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FINAL PROJECT
Simulation and performance evaluation of WiFi and WiMAX using OPNET

http://www.sfu.ca/~rpa28

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ABSTRACT

Wireless Local Area Network (WLAN) has become popular in the home due to ease of installation, and the increasing popularity of laptop computers. WLAN is based on IEEE 802.11 standard and is also known as Wireless Fidelity (WiFi). The coverage of one or more access points called hotspots when offering public access — generally comprises an area the size of a few rooms but may be expanded to cover many square miles, depending on the number of access points with overlapping coverage. Another standard with similar principles as WiFi is IEEE 802.16, also known as Worldwide Interoperability for Microwave Access (WiMAX). The main advantage of WiMAX over WiFi is that is covers larger area and has greater data rate. Figure 1 shows a comparison of WiMAX coverage versus WiFi coverage.

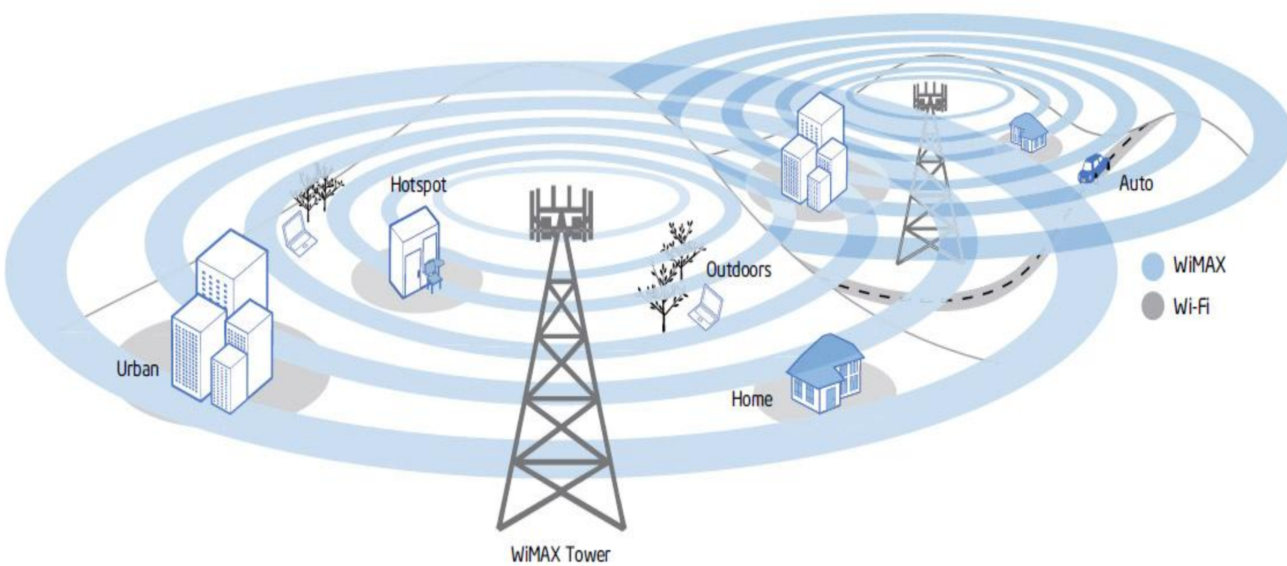


Figure 1: Coverage of WiMAX versus coverage of WiFi [7]

Wi-Fi typically provides local network access for around a few hundred feet with speeds of up to 54 Mbps, a single WiMAX antenna has a range of up to 40 miles with speeds of 70 Mbps or more. As such, WiMAX can bring the underlying Internet connection needed to service local Wi-Fi networks. Wi-Fi does not guarantee any QoS but WiMax will provide your several level of QoS. Both 802.11 (which include Wi-Fi) and 802.16 (which include WiMAX) define Peer-to-Peer (P2P) and ad hoc networks, where an end user communicates to users or servers on another Local Area Network (LAN) using its access point or base station. However, 802.11 supports also direct ad hoc or peer to peer networking between end user devices without an access point while 802.16 end user devices must be in range of the base station. The best way to enjoy the advantage of the WiMAX system is to combine the WiMAX and WiFi systems together. WiMAX can be used in offices and homes that are currently WiFi enabled.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

3G	Third Generation
ADSL	Asymmetrical Digital Subscriber Line
AP	Access Point
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transmitter System
CCK	Complementary Code Keying
CINR	Carrier to noise plus interference ratio
COFDM	Coded Orthogonal Frequency Division Multiplexing
CPE	Consumer Premises Equipment
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DMT	Discrete Multi-tone modulation
DSL	Digital Subscriber Line
DSP	Digital Signal Processing
DSSS	Direct Sequence Spread Spectrum
EIR	Equipment Identity Register
FDD	Frequency Division Duplexing
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HLR	Home Location Register

HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMT	International Mobile Telecommunications
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union- Radio communication
LAN	Local Area Network
ME	Mobile Equipment
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiplexing
PCU	Packet Control Unit
PDN	Packet Data Networks
PMP	Point-to-Multipoint
QoS	Quality of Service
SGSN	Serving GPRS Subscriber Node
SIM	Subscriber Identity Module
SOFDMA	Scalable Orthogonal Frequency-division Multiple Access
SS	Subscriber Station
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
VLR	Visitor Location Register
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

1. INTRODUCTION

Wireless Local Area Networks (WLANs) has become one of the most promising and successful technology in recent years. WLANs provide free wireless connectivity to end users, offering an easy and viable access to the network and its services. Worldwide Interoperability for Microwave Access (WiMAX) embodies the IEEE 802.16 family of standards that provide fixed and mobile broadband access in the telecommunications landscape. WiMAX refers to interoperable implementations of the IEEE 802.16 wireless-networks standard (ratified by the WiMAX Forum), in similarity with Wi-Fi, which refers to interoperable implementations of the IEEE 802.11 Wireless LAN standard. The IEEE 802.16 standard forms the basis of 'WiMAX' and is sometimes referred to colloquially as "WiMAX", "Fixed WiMAX", "Mobile WiMAX". Mobile WiMAX has launched WiMAX into 4th generation (4G) mobile data networks competing for subscribers demanding unprecedented levels of personalized, media-rich services.

Mobile WiMAX, is based upon IEEE Std 802.16e-2005. It is a supplement to the IEEE Std 802.16-2004, and so the actual standard is 802.16-2004 as amended by 802.16e-2005. In late 1990s, several companies formed WiFi Alliance to create a single standard for high-speed WLAN which would be accepted worldwide. WiMAX and Wi-Fi are frequent because both are related to wireless connectivity and Internet access. Although Wi-Fi and WiMAX are designed for different situations, they are complementary. WiMAX network operators typically provide a WiMAX Subscriber Unit which connects to the metropolitan WiMAX network and provides Wi-Fi within the home or business for local devices (e.g., Laptops, Wi-Fi Handsets, smartphones) for connectivity. This enables the user to place the WiMAX Subscriber Unit in the best reception area (such as a window), and still be able to use the WiMAX network from any place within their residence. IEEE 802.11 is a set of standards for implementing wireless local area WLAN computer communication in the 2.4, 3.6 and 5 GHz frequency bands.

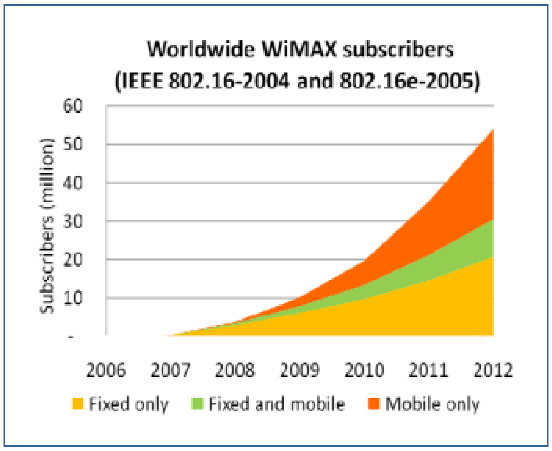


Figure 2: WiMAX Subscribers

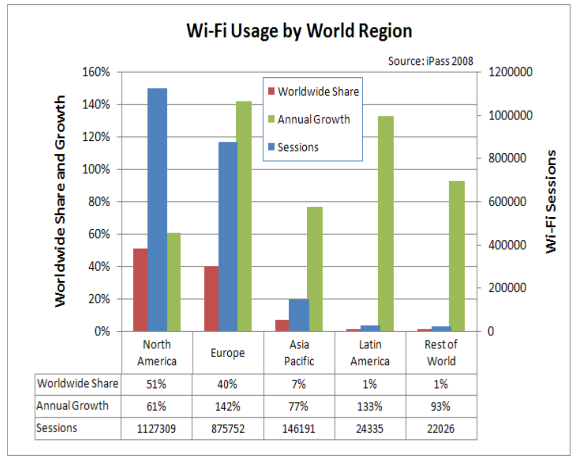


Figure 3: WiFi usage

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.

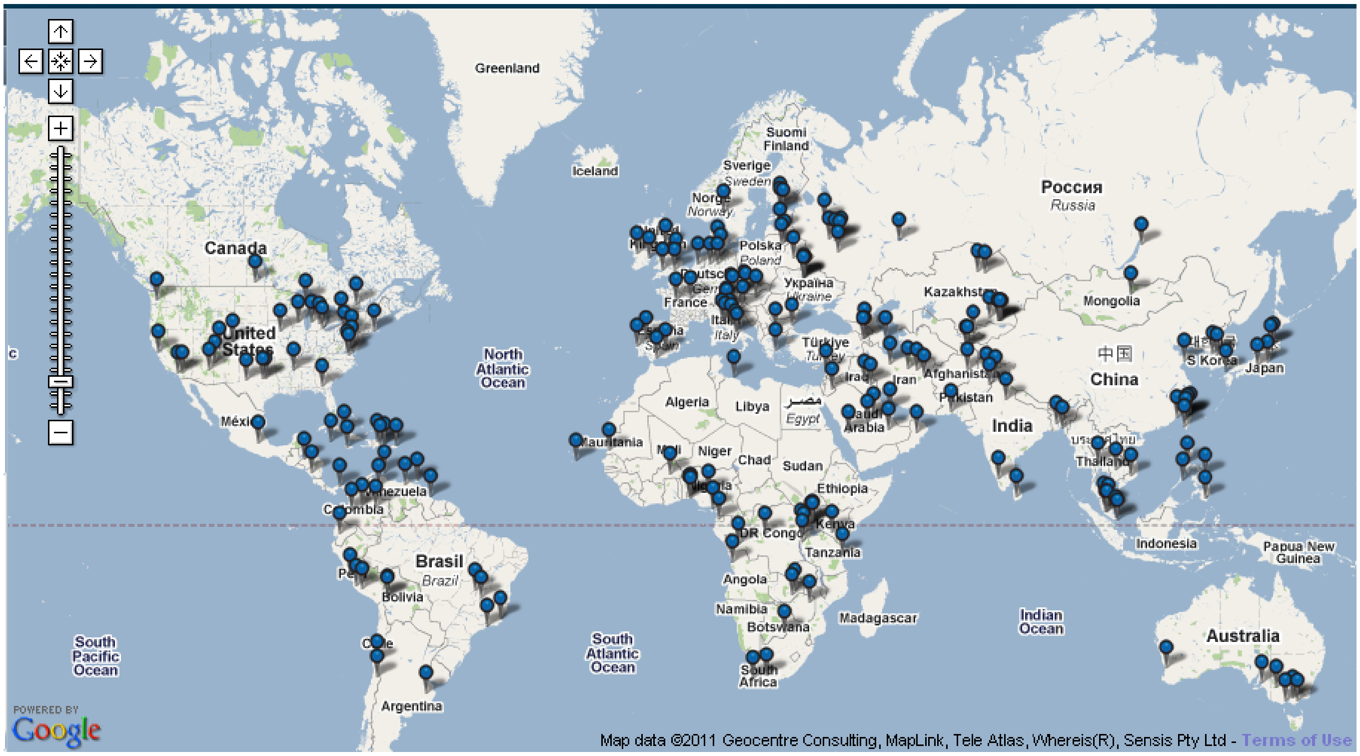


Figure 4: IEEE 802.16e WiMAX deployment [12]

1.1. What is WiMAX

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 and a maximum range of 50km (although, not both at the same time). WiMAX is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL. Compared to ADSL, which has a maximum local-loop range of approximately 5km, WiMAX has a marked advantage in total area coverage. WiMAX network can be connected with an IP based core network, which is typically chosen by operators that serve as Internet Service Providers (ISP). 802.16e-2005 uses Scalable Orthogonal Frequency-division Multiple Access (SOFDMA) rather than Orthogonal Frequency-division Multiplexing (OFDM). Multiple duplexing schemes used in WiMAX are Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD). 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 is an all-IP infrastructure deployed in a point-to-multi-point (PMP) topology where one or more subscribers communicate with a WiMAX base station. 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.

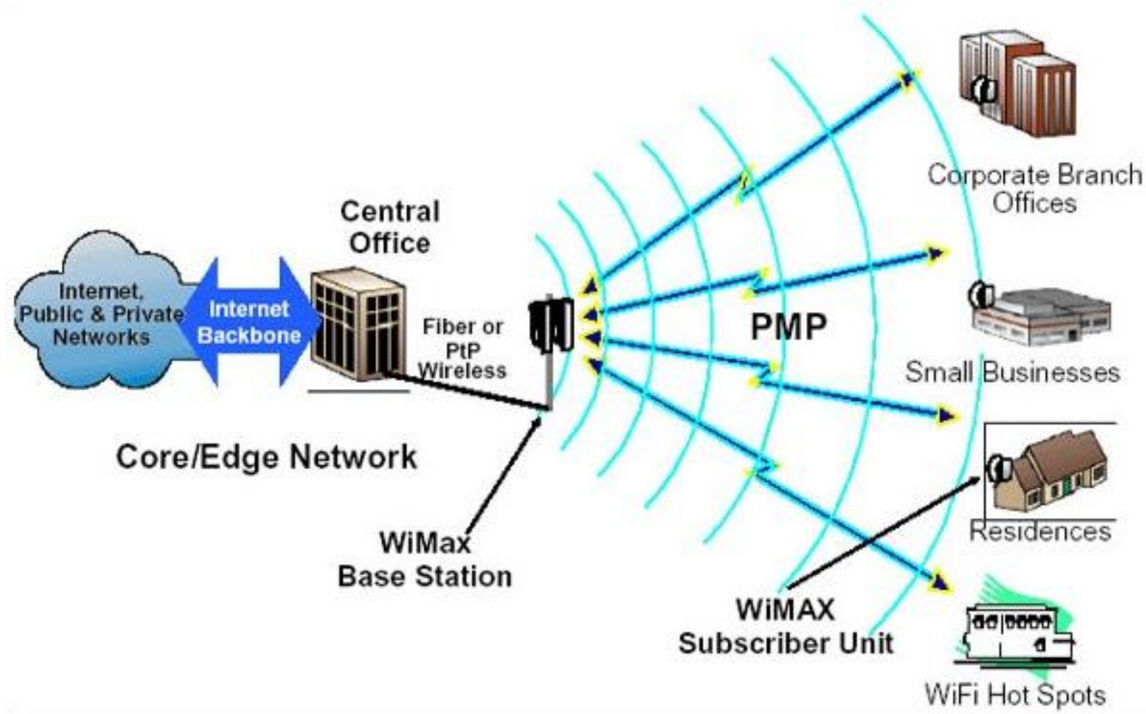


Figure 5: WiMAX Equipment

WiMAX provides a maximum transfer speed of 75Mbps per channel, and a maximum range of 50km (although, not both at the same time). Compared to ADSL, which has a maximum local-loop range of approximately 5km, WiMAX has a marked advantage in total area coverage. Also thanks to the large coverage area, users are able to stay connected to a high-speed internet connection while mobile, a major advantage over ADSL and cable. WiMAX simplifies the implementation of high-speed internet access to remote users, and is much cheaper to implement than wired systems.

This project focuses on the feasibility of using a WiMAX connection to provide last-mile internet connection for video conferencing. WiMAX is capable of providing the required bandwidth mentioned above over a large geographical area, however its QoS is, in general, lower than that of a wired connection. Compared to wired connections, wireless connections have a much higher bit error rate (BER) due to the unpredictable nature of the transmission medium (air) and the obstacles between the transmitter and receiver. This necessitates re transmissions, which leads to delay and jitter, and the need to buffer incoming data. WiMAX is often confused with Wi-Fi another wireless telecommunication standard, but both of these standards are much different in terms of infrastructure pre-requisites and network capabilities. Wi-Fi is basically a limited wireless extension of the conventional wired telecommunications network, using which we can access wireless internet within a small range of 10-100m from the WiFi access point, whereas WiMAX provides long range wireless internet access at broadband speed, with the help of a dedicated network infrastructure, built exclusively for wireless data communication at much higher speed.

Types: There have been majorly two developments with regard to WirelessMAN broadband: Fixed WiMAX and Mobile WiMAX. The earlier of the two WirelessMAN standards, Fixed WiMAX (or IEEE 802.16d) employs High gain-low portability unidirectional antenna at user's end and provides a limited wireless broadband access. It supports following sub-channels: Single High Gain carrier, OFDM 256 FFT (Fast Fourier Transform) and OFDMA 1K-FFT Mobile WiMAX (or IEEE 802.16e) takes the Wireless broadband access to much larger coverage area as it employs Low gain-High portability. Omni-directional antennas at user's end(in the form of Flash drive sized modem). Mobile WiMAX supports not only Single carrier, OFDM 256 FFT and OFDMA 1K-FFT but also OFDMA 2K-FFT, 512-FFT and 128-FFT sub-channels.

Infrastructure: Implementation of WiMAX requires a similar scale of basic telecommunication infrastructure, as built in case of a voice communication network (GSM, CDMA). Base Stations, sectorized antennas, control center and other critical constituents are generally a part of such infrastructure

Coverage: WiMAX network has often been claimed in media to be capable of providing broadband speeds to coverage of over 30 miles (with a single base station) but that's possible only in ideal conditions (Line-Of-Sight (LOS) area, No real-time traffic, negligible attenuation). Practically, a single base station can provide a satisfactory broadband access within a range of 4-5 miles (Non-LOS and real-time traffic conditions). With LOS conditions, the coverage can go upto 10 miles. Rest of the coverage and Quality-of-Service (QoS) details are solely dependent upon the terrain and population conditions.

Terminology: IEEE 802.16 standard is generally referred as "WirelessMAN" but the term "WiMAX" was actually given to IEEE 802.16 standard by WiMAX Forum, founded in mid 2001 to take care of conformity, interoperability and promote the IEEE 802.16 Standard (or Wireless broadband) at a global scale

Limitation: The major limitation of WiMAX is the effect of QOS in high traffic, non-LOS areas. It's quite impractical for WiMAX networks to support over 40 Mbps of internet speed at a distance of 15-20 miles. This limitation is quite unavoidable and found in other wireless networking standards as well.

Future: The future of WiMAX looks brighter as there are already over 475 WiMAX networks deployed in 140 countries worldwide and the network extension is happening at a very fast pace. See the list of deployed WiMAX networks here. Also, as it offers a cheaper and more bandwidth-efficient way of providing Wireless broadband (compared to 3G).

Deployment: As a standard intended to satisfy needs of next-generation data networks (4G), WiMAX is distinguished by its dynamic burst algorithm modulation adaptive to the physical environment the RF signal travels through. Modulation is chosen to be more spectrally efficient (more bits per OFDM/SOFDMA symbol). That is, when the bursts have high signal strength and a carrier to noise plus interference ratio (CINR), they can be more easily decoded using digital signal processing (DSP). In contrast, operating in less favorable environments for RF communication, the system automatically steps down to a more robust mode (burst profile) which means fewer bits per OFDM/SOFDMA symbol; with the advantage that power per bit is higher and therefore simpler accurate signal processing can be performed.

Burst profiles are used inverse (algorithmically dynamic) to low signal attenuation; meaning throughput between clients and the base station is determined largely by distance. Maximum distance is achieved by the use of the most robust burst setting; that is, the profile with the largest MAC frame allocation trade-off requiring more symbols (a larger portion of the MAC frame) to be allocated in transmitting a given amount of data than if the client was closer to the base station.

The client's MAC frame and their individual burst profiles are defined as well as the specific time allocation. However, even if this is done automatically then the practical deployment should avoid high interference and multipath environments. The reason for which is obviously that too much interference causes the network function poorly and can also misrepresent the capability of the network.

The system is complex to deploy as it is necessary to track not only the signal strength and CINR (as in systems like GSM) but also how the available frequencies will be dynamically assigned (resulting in dynamic changes to the available bandwidth.) This could lead to cluttered frequencies with slow response times or lost frames.

As a result the system has to be initially designed in consensus with the base station product team to accurately project frequency use, interference, and general product functionality.

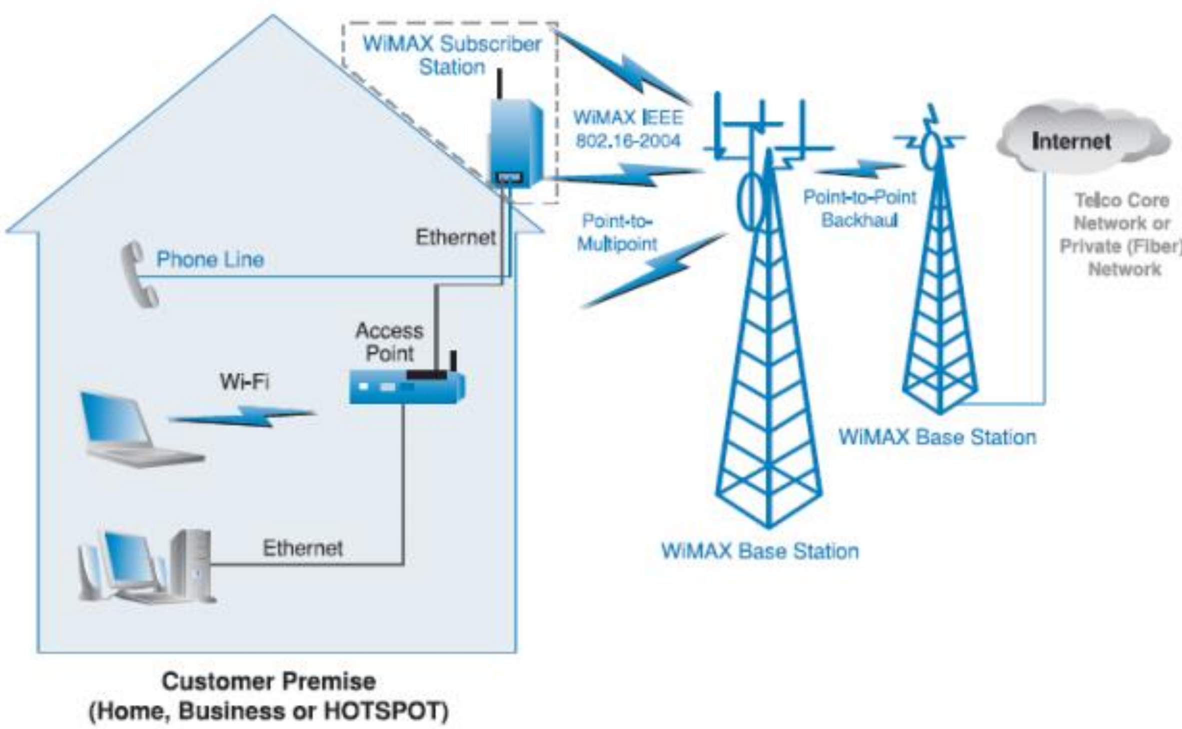


Figure 6: WiMAX client station connection [1]

1.2. What is WiFi

IEEE 802.11g is the third modulation standard for wireless LANs. It works in the 2.4 GHz band but operates at a maximum raw data rate of 54 Mbit/s, or about 19 Mbit/s net throughput. 802.11g hardware is fully backwards compatible with 802.11b hardware. The modulation scheme used in 802.11g is orthogonal frequency division OFDM copied from 802.11a with data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s, and reverts to complementary code keying (CCK) for 5.5 and 11 Mbit/s and direct-sequence spread spectrum (DSSS) for 1 and 2 Mbit/s.

- OFDM (orthogonal frequency-division multiplexing) is essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT). It is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier.
- CCK (complementary code keying) “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.”
- DSSS (direct-sequence spread spectrum) is a modulation technique in which the transmitted signal takes up more bandwidth than the information signal that is being modulated. The name 'spread spectrum' comes from the fact that the carrier signals occur over the full bandwidth (spectrum) of a device's transmitting frequency.

A Wi-Fi enabled device such as a personal computer, video game console, smartphone or digital audio player can connect to the Internet when within range of a wireless network connected to the Internet. The coverage of one or more (interconnected) access points— called hotspots when offering public access — generally comprises an area the size of a few rooms but may be expanded to cover many square miles, depending on the number of access points with overlapping coverage. 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.

1.3. Comparison between WiMAX and WiFi

WiMAX is similar to the wireless standard known as Wi-Fi, but on a much larger scale and at faster speeds. A nomadic version would keep WiMAX-enabled devices connected over large areas, much like today's cell phones. WiMAX has connection oriented MAC layer while WiFi is connectionless and uses carrier sense multiple access with collision avoidance (CSMA/CA) protocol. WiFi is more recognized and used in the consumer devices. We can compare WiMAX with WiFi based on the following factors.

IEEE Standards:

Wi-Fi is based on IEEE 802.11 standard where as WiMAX is based on IEEE 802.16. However both are IEEE standards.

Range:

Wi-Fi typically provides local network access for around a few hundred feet with speeds of up to 54 Mbps, a single WiMAX antenna is expected to have a range of up to 40 miles with speeds of 70 Mbps or more. As such, WiMAX can bring the underlying Internet connection needed to service local Wi-Fi networks.

Scalability:

Wi-Fi is intended for LAN applications, users scale from one to tens with one subscriber for each CPE device. Fixed channel sizes (20MHz).

WiMAX is designed to efficiently support from one to hundreds of Consumer premises equipments (CPE)s, with unlimited subscribers behind each CPE. Flexible channel sizes from 1.5MHz to 20MHz.

Bit rate:

Wi-Fi works at 2.7 bps/Hz and can peak up to 54 Mbps in 20 MHz channel.

WiMAX works at 5 bps/Hz and can peak up to 100 Mbps in a 20 MHz channel.

Quality of Service:

Wi-Fi does not guarantee any QoS but WiMax will provide your several level of QoS. As such, WiMAX can bring the underlying Internet connection needed to service local Wi-Fi networks. Wi-Fi does not provide ubiquitous broadband while WiMAX does.

Table 1: WiFi and WiMAX comparison [7]

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.

2. MOTIVATION:

WiMAX is readily available. As of April 2011, WiMAX forum claims there are over 582 WiMAX networks deployed in over 147 countries. Today, in every continent, one in ten people around the world use Wi-Fi at home, at work,and in countless ways. Video conferencing is becoming very popular, which enables face-to-face and real-time communications**.**

3. SIMULATION

Simulation tool

OPNET [15] software provides a comprehensive development environment for the modeling and simulation of communication networks and distributed systems. It was originally developed at MIT and was introduced as one of the first commercial network simulator in 1987. The software package provides tools for design, simulation, data collection, and data analysis [16].

OPNET Modeler enables users to create customized models and to simulate various scenarios. The Wireless module is an option that may be enabled when creating models for wireless scenarios. The modeler is object-oriented and employs a hierarchical approach to model communication networks. The modeler provides graphical user interfaces known as editors to capture the specifications that directly parallel the structure of deployed networks, equipment, and protocols. The three main editors are Project, Node, and Process Editors.

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 15.0 was used in this project for simulating 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, and 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."[9]

"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."[2]

4. PROJECT DESCRIPTION

4.1. Project Setup

In this project two scenarios were created for WiFi and one scenario for WiMAX. The first WiFi scenario has eight workstations and these workstations are stationary. The second scenario has eight mobile stations which are randomly located at different locations.

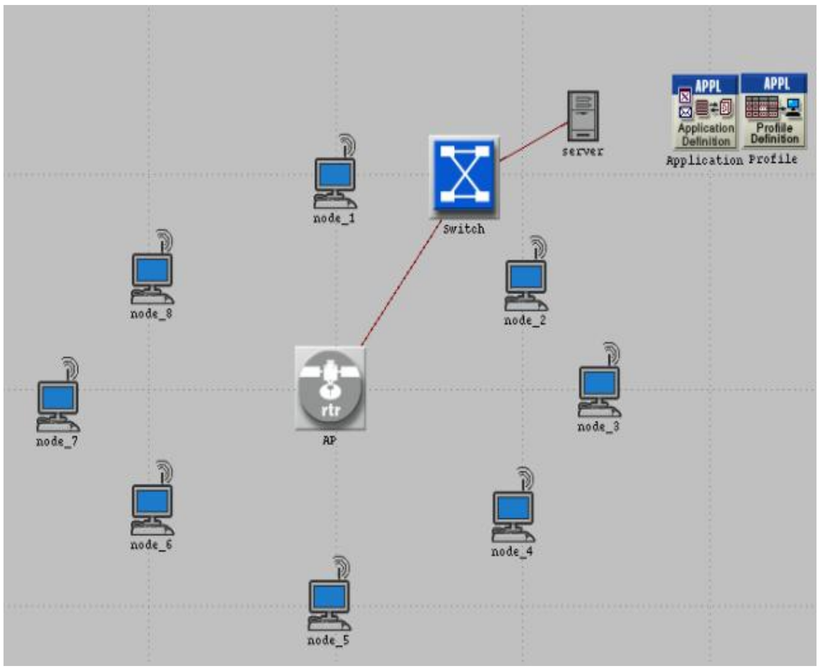


Figure 7: 1st WiFi Scenario

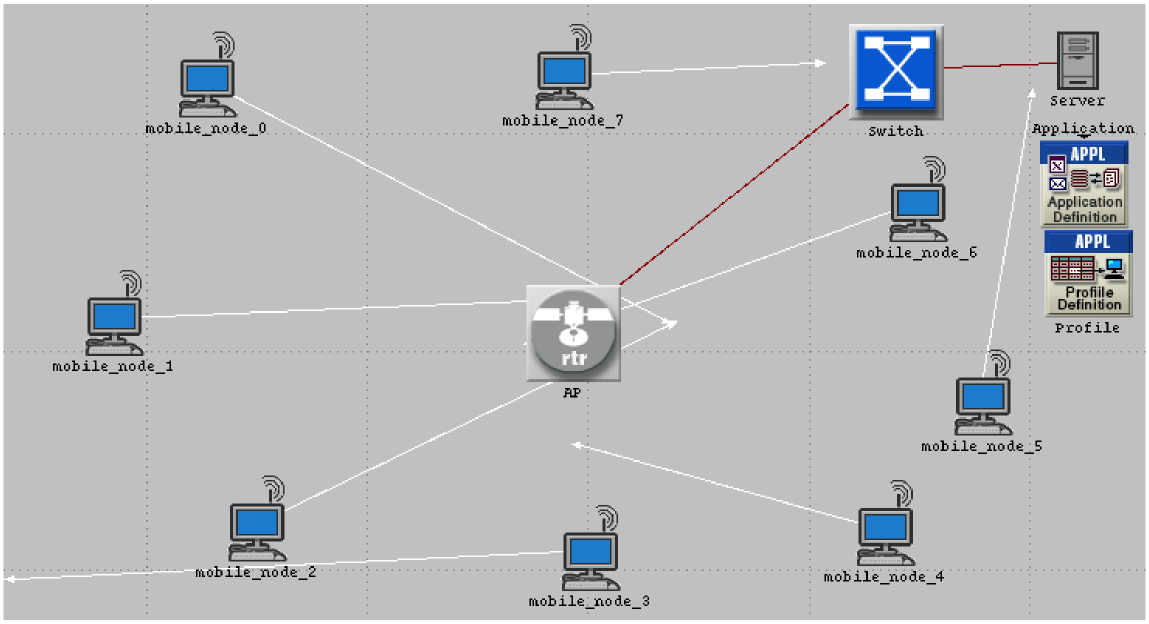


Figure 8: 2nd WiFi Scenario

The WiMAX scenario has three base stations and eight mobile stations which are randomly moving and are defined by a trajectory.

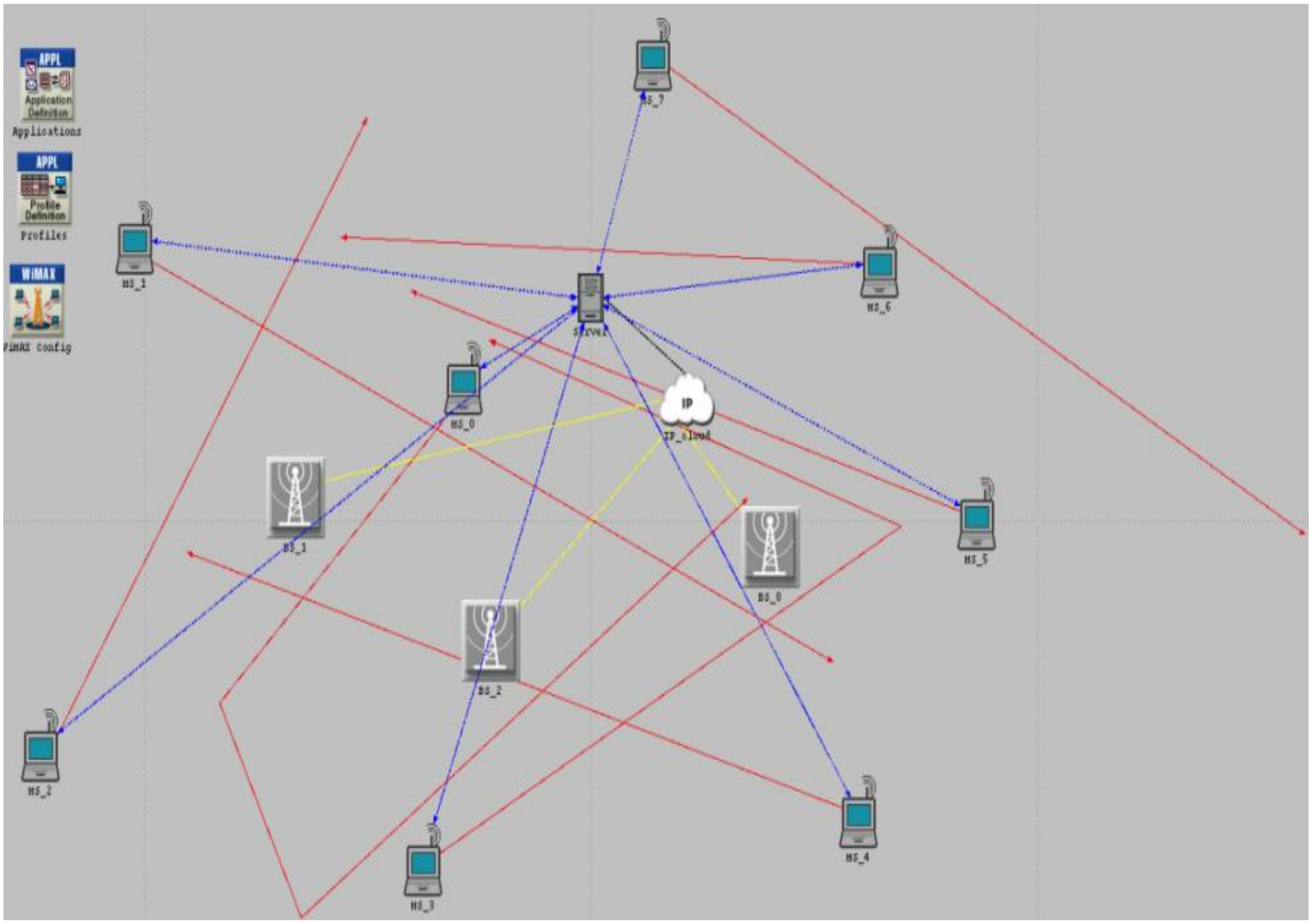
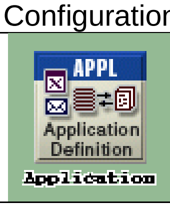
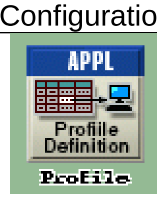
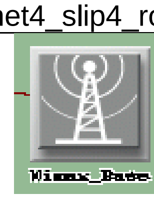


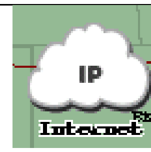
Figure 9: WiMAX Scenario

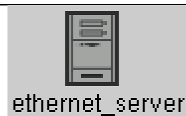
4.2. Models used

OPNET components used in this project are listed in Table 2.

Table 2: OPNET models used

Model Name	Application Configuration	Profile Configuration	WiMAX Configuration	wimax_bs_ethernet4_slip4_router
Model Icon				

Model Name	wlan_wkstn	10BasteT	ip32_cloud	Switch
Model Icon				

Model Name	ethernet_server
Model Icon	

4.3. Parameter Setup

The parameter setup is shown in Figure 10,11 and 12. The mobile station, workstation and router attributes are defined in the respective figures.

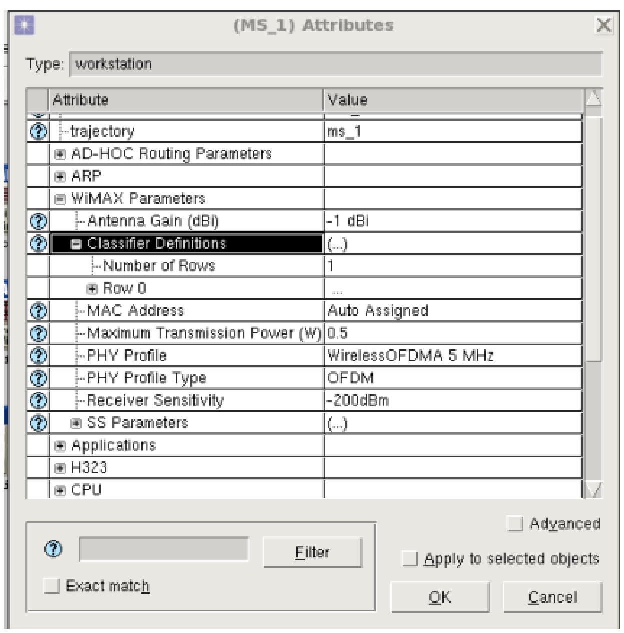


Figure 10: Mobile station configuration

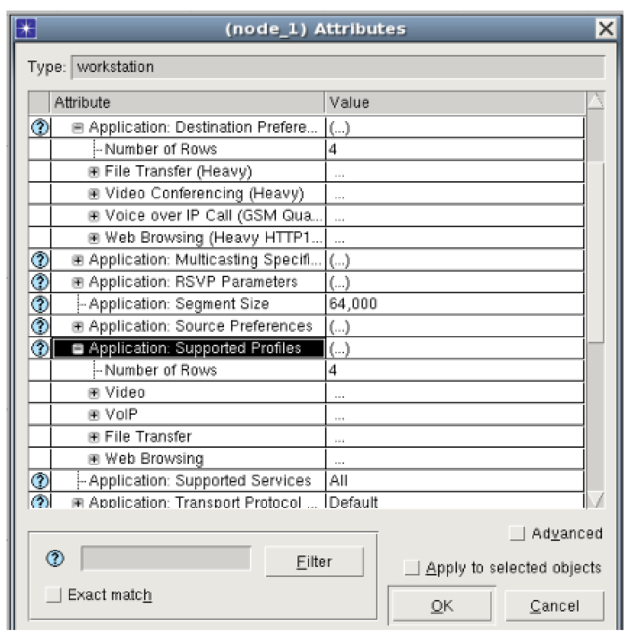


Figure 11: User node configuration

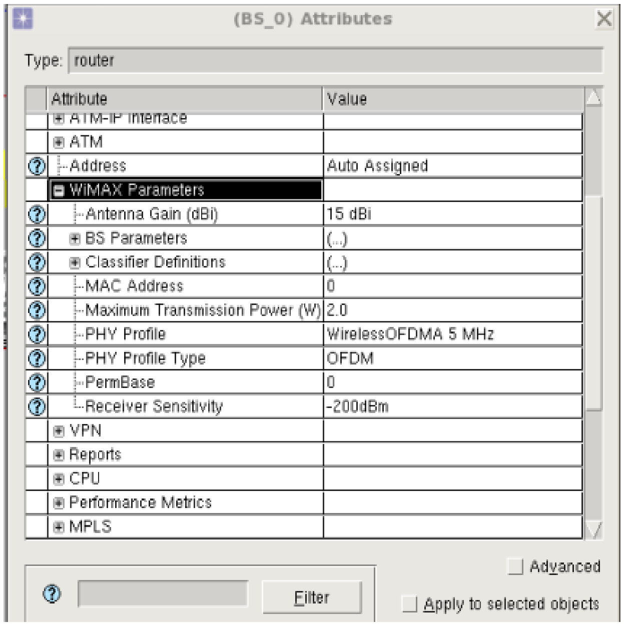


Figure 12: Base Station configuration

5. SIMULATION RESULTS

Issues to Analyse:

- **Throughput:** Throughput represents the average number of messages (packets or bits) that have been successfully transmitted or received by the transmitter or the receiver channel per second. Throughput is a measure of the consumption of the digital bandwidth in a network that is being considered. It is measured in bytes / sec (or bps).
- **Delay:** It is the average time of transit. It is the sum of Processing delay, propagation delay, and queuing delay.
- **Average Queuing Delay:** The Average Queuing Delay could be defined as the average time taken from the point at which a packet arrives into a queue up to the point where that packet is transmitted and leaves the queue. It is therefore desirable to keep this statistic as small as possible, especially in real-time applications such as voice and video.
- **Mean Opinion Score (MOS):** The Mean Opinion Score provides a numerical measurement of the quality of a voice signal that is perceived after it has been

transmitted [5]. Table 1 provides the rating scheme used to determine the perceived quality of voice signals.

Mean Opinion Score (MOS)		
MOS Value	Perceived Quality	Degree of Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Table 2: MOS Values and their Perceived Voice Quality.

- **Loss:** Packet loss refers to the failure of packets in reaching their destination when travelling across a network. One source of packet loss is buffer overflow that can be caused when packets entering into the queue are doing so at a faster rate than those which are leaving the buffer. Packet loss has a significant and noticeable effect on the overall quality of the received signal, especially in real-time applications. Other causes of packet loss include signal degradation and noise.

Applications:

- **Video conferencing:** It is a set of interactive telecommunication technologies which allow two or more locations to interact via two-way video and audio transmissions simultaneously.
- **HTTP:** It is the foundation of data communication for the World Wide Web. The standards development of HTTP has been coordinated by the Internet Engineering Task Force (IETF).
- **FTP:** It is designed for transferring files and offers faster overall throughput and better error checking.

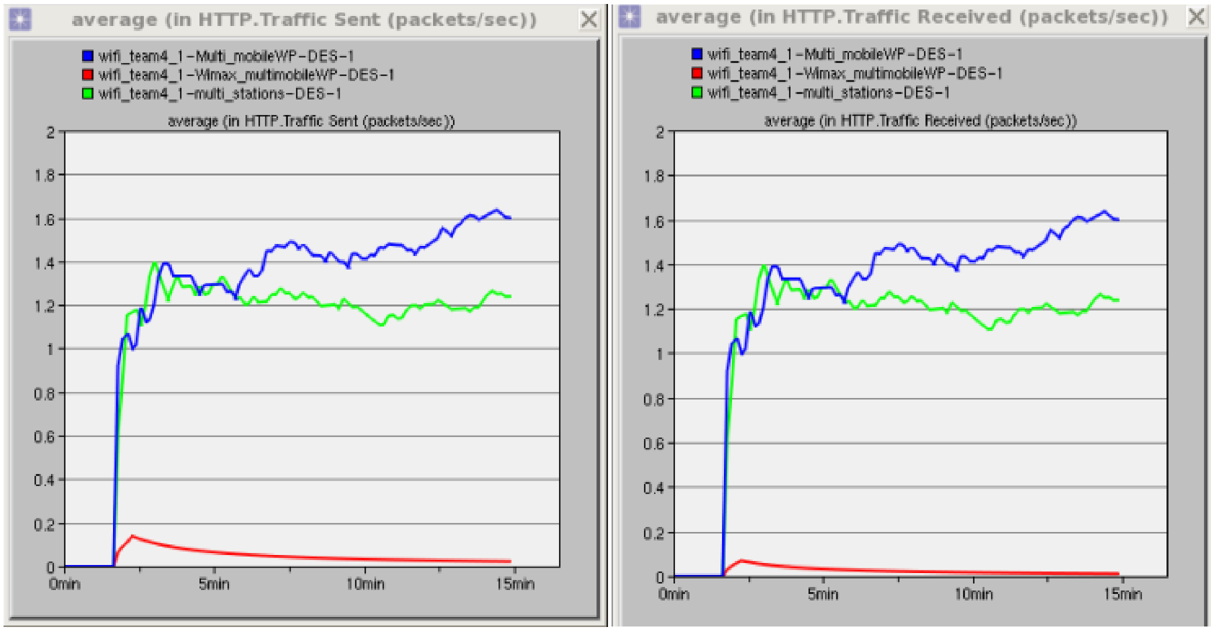


Figure 13 HTTP Traffic sent and received

Figure 13 depicts the HTTP traffic sent and received. As can be seen from the figure the traffic sent for both mobile and fixed WiFi is same as traffic sent, which means there is no loss. But, there is some loss in case of mobile WiMAX traffic sent and received.

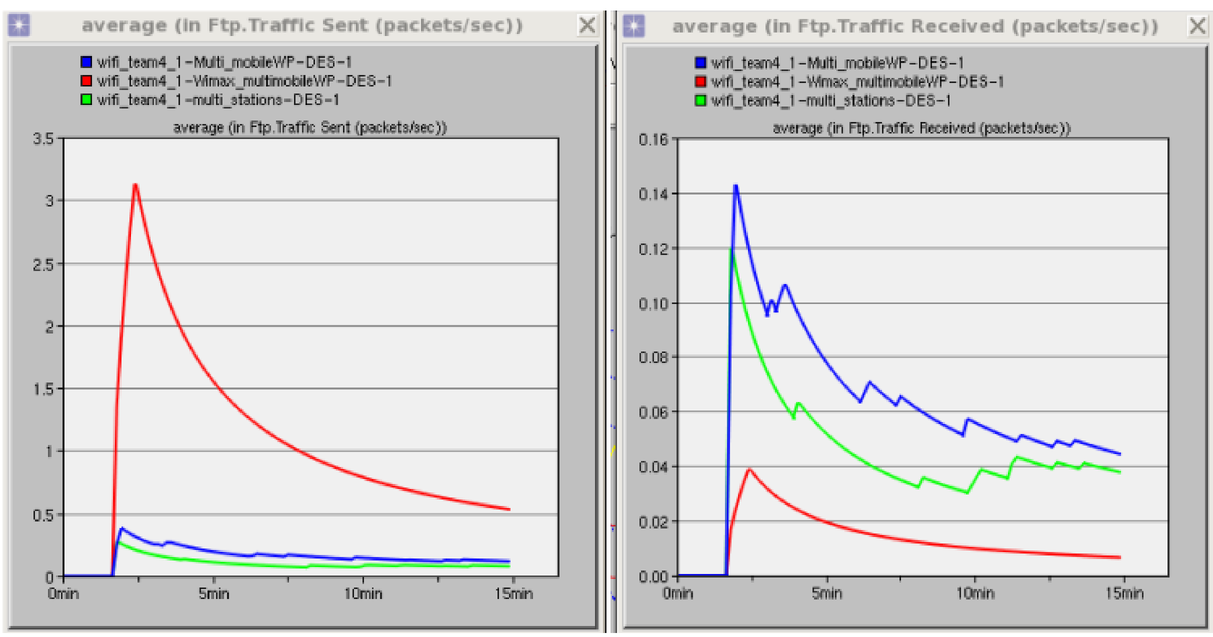


Figure 14: Time Average in FTP Traffic Sent and received (packets/sec)

Figure 14 illustrates the time average traffic in packets/sec that was sent through the network by the FTP workstation. As expected for FTP, fixed WiFi had the least amount of traffic sent and mobile WiFi has little more traffic sent. Mobile WiMAX has the highest average amount of traffic sent.

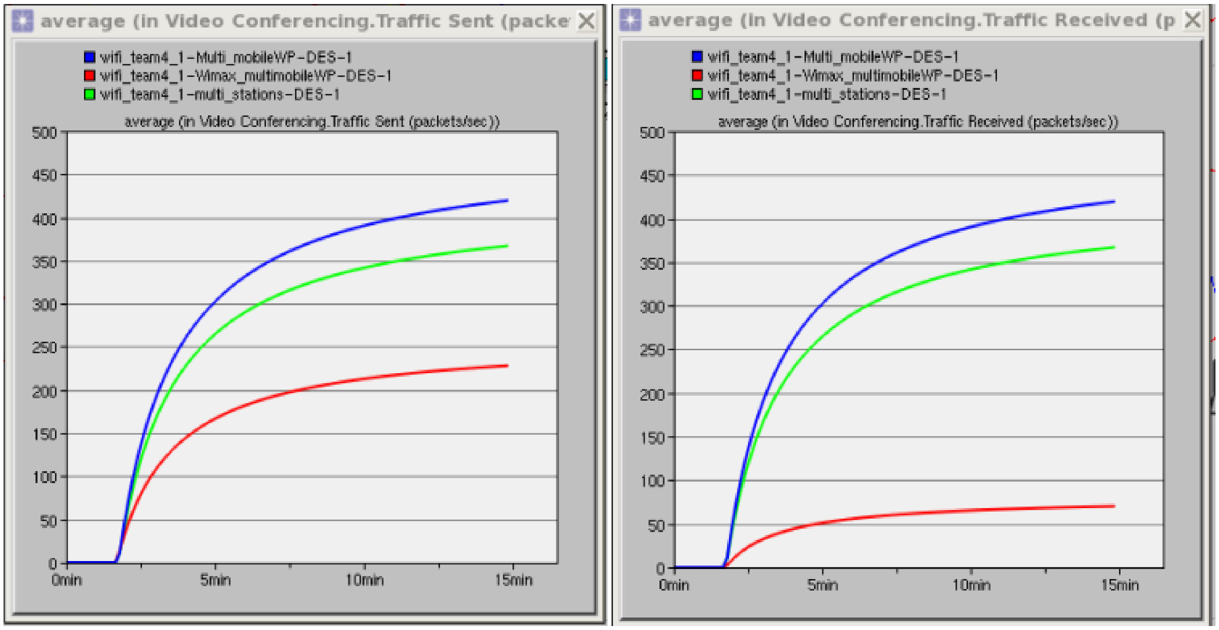


Figure 15: Video Conferencing Traffic sent and received

Video conferencing traffic sent is almost identical to traffic received for mobile and fixed WiFi whereas there is large loss in case of mobile WiMAX which is to be expected.

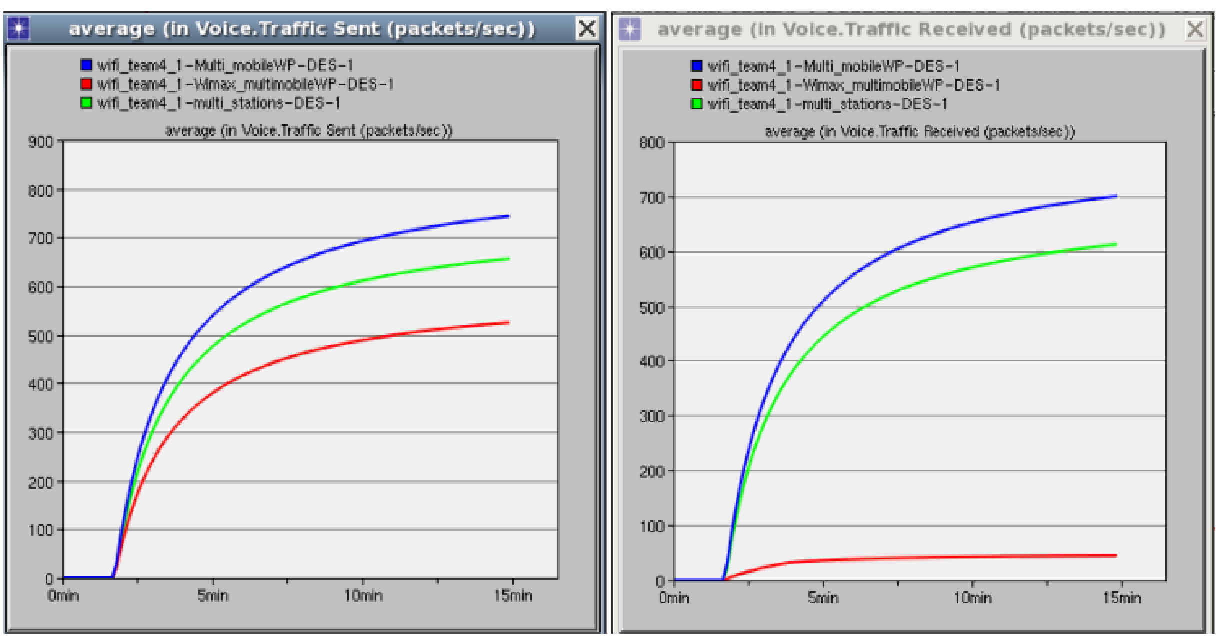


Figure 16: Voice Traffic sent and received

As expected and as can be observed in Figure 16, the time average in voice traffic that is sent and received is almost same for mobile WiFi and fixed WiFi. But the voice traffic received for mobile WiMAX is much lower as compared to voice traffic sent.

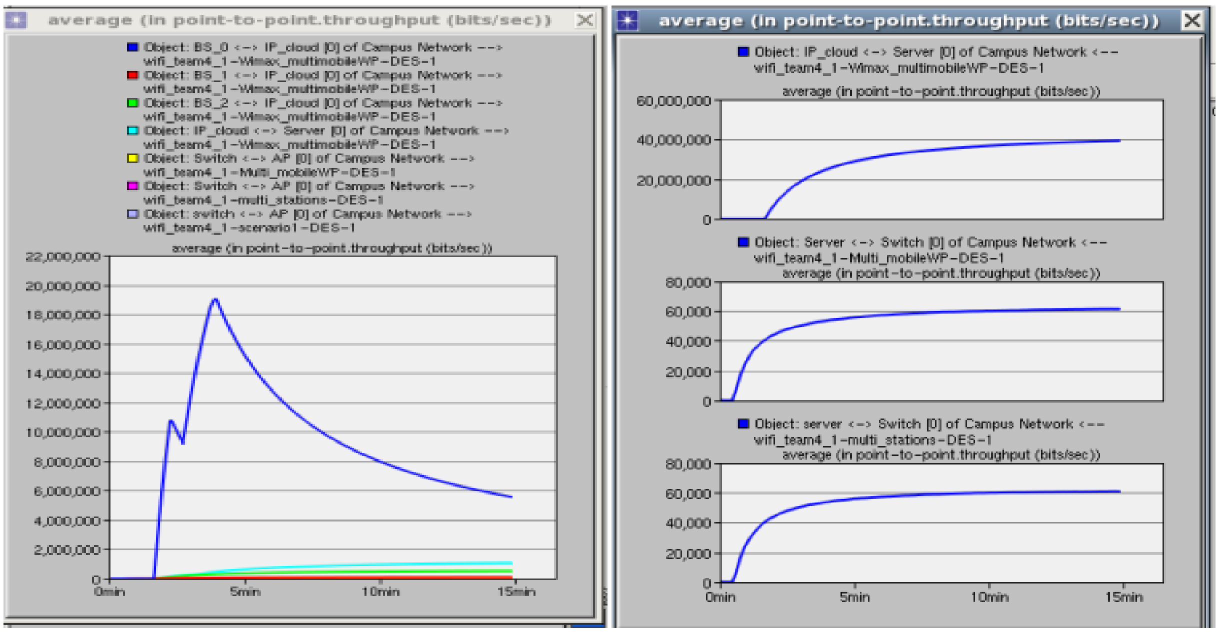


Figure 17: Point-to-point Throughput

The throughput statistic shows the average number of bits that were successfully received and transmitted by the receiver and the transmitter channels per second. As can be seen in Figure 17 and Figure 18, the best throughput was found for the mobile WiMAX scenario. As expected, throughput for fixed WiFi and mobile WiFi was found to be almost identical.

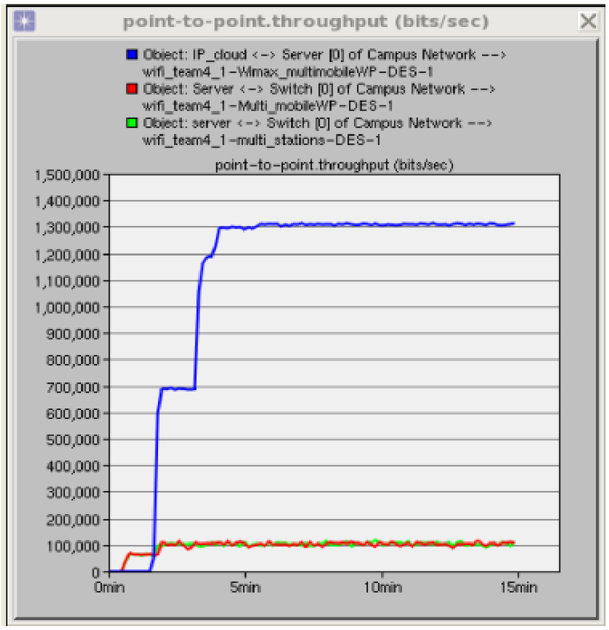


Figure 18: Throughput

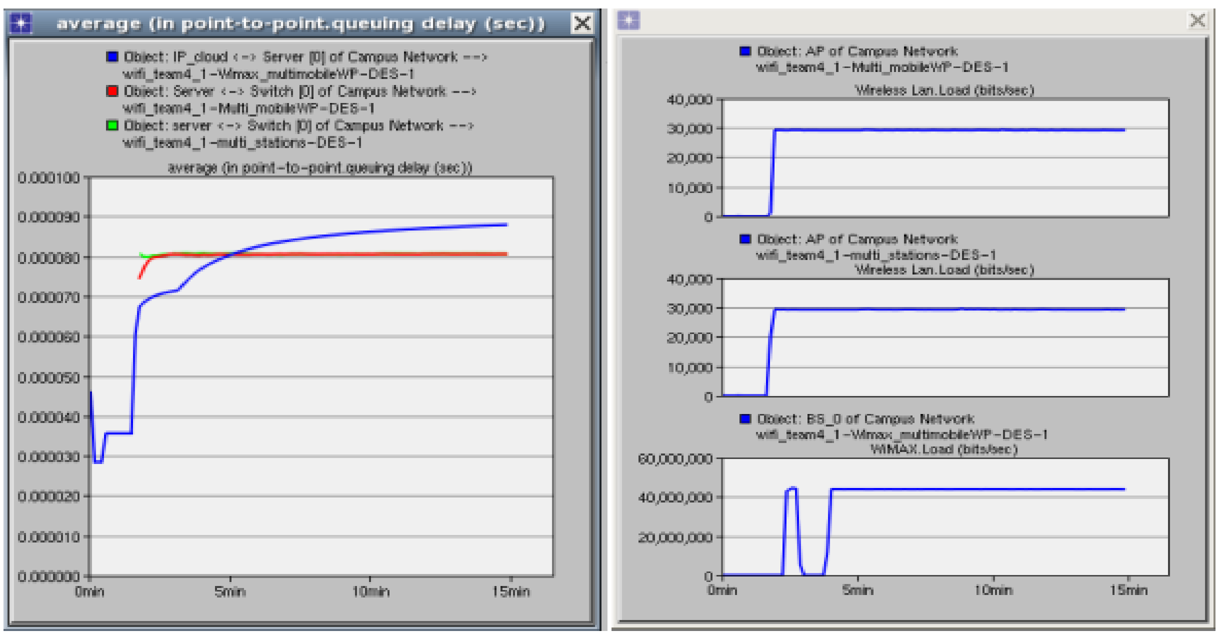


Figure 19: Queuing delay

The Average Queuing Delay represents the instantaneous measurement of packet waiting times in the transmitter channel's queue. The measurements of the Average Queuing Delay are taken from the moment that a packet arrives into the transmitter channel queue up to the time that the last bit of the packet is transmitted. As expected, this delay time was found to be the most for mobile WiFi in a small scale network whereas it is the same for fixed WiFi and mobile WiMAX. Figure 19 illustrates the results obtained.

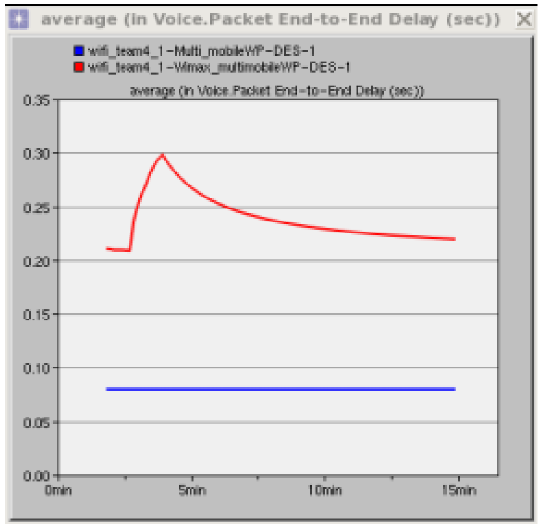


Figure 20: Voice Time Average in End-to-End Delay (sec)

Figure 20 illustrates the time average in the End-to-End delay observed during the fifteen minutes of simulation time for the Voice application in each of the three scenarios.

As can be observed, the time taken for packets to be transmitted from the source to the destination, or the End-to-End delay was found average out to approximatly 0.30 seconds for mobile WiMAX and approximatly 0.18 seconds for mobile WiFi. Real time applications such as voice reaquire the ETE to be as low as possible to provide for a seamless and more natural conversation to take place.

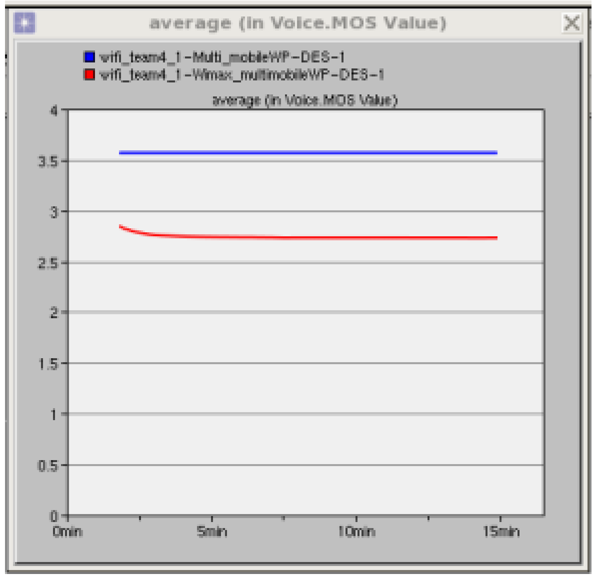


Figure 21: MOS value

As can be seen from Figure 21 the MOS value for mobile WiFi is higher than MOS value for mobile WiMAX. Mobile WiFi have preceived qualities that are good, with the degree of impairment falling between being slightly annoying and perceptible but annoying for mobile WiMAX.

6. CONCLUSION

- Throughput of WiMAX is better in case of larger traffic and wide area range.
- WiFi have less packet loss in small area network.
- Queuing delay in WiFi does not depend on mobility of the MS but in case of WiMAX it increases as MS start moving.
- There is packet loss in WiMAX when MS start moving with trajectory.
- WiMAX can handle more load as compared to WiFi.

Different parameters such as Delay, Load, Throughput affect the performance of WiMAX in a small area. The parameters for different models such as Base station, router and subscriber station were studied. Delay for base station and router was compared and as expected delay of router was less but it was for entire period of 30 minutes but in case of base station it had higher value but was present only for first few minutes. As expected WiFi works better in a small area as compared to WiMAX. This project presented several challenges, such as generating a working WiMAX network in OPNET and setting attributes to make the network realistic. Also, learning about the technical aspects of WiMAX and video conferencing enabled to determine a good set of scenarios to run.

We planned to implement this project in OPNET version 16 but we were unable to do so because we could not define trajectory in order to randomly locate the mobile stations and due to this the project was done in OPNET version 15.

7. FUTURE WORK

- Comparison of WiFi and WiMAX can be done on a larger network.
- Handoff comparison of small network vs. large network can be done.
- QoS of WiFi and WiMAX can be compared.
- Performance optimization with Request-to Send (RTS) and fragmentation could be done.
- To obtain better tuning of simulation's performance, there are several aspects of the simulation that could be used for further work such as changing parameters for different models used.
- Varying the simulated terrain between the user and the BS would effects of different physical landscapes.
- The path loss model could be other than chosen Free Space loss which was chosen for this project.
- Finally, increasing the video data rate to high-quality video settings would also be beneficial and would require changing all parameters.

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9. ORIGINAL PROJECT IDEA

Our original project idea was to use Renju Narayanan’s Master’s thesis project Modeling and Performance evaluation of General Packet Radio Service (GPRS) which was done in OPNET version 10.0A and upgrade to OPNET version 16.0.Unfortunately we spent a lot of time trying to find the errors in the model which was uploaded on OPNET contributed model depot. We could have created a new project in GPRS using OPNET but due to time restriction we were unable to do so.

9.1. GPRS ABSTRACT

General Packet Radio Service (GPRS) is a 2.5 generation network and is a predecessor to the third generation (3G) cellular networks. Global System for Mobile Communications (GSM) uses GPRS system for packet switched wireless network technology. GPRS architect includes: Mobile Station (MS), Base Station Subsystem (BSS), Home Location Register (HLR), Serving GPRS Support Node (SGSN), and Gateway GPRS Support Node (GGSN). GPRS offers efficient bandwidth utilization by allocating channels only when needed and by releasing them immediately after their use.

GSM is a 2G cellular network which operates at 900 and 1800 MHz in Europe and 850 and 1900 MHz in North America. It uses a combination of Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) schemes to access radio channels.

9.2. GPRS ARCHITECTURE

GPRS architecture is based on the GSM network. The components of a GPRS network are: Mobile station (MS), Base Station Subsystem (BSS), Serving GPRS support node (SGSN), Home Location Register (HLR), Gateway GPRS Support Node (GGSN), and an external packet data network. The BSS includes Base Transmitter Stations (BTSs) and a Base Station Controller (BSC).

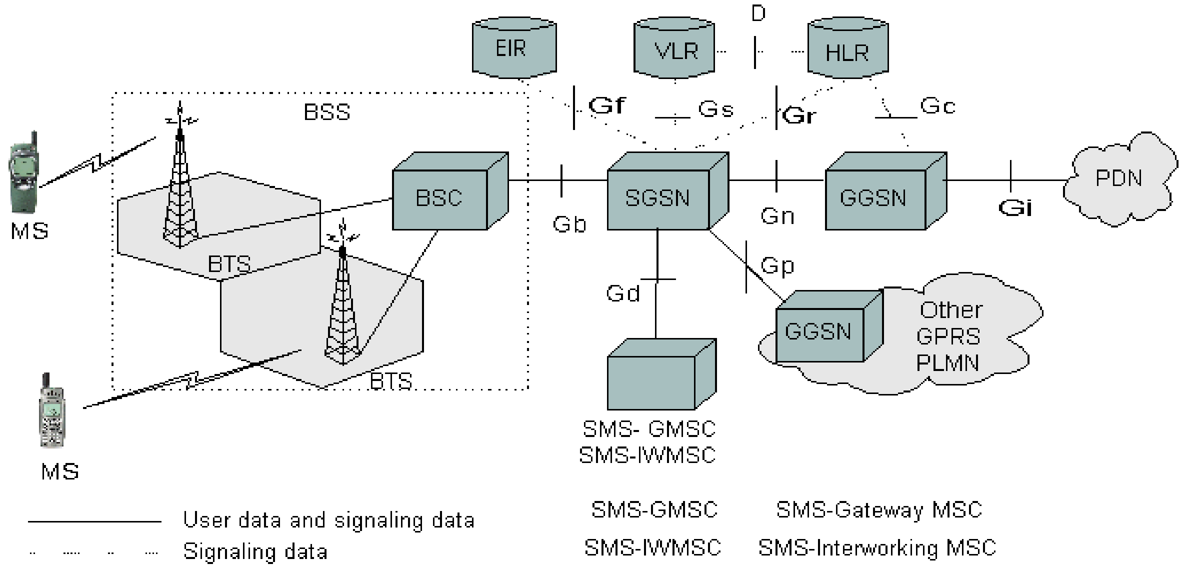

Figure 22: GPRS Network Architecture

Mobile Station (MS) consists of a Mobile Equipment (ME) and a Subscriber Identity Module (SIM). The ME is a device commonly known as the cell phone or mobile telephone. In addition to voice, these MSs support packet data transfer. MSs that support GPRS may be classified as Class A, Class B, and Class C. Class A MSs simultaneously support the GSM and GPRS services. Class B MSs and Class C MSs support either GSM or GPRS services at a time. However, in order to enable GSM services, Class C MSs have to explicitly disconnect from the ongoing GPRS services.

Base Station Subsystem (BSS) consists of a Base Station Controller (BSC) and one or more Base Transceiver Stations (BTSs). A Packet Control Unit (PCU), which is used to distinguish between voice and packet data transfer may be located at the BTS, BSC, or SGSN. BTSs communicate with MSs via the air interface. Its main functions are channel coding, ciphering and deciphering, modulation, power control, and timing advance. BSC controls several BTSs and provides an operation and maintenance access point for the entire BSS.

The SGSN exchanges messages between MSs within its service area and GGSN. Its functions are authentication, ciphering, session management, mobility management, logical management, and billing. The GGSN acts as a gateway between the GPRS system and external Packet Data Networks (PDNs).

Home Location Register (HLR) stores subscriber information, current SGSN address, and addresses for each user. Visitor Location Register (VLR) stores the current location and related information of a visiting subscriber. Equipment Identity Register (EIR) stores information regarding the ME.

9.3. GPRS REFERENCES

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