ENSC 895-g200: COMMUNICATION NETWORKS

Project Title: OPNET Simulation of IEEE 802.11(WiFi) and IEEE 802.16(WiMAX) in a small area

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FINAL PROJECT

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ABSTRACT

In the past few years the Wireless Local Area Network (WLAN) has been the most popular choice of communication amongst users. WLAN, which is based on the IEEE 802.11 standard, also known as Wireless Fidelity (WiFi), offers mobility and flexibility with a relatively low cost to users. In addition, wireless technology is providing easier internet access to areas that are too difficult and expensive to reach with traditional wired infrastructure. IEEE 802.16, also known as Worldwide Interoperability for Microwave Access (WiMAX), is another standard with similar general principles as WiFi with the main advantages being it covers a larger area and has a higher data rate. Comparing WiFi and WiMAX under optimal conditions, the fastest WiFi connection is 54 megabits/second (Mbit/s) while WiMAX is about 75 Mbit/s. WiFi has a range of about 30 meters and WiMAX can cover up to 50 kilometers. Figure 1 shows a comparison of WiMAX coverage versus WiFi coverage.

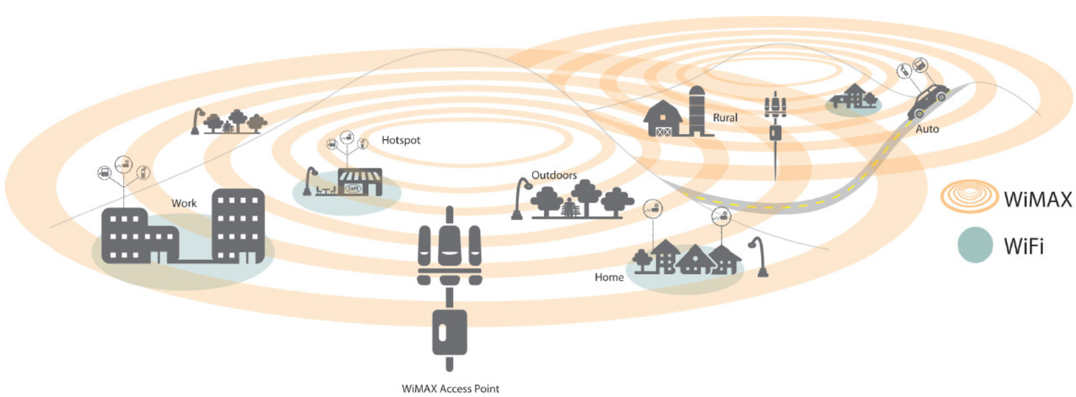

Figure 1: Coverage of WiMAX versus coverage of WiFi [4]

Although WiMAX greatly outperforms WiFi, user devices such as desktops, laptops and cell phones need to have WiMAX capability to be able to connect to WiMAX sources. Currently, not many user devices have WiMAX capability, the majority has WiFi capability. The best way to enjoy the advantage of the WiMAX system is to combine the WiMAX and WiFi systems together. With the use of

WiMAX enabled WiFi routers in WLANs, WiMAX can be used in offices and homes that are currently WiFi enabled. In this project the performance of using WiMAX (802.16e) and WiFi (802.11g) in small offices is evaluated.

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3G	3rd Generation Networks
BER	Bit Error Rate
Bps	bits per second
Bps	Bytes per second
BS	Base Station
CCK	Complementary Code Keying
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
DSL	Digital Subscriber Line
DSSS	Direct Sequence Spread Spectrum
GPS	Global Positioning System
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union- Radio communication
LAN	Local Area Network
LTE	Long Term Evolution
MAC	Media Access Control
MAN	Metropolitan Area Network
Mbit/s	megabits/second
MPEG	Motion Picture Experts Group
MS	Mobile Station
ms	millisecond
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
QoS	Quality of Service
RF	Radio Frequency
RTP	Real Time Protocol
UDP	User Datagram Protocol
SOFDMA	Scalable Orthogonal Frequency Division Multiple Access
SS	WiMAX Subscriber station
WiFi	Wireless Fidelity

WiMAX	Worldwide Interoperability for Microwave Access
WWAN	Wireless Wide Area Network

1. INTRODUCTION

IEEE802.11, Wireless Local Area Network (WLAN), was introduced in the early 1990s. The purpose was to provide best-effort packet access network without using wires. WLAN uses an unlicensed band, therefore any user can buy a WLAN product and use it without the need for gaining permission. This fact has allowed WLAN to quickly expand into the consumer market and be embedded in many portable devices. In late 1990s, several companies formed Wireless Fidelity (WiFi) Alliance to create a single standard for high-speed WLAN which would be accepted worldwide. This standard relies on IEEE 802.11. WiFi distributes high-speed Internet access from cables within wireless hotspots which has radically increased convenience and productivity for users. Today, millions of homes, offices, hotels, restaurants, airports and other public locations have WiFi high-speed WLAN connectivity. WiFi usage popularity has increased by more than 4 times from year the 2004 to 2009 in every market around the world. [6] Table 1 summarizes the number of Wi-Fi Users by Region in different years.

Table 1: Wi-Fi Users by Region (in thousands) [6]

	2004	2005	2006	2009
Asia Pacific	32,937	55,341	81,048	168,193
Western Europe	16,681	24,877	33,546	63,746
Central and Eastern Europe	2,109	3,172	4,383	9,875
Latin America	2,386	3,401	4,528	8,331
Africa/Middle East	287	684	1,096	2,747
North America	20,570	30,235	40,454	74,174
Total	74,969	117,690	165,056	327,066

IEEE 802.16, Worldwide Interoperability for Microwave Access (WiMAX), is a standard for providing wireless broadband access to large areas. WiMAX technology basically enables broadband Wireless data transmission for fixed and mobile terminals without the need of connecting to a cable network or Wi-Fi hotspot. WiMAX is "a standards-based technology enabling the delivery of last

mile wireless broadband access as an alternative to cable and DSL"[8]. WiMAX provides competitive broadband service to wired ADSL and cable and it can be easily and cost effectively deployed. IEEE 802.16e, mobile WiMAX, is based on orthogonal frequency division multiple access (OFDMA) technology and can support fixed and mobile users simultaneously. In March 2008, WiMAX forum has projected there will be approximately 133 million WiMAX subscribers by the year 2012 [2].

WiFi and WiMAX are both IEEE wireless standards that are designed for Internet Protocol (IP) based applications. WiMAX and WiFi have been designed for different purposes. WiFi is optimized for a very high speed WLAN while WiMAX is optimized for a high speed Wireless Wide Area Network (WWAN). By combining these two standards service providers can offer a more complete high speed broadband service to more users in different geographical areas. Currently only few users have WiMAX-enabled devices. They will either need to buy a compatible device or upgrade their current electronic device (i.e. desktop or laptop) to enjoy WiMAX capability. Users could also purchase a WiMAX-WiFi router and then send data to their computers via WiFi. Figure 2 shows the current IEEE 802.16e WiMAX deployment across all counties.

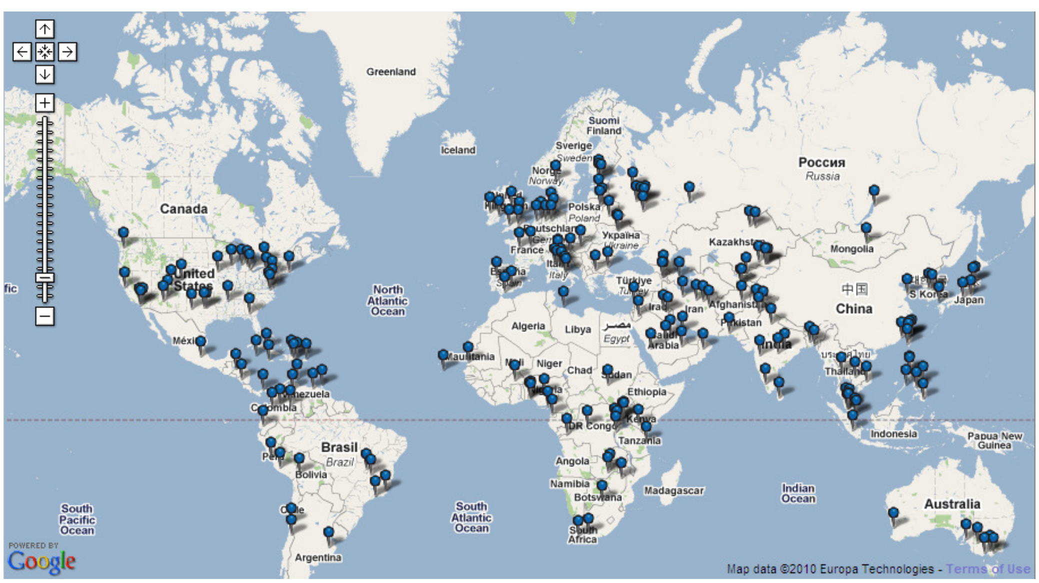


Figure 2: IEEE 802.16e WiMAX deployment [10]

2. WiFi (IEEE 802.11g) BACKGROUND

IEEE 802.11g standard for WLAN, also known as WiFi, operates in the 2.4 GHz unlicensed band with the maximum data rate of 54 Mbit/s. WiFi uses orthogonal frequency division multiplexing (OFDM) modulation scheme for data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s. For data rates of 5.5 and 11 Mbit/s, it uses complementary code keying (CCK), and for data rates of 1 and 2 Mbit/s it uses direct-sequence spread spectrum (DSSS) modulation scheme.

- OFDM is a frequency division multiplexing scheme with the orthogonal subcarriers modulation method. These subcarriers are spaced close to each other to carry the data that is divided into parallel data channels. The reason for choosing the subcarriers orthogonal to each other is to eliminate cross talk between them.
- CCK "are sets of finite sequences of equal length, such that the number of pairs of identical elements with any given separation in one sequence is equal to the number of pairs of unlike elements having the same separation in the other sequences."[11]
- DSSS is a modulation scheme that spreads the carrier signal over the full transmit spectrum. The transmit data is multiplied by a very high frequency noise signal, which is made of a sequence of pseudorandom ones and negative ones. The same high frequency noise is used on the receiver side to demodulate the transmit signal.

WiFi has two types of components, one is a wireless client station and the other one is an access point (AP). Wireless client station is any user device, such as computer and laptop, which has wireless network card. AP acts as a bridge between fixed and wireless network. It organizes and grants access from multiple wireless stations to the fixed network.

3. WiMAX (802.16e) BACKGROUND

WiMAX is a broadband wireless access that supports both fixed and mobile internet access. It is based on IEEE 802.16 and has maximum data rate of 75Mbits/sec under optimal conditions. WiMAX range covers up to several kilometers. As a result it can be used for providing wireless broadband across to cities and countries. It can be used as an alternative last mile solution to cable and DSL. WiMAX uses scalable orthogonal frequency-division multiple access (SOFDMA) with 256 sub-carriers. It also supports multiple antennas for better coverage and better power consumption. Medium access control (MAC) layer of WiMAX uses a scheduling algorithm for the initial entry of the subscriber stations (SS) into the network. Then the base station (BS) allocates an access slot to SS and other subscribers cannot use that slot. The scheduling algorithm is also used for controlling the bandwidth efficiency and quality of service (QoS) parameters by changing the time slot duration based on the SS's application needs. WiMAX uses 2.3 GHz, 2.5 GHz and 3.5 GHz licensed bands. Since 2007 WiMAX technology is included in the IMT-2000 set of standards. IMT-2000 standards are defined by the radio communication sector of the International Telecommunication Union (ITU-R). As a result any country that recognizes IMT-2000 standards is able to use to use WiMAX equipments.

4. COMPARISON OF WiFi AND WiMAX

WiMAX uses licensed spectrum and has coverage of many kilometers. WiFi is designed for local area network coverage in the range of tens of meters and uses unlicensed band. WiMAX has connection oriented MAC layer while WiFi is connectionless and uses carrier sense multiple access with collision avoidance (CSMA/CA) protocol. WiMAX uses scheduling algorithms to control the QoS, but in WiFi all the users have to compete to get service from an access point (AP) which is done based on a random interrupt basis. WiFi is more recognized and used in the consumer devices. Table 2 summarizes the implementation and deployment of WiMAX and WiFi.

Table 2: WiFi and WiMAX Comparison [4]

WiFi (IEEE 802.11 a/g/n)	WiMAX (IEEE 802.16e-2005)	Synergy Impact
Market		
Deployed in local coverage areas, such as public hotspots, homes, and businesses.	Deployed in wide coverage areas, including metropolitan areas for mobile broadband wireless as well as rural or remote areas for last-mile connectivity and portable service.	"Best-connected" model: users connect to WiMAX or WiFi depending on their location, coverage, and Quality of Service (QoS) requirements.
Products certified by the WiFi Alliance.	Products certified by the WiMAX Forum.	Interoperable clients and access points enable global roaming and multi-vendor competition.
Embedded in 97% of laptops and many handheld and CE devices.	Customer Premise Equipment (CPE) and PC cards available today; embedded in laptops and handheld devices starting in 2008.	Integration into devices is expected to reduce device subsidies and lower Cost Per Gross Add (CPGA). [6]
Characteristics		
Provides fixed and portable solutions.	Provides fixed and portable solutions.	Full range of services in the home and office, as well as on the road.
Operates in license-exempt spectrum. Current solutions use the 2.4 and 5 GHz bands.	Operates in licensed spectrum. Current solutions use the 2.3, 2.5, and 3.5 GHz bands.	Service providers can leverage both types of spectrum; for example, license exempt for best effort local area traffic and licensed for wide area and QoS sensitive traffic.
Short range with up to 100 meters for a single access point.	Metropolitan area mobile coverage of up to several kilometers for a single base station. Longer range (up to several miles) for fixed & lower-density deployments.	Economical coverage of large areas; for example, WiFi hotspots in cafés, hotels, and airports, and WiMAX for blanket coverage outside of hotspots.
OFDM air interface, as defined in IEEE 802.11a/g/n.	Scalable OFDMA air interface, as defined in IEEE 802.16e-2005.	Similar technologies mean cost savings at both the silicon and device levels.
Devices connect via a WiFi access point to the operator's IP network and to the Internet.	Devices connect via a base station to the operator's IP network and to the Internet.	Common IP network components, such as authentication servers, service platforms, and access gateways, can be used.
Implementing Multiple Input/Multiple Output (MIMO) in IEEE 802.11n to achieve higher data rates.	Certified WiMAX Release 1, Wave 2 clients support both MIMO and beamforming. [7]	The opportunity for devices to share antenna components, thus reducing the cost of integrated devices.
Options		
Evolution to mesh networks in metropolitan areas.	Evolution to multi-hop relay to improve range and data rates.	The options for providing extended coverage and services economically are further expanded.
Access points that include WiFi for access and WiMAX for network connectivity.	Leverages digital advances so that the entire base station can now be mounted on tower tops.	Deployment expense is expected to continue downward on a steady cost-reduction curve.
Voice over Internet Protocol (VoIP) is supported with enhancements IEEE 802.11e, k, and r. [8]	VoIP is supported by the extended real-time polling class of service.	Both specifications support VoIP; however, operations in license-exempt spectrum limit QoS assurance.
IEEE 802.11n high throughput will support digital home applications, such as Video over IP.	WiMAX provides high data rates and QoS classes to support broadcast and multi-cast video.	Both specifications support VoIP; however, operations in license-exempt spectrum limit QoS assurance.

5. SIMULATION

4.1) Simulation tool

OPNET is a research oriented network simulation tool. It is a very powerful software tool that simulates the real world behaviour of wired and wireless networks. OPNET Modeler version 14.0 was used in this project for simulating WLAN (WiFi) and WiMAX links.

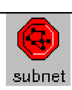
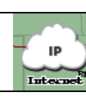
“The OPNET wireless module and the WLAN model provide high-fidelity modeling, simulation, and analysis of wireless networks, including the RF environment, interference, transmitter/receiver characteristics, full protocol stack, including MAC, routing, higher layer protocols and applications. Furthermore, the ability to incorporate node mobility and interconnection with wire-line transport networks provide a rich and realistic modeling environment.”[12]

“The OPNET WiMAX Specialized Model is available for OPNET Modeler® Wireless Suite and OPNET Modeler® Wireless Suite for Defense. It supports the IEEE 802.16-2004 and IEEE 802.16e-2005 standards. It was developed by OPNET with guidance from prominent industry leaders such as Motorola, Samsung, Alcatel-Lucent, and France Telecom.”[9]

4.2) Models used

OPNET models that are used in this project are listed in Table 3.

Table 3: OPNET models used

Subnet	Application	Profile	WiMAX Config	WiMAX Base Station	WiMAX-WLAN Router	WLAN Mobile Station	IP Cloud	Server	Router
									
Fixed Subnet	Application Config	Profile Config	WiMAX Config	wimax_bs_ethernet4_slip4_router	wimax_ss_wlan_router	wlan_wkstn	ip32_cloud	ethernet_server	CS_7204_4s_a1_e8_f1_sl8

4.3) Simulation Setup

In this project, I used OPNET Modeler 14.0 to simulate MPEG4 Video traffic over WiMAX-WiFi link. There is a subnet in Vancouver, BC that has a server, for streaming MPEG4 video, connected to the Internet cloud. There is another subnet in Ottawa, ON, which receives the MPEG4 video data and distributes the video content from a WiMAX Base Station to various subscriber station (SS) subnets around it. The SS subnets are all WiFi enabled and receive the WiMAX data through their WiMAX-WiFi routers and distribute the video content over WiFi link to different computers. The general simulation setup is shown in Figure3.

The MPEG4 video that is used in this project is Matrix III movie. This movie trace is taken from Will Hrudey's project [2] and he originally obtained this video trace from Arizona State University. For this simulation, video application is chosen in order to overload the Wireless link.

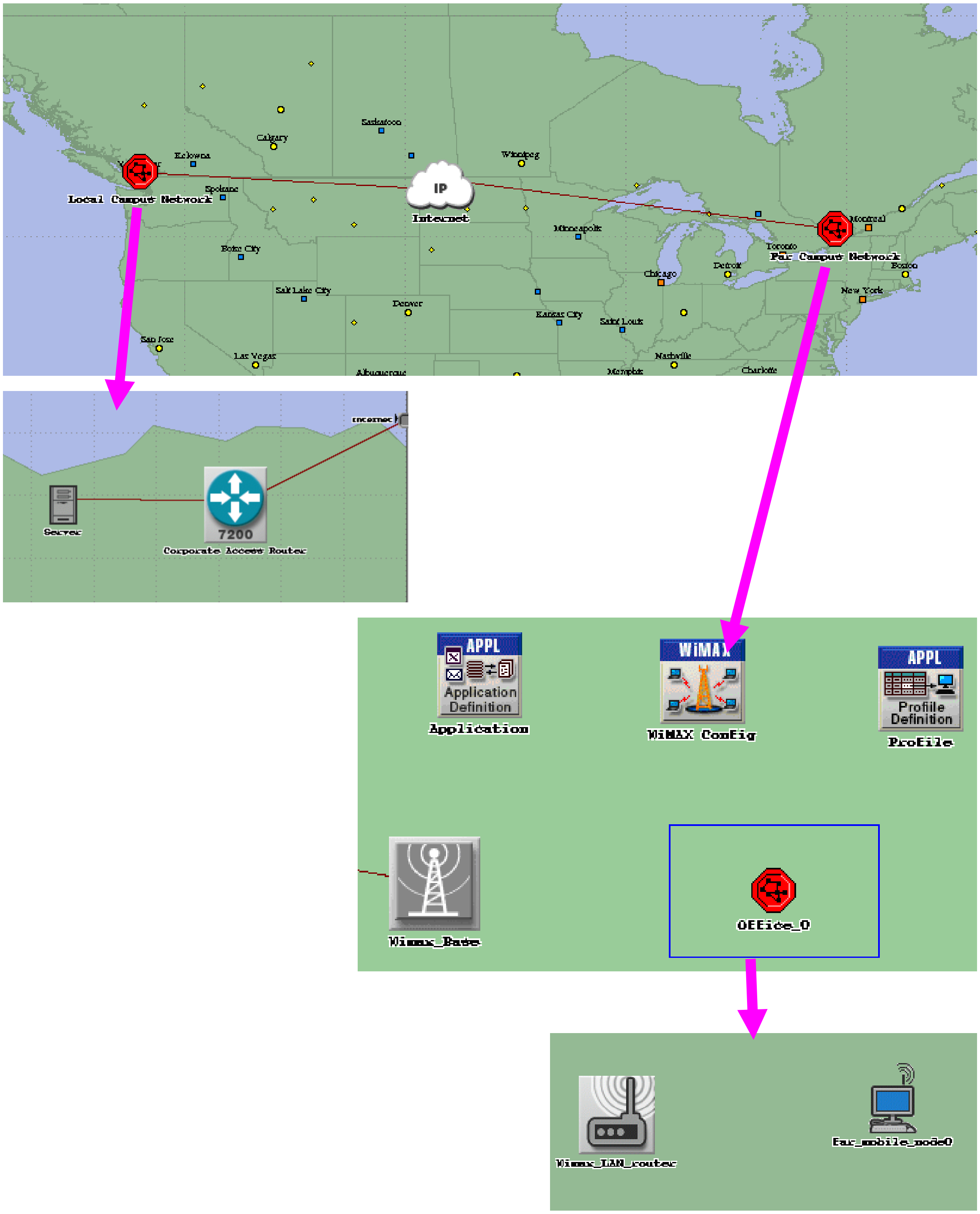


Figure 3: Overview of the simulation setup

4.4) General Description of Scenarios

There are 3 scenarios in this project. In the first scenario the effect of the vehicular and pedestrian multipath model effects in WiMAX link are examined. In the second scenario the maximum simulation range of the WiMAX link and WiFi link, under optimal conditions are measured. This test is done with maximum transmit power and "Free Space" path loss model just to compare the simulation range difference of WiFi and WiMAX. In the third scenario, the performance of having 2 to 8 WiFi users connected to a single Access Point (AP) is analyzed.

For all these simulations only up to the first 30 minutes of Matrix III is streamed from the server. For the first and the second scenarios the 30 minutes simulation time took about 35 minutes of real time. In the third scenario, with 8 WiFi users, the 30 minutes of simulation time took about 3.5 hours of real time.

4.5) Parameter Setup

Table 4 summarizes the parameters that are chosen for the WiFi link. Table 5 summarizes the parameters that are chosen for the WiMAX link.

Table 4: WiFi parameters

WiFi 802.11g		
	AP (Access Point)	**Mobile Node**
Tx Power	0.1W	0.1W
Data Rate	11Mbps	11Mbps
Receiver Power Threshold	-95dBm	-95dBm
Buffer Size	1024000 bits	256000 bits
Short Retry Limit	7	7
Long Retry Limit	4	9
Large Packet Processing	Fragment	Fragment
Access Point Functionality	Enabled	Disabled

Table 5: WiMAX parameters

WiMAX		
	BS (Base Station)	**SS (Subscriber Station)**
Tx Power	20W	0.5W
Antenna Gain	15dBi	15dBi
Path Loss	Free Space	Free Space
Bandwidth	20MHz	20MHz

4.6) Scenarios

Scenario 1: WiMAX - Multipath Channel Model

During the propagation of an RF signal from the source to the destination, the RF signal takes different paths. The RF signal may bounces to different directions when different objects, such as walls, people, vehicles and buildings, get in the way of the signal or it may go directly to its destination. This fact causes the signal to have different delays as some portion of the signal may travel longer paths to get to the destination.

OPNET has different multipath channel models defined for WiMAX link. They are defined based on International Telecommunication Union (ITU) multipath models. For this scenario ITU Pedestrian A and ITU Vehicular B multipath channel models are compared. ITU Vehicular model has more multipath than ITU Pedestrian. The multipath channel model is defined on the subscriber station (SS) and it applies to both the uplink and the downlink transmission between the BS and SS. Pedestrian and Vehicular multipath channels are explained in Table 6. For each test environment, Table 6 shows the average delay of channel A and B. It also shows the probability of that channel encountering the delay in percentage.

Table 6: Multipath channel models [13]

Test environment	Channel A		Channel B	
	r.m.s. (ns)	*P* (%)	r.m.s. (ns)	*P* (%)
Pedestrian	45	40	750	55
Vehicular	370	40	4 000	55

For this comparison two WiMAX subscriber stations (SS) are created to have the exact parameter settings except for the multipath channel models. The SS that has ITU Pedestrian A Multipath Channel Model is located 1 Km east of the Base station. And the SS that has ITU Vehicular B Multipath Channel Model is located 1 Km south of the Base Station. The simulation setup for this scenario is shown in figure 4.

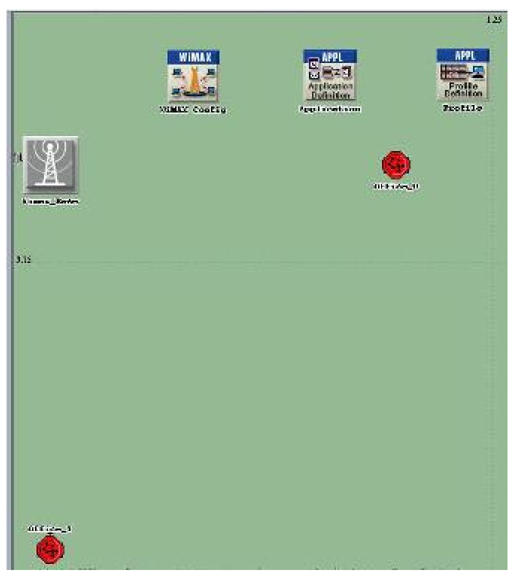


Figure 4: Simulation setup for comparing two WiMAX multipath channel models.

The delay and the throughput of the two WiMAX subscriber stations are compared.

In the subsequent scenarios ITU Pedestrian A Multipath Channel Model is used.

Scenario 2: WiMAX and WiFi range

The purpose of this scenario is to find the maximum simulation range of WiMAX and WiFi link with the chosen parameters shown in table 4 and 5.

In order to find the maximum range of the WiMAX link the SS is moved away from the BS up to the point that the video traffic is not received on the SS. As the path loss model is “Free Space” the results are expected to be much better than in the real life cases. Due to the fact that the SS node is a fixed node, the simulation has been run several times for different distances from 1 Km to 75Km between BS and SS. Figure 5 shows the simulation setup for finding the maximum WiMAX link distance.

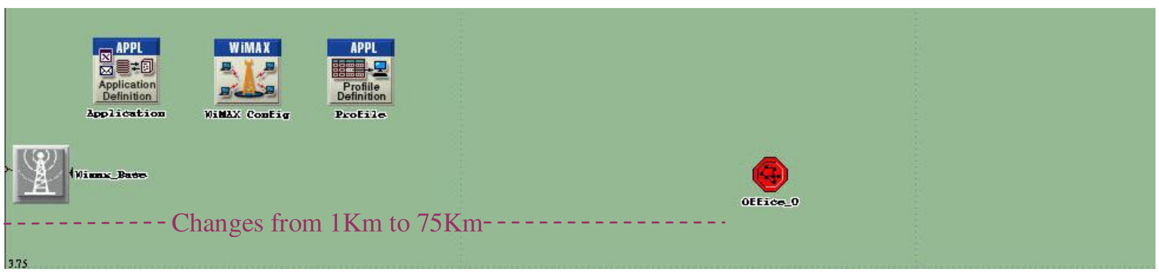


Figure 5: Simulation setup for finding the maximum WiMAX link.

Similar study is done on WiFi link to determine the maximum distance of a WLAN mobile node from the AP, i.e. router. As the WLAN node is a mobile node, by using the trajectory function of the OPNET, the maximum distance of WLAN link can be easily determined. Figure 6 shows a WLAN mobile node that is moving away from the AP by the trajectory that is defined from 0.3Km to 6Km away from the AP. The white line between the AP and the mobile node is the defined trajectory.

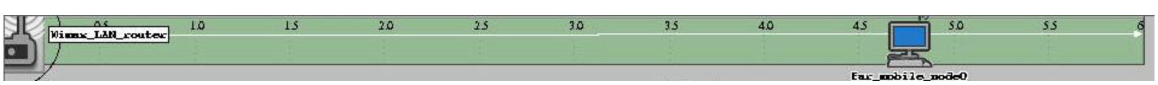


Figure 6: Simulation setup for finding the maximum WiFi link.

The received data on the mobile node is monitored while it is moving away from the AP.

Scenario 3: WiMAX & WiFi performance with 2, 4 and 8 WLAN mobile nodes

In this scenario the performance of an office with 2 mobiles nodes, 4 mobile nodes and 8 mobile nodes are compared. They are all sharing the same router and are placed at the same distance from the router. Figure 7, 8 and 9 show the WiFi setup with 2, 4 and 8 mobile users respectively.

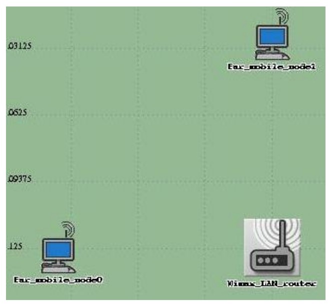


Figure 7: WiFi link with 2 mobile users and one AP

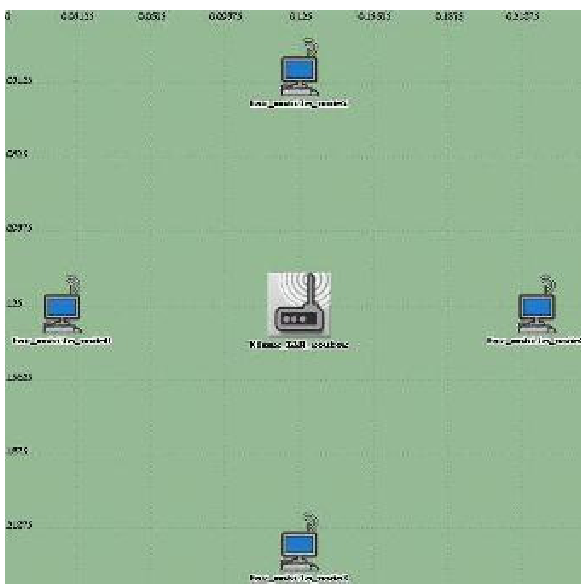


Figure 8: WiFi link with 4 mobile users and one AP

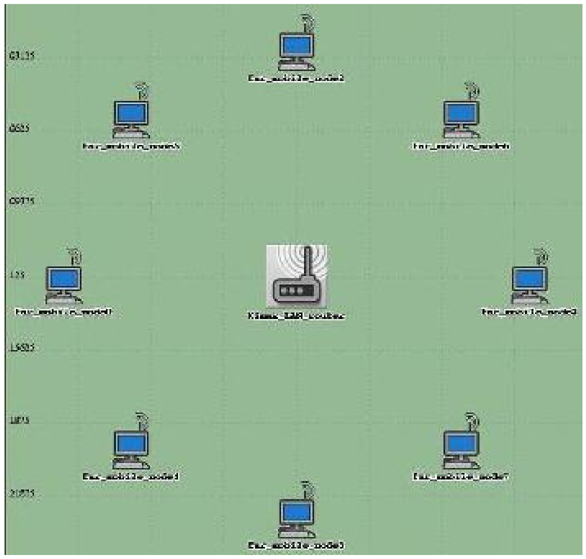


Figure 9: WiFi link with 8 mobile users and one AP

In this scenario, the traffic that is sent from the server, the delay, throughput and the packet delay variation of the WiFi link are measured.

6. SIMULATION RESULTS

Scenario 1: Multipath Channel Model for WiMAX

The WiMAX link delay of the two subscriber stations with different multipath channel models are shown in figure 10. The horizontal axes shows the time in minutes and the vertical axes shows the delay in seconds. The SS with the ITU Vehicular B multipath model has about 1ms more delay than the SS with ITU Pedestrian A multipath model.

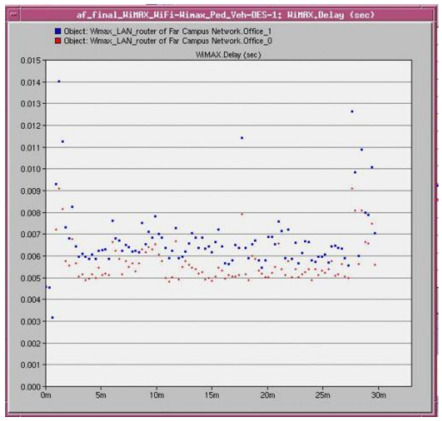


Figure 10: WiMAX delay of SS with different multipath models. Blue delay is for ITU Vehicular B model and red delay is for ITU Pedestrian A model.

Although the two offices are at the exact same distance from the BS and both receive the same data with the same transmit power, as expected, the delay is not the same between the two WiMAX links. Multipath effects cause different delay in the packets that are being sent over air.

The WiMAX throughput and the average WiMAX throughput of the two SS are shown in figure 11 and 12 respectively. The horizontal axes shows the time in minutes and the vertical axes shows the throughput in bits/sec.

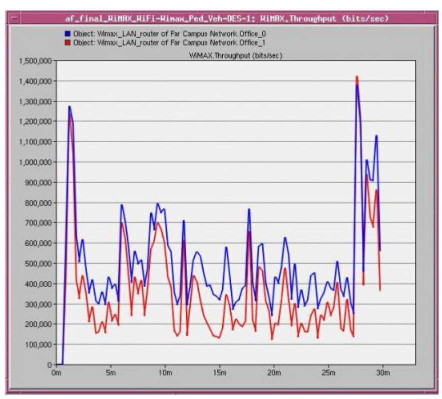


Figure 11: Throughput of SS with different multipath models. Red throughput is for ITU Vehicular B model and blue throughput is for ITU Pedestrian A model.

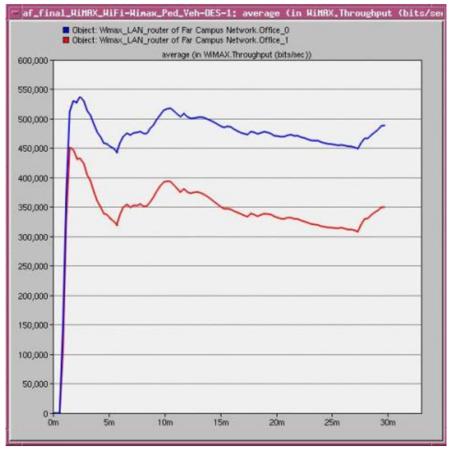


Figure 12: Average throughput of SS with different multipath models. Red line is for ITU Vehicular B model and blue line is for ITU Pedestrian A model.

The throughput is different as a result of multipath effects. On average the office with vehicular multipath has fewer throughputs than the one with pedestrian multipath.

Scenario 2: WiMAX and WiFi range

WiMAX rage is determined by increasing the distance from the BS and SS from 1 Km to 75 Km and monitoring the received traffic on the SS. The maximum distance from the SS to BS with 1Km resolution is found to be 73Km. Figure 13 shows the received data in bits/sec on the SS for 1Km, 30 Km, 73Km and 74Km from top to bottom.

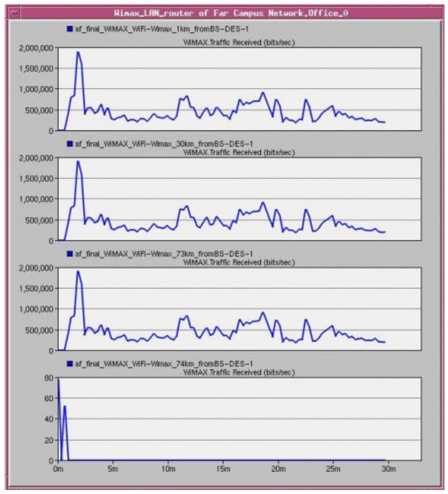


Figure 13: Received traffic on SS for distances of 1Km, 30Km, 73Km and 74Km.

As shown in Figure 13 the WiMAX SS does not receive any traffic data beyond 73Km as this is the maximum WiMAX coverage with the selected settings. Although the data is received up to 73Km distance from the BS, there is a slight increase in delay as the distance increases. The delay of 1Km, 30Km and 73Km distances are shown in figure 14. The delay between 1Km and 73Km is about 0.5ms.

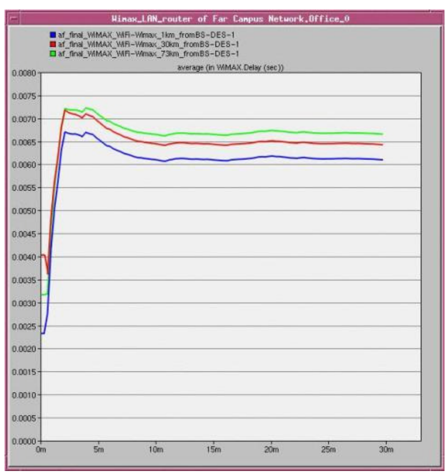


Figure 14: WiMAX delay on SS for distances of 1Km, 30Km and 73Km.

WiFi range is determined by moving the WLAN mobile node away from the AP and monitoring the received traffic data on the mobile node. The distance of the mobile node and AP is increased from 0.3Km to 6Km using a defined trajectory.

Figure 15 shows the received data on the WLAN mobile node while the mobile node is moving away from the AP on the defined trajectory. The displayed green vertical line on the received data graph shows the corresponding received data on the mobile node to the location of the mobile node at that moment. As the mobile node travels through the trajectory, the green line moves over the received data graph.

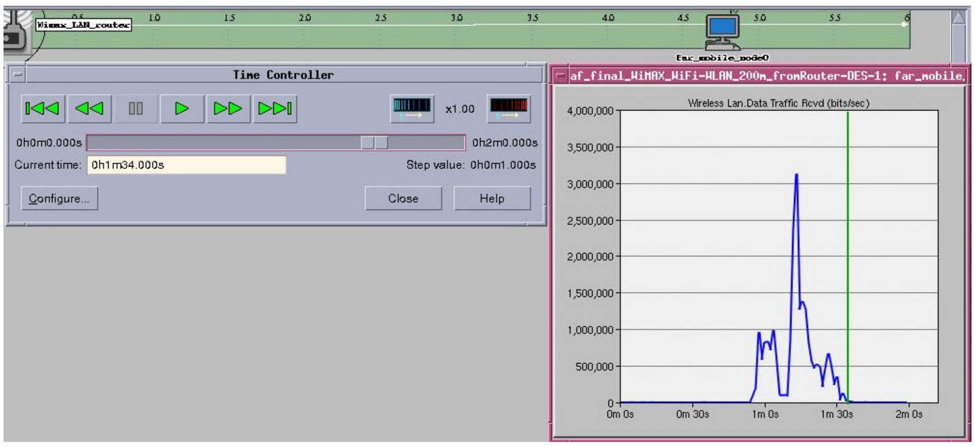


Figure 15: Received data on the WLAN mobile node while the mobile node is moving away from the AP.

Figure 16 shows the WiFi delay as the mobile node moves away from the AP. When the mobile node gets close to the range of the WiFi link the delay exponentially increases.

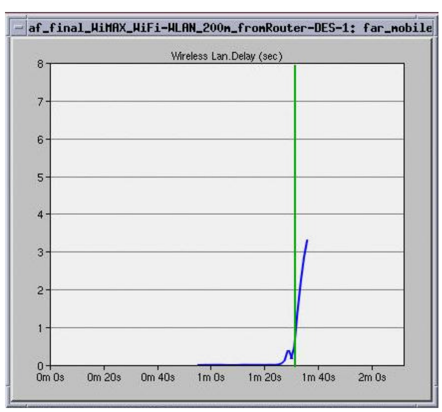


Figure 16: WiFi delay as the mobile node moves away from the AP.

The maximum simulation range for the WiFi link with the specified settings is 4.6Km.

Scenario 3: WiMAX & WiFi performance with 2, 4 and 8 WLAN mobile nodes

The WLAN subnet with 2, 4 and 8 mobile nodes has been setup to receive the MPEG4 movie from the server at the same time. The performances of these networks have been compared in this scenario.

First, the average traffic sent from the server is shown in figure 17.

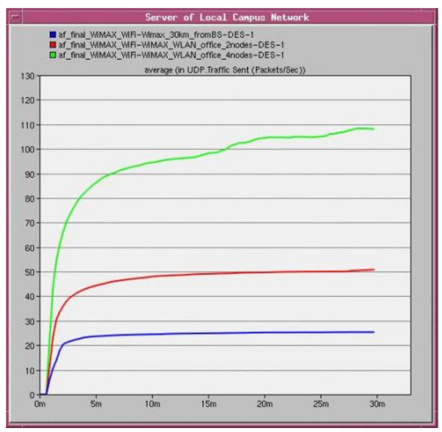


Figure 17: Average traffic sent from the server

As the number of WLAN users increase from 2 to 4 the average traffic sent from the server is doubled. Also as the number of WLAN users increase from 4 to 8, the average traffic sent from server is again doubled.

Figure 18 shows the WiFi data dropped due to buffer overflow in bits/sec.

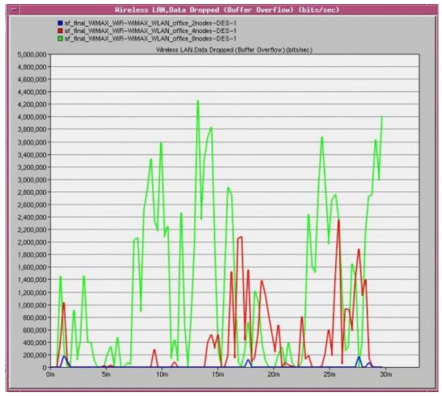


Figure 18: Data dropped in WiFi link due to buffer overflow in bits/sec for 2, 4 and 8 users.

As the number of users increases the number of data bits receiving at the WiFi router increases and the router buffer quickly overflows. The WiFi router buffer size is 1024000bits. The buffer size is barely large enough for two users.

The WLAN throughput is shown below in figure 19. Throughput increases proportional to the increase in the number of users.

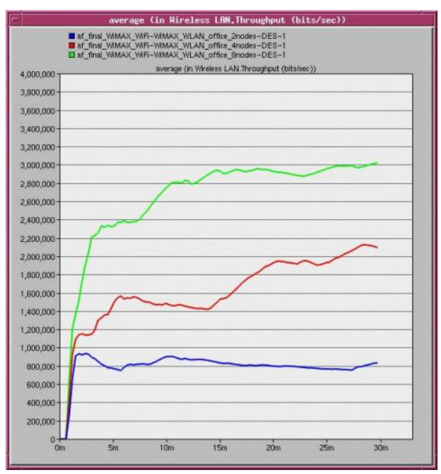


Figure 19: WiFi throughput in bits/sec for 2, 4 and 8 users.

Figure 20 shows the WiFi delay for 2, 4 and 8 mobile node users.

Figure 20: WiFi delay for 2, 4 and 8 mobile node users.

As the number of users increases, the WiFi delay increases. The delay is not proportional to the increase in the number of users. The reason for more delay for more users is due to the fact that the AP has to service more users in the limited time. So, users have to wait longer to get data from the AP.

For the video traffic to get to the WiFi user it has to pass through the WiMAX link. With the purpose of proving that the delay bottle neck is not the WiMAX link the global statistics delay of the WiMAX and WLAN with 8 WLAN users are compared in Figure 21.

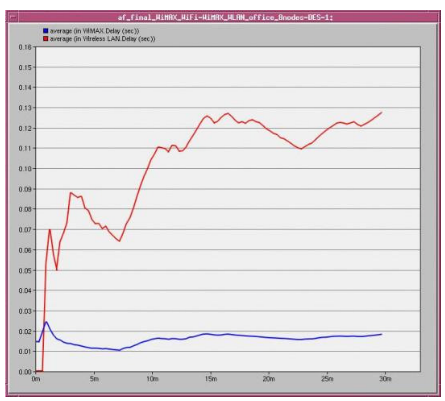


Figure 21: Global statistics delay of WiMAX and WiFi with 8 WiFi mobile users

As it can be seen in the above figure, the WiMAX delay is significantly lower than the WLAN link delay. The WiMAX delay is less about 20ms while the WiFi delay gets to about 125ms. Therefore, as expected the delay is not caused by the WiMAX link.

Figure 22 shows the packet delay variation of a single mobile user in office of 2, 4, and 8 mobile users.

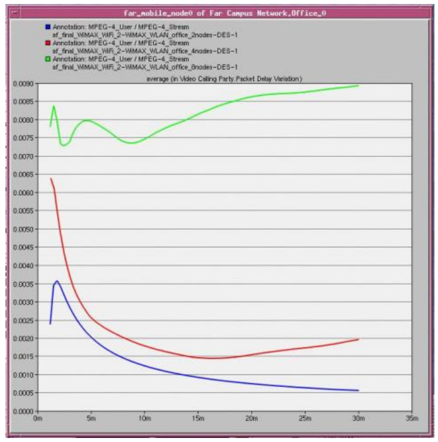


Figure 22: Packet delay variation of a single mobile user in office of 2, 4, and 8 users.

As the number of users in an area accessing the same AP increases, the packet delay variation also increases.

7. CONCLUSION

The multipath effect is an important factor in performance of the wireless technology. In this project the multipath effect on the WiMAX link was observed. Different multipath environments affect the WiMAX link performance.

The range difference of WiMAX and WiFi links were measured. In this project scenario the WiMAX range was about 16 times more than the WiFi link. The WiMAX range was measured to be 73Km and the WiFi link was measured to be 4.6Km.

The effect of increasing the number of users accessing the same access point in a WiFi link was studied. In summary, as the number of users increase the overall WiFi link performance degrades. The degradation is not proportional to the number of users.

8. FUTURE WORK

The path loss model was chosen to be "Free Space" for this project. This is not a realistic path loss. In order to get more realistic results a more realistic path loss model effects on the WiMAX link should be analyzed.

The main focus of the third scenario of this project was on the overloading the WiFi link and seeing the link performance effect of it. The same exercise should be done on the WiMAX link.

9. REFERENCES

1. H. Labiod, H. Afifi and C. Santis, *Wi-Fi, Bluetooth, Zigbee and WiMAX*, Dordrecht, Netherland: Springer, 2007, Chapter 2 and Chapter 5.
2. W. Hrudey and Lj. Trajkovic, "Streaming video content over IEEE 802.16/WiMAX broadband access," OPNETWORK 2008, Washington, DC, Aug. 2008.
3. Intel, Understanding Wi-Fi and WiMAX as metro-access solutions, White paper [Online]. Available: http://www.rclient.com/PDFs/IntelPaper.pdf (Accessed: March 2010).
4. Motorola and Intel, WiMAX and WiFi Together: Deployment Models and User Scenarios, White paper [Online]. Available: http://www.motorola.com/staticfiles/Business/Solutions/Industry%20Solutions/Service%20Providers/Wireless%20Operators/Wireless%20Broadband/wi4%20WiMAX/_Document/StaticFile/WiMAX_and_WiFI_Together_Deployment_Models_and_User_Scenarios.pdf (Accessed: March 2010).
5. B. Gi Lee and S. Choi, *Broadband Wireless Access and Local Networks: Mobile WiMAX and WiFi*, Artech House, 2008, Chapter 2 and Chapter 11.
6. "Wi-Fi Gaining Traction," *BusinessWeek,* Pyramid Research, Mar. 5, 2010. [Online]. Available: http://www.businessweek.com/technology/tech_stats/wifi051003.htm (Accessed: April 2010).

7. P. Sharma, “Facts About WiMAX And Why Is It “The Future of Wireless Broadband””, *TechPluto*, Jun. 20, 2009 [Online]. Available: http://www.techpluto.com/wimax-in-detail/ (Accessed: April 2010).
8. “WiMAX”, *Wikipedia*, [Online]. Available: http://en.wikipedia.org/wiki/WiMAX (Accessed: April 2010).
9. “WiMAX (802.16) specialized model”, *OPNET*, [Online]. Available: http://www.opnet.com/WiMAX/index.html (Accessed: March 2010).
10. “WiMAX Deployments”, *WiMAX MAPS*, Apr. 14, 2010 [Online]. Available: http://www.wimaxmaps.org/ (Accessed: April 2010).
11. “Complementary code keying”, *Wikipedia*, [Online]. Available: http://en.wikipedia.org/wiki/Complementary_code_keying (Accessed: April 2010).
12. “WLAN (802.11)”, *OPNET*, [Online]. Available: http://www.opnet.com/support/des_model_library/WLAN80211.html (Accessed: April 2010).
13. ITU ITU-R M.1225, ““Guidelines for evaluations of radio transmission technologies for IMT-2000”, 1997 [Online]. Available: http://www.itu.int/dms_pub/itu-r/oth/0A/0E/R0A0E00000C0001MSWE.doc (Accessed: April 2010).

10. ORIGINAL PROJECT IDEA

My original project idea was to understand and simulate IEEE1588 standard, which is a precision time protocol used in wireless technology. Due to the fact that I was not able to find an OPNET model for this protocol, I decided to change my topic. Creating an OPNET model for this protocol was considered, but due to the complexity of it and having a limited time for this course this activity is postponed to a later time.

10.1 IEEE1588 ABSTRACT

Wireless technology is transforming the mobile networks to an all packet network. Currently, the clock synchronization of the mobile backhaul is done by GPS and TDM. As a result of the network transformation, the mobile backhaul is progressing to IP and Ethernet to have more bandwidth and better performance. The mobile backhauls that require very precise timing will have to depend on packets for their timing, and the difficulty is due to the fact that Ethernet is asynchronous. New approaches/standards defining clock recovery mechanisms over packet Networks, such as IEEE 1588v2, have been proposed. IEEE 1588, also called Precision Time Protocol (PTP), is a standard protocol for accurate timing and frequency over IP networks. In this protocol, the packets carry time stamp information between the client and the server. My goal for this project is to understand the IEEE 1588 protocol and simulate it using OPNET in a mobile network and find the timing accuracy of this protocol with various traffic loads.

10.2 IEEE1588 INTRODUCTION

Mobile networks are changing to an all packet network and using IP and Ethernet for higher bandwidth and better performance. It is required to be able to exchange data within a specified time and synchronize all the network nodes very precisely. Therefore, a very precise timing will have to depend on Ethernet packet which is asynchronous. IEEE 1588 is a standard protocol for accurate synchronization of clocks used in network communication systems and defines precise clock recovery mechanism over packet Networks. Using this protocol, systems that have different clock precisions and resolutions and are from different manufacturers, can be synchronized together in the sub-microsecond accuracy. “Existing time synchronization protocols such as NTP and SNTP do not achieve the required synchronization accuracy or the convergence speed. Others, such as SynUTC from the Technical University in Vienna, were not accepted on the market.” [5]

In the IEEE1588 protocol, all the clocks in a network synchronize to one clock of the network, which is considered to be the most precise one of all. The most precise clock is going to be the master and the clock that is synchronizing to it, is called the slave. The synchronization between the master and slave is done by exchanging synchronization messages. The first step is that the master transmits a unique synchronization (SYNC) message to its slave every 2 seconds. The slave measures the time the sync message was received (TS1). Then master sends a follow up message containing the time that the sync message was sent (TM1). This way the offset time between the master and slave is corrected as shown in the Figure 23. Slave time is adjusted by the offset.

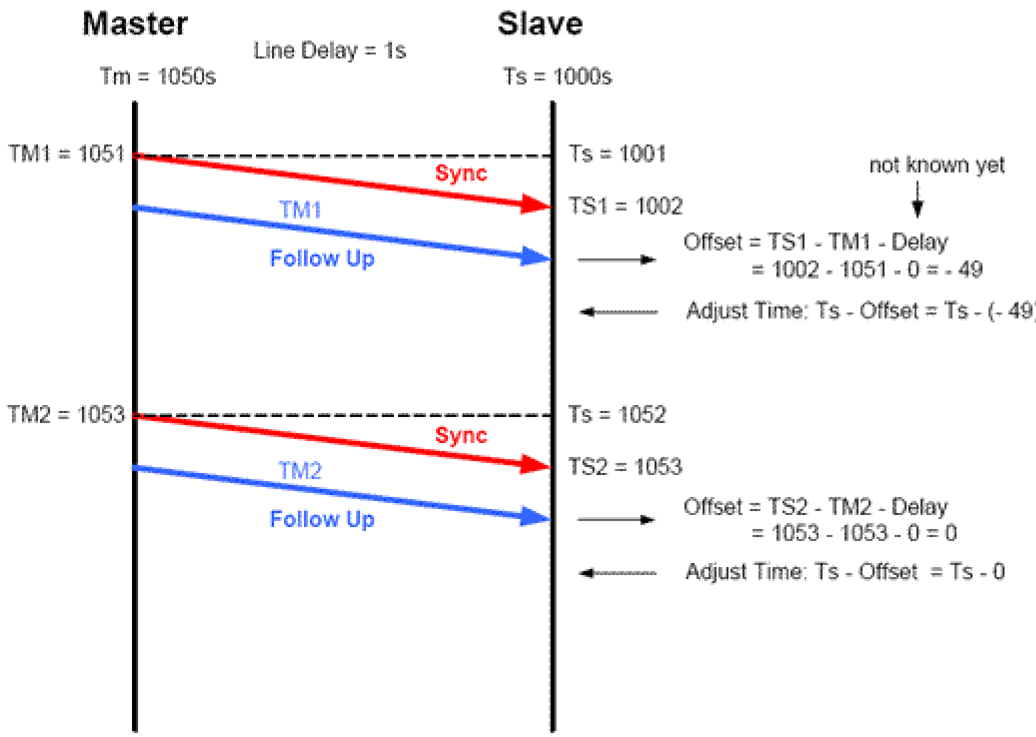


Figure 23: Master/Slave offset measurement [5]

In the next step the slave sends a delay request message to the master to measure the delay between the master and slave. The exact time that the delay request is send from slave is accurately determined by the slave clock to be TS3. The time that the delay request is received by the Master is measured to be TM3. The TM3 information is sent to the slave, and slave calculates the delay between the master and slave and adjusts its clock to take into account the delay, as shown in Figure 24.

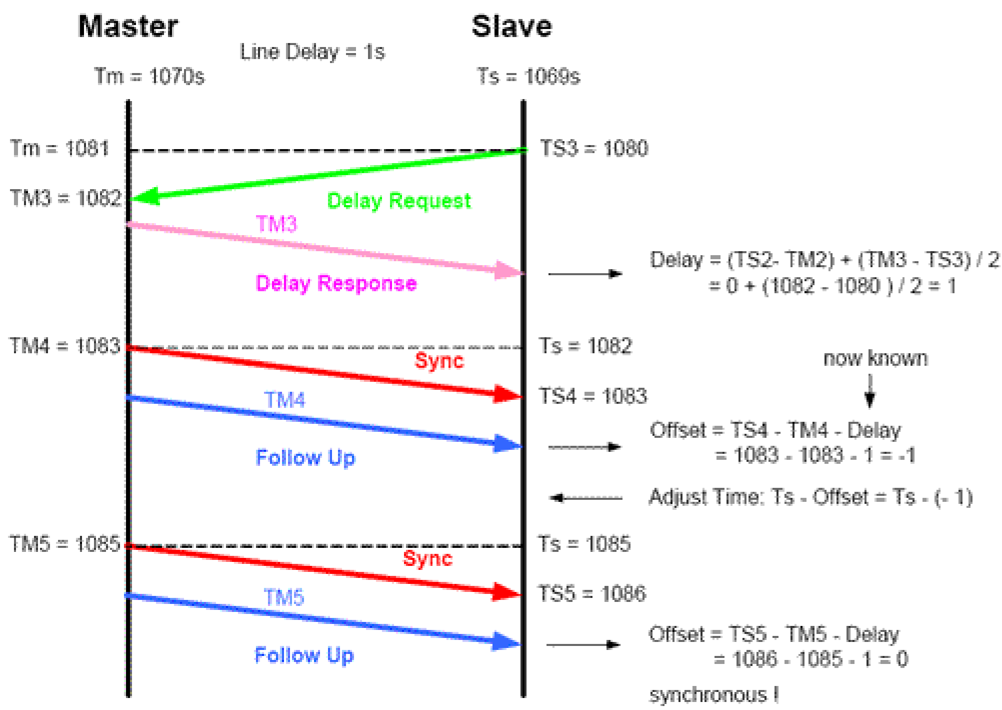


Figure 24: Master/Slave Delay measurement [5]

Unlike the offset measurement, the delay measurement is done randomly every 4 to 60 seconds.

In this project a mobile network that is using the IEEE 1588 protocol as its timing source is simulated. The timing accuracy of the various traffic loads on the network is analyzed.

For this project an IEEE1588 OPNET model will be used.

10.3 IEEE1588 REFERENCES

1. M. Howard, K. Allan, C. Frascogna, E. Schwartz, and R. Datta, "Using Ethernet to backhaul mobile voice with clock synchronization" Presentation Session 2 CTIA 2008, Las Vegas Nevada USA, April 2, 2008.

2. Symmetricom, Inc. "Building a unified synchronization platform for IP wireless backhaul" White paper, 2009.

3. J. Eidson, "IEEE-1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems", Agilent Technologies, October 10, 2005.

4. K. Lee, "IEEE1588TM-2002 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems," National Institute of Standards and Technology. 5 August 2002, updated: 25 February 2010 [Online] Available: http://ieee1588.nist.gov/ (Accessed: February 2010).

5. D. S. Mohl, "IEEE 1588 - Precise time synchronization as the basis for real time applications in automation," IEEE 1588. [Online] Available: http://www.ieee1588.com (Accessed February 2010).

6. IXXAT Automation GmbH, "IEEE 1588 PTP Introduction", IXXAT, 2004-2010. [Online] Available: http://www.ixxat.com/introduction_ieee_1588_en.html (Accessed February 2010).