the cell.

- **MCH (Multicast Channel)**
  This is a downlink channel and supports MBMS transmission on various cell and semi-static resource portion. It also broadcasts total coverage area of the cell.

- **DL-SCH (Downlink Shared Channel)**
  This is a downlink channel and supports Hybrid ARQ and dynamic link variation and verifying by the modulation, coding and transmitting power. This channel supports powerful and semi-static resource allocation and additionally supports UE discontinuous response and MBMS transmission.

- **RACH (Random Access Channel)**
  It is an uplink channel and carries minimum information. It may be lost due to crash while the transmission on this channel.

- **UL-SCH (Uplink Shared Channel)**
  This is also an uplink channel and supports powerful link variation. It verifies by transmit power, modulation and coding. This channel also supports dynamic and semi-static resource allocation [25].
3.4 Physical Layer

Physical layer provides higher layer data transport service by using transport channel through MAC sub-layer. It is one of the main functions for LTE, which can transfer dependable signal over a radio interface between eNodeB and UE. The LTE air interface is planned for using each paired FDD and unpaired TDD mode spectrum bands. The Physical layer is used for DL and SC-FDMA for UL and supports MIMO for higher data rates and protect multi path fading. Here, the physical layer provides the following function that can perform over the data transport services [26][27].

- It can detect error on the transport channel and send a signal to the higher layers.
- EFC encoding and decoding of the transport channel.
- Transport channel rate adaption and channel mapping to the physical channel.
- Modulation and demodulation.
- Synchronization frequency and time.
- Radio Characteristics capability and specifying to higher layer.
- MIMO (Multiple Input Multiple Output) antenna processing.
- RF (Radio Frequency) processing

3.4.1 Physical Layer Frame Structure

Transmission signals are divided into frames, and each of the frames include 10 sub-frames. Each sub-frame formed by two slots and time duration 0.5ms that can allocate both uplink and downlink transmission. Each slot contains 7 SC-FDMA symbols. Here, the general frame structure of the physical layer is shown:

![Frame Structure Diagram](image)

Figure 3.9 Frame Structure[27].

3.4.1.1 Downlink Frame Structure

Downlink frame structure contains different sub-carrier symbols for multi user. Each of the users assigns a number of subcarrier with time slot. The LTE re-
ferred this specification as PRBS (Physical Resource Blocks) and recognized by the factors which are time, frequency and eNodeB (Base Station).

![Diagram of Downlink Frame Structures](image)

In this Figure 3.10, it is usable for both full and half duplex FDD. Each of the frames contains 20 slots, which are numbered from 0 to 19. In FDD 10 sub-frames accessible for downlink and 10 sub-frames for uplink transmission. Each uplink and downlink transmission is in 10ms gap and divides in the frequency domain. In half-duplex FDD process, user cannot receive or transmit on the same time if there is no such limitation in full-duplex FDD.

### 3.4.1.2 Uplink Frame Structure

This frame structure is similar as downlink frame, sub-frames duration and slot. The uplink frame contains 20 slots and each sub-frame contains 2 slots. Time duration of each slot is 0.5ms [27].

### 3.4.2 Resource Block

In LTE, a resource element is the smallest time-frequency component for downlink transmission, which is assigned by the base station scheduler. In this Figure: 3.11, data assigned to each UE in part of RB.
The physical resource blocks are using standard CP (Cyclic Prefix). In one slot RB (Resource Block) length 12 contiguous sub-carriers with 15 KHz sub-carrier spacing. Over a slot, time duration is 0.5 ms for 7 consecutive symbols and CP is added for each symbol as a protector interval. Therefore, in one slot RB consist of 84 (12 sub-carriers x 7 symbols) resource elements in the time domain and resource of 180 KHz (12 sub-carrier x 15KHz) in the frequency domain. All bandwidths are same for each RB size. As a result, the physical resource block depends on the transmission bandwidth [27][13].

### 3.5 OFDMA Downlink Transmission

The growing demand for prime transmission and high data broadcast rates in the wireless communication system over a channel; the OFDMA (Orthogonal Frequency Division Multiple Access) downlink transmission system is the best option for multiple access technique for accessing mobile broadband wireless 3G and 4G system. OFDMA has recommended multi carrier resolution of wireless transmission. It is a multiple access scheme based on OFDM (Orthogonal Frequency Division Multiplexing) which provides high data flow each part adjusted with the separate subcarriers. Benefit of OFDM is that maintaining physical layer of present and future high speed data transmission within the wireless communication like WMAN (Wireless Metropolitan Area Networks) and MBWA (Mobile Broadband Wireless Access) standards [28].

In single user OFDM system, when CSI (Channel State Information) is accessible to the transmitter. It transmits power that every subcarrier can be
modified consistently with the CSI which increases high data rate. The single user OFDM, the data rate, is customized in the frequency time domain by supporting the necessity of common transition power. Benefits of increasing, high data rate over a channel. In the time, channel in the frequency time domain that transmits power adaption to produce larger data rate. This increase of data rate only happens in the frequency domain otherwise the time varying is going to be abused. In a single OFDM, the data rate increases by using transmit power adaption to either the spectral diversity effects in the frequency domain or temporal diversity effects in the time domain or both of them [29][30].

In multiuser OFDM, provides better flexible and improved data communication system that the analyzers focused their research to hold out the goal of improving the flexible data communication techniques. These techniques are higher than different TDMA and FDMA which may operate secure and prearranged subcarrier and time-slot allocation schemes. Though OFDMA based on OFDM techniques, the immunity of OFDM symbols that collected information of multi users division in wireless system. The BS (Base Station) is responsible for this and manages how the existing subcarriers are going to be circulated between different users [28]. In this Figure 3.12, OFDMA transmission is shown:

![OFDMA Transmissions](image)

**3.5.1 OFDM Transmitter**

At first OFDM transmitter, divides input high data stream into different low rate parallel data streams. All of the parallel streams are composed by a forwarding error correction scheme that IFFT input, measure the time part connection with the sub channels. In the guard interval, avoid ISI over the multiphase broadcast in the mobile radio channel. Finally, the transmission channel filters the time signal and converts into high frequency and transmission over the channel.
3.5.2 OFDM Receiver

OFDMA receiver firstly received the modified signal into different signals that are collected by the reception filter. Then removed the guard interval, the FFT is converted into the samples from time into the frequency domain. At the moment receive the complex symbol which is once more mapped and decoded. At last the unique serial data flow finally is received [32].

3.6 SC-FDMA Uplink Transmission

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a new developed technology for high data rate uplink transmission rate that accepted by 3GPP (3rd Generation Partnership Project) for present and next generation cellular system which is referred as LTE (Long Term Evolution). It is the most powerful technique used uplink over wireless broadband communication in LTE. So, it can support 1.25-20 MHz bandwidth and up to 20 Mbps transmission rate. SC-FDMA is adapted by the OFDM that in the result same of throughput activity and complexity. The most benefits of SC-FDMA are low PAPR (Peak-to-Average Power Ratio) than the OFDMA which is lower power consumption for uplink channel that creates longer battery lifetime of mobile stations and production cost [33][34][31]. In this Figure: 3.13 SC-FDMA transmission is shown:

![Figure 3.13 SC-FDMA Transmissions][31]

3.6.1 SC-FDMA Transmitter

The SC-FDMA transmitter, the signal transmitted by using QPSK, 16QAM or 64QAM. Then using N-point DFT (Discrete Fourier Transform), QPSK input and divided into N-symbol blocks. It converts to the frequency domain which is represented by Xk. Then each of this converted output modulated to the subscribers with mapping. The results of the subcarrier mapping produce the set Xl (l = 0, 1, 2, ..., M - 1). Then X1 converted to time domain signal Xm using M-point Inverse DFT (IDFT). Each of the Xm symbols on a single carrier and adding CP (Circular Prefix) for transmitting constantly to avoid IBI (Inner Block Interface) and pulse shaping. Benefits of reduce out-of-band energy.
3.6.2 SC-FDMA Receiver

The SC-FDMA receiver receives the signal then transforms it into the frequency domain using DFT, then de-maps the subscribers and then performs the frequency domain equalization to avoid ISI. ISI (Inter Symbol Interference) can be occurred in the single carrier modulation used by SC-FDMA, but for the practical consideration, MMSE (Minimum Mean Square Error) is preferred. Therefore, the robustness against noise MMSE is preferred over ZF (Zero Forcing). After equalization symbols are transformed back to time domain using IDFT. Detection and decoding of symbols take place in the time domain [31].
Chapter 4 SIMULATION

This chapter describes the network models implemented in OPNET Modeler, as well as their parameters and tools. Section 4.2 describes the simulation scenarios while section 4.4 deals with network traffic generation.

4.1 Evaluation Platform

It is essential to assess the performance of a well designed network model but evaluating the performance in real scenarios is challenging. Optimized Network Engineering Tool (OPNET), introduced by OPNET technologies [35], is used to meet the challenges. It is a proprietary simulation software containing a comprehensive set of built-in features. Moreover, it is based on object oriented and Discrete Event System (DES). In this thesis paper, we used OPNET modeler 16.0 for designing and developing simulation model. The motivation behind using OPNET modeler is discussed in the following section.

4.1.1 Why OPNET?

OPNET modeler has been chosen in spite of other, different simulators, because of these following features:

- It offers more simulator features than other simulator.
- Ability to access with a wide range of available standard and vendor communication network which allows modelers to develop models in simulation. Also, it reduces model development.
- Provides dynamic development environment and supports both modeling of communication network and distributed systems.
- It offers comprehensive documentation for users.
- It offers intuitive graphical interface which allows the user to work and view the results easily.
- Provides flexible results from OPNET with comprehensive tools to display, plot and analyze time series, probability, histograms, parametric curve and confidence intervals.

4.2 Simulation Scenarios

OPNET Modeler 16.0 has been used for the simulation analysis. This part of the thesis describes the network model used in this study. 3 network scenarios have been implemented. Scenario 1 is modeled as a Low Load Network without QoS implementation. Scenario 2 is modeled as a Medium Load Network while Scenario 3 is modeled as a High Load Network.

1. Scenario 1 (Low Load) Network.
2. Scenario 2 (Medium Load) Network.
3. Scenario 3 (High Load) Network.
Table 4.1 Network Traffic Load.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Uplink/Downlink Load</th>
<th>Uplink/Downlink Capacity</th>
<th>Network Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1 (Low Load)</td>
<td>0.5 Mbps</td>
<td>1.54 Mbps</td>
<td>32%</td>
</tr>
<tr>
<td>Scenario 2 (Medium Load)</td>
<td>65 Mbps</td>
<td>90 Mbps</td>
<td>138%</td>
</tr>
<tr>
<td>Scenario 3 (High Load)</td>
<td>67 Mbps</td>
<td>97 Mbps</td>
<td>144%</td>
</tr>
</tbody>
</table>

4.2.1 Scenario 1 (Low Load) Network

Scenario 1 (Low Load) Network has been implemented to compare with the study results from other scenarios (e.g. 2 and 3). LTE configuration, profile configuration, Application configuration is used in this network which are described in the following section.

Six eNodeBs namely eNodeB_1, eNodeB_2, eNodeB_3, eNodeB_4, eNodeB_5 and eNodeB_6 are used in above scenario. eNodeB is also called a base station. The interface between eNodeB and UEs is covered in E-UTRAN entire network. In eNodeB, there is one call admission control which is distinct by a position of actions to determine if the call request can be accepted or rejected [36]. In eNodeB, inactive bearer set to 20 seconds. Inactive bearer timeout is applicable for GBR bearers if the GBR bearer goes through the admission control protocol. LTE physical profile used by eNodeB, where eNodeB allocates physical layer resource for the uplink and downlink shared channels. Here, the physical profile is set to 20 MHz FDD. To identify the different eNodeB, it is
important to set the eNodeB name. Here we set ID 1 to 6 for all eNodeBs. These eNodeBs are connected with EPC through SONET/OC3 links. The speed of this link is 148.61 Mbps. In this network, eNodeB 1, eNodeB 2 and eNodeB 5 with each of four video work stations are working as a source and eNodeB 4, eNodeB 3 and eNodeB 6 with each of four video work stations are working as a destination. 20 MHz bandwidth is used in this simulation. Evolved Packet System (EPS) consists of Evolved UTRAN (E-UTRAN) and Evolved packet core (EPC). EPS bearer is used to specify which bearer or channel users (UEs) want to use. For the scenario 1 (Low Load) network, we used four EPS bearer UE_1_1, UE_1_2, UE_1_3 and UE_1_4 which are named by Platinum, Gold, Silver and Bronze respectively. The same sets of EPS bearers are also used in all cases. QCI is a scalar value which refers to a set of the parameters to determine packet forwarding characteristics. The Traffic Forwarding Policy (TFP) defines a set of parameter at every node along the path between the end users [11]. In QCI, the allowed value range is 1 to 9 where QCI value 1 to 4 represent GBR bearer and others are non-GBR bearers. In this above scenario, QCI values are 2, 4, 6 and 7 for Platinum, Gold, Silver and Bronze respectively.

Table 4.2 eNodeB LTE Attributes.

<table>
<thead>
<tr>
<th>Admission Control Parameters</th>
<th>PDCCH</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Factor (UL)</td>
<td>Default</td>
<td></td>
</tr>
<tr>
<td>Loading Factor (DL)</td>
<td>Default</td>
<td></td>
</tr>
<tr>
<td>Inactive Bearer Timeout (sec.)</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Parameters</th>
<th>Antenna Gain (dBi)</th>
<th>15 dBi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Capacity</td>
<td>Unlimited</td>
<td></td>
</tr>
<tr>
<td>Maximum Transmission Power (w)</td>
<td>0.00394</td>
<td></td>
</tr>
<tr>
<td>Operating Power</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>PHY Profile</td>
<td>LTE 20 MHz FDD</td>
<td></td>
</tr>
<tr>
<td>Receiver Sensitivity (dBm)</td>
<td>-200 dBm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CQI Transmission Parameters</th>
<th>Periodic Configuration Index</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subband Report Repetition Count (k)</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 LTE PHY Profiles.

<table>
<thead>
<tr>
<th>LTE 1.4 MHz FDD</th>
<th>UL SC-FDMA Channel Configuration</th>
<th>Base Frequency (GHz)</th>
<th>1920 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bandwidth (MHz)</td>
<td>20 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclic Prefix Type</td>
<td>Normal (7 Symbols per Slot)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DL SC-FDMA Channel Configuration</th>
<th>Base Frequency (GHz)</th>
<th>2100 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bandwidth (MHz)</td>
<td>20 MHz</td>
</tr>
<tr>
<td></td>
<td>Cyclic Prefix Type</td>
<td>Normal (7 Symbols per Slot)</td>
</tr>
</tbody>
</table>
4.2.2 Scenarios 2/3 (Medium/High Load) Network

A medium and high load networks have been implemented and presented in this subsection. The main objective of these two networks is to examine the effect on video conferencing over the traffic load. In this scenario, mixed traffic is introduced (Video conferencing and FTP). In order to introduce background traffic in the simulation, FTP traffic is used. Guaranteed Bit Rate (GBR) and Non-Guaranteed Bit Rate (NGBR) bearers are used for video conferencing traffic while only NGBR bearer is used for FTP traffic in the simulation scenario.

SixenodeB namely eNodeB_1, eNodeB_2, eNodeB_3, eNodeB_4, eNodeB_5 and eNodeB_6 are used in above scenario. Inactive bearer timeout is set to 20 seconds. Inactive bearer timeout is applicable for GBR bearers if the GBR bearer goes through the admission control protocol. In this network, four video work stations and two FTP clients are connected with eNodeB_1, eNodeB_2 and eNodeB_5 serving as a source and four video work stations with one FTP server are connected with eNodeB_4, eNodeB_3 and eNodeB_6 serving as a destination. 20 MHz bandwidth is used in this simulation. However, four EPS bearer are named Platinum, Gold, Silver and Bronze that are reused in this simulation. QCI values for these EPS bearer are set to 2, 4, 6 and 7 respectively.

4.3 Network Components

In this section, we will be discussing the network components which are used in the study network models in OPNET [37]. They are as follows:

- The Application_Config consists of name and description table for different parameters for different application such as voice and FTTP ap-
Chapter 4: SIMULATION

Applications. This application is used for the name by creating a user profile on "Profile Config".

- The Profile_Config used for creating a user profile which can specify different nodes in the network, and can produce application layer traffic. This traffic model can depends on application with user configure.
- The Lte_attr_definer_adv node used to keep PHY pattern and EPS bearer explanation in the network which can be mentioned through all the LTE nodes.
- The SONET/OC3 link used for Ethernet connection operating which is 148.61 Mbps with six nodes in running IP. This link is duplex.
- The lte_access_gw_atm8_ethernet8_slip8_adv node models used for IP-based gateway in LTE. It also supports more than 8 Ethernet and serial line interface at selectable data.
- The lte_enodeb_4ethernet_4atm_4slip_adv node model used for base station (eNodeB) in LTE that can maintain the serial line more than 4 Ethernet and serial line interfaces at selectable data.
- The lte_wkstn_adv node model used for workstation application consists of source and destination over the TCP/IP and UDP/IP.

4.4 Network Traffic Generator

In order to generate network traffic we need to consider 3 objects named as application definition attribute, profile definition attribute and LTE configuration node.

4.4.1 Application Definition Attributes

Application definition attribute consists of several predefined applications that will be customized as per user demands. Among those predefined applications like video, voice, FTP, email, HTTP etc. Figure 4.1 of application definition attribute is used in the simulation model. Here, we considered 5 bearers like Platinum, Gold, Silver, Bronze and FTTP where we considered Best Effort, Interactive Multimedia, Background, Streaming Multimedia, Standard and Best Effort. The application FTTP is modeled for setup background traffic in the simulation.
Figure 4.3 Application Definition.

Frame Inter-arrival time information for Scenario 1 (Low Load), Scenario 2 (Medium Load) and Scenario 3 (High Load) are set to 10 frame/second, 30 frame/second and 30 frame/second respectively.

Frame size information for Scenario 1 (Low Load), Scenario 2 (Medium Load) and Scenario 3 (High Load) are set to constant 9000, constant 24000 and constant 26000 respectively.

The services for Platinum, Gold, Silver and Bronze bearers are Interactive Multimedia, Excellent Effort, Background and Best Effort respectively.
### Table 4.4 Video Conferencing.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Low Load</th>
<th>Medium Load</th>
<th>High Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frame Interarrival Time Information</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incoming Stream Interarrival Time (seconds)</td>
<td>Constant (0.1)</td>
<td>Constant (0.0333)</td>
<td>Constant (0.0333)</td>
<td></td>
</tr>
<tr>
<td>Outgoing Stream Interarrival Time (seconds)</td>
<td>Constant (0.1)</td>
<td>Constant (0.0333)</td>
<td>Constant (0.0333)</td>
<td></td>
</tr>
<tr>
<td><strong>Frame Size Information (bytes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incoming Stream Frame Size (Bytes)</td>
<td>Constant (9000)</td>
<td>Constant (240000)</td>
<td>Constant (260000)</td>
<td></td>
</tr>
<tr>
<td>Outgoing Stream Frame Size (Bytes)</td>
<td>Constant (9000)</td>
<td>Constant (240000)</td>
<td>Constant (260000)</td>
<td></td>
</tr>
<tr>
<td><strong>Symbolic Destination Name</strong></td>
<td>Video Destination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type of Service</strong></td>
<td>Platinum</td>
<td>Interactive Multimedia</td>
<td>Interactive Multimedia</td>
<td>Interactive Multimedia</td>
</tr>
<tr>
<td></td>
<td>Gold</td>
<td>Excellent Effort</td>
<td>Excellent Effort</td>
<td>Excellent Effort</td>
</tr>
<tr>
<td></td>
<td>Silver</td>
<td>Background</td>
<td>Background</td>
<td>Background</td>
</tr>
<tr>
<td></td>
<td>Bronze</td>
<td>Best Effort</td>
<td>Best Effort</td>
<td>Best Effort</td>
</tr>
<tr>
<td></td>
<td>FTP</td>
<td>Best Effort</td>
<td>Best Effort</td>
<td>Best Effort</td>
</tr>
<tr>
<td><strong>RSVP Parameters</strong></td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Traffic Mix (%)</strong></td>
<td>All Discrete</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.5 FTP table.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command Mix (Get/Total)</td>
<td>50%</td>
</tr>
<tr>
<td>Inter-Request Time (seconds)</td>
<td>Exponential (360)</td>
</tr>
<tr>
<td>File Size (bytes)</td>
<td>Constant (50000)</td>
</tr>
<tr>
<td>Symbolic Server Name</td>
<td>FTP Server</td>
</tr>
<tr>
<td>Type of Service</td>
<td>Best Effort (0)</td>
</tr>
<tr>
<td>RSVP Parameters</td>
<td>None</td>
</tr>
<tr>
<td>Back-End Custom Application</td>
<td>Not Used</td>
</tr>
</tbody>
</table>
4.4.2 Profile Definition Attribute

Now it is necessary to configure the profile definition. Figure 4.4 illustrate the profile definition attribute that is used in simulation.

In profile definition, configure the profile time set to 120 seconds and 0 second for application. So the video conferencing is established at the 120th second of the simulation. The duration for the profile and its application is set to end of the simulation.
### Table 4.6 EPS bearer definition.

<table>
<thead>
<tr>
<th>Name of the EPS bearer</th>
<th>QoS Class identifier</th>
<th>Allocation Retention Priority</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Platinum</strong> 1 (GBR)</td>
<td>1</td>
<td>2</td>
<td><strong>Uplink Guaranteed Bit Rate</strong> 7 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Guaranteed Bit Rate</strong> 7 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Uplink Maximum Bit Rate</strong> 7 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Maximum Bit Rate</strong> 7 Mbps</td>
</tr>
<tr>
<td><strong>Gold</strong> 2 (GBR)</td>
<td>2</td>
<td>4</td>
<td><strong>Uplink Guaranteed Bit Rate</strong> 6 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Guaranteed Bit Rate</strong> 6 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Uplink Maximum Bit Rate</strong> 6 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Maximum Bit Rate</strong> 6 Mbps</td>
</tr>
<tr>
<td><strong>Silver</strong> 6 (Non-GBR)</td>
<td>6</td>
<td>6</td>
<td><strong>Uplink Guaranteed Bit Rate</strong> 5 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Guaranteed Bit Rate</strong> 5 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Uplink Maximum Bit Rate</strong> 5 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Maximum Bit Rate</strong> 5 Mbps</td>
</tr>
<tr>
<td><strong>Bronze</strong> 7 (Non-GBR)</td>
<td>7</td>
<td>7</td>
<td><strong>Uplink Guaranteed Bit Rate</strong> 3 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Guaranteed Bit Rate</strong> 3 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Uplink Maximum Bit Rate</strong> 3 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Downlink Maximum Bit Rate</strong> 3 Mbps</td>
</tr>
</tbody>
</table>

### 4.5 Simulation Run-Time

Simulation run time is set to 1200 seconds and all of the applications that generate the traffic i.e. video conferencing start at 120 seconds. The simulation is implemented in OPNET Modeler 16.0 on HP laptop Pentium Core2Duo 1.7 GHz, 2GB Ram with Windows Vista.
Chapter 5  RESULTS AND ANALYSIS

The aim of this thesis is to evaluate the performance of QoS in LTE network. So, it is necessary to evaluate the quality of service under congested network. This chapter is aimed to discuss about E2E delay performance, packet loss, packet delay variation. In general, Platinum (GBR), Gold (GBR), Silver (NGBR) and Bronze (NGBR) bearers are transferred through UE_1_1, UE_1_2, UE_1_3 and UE_1_4 respectively and the same sets of EPS bearers are used in the cell number 1, 2 and 5. On the other hand those four bearers are received by the cell number 4, 3 and 6. All the cells are working as a source and destination as well. For better understanding we discussed only one cell. In this chapter, section 5.1 describes the performance metrics such as E2E delay while section 5.2 deals with packet loss performance. Finally section 5.3 focused on Packet Delay Variation (PDV).

5.1  End-to-End (E2E) Delay Performance

Time needed for a packet to traverse from the User Equipment (Source) to User Equipment (Destination) in the network is called End-to-End (E2E) delay and measured in seconds. However, E2E delay is a key metric to evaluate the performance of networks as well as the quality of service to understand by end users [38]. When packets are traverse from source to destination, there might be three types of delays, i.e. sender delay, network delay and receiver delay.

Following subsection describes the results of E2E delay for three network scenarios. Scenario 1, 2 and 3 describes the low, medium and high load network respectively. Only video conferencing application with very low load is designed in scenario 1, FTP applications are added in scenario 2 and 3. In all the scenarios, traffic is generated from 120 seconds till to the end of simulation. In all the graphs in the following subsection, simulation time is represented in X-axis and E2E delay in seconds represented in Y-axis.

5.1.1  E2E delay Performance for Scenario 1 (Low Load) Video Conferencing Network

In scenario 1, frame inter-arrival time and frame size for video application are set to 10 Frame/second and 9000 Bytes/second for Platinum, Gold, Silver and Bronze bearers.

The comparable performance of the E2E delay for different bearers in scenario 1 (Low Load) video conferencing network is depict in Table 5.1 and observed in Figure 5.1. In the Figure 5.1, E2E delay in UE_1_1 (GBR bearer-Platinum) varies from 0.0210s to 0.0211s where the average delay is 0.0210s. Again E2E delay for UE_1_2 (GBR bearer-Gold) varies from 0.0260s to 0.0261s, on an average 0.0260s. On the other hand E2E delay for UE_1_3 (NGBR bearer-Silver) starts from 0.0328s and end with 0.0329s and average delay is 0.0329s. Again the delay for UE_1_4 (NGBR bearer-Bronze) varies
from 0.03990s to 0.03999s on an average 0.03999s. Here it is shown that, E2E delay for UE_1_4 (Bronze NGBR) bearer is 90 %, 34% and 21% higher than UE_1_1 (Platinum GBR), UE_1_2 (Gold GBR) and UE_1_3 (Silver NGBR).

Table 5.1: E2E delays for Scenario 1 (Low Load) Network.

<table>
<thead>
<tr>
<th>Bearer</th>
<th>Min. (sec.)</th>
<th>Avg. (sec.)</th>
<th>Max. (sec.)</th>
<th>Std. Dev. (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>0.0210</td>
<td>0.0210</td>
<td>0.0211</td>
<td>1.22E-005</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.0260</td>
<td>0.0260</td>
<td>0.0261</td>
<td>1.73E-005</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.0328</td>
<td>0.0329</td>
<td>0.0329</td>
<td>1.42E-005</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>0.03990</td>
<td>0.03999</td>
<td>0.03999</td>
<td>1.12E-005</td>
</tr>
</tbody>
</table>

5.1.1.1 Discussion

Analysis of E2E delay performance for video conferencing and mapping to EPS QoS Classes is performed in order to evaluate LTE QoS for different bearers within EPS, each being associated with a QoS. From the figure 5.1 it can be seen that, improved E2E delay is achieved by applying prioritization. Allocation Retention Priority (ARP) for Platinum, Gold, Silver and Bronze is set to 2, 4, 6 and 7 respectively. Here it can be seen that, GBR bearers are able to reduce average delays than NGBR bearers. The delay for both GBR and NGBR bearers are acceptable, cause in order to maintain the quality for an interactive conversational video, such as video conferencing, the delay should be equal or less than 150 ms (milliseconds).

In conclusion, the simulation results show that the different levels of potential E2E delay performance can be achieved by employing prioritization associated with LTE QoS.
5.1.2 E2E Delay Performance for Scenario 2 (Medium Load) Video Conferencing Network

In Table 5.2 and Figure 5.2, we described the E2E delay performance for video conferencing with medium load network.

In the Figure 5.2 E2E delay in UE_1_1 (GBR bearer-Platinum) varies from 0.0281s to 0.0288s where the average delay is 0.0281s. Again E2E delay for UE_1_2 (GBR bearer-Gold) varies from 0.040s to 0.0664s on an average 0.0418s. On the other hand E2E delay for UE_1_3 (NGBR bearer-Silver) starts from 0.906s and ends with 3.289s, on an average 3.150s. The delay for UE_1_4 (NGBR bearer-Bronze) varies from 4.929s to 40.681s and average is 39.31s. In the Scenario 2 (Medium Load), the average delay for UE_1_2 (Gold GBR) bearer is 48% higher than the UE_1_1 (Platinum).

![Figure 5.2E2E delays for Scenario 2 (Medium Load) Network](image)

<table>
<thead>
<tr>
<th>Bearer</th>
<th>Min. (sec.)</th>
<th>Avg. (sec.)</th>
<th>Max. (sec.)</th>
<th>Std. Dev. (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>0.0281</td>
<td>0.0281</td>
<td>0.0288</td>
<td>9.22E-005</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.040</td>
<td>0.0418</td>
<td>0.0664</td>
<td>0.0031</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.906</td>
<td>3.150</td>
<td>3.289</td>
<td>0.038</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>4.929</td>
<td>39.31</td>
<td>40.681</td>
<td>5.768</td>
</tr>
</tbody>
</table>

**5.1.2.1 Discussion**

We can see from Figure 5.2 that improved E2E delay is achieved by applying prioritization. ARP for Platinum, Gold, Silver and Bronze are set to 2, 4, 6 and 7 respectively. Platinum and Gold bearers are able to reduce average delay dramatically, whereas Silver and Bronze are having worst delay performance.
Chapter 5: RESULTS AND ANALYSIS

From the point of QoS, delay for Silver and Bronze NGBR is not acceptable. This means that, in order to maintain the quality for an interactive conversational video, the delay should be equal or less than 150ms. E2E delay for NGBR bearers, (i.e., UE_1_3(Silver) and UE_1_4 (Bronze) along with ARP 6 and 7 is definitely too high for real-time application such as video conferencing compared with Platinum and Gold bearers.

5.1.3 E2E Delay Performance for Scenario 3 (High Load) Video Conferencing Network

In the Figure 5.3 and Table 5.3, E2E delay in UE_1_1 (GBR bearer-Platinum) varies from 0.037s to 0.038s and in UE_1_2 (GBR bearer-Gold) delay varies from 0.484s to 2.679s where the average delays are 0.0371s and 2.490s respectively. On the other hand E2E delay for UE_1_3 (NGBR bearer-Silver) starts from 1.322s and ends with 2.117s. The average delay for this UE is 2.108s. UE_1_4 (NGBR bearer-Bronze) starts from 5.551s whereas ends with 34.58s. The average delay is 33.612s.

![Figure 5.3 E2E delays for Scenario 3 (High Load) Network](image)

Table 5.3 E2E delays for Scenario 3 (High Load) Network.

<table>
<thead>
<tr>
<th>Bearer</th>
<th>Min. (sec.)</th>
<th>Avg. (sec.)</th>
<th>Max. (sec.)</th>
<th>Std. Dev. (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>0.037</td>
<td>0.0371</td>
<td>0.038</td>
<td>0.0002</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.484</td>
<td>2.490</td>
<td>2.679</td>
<td>0.374</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>1.322</td>
<td>2.108</td>
<td>2.117</td>
<td>0.083</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>5.551</td>
<td>33.612</td>
<td>34.58</td>
<td>4.428</td>
</tr>
</tbody>
</table>
5.1.3.1 Discussion

Analysis of E2E delay performance for video conference and mapping to EPS QoS Classes is performed in order to evaluate LTE QoS for different bearers within EPS, each being associated with a QoS. We can see from Figure 5.3 that the delay is improved by applying prioritization. For instance, Platinum bearer with ARP 2 seems to be able to reduce average delays whereas Gold, Silver and Bronze are having worst delay performance. Delays for these three bearers are not acceptable from QoS point of view. This means that in order to maintain the quality for an interactive conversational video such as video conferencing, the delay should be equal or less than 150 ms (milliseconds).

When we focus on the performance of E2E delay for NGBR bearer, an increase in delay for NGBR is forcing low priority traffic UE_1_2, UE_1_3 and UE_1_4. E2E delay for UE_1_2, UE_1_3 and UE_1_4 along with Allocation Retention Priority ARP 4, 6 and 7 are definitely too high for real-time application such as video conferencing compared with the bearer Platinum.

In conclusion, the simulation results show that the different levels of potential E2E delay performance can be achieved by employing prioritization associated with LTE QoS.

5.1.4 Summary of E2E Delay Performance

![Figure 5.4 E2E delays for three different scenarios.](attachment:image)

Figure 5.4 depicts the average E2E delay comparison between 3 scenarios based on different load. In the Y-axis E2E delay are represented in second while different GBR and NGBR bearers are presented in the X-axis.

In the Platinum GBR bearer, the E2E delay for video conferencing in Scenario 3 (high load) is 32% higher than Scenario 2 (Medium Load) network and 76% higher than Scenario 1 (Low Load) network. Apart from that, the delay for Gold bearer (UE_1_2), in scenario 2 is 60% higher than scenario 1.
5.2 Packet Loss Performance

In the network, when packets of data travelling from source to destination, there might be a chance to lose packets. The equation for the packet loss is determined by the following formula:

\[
\text{Packet loss} = \left( \frac{\text{Sent packet} - \text{Received packet}}{\text{Sent packet}} \right) \times 100
\]

In this sub-section the ratio of the packet loss for different scenarios are presented.

5.2.1 Packet Loss Performance for Scenario 1 (Low Load) Video Conferencing Network

This subsection evaluates the packet loss performance for Scenario 1 (Low Load) video conferencing network. Figure 5.5 representing the video conferencing traffic sent and receive. Y-axis and X-axis represents the video traffic sent in bytes/sec and the simulation time in minutes respectively.

![Figure 5.5 Video Conferencing with Scenario 1 (Low Load) network](image)

We can see that, the average data sent and received for the Scenario 1 (Low Load) network is same (60674 Bytes) for both the GBR and NGBR bearer traffic. Average packet loss for this network is almost 0%.

5.2.1.1 Discussion

Figure 5.5, describes the high priority and low priority video applications that are sent around 60674 bytes/sec of traffic which translate to load of 485392 bits/sec for the application layer. At the MAC layer, this is about 497909 bits/sec due to MAC overhead whereas sent video traffic at MAC layer is higher than application layer traffic load. Because of Scenario 1 (Low Load) traffic load, there are no preemptions and rejections happen to be experienced in the cell of eNodeB_1. The entire traffic load is getting opportunity to use the available resources in EPS in eNodeB_1 cell. Table 5.4 and 5.5 summarizes the packet loss for different traffic classes.
Table 5.4 Statistic of traffic sent for Scenario 1 (Low Load) Network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>60674</td>
<td>81000</td>
<td>25303</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.5 Statistic of traffic received for Scenario 1 (Low Load) Network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>0.0</td>
<td>60674</td>
<td>81000</td>
<td>25303</td>
<td>0%</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.0</td>
<td>60674</td>
<td>81000</td>
<td>25303</td>
<td>0%</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.0</td>
<td>60674</td>
<td>81000</td>
<td>25303</td>
<td>0%</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>0.0</td>
<td>60674</td>
<td>81000</td>
<td>25303</td>
<td>0%</td>
</tr>
</tbody>
</table>

5.2.2 Packet Loss Performance for Scenario 2 (Medium Load) Video Conferencing Network

Figure 5.6 Video Conferencing with Scenario 2 (Medium Load) network (a). Traffic Sent and (b). Traffic Received.

In the graph it seems the amount of traffic sent and receives for the medium load network is described in Figure 5.6. Here it can be seen that, the amount of average data packet sent through the UE_1_1, UE_1_2, UE_1_3 and UE_1_4 is approximately 485829 bytes. On the other hand, the average traffic received by the UE_1_1 (Platinum GBR) and UE_1_2 (Gold GBR) bearers are almost same. But the traffic received by the UE_1_3 (Silver NGBR) is lower than that of UE_1_1 and UE_1_2 bearers and the traffic received by the UE_1_4 (Bronze NGBR) bearer is much lower than that of others. The average packet loss for the UE_1_1, UE_1_2, UE_1_3 and UE_1_4 are 0.001%, 0.005%, 89% and 99% respectively.
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In conclusion, the packet loss for UE_1_4 and UE_1_3 is higher than the UE_1_1 and UE_1_2 respectively because the priority of UE_1_1 and UE_1_2 is higher and it carries GBR bearer.

5.2.2.1 Discussion

From Figure 5.6 (b) it can be described that high priority video traffic interrupted low priority video traffic received by UE_1_3 and UE_1_4. It means that after the high and low priority video applications start (t=120 seconds), we see that preemptions and rejections happen to be experienced in the cell of eNodeB_1. Around t=120 seconds, we see 2 NGBR bearers being preempted. These are the Silver bearer of UE_1_3 and Bronze UE_1_4. Around t=120 seconds, it is observed that 2 of NGBR bearers start getting rejected due to the high priority video traffic. We can see from the Figure 5.6, video applications of UE_1_1, UE_1_2, UE_1_3 and UE_1_4 sent around to 485829 bytes /sec of traffic which translate to a load of 3886632 bits/sec for the application layer. At the MAC layer, this is about 3975429 bits/sec due to MAC overhead whereas sent video traffic at MAC layer is higher than application layer traffic load. From our simulation results, we make sure that MAC traffic sent for both UE_1_1 and UE_1_2 is around 3975429 bits/sec so that, overhead added by other layer protocol and MAC layer protocol can be confirmed to the correctness of the GBRs. On the other hand, lowest priority traffic corresponded with Bronze NGBR (UE_1_4) is almost rejected due to the fact that highest priority traffic is getting opportunity to use the available resources in EPS in eNodeB_1 cell. Table 5.6 and 5.7 summarizes the packet loss for different traffic classes.

Table 5.6 Statistic of traffic sent for Scenario 2 (Medium Load) Network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>485829</td>
<td>648620</td>
<td>202683</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.7 Statistic of traffic received for Scenario 2 (Medium Load) Network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>0.0</td>
<td>485820</td>
<td>648620</td>
<td>202641</td>
<td>0.001%</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.0</td>
<td>485804</td>
<td>648620</td>
<td>202642</td>
<td>0.005%</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.0</td>
<td>50192</td>
<td>95500</td>
<td>20813</td>
<td>89%</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>0.0</td>
<td>3500</td>
<td>10235</td>
<td>2364</td>
<td>99%</td>
</tr>
</tbody>
</table>
5.2.3 Packet Loss Performance for Scenario 3 (High Load) Video Conferencing Network

Around 526315 bytes data is sent to make this network Scenario 3 (High Load). When all the UE start video conferencing at 120 seconds, there is a high load in this network. From the Figure 5.7 it seems that the UE_1_1 is received on an average 526291 bytes which is almost the same as the data sent because of carrying GBR bearer with highest priority. On the other hand UE_1_2, UE_1_3, and UE_1_4 are getting rejected due to lowest priority GBR and NGBR bearers. The packet loss for the UE_1_1, UE_1_2, UE_1_3, UE_1_4 are almost 0.004%, 82%, 96% and 99%.

5.2.3.1 Discussion

From Figure 5.7 (b), we can see that the video traffic received by UE_1_2, UE_1_3, and UE_1_4 using Gold, Silver, and Bronze bearers respectively, are interrupted by the high priority video traffic. This can be better explained in way that after the high and low priority video applications start (t=120 seconds), we see that preemptions and rejections happen to be experienced in the cell of eNodeB_1. Around t=120 seconds, we see 1 GBR and 2 NGBR bearers being preempted. These are the bearer of UE_1_2, UE_1_3, and UE_1_4. Around t=120 seconds, it is observed that, three of GBR and NGBR bearers start getting rejected due to the high priority video traffic. Looking at the Figure 5.7, the high priority video applications UE_1_1 sent around 526315 bytes/sec of traffic which translates to a load of 4210520 bits/sec for the application layer. At the MAC layer, this is about 4307854 bits/sec due to MAC overhead whereas sent video traffic at MAC layer is higher than application layer traffic load. In that case, we set the Guaranteed Bit Rate for the Platinum BGR as 4307854 bits/sec, giving some room for the MAC overhead. From our simulation results, we make sure that MAC traffic sent for UE_1_1 is around 4307854 bits/sec so that, overhead added by other layer protocol and MAC layer protocol can be confirmed to the correctness of the Guaranteed Bit Rates.

Apart from the highest priority GBR bearers, lowest priority traffic corresponded with Gold Bearer (UE_1_2) is partially rejected whereas Silver NGBR
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(UE_1_3) and Bronze NGBR (UE_1_4) are almost rejected due to the fact that highest priority traffic is getting opportunity to use the available resources in EPS in eNodeB_1 cell. Table 5.8 and 5.9 summarizes the packet loss for different traffic classes.

Table 5.8 Statistic of traffic sent for Scenario 3 (High Load) Network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>526315</td>
<td>702671</td>
<td>219524</td>
</tr>
</tbody>
</table>

Table 5.9 Statistic of traffic received for Scenario 3 (High Load) Network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>0.0</td>
<td>526291</td>
<td>702671</td>
<td>219528</td>
<td>0.004%</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.0</td>
<td>94447</td>
<td>197011</td>
<td>41783</td>
<td>82%</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.0</td>
<td>16661</td>
<td>61930</td>
<td>13342</td>
<td>96%</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>0.0</td>
<td>3498</td>
<td>10697</td>
<td>2420</td>
<td>99%</td>
</tr>
</tbody>
</table>

5.2.4 Summary of Packet Loss Performance

This subsection is described the packet loss performance for the different GBR and NGBR bearers. Three scenarios of video conferencing for Scenario 1 (Low Load), Scenario 2 (Medium Load) and Scenario 3 (High Load) network are shown in Figure 5.8. X-axis represents UE_1_1 (Platinum-GBR), UE_1_2 (Gold-GBR), UE_1_3 (Silver-NGBR) and UE_1_4 (Bronze-NGBR) and Y-axis represents Packet Loss Rate (%).

![Figure 5.8 Summary of Packet Loss Rate (%) for different scenarios.](image)

For the Platinum (GBR) and Gold (GBR) bearers, the average packet loss in the Scenario 3 (High Load) network is 24.9% higher than Scenario 2 (Medium Load).
Load) network while 87% higher than Scenario 1 (Low Load) network. The average packet loss for the Bronze (NGBR) for Scenario 3 (High Load) network is 61% lower than medium load network on the other hand 74% higher than Scenario 1 (Low Load) network. For the Platinum (NGBR) bearer the average loss for Scenario 2 (Medium Load) network is 65% higher than that of Scenario 1 (Low Load).

5.3 Packet Delay Variation (PDV) Performance

The Packet Delay Variation (PDV) sometimes called “Jitter”. “Jitter” commonly has two meanings. Variation of the signal with respect to some clock signal it’s the first meaning of “Jitter” and the second meaning of “Jitter” is the variation of a delay with respect to some reference metric like average delay or minimum delay. Delay variation is important to size of play-out buffers for applications requiring the regular delivery of packets like voice or video play-out [39]. The performance metric is based on the difference in the One-Way-Delay of selected packets. In subsequent sections, scenarios 1, 2, and 3 correspond namely to the Scenario 1 (Low Load), Scenario 2 (Medium Load) and Scenario 3 (High Load) respectively. An extensive performance evaluation has been carried out, by means of simulations, to investigate PDV performance for different traffic classes which are simultaneously active flows in the three different network scenarios and to provide insights on PDV parameters tuning. Results are summarized in the figures and minimum, maximum, average and standard deviation values of PDV have been reported in the tables for the respective scenarios. In all of the figures presented in the following sub subsections, X axis represents the simulation time in second while Y axis represents Packet Delay Variation (PDV) in second.

5.3.1 PDV performance for Scenario 1 (Low Load) Network

![Figure 5.9 PDV performance for Scenario 1 (Low Load) network.](image-url)
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In this Figure 5.9 and Table 5.10 packet delay variation for Platinum (GBR) bearers in UE_1_1 varies from 0.000093ms to 0.00165ms where the average packet delay is 0.000253ms. PDV for Gold (GBR) bearers in UE_1_2 is started from 0.000012ms to 0.00212ms on an average 0.00032ms. In the case of UE_1_3 (NGBR) for Silver, the average PDV is 0.0002481ms and for Bronze (NGBR) bearer in UE_1_4 the lowest PDV is 0.000143ms while the highest PDV is 0.00143ms on an average 0.000219ms.

Table 5.10 PDV performance for Scenario 1 (Low Load) network.

<table>
<thead>
<tr>
<th>Bearer</th>
<th>Min. (sec.)</th>
<th>Avg. (sec.)</th>
<th>Max. (sec.)</th>
<th>Std. Dev (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>9.394E-008</td>
<td>2.535E-007</td>
<td>1.656E-006</td>
<td>2.523E-007</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>1.205E-007</td>
<td>3.252E-007</td>
<td>2.121E-006</td>
<td>3.232E-007</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>9.199E-008</td>
<td>2.481E-007</td>
<td>1.619E-006</td>
<td>2.467E-007</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>8.126E-008</td>
<td>2.193E-007</td>
<td>1.433E-006</td>
<td>2.182E-007</td>
</tr>
</tbody>
</table>

5.3.2 PDV performance for Scenario 2 (Medium Load) Network

Packet delay variation for different GBR and NGBR bearer is established in Figure 5.10 and described in Table 5.11.

![Figure 5.10 PDV performance for Scenario 2 (Medium Load) network.](image-url)
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PDV for UE_1_1 (Platinum GBR) bearer is started from 0.0027ms and finished at 0.0296ms with average 0.0055ms. In the case of Gold (GBR) bearer UE_1_2, the PDV is from 0.09641ms to 1.23ms and the average packet delay is 0.23ms.

Table 5.11 PDV performance for Scenario 2 (Medium Load) network.

<table>
<thead>
<tr>
<th>Bearer</th>
<th>Min. (sec.)</th>
<th>Avg. (sec.)</th>
<th>Max. (sec.)</th>
<th>Std. Dev (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>2.758E-006</td>
<td>5.5249E-006</td>
<td>2.960E-005</td>
<td>4.346E-006</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>9.641E-005</td>
<td>0.00023</td>
<td>0.00123</td>
<td>0.000201</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.2565</td>
<td>1.036</td>
<td>1.113</td>
<td>0.119</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>16.672</td>
<td>439.50</td>
<td>508.94</td>
<td>111.425</td>
</tr>
</tbody>
</table>

PDV value for Silver (NGBR) bearer of UE_1_3 is from 3256ms to 1113ms and UE_1_4 which carries Platinum (NGBR) is started from 16672ms to 508940ms where the average packet delays are 1036ms and 439500ms.

In the case of Scenario 2 (Medium Load) network, it can be seen that the PDV for UE_1_2 (Gold GBR) bearer is 400% higher than Platinum (GBR) bearer.

5.3.3 PDV performance for Scenario 3 (High Load) Network

Figure 5.11 shown and Table 5.12 described the PDV for different GBR and NGBR bearer under the Scenario 3 (High Load) network.

Figure 5.11 PDV performance for Scenario 3 (High Load) network.
The delay variation for UE_1_1 Platinum (GBR) bearer is growing from 4.728E-006s to 6.33E-005s on an average 1.078E-005s. For Gold (GBR) bearer UE_1_2, the PDV is started from 0.0372s to 0.678s where the average value is 0.612s. Again for Silver UE_1_3 (NGBR) bearer minimum PDV is 0.5603s and highest PDV is 0.8345s on an average 0.8219s.

Table 5.12 PDV performance for Scenario 3(High Load) network.

<table>
<thead>
<tr>
<th>Bearer</th>
<th>Min. (sec.)</th>
<th>Avg. (sec.)</th>
<th>Max. (sec.)</th>
<th>Std. Dev (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE_1_1</td>
<td>4.728E-006</td>
<td>1.078E-005</td>
<td>6.337E-005</td>
<td>9.522E-006</td>
</tr>
<tr>
<td>UE_1_2</td>
<td>0.0372</td>
<td>0.61214</td>
<td>0.678</td>
<td>0.1247</td>
</tr>
<tr>
<td>UE_1_3</td>
<td>0.5603</td>
<td>0.8219</td>
<td>0.8345</td>
<td>0.0339</td>
</tr>
<tr>
<td>UE_1_4</td>
<td>17.912</td>
<td>332.581</td>
<td>378.126</td>
<td>77.307</td>
</tr>
</tbody>
</table>

In the case of Scenario 3(High Load) network, the average PDV for UE_1_2, UE_1_3 and UE_1_4 bearer are very high and getting rejected due to the fact that, highest priority GBR bearer is getting opportunity to use the available bandwidth.

5.3.4 Summary of PDV Performance

PDV performance has been shown in preceding discussion in Figure 5.12 and described the summary for the PDV performance from the above section where X-axis represents different GBR and NGBR bearers while Y-axis represents packet delay variation (seconds). The average PDV for UE_1_1 (Platinum GBR) bearer in Scenario 3 (High Load) network is 96% higher than Scenario 2 (Medium Load) network and 4160% higher than Scenario 1 (Low Load) network.

Figure 5.12 Summary of PDV Performance (Sec) for different scenarios.
In conclusion, PDV for scenario 3 (high load) network is higher than Scenario 2 (Medium Load) network and Scenario 1 (Low Load) network. In the case of Scenario 1 (Low Load) network PDV for GBR and NGBR bearers are not high. For medium and high load network, the PDV for NGBR is much higher than GBR bearer. Moreover there is very low traffic flow through UE_1_2, UE_1_3 and UE_1_4 under scenario 3 (high load) due to highest priority GBR bearer traffic.
Chapter 6 CONCLUSION AND FUTURE WORK

In this research we have investigated the effect of QoS performance for video conferencing in the LTE network with E2E delay, packet loss and packet delay variation metrics. Three networks scenarios have been created namely Scenario 1 (Low Load) network, Scenario 2 (Medium Load) network and Scenario 3 (High Load) network. Comparison were carried out between them and presented in Chapter 4. OPNET Modeler 16.0 has been used to simulate the network scenarios to evaluate the answers for the research questions by graphical representation. The simulation result shows that GBR and Non GBR bearers have great impact on video conferencing under congested network.

E2E delay for low load scenario is almost zero for both GBR and NGBR bearers. For medium load network, the delay ranges 0.0281~0.041 seconds and 3.150~39 seconds for GBR and NGBR bearers respectively. This indicates that packet partially rejected for NGBR. Whereas in scenario 3 (High Load) network, only highest priority GBR has tolerable E2E delay of 0.0371 seconds.

The average PDV for GBR and NGBR bearers in low load network are varies from 0.00021~0.00032ms. For medium load network, packet delay variations for NGBR bearer are very high compared to GBR bearer. Whereas only highest priority GBR bearer (UE_1_1) is getting opportunity to use the available bandwidth rather than other bearer in high load network due to highly congestion.

The packet loss rate for low load network corresponding to GBR and NGBR bearer are almost 0%. Whereas, in case of congested (medium and low load) network, the average packet loss of video traffic for highest priority GBR bearer was found to varies within 0.001%~0.005% while for lower priority NGBR bearer varies between 89%~99%.

In all cases we can conclude that, highest priority GBR bearer is getting more opportunity to use available resources in ESP of eNodeB while the network is congested. Compared to GBR bearers’ traffic, NGBR are almost rejected.

In future, there are scopes for studies focusing on other QoS metrics with larger network model. Also, studies can be done for GBR and NGBR bearers’ behavior with mobility.
BIBLIOGRAPHY


