

ENSC 427: COMMUNICATION NETWORKS

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Project: Final Project Report

Performance Analysis of Video Streaming over LTE using Riverbed Modeler

TEAM NUMBER: 2

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1. Introduction

With the increase in user requirements for internet browsing and streaming videos online, various technologies have come forward to provide best services and solutions according to the needs. In this era of using advanced cell phone technology, most internet browsing and video streaming is done over Wi-Fi or LTE. These days, users prefer watching videos on their cell phones while at work or while traveling, and thus, use technologies mentioned above to stay connected and to stream videos while being mobile or stationary. Due to this, the telecommunication industry has improved services provided to users at a level where they can enjoy fast streaming for any YouTube video while on the go. The main idea behind our project is to analyze the performance of Long Term Evolution (LTE), a wireless network technology used by network operators around the world meant for high-speed communication between data terminals and observe the packet transfer, drop rate and delays for using the technology. We will be using Riverbed Modeler to simulate various scenarios where data would be transferred to stationary or mobile terminals and observe how LTE performs.

We will be analyzing one of the most commonly used video streaming applications: YouTube. YouTube has become one of the most widely used applications due to its best video streaming system. In order to analyze the packets while streaming a single 720p music video over YouTube, Wireshark was used to analyze the packets. "port 80" filter was used to see the data traffic. This was done to have a more realistic setting for the video streaming application that will be used for the simulation. Since YouTube buffers the packets for streaming, we found that it used TCP for on the transport layer.

The simulation is to be performed using Riverbed 18.0 where different scenarios will be created to simulate a server such as a YouTube server that has the video database and various types of clients trying to access videos from the server for streaming. There will be stationary terminals as well as mobile nodes to have a more realistic simulation for the project, and the server will be placed at a place far away from the users in our case. We will collect different statistics to have a reliable analysis of the LTE network simulation.

2. LTE Technology

Long Term Evolution is one of the most commonly used and fast growing wireless telecommunication technology used these days. It is used by network operators around the globe for high-speed communication for smartphones or data terminals [1]. Initially, it was created to enhance the speed of wireless data networks and allow the usage of DSP. It provides a relatively fast downloading rate of 5-12 Mbps which is an enough for streaming videos online [2].

3. Wireshark Data Collection

We used Wireshark to collect information about streaming video using YouTube. Wireshark is an open-source packet analyzer. We used it to view the packets for YouTube streaming. The following screenshot shows the packets when we opened up the browser, went to YouTube, and loaded a 720p video.

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	207.23.168.151	54.243.128.120	TCP	66	51511 → 80 [SYN] Seq=0 Win=8192 Len=0 MSS=1460 WS=256 SACK_PERM=1
2	0.066348	54.243.128.120	207.23.168.151	TCP	60	80 → 51511 [SYN, ACK] Seq=0 Ack=1 Win=26883 Len=0 MSS=1396
3	0.066405	207.23.168.151	54.243.128.120	TCP	54	51511 → 80 [ACK] Seq=1 Ack=1 Win=64216 Len=0
4	0.066636	207.23.168.151	54.243.128.120	HTTP	607	GET /client_cgi/unblocking_rate?rmt_ver=1.11.973&ext_ver=1.11.973&browser=chrome&product=cws&iccg1=...
5	0.132841	54.243.128.120	207.23.168.151	TCP	60	80 → 51511 [ACK] Seq=1 Ack=554 Win=27097 Len=0
6	0.133283	54.243.128.120	207.23.168.151	TCP	1354	[TCP segment of a reassembled PDU]
7	0.133941	54.243.128.120	207.23.168.151	TCP	1354	[TCP segment of a reassembled PDU]
8	0.133942	54.243.128.120	207.23.168.151	TCP	1354	[TCP segment of a reassembled PDU]
9	0.133945	54.243.128.120	207.23.168.151	TCP	1354	[TCP segment of a reassembled PDU]
10	0.133995	207.23.168.151	54.243.128.120	TCP	54	51511 → 80 [ACK] Seq=554 Ack=5201 Win=64216 Len=0
11	0.134182	54.243.128.120	207.23.168.151	TCP	1354	[TCP segment of a reassembled PDU]
12	0.134183	54.243.128.120	207.23.168.151	HTTP	76	HTTP/1.1 200 OK (application/json)
13	0.134218	207.23.168.151	54.243.128.120	TCP	54	51511 → 80 [ACK] Seq=554 Ack=6523 Win=62894 Len=0

Figure 1 - Wireshark information of connecting to YouTube.

Once the video plays, the following screenshots show the packet details of what protocols are being used by the HTTP application.

No.	Time	Source	Destination	Protocol	Length	Info
25	11.375375	199.212.24.16	207.23.168.151	TCP	1450	[TCP segment of a reassembled PDU]
26	11.375663	199.212.24.16	207.23.168.151	HTTP	1076	HTTP/1.1 200 OK (text/html)
27	11.375727	207.23.168.151	199.212.24.16	TCP	54	51664 → 80 [ACK] Seq=288 Ack=2419 Win=65536 Len=0
28	23.203122	74.125.28.95	207.23.168.151	TCP	60	80 → 65134 [FIN, ACK] Seq=1 Ack=2 Win=344 Len=0
29	23.203245	207.23.168.151	74.125.28.95	TCP	54	65134 → 80 [ACK] Seq=2 Ack=2 Win=256 Len=0
30	32.332730	207.23.168.151	74.125.28.95	TCP	54	65134 → 80 [FIN, ACK] Seq=2 Ack=2 Win=256 Len=0
31	32.345979	74.125.28.95	207.23.168.151	TCP	60	80 → 65134 [ACK] Seq=2 Ack=3 Win=344 Len=0
32	45.135637	207.23.168.151	54.243.128.120	TCP	55	[TCP Keep-Alive] 51511 → 80 [ACK] Seq=553 Ack=6523 Win=62894 Len=1
33	45.203336	54.243.128.120	207.23.168.151	TCP	60	[TCP Keep-Alive ACK] 80 → 51511 [ACK] Seq=6523 Ack=554 Win=27097 Len=0
34	53.409429	207.23.168.151	23.235.47.192	TCP	55	[TCP Keep-Alive] 65136 → 80 [ACK] Seq=1 Ack=1 Win=256 Len=1
35	53.434616	23.235.47.192	207.23.168.151	TCP	66	[TCP Keep-Alive ACK] 80 → 65136 [ACK] Seq=1 Ack=2 Win=60 Len=0 SLE=1 SRE=2
36	55.689192	207.23.168.151	142.231.1.182	TCP	55	[TCP Keep-Alive] 65205 → 80 [ACK] Seq=1 Ack=1 Win=255 Len=1
37	55.697261	142.231.1.182	207.23.168.151	TCP	66	[TCP Keep-Alive ACK] 80 → 65205 [ACK] Seq=1 Ack=2 Win=961 Len=0 SLE=1 SRE=2
38	56.375730	207.23.168.151	199.212.24.16	TCP	55	[TCP Keep-Alive] 51664 → 80 [ACK] Seq=287 Ack=2419 Win=65536 Len=1
39	56.389421	199.212.24.16	207.23.168.151	TCP	66	[TCP Keep-Alive ACK] 80 → 51664 [ACK] Seq=2419 Ack=288 Win=30336 Len=0 SLE=287 SRE=288
40	65.156487	54.243.128.120	207.23.168.151	TCP	60	80 → 51511 [FIN, ACK] Seq=6523 Ack=554 Win=27097 Len=0
41	65.156532	207.23.168.151	54.243.128.120	TCP	54	51511 → 80 [ACK] Seq=554 Ack=6524 Win=62894 Len=0
42	71.813809	199.212.24.16	207.23.168.151	TCP	60	80 → 51664 [FIN, ACK] Seq=2419 Ack=288 Win=30336 Len=0
43	71.813811	199.212.24.16	207.23.168.151	TCP	60	[TCP Out-Of-Order] 80 → 51664 [FIN, ACK] Seq=2419 Ack=288 Win=30336 Len=0
44	71.813894	207.23.168.151	199.212.24.16	TCP	54	51664 → 80 [ACK] Seq=288 Ack=2420 Win=65536 Len=0
45	71.814106	199.212.24.16	207.23.168.151	TCP	60	[TCP Out-Of-Order] 80 → 51664 [FIN, ACK] Seq=2419 Ack=288 Win=30336 Len=0
46	71.814143	207.23.168.151	199.212.24.16	TCP	54	[TCP Dup ACK 44#1] 51664 → 80 [ACK] Seq=288 Ack=2420 Win=65536 Len=0
47	72.336787	207.23.168.151	54.243.128.120	TCP	54	51511 → 80 [FIN, ACK] Seq=554 Ack=6524 Win=62894 Len=0
48	72.637155	207.23.168.151	54.243.128.120	TCP	54	[TCP Retransmission] 51511 → 80 [FIN, ACK] Seq=554 Ack=6524 Win=62894 Len=0
49	72.642488	54.243.128.120	207.23.168.151	TCP	60	80 → 51511 [RST] Seq=6524 Win=0 Len=0
50	72.835951	54.243.128.120	207.23.168.151	TCP	60	80 → 51511 [RST] Seq=6524 Win=0 Len=0
51	81.385450	207.23.168.151	199.212.24.16	TCP	54	51664 → 80 [FIN, ACK] Seq=288 Ack=2420 Win=65536 Len=0
52	81.387298	199.212.24.16	207.23.168.151	TCP	60	80 → 51664 [RST] Seq=2420 Win=0 Len=0
53	92.339712	207.23.168.151	142.231.1.182	TCP	54	65205 → 80 [FIN, ACK] Seq=2 Ack=1 Win=255 Len=0
54	92.339913	207.23.168.151	23.235.47.192	TCP	54	65136 → 80 [FIN, ACK] Seq=2 Ack=1 Win=256 Len=0
55	92.342591	142.231.1.182	207.23.168.151	TCP	60	80 → 65205 [FIN, ACK] Seq=1 Ack=3 Win=961 Len=0
56	92.342683	207.23.168.151	142.231.1.182	TCP	54	65205 → 80 [ACK] Seq=3 Ack=2 Win=255 Len=0

Figure 2 - Wireshark information of playing the video.

As seen above in the screenshots, YouTube mainly uses TCP and HTTP regarding protocols. YouTube provides reliable video streaming. It allows users to buffer and pause the video, so YouTube uses TCP protocol. We pinged 'www.youtube.com' and found that the IP address for YouTube is 199.212.24.21, the time to live (TTL) for YouTube is 58 seconds (Figure 3).

```

Reply from 199.212.24.21: bytes=32 time=10ms TTL=58
Reply from 199.212.24.21: bytes=32 time=1ms TTL=58
Reply from 199.212.24.21: bytes=32 time=2ms TTL=58
Reply from 199.212.24.21: bytes=32 time=2ms TTL=58
Reply from 199.212.24.21: bytes=32 time=1ms TTL=58
Reply from 199.212.24.21: bytes=32 time=1ms TTL=58
Reply from 199.212.24.21: bytes=32 time=2ms TTL=58
Reply from 199.212.24.21: bytes=32 time=2ms TTL=58

```

Figure 3 - Ping to YouTube.

We chose similar application configuration for our simulation.

4. Application Setup and Configuration settings

For the application as mentioned earlier, the aim of the project was to analyze the performance of LTE networks while streaming videos. The first approach was to use the default video streaming model for the application and change the setting so that it mimics the behavior we observed for YouTube. The video streaming application model was tried as the main application but we were unable to receive and send any traffic to the nodes we created using Modeler. Eventually, we moved to creating the application and set it up as an HTTP application that replicates the video streaming for a YouTube video. Since YouTube uses HTTP and TCP protocols for the streaming videos, HTTP Application named YouTube was created and used for simulating different scenarios for this project. Under the Application definition, a new application was created that uses HTTP as the base application and it was named YouTube1080p.

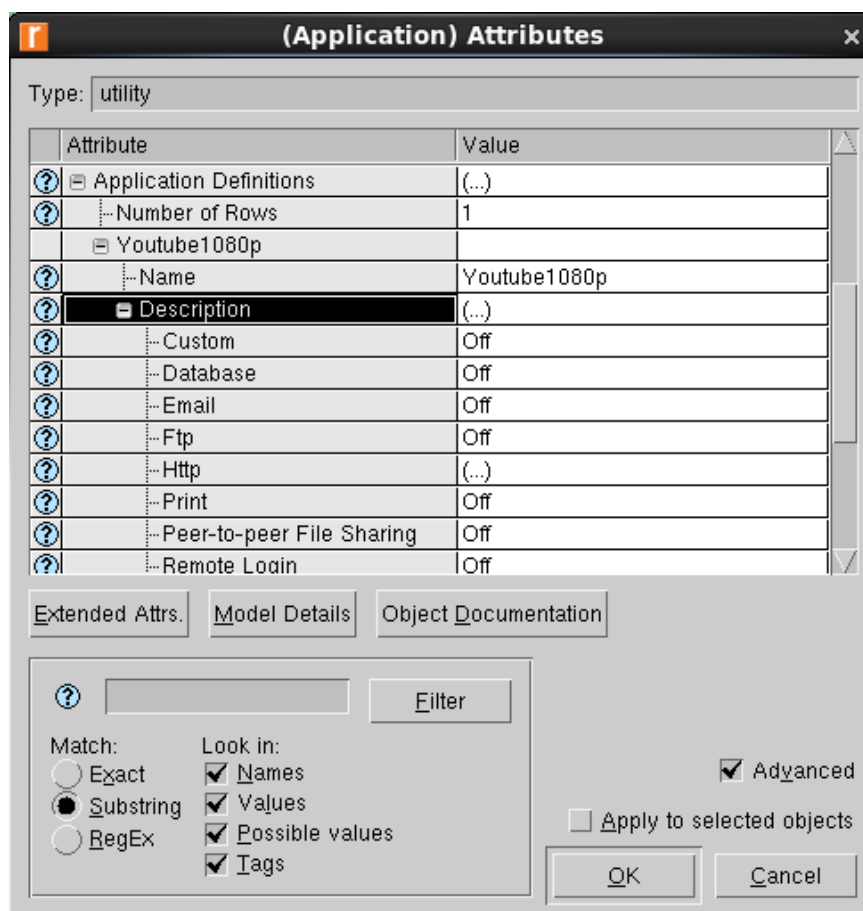


Figure 4- Application Definition Attributes.

The figure below shows the attributes that were chosen based on the Wireshark data collected to replicate video streaming. Since YouTube is using the video codex H-264 and MPEG4 the average encoding speed is somewhere between 20 frames/second to 30 frames/second [4]. Using the rate of the encoder we calculated usual page inter-arrival time for video streaming for the H-264 codec. For our simulation, we chose that number to be between 0.0333333 and 0.06666666.

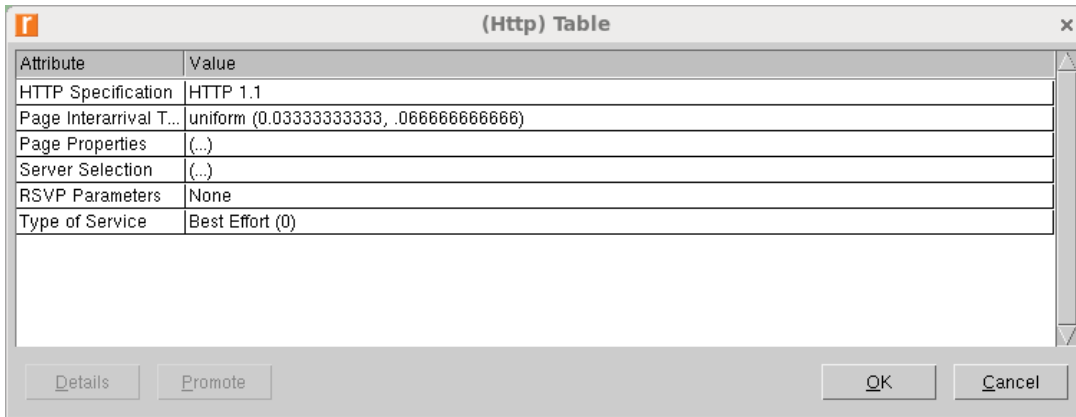


Figure 5- HTTP Attributes to Replicate YouTube Video Streaming Behaviour.

Under the page properties section, the size of the page was taken based on the size of each frame for the 1080p resolution. H-264 has a rate of 25Mbps for the 1080p videos and since the rate is roughly around 30 frames/second. Using those two numbers, we calculated the object size to be 109227 bytes as shown in the figure below.

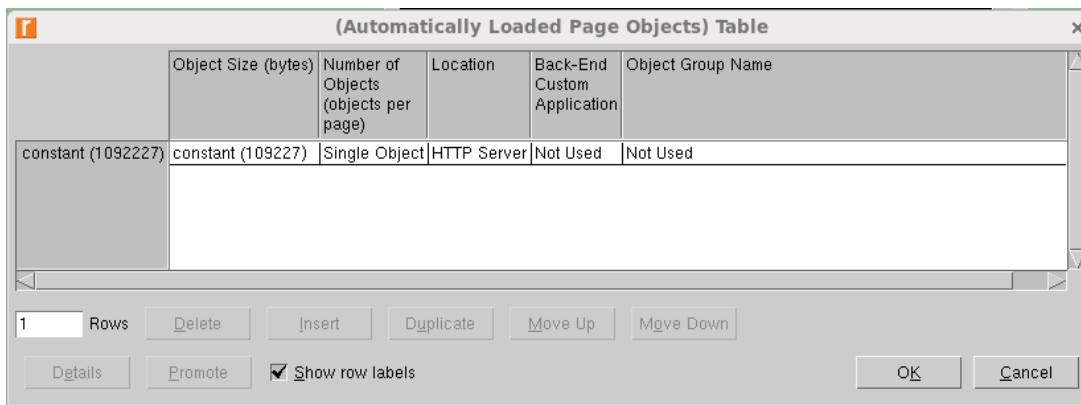


Figure 6- Page Attributes for the HTTP Application.

Lastly, we chose the object to be a video and used the default settings as suggested by the Riverbed Modeler.

Once the Application was defined and the attributes were set to simulate the streaming of a YouTube video with resolution 1080p the next step was to configure the application so that all the nodes in the scenario uses the same application. The following figure shows the attribute settings for the Profile Configuration.

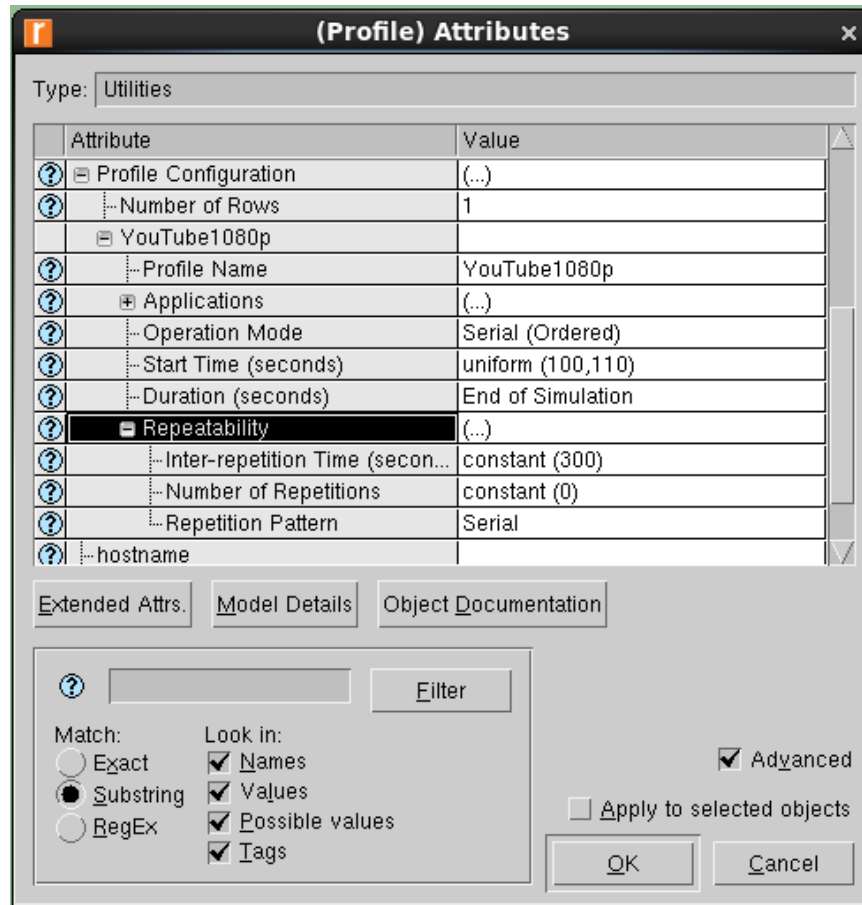


Figure 7- Profile Configuration for the Application Definition.

5. Validation LTE Simulation

The first step required to analyze LTE technology in detail was to create a basic topology with a very simple network and try and run the application and observe the packet throughput and the delay for each node and see whether there was any communication between different nodes of the network. The Validation Scenario was created with the server, base station and the workstations all in the vicinity near the Vancouver area.

5.1 Validation Scenario

The following figure shows the basic topology for sanity checking. The network was created to check whether the user (Fixed_Workstation) was able to receive any data from the server. The basic scenario can be seen in the figure below. A server runs the Application, which was defined as a first step. The server is connected to a Cisco router which is then connected to the Ethernet router (EPC) for the LTE network. The EPC can be connected to various base stations that can transfer the information further to either fixed or mobile nodes.

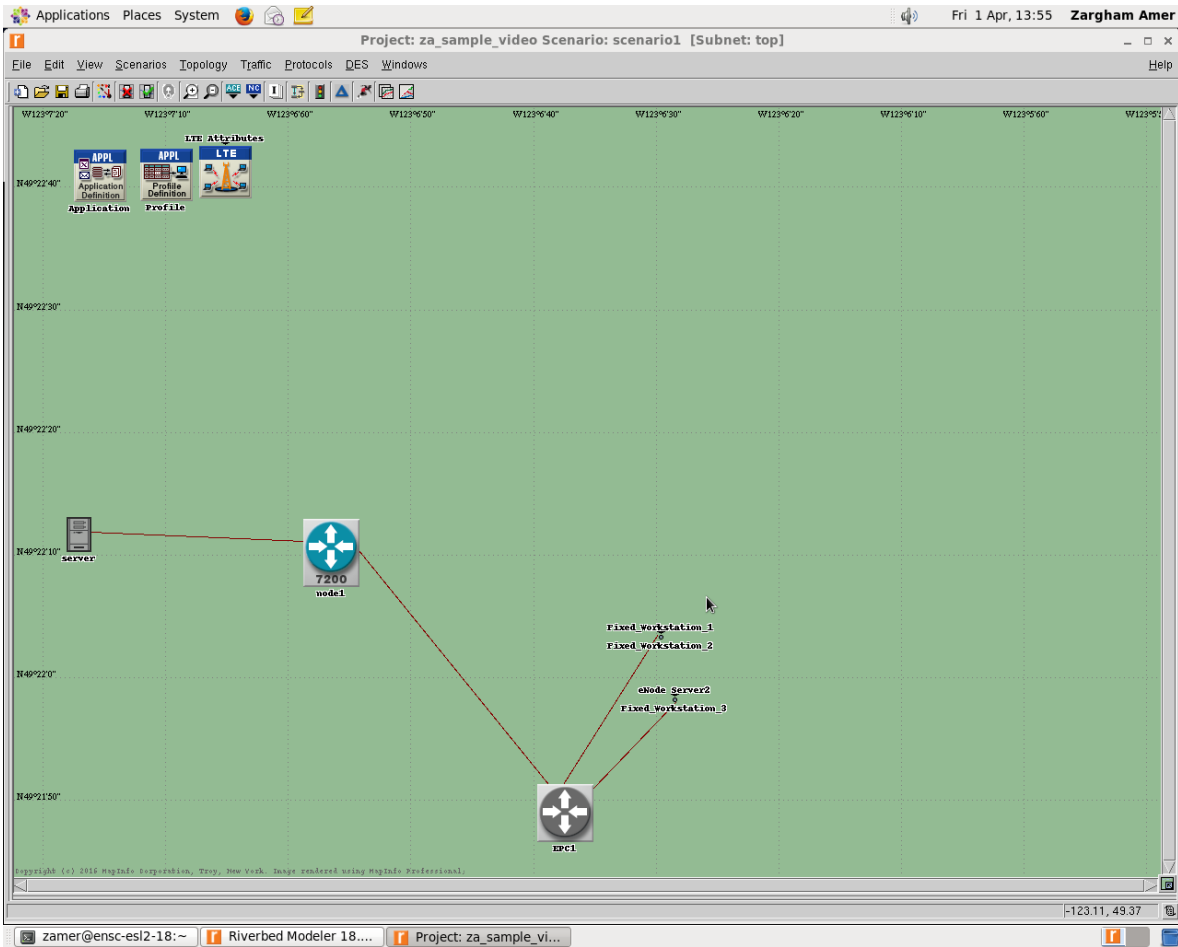


Figure 8- Validation Scenario for Sanity Check.

The only wireless communication in the scenario shown above is between the LTE Base Station and the workstation nodes, rest of the nodes are all connected to each other using the 100BaseT links for traffic transfer. If we zoom into the section where we have the base station and the fixed node, it will look as shown in the figure below.

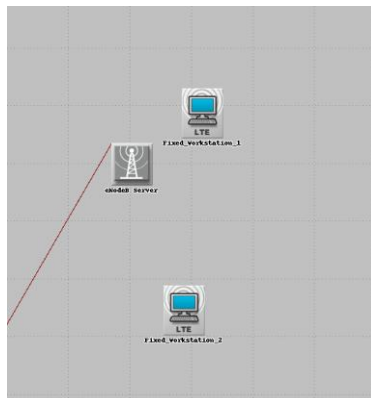


Figure 9- Zoomed in version for the Base Station and Fixed Workstation.

It can be seen from the figure above that Workstation1 is closer to the base station as compared to the Workstation2. The next figure shows the second base station that is connected to the same router and is sending same packets as the first base station. In the following figure, the Workstation3 is at the farthest distance from the base station as compared to the other Workstation as shown in the previous figure.

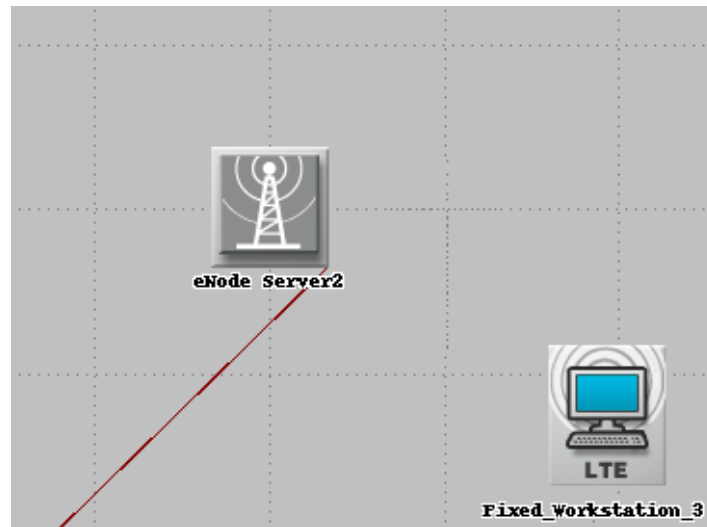


Figure 10- Single Work Station with Single Base Station.

The simulation was running for the above-mentioned scenario for 15 minutes, and the node statistics were collected and the graphs can be seen in the simulation results section of the project report where the detailed discussion is provided on the results and how do they relate to the scenario settings.

5.2 Simulation Result

5.2.1 Throughput

As shown in Figure 11, we see that the throughput for all workstations is constant, as expected since they are stationary nodes, and thus the distance between the nodes and the base stations does not change. However, workstation 3 is further from the base station than workstations 1 and 2, and as a result has a lower throughput, which is as expected.

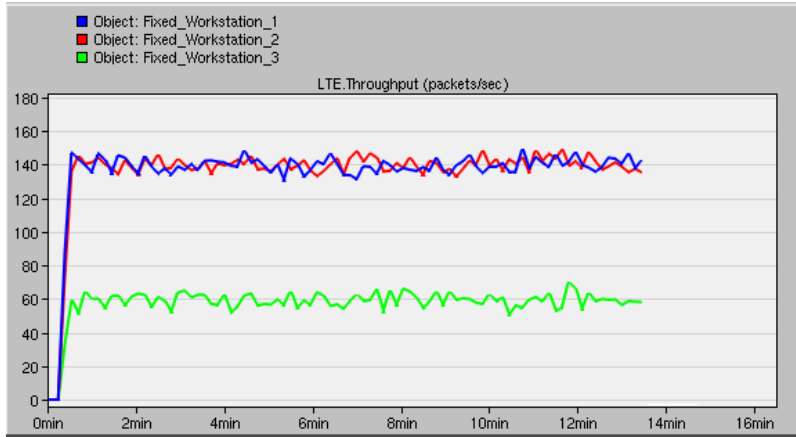


Figure 11 - Throughput results of fixed workstations.

5.2.2 Delay

From the graph below, we collected the delay of the LTE network at three fixed workstations. In this scenario, workstation 1 (blue) and workstation 2 (red) are close to the base station whereas workstation 3 (green) is far away from the base station. The result shows clearly that workstation 3 has a higher delay than the other two in average per second. Analysis of the delay on a mobile workstation in the results analysis of Scenario 1.

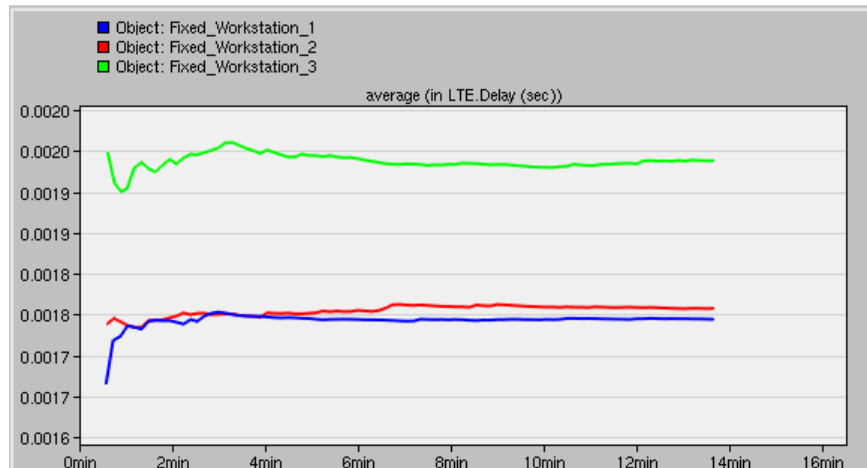


Figure 12- Delay results of fixed workstations.

6 Advanced Scenarios

6.1 Introduction to Scenarios One, Two, and Three

For the following three scenarios, the parent subnet topology consists of an IP cloud backbone, a server subnet, and a client subnet, as seen in Figure 13. The server subnet topology and settings will be constant for each scenario while the client subnet topology and settings will vary. The client subnet will be located in Vancouver, and although the IP address we obtained is located in Ottawa, the servers are located in Los Angeles.

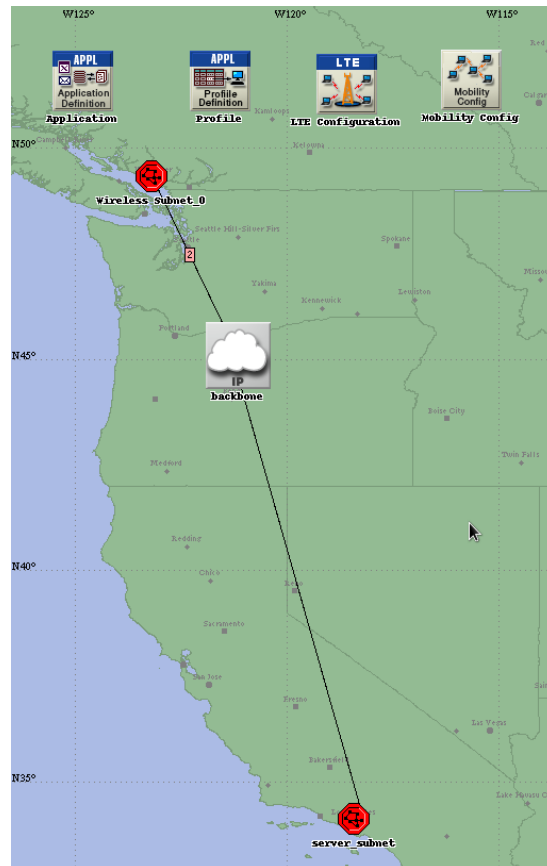


Figure 113- Parent subnet topology.

The server subnet will consist of a Cisco router and a server configured to the YouTube profile, as seen in Figure 14 and Figure 15. The server provides the HTTP YouTube streaming service to the client subnet.

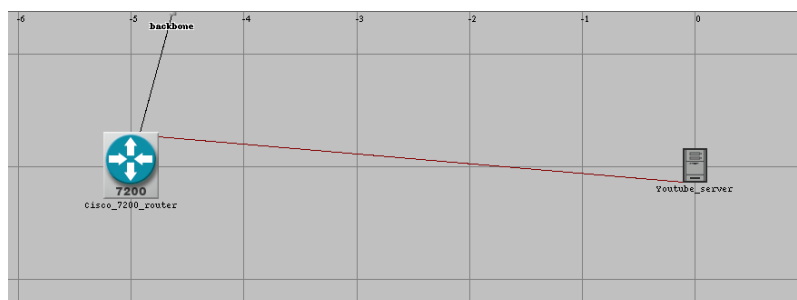
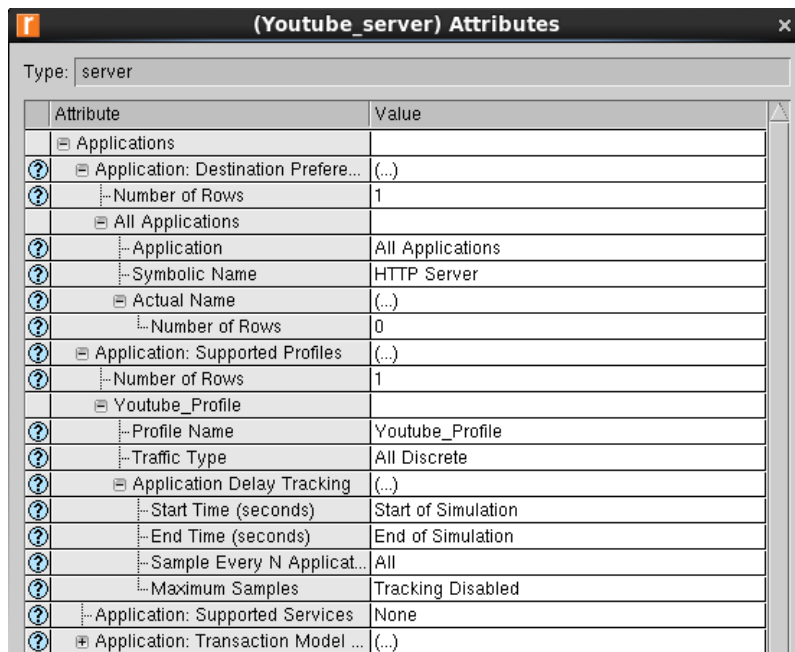


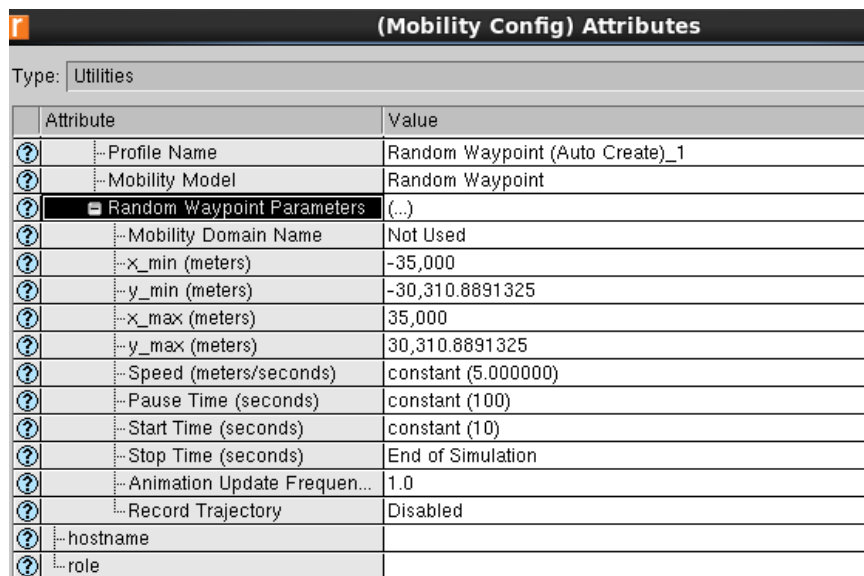
Figure 124- Server subnet topology.



Attribute	Value
Applications	
Application: Destination Preference...	(...)
Number of Rows	1
All Applications	
Application	All Applications
Symbolic Name	HTTP Server
Actual Name	(...)
Number of Rows	0
Application: Supported Profiles	(...)
Number of Rows	1
Youtube_Profile	
Profile Name	Youtube_Profile
Traffic Type	All Discrete
Application Delay Tracking	(...)
Start Time (seconds)	Start of Simulation
End Time (seconds)	End of Simulation
Sample Every N Applicat...	All
Maximum Samples	Tracking Disabled
Application: Supported Services	None
Application: Transaction Model ...	(...)

Figure 135- YouTube server attribute configuration.

The mobility attributes are also set to define the distance that each base station reaches, as seen in Figure 16. We have chosen the base stations to reach up to approximately 35km to be realistic.



Attribute	Value
Profile Name	Random Waypoint (Auto Create)_1
Mobility Model	Random Waypoint
Random Waypoint Parameters	(...)
Mobility Domain Name	Not Used
x_min (meters)	-35,000
y_min (meters)	-30,310.8891325
x_max (meters)	35,000
y_max (meters)	30,310.8891325
Speed (meters/seconds)	constant (5.000000)
Pause Time (seconds)	constant (100)
Start Time (seconds)	constant (10)
Stop Time (seconds)	End of Simulation
Animation Update Frequen...	1.0
Record Trajectory	Disabled
hostname	
role	

Figure 146- Mobility parameters of the base stations used.

6.2 Scenario One - Single Base Station with Two Fixed and One Mobile Node

6.2.1 Topology

In Scenario One, there is an Evolved Packet Core (EPC), that handles traffic throughout the network [3], a base station, one fixed node 35km from the base station at the edge of the cell, one fixed node located 5m from the base station, and one mobile node 5m from the base station, as seen in Figure 17. The EPC and base station are connected to the IP backbone. The fixed node has a trajectory that moves the mobile node from the center of the cell to outside it. The reason for setting these nodes at various distances is to observe how the throughput and delay are affected as the distance varies from the base station, how the throughput and delay changes as the mobile node moves further away, and how the throughput and delay behave at the boundary of the base station range. We predict that the throughput would decrease, and the delay would increase the further the client is from the base station.

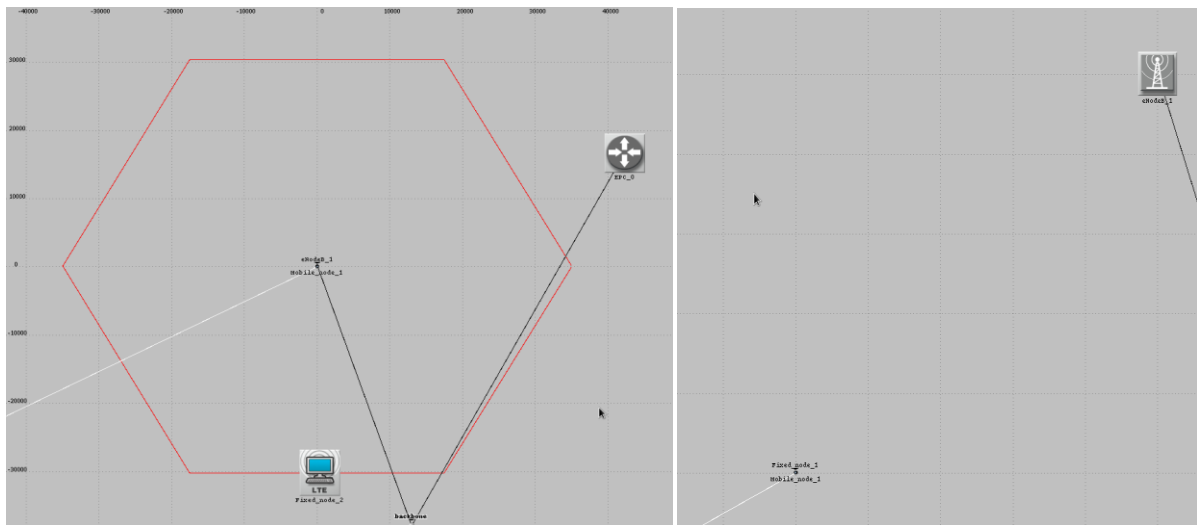
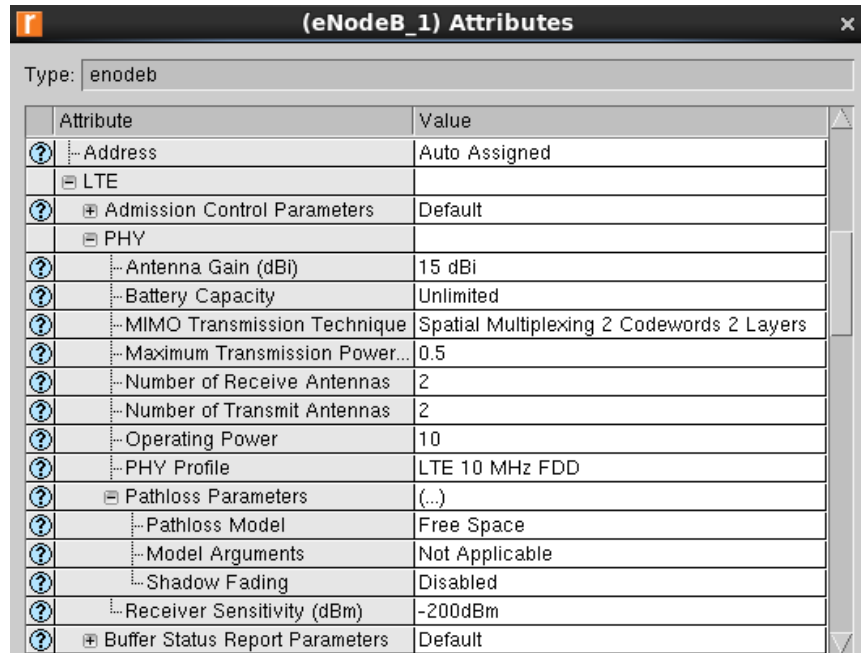


Figure 157- Scenario One client subnet topology (left) and close up of center of topology (right).

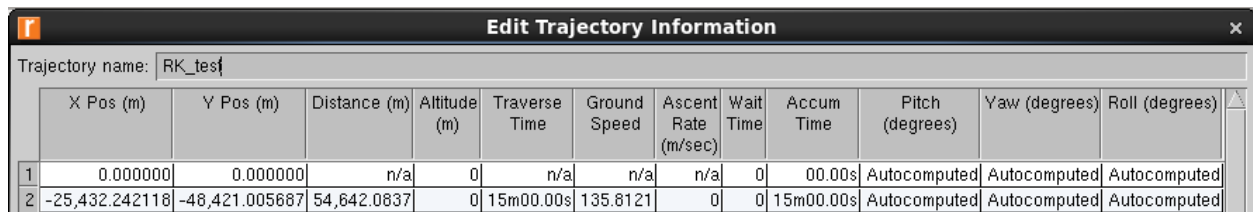
As seen in Figure 18, the base station attributes are set to default except for the channel bandwidth. We have selected 10MHz Frequency Division Duplex (FDD) for this scenario [6]. However, 5MHz is also typical to use [7].



Attribute	Value
Address	Auto Assigned
LTE	
Admission Control Parameters	Default
PHY	
Antenna Gain (dBi)	15 dBi
Battery Capacity	Unlimited
MIMO Transmission Technique	Spatial Multiplexing 2 Codewords 2 Layers
Maximum Transmission Power...	0.5
Number of Receive Antennas	2
Number of Transmit Antennas	2
Operating Power	10
PHY Profile	LTE 10 MHz FDD
Pathloss Parameters	(...)
Pathloss Model	Free Space
Model Arguments	Not Applicable
Shadow Fading	Disabled
Receiver Sensitivity (dBm)	-200dBm
Buffer Status Report Parameters	Default

Figure 168 - Base station attributes.

As seen in Figure 19, the trajectory distance is set to an arbitrary value such that the mobile node can exit the cell. The traverse time is set to the simulation time. From these two values, the rest of the table is automatically calculated.



	X Pos (m)	Y Pos (m)	Distance (m)	Altitude (m)	Traverse Time	Ground Speed	Ascent Rate (m/sec)	Wait Time	Accum Time	Pitch (degrees)	Yaw (degrees)	Roll (degrees)
1	0.000000	0.000000	n/a	0	n/a	n/a	n/a	0	00.00s	Autocomputed	Autocomputed	Autocomputed
2	-25,432.242118	-48,421.005687	54,642.0837	0	15m00.00s	135.8121	0	0	15m00.00s	Autocomputed	Autocomputed	Autocomputed

Figure 179- Trajectory information of the mobile node.

6.2.2 Simulation Result

6.2.2.1 Throughput

In Scenario One, where there was one base station, one fixed node 5m from the base station (blue), another fixed node 35km from the base station (red), and one mobile node (green), the simulation results were as predicted. The initial spike is believed to come from the initial handshake where many packets are sent to the node until the node sends and ACK to the base station, which is when throughput stabilizes. The node closest to the base station has a constant throughput while the throughput of mobile node eventually reaches zero as it leaves the physical range of the base station. The base station at the edge of the cell has zero throughputs because throughout the simulation it has

been too far. However, it is unclear where the drop in throughput for all nodes at approximately the 7-minute mark originates from.

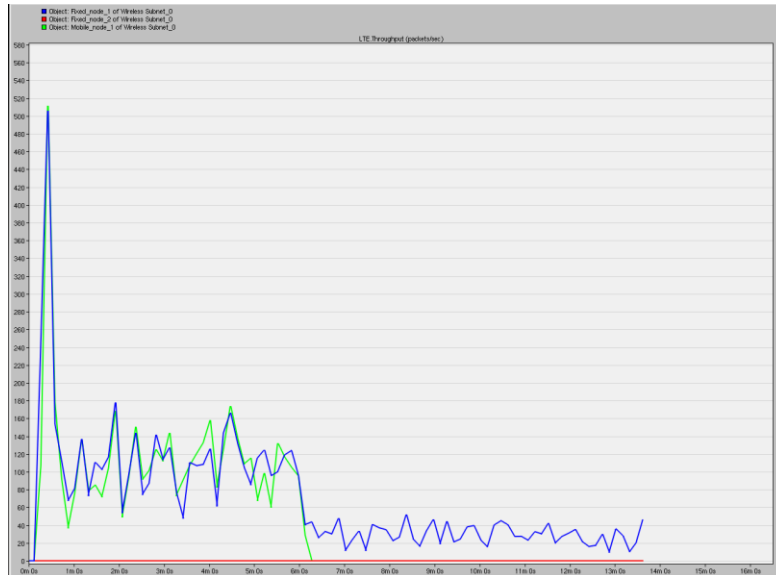


Figure 20 - Throughput of LTE network with two fixed nodes (red and blue), and one mobile node (green), with 10MHz base station frequency.

6.2.2.2 Delay

In this scenario, we collected the delay of the LTE network at two fixed nodes and a mobile node. The fixed node1 has a flat graph of delay as we expected. However, the fixed node 2 is not shown in the graph. The reason is that we put fixed node2 outside the coverage of the base station. The mobile node has a trajectory that moves away from the base station. As a result, we see a rapid increase in delay at the beginning due to the increase in distance.

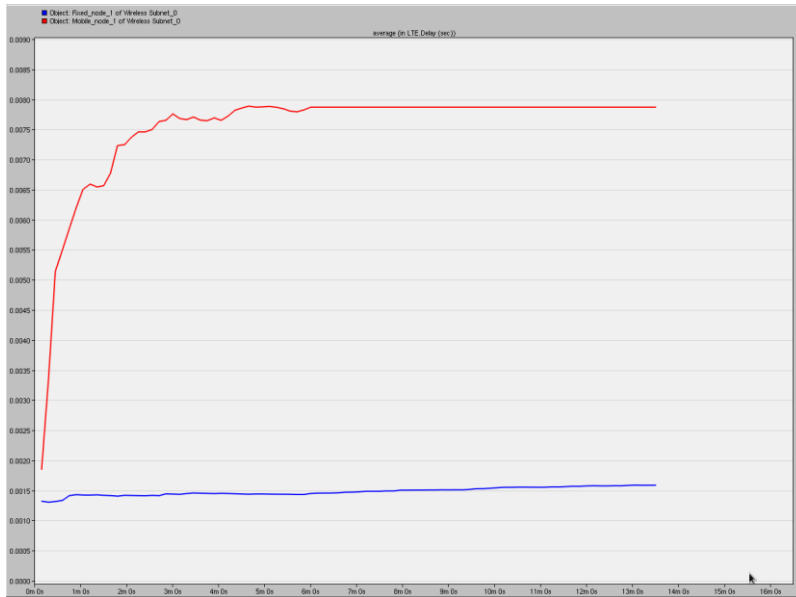


Figure 21- Delay results of fixed nodes (blue) and the mobile node (red).

6.3 Scenario Two - Two Base Stations and One Mobile Node

6.3.1 Topology

In Scenario two, we inherit the basic topology from Scenario one. We added an additional base station which has the same coverage range. The only difference is that new base station eNodeB_1 has a different bandwidth of 5 MHz. We want to know how the bandwidth affects our simulation result. Moreover, we set the trajectory to stop at the boundary for 4 minutes to observe the traffic when the node is on the boundary.

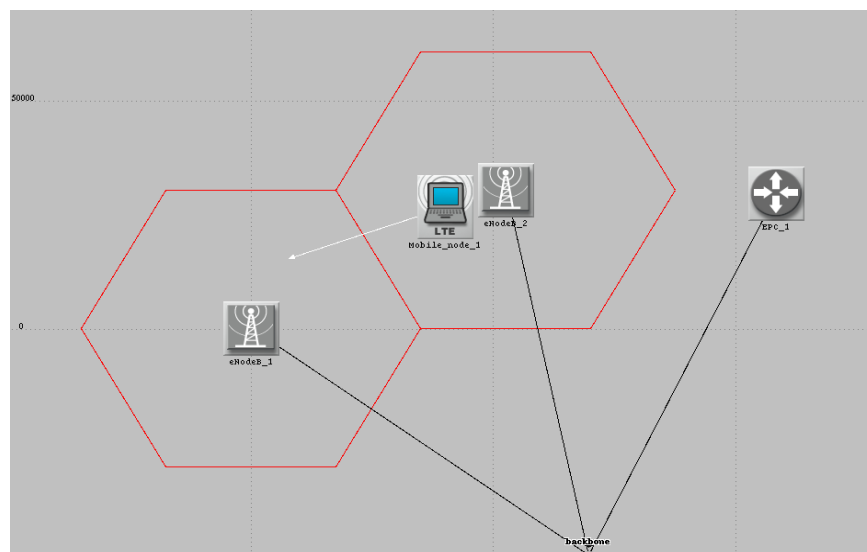


Figure 22- Scenario Two client subnet topology.

(eNodeB_1) Attributes	
Type:	enodeb
Attribute	Value
PHY	
Antenna Gain (dBi)	15 dBi
Battery Capacity	Unlimited
MIMO Transmission Technique	Spatial Multiplexing 2 Codewords ...
Maximum Transmission Power...	0.5
Number of Receive Antennas	2
Number of Transmit Antennas	2
Operating Power	10
PHY Profile	LTE 5 MHz FDD
Pathloss Parameters	(...)
Receiver Sensitivity (dBm)	-200dBm
Buffer Status Report Parameters	Default

(eNodeB_2) Attributes	
Type:	enodeb
Attribute	Value
PHY	
Antenna Gain (dBi)	15 dBi
Battery Capacity	Unlimited
MIMO Transmission Technique	Spatial Multiplexing 2 Codewords ...
Maximum Transmission Power...	0.5
Number of Receive Antennas	2
Number of Transmit Antennas	2
Operating Power	10
PHY Profile	LTE 10 MHz FDD
Pathloss Parameters	Free Space
Receiver Sensitivity (dBm)	-200dBm
Buffer Status Report Parameters	Default
CQI Transmission Parameters	Default

Figure 23- Scenario Two base stations attributes.

6.3.2 Simulation Result

6.3.2.1 Throughput

In Scenario Two, we have a mobile node traversing from a 10MHz channel bandwidth base station to a 5 MHz base station. Similar to Scenario One, the initial spike is believed to come from the initial handshake until throughput stabilizes. As the mobile node crosses the boundary from one base station to another, as expected, throughput drops. However, we did not expect the throughput of the 5MHz base station to be larger than that of the 10MHz base station. It is unclear where this result comes from.



Figure 24- LTE network throughput of a mobile node traversing the cells from a 10MHz frequency base station to a 5MHz frequency base station.

6.3.2.2 Delay

In this scenario, we only collect the delay at one mobile workstation. Mobile_node_1 moves away from basestation1 (10MHz) and eventually entered the coverage of basestation2 (5MHz). We observe that delay in basestation2 is slightly higher than the delay in basestation1.

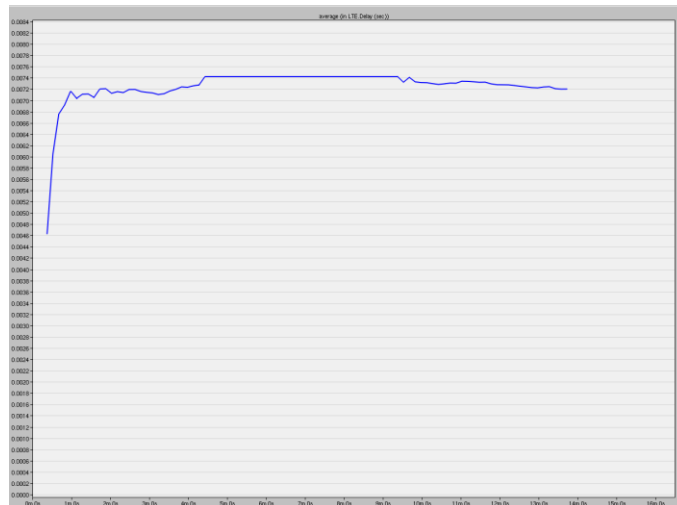


Figure 25- LTE network delay of a mobile node traversing the cells from a 10MHz frequency base station to a 5MHz frequency base station.

6.4 Scenario Three - Three Base Stations with Two Mobile Nodes

6.4.1 Topology

In Scenario three, we want a more realistic configuration. We add 3 base station and 2 mobile nodes while other settings remain the same from Scenario one and Scenario two. The middle base station has 5 MHz bandwidth and the other two base stations have 10 MHz bandwidth. We want to collect the data when mobile keep moving in and out of the range of the base station. Then we can compare the result with another node which stays in the range of the base station.

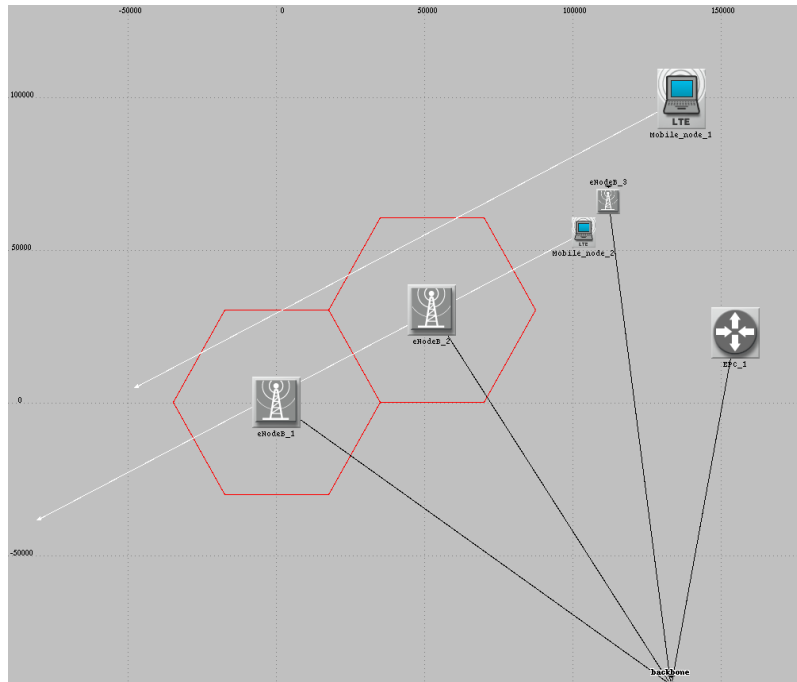


Figure 26- Scenario Three client subnet topology.

We set two parallel trajectories for two nodes. They have the same speed but node1 will move in and out from the range of three base station.

Edit Trajectory Information												
Trajectory name: RK_test												
	X Pos (m)	Y Pos (m)	Distance (m)	Altitude (m)	Traverse Time	Ground Speed	Ascent Rate (m/sec)	Wait Time	Accum Time	Pitch (degrees)	Yaw (degrees)	Roll (degrees)
1	0.000000	0.000000	n/a	0	n/a	n/a	n/a	0	00.00s	Autocomputed	Autocomputed	Autocomputed
2	-184,871.759327	-94,624.327773	206,287.0604	0	15m00.00s	512.7233	0	0	15m00.00s	Autocomputed	Autocomputed	Autocomputed

Figure 27- Scenario Three trajectory of the mobile node.

6.4.2 Simulation Result

6.4.2.1 Throughput

In Scenario Three, first, we have a single mobile node traversing from a 5MHz base station to a 10MHz base station and again to a 5 MHz base station, entering and leaving each cell range between each transition to the next base station. Similar to Scenario One, the initial spike is believed to come from the initial handshake until throughput stabilizes. As the mobile node crosses the boundary from the 5MHz base station to the 10MHz base station throughput increases, and when it travels through the next 5MHz base station, throughput decreases, as expected.

Next, we have the same conditions, except we have another mobile node traversing through the base station ranges without ever not being within the range of at least one cell. For this mobile node, instead of a complete drop to zero in throughput when transitioning from the base station to base station, we see a weaker non-zero throughput, as expected since the node is always within the base station range.

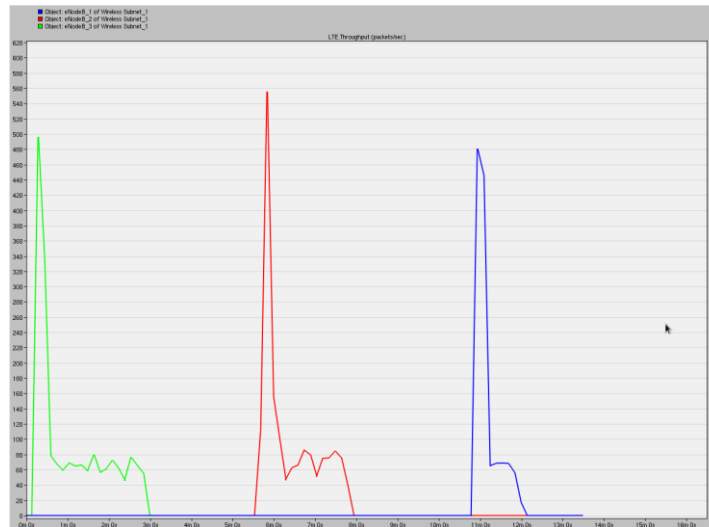


Figure 28- LTE network throughput of a mobile node traversing the cells of three base stations with two 5Mhz frequency and one 10MHz frequency.

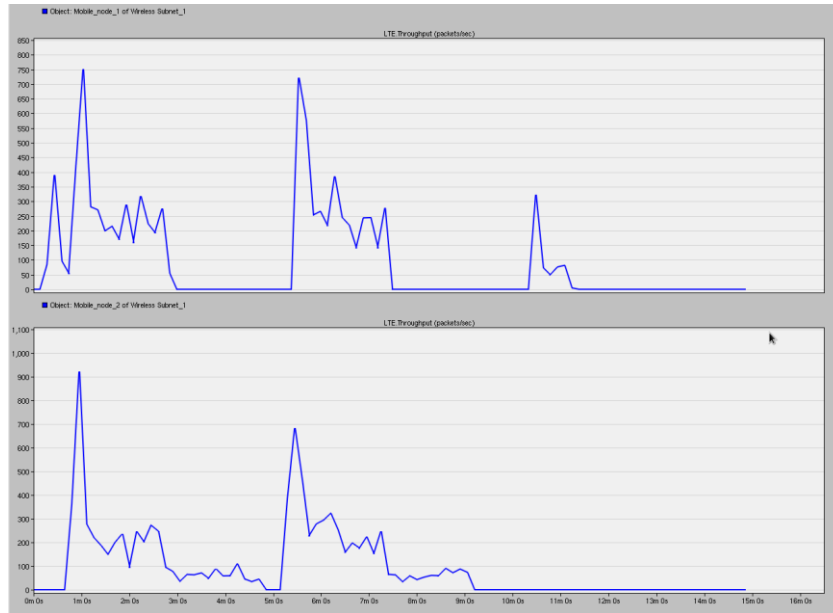


Figure 29 – LTE network throughput of two mobile nodes passing through three base station cells, where one mobile node traverses in and out of each cell (top) and one passes through each cell (bottom).

6.4.2.2 Delay

In this scenario, we observe the delays of the LTE network at two mobile workstations. In Figure 30, mobile_workstation1 has discontinuous delays during the simulation because it moves in and out through 3 different base stations. For mobile_wokrstation2, delays are continuous until the workstation are far away from the third base station.



Figure 30- LTE network delay of a mobile node traversing the cells of three base stations with two 5MHz frequency and one 10MHz frequency.

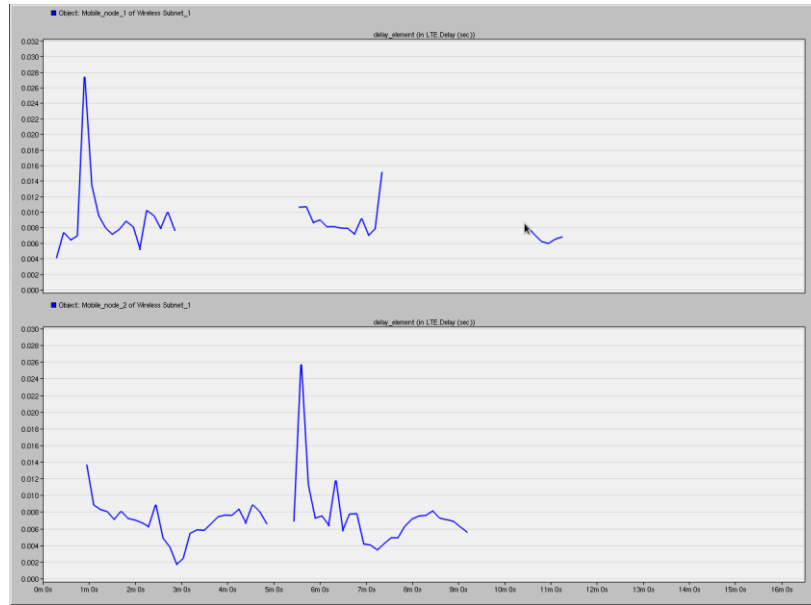


Figure 31 – LTE network delay of two mobile nodes passing through three base station cells, where one mobile node traverses in and out of each cell (top) and one passes through each cell (bottom).

7 Conclusion

The entire project was a great learning experience as we got to know more about the LTE technology. It is something we use quite often in our daily lives without knowing anything about it. Our understanding from the course material and some self-learning helped a great deal to complete the project successfully. The main understanding was the change in throughput and the delay as the users go away from the base stations, even though in real life a user would not care where the base stations are and how the data is being transferred it was one of the things we wanted to investigate and get a better understanding. As mentioned in the results for the scenarios and various simulation the results obtained met our expectations. We also learned that it is a good practice to start off by creating a validation scenario and perform a simple simulation to get a better picture of how to use the tool properly.

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