Performance evaluation of mobile devices in Long Term Evolution (LTE) during handover

James Guerra – 301006524
Shams S Narsinh – 301277255
Team 2
ENSC 833 NETWORK PROTOCOLS AND PERFORMANCE
SPRING 2016

Table of Contents

List of Figures....2

List of Tables....3

List of Acronyms:.... 4

1 Abstract....5

2 Introduction....5

3 Background....5

3.1 LTE NETWORK....5

3.2 LTE HANDOVER.... 8

3.2.2 Handover decision.... 9

4 Experiments....10

4.1 MODELER Capabilities....10

4.1.1 Validation of handover....11

4. 2 SIMULATION SCENARIOS AND RESULTS.... 15

4.2.1 Handover Delay Setup.... 15

4.2.2 Handover Delay Data....16

4.2.3 Throughput and Delay Setup....18

4.2.4 Throughput and Delay Data....19

5 Discussions and Results....25

5.1 HANDOVER DELAY RESULTS....25

5.2 Througphput and DELAY Results....25

6 Conclusion....27

6.1 FUTURE WORK....27

7 References.... 28

Appendix.... 29

A. Modeler settings.... 29

Application settings....29

Profile settings....29

LTE Configuration....30

eNodeB.... 31

UE.... 31

HTTP Server....32

B. GRAPHS FOR OTHER RESULTS....33

List of Figures

Figure 1: EPC Logical Nodes 6

Figure 2: User plane protocol stack 7

Figure 3: Control plane protocol stack 7

Figure 4: Reproduced from paper 9

Figure 5(a): RSRP and RSRQ value statistics during handover as shown in Modeler 18.5. 12

Figure 6: eNodeB_1 to eNodeB_3 GTP packet forwarded 13

Figure 7: Best Operational Wideband MCS Index 13

Figure 8: Connection and Re-establishment attempt statistic for a failed handover 14

Figure 9: EPS Bearer Traffic Sent by eNodeB_1 and eNodeB_2 and EPS bearer traffic receiveed by the UE 14

Figure 10(a): 3-cell Handover Delay Setup 15

Figure 10 (b): 7-cell Handover Delay Setup 15

Figure 10 (c): 19-cell Handover Delay Setup 16

Figure 11: Handover Delay with 10 handovers for each scenario 17

Figure 12: Handover delay with fixed 30 minutes of time frame 17

Figure 13: Handover setup with background traffic 18

Figure 14: Graph of successful handovers 20

Figure 15(a): Video traffic with no background traffic 20

Figure 15(b): Video traffic with background voice traffic 21

Figure 15(c): Video traffic with background video traffic 21

Figure 15(d): Video traffic with background HTTP traffic 21

Figure 16(a): EPS Bearer Delay for video traffic with no background traffic 22

Figure 16(b): EPS Bearer Delay for video traffic with video background traffic 22

Figure 16(c): EPS Bearer Delay for video traffic with voice background traffic 23

Figure 16(d): EPS Bearer Delay for video traffic with http background traffic 23

Figure 17(a): Traffic received for video traffic with voice background traffic 24

Figure 17(b): Traffic received for voice traffic with HTTP background traffic 24

Figure 17(c): Traffic received for voice traffic with voice background traffic 25

Figure 18(a): DAR bits and losses for voice traffic with no background traffic 33

Figure 18(b): DAR bits and losses for voice traffic with video background traffic 33

Figure 18(c): DAR bits and losses for voice traffic with voice background traffic 34
Figure 18(d): DAR bits and losses for voice traffic with HTTP background traffic..............................34
Figure 19(a): DAR bits and losses for HTTP traffic with no background traffic 35
Figure 19(b): DAR bits and losses for HTTP traffic with video background traffic 35
Figure 19(c): DAR bits and losses for HTTP traffic with voice background traffic 36
Figure 19(d): DAR bits and losses for HTTP traffic with HTTP background traffic 36
Figure 20(a): EPS Bearer Delay for voice traffic with no background traffic 37
Figure 20(b): EPS Bearer Delay for voice traffic with video background traffic 37
Figure 20(c): EPS Bearer Delay for voice traffic with voice background traffic 38
Figure 20(d): EPS Bearer Delay for voice traffic with HTTP background traffic 38
Figure 21(a): EPS Bearer Delay for HTTP traffic with no background traffic 39
Figure 21(b): EPS Bearer Delay for HTTP traffic with video background traffic................................. 39
Figure 21(c): EPS Bearer Delay for HTTP traffic with voice background traffic.................................. 40
Figure 21(d): EPS Bearer Delay for HTTP traffic with HTTP background traffic 40

List of Tables

Table 1: Application Profiles with specifications 11
Table 2: Physical Layer Parameters 11
Table 3: Attributes of Simulations 12
Table 4: Application Settings for Riverbed Modeler 18.5 29
Table 5: Profile settings for Riverbed Modeler 18.5..30
Table 6: Configurations specific to LTE in Riverbed Modeler 18.5..30
Table 7: Configurations for eNB in Riverbed Modeler 18.5 31
Table 8: Configurations for UE in Riverbed Modeler 18.5 32
Table 9: Specifications for HTTP applications in Riverbed Modeler 18.5 32

List of Acronyms

3GPP	3rd Generation Partnership Project
DAR	Delay and Retransmitted
eNB (eNodeB)	Enhanced node B (Base Station)
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Radio Access
HO	Handover (Handoff)
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscriber Server
L1	Physical Layer – Layer 1
L3	Network Layer – Layer 3
LTE	Long Term Evolution
MCS	Modulation Coding Scheme
OFDMA	Orthogonal Frequency Division Multiple Access
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PGW	Packet Data Network Gateway
RLC	Radio Link Control Protocol
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SC – FDMA	Single Carrier – Frequency Division Multiple Access
SGW	Serving Gateway
UE	User Equipment
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature Amplitude Modulation
VoLTE	Voice over LTE
X2	Interface connecting two eNBs

1 Abstract

Handover performance is crucial for modern mobile communications networks, particularly in LTE (Long Term Evolution) because of the tremendous growth of data intensive applications amongst mobile devices. The factors that can affect this handover performance are the type of interface in which the handover exists, either X2 or S1 interface; the mobility of the UE and the QCI (Quality of Service Class Identifiers). This project looks at the handover delay time and information loss (e.g. EPS bearer bit loss) in the eNodeB (eNB) – UE and the packet delay (EPS bearer delay) between the eNodeB and UE during handover. Three different applications, namely, Video conferencing, HTTP web TV and VoLTE (Voice LTE), running on a mobile UE were evaluated with a background traffic. Our results show handover delay increases with an increasing cell count in the network and the aggregate handover delay time increases for higher speeds. The EPS bearer throughput in terms of losses and "delay and retransmitted bits" is better with using the X2 interface enabled than just with the S1 interface. The bearer delay on the other hand is affected by the scheduling and load of the background traffic than type of interface the handover is happening on.

2 Introduction

Modern mobile communications use the LTE technology because of its high data rates and the promise of fulfilling the internet of things (IoT) implementation. LTE allows for a packet switch mobile network with interactions between people-to-people (P2P), people-to-machine (P2M) and machine-to-machine (M2M) [5]. It is therefore imperative that the handover experienced by end-users, or user equipment (UEs), be minimized so that certain QoS parameters will be met. There are several factors and scenarios that can affect the handover experienced by UEs. This project however, will only focus on evaluating the intra-frequency handover on the X2 and S1 interface given the mobility of the target UE and the background QoS of other UEs. We intend to evaluate performance by measuring the handover delay when the UE transitions amongst eNodeBs and the loss of information as data transits from EPC to UE.

LTE handover is a fairly well researched area. In [2], the performance evaluation for intra-frequency handover for TCP and UDP in terms of throughput in Mbps and downlink delay is evaluated while varying the physical layer parameters that influences the handover performance using the A3 trigger mechanism. In [7], stochastic analysis of real world devices (smartphones) wherein the handover interruption time was measured and broken down into further smaller components was done. In [5], proposed downlink scheduling algorithms that Qos-aware and/or Channel-aware were presented and analyzed. The simulations however doesn't include a handover scenario. In [4], a "handover preparation" algorithm was proposed where multiple handover messages are sent to the UE for a quicker handover.

3 Background

3.1 LTE NETWORK

The term LTE comes from the evolution of UMTS (universal mobile telecommunication system) through Evolved UTRAN (E-UTRAN), although the non-radio component also evolved which is now known as the system architecture evolution (SAE). LTE and SAE together forms the evolved packet core (EPS). [1]

3.1.1 Evolved packet core (EPC)

In the EPS, the Evolved Packet Core (EPC) or the core network (CN) performs the overall management of the UE which includes establishing packet connections to the UE from some other IP based machine. The CN consist of many logical nodes as shown in figure 1, with the following nodes worth noting. [1]

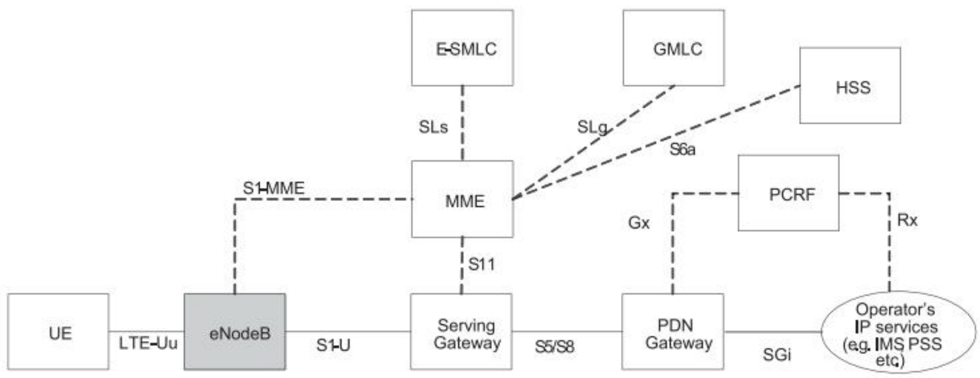

Figure 1: EPC Logical Nodes [1]

The Mobility Management Entity (MME) manages the UEs by executing the protocols (non-access stratum protocols) necessary for the UE's secure connection to the network. The MME manages and establishes the different EPS bearers used for UE connection. EPS bearers are IP connections which are associated with a certain QoS. The MME also manages handover between current and LTE and legacy mobile networks.

The P-GW or the Packet data network (PDN) gateway is responsible for assigning the IP address of the traffic intended for the UE to the appropriate EPS bearers. The S-GW or the Serving Gateway interfaces with the P-GW and is responsible for monitoring the bearers associated with UE as it moves through the radio network, for example, the S-GW will maintain the information while the UE is in an EPS connection management state (ECM-IDLE).

The PCRF or Policy Control and Charging Rules function, as the name indicates provide policy information that would affect the quality of service that the UE subscriber might receive. The Home Subscriber Server (HSS) provides profile information for the UE subscriber, which is useful for authentication and roaming while the Evolved Serving Mobile Location (E-SLMC) predicts and manages the resources needed for providing services to a mobile UE.

The reader is further invited to explore [1] for detailed information and other functions and other nodes in the CN.

3.1.2 E-UTRAN

eNodeBs and UEs comprise the access network for LTE. The access stratum protocols provide the radio related management procedures in the E-UTRAN. The eNodeBs can be linked together using the X2 interface while eNodeBs are also connected to the MME by S1 interface. Finally, the eNodeB interfaces with the UE via LTE – Uu [1].

3.1.3 EPS Network

The EPS interfaces in general can be classified as per function; the user plane and the control plane protocols. The user plane protocol stack defines the mapping of an IP packet from the P-GW to the UE via tunneling protocols, such as the GTP (GPRS Tunneling protocol). The control plane defines the management of UEs which includes radio bearer management. [1] The following figure shows the two protocol stack with their acronyms expanded.

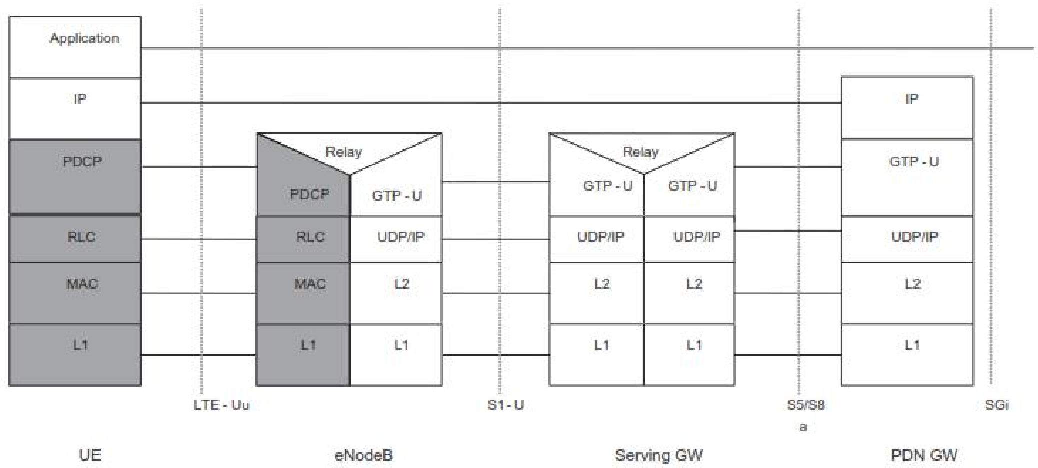

Figure 2: User plane protocol stack – Reproduced from "LTE - The UMTS Long Term Evolution" [1]

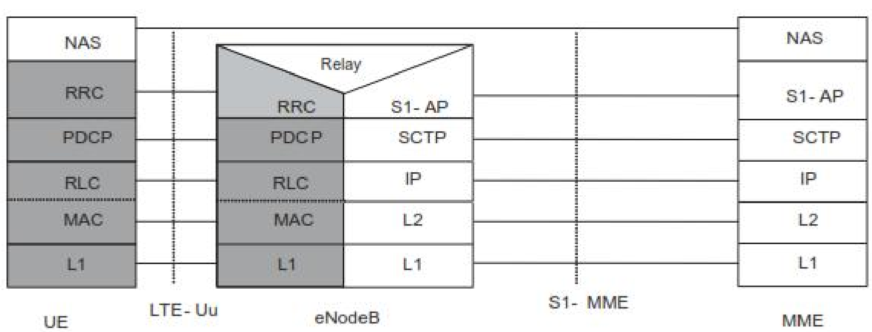

Figure 3: Control plane protocol stack - Reproduced from "LTE - The UMTS Long Term Evolution" [1]

An IP packet is associated with an EPS bearer which has to cross multiple interfaces. The S5/S8 interface between P-GW and S-GW; the S1-U interface between the S-GW and eNodeB, and the LTE-Uu interface between the eNodeB and UE. An IP packet is mapped to an S5/S8 bearer with a one-to-one mapping to an S1 bearer which can be identified by the GTP tunnel ID. Finally, the radio bearer traverses the packet through the LTE-Uu interface.

In the uplink direction, packet filtering is used using Traffic Flow Templates (UL-TFTs) which classifies the IP packet according to its IP header which includes the source and destination addresses (IP) and ports (e.g. TCP), and maps them to the appropriate headers based on the applications' QoS. A similar method (DL-TFT) is employed by the P-GW at the downlink direction [1].

In the physical layer, the downlink radio in the eNodeB uses Orthogonal Frequency Division Multiple Access (OFDMA) while the uplink radio provided by the UE uses Single-Carrier Orthogonal Frequency Division Multiple Access (SC-FDMA). The bandwidth used can be from 1.4 MHz to 20 MHz with a bit rate of up to 90 Mbps for using the 20 MHz bandwidth. The MCS or Modulation Coding Scheme is the modulation scheme used in the physical layer. The modulation code spans from QPSK (quadrature amplitude phase shift keying) to 16-QAM (quadrature amplitude modulation) and up to 64-QAM modulation type [1].

3.2 LTE HANDOVER

There are two methods of handover based on protocol interface, they are the S1 handover and X2 handover. The X2 handover is present if there is an X2 interface connection between two eNodeBs. For both cases, the steps for handover can be divided into three phases: the preparation phase, execution phase and completion phase [5].

3.2.1 X2 and S1 handover

In the preparation phase, measurement reports from the UE will trigger the source eNodeB to initiate a handover procedure by sending a handover request from the source eNodeB to the target eNodeB. The request is acknowledged by the target eNB and the execution phase begins with HO (handover command) sent to the UE by the source eNB. On the execution phase, link interruption happens and data packets are forwarded to the target eNB while simultaneously having the UE establish its radio connection to the target eNB. Completion phase starts when the handover confirmation message is received by the target eNB [5]. The target eNB informs the MME that the UE has changed cells; the MME asks for a user plane update request from S-GW; the S-GW confirms the new downlink path to the target eNB and halts the transmission packets to the source eNB; then the MME confirms a successful handover to the target eNB. A detailed handover diagram is shown on the next figure.

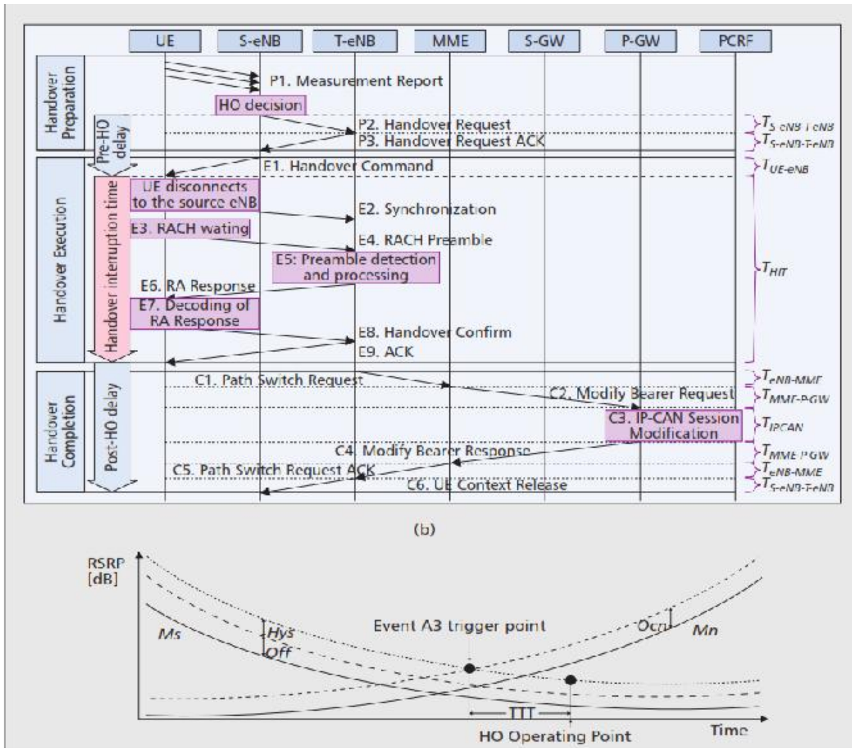

Figure 4: Detailed Handover Phases and the A3 trigger mechanism for the handover - Reproduced from "Measurement and stochastic modeling of handover delay and interruption time of smartphone real-time applications on LTE networks" [7]

The difference with the S1 handover with the X2 handover is that a source MME would initiate a RELOCATION REQUEST to the target MME while the target eNB also helps in identifying itself to the target MME. The completion phase will include the forward relocation completion completed as the target eNodeB notifies the target MME of the handover completion [1], [7].

3.2.2 Handover decision

For an LTE intra-frequency handover, handover can be triggered using different events, one of which is the A3 event wherein the RRSP or Reference Received Signal Power of the source eNB is lower than that of the target eNB. In [2], the A3-offset is varied showing that the handover will trigger when the RSRP + A3 offset power is lower on the source eNB, i.e. A3-offset is 2dB. To minimize the Ping-Pong problem and to increase throughput (see [2]), we used an A3-offset of 2dB in our simulations. The time to trigger (TTT), is the time required for the event to trigger the handover after the criteria is met.

Aside from the RSRP, the Reference Signal Received Quality metric can be used in determining which eNodeB the UE would handoff too. RSRQ is a metric in determining the quality of the signal used by the UE for a particular eNodeB [1].

4 Experiments

4.1 MODELER CAPABILITIES

Most of the information described in this section is from [8]. We recommend the reader to consult the modeler documentation for the LTE model, for detailed description described in this model.

Modeler 18.5 has an LTE module which can be deployed rapidly using the Wireless Network Deployment Tool. The LTE module supports the different EPS bearer definitions with the associated GBR (guaranteed bit rate) and Non-GBR applications. The model also supports GTP tunneling between the eNodeB and the EPC by padding an IP/UDP/GTP header on a typical IP packet. Downlink and uplink traffic flow templates (TFTs) are supported and the mapping between TFT → EPS bearer based on the ToS available. In the LTE configuration node, bitrates of each GBR bearers can be defined as well as the scheduling mechanism supported by the specific bearer. The scheduling mechanism supported are dynamic and semi-persistent scheduling. In semi-persistent scheduling, there is a periodic downlink radio frames allocated for small packet transmissions which can be used in VoIP traffic.

Channel dependent scheduling is enabled by default in the UE. That is, depending on the target link quality (channel quality), an appropriate modulation and coding scheme would be selected. The modulation and coding scheme is the “chipping” code used on the channel for orthogonal frequency division modulation access (OFDMA).

Modeler has an eNodeB model, a UE model which can be a workstation or cellphone and an EPC or evolved packet core. The eNodeB model contains the access stratum protocols that will service the radio link between the UE and eNodeB. The EPC node contains the MME, P-GW and S-GW, in other words, it has the non-access stratum protocols for the “higher layer” of LTE.

The LTE model supports intra frequency handover on the S1 interface and X2 interface and UE reporting for RSRP parameter. The X2 handover happens if the X2 capability is enabled in eNodeB and UE. It supports 5 different trigger mechanisms for handover, but for this project, we choose the A3 mechanism, where at a certain lower offset of RSRP parameter, handover will be triggered. The model however considers the RSRQ value and the weighted values of the RSRP and RSRQ parameters are considered as the selection criteria for the target eNodeB. The model also supports handover failures or “incomplete handover”. One such failure is when the UE loses connection to the serving eNodeB before it receives a handover command message. In this case, connection re-establishment procedure will be followed so that the UE would be connected to new eNodeB.

The parameters useful for our analysis includes the LTE handover delay and the throughput (EPS bearer throughput) in terms losses or delayed and retransmitted bits. The EPS bearer delay will be considered in tandem with EPS bearer throughput. The idea for measuring delayed and retransmitted bits came from [6]. Finally, the LTE handover delay mechanism is conveniently given by the tool.

4.1.1 Validation of handover

The following table summarizes our setup for the applications we used for the simulations.

Traffic	Bearer	Description
Voice	2 (Gold)	PCM Quality Speech 64 kb/s (G.711). Semi-persistent scheduling enabled in Gold bearer [4], [5]
Video Conferencing	3 (Silver)	Live streaming video, CBR traffic: packet arrival 20ms (50 packets /s) with a target bit rate of 312 kb/s; DSCP = AF41 [5]
HTTP	6 (Bronze)	HTTP web TV; Best effort ToS(0); Radio link control is set for "acknowledge mode"
HTTP Background	6 (Bronze)	HTTP heavy browsing with page arrival time 1s; Best effort ToS(0); Radio link control is set for "acknowledge mode"

Table 1: Application Profiles with specifications

For Voice traffic, we used PCM Quality Speech as specified in [4] and the VoIP of choice in paper [5]. For the Video traffic, we chose live streaming video which is a constant bit rate of 312 kb/s with differentiated service code point AF41 which emphasizes throughput and low drop probability. For the HTTP traffic, we chose HTTP web TV just so we have a continuous traffic being sent to the downlink of the LTE protocol stack. We've also enabled an ARQ protocol in the radio link control (RLC) layer of the LTE-Uu interface.

The following table summarizes the physical layer aspects considered in our simulations.

Physical layer parameters	Value
Channel bandwidth	20MHz
Uplink antenna model	Uplink SC-FDMA
Downlink antenna model	Downlink OFDMA
Pathloss	Free space
Scheduling	Link adaptation and channel dependent scheduling

Table 2: Physical Layer Parameters

We chose a channel bandwidth of 20 MHz to maximize the throughput (up to 90 Mbps on the downlink) that we can use on the radio layer. This ensures that our throughput is not limited by our bandwidth. We chose a pathloss of free-space to avoid physical layer aspects that can limit our throughput, but we have no choice but to use the uplink and downlink antenna model. Channel dependent scheduling is also enabled.

The following table summarizes the setup used for our simulations.

Simulation Setup	Values
Speed of the UE	30,60,120
Number of cells	3-cell, 7-cell, 19-cell
Background traffic	Video, Voice, HTTP
Interfaces for handover	S1, X2

Table 3: Attributes of Simulations

In order to verify that handover is happening, some statistics can be observed in modeler 18.5

There RSRP and RSRQ parameters provide the trigger for the handover. The following figures shows RSRP and RSRQ measured as reported by the UE to the eNodeB.

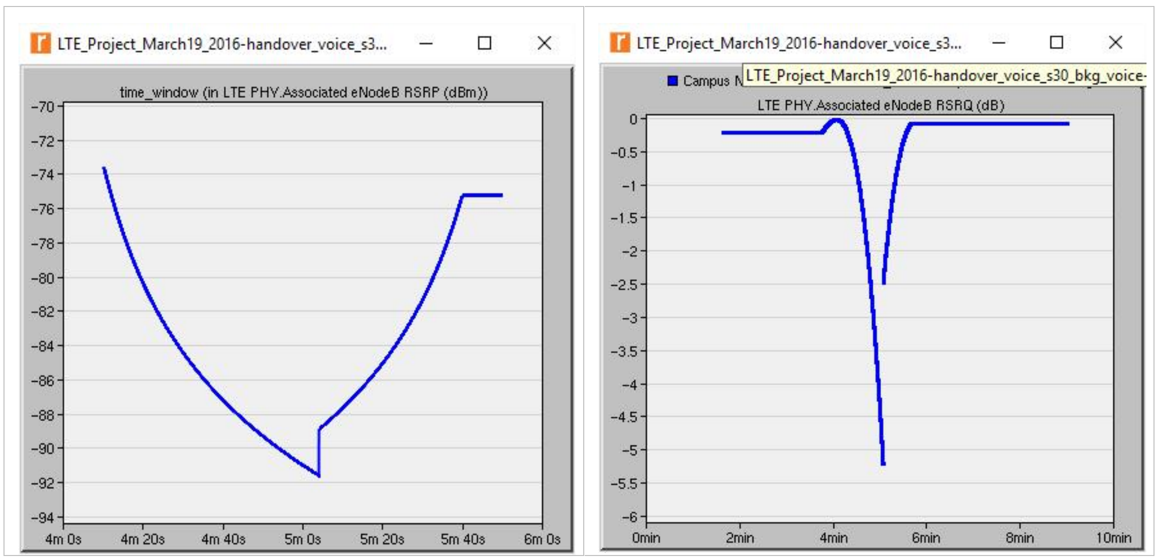

Figure 5(a): RSRP value goes lower than -90dB our trigger point for RSRP, while Figure 5(b) shows the handover trigger point when RSRQ goes below -5dB.

GTP packet forwarding is implemented when the X2 interface is enabled between 2 eNodeBs. For our model, we enabled X2 capability in the eNodeB models and also added point to point connection between the eNodeBs. This simulates a fiber channel type connection between eNodeB so that the GTP packet will not be routed back to the EPC. This kind of X2 interface is known as a "fast X2" type. The figure below shows GTP packet being forwarded from eNodeB_1 → eNodeB_3 during handover.

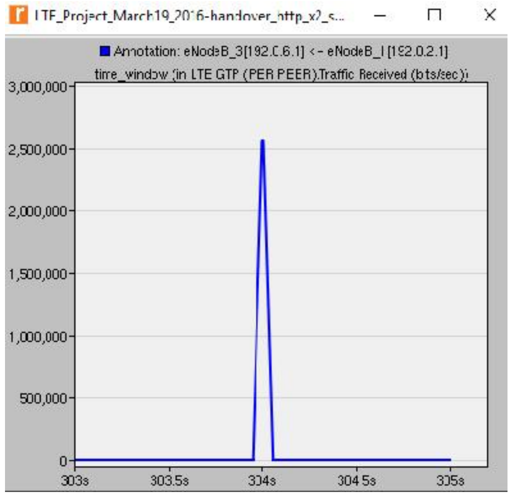

Figure 6: eNodeB_1 to eNodeB_3 GTP packet forwarded

Channel dependent scheduling is confirmed by the changing modulation and coding scheme during handover as shown below. The figure shows how the modulation coding scheme changes for two different runs. For simulation run 1, the modulation and coding scheme (see blue line) degrades more slowly than the red line. Note that the coding scheme of 0-9 means the UE is using QPSK, at 10-16 the UE is using 16-QAM, and the rest, the UE is using 64-QAM. This means the bitrate supported by the radio layer is lower for a longer period of time in the 1st simulation (blue line) compared to the other run (redline, run simulation 2).

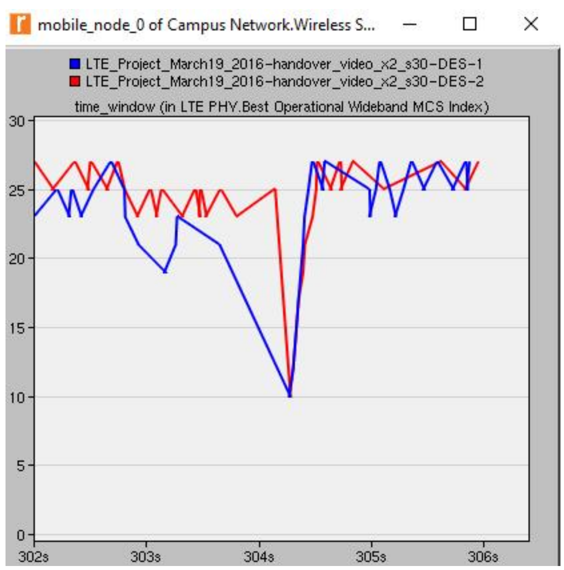

Figure 7: Best Operational Wideband MCB Index

In some cases, we encountered an RRC connection and re-establishment failure. This is the case where there is a handover failure. To confirm this, one can check the connection and re-establishment attempt statistics.

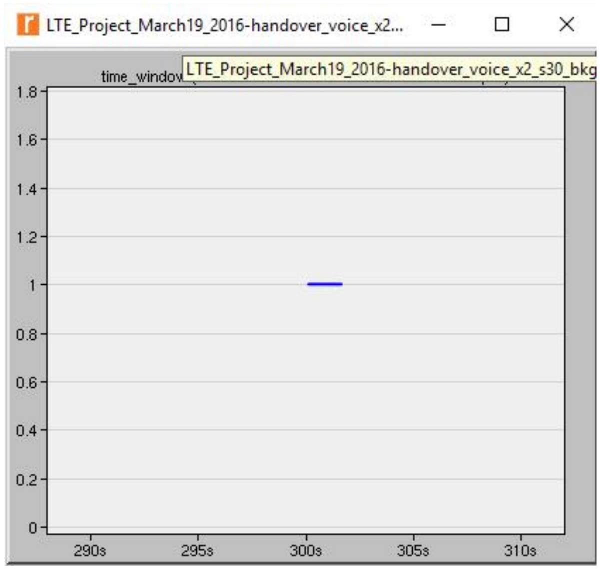

Figure 8: Connection and Re-establishment attempt statistic for a failed handover

The statistic EPS bearer traffic sent (bits/s) is the input to the entire LTE-Uu interface. In an ideal case, the EPS bearer traffic sent by the eNodeB should match the EPS bearer traffic received in bits/s at the UE. However during handover, it is expected that the EPS bearer traffic received would decrease signifying a loss. After the handover, there will bits would be retransmitted or delayed in order to recover from the loss information during handover causing the EPS bearer traffic received value to be higher than the EPS bearer traffic sent.

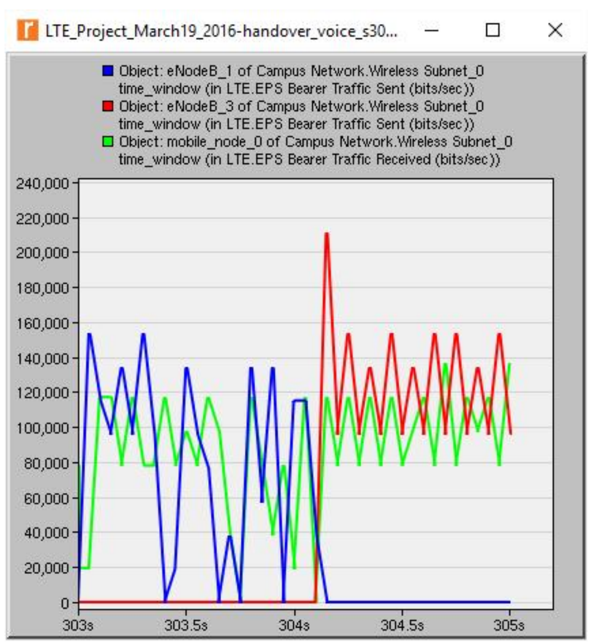

Figure 9: EPS bearer traffic sent (blue line) by eNodeB_1 decreases to 0 as EPS bearer traffic sent by eNodeB_3 increases (red line) during the handover point. EPS bearer traffic received by the UE (green line) drops to near 0 bits/s at the handover point

4. 2 SIMULATION SCENARIOS AND RESULTS

4.2.1 Handover Delay Setup

To evaluate the performance in terms of handover delay, three different network topologies were considered with different numbers of eNodeBs in each topologies. The first topologies contained 3 eNodeBs creating 3 cells for 1 UE to move around. The purpose of this simple topology was to verify the working conditions and parameters. Next we considered two standard topologies which have been utilized by many researchers in various papers, e.g. see paper [4]. We created topologies with 7 eNodeBs and 19 eNodeBs creating 7 cell and 19 cell topologies respectively allowing to move 1 UE among these cells. Below are the snapshots of topologies:

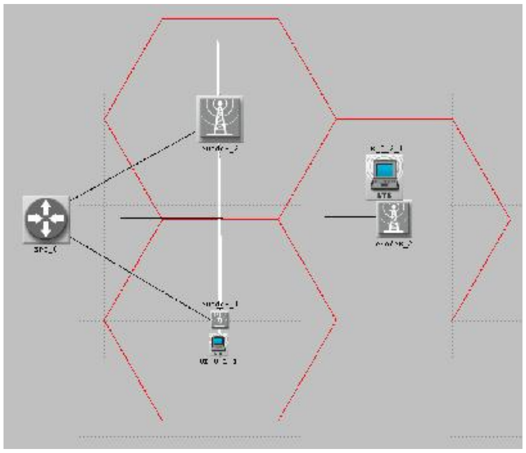

Figure 10(a): 3-cell Handover Delay Setup

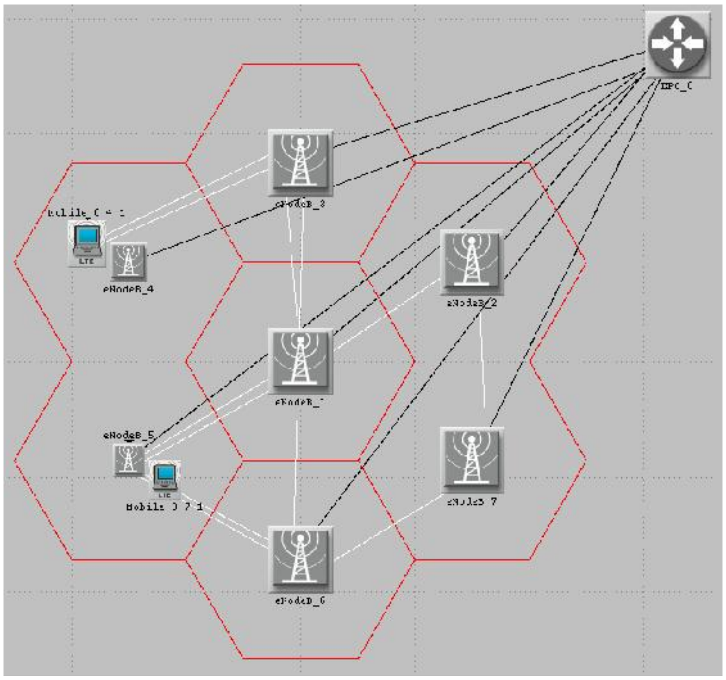

Figure 10 (b): 7-cell Handover Delay Setup

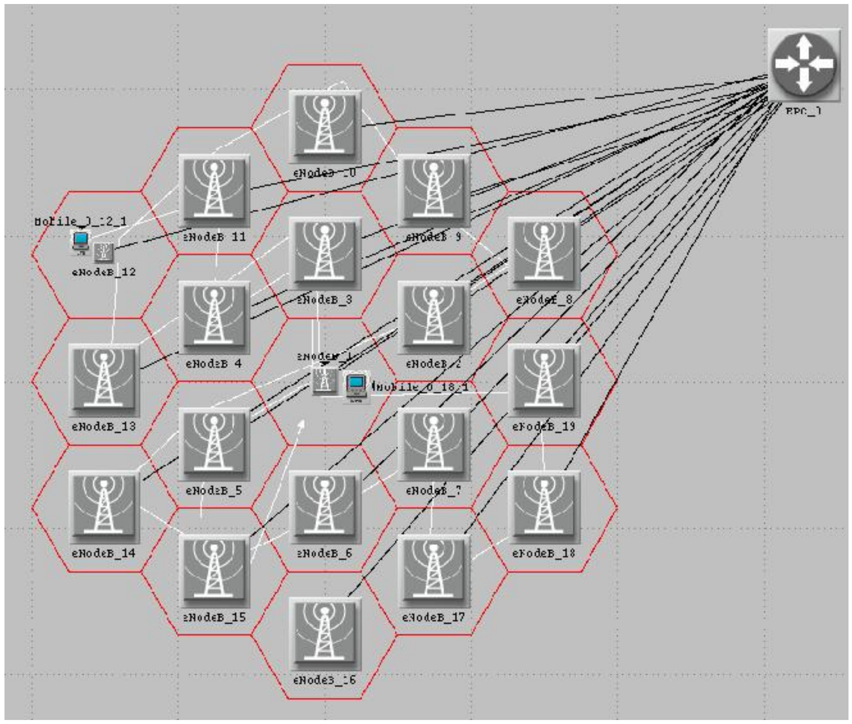

Figure 10 (c): 19-cell Handover Delay Setup

We have used three applications namely Voice, Video Conference, HTTP Web TV for evaluation of Handover Delay with four different speeds 3, 30, 60, and 120 km/h. As we are dealing with applications like Voice and Video Conferencing which happens between 2 UEs, we have also included another stationary UE in one the cells in out topology. For HTTP Web TV, HTTP server is connected with the Evolved Packet Core (EPC) in order to communicate with UE. White lines in the topology show the trajectory of the UE in the simulation.

There are two simulation scenarios considered for this experiment:

(1) For each of the three applications considered, 10 handovers are performed for each of the three speeds (30, 60, and 120) considered over both S1 and X2 interfaces of handover on 3 cell topology.
(2) Fixed 30 minutes of simulation is performed for Voice over LTE (VoLTE) with four different speeds (3, 30, 60, and 120) on all three topologies (3 cell, 7 cell, and 19 cell).

4.2.2 Handover Delay Data

The following graphs are based on the data obtained from the above mentioned scenarios:

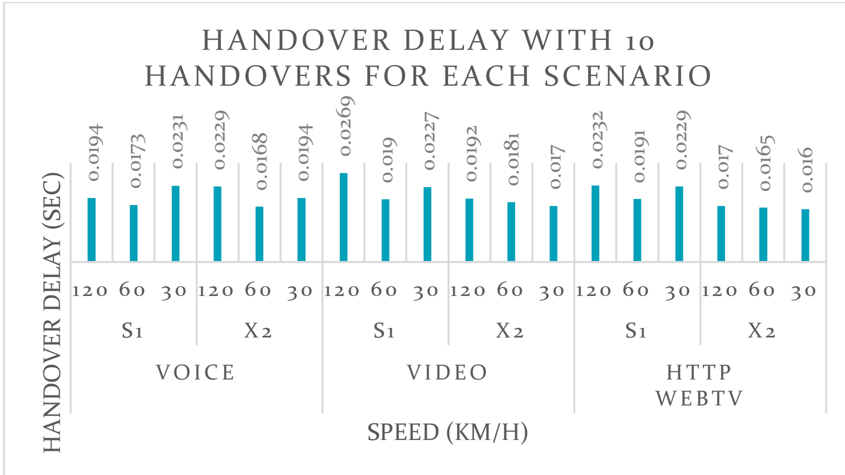

Figure 11: Handover Delay with 10 handovers for each scenario

The chart above shows the average value of 10 handovers for each application and for each speed over 3 cell topology. During the simulation we found some peaks in the handover delay which were quite larger than other values of same simulation. Overall, we see that the value of handover delay for X2 interface is lower than that of S1 interface.

The following chart shows the data for the second scenario where we observed that the handover delay increases with increasing the number of cells connected to Evolved Packet Core (EPC). It is due to the increased interferences from the neighboring cells that surround the cell where handover is taking place. For 3-cell topology the interference is less as it is only surrounded by one other cell, while 7 cell and 19 cell shows much higher interference due to larger number of neighboring cells. We also observed the similar result in this scenario in terms of interfaces that X2 interface shows less handover delay than S1 interface for all cells with all different speeds considered.

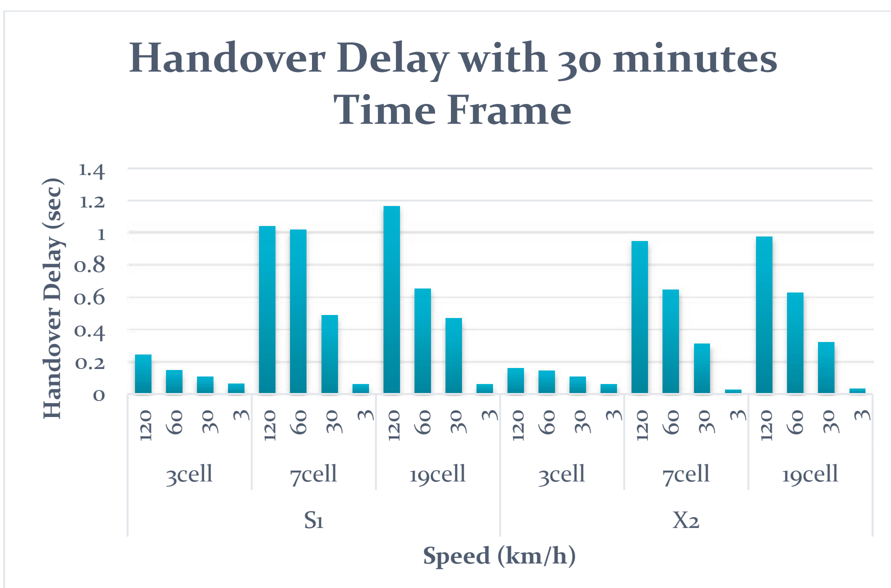

Figure 12: Handover delay with fixed 30 minutes of time frame

4.2.3 Throughput and Delay Setup

To evaluate throughput and delay, one UE will be considered as the moving UE between 2 eNodeBs. There will be 1 UE for each eNodeB that will serve as the source of the background traffic. In the interest of time and to minimize the physical layer aspects that might affect the handover, we are only considering a single trajectory and single speed as shown in the next figure. The speed is 30 km/hr.

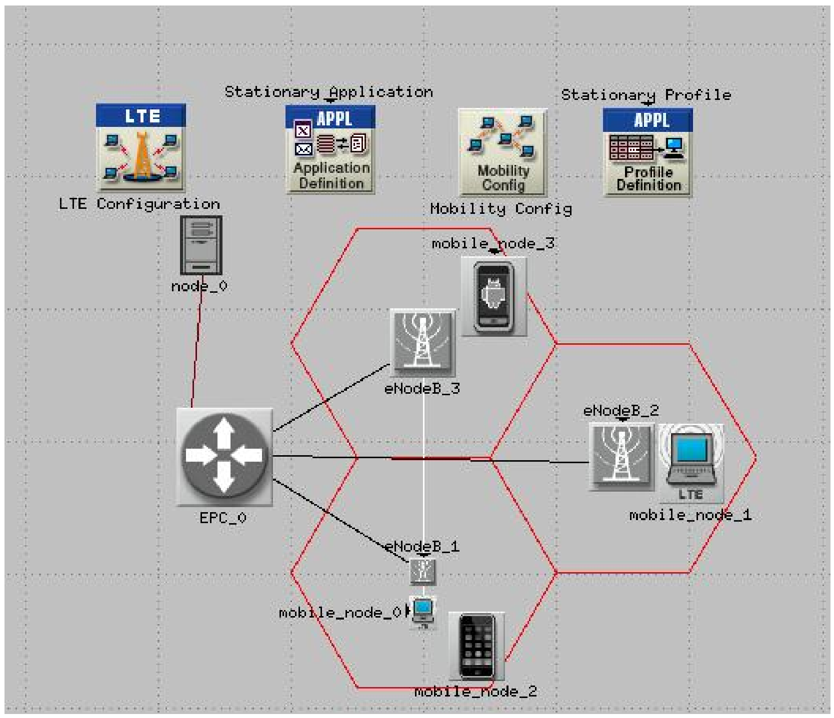

Figure 13: Handover setup with background traffic

For the throughput and delay measurements, the EPS bearer throughput statistic and EPS bearer delay is considered. The eNodeB provides the EPS bearer sent statistic in bits/s, while the UE provides and EPS bearer throughput received statistic in bits /s. There will be loses if there are EPS bearer sent > EPS bearer received. On the opposite case, one can assume that there have been retransmissions or delayed bits received if EPS bearer sent < EPS bearer received. The following formulae are considered in calculating the % in terms of losses or "delay and retransmitted" (DAR) bits.

If output > input, (EPS bearer received bits/s by the UE > EPS bearer sent bits /s by the eNodeB), then the extra bits received by the UE are either delayed or retransmitted bits,

$$Delayed\ and\ Retransmitted\ bits\ \% = \frac{EPS\ bearer\ received\ \left(\frac{bits}{s}\right) - EPS\ bearer\ sent\ \left(\frac{bits}{s}\right)}{EPS\ bearer\ received\ \left(\frac{bits}{s}\right)}$$

If input < output, (EPS bearer received in bits/s by the UE is less than the EPS bearer sent in bits/s by the eNodeB), then there are losses,

$$Loss\ \% = \frac{EPS\ bearer\ received\ (\frac{bits}{s})}{EPS\ bearer\ sent\ (\frac{bits}{s})} - 1$$

The subtraction to 1 will provide a negative value for the loss.

While it is tempting to look at other statistics such as MOS statistics for VoIP, or the number of pages/objects received by the HTTP client, we settle on the traffic received in bytes/sec statistics which are used only to explain some exceptional behavior observed in EPS bearer throughput and delay statistics.

We also considered the variability that happens in the model so it is not sufficient to just run one simulation. We ran 10 simulations for each setup by varying the start time offset of the application from 40s to 50s, in increments of 1 sec. This blew up our data to be post-processed, considering we are looking at 3 types of applications, 3 types of background traffic, 3 types of statistics and 10 simulation runs! We also ensured that the simulations would guarantee a data point every 50ms, for a 9-minute simulation run time. This is our limitation considering our hard disk capacity for the Linux terminal. 19-cell simulation run with multiple sources of traffic is definitely out of the plan, although we tried.

4.2.4 Throughput and Delay Data

The following graph shows the breakdown of how many successful handovers occurred vs how many failed. The failed handover is because of UE executing the "connection reestablishment procedure". There are also simulation failures ("errors") in some runs observed when the background is HTTP. For our analysis we will only consider the results obtained from successful handover data points.

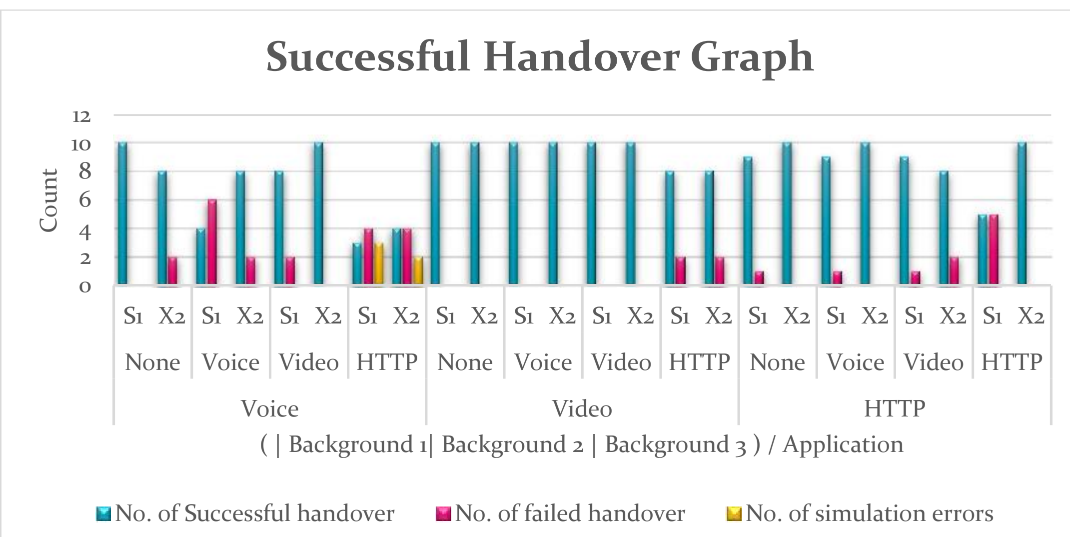

Figure 14: Graph of successful handovers

Note that even with just the same speed and trajectory, there are instances where handover failure occurs.

4.2.4.1 DAR bits and bit loss

Handover happens within 340 – 340.25 ms 80% of the time. We refer to this time as the "handover interval" in our analysis section.

The following graphs shows the % "delayed-and-retransmitted" (DAR) bits and Losses for each application given a background traffic. Again for every positive value, we can consider them as delayed and retransmitted bits, while for every negative value, we can consider the graph as bit loss. Note that each data point in the graph is the average of 10 or less simulation runs (because of previous data filtering mentioned). Below are the graphs for Video traffic. The rest of the graphs are shown in Appendix B.

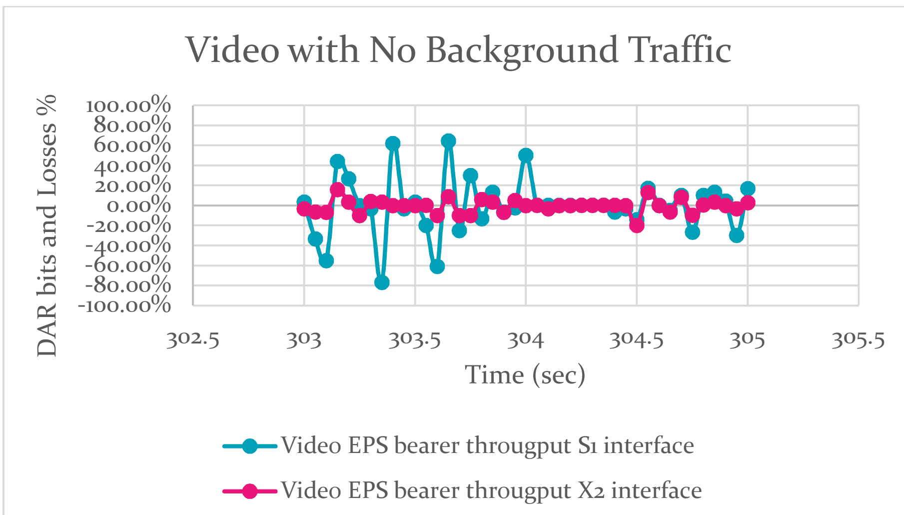

Figure 15(a): Video traffic with no background traffic

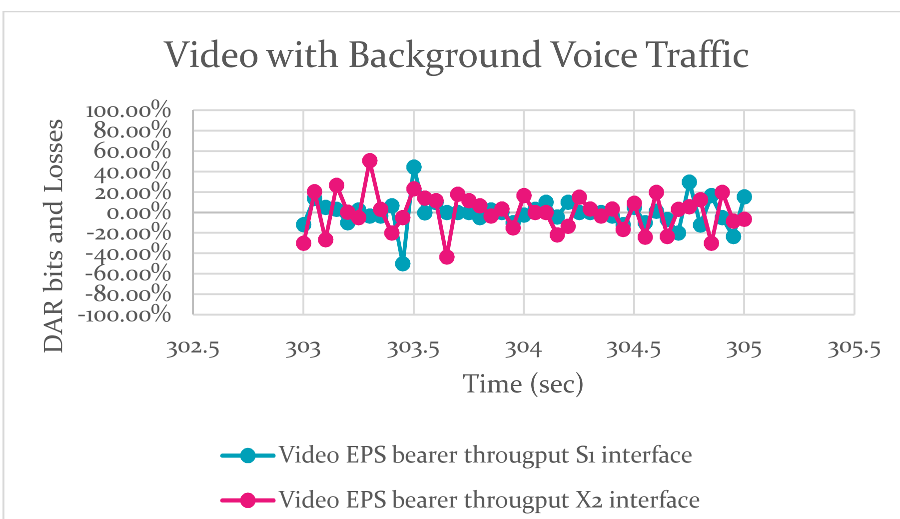

Figure 15(b): Video traffic with background voice traffic

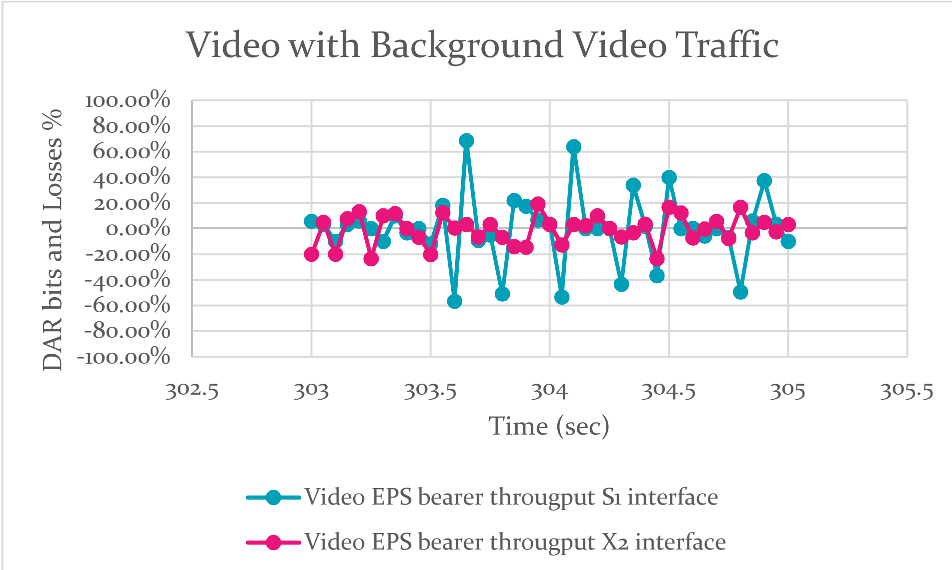

Figure 15(c): Video traffic with background video traffic

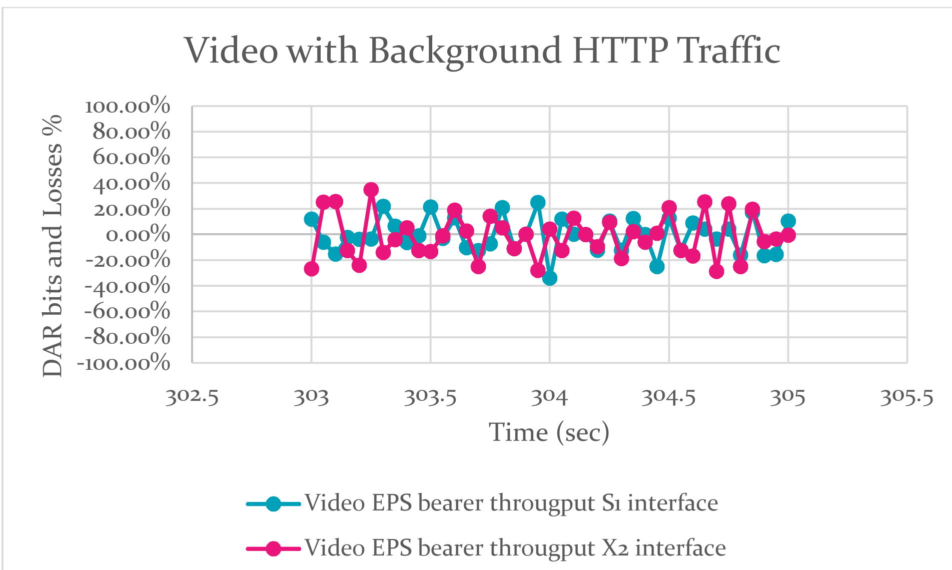

Figure 15(d): Video traffic with background HTTP traffic

4.2.4.2 EPS bearer delay

The following graphs shows the EPS bearer delay for a given type of traffic with a given background traffic. The size of the dots in the graphs corresponds to the number of samples the data was taken from. The biggest circle means the data point is an average from 10 simulations while the smallest circles is to a minimum of data obtained from 1 simulation run, hence less significant in terms of our analysis. Again, we are only showing the Video traffic – EPS bearer delay graphs here, the rest is in Appendix B.

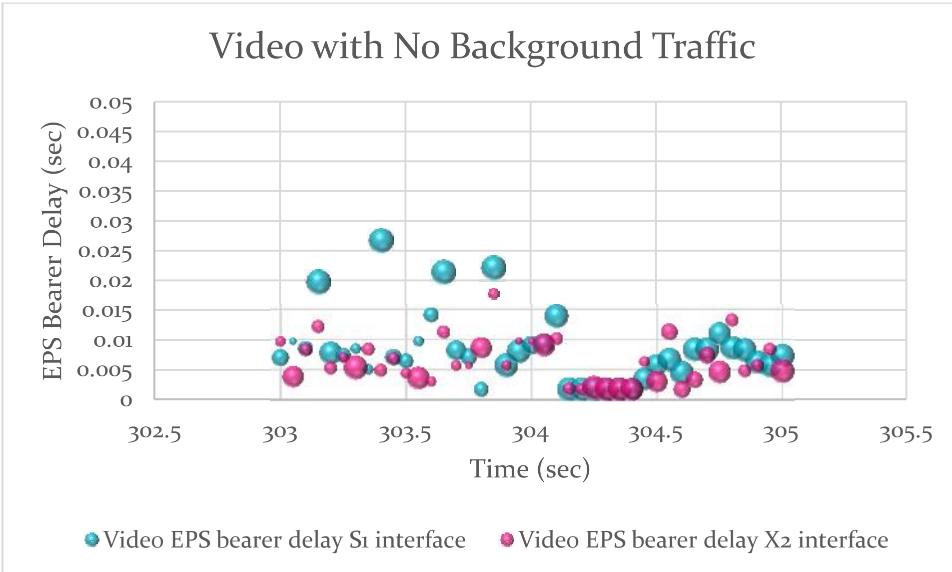

Figure 16(a): EPS Bearer Delay for video traffic with no background traffic

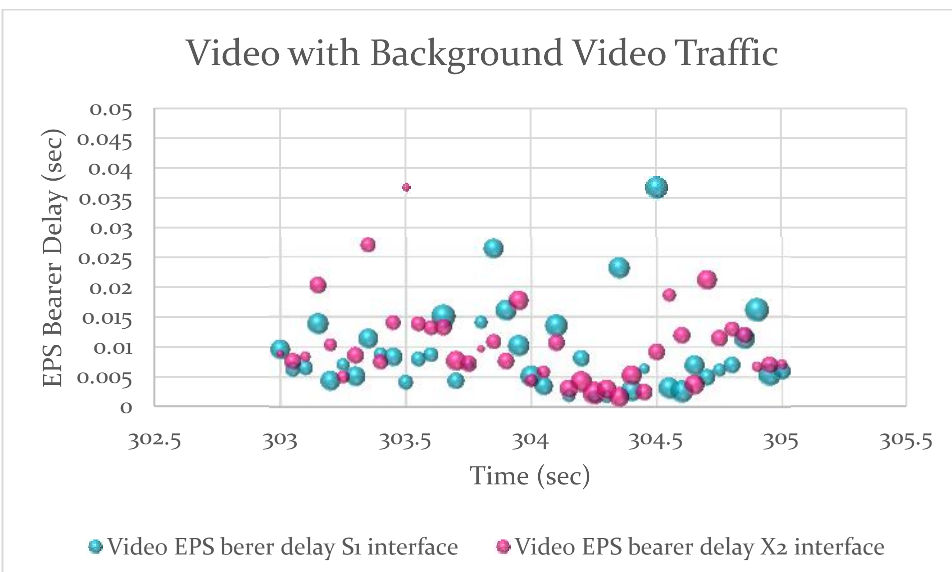

Figure 16(b): EPS Bearer Delay for video traffic with video background traffic

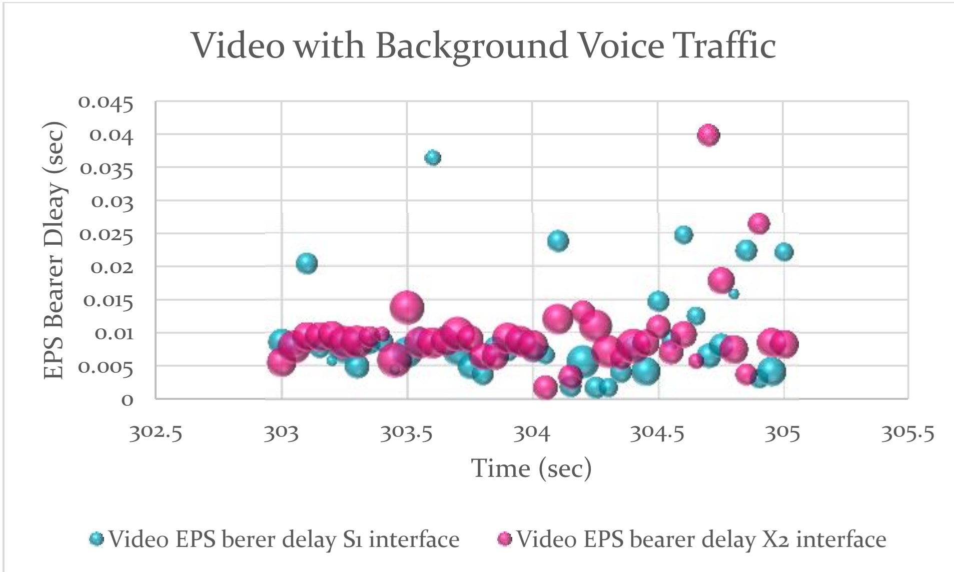

Figure 16(c): EPS Bearer Delay for video traffic with voice background traffic

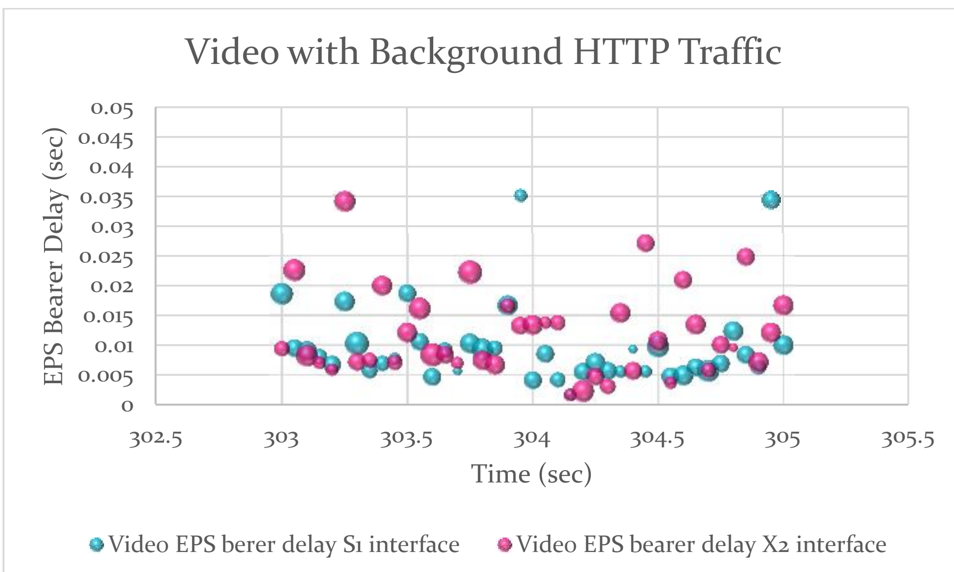

Figure 16(d): EPS Bearer Delay for video traffic with http background traffic

4.2.4.3 Other Metrics

As a part of our analysis, we also graphed a selected Traffic received (bytes/s) statistics for some applications. This is the traffic received by the UE's application after all the encapsulation from the LTE protocol stack has been removed. The following selected traffic received graphs are shown below.

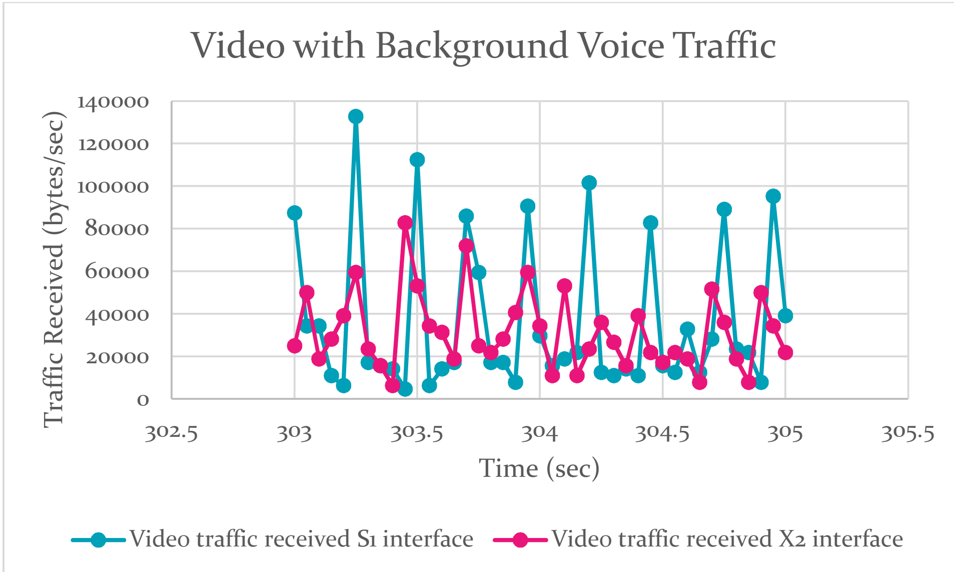

Figure 17(a): Traffic received for video traffic with voice background traffic

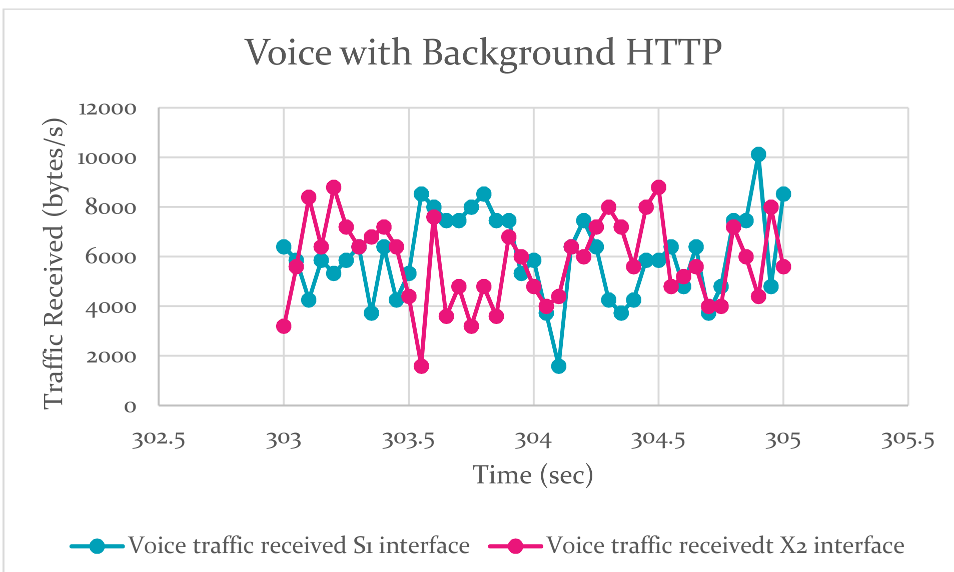

Figure 17(b): Traffic received for voice traffic with HTTP background traffic

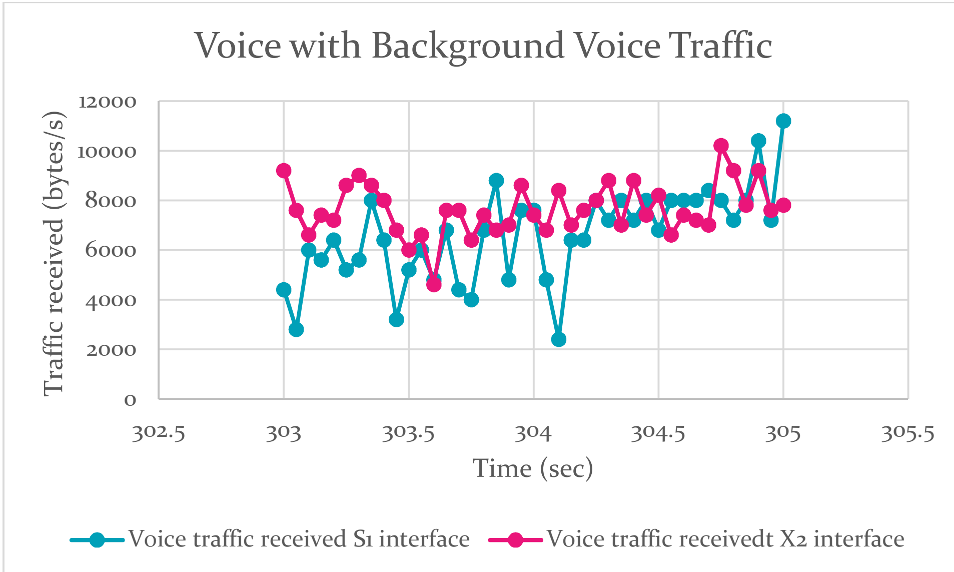

Figure 17(c): Traffic received for voice traffic with voice background traffic

5 Discussions and Results

5.1 HANDOVER DELAY RESULTS

The handover delay is higher when using S1 interface for handover procedure (transmitting the control information via Evolved Packet Core) as compared to X2 interface. X2 interface shows lower handover delay due to the presence of direct link connecting two eNBs resulting in less transmission overhead.

As we go on increasing the number of cells in the topology, the interference from the neighboring cells increases on the handover procedure between the source and the target eNB, resulting in overall higher handover delay. Also as farther the handover takes place from the center of the cell, higher is the handover delay.

5.2 THROUGPHPUT AND DELAY RESULTS

The voice throughput in X2 interface with the exception of case where there is a background HTTP, is strikingly similar near the handover interval 304 – 304.25 sec, and even for the whole 304 – 305 sec interval. This is expected as the Voice has the highest level of QoS and has semi-persistent scheduling. The case where there is background HTTP we would argue is exceptional since there are only 3 available data points for that case, so one should be careful to draw any conclusions. If we take a look at the actual traffic received in bytes/s for "Voice with background HTTP", we can see that the X2 interface has a higher traffic received in bytes/s during the handover interval, i.e. 50% more than the S1 interface equivalent. This signifies that having the X2 interface is still better than just having the S1 interface.

The traffic that affected voice the most in the handover interval, is shown with S1 interface data, where the voice traffic has up to 80% loss in its EPS bearer throughput. There are only 4 data points included on this simulation however, but the general trend is still displayed where huge throughput degradation are incurred during the handover interval as evidently shown in the "Voice with Background Voice Traffic" – Traffic Received (bytes/s) graph.

When it comes to the EPS bearer delay, there is an obvious pattern that for a semi-persistent scheduled bearer, the decreasing quality of the channel contributes to a higher delay as bit rate decreases. After the handover, the bearer delay is almost minimal, (i.e. less than 0.2 s), as the UE finally established connection to the target eNodeB. Another peculiar data point is voice with background HTTP and voice with background voice on the S1 interface. We would argue that there aren't enough data points to justify almost no bearer delay for the case where there is background HTTP and that the bearer delay for the S1 interface is less than that of the x2 interface. Overall, in terms of handover delay, there is no significant difference between handover on X2 and S1 interface and up to 500 ms after the handover interval, despite having the X2 interface buffer the data to the target eNodeB.

The video throughput in the X2 interface in the handover interval is within +20% and -20% regardless of any background traffic. Again this points to the consistency of the traffic when it comes to having the X2 interface available during handover. The background traffic that affected video the most is the video traffic in the handover interval for the S1 interface. There was a loss of close to 60% during that handover delay interval. This is a similar result with the voice traffic, where the voice is affected by another background voice traffic. Two peculiar data points however is at point 340.200 and 340.250 s of the voice with background voice traffic scenario at X2 interface. These data points shows lower performance compared to S1 interface case, however, looking at our raw data, all the handover points happened in exactly 304s for the X2 interface case. This suggests that with the X2 interface, after the handover, there are actually no losses or retransmissions despite a good throughput of 15k-60k bytes/sec received by the UE (see Video with background Voice traffic - Traffic received (bytes/s) statistic for X2 interface).

The video EPS bearer delay shows an increase in bearer delay as background traffic was added. Without a background traffic, or with minimal background traffic such as voice, the video EPS bearer delay with the x2 interface seam to stay within 0.015s during 304-304.750 s (which includes the handover interval). The S1 interface shows higher bearer delays within 304-304.75 sec interval compared to X2 interface for background traffic None, Voice and Video. With HTTP background traffic however, the S1 interface seam to perform better for the Video EPS bearer delay. Our theory for this behavior is that HTTP traffic is bursty and higher loads in the background contributes to EPS bearer delay as both video and http are dynamically scheduled. This leads us to an observation that scheduling and background load affects the bearer delay more despite the buffering capability of the X2 interface handover.

HTTP traffic stay well within +20% to -20% interval during the considered handover interval of 304-304.25 s, regardless of the interface and the background traffic. Looking at our raw data, HTTP traffic is very bursty that the variance in activity is high on or 500 ms after the handover occurred. We also note that unlike the Voice and Video traffic, the HTTP traffic varies with each simulation run despite the same exact conditions applied to it, hence it is hard to make conclusions with our limited 10-point data sample. The background traffic that affected HTTP the most however is HTTP traffic as well. This solidifies our observation that the same type of traffic affect each other more during handover. In terms of the EPS bearer delay, there are higher delays observed during the handover interval and 500ms later, when the background traffic is both HTTP and video, which are both dynamically scheduled.

6 Conclusion

The handover delay increases with increasing the number of eNBs in the topology due to the interference from the neighboring cell. Obviously for a given fixed time, the UE would experience more handover at faster speeds, thus degrading the performance of the application. Overall, we have shown that performance during handover is better when the X2 interface is enabled in terms of the EPS bearer throughput and handover delay. Each type of traffic affects the same traffic the most during the handover interval of 340-340.250 s. However, the bearer delay is dependent more on scheduling and the load of the background traffic than the interface that the handover is taken place on. Initially we were expecting that buffering on the X2 interface would help in the delay, however, this is not the case.

6.1 FUTURE WORK

As an immediate improvement to our work, better aligning of the data points with the anchor point as the handover, would provide better results for analyzing general trend in the data.

The throughput captured is based on estimates that delay and retransmitted bits are counted as one statistic. It would be better to separate this two by identifying the packets that are retransmitted or delayed. Higher samples and better stochastic analysis can help in describing the data obtained specially for bursty traffic like HTTP. We could also have added more background traffic or expand the cell count in order provide a more realistic evidence for the EPS bearer throughput and delay results.

7 References

[1] S. Sesia and I. Toufik, *LTE - The UMTS Long Term Evolution*, 2nd ed. West Sussex, United Kingdom: Wiley, 2011

[2] L. Zhang, T. Okamawari, T. Fujii, "Performance evaluation of TCP and UDP during LTE handover," in Proc. 2012 IEEE Wireless Communications And Networking Conference, Shanghai, China, April 2012, pp. 1993-1997.

[3] A. Vizzarri, "Analysis of VoLTE end-to-end Quality of Service using OPNET," in Proc. 2014 UKSim-AMSS 8th European Modelling Symposium, Pisa, Italy, Oct. 2014, pp. 452-457.

[4] H. S. Park and Y. S. Choi, "Taking Advantage of Multiple Handover Preparations to Improve Handover Performance in LTE Networks," Future Generation Communication and Networking (FGCN), 2014 8th International Conference on, Haikou, 2014, pp. 9-12.

[5] S. Trabelsi, A. Belghith and F. Zarai, "Performance evaluation of a decoupled-level Qos-aware downlink scheduling algorithm for LTE networks," in Proc. 2015 IEEE International Conference on Data Science and Data Intensive Systems, Sydney, Australia, Dec. 2015, pp. 696-704

[6] F. Amirkhan, O. Arafat and M.A. Gregory, "Reduced packet loss vertical handover between LTE and mobile WiMAX," in Proc. 2014 2014 International Conference on Electrical, Electronics and System Engineering, Kuala Lumpur, Malaysia, Dec. 2014, pp. 24-59

[7] D. Han, S. Shin, H. Cho, J. m. Chung, D. Ok and I. Hwang, "Measurement and stochastic modeling of handover delay and interruption time of smartphone real-time applications on LTE networks," in IEEE Communications Magazine, vol. 53, no. 3, pp. 173-181, March 2015.

[8] Modeler Documentation Set, 18.5, Riverbed Technology, San Francisco, CA, 2015, Chapter 12.

Appendix

A. MODELER SETTINGS

The following tables shows the modeler setting used during the simulation.

Application settings

Application Definitions	
Name	HTTP video
Description	Web TV
ToS	Best Effort
Name	VoLTE / Voice Background
Description	PCM Quality speech
Encoder scheme	G.711
ToS	Interactive Voice
Silence Length (s)	0.65
Talk spurt Length (s)	0.35
Name	Video / Video Background
Description	Video Conferencing
Frame Interarrival Time Information (s) (Incoming/Outgoing stream)	0.020
Frame Size Information (bytes)	781
ToS	AF41
Name	HTTP Background
Description	HTTP heavy browsing
Page interarrival Time (s)	Exponential (1)
ToS	Best Effort (0)

Table 4: Application Settings for Riverbed Modeler 18.5

Profile settings

Profile Configuration	
Profile Name	HTTP Profile / Voice Profile / Video Profile
Application	
Name	Http Video/ Video / VoLTE
Start Time Offset (s)	Constant(40)

Duration (s)	End of Profile
Repeatability	(default)
Operation mode	Simultaneous
Start Time (s)	**Promoted**
Duration	End of Simulation
Profile Name	HTTP Background Profile / Video Background Profile / Voice Background Profile
Application	
Name	HTTP Background / Video Background / Voice Background
Start time Offset (s)	None
Repeatability	(default)
Start Time (s)	Constant(0)
Duration	End of Simulation

Table 5: Profile settings for Riverbed Modeler 18.5

LTE Configuration

EPS bearer definitions	
Name	Gold
QoS Class Identifier	1 (GBR)
Allocation Retention Priority	1
Scheduling mechanism	Semi-persistent
Name	Silver
QoS Class Identifier	4 (GBR)
Allocation Retention Priority	4
Scheduling mechanism	dynamic
Name	Silver
QoS Class Identifier	6 (Non-GBR)
Allocation Retention Priority	5
Scheduling Mechanism	dynamic

Table 6: Configurations specific to LTE in Riverbed Modeler 18.5

eNodeB

LTE	
PHY	
PHY Profile	LTE 20MHz FDD
Pathloss	Free space
Handover parameters	
Measurement report triggers	
Event A3	Enabled
Report interval	240ms
RSRP Offset (dB)	2
RSRP Hysteresis (dB)	1
RSRQ Offset (dB)	0
Handover triggers	
RSRP threshold (dB)	-90
RSRQ threshold (dB)	-5
Semi-Persistent Scheduling	Default
Scheduling Mode	Link Adaptation and Channel Dependent scheduling
Uplink power control parameters	
MCS compensation	Enabled
X2 Capability	Enabled / Disabled (for S1 handover)

Table 7: Configurations for eNBs in Riverbed Modeler 18.5

UE

Trajectory	**3, 30, 60 or 120 km/hr for handover UE,** **None for stationary UE or Backround UE**
LTE	
PHY	
Multipath Channel Model (downlink)	LTE OFDMA ITU Vehicular B
Multipath Channel Model (uplink)	LTE SCFDMA ITU Vehicular B
Pathloss parameters	
Pathloss Model	Free space
EPS Bearer Configuration	
Bearer Name	Bronze/ Silver /Gold
TFT Packet filters	

Match Property	ToS
Radio Bearer RLC configuration	
Direction	Uplink
Mode	Unacknowledged / Acknowledged (for HTTP)
Direction	Downlink
Mode	Unacknowledged / Acknowledged (for HTTP)
Handover parameters	(same as eNodeB above)
Application	
Application: Destination preference	HTTP
Application	HTTP Video / Video / VoLTE / Voice Background / Video Background / HTTP Background
Actual Name	
Name	Campus network.Wireless subnet. Mobile_node_0 / 1 / 2 / 3 or Node_0
Application supported profile	Http profile / VoLTE Profile / Video Profile / Voice background / Video Background / HTTP Background

Table 8: Configurations for UE in Riverbed Modeler 18.5

HTTP Server

Application	
Application : Destination Preference	
Application	HTTP Video / HTTP Background
Symbolic name	HTTP Server
Actual Name	
Name	Campus network.Wireless subnet. Mobile_node_0 / 2 / 3
Application supported profile	Http profile / HTTP Background

Table 9: Specifications for HTTP applications in Riverbed Modeler 18.5

B. GRAPHS FOR OTHER RESULTS

Other results for DAR bits and losses:

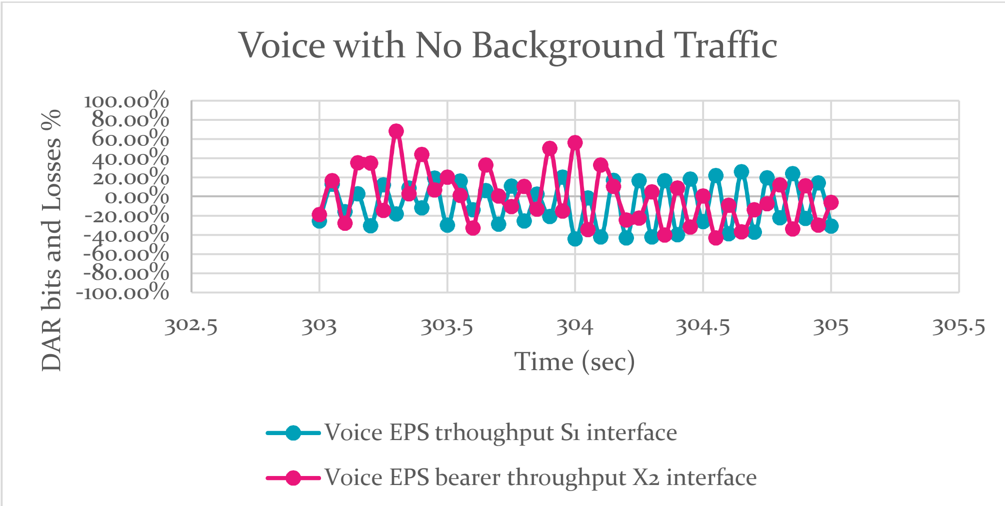

Figure 18(a): DAR bits and losses for voice traffic with no background traffic

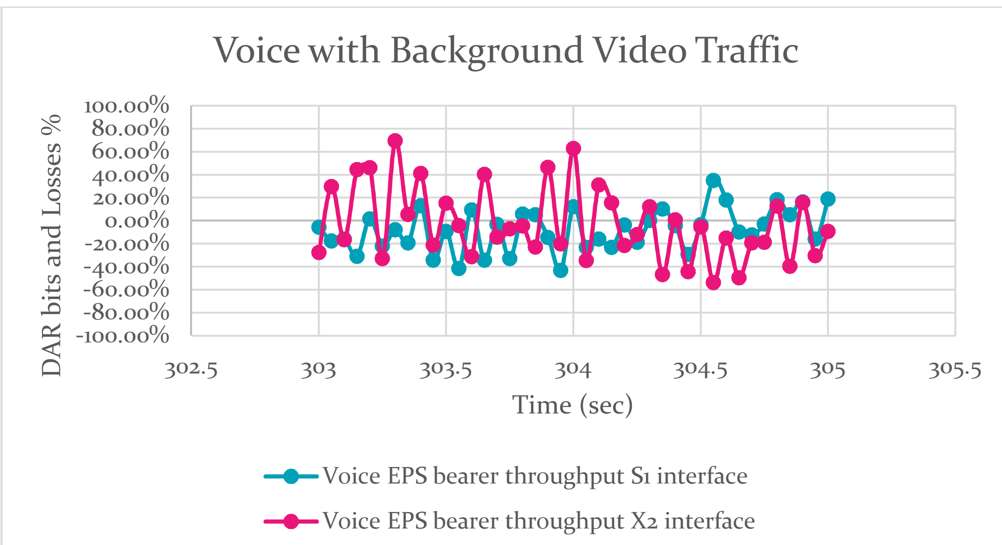

Figure 18(b): DAR bits and losses for voice traffic with video background traffic

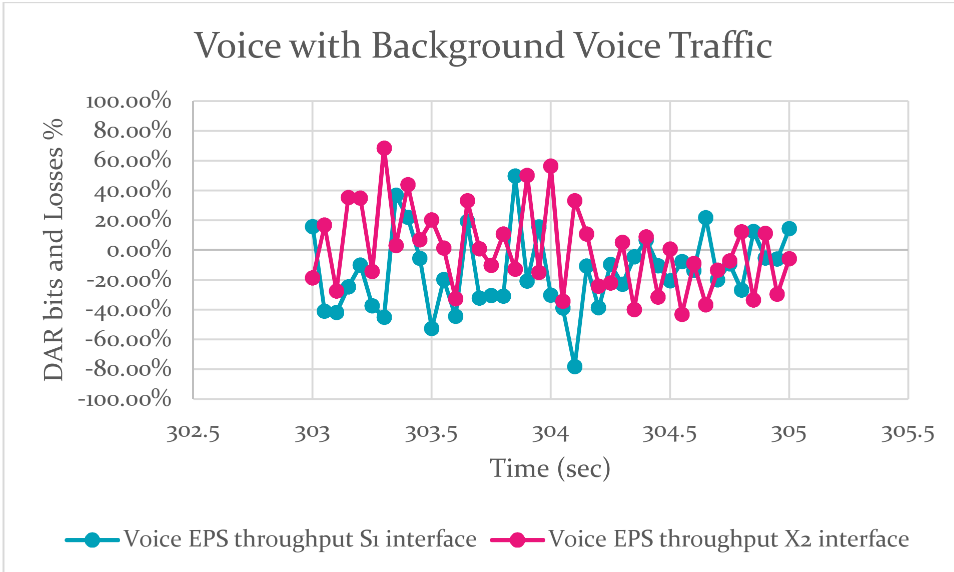

Figure 18(c): DAR bits and losses for voice traffic with voice background traffic

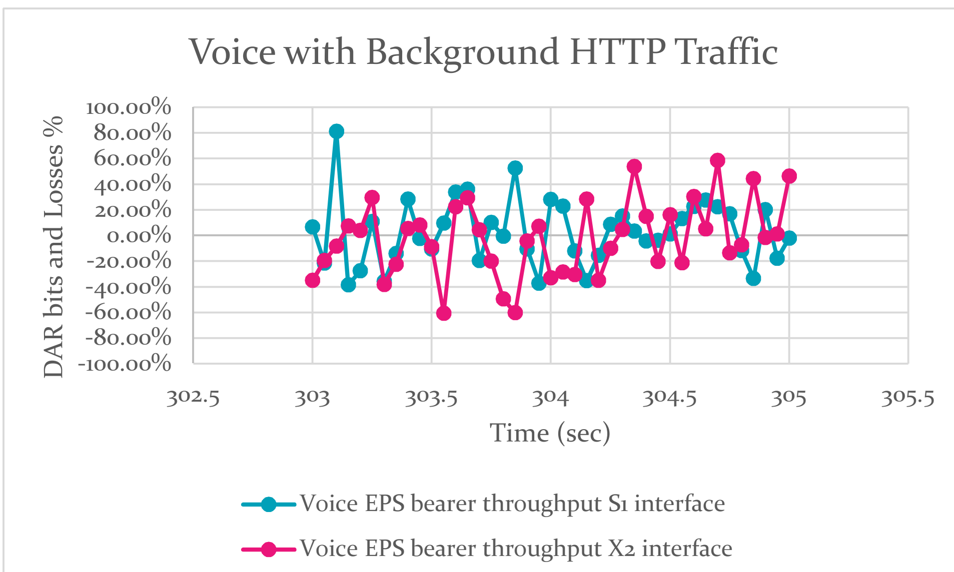

Figure 18(d): DAR bits and losses for voice traffic with HTTP background traffic

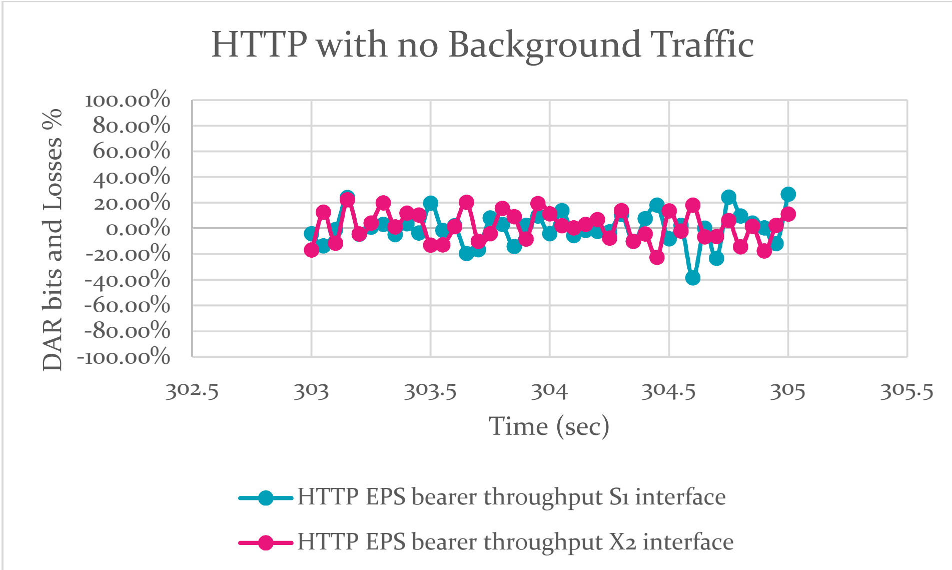

Figure 19(a): DAR bits and losses for HTTP traffic with no background traffic

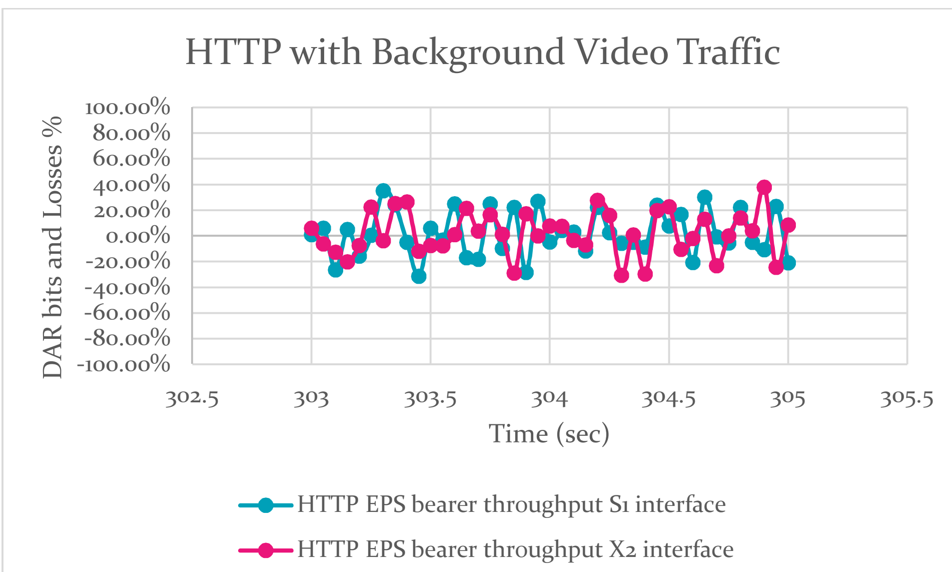

Figure 19(b): DAR bits and losses for HTTP traffic with video background traffic

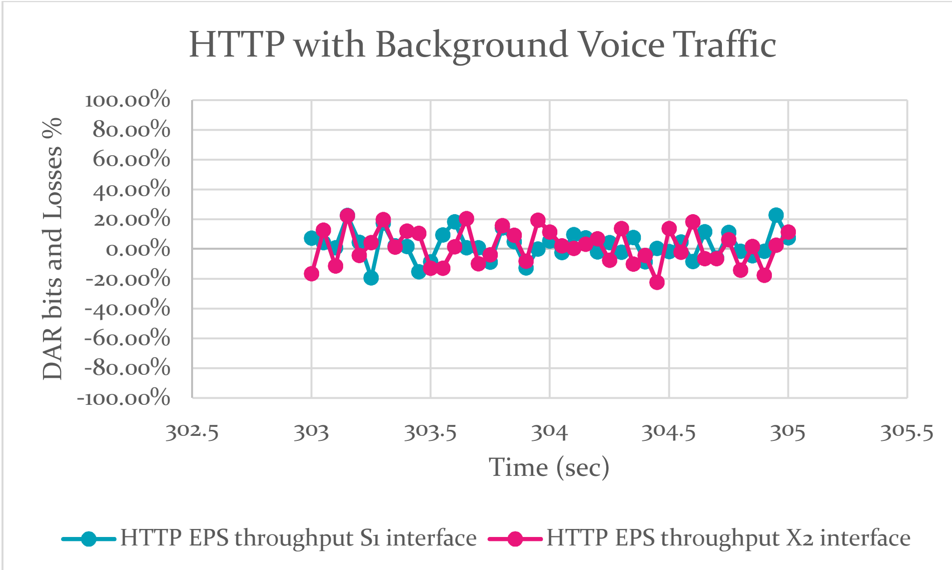

Figure 19(c): DAR bits and losses for HTTP traffic with voice background traffic

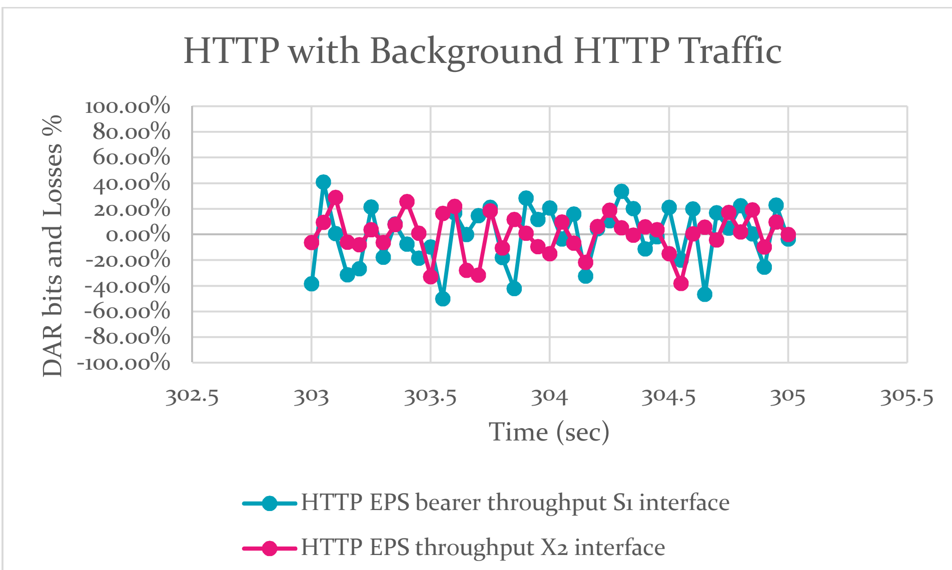

Figure 19(d): DAR bits and losses for HTTP traffic with HTTP background traffic

Other results for EPS Bearer Delay:

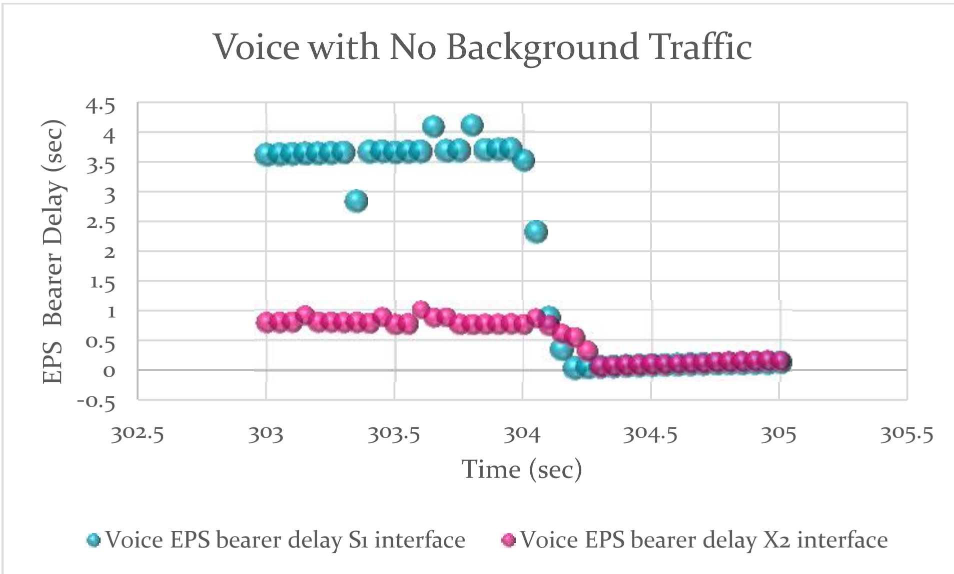

Figure 20(a): EPS Bearer Delay for voice traffic with no background traffic

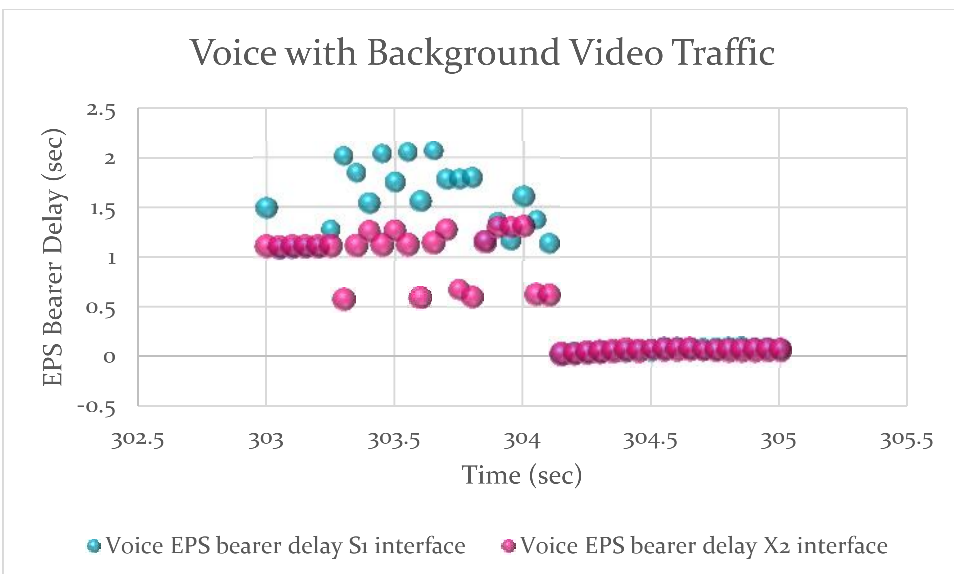

Figure 20(b): EPS Bearer Delay for voice traffic with video background traffic

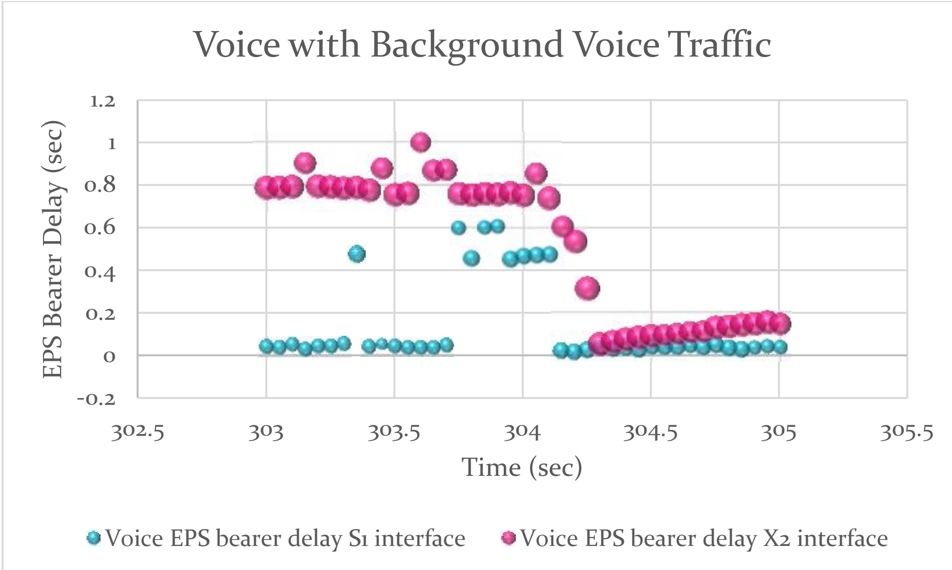

Figure 20(c): EPS Bearer Delay for voice traffic with voice background traffic

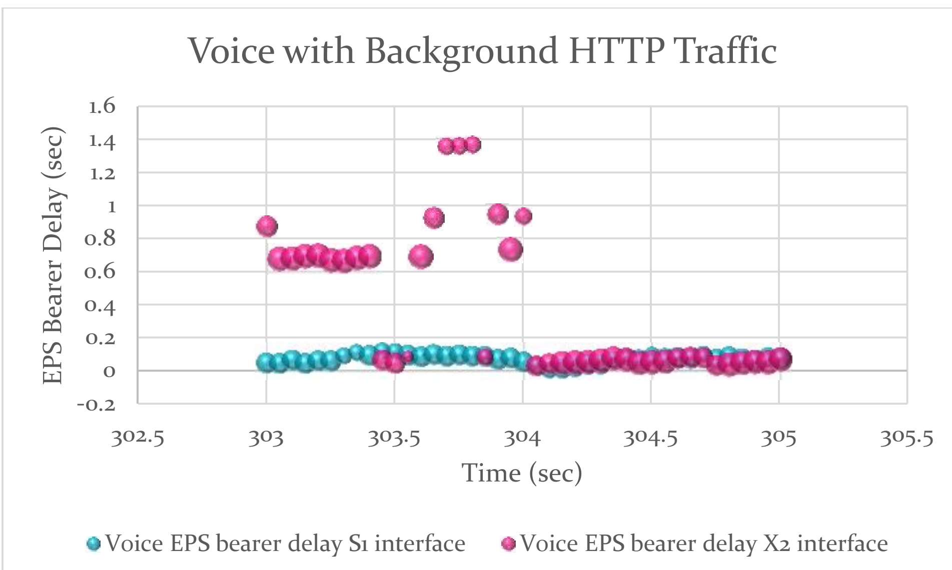

Figure 20(d): EPS Bearer Delay for voice traffic with HTTP background traffic

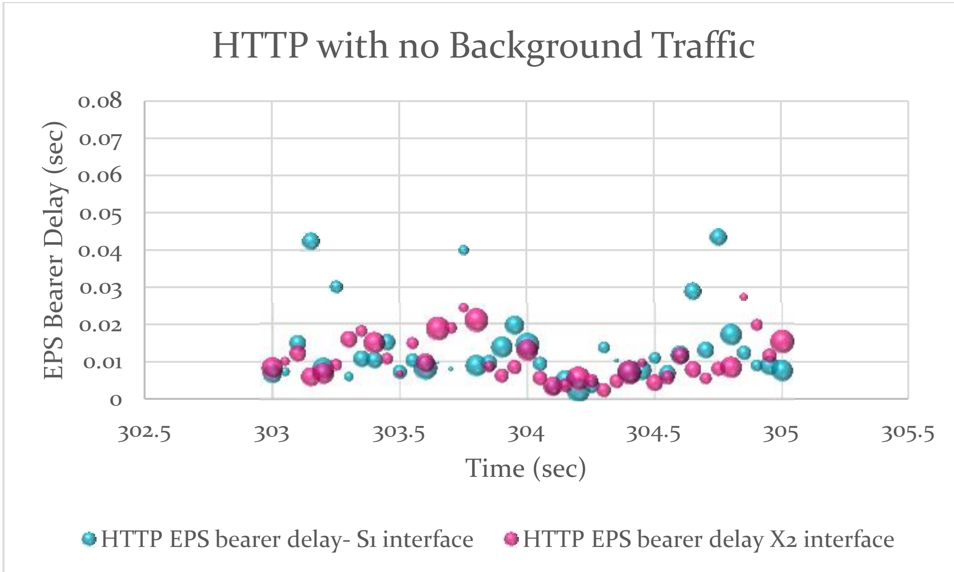

Figure 21(a): EPS Bearer Delay for HTTP traffic with no background traffic

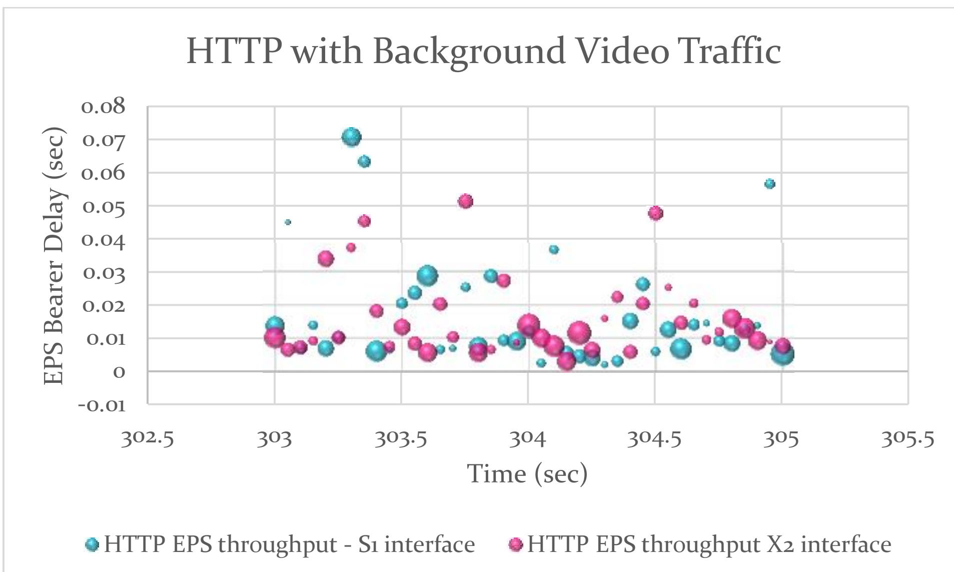

Figure 21(b): EPS Bearer Delay for HTTP traffic with video background traffic

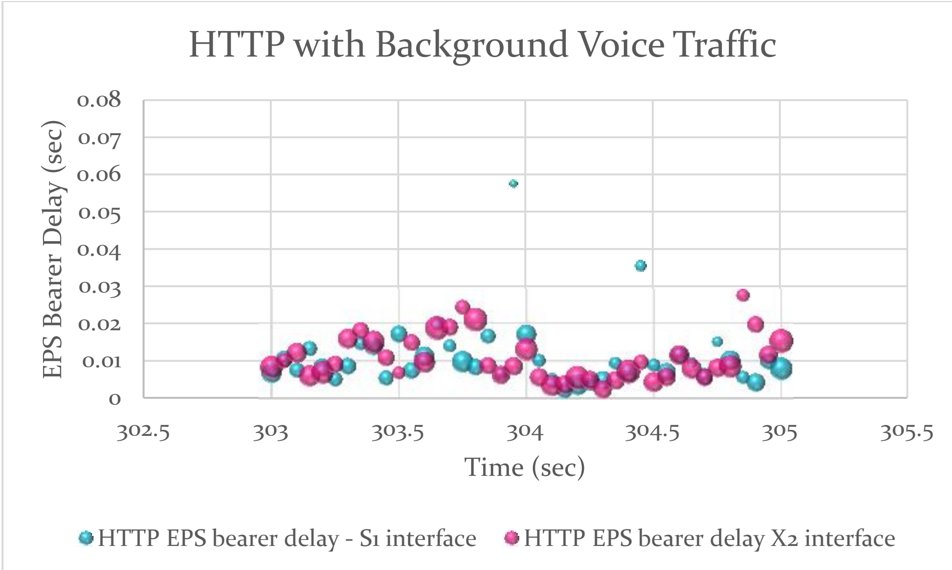

Figure 21(c): EPS Bearer Delay for HTTP traffic with voice background traffic

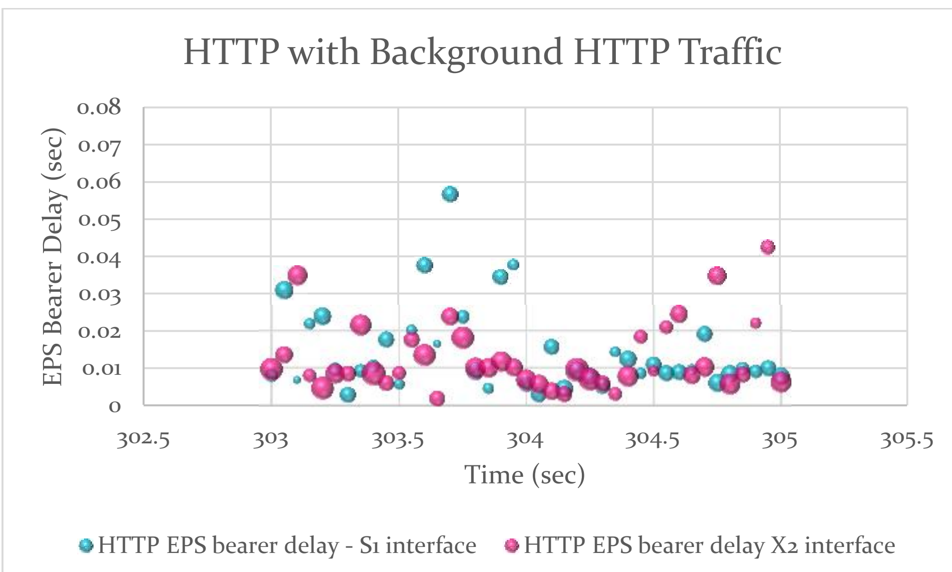

Figure 21(d): EPS Bearer Delay for HTTP traffic with HTTP background traffic