Coverage Area and Capacity Evaluation for WiMAX Networks

Awan Nahel Mahmood

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Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Computer Engineering.

Prof. Dr.Işık Aybay
Chair, Department of Computer Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Computer Engineering.

Asst. Prof. Dr.Gürcü Öz
Co-Supervisor

Assoc. Prof. Dr. Ali Hakan Ulusoy
Supervisor

Examining Committee

1. Assoc. Prof. Dr. Ahmet Rizaner
2. Assoc. Prof. Dr. Mohammed Salamah
3. Assoc. Prof. Dr. Ali Hakan Ulusoy
4. Asst. Prof. Dr. Yıltan Bitirim
5. Asst. Prof. Dr. Gürcü Öz

ABSTRACT

WiMAX stands of Worldwide Interoperability for Microwave Access based on IEEE 802.16. It can support both fixed and mobile terminals of VoIP over optimal wireless broadband networks. Due to the increasing demands of wireless broadband services, WiMAX researches become one of the hot topics nowadays, i.e.; throughput, speed of transmission, load, delay, jitter, congestion control, coverage area, hand off, cost and others. For that, the main objective is to do tradeoff between the quality of services with the cost. WiMAX gives an outlook and a good indication of successful future and successful technology that will provide last-mile connectivity. In this thesis five different scenarios that monitor throughput, delay and load are discussed to find out the coverage area of the Base Station (BS), maximum number of Subscriber Stations (SSs) within the coverage area of the BS and the intersection point for the coverage area for each of two neighbouring BSs. The number of fixed nodes (fixed SSs) and the distance are changed in each scenario. We need more than one BS in order to cover more nodes or if nodes are outside the coverage area.

Keywords: Optimized Network Engineering Tools Modeler (OPNET), quality of service (QoS), Worldwide Interoperable for Microwave Access (WiMAX), area, throughput, delay and IEEE 802.16.

ÖZ

Mikrodalga erişim için dünya çapında birlikte çalışabilirlik anlamına gelen WiMAX (Worldwide Interoperability for Microwave Access), IEEE 802.16 standartlarını kullanan cihazlar için bir sertifika işaretidir. WiMAX kablosuz geniş bant ağları üzerinde hem sabit hem de hareketli VoIP kullanan terminalleri destekleyebilmektedir. Kablosuz geniş bant hizmetlerine artan talepten dolayı, WiMAX alanında yapılan verim, iletim hızı, yük, gecikme zamanı, gecikme farklılık problemi, tıkanıklık kontrolü, kapsama alanı, devir mekanizması, maliyet araştırmaları gibi konulardaki çalışmalar günümüzde sıcak araştırma konuları haline gelmiştir. Tüm bu çalışmalardaki temel amaç, en iyi hizmet kalitesini en uygun fiyata sunabilmektir. Bu aşamada WiMAX teknolojisi gelecek için son kilometre bağlantısı sağlayacak başarılı bir teknoloji adayı olarak görünmektedir. Bu tez çalışmasında beş değişik senaryo ile WiMAX teknolojisi kullanılan sistemin verimi, gecikme zamanı ve yükü incelenerek bir baz istasyonunun sağlayabileceği en uygun kaplama alanı ve bu alan içerisinde destekleyebileceği abone sayısı bulunmaya çalışılmıştır. Tez ayrıca iki komşu baz istasyonu arasındaki en uygun mesafenin ne olması gerektiği yönünde çalışmaları da içermektedir. Bu çalışmalar sırasında sabit durumda olan abonelerin sayıları ve baz istasyonuna olan mesafeleri değiştirilerek sonuçlar elde edilmiştir. Artan abone sayısına göre ihtiyaç duyulan baz istasyonu sayısının ne olması gerektiği sonuçlarla gösterilmiştir.

Anahtar Sözcükler: OPNET, hizmet kalitesi (QoS), Mikrodalga erişim için dünya çapında birlikte çalışabilirlik (WiMAX), en uygun kapsama alanı, verim, gecikme, IEEE 802.16.

DEDICATION

I want to seize the opportunity to fully thanks my parents; my father and my mother, who were always beside me spiritually, supporting me with all their truth feelings, praying for me to achieve success and exist my and their dream by getting my master certificate from this reputed university.

A very special thanks for my wife Dr. Um-Mo'amen, that she never ever hesitate to provide me with love, bravery, patience and self-confidence. Really she is a great wife for me, a great mother for my children, a great relative to my family and a great daughter to my parents with the absence of me from there in my lovely country Iraq.

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LIST OF ABBREVIATIONS

AAS	Adaptive Antenna System
BE	Best Effort
BER	Bit Error Rate
BS	Base Station
BWA	Broadband Wireless Access
CSS	Cascading Style Sheet
DL	Downlink
Ert-PS	Extended Real-Time Polling Service
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
FPS	Frames Per Second
FTP	File Transfer Protocol
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol Services
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISP	Internet Services Provider
LMDS	Local Multipoint Distribution Service
LOS	Line of Sight
MAC	Medium Access Control

MAN	Metropolitan Area Network
MC	Multi-carrier
MIMO	Multiple Input Multiple Output
MTM	Multipoint-to-Multipoint
NLOS	Non Line of Sight
Nrt-PS	Non Real Time Polling Service
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open System Interconnection
PHY	Physical
PMP	Point-to-multipoint
PTP	Point-to-point
POP	Post Office Protocol
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
Rt-PS	Real Time Polling Service
RS	Relay Station
SC	Single Carrier
SMTP	Simple Mail Transfer Protocol
SNR	Signal to Noise Ratio
SS	Subscriber Station
TCP	Transmission Control Protocol

TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
UDP	User Datagram Protocol
UGS	Unsolicited Grant Service
UL	Upper Link
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
VoIP	Voice over Internet Protocol
WiMAX	Worldwide Interoperability for Microwave Access
WWW	World Wide Web
XML	Extensible Markup Language

Chapter 1

INTRODUCTION

1.1 Problem Definition and Motivation

IEEE 802.16 standard is based on Worldwide Interoperability for Microwave Access (WiMAX) wireless broadband. According to this standard, the physical (PHY) and medium access control (MAC) can support efficiently the broadband wireless access (BWA). Fixed and mobile broadband connectivity devices can be supported by the BS through many versions of WiMAX. A major factor that plays an important role is to limit the ability of the system from the capacity perspective to the number of users through the network at the same time [1].

The use of multimedia services became one of the most important requirements. Therefore, giving a suitable throughput and delaying each nominal application are being a challenge to the systems. For that reason, the traditional systems are not able to cover the increasing number of users and multimedia services [2].

One of the new systems that aims to provide the users with high capacity and different services is the WiMAX. Hence; the design of WiMAX is a technology for BWA depends on the IEEE 802.16 family standards (802.16a, 802.16b, 802.16c, 802.16d, 802.16e and 802.16m) which supports fixed, portable and mobile devices. Different operation modes are designed in this system which contains point-to-point (PTP), point-to-multipoint (PMP) and multipoint-to-multipoint (MTM) or mesh as mentioned in Figure1.1. It provides Quality of Service (QoS) by transferring the data over a unidirectional connection. The WiMAX can control the properties of the both directions links; the upper link (UL) and the downlink (DL) in an independent manner [3].

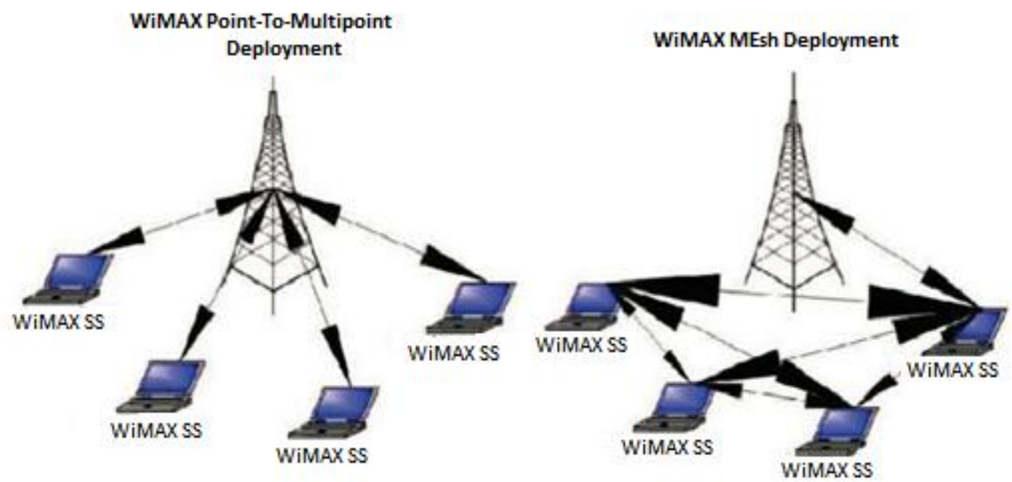

Figure1.1: Mesh and point-to-multipoint mode [3].

The basic standard of WiMAX (802.16) has a range up to 50 km and data rates up to 134 Mbps. Aside from the frequency ranges from 11 to 66 GHz can be covered. Different types of applications can be supported by WiMAX such as web browsers, chatting, files, sharing, e-mail, video and voice communications with the help of the high capacity of the system. The basic standard of WiMAX (802.16) has frequency ranges from 11 to 66 GHz that can be covered and also a range up to 50 km with data rates up to 134 Mbps [4]. There are other standards that are employed like the IEEE802.16e-2005 standards for the mobile services and also the IEEE 802.16d-2004 standards used for the fixed services. The PMP mode of communication in between the Base Station (BS) and a Subscriber Station (SS) and mesh mode permit transmitting and forwarded data between neighboring SSs. WiMAX depends on Wireless Metropolitan Area Network (MAN). The physical layer in mobile WiMAX which is IEEE 802.16e standard is the main part that this thesis will cover. Increasing the capacity or the bandwidth in wireless communication systems was exist by the use of Multi-Input Multi-Output (MIMO) and using different antennas in receiving and transmitting the signal from one side to the other [5].

1.2 Research Objectives

The thesis focuses on QoS of the connectivity between different BSs with the SSs. Hence; the BS has a specific coverage area and number of subscribers that can be covered according to the WiMAX characteristics.

A number of subscribers and a connectivity distance of a BS with another BS and / or SSs leads to be a critical point in such applications. This research focuses on making the throughput and load to be the maximum while the delay preferred to be as minimum as possible. This is done by selecting the distances and number of subscribers.

Using the OPNET it is shown that after capacity for each BS; the delay will be very high and the throughput will approach to zero. It is also shown that after a certain distance between two BSs a disconnection may occur. Thus, this research developed methodologies and techniques of finding these values through different scenarios and strategies as will be discussed in next chapters.

1.3 Thesis Layout

In addition to the previously shown introduction in this chapter, the next chapters will be organized as follows :

Chapter two includes a brief overview of WiMAX system, presenting WiMAX classes and some applications that belongs to WiMAX.

Chapter three includes types of WiMAX technologies and the five classes of QoS in details.

Chapter four presents simulation configuration and parameters, presenting simulation results via OPNET 14.5 modeler and Chapter five presents conclusion and suggested works for the future.

1.4 Contributions

This research depends mainly on the studies in [1], [2] and [3] to discover the values and it presents:

1- The maximum distance between one SS and one BS.
2- The maximum number of SSs that one BS supports.
3- The distance between two BSs and one SS.
4- The distance between two BSs for different number of SSs.
5- The number of SSs that two BSs support.

Chapter 2

THEORETICAL REVIEW

2.1 Introduction

In 1990 service providers and cell phone companies began to work on the technology of wireless broadband connections. This technology was pictured as a way to keep the security and speed of a hardwired network, with keeping into their account the low cost of wireless networks. The 802.16 standard was established in 1999 by the IEEE. The release of this technology was in 2001 but it had a small range and restricted to line-of-sight (LOS) transmissions. In addition, WiMAX forum began in 2001 which can act a way to advertise and market the use of the 802.16 standard.[6]

The convention is a noncommercial organization that includes members more than 520 companies which share a same aim and goal to combine WiMAX technologies with users and into businesses all over the world. During the growing of this technology through the years; there were many bursts noticed. One of the largest impressive periods of growth happened in 2005 when the standard 802.16e was discovered. It was the first mobile WiMAX system. This technology is growing in a rapid way and we will notice even faster speeds and more coverage as WiMAX technology remains to introduce internet capabilities [6].

IEEE in the date 1998, treated with a group of protocol 802.16 in order to establish a standard that is called a wireless MAN. Basically, this group concentrated on creating solutions for the band of the range between 10-66 GHz via the fundamental application transmitting connections of high-speed that does not have fiber. Hence; these systems such as Local Multipoint Distribution Service (LMDS), were believed that they were able to plunk between fiber rings and to spread that bandwidth via a configuration of PTM connections to LOS businesses. This group made once again a standard that was agreed on in 2001. In such standard, wireless MAN made a specific corporation between the physical layer and the MAC layer and a single-carrier modulation techniques into a spurt Time Division Multiplexing (TDM) modulation that propped both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) [5][17].

In 2003, the group began to expand and adjust its work in both licensed and license- immune band of frequencies in the range of 2-11 GHz, that could allow Non Light of Sight (NLOS) arrangements. These adjustments leads the IEEE group to propose the IEEE 802.16a by adding the Orthogonal Frequency Division Multiplexing (OFDM) modulation within the first layer of the Open System Interconnection (OSI) reference model which is known as the physical layer to support adjustment in environments of multipath. Before the expected time that was mentioned in their planes, OFDM modulation had created a method of choice to deal with broadband of multipath and it became as a part of the amendment IEEE 802.11 standards. In addition IEEE 802.16a also added a specific options from MAC-layer to the OFDM physical layers, that becomes as an entrance for the proposing Orthogonal Frequency Division Multiple Access (OFDMA) [5].

2.2 Literature Review

In [2] performance of WiMAX is discussed for different multimedia applications for real time services like Voice over IP (VoIP) and the performance of network metrics like end to end delay, throughput and jitter are presented. The simulation results modified that G.723 is preferable and better than codecs G.728, G.711, G.726 and G.729 due to its lower delay, throughput and traffic received.

Bagoria and Garhwal in [3] proposed the performance analysis of physical layer with the use of OFDM of the WiMAX system and the use of Quardrature Phase Shift Keying (QPSK), 64 Quardrature Amplitude Modulation (QAM) and 16QAM for both uplink/ downlink on the basis of Signal to Noise Ratio (SNR) and Bit Error Rate (BER) and applying video and audio by the use of OPNET simulator. Delay, load and throughput took place in discussion with all adaptive modulation techniques.

The research in [8] shows how to make a model for the physical layer by the use of Matlab. It discussed the physical layer with the use of convolution encoding rate of 5/6 with QPSK modulation and the transmission with 256 carrier OFDM symbols. SNR and BER are proposed clearly in this paper. Relay Station (RS) is offered to intensify the throughput and coverage area of the WiMAX system but it is shown that narrow channel size is not good for a system with RSs.

Research in [10] displays WiMAX physical layer threats, scrambling and jamming. The performance of the system is created to classify the use of different jamming signals that permits to identify central areas where the development of the system should concentrate. Surprising results are found from the point of view of the basic theory revealing that forms of interference minimized the performance of the system in a rapid way. For this reason, the form of incoming jamming should be taken in consideration and has to be well known before spreading the system. The study also talks about the noise Multi-carrier (MC) jamming, noise jamming and some techniques to reduce jamming. As scrambling and jamming can damage communication in the targeted area, the OFDM based physical layer in WiMAX makes MC jamming a challenge.

Sharef and Alaradi in [11] discuss link layer simulation that upgrades the WiMAX physical layer of IEEE 802.16e, in the order of using ITU- Reference channel models. The study interprets the fading channel effect, cyclic prefix and

Doppler shift on the performance of the system design. A differentiation and evaluation of the performance of QPSK modulation technique by the use of bit energy-to-noise density ratio versus BER curves. It presents that using the channel estimation makes the system performance better. Hence; the performance and evaluation built on the synchronization between the receiver and the transmitter.

Abbas and Naqvi in [13] discuss the performance evaluation of WiMAX by studying fixed WiMAX and mobile WiMAX with the use of network simulator NS version 2.34. Results obtained from the simulation present the delay, throughput and jitter and can be affected by the change of modulation scheme through changing number of nodes or changing distances between the SSs and the BS. Simulation of performance is achieved for User Datagram Protocol (UDP) over mobile and fixed WiMAX. Increasing in throughput encourage into increasing the average jitter and average delay values by increasing in the number of SSs. The effect of different modulation scheme is considered and QAM is found to be the best. Another result that is found that larger distance can be supported with fixed WiMAX rather than the mobile WiMAX.

In [14], the effect of jamming on WiMAX performance is discussed at the physical layer which depends on OFDM by the use of different jamming signals and without jamming. This paper studies both mobile NLOS and fixed NLOS using OPNET simulator. In addition; the results show the relations of BER, throughput and jam signal via downlink/uplink.

In [16], it modifies the model of the WiMAX physical layer by the use of Matlab. It is known that this model is useful for the performance evaluation of BER for the real and non-real time audio/video communication by the use of the physical layer of WiMAX with respect to variable encoding rate, channel conditions and digital schemes. In this paper, in order to evaluate the performance; the receiver and transmitter model are simulated under standard parameters. Even though, involution coding is proposed to set up a better performance for the system, the analytical part of the system is done by controlling the parameters of each of the missing bet ration and missing packet ratio through the overall of transmission during the network.

Researchers in [18] discuss the effectiveness of IEEE 802.16a MAC layer operation. Two approaches of distributed and centralized scheduling are examined but the adaptive modulation is not included in this paper. The results reveal that the efficiency decreases with the number of connections increases and hops for the distributed and centralized scheduling .

The research in [29] proposes the calculation of OFDMA based IEEE 802.16 WiMAX systems downlink. The author focuses in the effect of adaptive modulation and coding rate, elastic data, reuse partitioning, constant-bit-rate streaming and underlying collisions where there is more than one cell for two flows types.

2.3 Brief Overview of WiMAX

Multiple physical specifications at licensed/unlicensed bands are supported by IEEE 802.16 standard. The frequency band ranges are in between 10 – 66 GHz and the based version of standard is selected to support a single modulation carrier [5]. Applications under 11 GHz frequency bands are also being supported by the mentioned standard. The selection of the 2-11 GHz PHY layer design was in order to operate in NLOS situations, which are suspected in metropolitan areas. Furthermore, the standard IEEE 802.16 determines two modes of operations, PTP mode and mesh or PMP mode. PMP mode through over the traffic is pointed from the BS to SSs whether directly or via fixed RSs and vice versa. However, subscribers which are far away from BS can depend on near subscribers that act temporally as a RS [7]. Adaptive Antenna System (AAS) is an elective feature. It improves the capacity and coverage in addition to spectral efficiency. It contains an advantage that it can apply only one antenna at the SS side, which will result in making the SS implementation procedure simple [5].

The existing and new operators can also try to use WiMAX to propose differentiated personal broadband services, like mobile entertainment. The different levels of QoS and flexible channel bandwidths support can permit the service providers to use WiMAX as shown in Figure 2.1. In order to distinguish between high-bandwidth and low latency entertainment applications, for instance, WiMAX can be installed into a portable gaming device to be used in a mobile and fixed environment for interactive games. Other examples are streaming audio services, video services, MP3 players and portable media players [15].

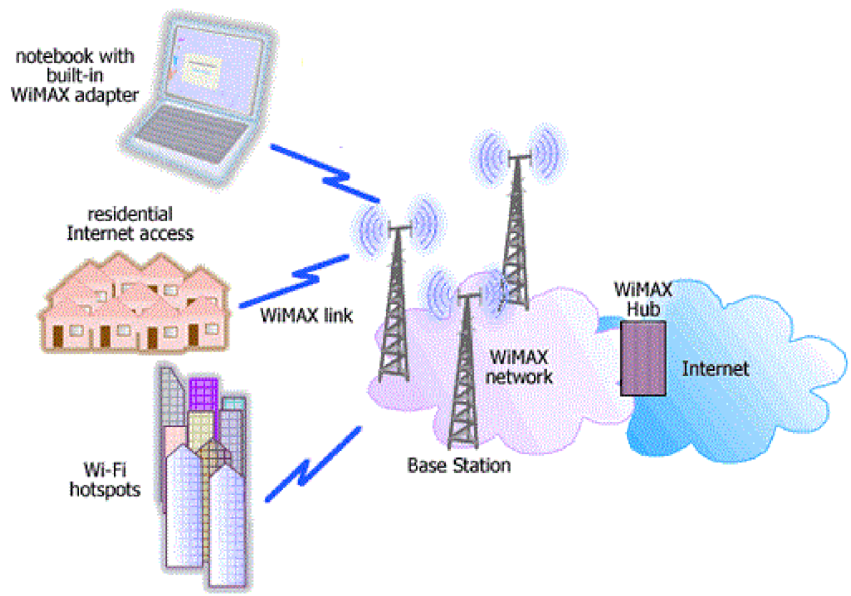

Figure 2.1: How WiMAX works [15].

2.4 Comparison between WiMAX and WiFi

The technology of WiMAX depends on an open standard to qualify the requirements of a wide area very high speed internet access with a flexible way and low cost. The goal is to support consumers and Internet Service Providers (ISPs) with the same facilities of MAN. It is formed for a high-speed data transmission and motivates change in contents of services and upgrading in mobile devices. It is generated to work properly for IP-based wireless broadband with high-speed which leads to have a better internet experience in wireless broadband mobile. The BS is responsible to establish and organize the connection between the SSs with the core network itself [21].

Since of high transmission rate and large frequency band range, WiMAX can be the intensity of 802.11 contributions for internet connection. On the other hand, users are able to connect mobile devices like laptops and handsets with no intermediate (802.11) with the WiMAX BS. The WiMAX scheme is able to supply a very cheap and fast broadband connection to markets which have no infrastructure (fiber optics or copper wire) like unwired countries and rural areas.

WiMAX consists of two standard connectivity and are presented as, mobile WiMAX (IEEE 802.16e-2005) and fixed WiMAX (IEEE 802.16d-2004). Fixed WiMAX is a PTM technology but mobile WiMAX is MTM (mesh) technology, same as cellular infrastructure. Both solutions are made to transfer a universal low cost with high-throughput broadband wireless services. Mobile WiMAX uses OFDMA technology which has taken advantages in latency, advanced antenna performance, spectral efficiency and better multipath performance in an NLOS environment. The WiMAX specification become better even with many restrictions of the Wi-Fi standard (802.11b) by providing a stronger encryption and increased bandwidth [21].

2.5 WiMAX Standards

WiMAX IEEE802.16 standard assigns a set of MAC and PHY layer criterions purposed to supply fixed broadband wireless access in PTP or even PMP topology. As mentioned before the PHY layer has one carrier scheme for the frequency band in the range between 10 GHz and 66 GHz. BS is responsible for the decision of transmission times, durations and modulations and communicates with all SSs in the network by broadcasting its table through uplink and downlink directions. The only responsibility of the SS is to listen to the BS that are located in its coverage area and they are not restricted to hear any other node in the network. SS is concerned to negotiate the proper bandwidth on a burst to burst essential in a flexible manner. The standard dispatches each of QPSK, 64 QAM and 16 QAM as amendment scheme. Standard can be adjusted depending on the appropriate performance and powerful of the communication and can be varied from packet to packet and SS to SS [21]. WiMAX IEEE802.16 standard supports both FDD and TDD as mentioned in Table 2.1.

2.5.1 IEEE 802.162001 Standard

The first issue of this standard specifies a set of MAC and PHY layer standards intended to provide fixed BWA in PTP or PMP topology. The PHY layer uses Single Carrier (SC) modulation in the 10–66 GHz frequency range. Transmission times, durations and modulations are assigned by a BS and shared with all nodes in the network in the form of broadcast Uplink and Downlink maps. SSs need only to hear the BS that they are connected and do not need to listen any other node of the network. SS has the ability to negotiate for bandwidth allocation on a burst to burst basis, providing scheduling flexibility [9].

2.5.2 IEEE 802.16c2002 Standard

IEEE 802.16c got the approval from the IEEE standard group on December 2002. This improvement standard adopted the frequency band between 10 to 66 GHz range and error corrections were exist for some discrepancy of the first version of the standard [9]

2.5.3 IEEE 802.16a2003 Standard

IEEE 802.16a2003 standard is an improvement of the IEEE 802.162001 standard. In this standard it also provides improvement on both PHY and MAC layer. These modifications were proposed in January 2003 by IEEE 802.16 group. This proposed improvement in the physical layer provides a band frequency in the range of 2 to 11 GHz and it supports both licensed and license immune bands as categorized in Table 2.1. NLOS implementation becomes qualified through via the containment of band frequency below 11 GHz range and by expanding the coverage area of the network. Because of NLOS implementation, a multipath connectivity had a problem. The option of applying OFDM scheme was added as another option to SC modification. In this standard, it becomes more secure and many of privacy layer characteristic became compulsory but they were optional in 802.162001. Also, in addition to PMP IEEE 802.16a2003 induce the mesh topology as optional [9].

2.5.4 IEEE 802.16d2004 Standard

802.16a2003, 802.16c2002 and 802.162001 all together were combined and a new standard known as 802.162004 was made. Initially, it was released under the name 802.16REVd as a revision of the standard, but the changes were so real and absolute which made the standard to be reissued at September 2004 under the name 802.16d2004. The whole family of the standard in this version is authorized and confirmed [9].

2.5.5 IEEE 802.16e2005 Standard

This standard was proposed and modified in December 2005 based on the IEEE 802.16d2004 standard. Modifications took place specially on the PHY and MAC layer prompting to allow combination between mobile and fixed practicability in licensed band. Table 2.1 shows main classes of IEEE 802.16 standard [9].

Table 2.1: IEEE 802.16 standard main classes [21].

Standard	Features
802.162001	Support MAC and PHY specification for 10-66GHz.
802.16 c (2002)	Air interface for fixed broad wireless access system, MAC and PHY specification for 10-66GHz(LOS).
802.16a (January 2003)	Amendment to 802.16; MAC modifications and additional PHY specifications for 2-11GHz (NLOS); three physical layers-OFDM, OFDMA, single carrier; additional MAC functions; mesh topology support; ARQ.
802.16d (July 2004)	Combine 802.16a2003, 802.16c2002 and 802.162001.
802.16e (December 2005)	Amendment to the IEEE 802.16d2004, some modification to MAC and PHY.

2.6 Applications and their Descriptions

WiMAX supports different applications because of its high capacity. Applications differ from multiple points of views like bandwidth needs, the protocols based on real-time or non-real-time, etc. Most common applications are selected in this research as illustrated in Figure 2.2 [21].

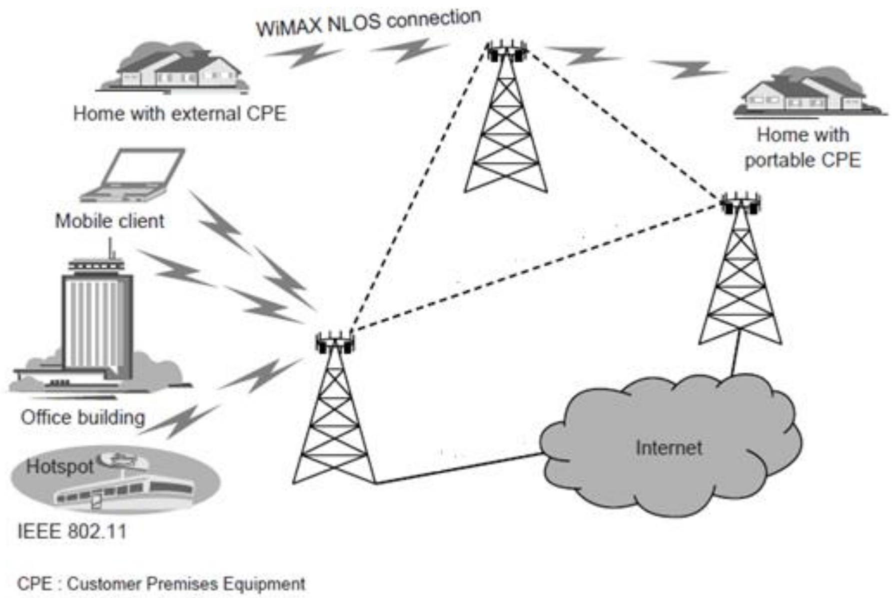

Figure 2.2: Applications of IEEE 802.16 (WiMAX) [21].

2.6.1 World Wide Web

A web browser is a World Wide Web (WWW) application that can get an access, retrieve and present information from internet with respect to user's demands which can be specified by the Uniform Resource Identifier (URI). This information may be a video, web page, image or other contents. Users can easily do search into their browsers to relevant resources through hyperlinks. Even though; initially browsers was made to use the WWW, which then improved to get an access into files from the file system or shared information announced on a private web server. The main popular web browsers are Opera, Google, Internet Explorer, Safari, Mozilla Firefox and Netscape. Information retrieval fetching is the main aim of using web browser, which allows users to display the information and navigate or rooting information through the internet [31].

When user enters Uniform Resource Locator (URL) into any kind of browsers, web browsing starts its procedure, then the URI will identify and analyze the entered URL. Most of the URI in the link bar starts with the Hypertext Transfer Protocol (HTTP) or sometime with the Hypertext Transfer Protocol Security (HTTPS) for File Transfer Protocol (FTP) and web banking which is more secure against victim [31].

After applying information retrieval a software component that takes encoded content or called metric data as done in Hyper Text Markup Language (HTML) FTP or Extensible Markup Language (XML) or even in image files and constructing information such Cascading Style Sheets (CSSs) and then on the screen in front of the end user the designed content is going to be display. This is called as “rendering” [31].

2.6.2 E-mail

Simple Mail Transfer Protocol (SMTP) is a protocol that support the electronic mail or (e-mail) for sending messages to mail server. SMTP is one of the application layer protocols in the OSI referenced model, and is a connection-oriented protocol because of reliability and classified under a Transmission Control Protocol (TCP) connection. E-mail applications are thought to be applications that is asynchronous, i.e. non real-time. Post Office Protocol (POP) is a protocol that can also support e-mail application for receiving mail from mail server [31].

2.6.3 File Transfer

One of the initial activities discovered on the internet is transferring the files. Every second of every day, internet users are downloading files from different websites and webmasters are uploading files and web pages to their website. The most common way to transfer files over the internet is through the FTP. It is a client-server connection and an application layer protocol [31].

2.6.4 Voice over IP (VoIP)

VoIP is a methodology for delivery of voice communications and multimedia sessions over internet and is broadly distributed technology and telecommunication operators are looking for to gain from it. VoIP is so efficient because it uses an existing infrastructure in the form of internet connection aside from the low cost of using this type of communication. But there is tradeoff between the cost and QoS that is why many vendors and users prefer to use a circuit switching “analog telephony” instead of using this type of packet switching VoIP [24]. VoIP implementation may face problems with latency, packet loss and jitter which may affect the QoS. VoIP may deliver voice communications and multimedia sessions over Internet Protocol (IP). This process includes fragmentation and defragmentation of voice, and to isolation of jam signals and then compression the voice signal with the use of compression/ decompression (coding/ encoding) algorithms. Finally, voice is going to be encapsulated into packets and sent via IP into their destination address. In the receiver side packets are decapsulated and cyclic redundancy check is taking place for error detection. Since we guarantee that packets are received in order through the sequence number of packet and with no error a decompression methodology is taking place to retrieve the packet in the way of being sent. We need to take care of the synchronization and delay management to make sure that there is adequate spacing [31].

2.6.5 Video Conferencing

To make a video conference, users need a camera, speakers, screen, software, microphone to process the video and audio and a connection between the computers. Most new computers have hardware with all the necessary items. There are several available free video conferencing programs as well as paid programs with more features, commonly needed for business conferences. The connection needed among computers is usually an internet connection, but cell-phone networks, local area networks and other proprietary networks are also used. Video conferencing contains the transfer of audio and video among two users (PTP) or multiple users (MTM). The video is encoded as a series of video frames, with frame rates ranging from 8 frames per second (fps) for low-bandwidth, video with low quality, to 30 fps or higher for video with high-quality. The video is compressed by using lossy compression codes like MPEG-4 or H.264 to save bandwidth. This enables transmission of high-quality video with low as 256 kbps of bandwidth, instead of different megabits per second with no compression. Lossless compression may be used, but it has lower compression ratios and the difference is mostly negligible between the quality lossless and lossy video compression to most users. Video conferences are conducted at different video resolutions. It is always preferred to have higher resolutions, but they need high data rates so they can keep the video with good quality [31].

Chapter 3

WiMAX TECHNOLOGIES

3.1 Fixed Broadband Wireless

Fixed WiMAX (IEEE 802.16d:2004) depends on the LOS which can support different applications. It gives a rate of transmission up to 75 Mbps with a distance of nearly 50 km and works in frequency band in the range of 2 to 11 GHz. In fixed WiMAX there is a use of a SC modulation with fixed wireless applications and can be categorized to be PMP or PTP. Figure 3.1 demonstrates different PMP WiMAX applications [5].

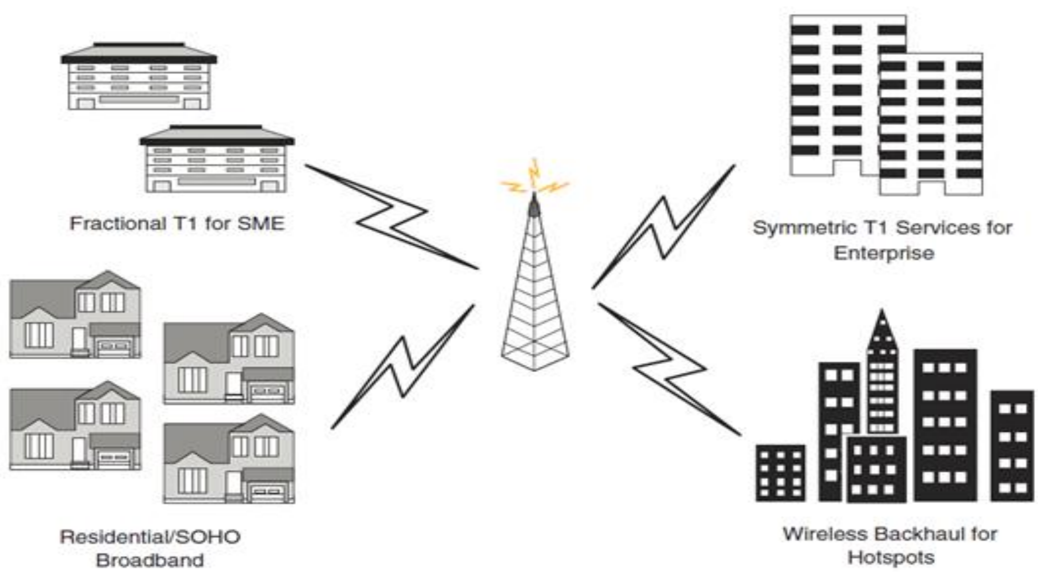

Figure 3.1: WiMAX applications over PMP topology [5]

3.2 Mobile Broadband Wireless

Mobile WiMAX (IEEE 802.16e:2005) relays on NLOS which can support fixed, portable, nomadic and mobile applications. It gives a rate of transmission up to 75 Mbps with a distance of nearly 15 km and works in frequency band in the range of 2 to 6 GHz. In mobile WiMAX there is a use of a MC modulation at physical layer [5].

Mobile broadband wireless has been improved by fixed methodology that manipulates both the access to plain broadband and the wireless mobility value chain. Hence; end users used to work with a high speed bandwidth at either work or home, then definitely they are willing to have same services in a mobile or movable device [27]. To reach mobility; that could happen by cooperate between the fixed broadband and the movable capabilities. By supplying WiMAX broadband services to any type of portable devices that will enable the end users to get a high bandwidth not only at work or home but can also everywhere. Broadband connections can cover users with specific coverage area even if they want to travel into different situations. Roaming and hand-off or handover may not be supported with movable access at vehicular-speed but can permit pedestrian-speed mobility within the coverage area. Table 3.1 shows the differences between IEEE 602.16d:2004 and IEEE 602.16e:2005 [22].

Table 3.1: Comparison of fixed WiMAX and mobile WiMAX [22].

Features	**Standard**	
	IEEE 802.16d:2004	IEEE 802.16e:2005
Spectrum	2 to 11 GHz	Fixed:2 to 11 GHz Mobile:2 to 6 GHz
Modulation techniques	16-QAM,64-QAM and QPSK	16-QAM,64-QAM and QPSK
Multiple access method	OFDM	OFDMA/S-OFDMA
FFT size	256	128,512,1024 and 2048
Support services	Fixed, Nomadic and Portable	Mobile Fixed, Nomadic and Portable
Duplexing	FDD	TDD
Coverage area	Up to 50 km maximum	2-5 km approximately
Diversity Technique	SISO	MIMO, Matrix A and Matrix B
Sub-Channelization	DL only	DL and UL
QoS classes	UGS, Rt-PS, Nrt-PS and BE	UGS, Rt-PS, Nrt-PS, Ert-PS and BE

3.3 Quality of Service (QoS)

QoS is one of the important advantages of WiMAX system, where WiMAX broadband provides five classes of QoS. Every service can be classified according to those different types: Unsolicited Grant Service (UGS), Extended Real-Time Polling Service (Ert-PS), Real-Time Polling Service (Rt-PS), Non-Real Time Polling Service (Nrt-PS) or Best Effort (BE). WiMAX supplies the five QoS classes via an architecture that emphasize process requests, access control and assign the fundamentals of radio frequencies that can achieve the needed target through each service [12][19].

3.3.1 Unsolicited Grant Service (UGS)

UGS is concerned to support real-time data streaming for fixed relay and fixed packets size which released in fixed time intervals VoIP but with no silence periods. This class insures a fixed bandwidth and compatible delay for a connection [5].

The BS makes an appropriate uplink connection with SS for the assigned bandwidth between both sides where SS can use the uplink to assure a minimum jitter because of changing in the delay times. Whereas; in the direction of downlink, UGS in the BS assures that transmitted packets through the network will be forwarded to the SS at the adequate rate. Hence; the requested bandwidth is assigned. There is no need for the SS to start transmitting the requests through the uplink bandwidth at the start of an uplink connection. In the SS side there is a buffer, in some cases this buffer may grow over time because of a minimal fluctuation on the rate of data whether in SS or in the network. After each transmission with uplink and downlink in such scenario the BS will repeat same procedures with different SSs after drainage the uplink buffer from the current SS [12].

3.3.2 Extended Real-time Polling Service (Ert-PS)

Ert-PS is concerned to provide extended real-time data streaming with different rates as in VoIP but with interactive gaming, video conferencing and with silence periods [5].

3.3.3 Real Time Polling Service (Rt-PS)

Rt-PS is concerned to provide real-time data streaming for different relay and different packets size which released at different time intervals like MPEG video, interactive gaming, audio and video streaming [5]. To assure their needed bandwidth, the BS supply adequate unicast request chances to the SSs. That leads to make it available for the network to mention in the uplink sub-frame in the second field where the SS is allowed to send request in the uplink bandwidth instead of using the contention-based uplink request area [12].

3.3.4 Non-real time Polling Service (Nrt-PS)

Nrt-PS is concerned to provide delay-tolerant data streaming for different relay and different packet size which released at different time intervals like video download, browsing and FTP [5]. The network asks to the SS to decide clearly whether it needs to share the uplink bandwidth. Hence; the frequency of such decision messages is in the order of negligible amount of time. While the network is not responsible to assure the delay and bandwidth, the SS is permitted to use the selected area for the uplink request frame in the second field of an uplink sub-frame of the contention-based to increase the speed of connection. The BS can cluster different SSs into a multicast uplink request in order to allow individual uplink requests in case if there are too many SSs in the cell for the BS. Then the BS notifies the whole cluster with time transmission for the SSs requests during the uplink bandwidth. Congestion between requests may happen, then SSs that do not have permission to allocate the uplink bandwidth they should to repeat the procedure [12].

3.3.5 Best Effort (BE)

BE is concerned to provide data streaming in the case of having no guarantee to deliver the packets on the same time or even with no minimum requirements for the service like in e-mail and internet browsing [5]. In this class there is no guarantee of any delay or even bandwidth and SSs at startup of an uplink sub-frame for their bandwidth requests have to use the contention base area. The number of cells and the coverage area are the main points that may affect on the collisions and congestions between SSs. Table 3.2 shows the main QoS categories with their applications and specifications [12].

Table 3.2: Sample traffic parameters for broadband wireless applications [22].

QOS Category	**Applications**	**QOS Specifications**
UGS	VoIP	Maximum sustained rate Maximum latency tolerance Jitter tolerance
Rt-PS	Streaming audio or video	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Traffic priority
Ert-PS	Voice with activity detection (VoIP)	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Jitter tolerance Traffic priority
Nrt-PS	File transfer protocol FTP	Minimum reserved rate Maximum sustained rate Traffic priority
BE	Data transfer, web browsing ,etc.	Maximum sustained rate Traffic priority

Chapter 4

SIMULATION SETUP AND RESULTS

The aim of the thesis is to find out the main attributes of BS and SSs with their relations. These attributes that will be discussed in the next sections are as follows:

- coverage area of the BS.
- number of SSs that can be supported and covered by BS.
- distance between BSs.
- maximum distance between BSs before disconnection occurs.

4.1 Performance Metrics

The proposed studies and scenarios are related to different performance metrics to find out results and decisions with respect to the main attributes of BS and SSs. These metrics are:

- **Average throughput** (**bits/sec**): Average throughput is the average number of bits of successful message delivery over a communication channel per unit of time (second) [25]. Average throughput can be calculated using the general formula as follows:

$$\textit{Average throughput} = \sum_{tn}^{tn+1} Packet\ Size \quad \text{(bit/sec)} \qquad (1)$$

where Packet Size is the size of served data in frame *n* between the start time, t_n, of frame *n* and the start time, t_{n+1}, of the next frame *n* + 1 [28].

-**Average delay** (**sec**): Average delay is the end-to-end transmission time between BS and SS. It represents how long it takes to transmit a bit from source node to destination node [25]. Average delay can be calculated using the general formula as follows:

$$Average\ delay = \frac{\sum_{tn}^{tn+1} Delivery\ Time - \sum_{tn}^{tn+1} Arrival\ Time}{\sum_{tn}^{tn+1} Recieved\ Packet} \qquad (2)$$

where, the Arrival Time is the time at which the packet arrives at the MAC layer of the source node, the Delivery Time is the time at which the packet is delivered to the MAC layer of the destination node, Received Packets is the total number of packets received between the start time, t_n, of frame *n* and the start time t_{n+1} of the next frame *n*+1 [28].

-**Average load** (**bits/sec**): Average load is the number of bits being submitted to the WiMAX MAC layer by its upper layer in second [23][25].

-**Jitter** (**sec**): Jitter is the variation in delay [28]. The value of jitter is calculated from the end-to-end delay as computed in(3).

$$Average\ jitter = \frac{\sum_{i=0}^{n}(Delay_i - \overline{Delay}\,)}{N} \qquad (3)$$

where $Delay_i$ represents the end-to-end delay for frame i where i is changing from 1 to n and N represents number of SSs [23].

4.2 Setup Configurations of OPNET

In the thesis OPNET modeler 14.5 – educational version as illustrated in Figure 4.1 is used to simulate the WiMAX network. In this section the main assumptions and setup configuration will be presented.

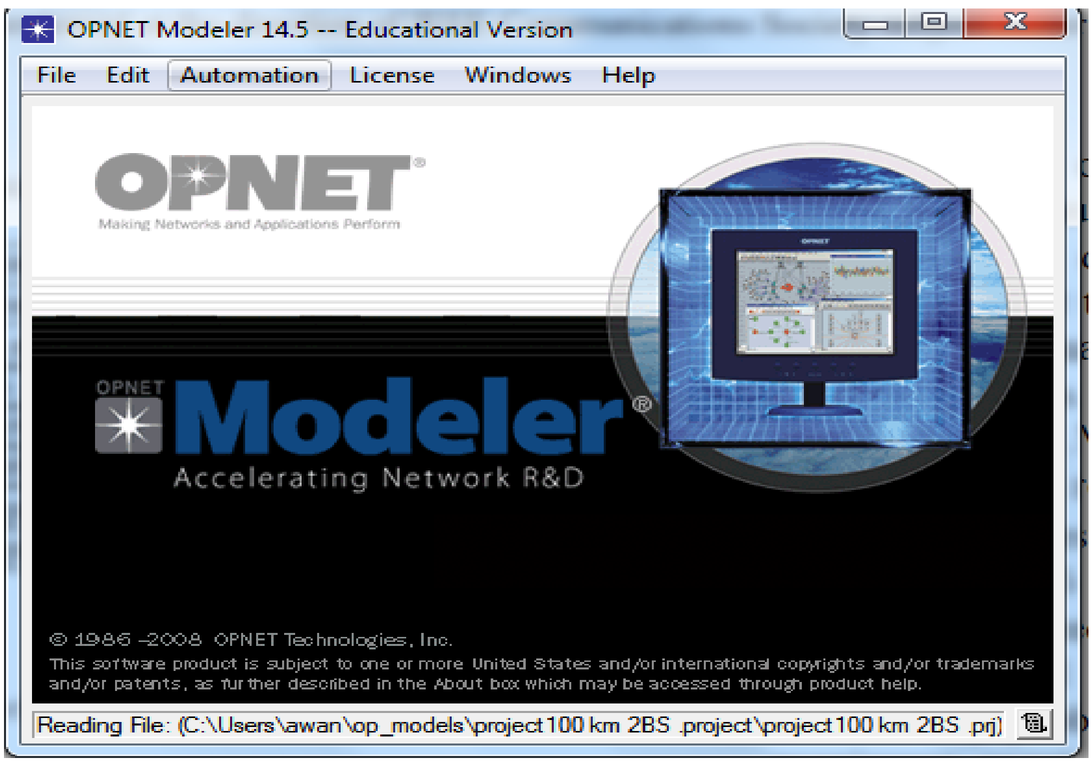

Figure 4.1: OPNET modeler 14.5 – educational version [25].

4.2.1 Assumptions

In the simulations a BS communicating with SSs in a PMP mode is considered. We only focus on the downlink traffic with OFDMA for the physical interface. OFDMA is based on a mathematical process known as Fast Fourier Transform

(FFT), that may enable 52 channels without losing their individual characteristics. Even though; static SSs take place in our studies and they are distributed randomly in each scenario. For the QoS classes we dealt identically for all BSs and SSs with UGS and Rt-PS. Hence; SSs are running similar applications in community environment. Table 4.1 simply clarifies the main assumptions of our simulation part.

Table 4.1: Simulation Attributes [1].

Attribute	Value
MAC Service Class Definition (QoS)	UGS and Rt-PS
Modulation Technique	Wireless OFDM
Number of SSs	Varied
Bandwidth	20 MHz
Duplexing Technique	TDD
Frame Duration	1 ms
Max Transmission Power	0.5 watt

4.2.2 Setup Enviroment of OPNET

With regards to related references it was decided to construct the simulation module for the different scenarios as well as mentioned in the Figures 4.2 and 4.3 to insure the connectivity of our proposed WiMAX network.

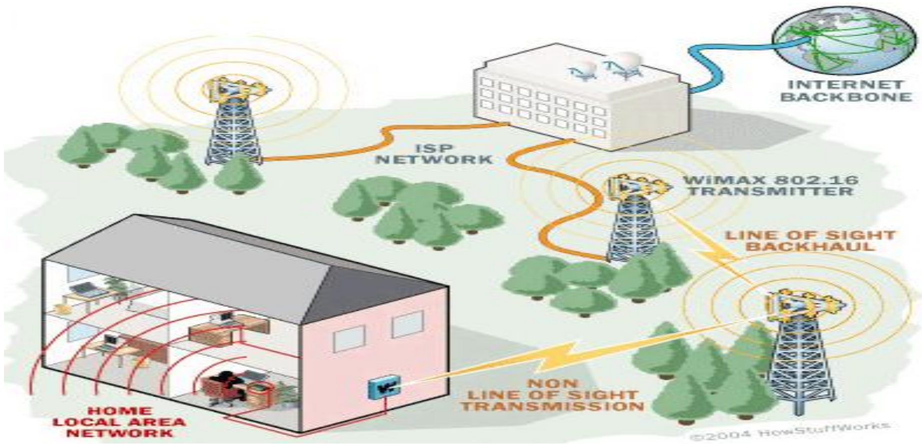

Figure 4.2: WiMAX connection [30].

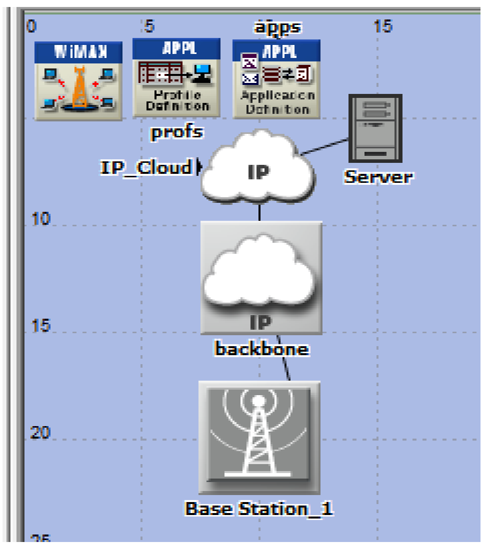

Figure 4.3: Construction of proposed simulation.

In Figure 4.3 server is used to support type of application (i.e. VoIP), while IP cloud standard is used as a link between source and destination. In addition, IP backbone standard is concerned to distribute services to BS. WiMAX configuration of physical layer and MAC layer can provide type of QoS such as UGS, Rt-PS. Profile configuration is used to create voice user profile in SS over

WiMAX. In addition, application configuration is used to choose type of application for the network (such as VoIP).

After we construct our proposed module, the configurations are set as presented in Table 4.2. The full details about the OPNET configurations of all network devices can be seen in Appendix A.

Table 4.2: Configuration of our proposed WiMAX networks

Attribute	**Value**
WiMAX_Config	
Efficiency Mode	Physical Layer Enabled
Max Sustained Traffic Rate (bits)	96000
Max Received Traffic Rate (bits)	96000
Max Latency (ms)	10
Service Class Name	Gold
Scheduling Type	UGS/ Rt-PS
Profile_Config	
Num of Rows	1
Voice User	Voice over IP Call (PCM Quality)
Application_Config	
Voice User	Voice over IP Call (PCM Quality)
Type of Service	Interactive Voice
BS	
Number of Rows	2
Match Value	Interactive Voice
Service Class Name	Gold
SS	
Match Value	Interactive Voice
Service Class Name	Gold
Modulation and Config	QPSK1/2
Profile Name	Voice User
ppp_Server	
Call(PCM Quality)	Voice over IP Call (PCM Quality)
ip32_Cloud	Standard
ip_Backbone	Standard

4.3 Simulation Scenarios and Results

For the simulations we constructed five scenarios. The position of a BS is changed relative to its function in different scenarios. Even the number of SSs is changed depending on the main fact of each scenario.

For more accuracy we run the simulations several times with different seeds and then we concluded that five times with random seeds is enough. The seed values are used as128, 256, 512, 1024, 2048 respectively in each run and average values are calculated. Simulation time is fixed with 600 seconds for each run. The average results are presented in this section, but the full details of results, can be found in Appendix B.

4.3.1 Scenario One

Scenario one is simulated in an area of 50 km × 50 km. The base station is located at (10 km, 20 km) position and the location of SS is changed away from the BS as presented in Figure 4.4. The main purpose of this scenario is to find the maximum coverage area of a BS. The average throughput, delay and load results are presented in Table 4.3 and illustrated in Figures 4.5 – 4.7.

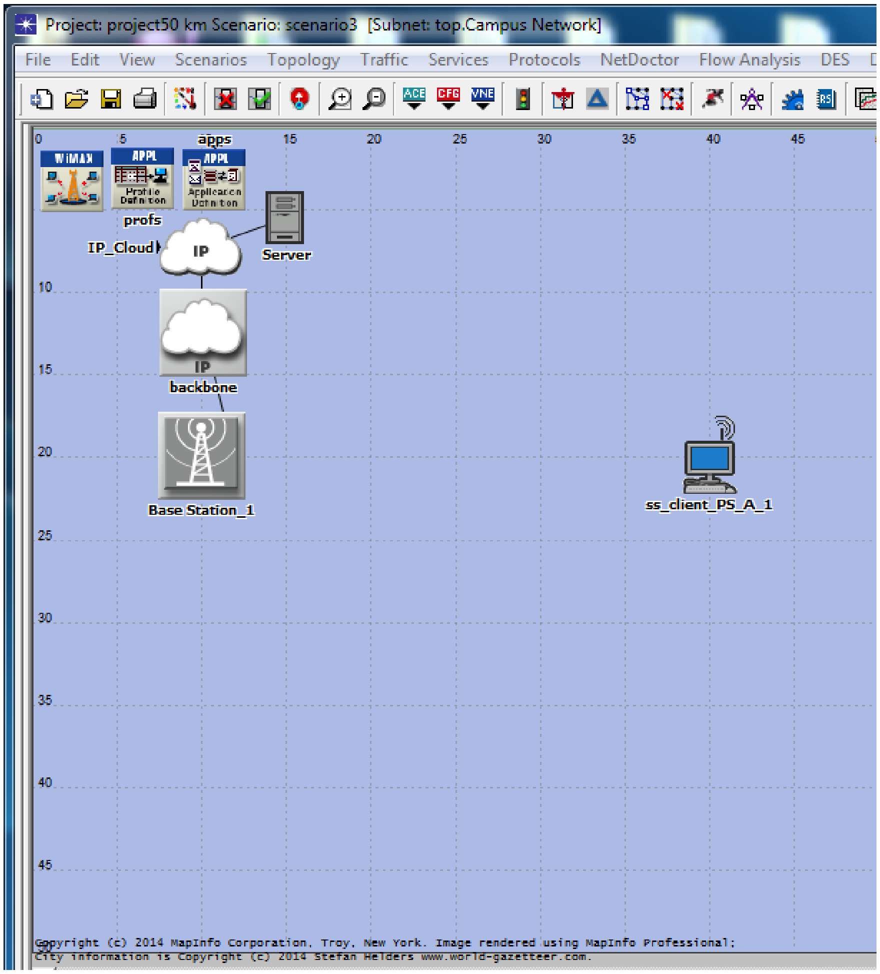

Figure 4.4: Scenario one with SS on position (20 km, 40 km).

Table 4.3: Simulation results for scenario one.

Distance (Km)	Average throughput (Kbit/sec)	Average delay (ms)	Average load (Kbit/sec)
10	14.946	6.7	24.395
20	4.907	6.563	24.198
30	0.016	8.990	21.067
32	0.001	9.107	14.055
34	0	ND	12.434
36	0	ND	12.286
38	0	ND	12.286
40	0	ND	12.286

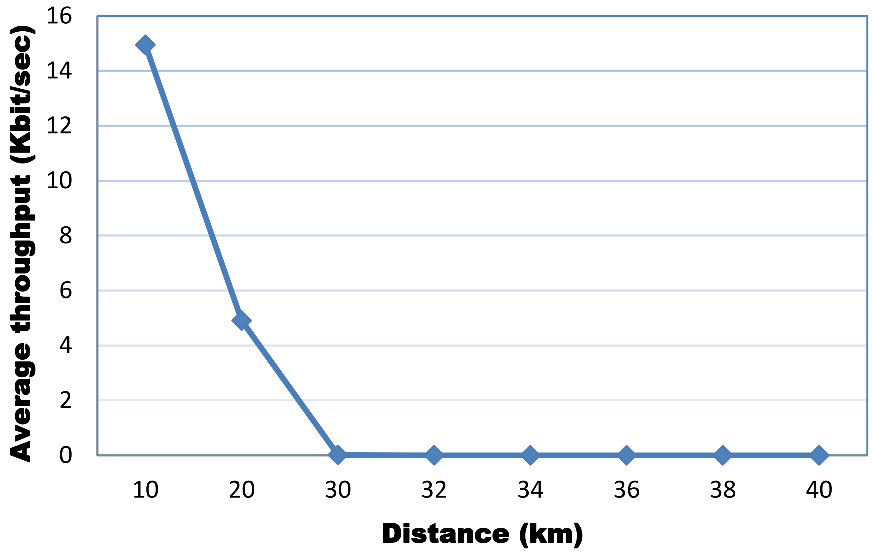

Figure 4.5: Average throughput versus distance in scenario one.

As it can be seen from Figure 4.5, the average throughput decreases as the SS moves away from the BS and becomes almost zero when the SS is 30 km away from the BS showing that the SS is out of the coverage area of the BS.

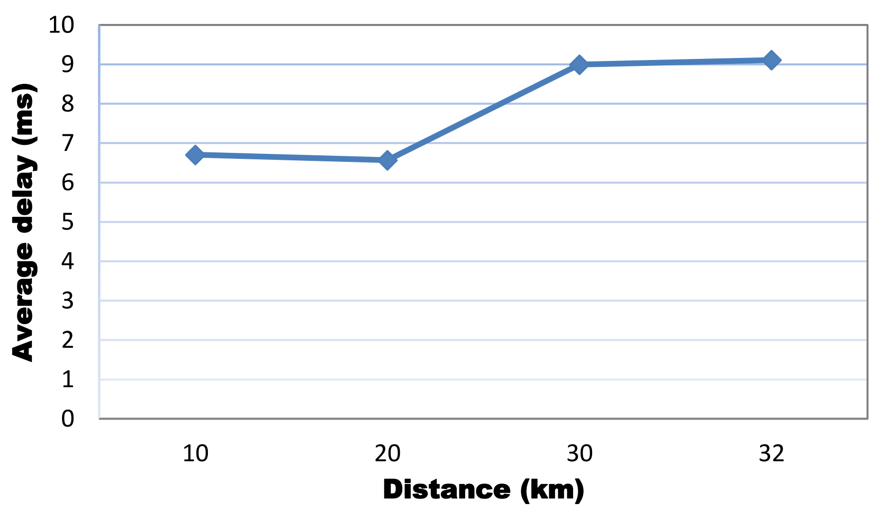

Figure 4.6: Average delay versus distance in scenario one.

Figure 4.6 presents the coverage area of the BS with the discussion of average delay. As the distance between the BS and SS increases from 20 km to 30 km the average delay increases sharply and with 34 km it is not defined at all showing that the SS is out of coverage area of the BS and communication between BS and SS is disconnected.

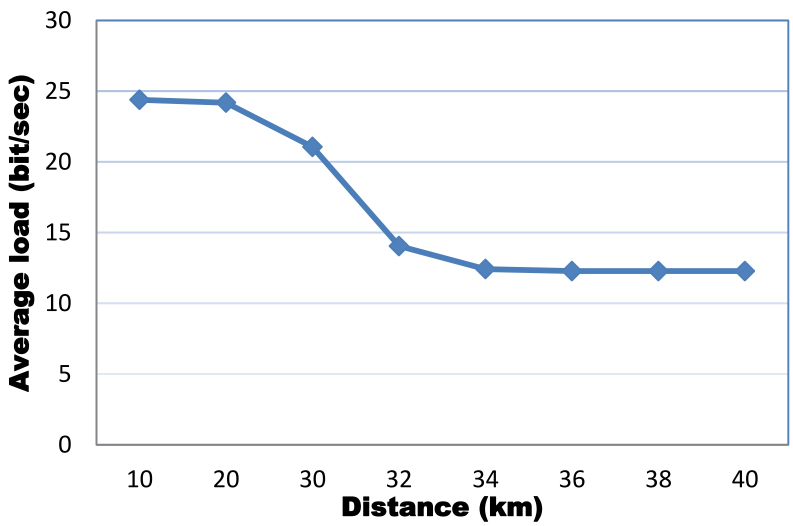

Figure 4.7: Average load versus distance in scenario one.

The results of average load is presented in Figure 4.7 showing that after 30 km distance between the BS and SS the number of bits being submitted to the MAC layer decreases giving another evidence of coverage area of the BS.

4.3.2 Scenario Two

Scenario two is simulated in an area of 20 km × 20 km where BS is located at a position of (10 km, 10 km). The number of SSs is changed as 1, 10, 20, 30, 40, 50 and 60 as presented in Figure 4.8. For each case, SSs are distributed randomly in the given area. The main purpose of this scenario is to find out the maximum number of SSs that can be supported by a BS with high throughput and low delay. The results are presented in Table 4.4 and illustrated in Figures 4.9 – 4.11.

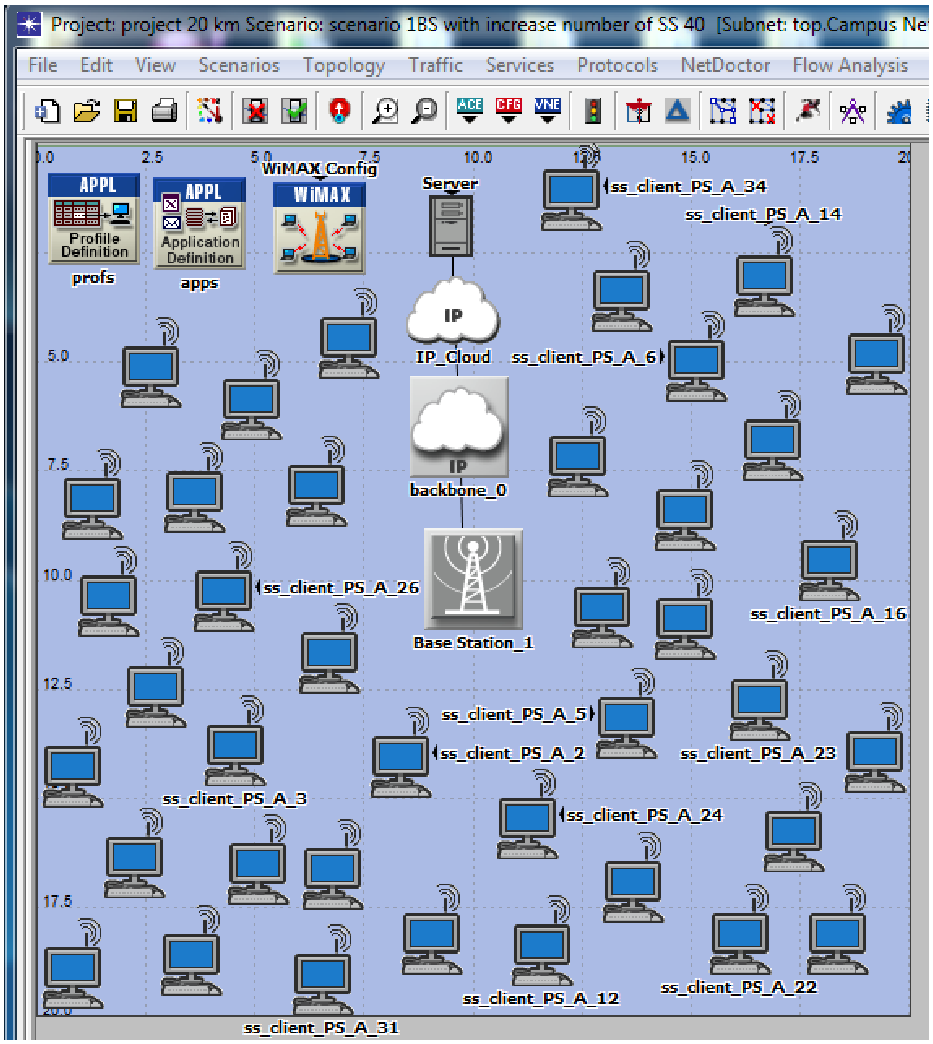

Figure 4.8: Scenario two with 40 SSs.

Table 4.4: Simulation results for scenario two.

Number of nodes	Average throughput (Kbit/sec)	Average delay (ms)	Average load (Kbit/sec)
1	17.408	6.759	25.254
10	168.134	5.841	245.603
20	328.552	6.143	490.438
30	500.899	6.836	735.916
35	573.214	6.889	857.693
40	645.338	102.259	978.610
50	763.744	1,230.985	1,224.845
60	766.358	1,306.920	1,350.766

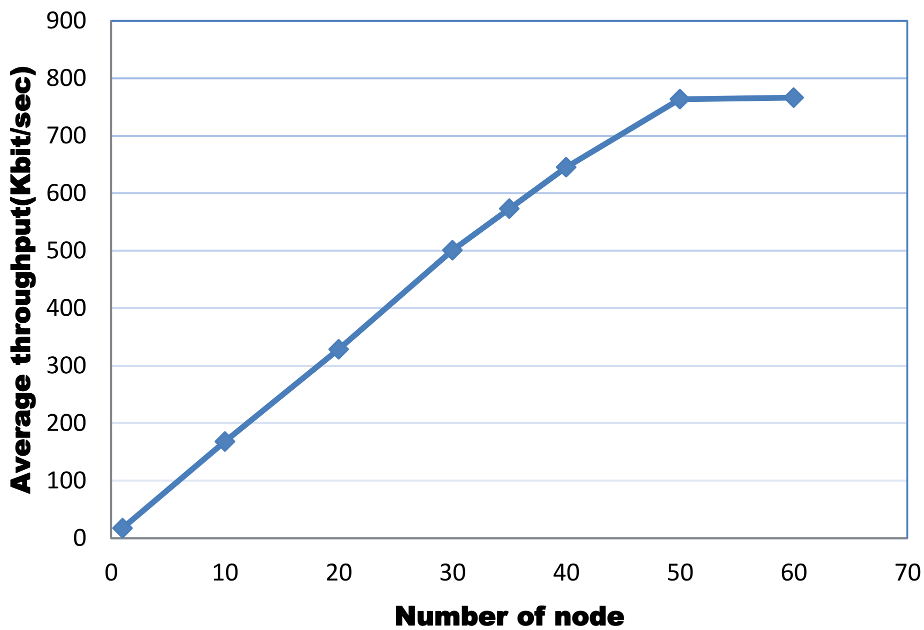

Figure 4.9: Average throughput versus number of nodes in scenario two

Figure 4.9 presents an increasing throughput till 50 SSs and then it becomes constant showing that the capacity of the BS is reached.

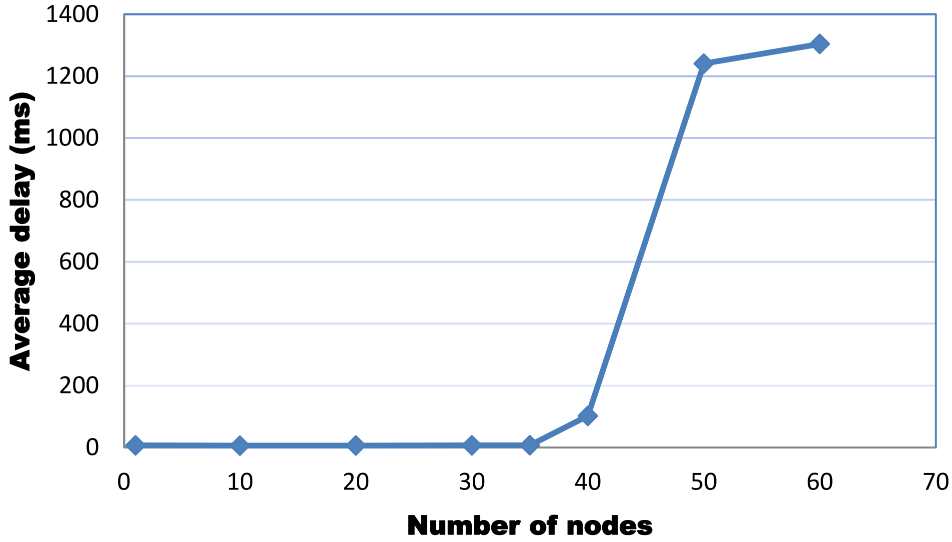

Figure 4.10: Average delay versus number of nodes in scenario two

As it can be seen from the results presented in Figure 4.1, the average delay is slightly varying when the number of SSs is in the range 1 to 35 and increases slowly when the number of SSs changes from 35 to 40. After wards, it increases sharply when the number of SS increases from 40 to 50 SSs. This shows that the BS can support up to 35 SSs with a low delay

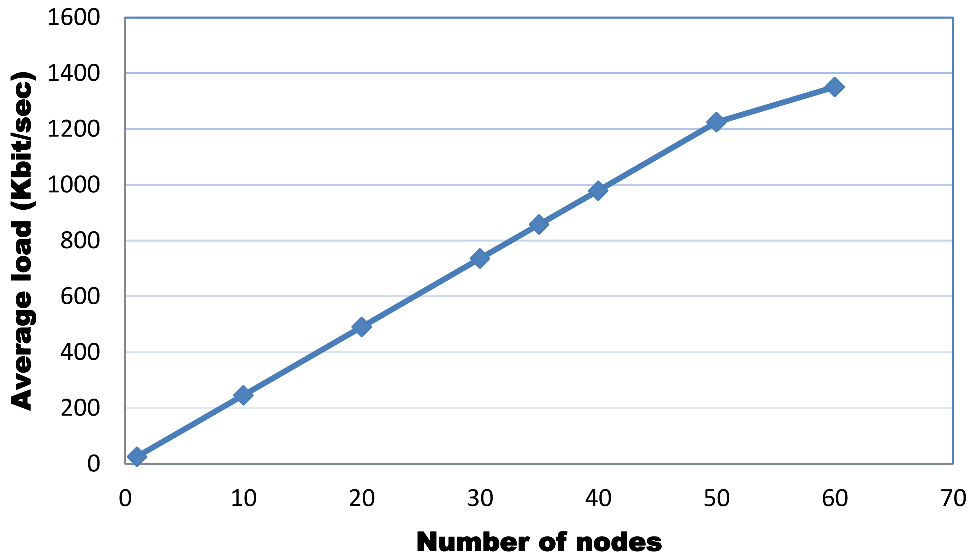

Figure 4.11: Average load versus number of nodes in scenario two

The results presented in Figure 4.11 shows that the average load increase as the number of SSs increases. Starting with 40 SSs the system is creating higher delays that limits the capacity of the BS.

4.3.3 Scenario Three

Scenario three is structured with two BSs and one SS (BS1 is located at fixed position of (10 km, 50 km), while BS2 changes its position. In the scenario (SS) also changes its positions together with BS2 but it is always located in the middle of the two BSs in an area of 100 km × 100 km as shown in Figure 4.12. The main purpose of this scenario is to find the maximum intersection point between two BSs where the disconnection between BSs occurs. The results are presented in Table 4.5 and illustrated in Figures 4.13 – 4.15.

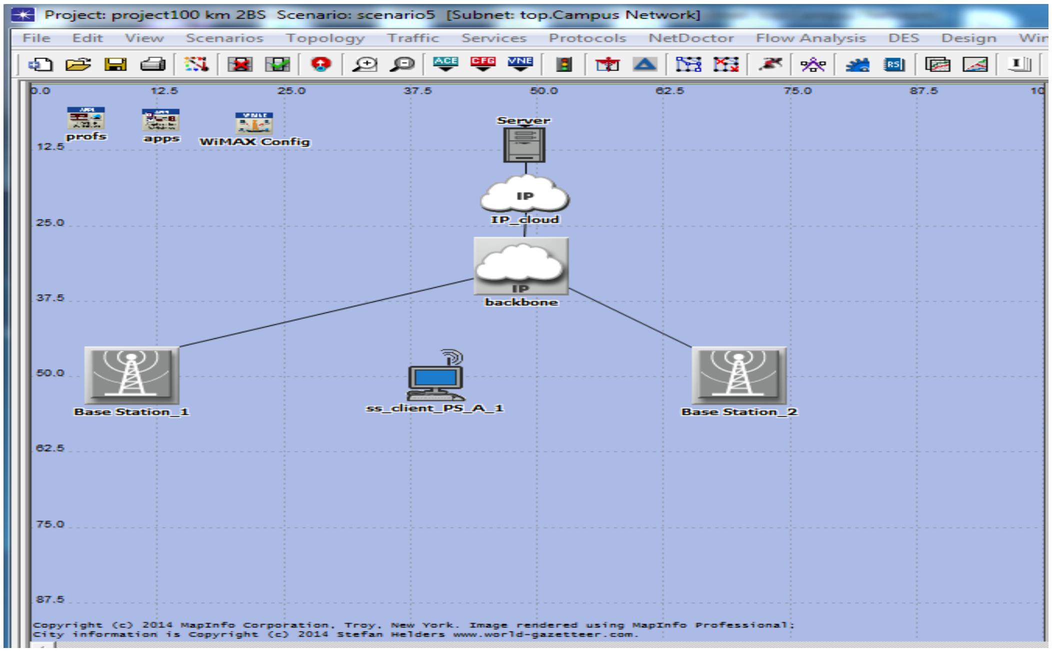

Figure 4.12: Scenario three with distance between BSs as 60 km

Table 4.5: Simulation results for scenario three.

Distance (km)	Average throughput of the system (Kbit/sec)	Average throughput of BS1 (Kbit/sec)	Average throughput of BS2 (Kbit/sec)	Average delay (ms)	Average load (Kbit/sec)
20	15.055	10.408	0	6.497	24.581
30	9.296	8.179	0	5.799	22.404
40	5.051	0	4.374	6.802	24.983
50	0.806	0.721	0	7.179	24.575
60	0.015	0.015	0	7.967	21.019
70	0	0	0	ND	12.186
80	0	0	0	ND	12.149
90	0	0	0	ND	12.149

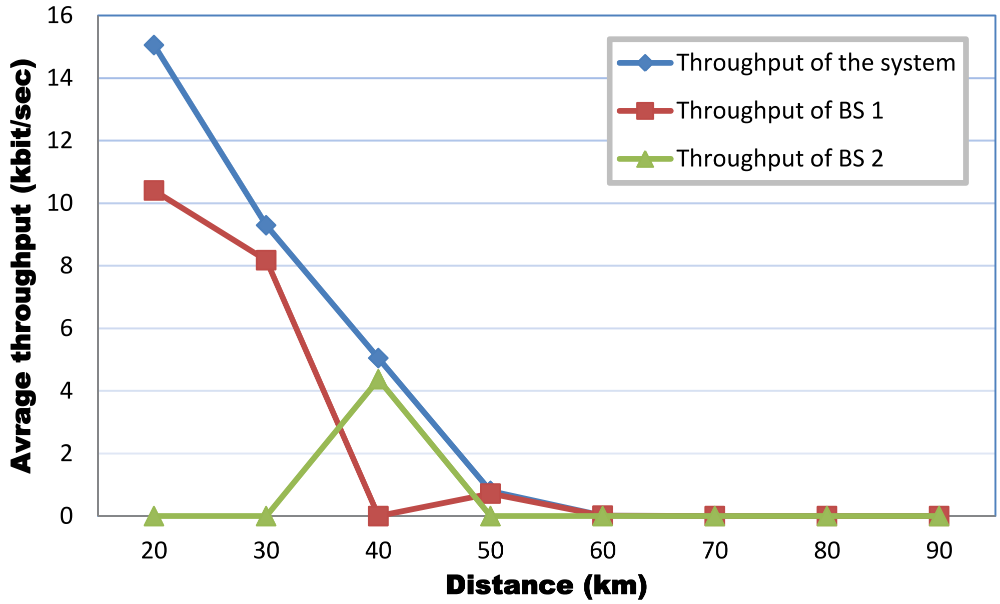

Figure 4.13: Average throughput versus distance in scenario three

Results presented in Figure 4.13 shows that the average throughput of the system decreases as the distance between two BSs increases and it becomes almost zero at 60 km.

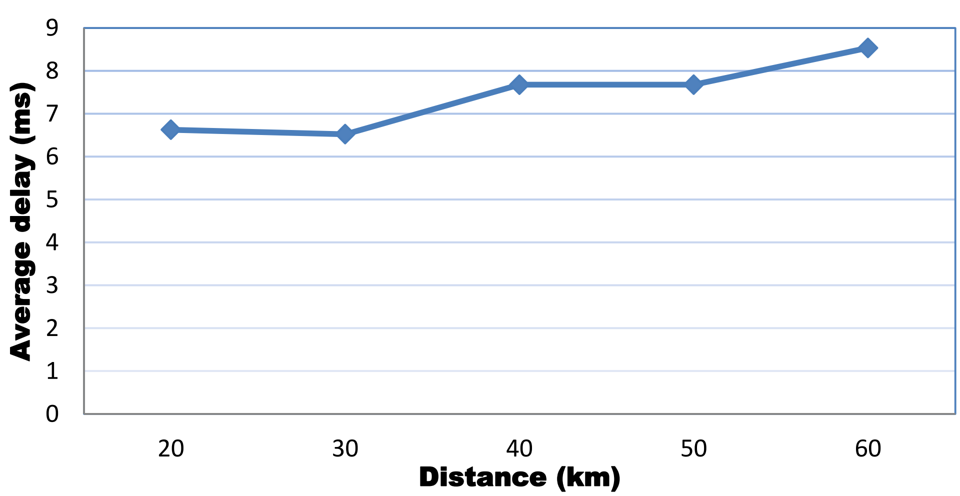

Figure 4.14: Average delay versus distance in scenario three

The results of average delay presented in Figure 4.14 also show that the communication is not possible when two BSs are away from each other more than 60 km. This can be understood from the results since the delay is not defined after 60 km.

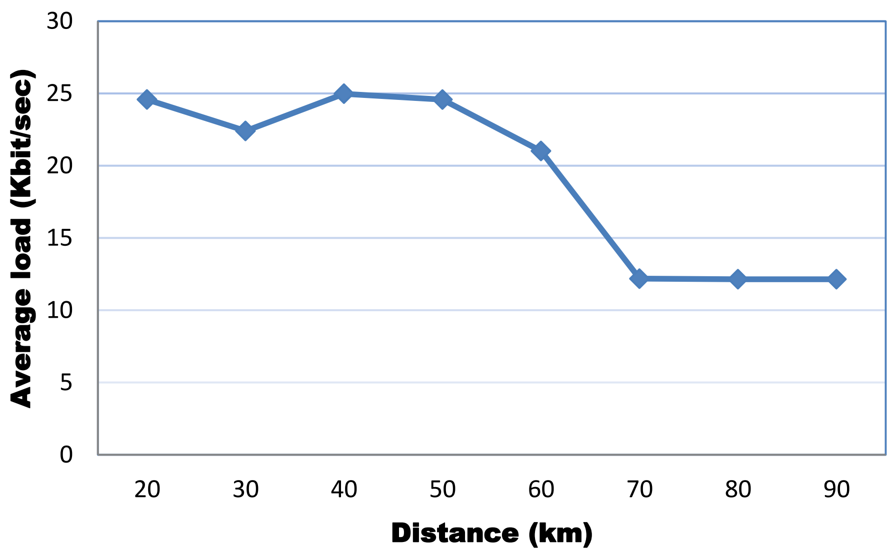

Figure 4.15: Average load versus distance in scenario three

The results of average load is presented in Figure 4.15 to show that after 60 km distance between the BSs the number of bits being submitted to the MAC layer decreases giving another evidence that the communication is not possible after that distance between the BSs.

While the maximum distance between the BS and the SS is presented in the first scenario to be 30 km, the maximum distance between two BSs in second scenario is illustrated to be 60 km. However, based on the simulation results to have a reasonable throughput and delay, the distance between the two BS has be selected as 40 km.

4.3.4 Scenario Four

Scenario four is structured with two BSs both in fixed positions and changing number of SSs in an area of 125 km × 60 km as shown in Figure 4.16. The main purpose of this scenario is to verify scenario two of maximum number of SSs that can be supported with the coverage area of two BSs. The results are presented in Table 4.6 and illustrated in Figures 4.17 – 4.20.

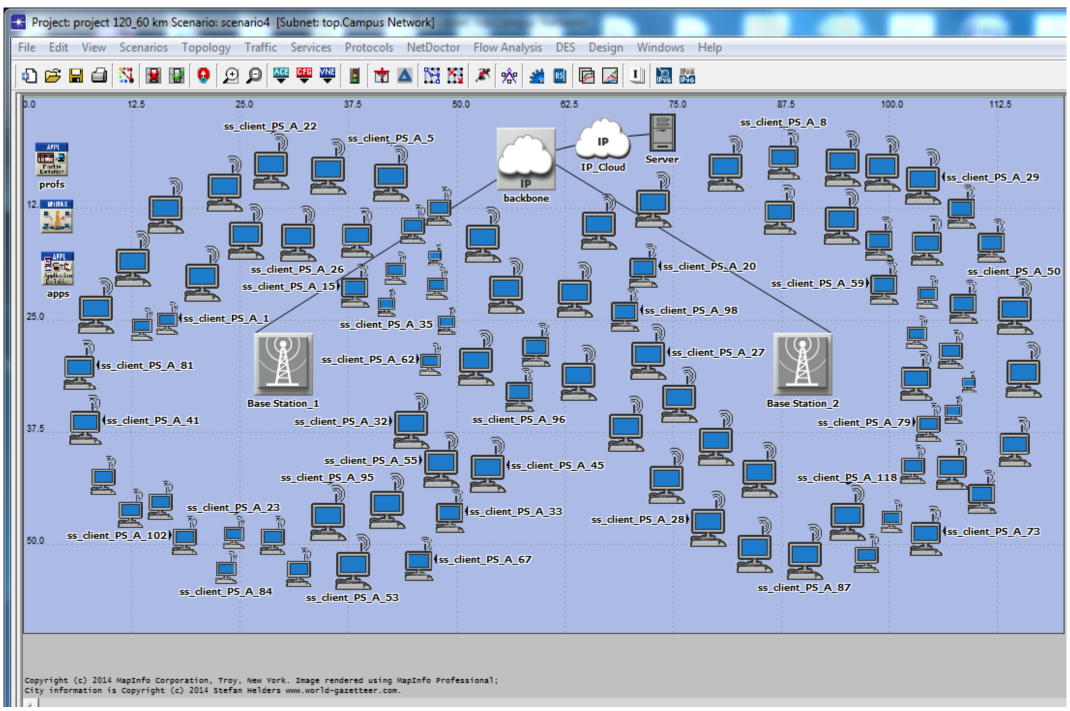

Figure 4.16: Scenario four with 90 SSs

Table 4.6: Simulation results for scenario four

Number of nodes	Average throughput of system (Kbit/sec)	Average throughput of BS1 (Kbit/sec)	Average throughput of BS2 (Kbit/sec)	Average delay (ms)	Average load (Kbit/sec)	Average jitter (μs)
40	2.208	0.210	0.587	6.599	652.573	3.8
50	6.221	1.477	1.446	5.449	901.736	1.14
60	7.933	1.870	3.385	6.742	1,070.057	1.62
70	9.274	2.602	3.489	6.687	1,272.806	1.06
80	21.510	8.209	4.140	6.843	1,519.358	2.1
90	28.708	6.220	9.424	6.044	1,718.914	5.08
100	32.529	7.100	10.914	536.78	2,195.169	34,740
110	41.766	10.021	7.138	420.434	2,290.138	25,955
120	59.124	12.497	12.901	567.625	2,467.243	21,696

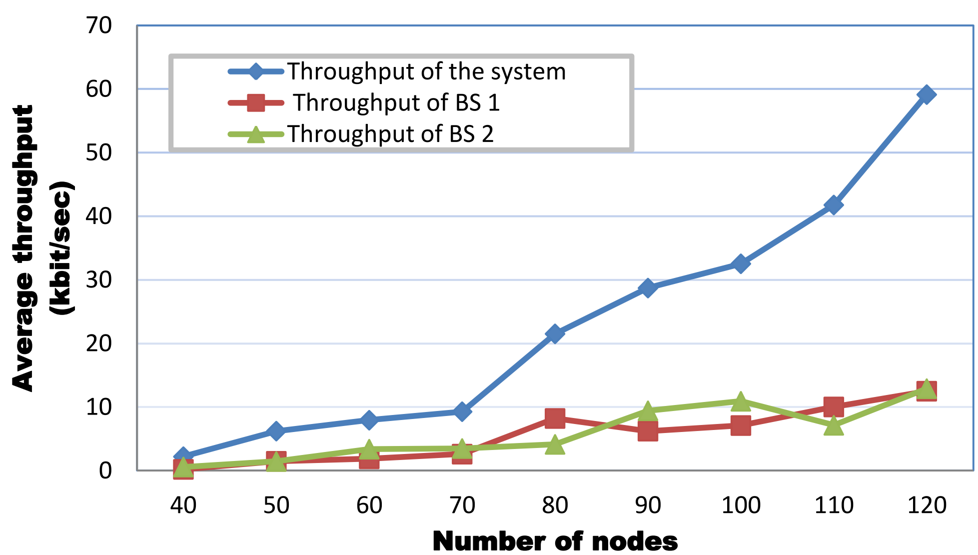

Figure 4.17: Average throughput versus number of nodes in scenario four

Although it is shown in Figure 4.17 that average throughput of the system increases as the number of SSs increases. The average delay presented in Figure 4.18 has a sharp increase when the number of SSs changes from 90 to 100. These results present that the maximum number of SSs that can be covered with two BSs with a high throughput and low delay is 90.

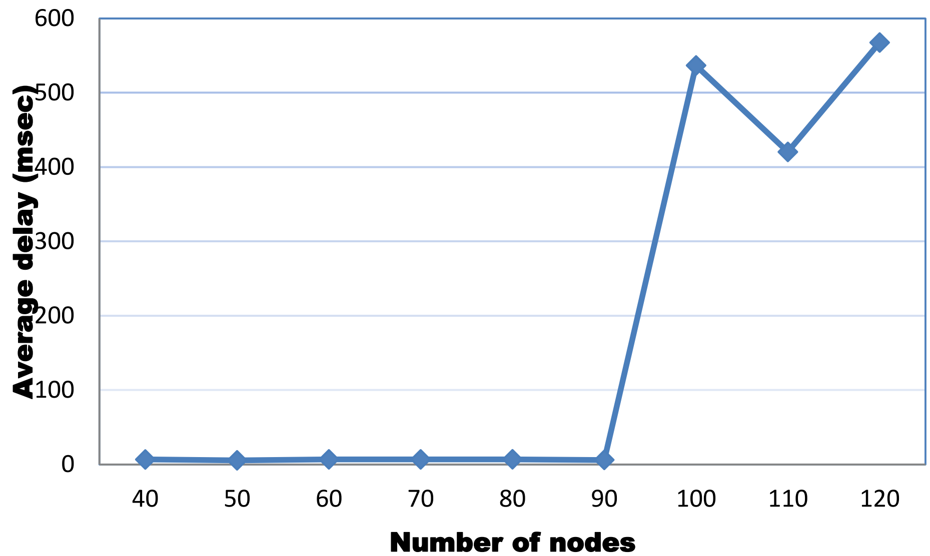

Figure 4.18: Average delay versus number of nodes in scenario four

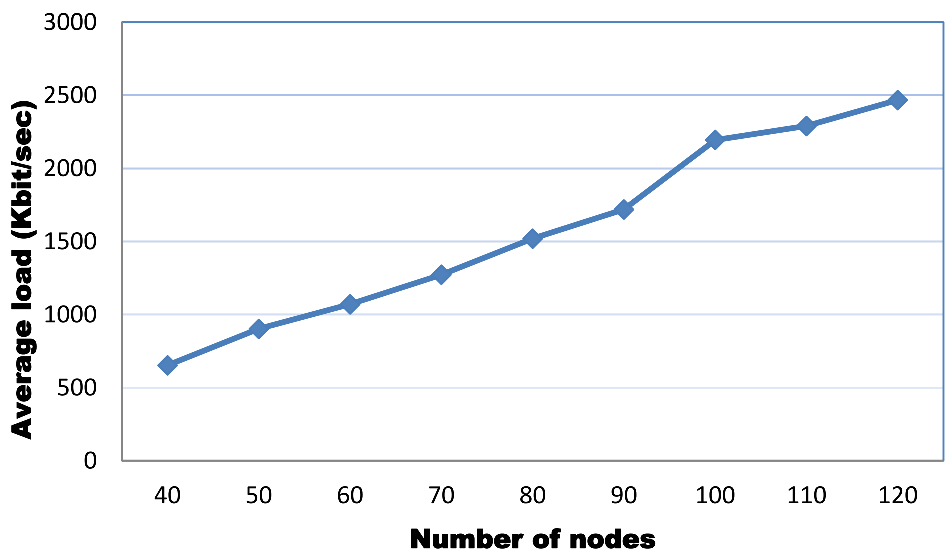

Figure 4.19: Average load versus number of nodes in scenario four

The results presented in Figure 4.19 also shows that the average load increases linearly as the number of SSs increases causing higher delays with more SSs.

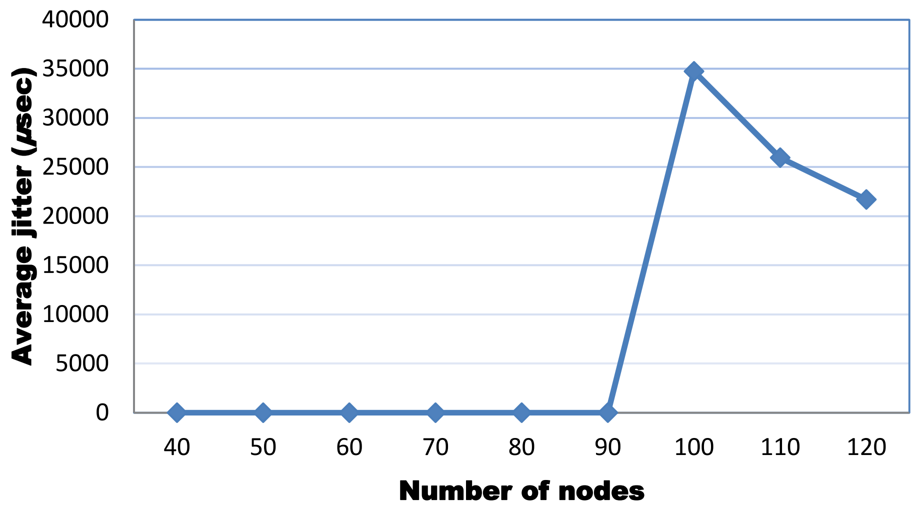

Figure 4.20: Average jitter versus number of nodes in scenario four.

The average jitter performance is also presented in Figure 4.20 to show the maximum number of SSs that can be supported by two BSs. As it is clearly shown in the figure the average jitter increases sharply as the number of SSs increases from 90 to 100 stating the maximum number of SSs to be 90.

From the Figures 4.17 – 4.20 we can recognize that after we increase the number of SSs from 90 to 100 nodes a dramatic increase occurs in the average delay from 6.044 ms to 536.78 ms which gives an indication of the maximum number of SSs within two BSs to be as 90.

4.3.5 Scenario Five

Scenario five is structured with three BSs in fixed positions with changing number of SSs in an area of 125 km × 125 km as shown in Figure 4.21. The main purpose of this scenario is to verify scenario two of maximum number of SSs that can be covered with the coverage area of three BSs. The results are presented in Table 4.7 and illustrated in Figures 4.22 – 4.25.

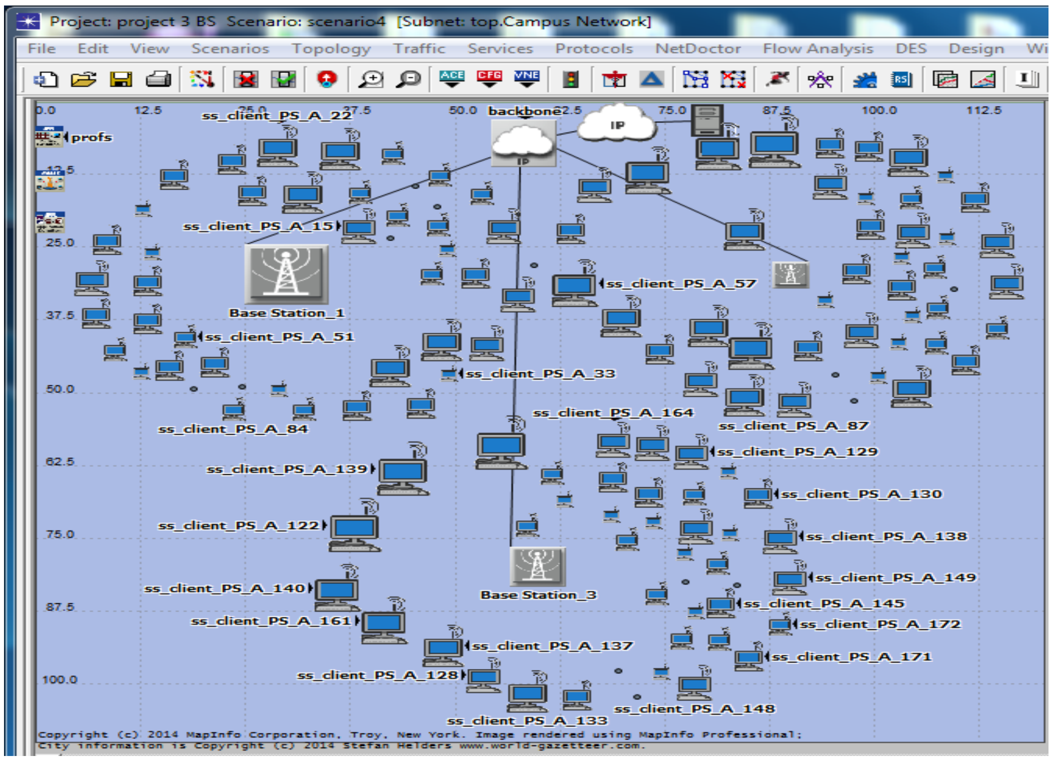

Figure 4.21: Scenario five with 135 SSs

Table 4.7: Simulation results for scenario five.

Number of nodes	Average throughput of the System (Kbit/sec)	Average throughput of BS1 (Kbit/sec)	Average throughput of BS2 (Kbit/sec)	Average throughput of BS3 (Kbit/sec)	Average delay (ms)	Average load (Kbit/sec)	Average jitter (μsec)
90	5.584	1.370	0.760	0.492	5.889	1,360.950	1.22
105	8.350	2.470	2.174	0.929	6.001	1,679.567	1.69
120	18.598	4.419	3.724	1.297	5.739	1,941.155	1.18
135	22.703	2.604	2.934	2.306	5.272	2,174.887	1.07
150	33.726	2.585	2.516	1.482	240.652	2,662.694	5,273
165	47.425	2.136	2.393	2.978	189.844	2,935.264	5,323
180	42.515	2.507	2.506	2.627	202.171	3,100.981	4,630

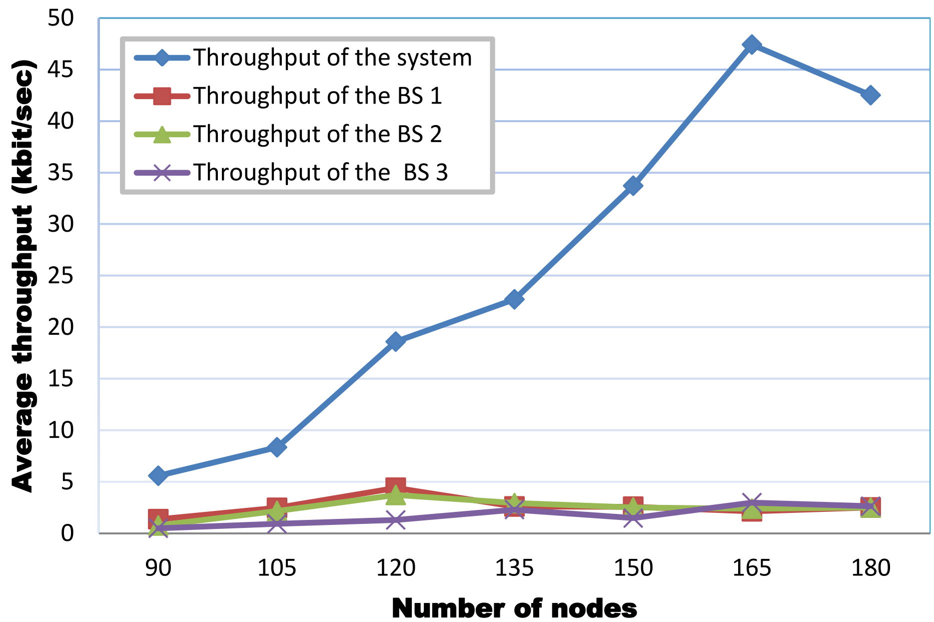

Figure 4.22: Average throughput versus number of nodes in scenario five

It is shown in Figures 4.22 and 4.23 that a high throughput and low delay with three BSs can be obtained when the number of SSs is 135 maximum.

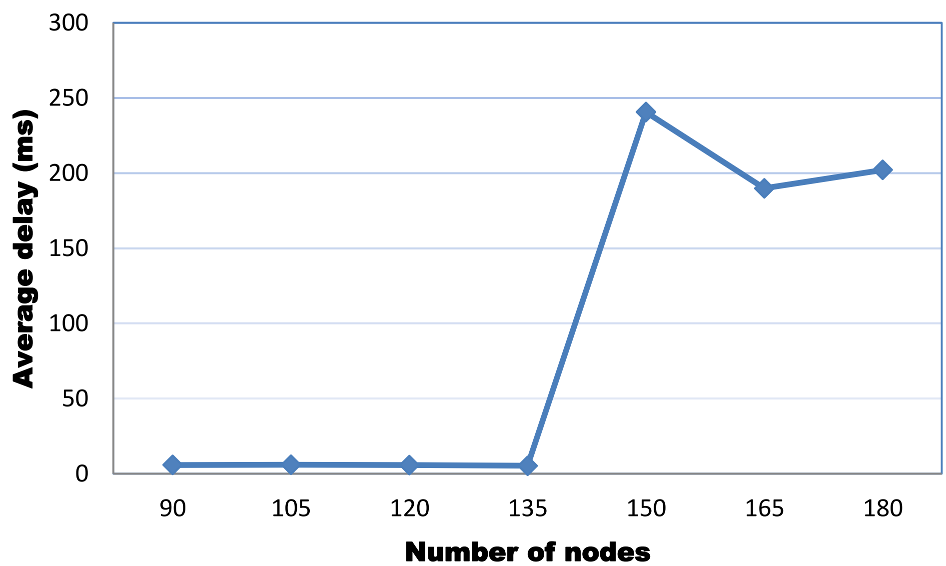

Figure 4.23: Average delay versus number of nodes in scenario five

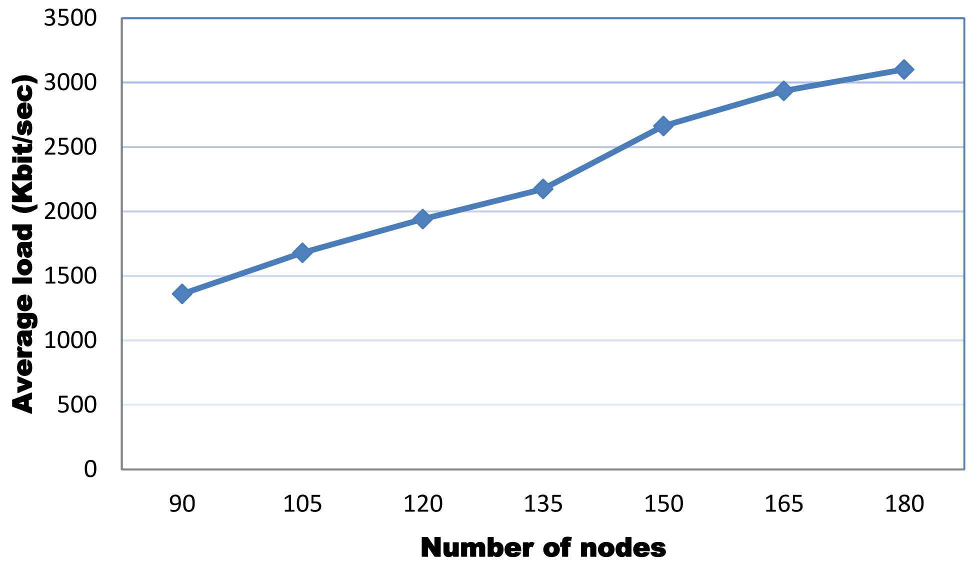

Figure 4.24: Average load versus number of nodes in scenario five

The results in Figure 4.24 is presented to show that the average load increases linearly as the number of SSs increases causing higher delays with more SSs.

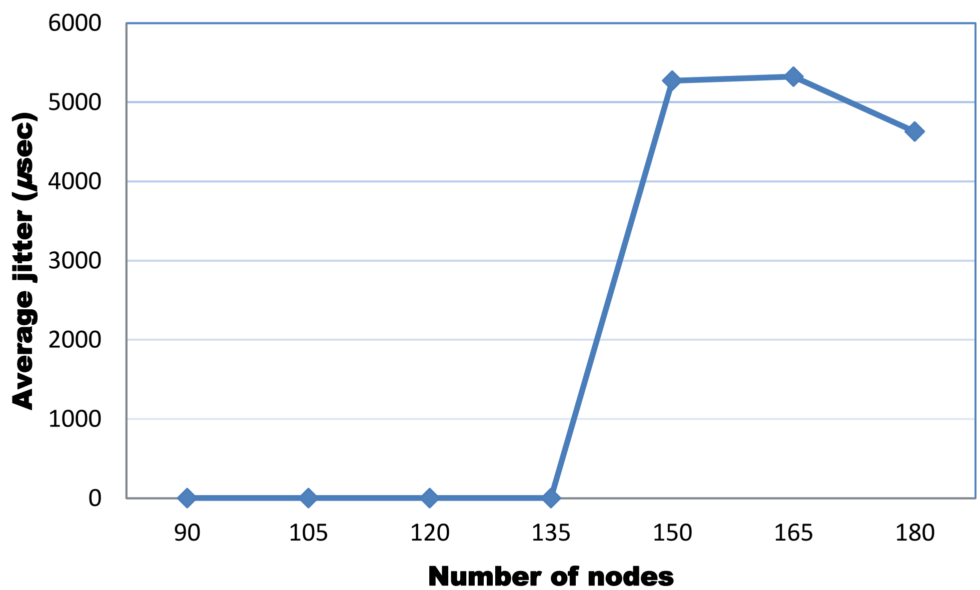

Figure 4.25: Average jitter versus number of nodes in scenario five

The average jitter performance presented in Figure 4.25 shows from another perspective the maximum number of SSs that can be supported by three BSs is 135 since after this point the average jitter increases sharply.

In practice ;WiMAX performance may depend on the types of the modulation technique (i.e. QPSK,16QAM,64QAM),and bandwidth. The performance can be affected by barriers, mountains and geography of the land and buildings and other signals. Rain may also affect the quality of the signal [34].

Chapter 5

CONCLUSION

In this thesis we discussed the investigation of WiMAX network which is characterized by low cost and high capacity through built in circuit by using a type of fixed WiMAX and the study of different states of changing distance with number of nodes to get coverage area and number of nodes using variables such as: throughput, delay, load, jitter in different scenarios.

The thesis focused on the part of fixed WiMAX IEEE 802.16d 2004. The coverage area and capacity of a BS and the distance of connectivity between two BSs are investigated. For that aim we proposed five different scenarios as summarized below.

Scenario one: We have one BS and one node since the position of the BS is fixed and the position of the node was changing far away from the BS to find out the coverage area. Scenario two: We have one BS and different number of nodes in an increasing manner to find out the capacity of the BS. Scenario three: We have two BSs and one node.

One of the BSs and the node change their positions in a condition of keeping the position of the node in the middle of two BSs to find out the distance that disconnection occurs.

Scenario four: We have two BSs with fixed positions and changing number of nodes to find out the capacity of the BS as done in scenario two.

Scenario five: We have three BSs with fixed positions and changing number of nodes to find out the capacity of the BS as done in scenarios two and four. According to the simulation results of our studies, some factors of fixed WiMAX standard of optimality were cleared as following:

- The coverage area of a BS is 30 km.
- The number of SSs that can be supported by a BS is 35.
- The distance between two BSs that disconnection occurs is 60 km.
- The distance between two BSs that provide service to a SS with a reasonable throughput and delay is 40 km.
- The maximum number of SSs that can be covered with two BSs with a high throughput and low delay is 90.
- The maximum number of SSs that can be covered with three BSs with a high throughput and low delay is 135.

Future Works

Further studies that include mobile WiMAX IEEE 802.16e2005 and comparison between both standard IEEE 802.16d2004 and IEEE 802.16e2005 on different parameters such as number of SSs and distance using four different rows of QoS classes (*i.e.* UGS, Er-tps, Rt-PS, Nrtps and BE) can be conducted. The studies can be applied to VoIP and video streaming. Another study could be a comparison between fixed WiMAX and mobile WiMAX using different performance metrics (*i.e.* throughput, delay, jitter and load).

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APPENDICES

APPENDIX A: WiMAX Configuration

- WiMAX configuration of BS and SS.

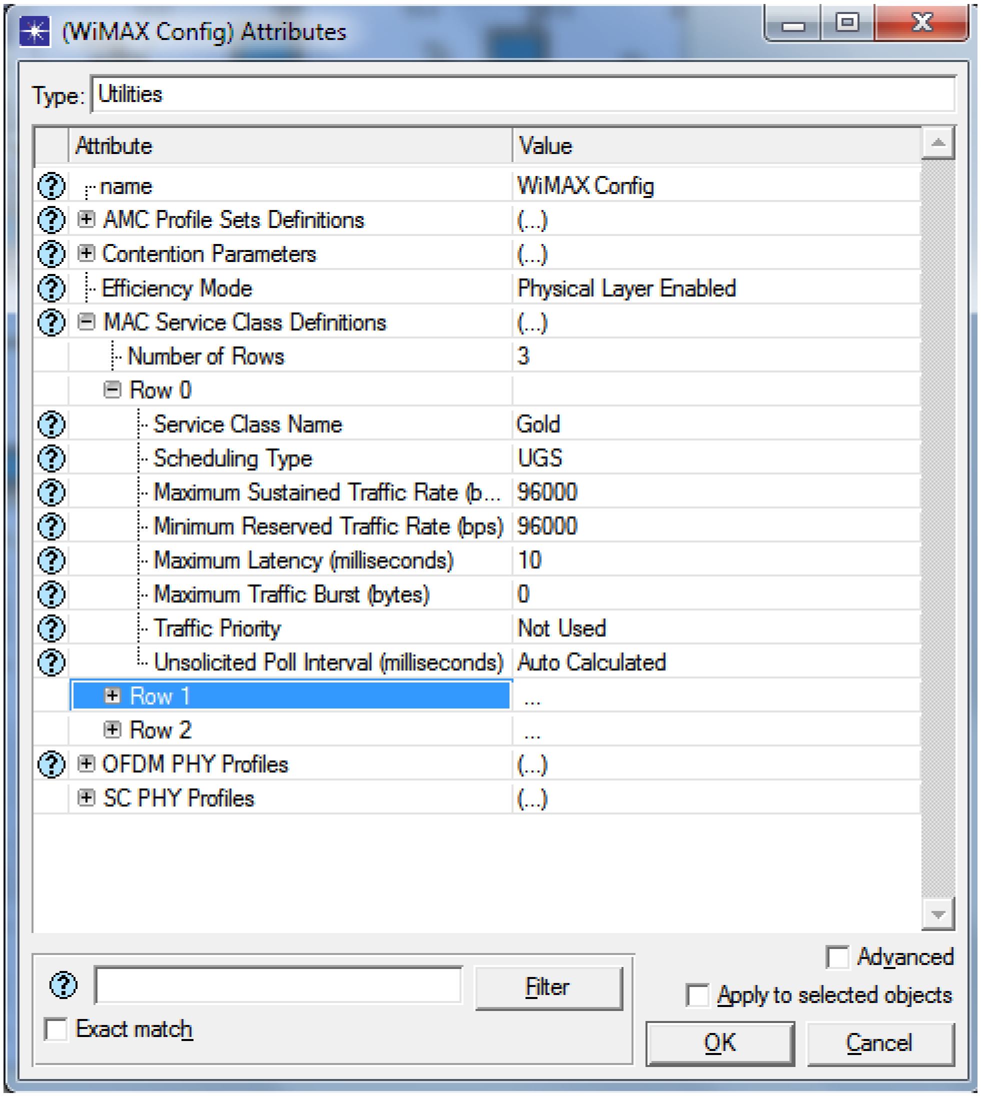

Figure A1: WiMAX configuration.

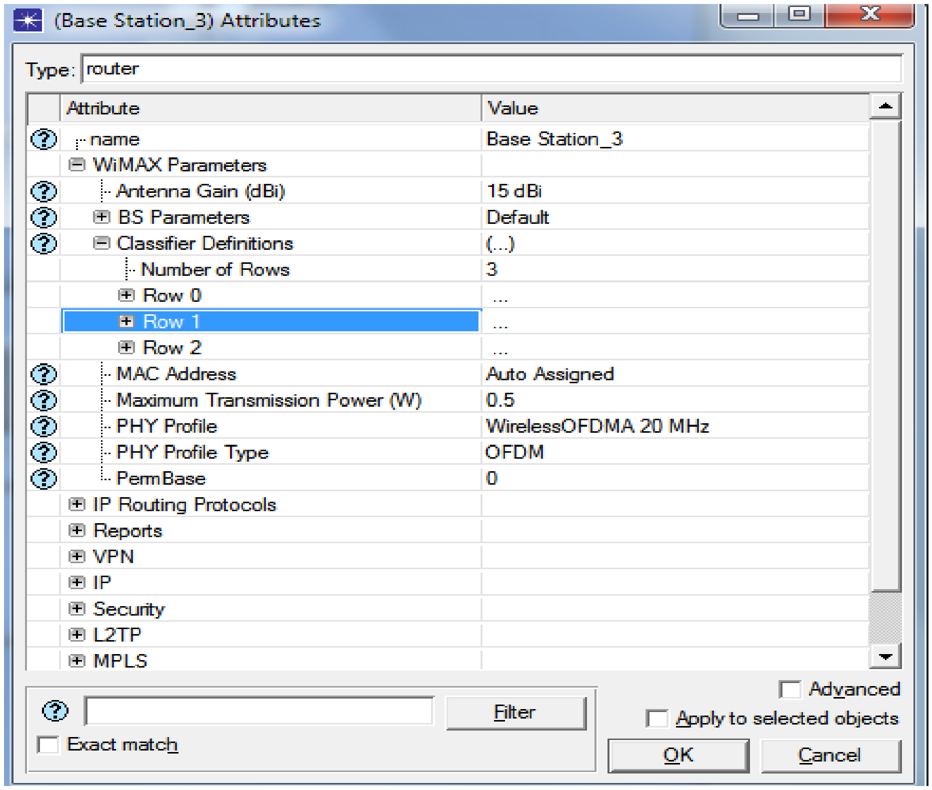

Figure A2: WiMAX attributes of BS.

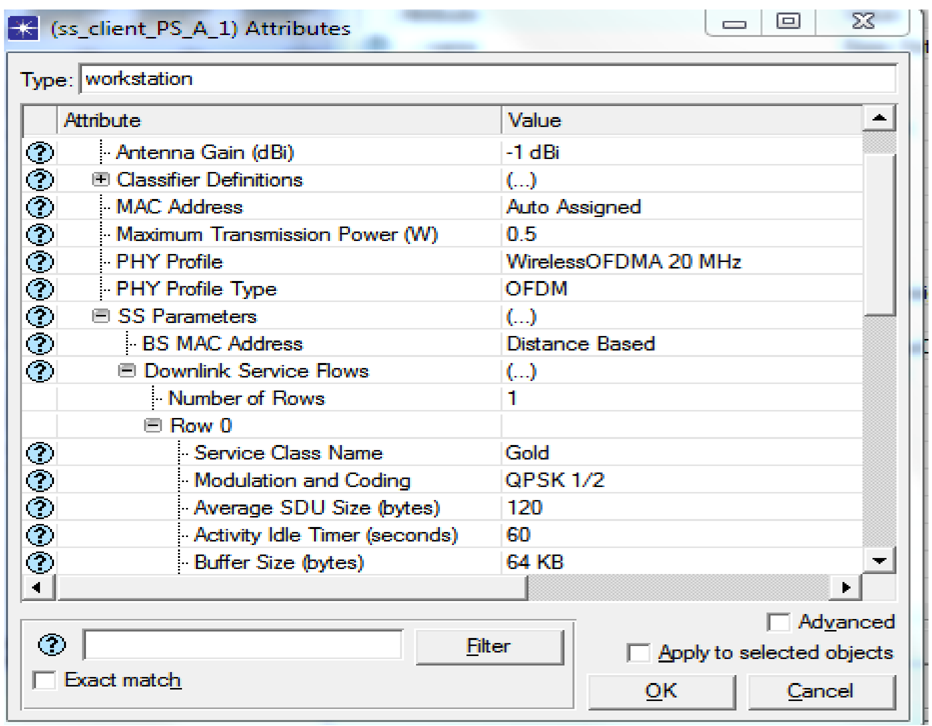

Figure A3: WiMAX attributes of SS provide downlink and uplink.

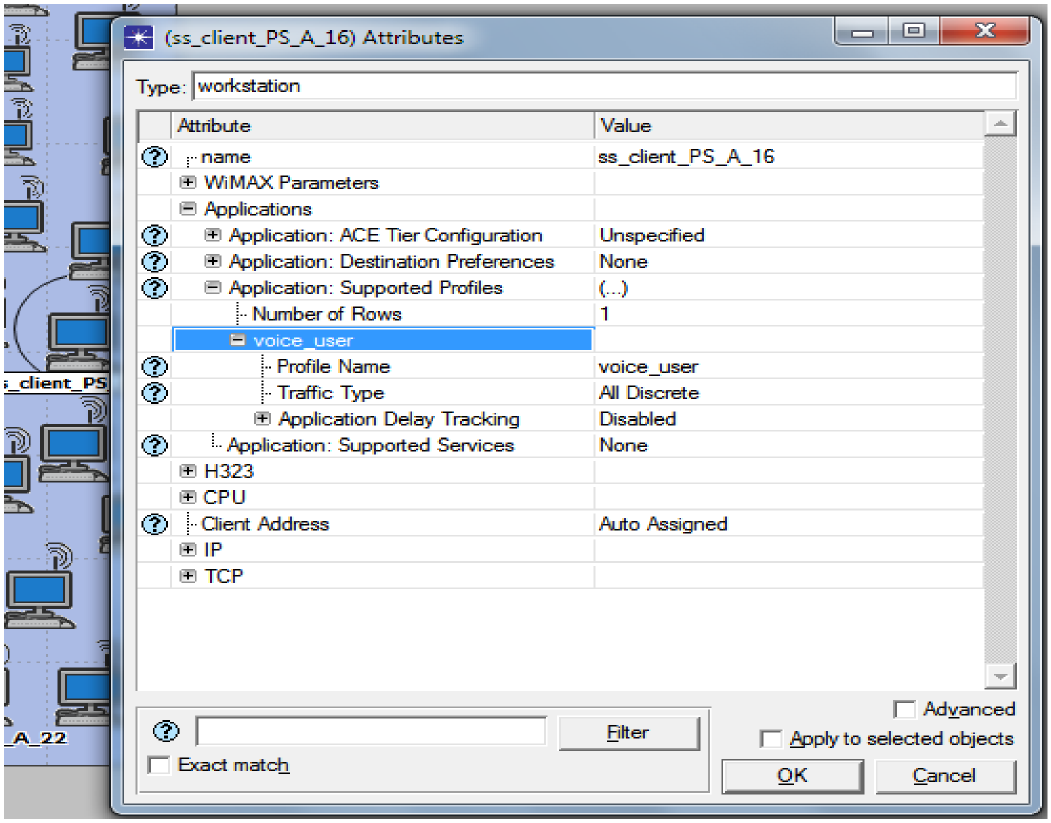

Figure A4: WiMAX attributes of SS supported profile.

- WiMAX attributes of server.

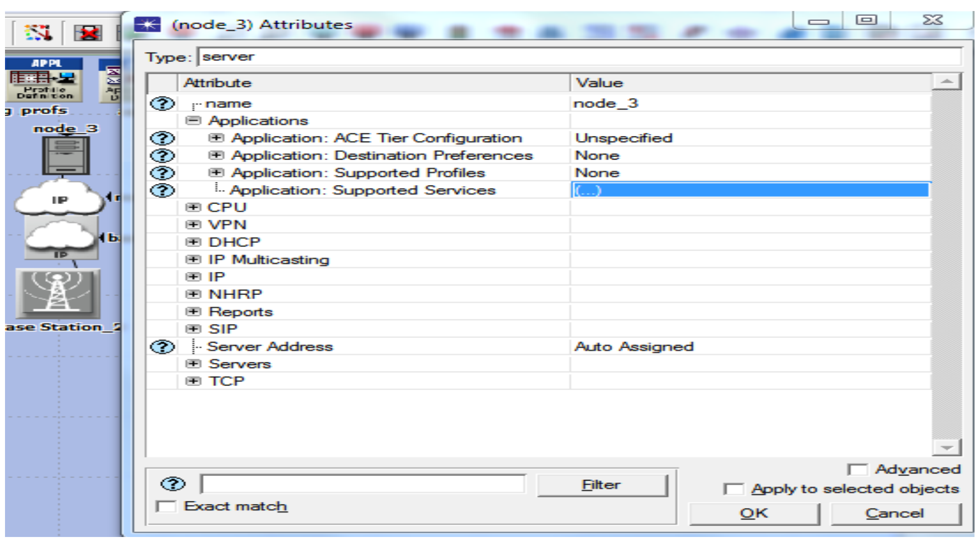

Figure A5: WiMAX attributes of server.

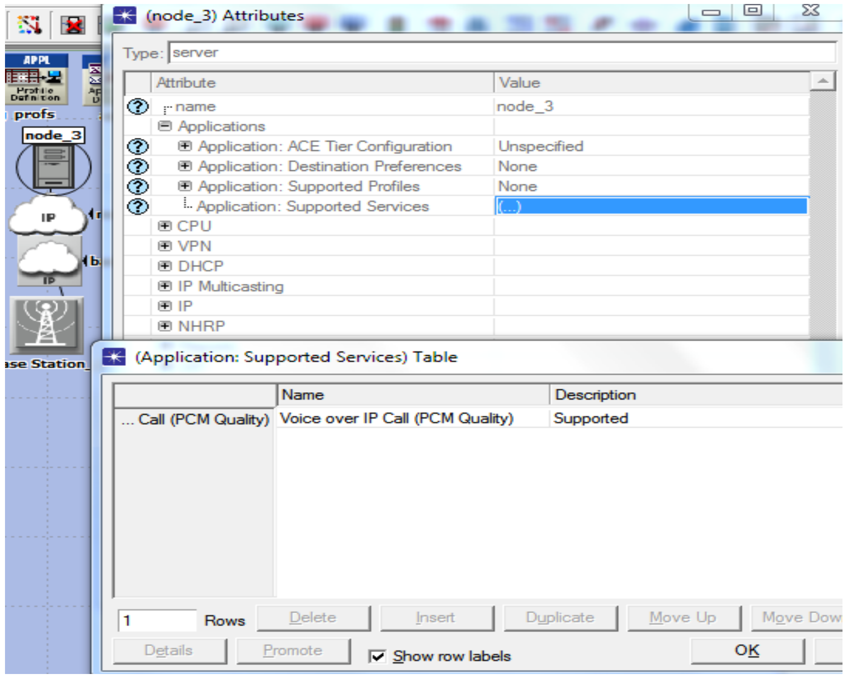

Figure A6: WiMAX attributes to set application for server.

- IP-Cloud Configuration:

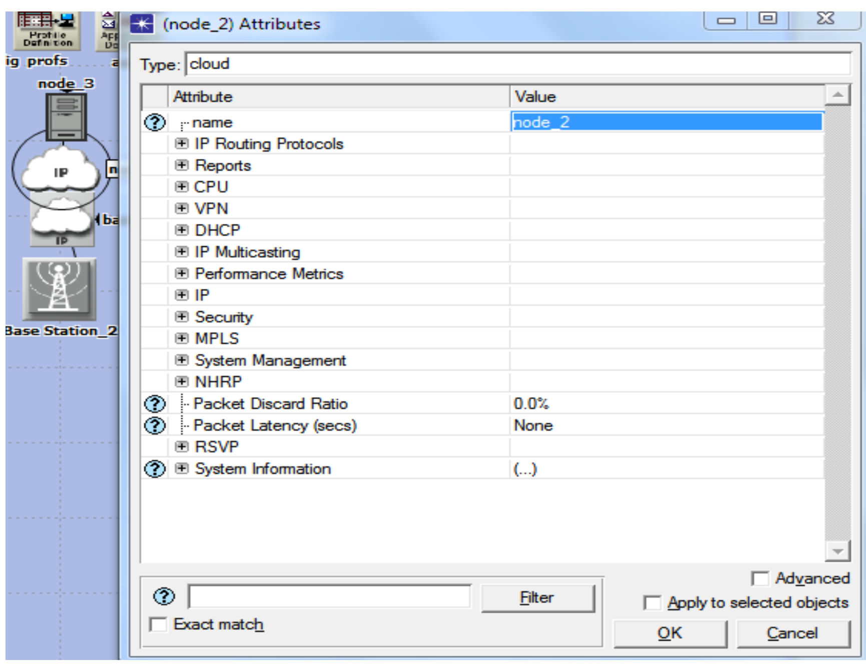

Figure A7: WiMAX attributes of IP-Cloud.

- IP-Backbone:

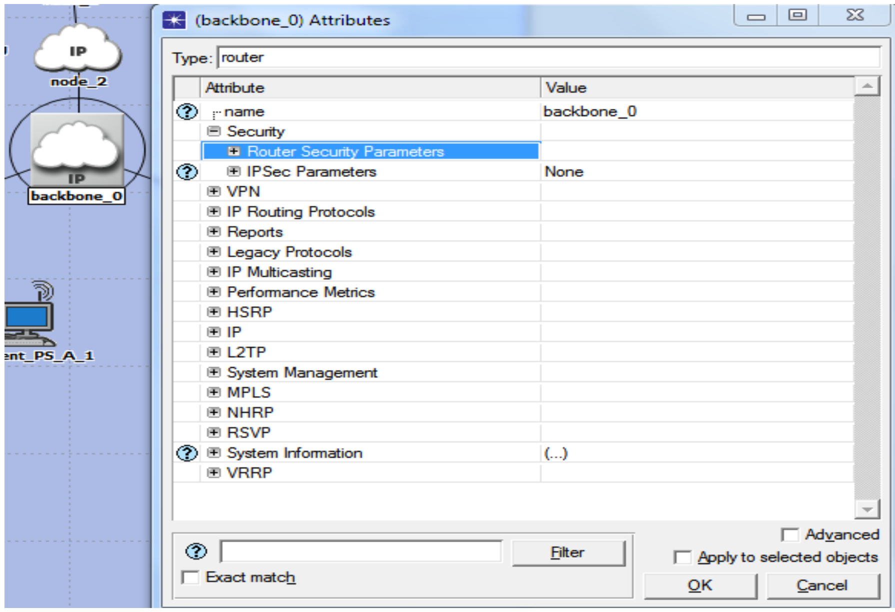

Figure A8: WiMAX attributes of IP-Backbone

APPENDIX B: Simulation Results for the Five Scenarios

SCENARIO ONE:

Table B1: Average throughput of scenario one.

Throughput(bit/sec)						
Distance	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
10	15,344.48	14,773.98	14,157.01	14,860.72	15,595.18	14,946.28
20	4,990.873	5,042.937	4,764.849	4,818.794	4,910.932	4,905.677
30	27.88213	13.69663	12.35081	12.50062	15.80895	16.44783
32	1.582174	2.184021	1.038934	0.883045	0.39529	1.216693
34	0	0	0	0	0	0

Table B2: Average delay of scenario one.

Delay(sec)						
Distance	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
10	5.747	4.635	8.005	7.868	7.243	6.7
20	7.54	5.23	7.306	8.833	8.612	6.563
30	9.397	8.754	10.262	8.597	7.941	8.99
32	8.342	7.368	9.968	6.641	13.217	9.107
34	ND	ND	ND	ND	ND	ND

Table B3: Average load of scenario one.

Load(bit/sec)						
Distance	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
10	24,906	24,138.27	23,140.52	24,481.63	25,309.36	24,395.16
20	24,757.2	24,813.56	23,535.88	23,573.45	24,312.37	24,198.49
30	21,846.74	20,807.82	19,636.43	21,355.02	21,689.94	21,067.19
32	14,048.02	16,435.55	14,233.17	12,655.06	12,906.56	14,055.67
34	12,976.66	12,175.7	12,846.82	11,981.53	12,192.05	12,434.55
36	12,976.66	12,175.7	12,108.47	11,981.53	12,192.05	12,286.88
38	12,976.66	12,175.7	12,108.47	11,981.53	12,192.05	12,286.88
40	12,976.66	12,175.7	12,108.47	11,981.53	12,192.05	12,286.88

Scenario Two:

Table B4: Average throughput of scenario two.

Throughput(bit/sec)						
#nodes	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
1	17,220.59	17,465.34	17,811.58	16,459.44	18,084.6	17,408.31
10	167,642.5	169,403.9	167,169.7	166,511.8	169,958.7	168,137.3
20	330,362.1	330,147.2	327,763.9	329,612.4	324,877.6	328,552.7
30	499,244.6	506,160.4	501,383.7	501,661.2	496,047.6	500,899.5
35	577,194.4	572,976.6	583,051.0	564,711.1	568,138.5	573,214.3
40	644,359.7	641,567.8	644,975.5	642,966.2	652,821.8	645,338.2
50	757,402.8	766,345.4	759,042.1	763,614.1	772,317.9	763,744.5
60	771,333.7	764,320.5	764,755.0	761,571.7	769,812.2	766,358.6

Table B5: Average load of scenario two.

Load(bit/sec)						
#nodes	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
1	25,046.6	25,390.1	25,627.9	23,993.6	26,216.0	25,254.8
10	244,874.7	247,320.6	244,498.6	243,408.1	247,913	245,603.0
20	493,732.9	491,709.3	489,858.8	492,026.7	484,864.4	490,438.4
30	732,995.0	742,610.4	733,332.2	742,703.4	727,940.3	735,916.3
35	858,573.2	858,898.8	867,672.0	848,531.1	854,792.5	857,693.5
40	978,050.1	972,710.0	979,438.8	977,304.3	985,550.9	978,610.8
50	1,218,970.0	1,227,232.0	1,216,506.0	1,226,010.0	1,235,505.0	1,224,845.0
60	1,355,234.0	1,345,816.0	1,349,050.0	1,345,681.0	1,358,047.0	1,350,766.0

Table B6: Average delay of scenario two.

Delay(msec)						
#nodes	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
1	6.6	6.166	6.692	7.763	5.95	6.6342
10	5.506	5.207	5.482	5.989	6.216	5.68
20	6.628	6.756	6.379	5.661	6.208	6.3264
30	5.955	7.328	6.871	6.399	7.304	6.7714
35	8.136	6.7	7.575	6.243	6.673	7.0654
40	98.386	103.967	104.033	105.585	97.523	101.8988
50	1,254.161	1,266.299	1,181.385	1,248.978	1,252.844	1,240.733
60	1,335.872	1,263.492	1,328.368	1,251.479	1,343.327	1,304.508

Scenario Three:

Table B7: Average throughput of the system of scenario three.

	Throughput(bit/sec)					
	Seed1	Seed2	Seed3	Seed4	Seed5	Average
Distance	128	256	512	1024	2048	
20	15,525.87	14,748.84	15,170.12	15,072.39	14,761.11	15,055.67
30	10,808.24	14,748.84	6.576464	10,585.47	10,331.22	9,296.069
40	5,005.347	5,439.944	4,781.81	5,195.631	4,833.255	5,051.197
50	842.7091	833.8846	799.1989	773.3553	784.516	806.7328
60	22.03732	19.99712	11.58191	10.00878	14.07689	15.5404
70	0	0	0	0	0	0

Table B8: Average throughput of BS1 scenario three.

	Throughput BS 1					
Distance	seed 128	seed 256	seed 512	seed 1024	seed 2048	Average
20	10,639.85	10,607.76	10,393.93	10,333.35	10,069.82	10,408.94
30	8,196.571	8,814.08	8,108.015	7,918.406	7,861.23	8,179.66
40	0	0	0	0	0	0
50	754.1458	771.8333	714.6406	688.1993	679.0414	721.5721
60	22.03732	20.83033	11.58191	10.00878	14.07689	15.70705
70	0	0	0	0	0	0

Table B9: Average throughput of BS2 scenario three.

	Throughput of BS 2					
Distance	seed128	seed 256	seed 512	seed 1024	seed 2048	Average
20	0	0	0	0	0	0
30	0	0	0	0	0	0
40	4,344.82	4,743.975	4,141.238	4,494.396	4,149.369	4,374.76
50	0	0	0	0	0	0

Table B10: Average delay of scenario three.

	Delay(msec)					
Distance	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
20	7.283	6.361	5.461	6.406	7.631	6.628
30	10.154	5.946	3.484	6.134	6.909	6.526
40	12.045	6.644	8.055	5.412	6.227	7.677
50	10.169	8.35	6.067	5.766	8.036	7.678
60	11.362	9.355	8.364	7.079	6.508	8.534
70	0	0	0	0	0	0

Table B11: Average load of scenario three.

	Load(bit/sec)					
Distance	Seed1 128	Seed2 256	Seed3 512	Seed4 1024	Seed5 2048	Average
20	25,378.21	24,168.51	24,828.11	24,559.07	23,974.71	24,581.72
30	24,954.57	26,008.74	12,443.22	24,707.49	23,907.81	22,404.37
40	25,329.94	26,556.58	23,508.06	25,407.37	24,116.4	24,983.67
50	25,314.76	25,170.15	24,941.1	24,000.41	23,450.52	24,575.39
60	22,241.17	22,631.63	17,313.37	19,349.56	23,562.75	21,019.7
70	12,478.77	12,475.37	12,519.21	11,800.12	11,657.45	12,186.18
80	12,478.42	12,475.37	12,338.08	11,800.12	11,657.45	12,149.89
90	12,478.42	12,475.37	12,338.08	11,800.12	11,657.45	12,149.89

Scenario Four:

Table B12: Average throughput of scenario four.

Number Of Nodes	System Throughput (bit/sec)	BS 1 Throughput (bit/sec)	BS 2 Throughput (bit /sec)
40	2,208.22988	210.460356	587.1770428
50	6,221.597674	1,477.950174	1,446.56197
60	7,933.829624	1,870.045574	3,385.129177
70	9,274.498495	2,602.403205	3,489.965322
80	21,510.72412	8,209.375624	4,140.730214
90	28,708.74865	6,220.322766	9,424.44698
100	32,529.8466	7,100.223481	10,914.17454
110	41,766.12134	10,021.68382	7,138.618316
120	59,124.36558	12,497.14299	12,901.48203

Table B13:Average delay of scenario four.

Number of Nodes	End-To-End Delay (ms)
40	6.599
50	5.449
60	6.742
70	6.687
80	6.843
90	6.044
100	536.78
110	420.434
120	567.625

Table B14:Average jitter of scenario four.

Number of Nodes	Jitter (мsec)
40	3.80495
50	1.14265
60	1.61659
70	1.05568
80	2.09726
90	5.08229
100	34,740.068
110	25,954.751
120	21,695.913

Table B15:Average load of scenario four.

Number of Nodes	Load (bit/sec)
40	652,573.2548
50	901,736.858
60	1,070,057.423
70	1,272,806.432
80	1,519,358.241
90	1,718,914.032
100	2,195,169.427
110	2,290,138.369
120	2,467,243.218

Scenario Five:

Table B16:Average throughput of scenario five.

Number of Nodes	System Throughput (bit/sec)	BS1 Throughput	BS2 Throughput	BS3 Throughput
90	5,584.421454	1,370.890645	760.6730778	492.4183056
105	8,350.27326	2,470.461893	2,174.16284	929.9351268
120	18,598.32394	4,419.641564	3,724.894456	1,297.828607
135	22,703.09951	2,604.662632	2,934.441523	2,306.209498
150	33,726.54164	2,585.009086	2,516.08986	1,482.209921
165	47,425.99375	2,136.091718	2,393.008371	2,978.882827
180	42,515.27949	2,507.943572	2,506.073887	2,627.942708

Table B17:Average delay of scenario five.

Number of Nodes	Delay(ms)
90	5.889
105	6.001
120	5.739
135	5.272
150	240.652
165	189.844
180	202.171

Table B18:Average jitter of scenario five.

Number of Nodes	Jitter(мsec)
90	1.21656
105	1.69254
120	1.1824
135	746
150	5,273.1
165	5,323.092
180	4,629.501

Table B19:Average load of scenario five.

Number of Nodes	Load(bit/sec)
90	1,360,949.891
105	1,679,567.185
120	1,941,155.263
135	2,174,887.368
150	2,662,693.628
165	2,935,264.161
180	3,100,980.662