ENSC 833
NETWORK PROTOCOLS AND PERFORMANCE

Investigation on Handover in WiMAX and Performance Comparison over WiMAX and LTE

by

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Abstract

WiMAX (Worldwide Interoperability for Microwave Access) and LTE (Long-Term Evaluation) utilize advanced technologies, such as Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple-Input and Multiple-Output (MIMO). They are both based on IP (Internet Protocol) with high speed data transmission capability which can accomplish quick Internet access. Handover is a significant factor to evaluate the performance for both WiMAX and LTE networks and it occurs when a Mobile Station (MS) moves between Base Stations (BSs). In this project, we implemented one part of the Dual-Trigger Handover (DTHO) Algorithm first. Accuracy of handover decision can be enhanced by selecting an appropriate value of handover threshold hysteresis depending on signal to noise ratio (SNR). Secondly, we compared the performance of WiMAX and LTE in terms of traffic sent and received rate and throughput.

Acknowledgments

Before starting to introduce our project report, we think that it is necessary to acknowledge the people who helped us with this project. Without their help, the project could not be carried out and we could not achieve the excellent performance during spring 2016.

First of all, we would like to thank Simon Fraser University (SFU) for providing me with this project opportunity. In the second place, we would give our sincere thanks and appreciation to our supervisor Prof. Ljiljana Trajković who gave this special chance to us that we would never forget. We would like to thank Alejandro Llibre Beltri who gave his suggestions and helped us when we had difficulties. Besides, we are extremely grateful for our good friend Jiawei He for correcting our English for this report.

Abbreviations

4G	Fourth Generation
ADSL	Asymmetric Digital Subscriber Line
AMC	Adaptive Modulation and Coding
BS	Base Station
BWA	Broadband Wireless Access
CDMA	Cellular Division Multiple Access
CINR	Carrier to Noise Ratio
DL	Downlink
DSP	Digital Signal Processing
GSM	Global System for Mobile
HHO	Hard Handover
HO	Handover
LTE	Long Term Evolution
MAC	Multiple Access Control
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PDU	Protocol Data Units
QoS	Quality of Service
RF	Radio Frequency
SHO	Soft Handover
SNR	Signal-to-Noise Ratio
SOFDMA	Scalable Orthogonal Frequency Division Multiple Access
TBS	Target Base Station
UE	User Equipment
UL	Uplink
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

Contents

Chapter 1

Introduction

In this day and age, with the rapid development of the economy and the steady growth of people's living standard, it is commonly believed that modern Broadband Wireless Access (BWA) technologies are in-dispersible.The main aims of this project are to implement Worldwide Interoperability for Microwave Access (WiMAX) and Long-Term Evolution (LTE) networks using Riverbed Modeler 18.5 running on Linux CentOS 6.7 operating system, analyze the performance of WiMAX and LTE by considering handover and data transmission, and compare the performance of WiMAX and LTE in terms of throughput and traffic sent and received rate. It requires a strong background in computer networking and experience with simulation tools such as Riverbed Modeler, NS2, or NS3.

Our original goal is to implement Dual-Trigger Handover (DTHO) algorithm [1] for WiMAX network. DTHO algorithm improves the accuracy of handover process. Handover is a significant factor to affect the performance of a WiMAX network and it occurs when a Mobile Station (MS) moves among Base Stations (BSs). To achieve seamless handover, both MS and BS scan the neighboring BSs for selecting the best BS for a potential handover. The signal strength is a dominant factor for handover decision, which is based on the computation of signal-to-noise ratio (SNR) received at the MS from various BSs. SNR and free capacity of the target BS have been considered in the DTHO algorithm that prevents an MS from implementing low-efficiency handover decisions if the target BS does not have enough free capacity. Due to the limitation and difficulty, we implemented one part of the DTHO algorithm by changing the value of handover threshold hysteresis for MS. Unnecessary handovers can be avoided and loss of traffic data will be ameliorated by changing handover threshold hysteresis parameter.

As nobody has compared the performance of WiMAX and LTE in ENSC 833 before, it is a good opportunity to dig into them. Three scenarios will be considered in our project. The first scenario comprises two BSs and one MS, the second scenario consists of four BSs and one MS, and the third scenario has four BSs and six MSs. The bidirectional signal between the MS and the BS is considered in our project. We employed Voice of IP application for both WiMAX and LTE simulations. Furthermore, application and profile configurations, trajectory, traffic type, segment size, and speed are identical. Studying the DTHO algorithm helps a lot for understanding handover process. We selected an appropriate handover threshold hysteresis value in WiMAX simulation when we performed the comparison. According to our results, LTE achieves higher voice traffic sent and received rates and throughput.

Chapter 2

WiMAX and LTE

WiMAX and LTE technologies are introduced in this chapter. WiMAX and LTE utilize advanced technologies, such as Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple-Input and Multiple-Output (MIMO). Besides, they are both based on IP (Internet Protocol) with high speed data transmission capability which can accomplish quick Internet access. These two standards are developed in different historical background. The International Telecommunication Union defines WiMAX and LTE as 3G and some people believe that these two standards are close to 4G. In terms of their standards, WiMAX employs IEEE 802.16 standard while LTE uses 3GPP. WiMAX and LTE technologies have a lot of similarities and seem to be competitive at the beginning. Both technologies aim to provide mobile voice and data service by promoting low cost deployment.

2.1 WiMAX Technology

WiMAX is a developing technology that enables high speed connection all over wide range. It is an extension of WiFi to some extent. WiMAX combines the cellular technology with the Wi-Fi speed. WiMAX can provide a transmission speed up to 70 Mbps and its maximum area coverage can be 50 km [2]. The advantages of WiMAX are good QoS (quality of service), high transmission speed, and various business operations. It utilizes a new physical (PHY) layer radio access technology called OFDMA for uplink and downlink [3]. WiMAX can be categorized into two classes depending on the mobility. Theses two classes are fixed WiMAX and mobile WiMAX, based on IEEE 802.16 [4] and IEEE 802.16e [5] standards, respectively. There is no nomadic access and handover in the presence of fixed WiMAX, while the mobile WiMAX provides new features and functionalities that support enhanced QoS and high mobility services. It allows handover as the users moves among radio towers. The speed of the MS can be 120 km/h. The mobility is one of the main weaknesses of WiMAX.

2.1.1 Operating Principle

WiMAX has been considered as the best access to the cellular networks, allowing users to connect broadband wireless network easily at any place and providing better experience than using Wi-Fi. WiMAX is a metropolitan area network (MAN) technology. When the network operators deploy a signal tower or base station, they will obtain miles of coverage area. Local users can immediately be able to connect to the Internet within the coverage area.

2.1.2 Main Structure

Transmission Unit

The connection approach of the WiMAX network is similar to cellular network. We divide a specific geographical area into a number of overlapping areas. When the user equipment moves from one area to another, the wireless connection changes from one BS to another as well.

Main Equipment

A base station and a user equipment consist the main components of WiMAX network. WiMAX base station is set up separately or at the top of the building and its purpose is to broadcast wireless signal. The signal can be received using WiMAX features on a laptop, mobile internet device, or WiMAX modem.

Licensed Spectrum

WiMAX uses licensed spectrum of: 2.3 GHz, 2.5 GHz, and 3.5 GHz.

Cost

The cost of the infrastructure is similar to basic telecommunication infrastructure for voice communication network such as global system for mobile and code division multiple access.

2.2 LTE Technology

LTE was designed by the 3GPP (Third Generation Partnership Project) [6] as a highly flexible radio interface. LTE evolved from an earlier 3GPP system known as the UMTS (Universal Mobile Telecommunication System), which in turn evolved from the GSM (Global System for Mobile Communication) [7]. LTE supports both FDM (Frequency-Division Multiplexing) and TDM (Time-Division Multiplexing). Also, LTE supports a wide range of system bandwidth in order to implement in a large number of different spectrum allocations. It supports frequency bandwidths of 800, 900, 1800 and 1900 MHz and new frequency bandwidths that range from 800 MHz to 2.62 GHz.

2.2.1 Transmission Schemes

OFDM is the core of the LTE downlink radio transmission, which is robust to time dispersion on channels [8]. The transmission capacity for the uplink is significantly lower than that of the downlink. LTE network is able to provide 300 Mbps for downlink and 75 Mbps for uplink under certain antenna configuration and modulation depth.

2.2.2 Protocol Structure

LTE applies e-UTRA (evolved UMTS Terrestrial Radio Access) [9] environment in the network. The user plane protocol stack between e-NodeB (the base station for LTE) and UE (user equipment) consists of sub-layers of PDCP (Packet Data Convergence Protocol), RLC (Radio Link Control), and MAC (Medium

Access Control). Fig. 2.1 illustrates the basic protocol structure of LTE. Physical layer carries all the information from the MAC transport channels over the interface [10]. It helps with the power control, link adaptation, cell search for initial synchronization and handover purposes, etc. MAC layer is responsible for mapping between logical channels and transport channels. Error Correction is one of the main functions in MAC layer. There are three modes of operation in RLC, TM (Transparent Mode), UM (Unacknowledged Mode), and AM (Acknowledged Mode). RLC layer is responsible for transferring upper layer PDUs (Protocol Data Units).

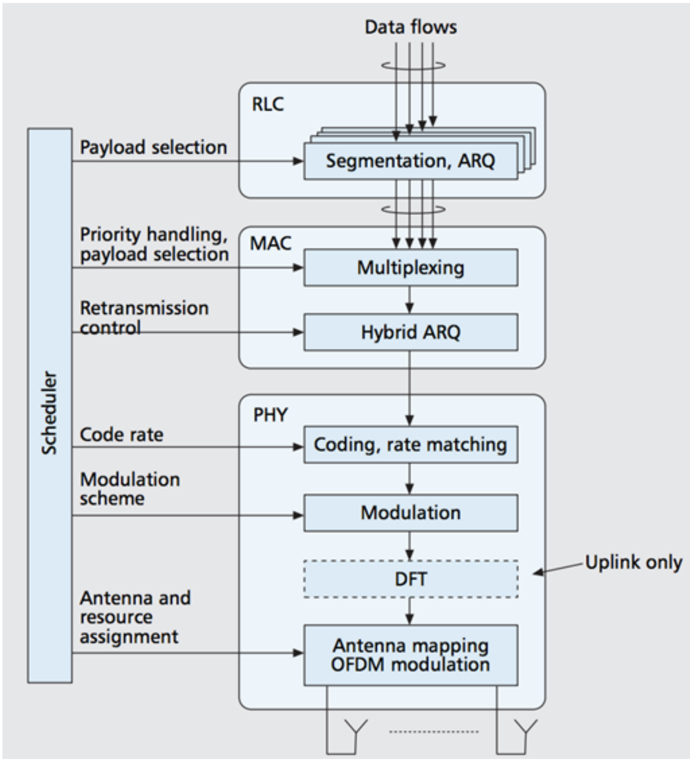


Figure 2.1: LTE simplified protocol structure [8].

2.2.3 Mobility

The locations of the the UEs are tracked in LTE, which ensures incoming calls to be delivered correctly. In general, mobility management includes location update and paging. The UE reports its new location to the network through the location update procedure. When an incoming call arrives, the network would identify the location of the UE through the paging procedure [11]. LTE supports high performance mobile access up to 350 km/h while WiMAX can only support good QoS with ground speed of 120 km/h.

Fig. 2.2 shows evolution path of mobile wireless technologies towards 4G for WiMAX and LTE. Both WiMAX and LTE target to achieve the data reates set by the 4G "IMT-Advanced" standard.

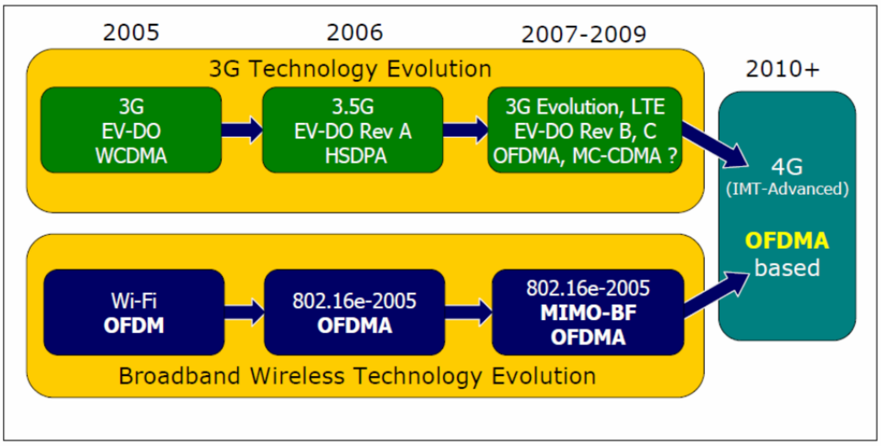


Figure 2.2: Evolution path of mobile wireless technologies towards 4G [12].

Chapter 3

Goal and Challenge in the Project

We briefly describe the challenges such as trying to solving DTHO algorithm and building the same scenarios using both WiMAX and LTE library.

- Our first goal is to build the same scenarios for both WiMAX and LTE using Riberbed Molder 18.5. It spends much time to acquire the knowledge to manage the Riberbed Modeler tool and build different scenarios required to achieve reasonable simulation results. We realize the comparison by setting same initial conditions such as application configuration, the number of BS and MS, and speed of the moving MS.

- The second challenge is to implement DTHO algorithm. Trying to understand the handover mechanism and implement the DTHO algorithm spends a lot of time. The SNR and the free capacity of the target BS have been considered as the main factors in DTHO algorithm.

- For the comparison, we aim to compare the performance of WiMAX and LTE by considering handover and data rate with different speeds. Therefore, the data transmission and mobility condition for both technologies can be observed obviously.

- We get some errors when we copy a project from one user account to another. We guess that different accounts may exist mismatch in model library as the administrator assigning different Modeler version to each user's account. We rebuild everything when we have this condition and it is ineffective to realizing many simulations.

Chapter 4

Handover

In this chapter, we first gain the knowledge of handover and its procedure. Furthermore, the calculation of the signal to noise ratio (SNR) is present as it becoming one requirement of the DTHO algorithm. We also analyze SNR in our later chapter of simulation result. We take WiMAX for example to explain handover process.

4.1 Handover

Handover is considered as a highly important issue in WiMAX and LTE and it provides continuous connection. Handover occurs when a mobile station migrates from one BS to another BS. In terms of the type of handover, it is characterized as hard handover and soft handover [13]. Hard handover is known as break-before-make, which means that the MS disconnects the existing link before establishing communication with new BS. Soft handover comprises macro diversity handoff (MDHO) and fast base station switching (FBSS) that improve the QoS performance while adding more BSs [1]. We implement our simulation by considering hard handover in our project. SNR or the received signal strength indicator (RSSI) has been chosen as handover criteria for most reported algorithms. These algorithms can be divided into three classes [14]:

1. When MS migrates from one BS to another, the system initiates handover process if the received signal strength of the serving BS is lower than that of target BS. Unnecessary handovers may occur even if the MS receives a

signal which its SNR can be accepted. The increasing handovers cause the data loss and eventually affect the QoS of the connection.

2. The handover decision depends on signal strength and the threshold. This method can avoid unnecessary handovers to some extent if a appropriate threshold value is selected. Small threshold value causes repeated handovers while big threshold value may degrades the connection quality.

3. The handover decision depends on signal strength with a threshold and a margin. The handover process is performed when received signal strength from the serving BS is lower than threshold and SNR of the serving BS is lower than the target BS.

4.2 Handover Procedure

The handover procedure can be explained using a flow chat of MS-initiated handover as shown in Fig. 4.1.

- First, we describe preparation process. When a MS connects to its serving BS, the serving BS broadcasts a message (MOB-NBR-ADV) periodically and the MS can acquire the information of the neighboring BS. The MOB-NBR-ADV contains important messages such as the ID of the target BS, downlink channel descriptor, and uplink channel descriptor [14]. The MS then sends a scan request message (MOB-SCN-REQ). The MS also sends MOB-MSHO-REQ message which contains the QoS of the candidate BS. Once the serving BS receives MOB-MSHO-REQ message, it indicates an appropriate target BS that can provide better data transmission and notifies the information to MS by sending handover response message (MOB-BSHO-RSP).

- Second, in terms of action process, in response to MOB-BSHO-RSP message sent by serving BS, the MS sends MOB-HO-IND message back to confirm whether the MS disconnects the link or cancels the handover decision. If the MS choose to disconnect the serving BS, the serving BS triggers the handover.

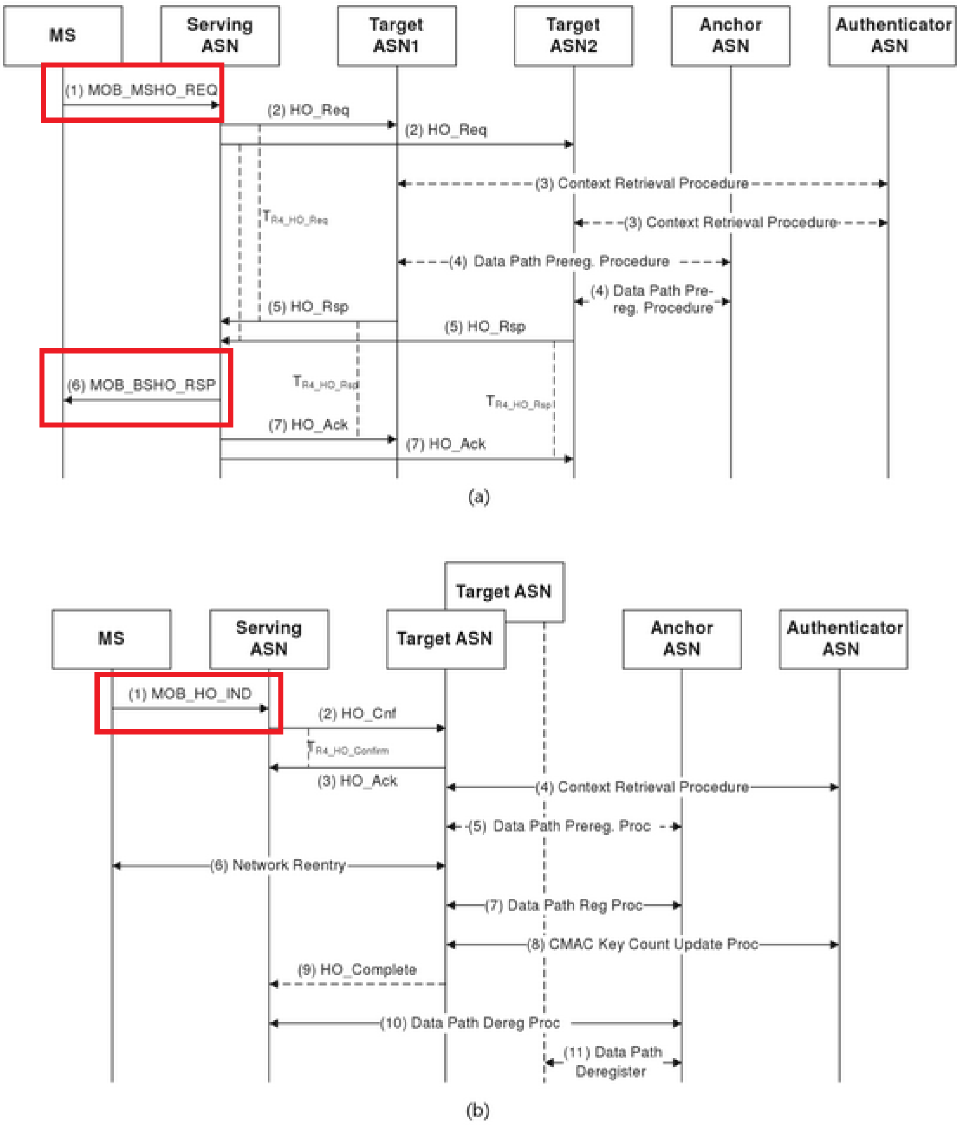


Figure 4.1: Illustration of MS-initiated handover execution process: (a) preparation process and (b) action process [14].

4.3 Handover Criteria – SNR

In our WiMAX part, we concentrate on two parameters: scanning threshold and handover threshold hysteresis. These parameters can be studied in Fig. 4.2. When the SNR of the serving reaches the scanning threshold, the MS is in the scanning mode. The handover triggering condition related to handover threshold hysteresis can be defined as:

$$SNR_{maxDT} - SNR_{DS} \geq H_1 \tag{4.1}$$

where SNR_{maxDT} and SNR_{DS} are the maximum downlink SNR of the target BS and downlink SNR of the serving BS, respectively.

Equation (4.1) indicates that if the difference between the SRN of the target BS and serving BS is greater than H_1, the MS will initiate the handover process by sending MOB-MSHO-REQ message.

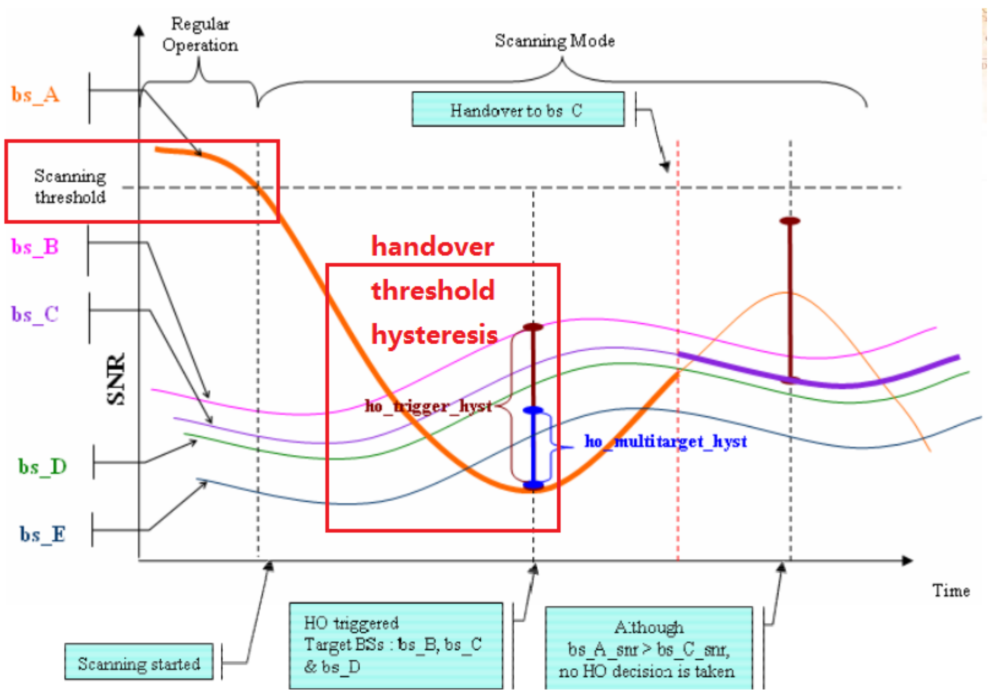


Figure 4.2: Illustration of scanning threshold and handover threshold hysteresis parameters [15].

Chapter 5

Simulations and Result Analysis

Three scenarios have been simulated for both WiMAX and LTE. We implement WiMAX and LTE networks on Riverbed Modeler 18.5, analyze the handovers and data transmission rates of WiMAX and LTE, and compare the performance of WiMAX and LTE.

5.1 Simulation Environment

The following are the entities which we have selected from the *Object Palette Tree* from the Riverbed Modeler 18.5.

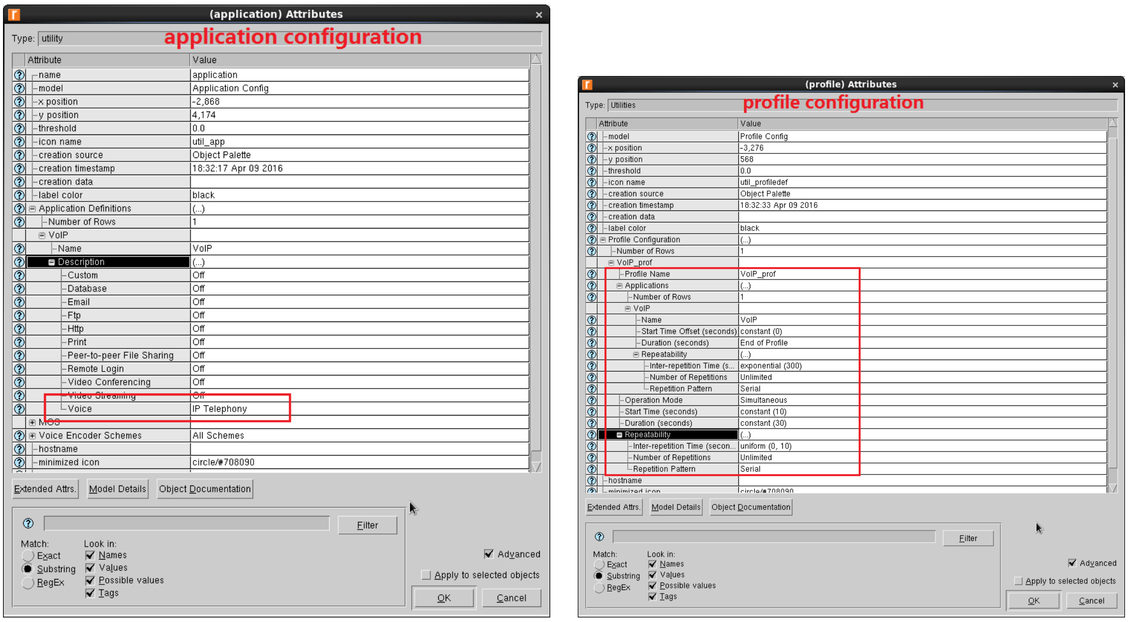
- *Profile_Config*
- *Application_Config*
- *WiMAX_Config* and *lte_attr_definer_adv*
- Server: *ethernet_server*
- Link: 1000*BaseX*
- Mobile station: *wimax_ss_wkstn_adv* and *lte_wkstn_adv*
- Base station: *wimax_bs_router_adv* and *lte_enodeb_4ethernet_4atm_4slip_adv*
- Router: *router_slip*64*_dc_2_upgrade* and *router_slip*64*_dc*

In our simulations, application, profile, and server configurations and mobile station setting are identical for WiMAX and LIE as shown in Figs. 5.1 and

5.2. Both WiMAX and LTE employ Voice IP application. In terms of profile configuration setting, the profile name is called VoIP_prof and the important parameters highlighted have been specified. Each base station has its own ID and it is assigned as follows:

- Base Station_i (i=1, 2, 3, or 4) in WiMAX.
- eNodeB_i (i=1, 2, 3, or 4) in LTE.

Note that the application segment size for mobile station is 64000, therefore, the speed of traffic sent is 64 kbps. Each BS initially has 2.6 Msps free upload link capacity in WiMAX scenario.



(a) Application configuration.

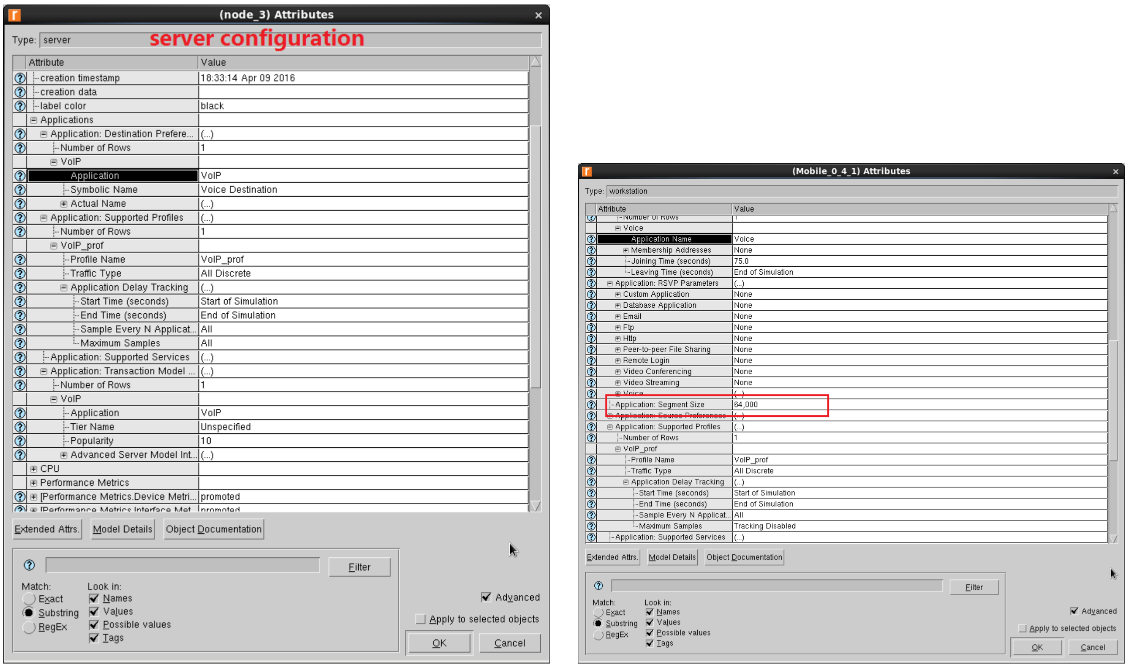
(b) Profile configuration.

Figure 5.1: Application and profile configurations for WiMAX and LTE.

5.2 Simulation Results

5.2.1 WiMAX

Tables 5.2.1 and 5.2.1 show mobility parameters for simulation Scenarios 1, 2 , and 3, which could be set in the attribute of MS.



(a) Server configuration. (b) Mobile station setting.

Figure 5.2: Server and mobile station settings for WiMAX and LTE.

Scanning Thresholds (db)	5
Scan Duration (N) (Frames)	25
Interleaving Interval (P) (Frames)	240
Maximum Scan Request Retransmissions	10

Table 5.1: Scanning parameters.

WiMAX Scenario 1

The network topology shown in Fig. 5.3 consists of two WiMAX cells, an MS, a server, and a backbone router. The MS migrates from BS1 to BS2 based on a predefined trajectory. The simulation results for WiMAX Scenario 1 are shown in Fig. 5.4.

- The top plot shows the WiMAX traffic sent by MS. Traffic data are lost during handover process.
- The middle plot indicates the number of handovers in Fig. 5.4 (a). The y-axis stands for the ID of BSs. The BS ID number changes from BS1 to BS2 in this case.
- The bottom plot shows the WiMAX physical downlink SNR received by

Handover Threshold Hysteresis H_1 (dB)	0.4
MS Handover Retransmission Timer (ms)	30
Maximum Handover Attempts per BS	6
Multitarget Handover Thresholds Hysterias (dB)	0.0
Maximum Handover Attempts per BS	3

Table 5.2: Handover parameters.

MS.

It could be observed in Fig. 5.4 (a) that during the time when the handover is processed, the rate of traffic sent would drop from 43000 bits/sec to 18000 bits/sec when H_1=0.4 dB, which is only 42% of the original rate. We improved the performance by increasing the handover threshold hysteresis H_1 to 6 dB as shown Fig. 5.4 (b). The traffic sent rate could still be almost 80% around (decrease to 34000 bits/sec) the steady rate. Therefore, larger H_1 helps to avoid repeated handovers and reduce traffic loss.

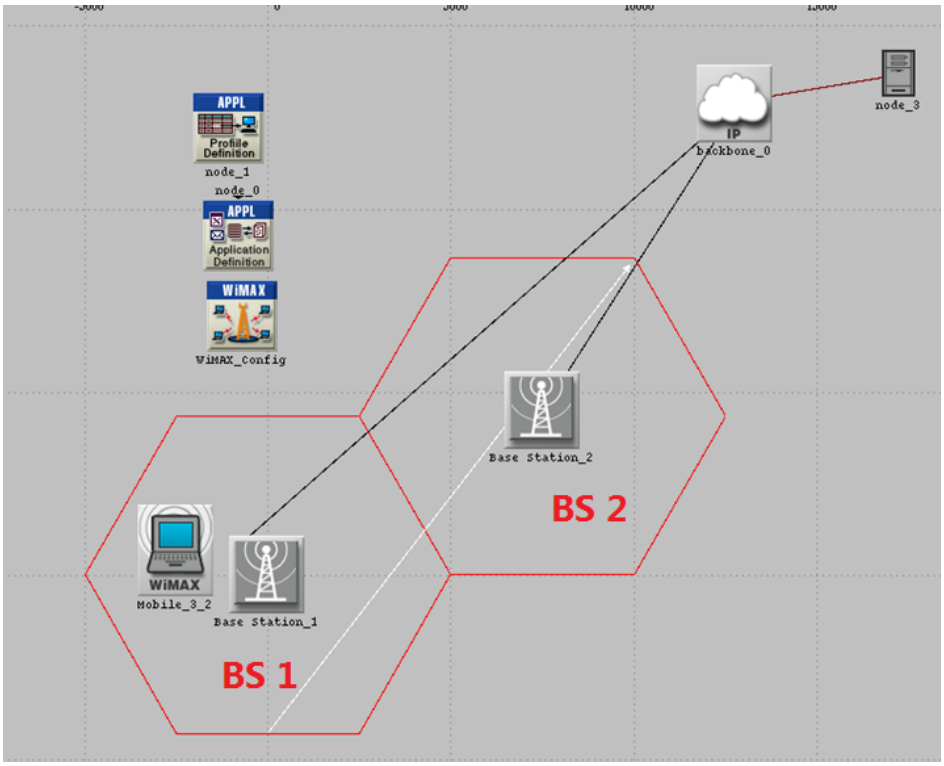
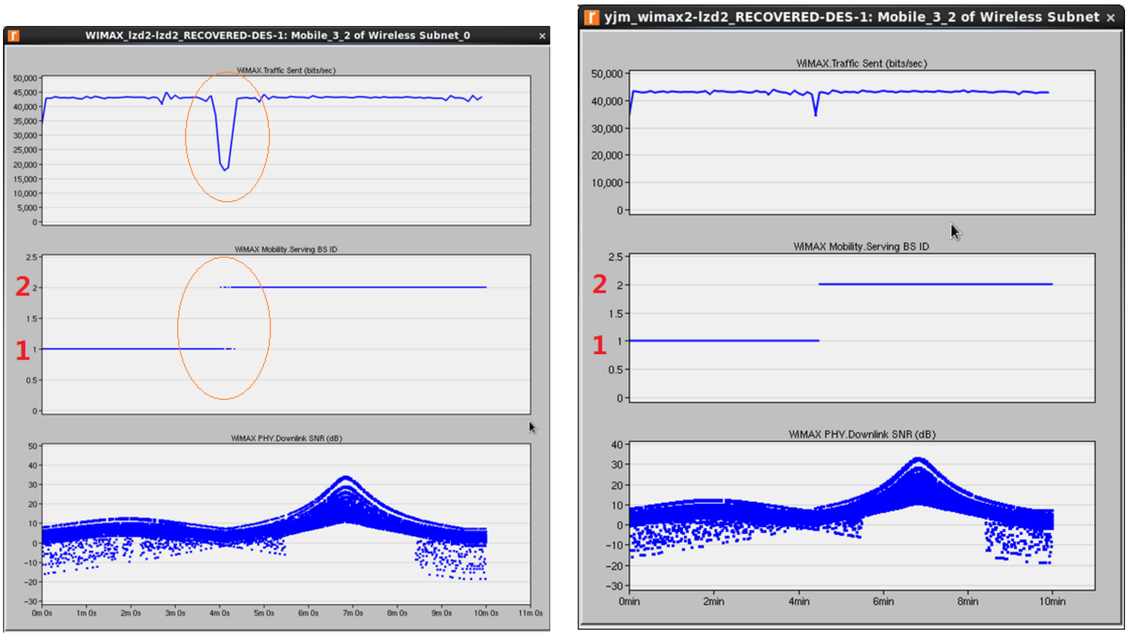


Figure 5.3: Riverbed Modeler network model: WiMAX Scenario 1.



(a) Handover threshold hysteresis H_1 = 0.4 dB. (b) Handover threshold hysteresis H_1 = 6.0 dB.

Figure 5.4: Traffic Sent (top), serving BS ID (middle), and downlink SNR (bottom) for WiMAX Scenario 1.

WiMAX Scenario 2

The network topology for WiMAX Scenario 2 comprises four WiMAX cells, an MS, a server, and a backbone router as shown in Fig. 5.5. The MS migrates from BS4 to BS1 in this case. The simulation results for WiMAX scenario 2 are shown in Fig. 5.6. It is obvious that larger H_1 can achieve better performance as shown in Fig. 5.6 (b).

In the first handover process, traffic sent rate drops from 43000 bits/sec to 21000 bits/sec (49%) with H_1=0.4 dB while it only decreases to 41500 bits/sec (96%) with H_1=6 dB. In the second handover process, the rate of traffic sent would decrease to 10000 bits/sec with H_1=0.4 dB. However, traffic sent rate declines to 41000 bits/sec (95%) with H_1=6 dB.

WiMAX Scenario 3

We added five fixed MSs near base staion_2 as shown in Fig.5.7. The neighboring BSs are BS 2 and BS 0 which are the same as WiMAX Scenario 2. We utilized this network topology to research traffic loss problem. Base Staion_2 serves five

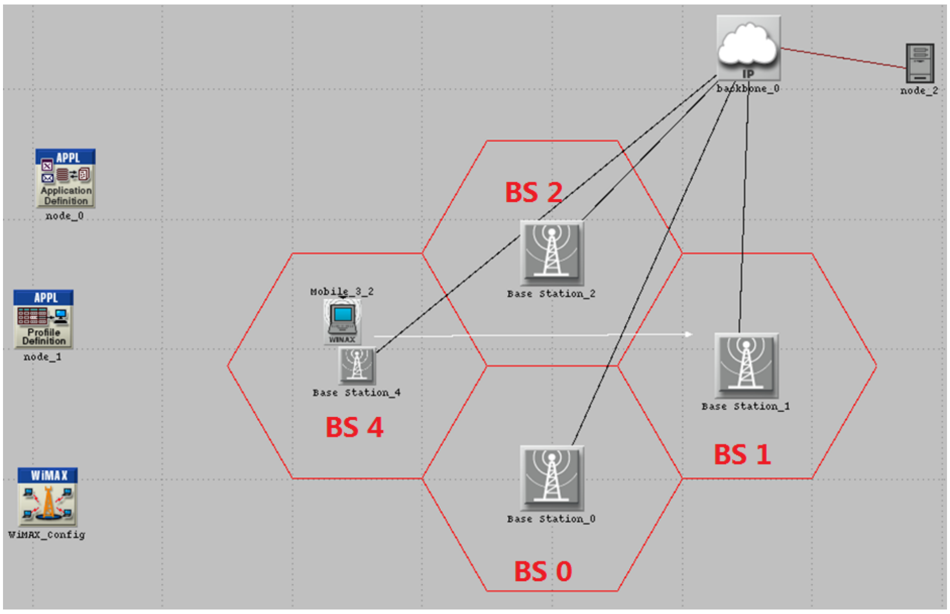
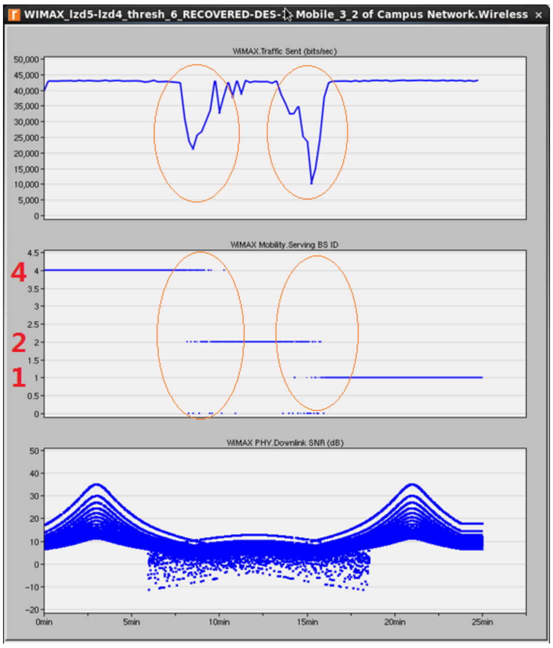
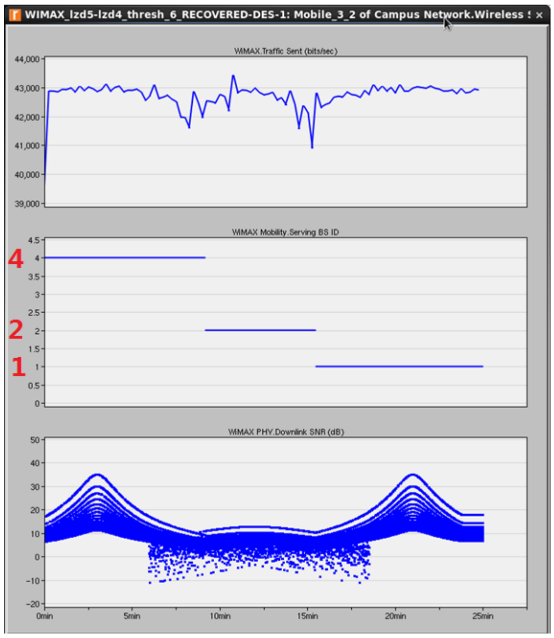


Figure 5.5: Riverbed Modeler network model: WiMAX Scenario 2.



(a) Handover threshold hysteresis $H_1 = 0.4$ dB.



(b) Handover threshold hysteresis $H_1 = 6.0$ dB.

Figure 5.6: Traffic Sent (top), serving BS ID (middle), and downlink SNR (bottom) for WiMAX Scenario 2.

fixed MSs and it does not have enough resources for the coming Mobile_3_2. However, the free capacity handover scheme has not been taken into account in our case. The moving MS will still perform handover to Base Staion_2. We can observe that traffic data sent by MS are almost lost when the MS moves into the covered region of Base Station_2 as shown in Fig. 5.8 (b). The results imply that the Riverbed Modeler cannot perform BS-initiated handover. Note that we selected Handover threshold hysteresis $H_1 = 6.0$ dB in this case.

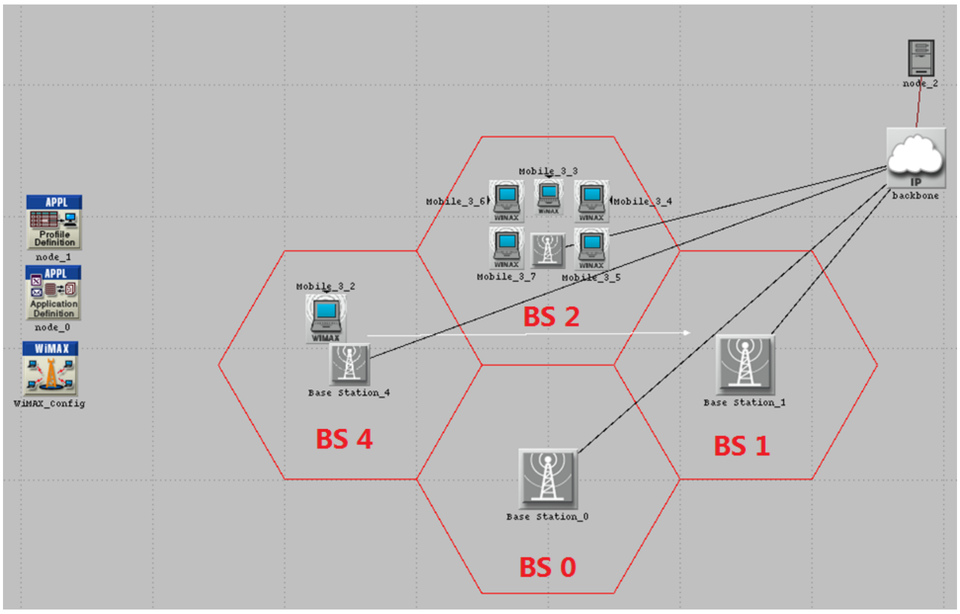
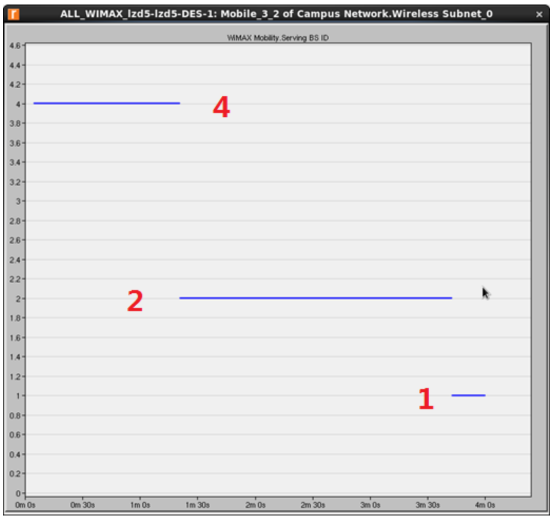
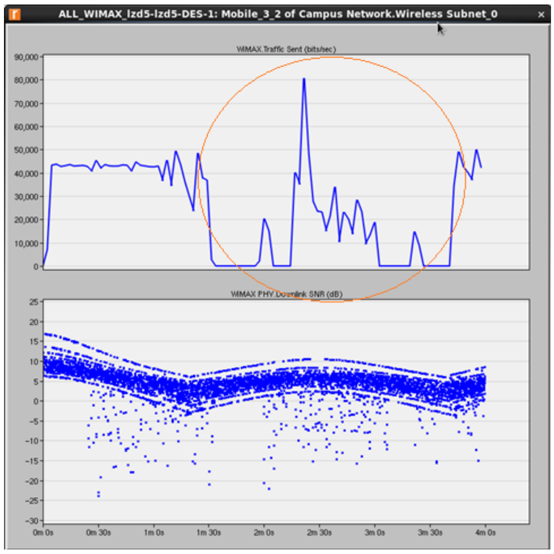


Figure 5.7: Riverbed Modeler network model: WiMAX Scenario 3.

5.2.2 LTE

We implemented the same network topologies successfully as WiMAX in LTE using Riverbed Modeler 18.5. The MS moves from the covered area from one eNodeB to another. Therefore, handover would be realized when the MS arrives at the boundary of the coverage of the two eNodeBs. The process of MS performing handover is shown in Figs.5.9(b), 5.10(b), and 5.11(b).

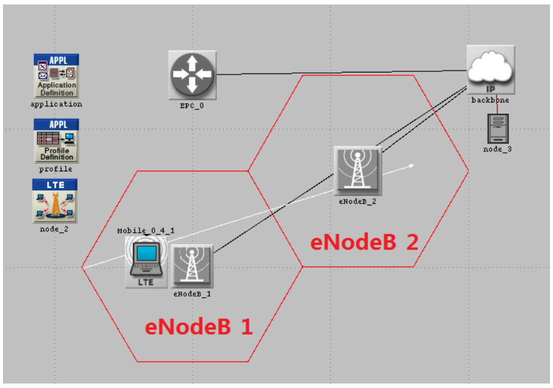


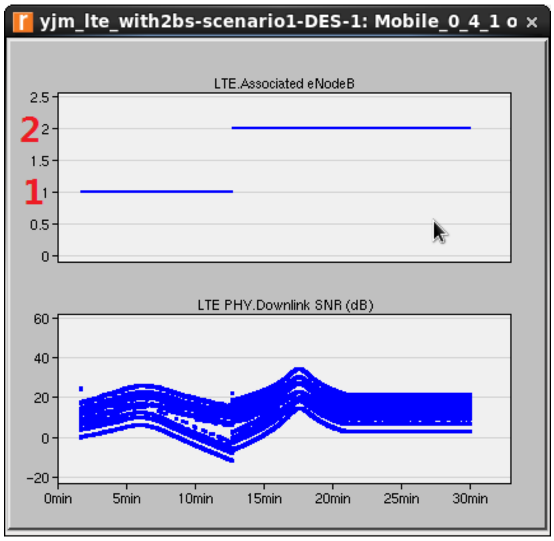


(a) Serving BS ID.

(b) Traffic Sent (top) and downlink SNR (bottom).

Figure 5.8: Simulation results for WiMAX Scenario 3.

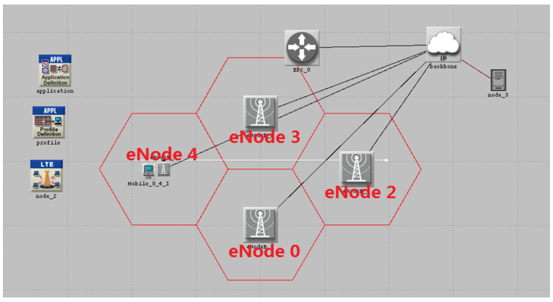




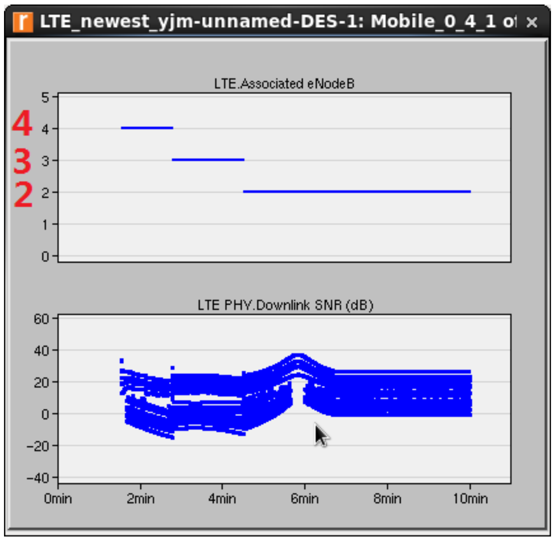
(a) Riverbed Modeler network model: LTE Scenario 1.

(b) Serving eNodeB (top) and downlink SNR (bottom).

Figure 5.9: Simulation results for LTE Scenario 1.

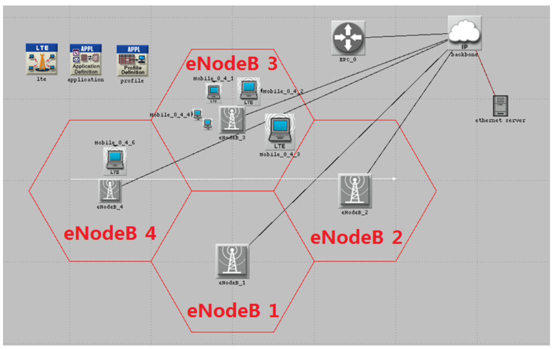


(a) Riverbed Modeler network model: LTE Scenario 2.

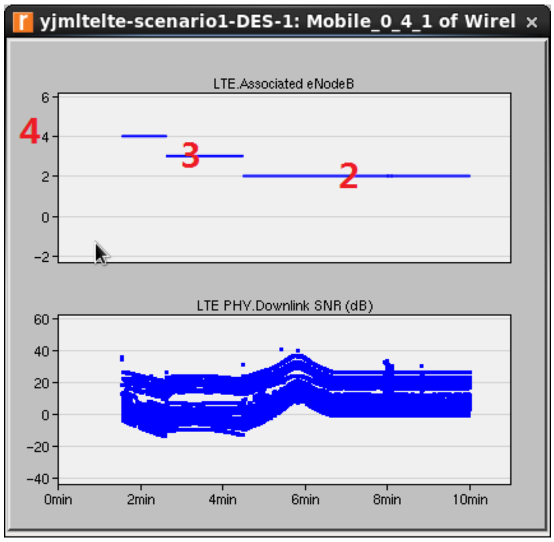


(b) Serving eNodeB (top) and downlink SNR (bottom).

Figure 5.10: Simulation results for LTE Scenario 2.



(a) Riverbed Modeler network model: LTE Scenario 3.



(b) Serving eNodeB (top) and downlink SNR (bottom).

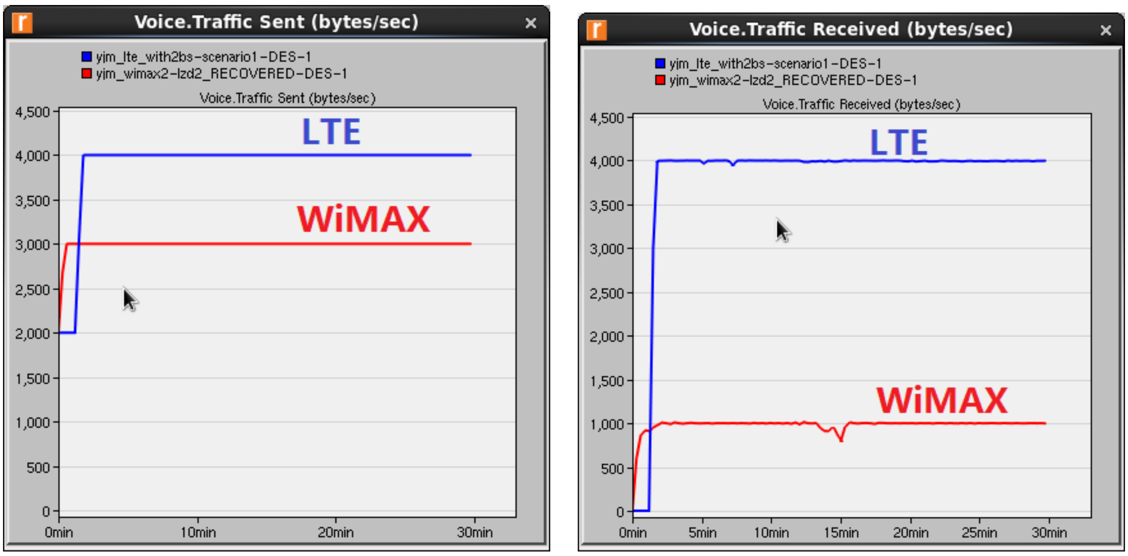
Figure 5.11: Simulation results for LTE Scenario 3.

5.2.3 Performance Comparison between WiMAX and LTE

Application and profile configurations, trajectory, traffic type, segment size (64000 bits/segment), and speed (10 m/s) are identical in WiAMX and LTE simulations. Both WiMAX and LTE utilized the same network topologies. Figs. 5.12, 5.13, and 5.14 show voice traffic sent, voice traffic received, and throughput for Scenario 1 and 2. The results indicate that LTE outperforms WiMAX in the presence of voice traffic sent, received, and throughput, as shown in Table 5.2.3.

		Scenario 1	Scenario 2
Voice traffic sent (bytes/sec)	WiMAX	3000	3000
	LTE	4000	4000
Voice traffic received (bytes/sec)	WiMAX	1000	1000
	LTE	4000	4000
Throughput (bits/sec)	WiMAX	40000	40000
	LTE	75000	68000

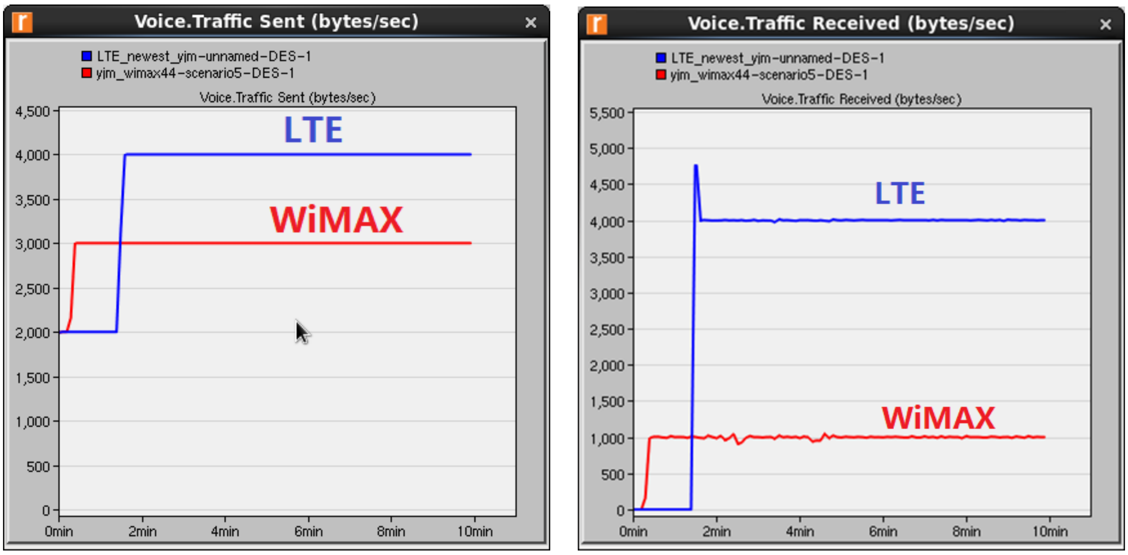
Table 5.3: Results of WiMAX and LTE for Scenario 1 and Scenario 2.



(a) Voice traffic sent.

(b) Voice traffic received.

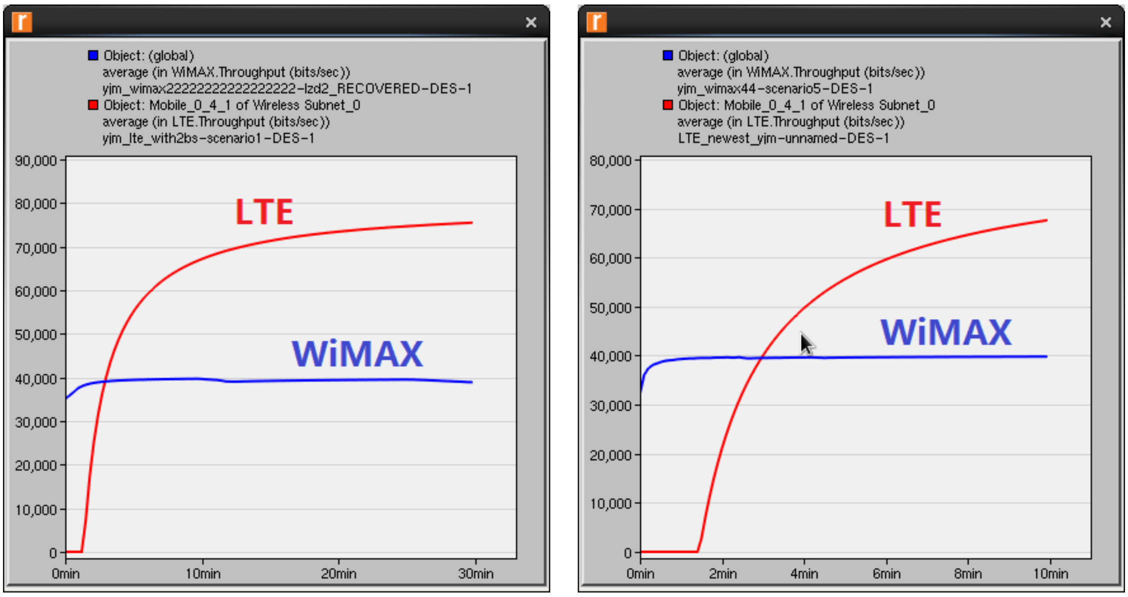
Figure 5.12: Comparison of traffic transmission rate between WiMAX and LTE for Scenario 1.



(a) Voice traffic sent.

(b) Voice traffic received.

Figure 5.13: Comparison of traffic transmission rate between WiMAX and LTE for Scenario 2.



(a) Comparison of throughput between WiMAX and LTE for Scenario 1.

(b) Comparison of throughput between WiMAX and LTE for Scenario 2.

Figure 5.14: Comparison of throughput between WiMAX and LTE for Scenario 1 and 2.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In this project, we have exploited knowledge of MS-initiated handover by analyzing SNR using three WiMAX network topologies. To be more specific, in Chapter 2 of this report, we briefly described the WiMAX and LTE technologies. Furthermore, their specifications are compared by considering standard, access technology, frequency band, peak data rate, cell radius, and mobility. Chapter 3 documented the major goals and challenges in our project. We explained handover procedure according to a flow chart of MS-initiated handover execution process in Chapter 4. A handover triggering mechanism was introduced based on a significant handover criteria – SNR, which was formulated as $SNR_{maxDT} - SNR_{DS} \geq H_1$. In Chapter 5, we firstly improved the accuracy of handover decisions by selecting an appropriate value of handover threshold hysteresis. After that, we simulate both WiMAX and LTE under same conditions for two different scenarios.

All in all, in this project, we have exploited knowledge of MS-initiated handover by analyzing SNR using three WiMAX network topologies. Choosing larger handover threshold hysteresis parameter H_1 achieves better performance in the presence of traffic loss and the number of handovers. However, large H_1 value may degrade the connection quality in WiMAX network. We have also demonstrated that LTE outperforms WiMAX by considering three significant types of collecting data including voice traffic sent, voice traffic received, and throughput.

6.2 Future Work

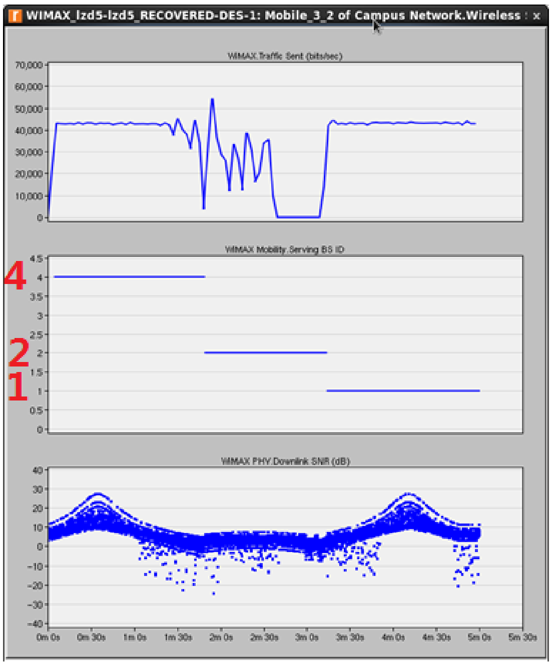
In this project, we succeed with implementation of WiMAX and LTE using identical network topologies and similar parameters. Additionally, we achieved one part of the DTHO algorithm. We recommend further works to address the following remained aspects:

1. The second part of DTHO algorithm in WiMAX, which is the BS initiated handover. The triggering condition for BS initiated handover is defined as:

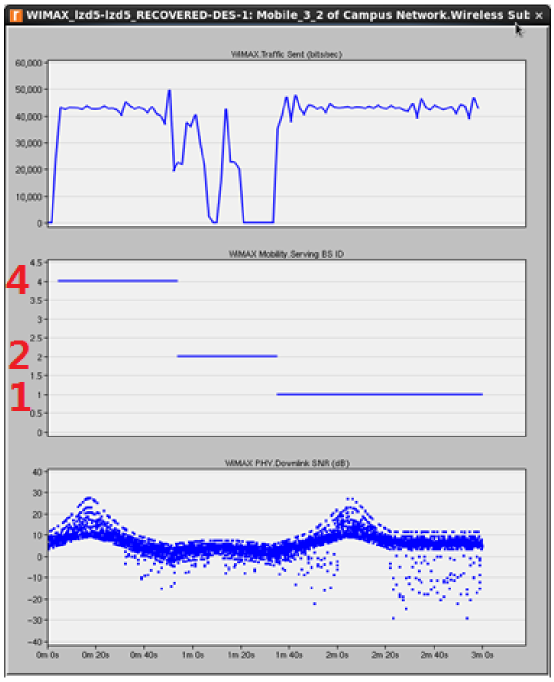
$$C_{EF} \geq H_2 \times C_{max} \tag{6.1}$$

   where C_{EF} denotes the estimated free capacity of the serving and C_{max} represents the estimated maximum capacity of the serving BS. The free capacity of the candidate BS should not be less than H_2.

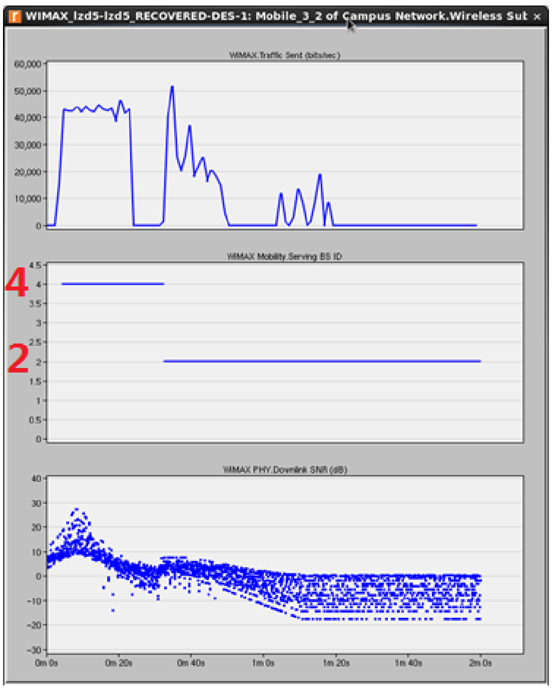
2. We can compare the difference of mobility between WiMAX and LTE by considering different speeds of MS. We take WiMAX Scenario 3 as shown in Fig. 5.7 for mobility implementation. Fig. 6.1 shows the mobility performance of WiMAX. We find that the MS does not perform handover as it moves from the coverage region of Base Station_2 to Base Station_1. All the traffic sent data are lost when MS enters into the signal coverage region of Base Station_1. Utilizing higher speed of MS might achieve better performance in LTE scenario.



(a) MS moving speed = 50 km/h.



(b) MS moving speed = 100 km/h.



(c) MS moving speed = 200 km/h.

Figure 6.1: Traffic Sent (top), serving BS ID (middle), and downlink SNR (bottom) for WiMAX Scenario 3 with different speeds.

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