OPTIMISATION OF 802.16m (WiMAX2) RELAY STATION FOR ENHANCED PERFORMANCE

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By

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A thesis submitted to the University of Bedfordshire, in fulfilment of the requirements for the degree of Master by Research

DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Master by Research at the University of Bedfordshire.

It has not been submitted before for any degree or examination in any other University.

Candidate Name: ______________________

Signature: ______________________

Date: ____________________

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In the name of God the most gracious and merciful who bestow me with health and abilities to complete this research thesis. By only his will my effort and hard work for this thesis could lead me to success in life.

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ABSTRACT

The relay stations are widely used in major wireless technologies such as WiMAX (Worldwide Interoperability for Microwave Access) and LTE (Long term evolution) which provide cost effective service to the operators and end users. It is quite challenging to provide guaranteed Quality of Service (QoS) in WiMAX networks in cost effective manner. In this thesis the WiMAX RS (relay station) is investigated for the purpose of saving overall cost by decreasing the number of RS to cover the territory of base station and also to provide the services to mobile users out of the range of base station. Secondly, the throughput and delay matrices have been taken to enhance the system performance. In addition to cost effective deployment of RS and evaluation of throughput and delay using relay station, the third factor which is with comparison of QoS classes is also made in order to see the overall performance of WiMAX network. As a technical challenge, radio resource management, RS selection, and QoS parameters are also primarily considered.

The main objective is to decrease the overall deployment cost in relay stations and utilize the available spectral resources as efficiently as possible to minimize the delay and improve throughput for end users with high demanding applications such as voice and video.

Having in mind the cost and the increasingly more demanding applications with ever growing number of subscribers, main consideration of this thesis have set the parameters and contribute to the technology in cost effective way to improve QoS. Within the pool of scheduling algorithms and for the purpose of achieving efficient radio resource management, link adaptation methods, AMC scheme, cell sectoring and directional antenna have been studied in detail. Some of the IEEE802.16m standard parameters are not supported in current version of OPNET 16 due to new amendment and evolution of new techniques applied in WiMAX2.

LIST OF ACRONYMS

AF	Amplify and Forward
AMC	Adaptive Modulation and Coding
BE	Best Effort
BER	Bit Error Rate
BS	Base Station
CapEx	Capital Expenditure
CTS	Clear To Send
DF	Decode and Forward
DL	Downlink
ertPS	Extended Real Time Polling Service
EN	End nodes
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
GSM	Global System for Mobile Communication
LOS	Line-of-Sight
LTE	Long Term Evolution
MIMO	Multiple-input Multiple-output
MS	Mobile Station
NLOS	Non Line-of-Sight
nrtPS	Non Real Time Polling Service
OFDMA	Orthogonal Frequency Division Multiple Access
OpEx	Operational Expenditure
PMP	Point to Multipoint

QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature phase shift keying
RRM	Radio Resource Management
RS	Relay Station
rtPS	Real Time Polling Service
RTS	Request to Send
SOFDMA	Saleable Orthogonal Frequency Division Multiple Access
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
TDMA	Time Division Multiplexing Access
UGS	Unsolicited Grant Service
UL	Uplink
WiMAX	Wireless Interoperability for Microwave Access
3GPPP	Third Generation Partnership Project

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Chapter 1

Introduction

1.Introduction

In the last few years, there have been revolutionary changes in the field of wireless networking. This revolutionary evolution became stronger with the adaption of mobility in wireless communication world as mobile and computer technology made everything possible to communicate and provide services to the user while driving, in the restaurant, on buses and train. Most commonly people use mobile wireless internet to download music, navigation, mobile shopping, network gaming, mobile banking and so on.

WiMAX stands for "worldwide interoperability for microwave access". It has emerged as a mobile broadband solution and covers most of the demands of users by providing number of services, such as data, voice and video. WiMAX are set by IEEE which evolved from IEEE 802.16 family. Nowadays, more and more users are subscribing for mobile internet and this is causing the congestion over the service network hence, affecting the QoS (Quality of Service).

In WiMAX, various features are introduced to ensure guaranteed QoS (Quality of service) for the end users. Along with, these standard features other techniques are also used to further enhance WiMAX capabilities such as use of Relay stations, various types of antennas, modulation and coding schemes to increase throughput and cell coverage. Although, these techniques are very effective but there is still scope for further evolution and improvements.

Relay Stations are very effective and widely used to increase the cell capacity and coverage area. Researchers are working to use the WiMAX resources more and more effectively to cut down the costs while improving the QoS standards which eventually lead towards making mobile internet more affordable for common people to use of mobile devices to perform everyday internet related tasks.

1.1 WiMAX and WiMAX2

In the field of telecommunication, cable or wired broadband connections are very commonly used by average internet users because they are affordable, fast and reliable. WiMAX has the potential to allow the broadband service providers to provide fast and reliable wireless broadband. WiMAX was first established as a Standard for wireless Metropolitan Area Networks by IEEE and based on 802.16 protocol family. The first WiMAX protocol was developed for fixed wireless broadband access and later approved by IEEE in 2005 with mobility support and named IEEE 802.16e [2]. The first WiMAX operate the range of 10-66 GHz and lower band operates in frequency range from 2-11 GHz. WiMAX technology is based on point to multi point technology.

WiMAX2 or IEEE 802.16m is the advance version of WiMAX which is based on its previous version IEEE 802.16e with added features [1, 6] such as it supports 300 Mbps data rates with mobility whereas 802.16.2-2004 supports data rate of 100 Mbps. Therefore, IEEE 802.11 can increase VoIP capacity with low latency to meet the requirement of 4G (International telecommunication union) [1, 5]. WiMAX forum has name IEEE 802.16m as WiMAX2. WiMAX2 uses the OFDM (orthogonal frequency division multiplex) and other advance antenna technology like MIMO (multiple inputs and multiple outputs) for better performance. The main purpose of IEEE 802.16m WiMAX standard is to improve spectral efficiency, improve VoIP capacity, handover, and speed coverage range. The IEEE 802.16m works with the radio frequency range from 2 to 6 GHz as well as it also supports scalable bandwidth of range 5 to 20MHz [1].

The main features of WiMAX2 are [1];

- The peak and channel spectral efficiency has been increased which helps and provides better spectral efficiency for the users at the cell edge
- The overall VoIP capacity has also increased with the help of user plane latency, also the handover drawback also decreased. The available channel bandwidth in WiMAX2 is scalable to 40MHz.
- Throughput supposes to be at least three times more than the existing IEEE 802.16e or mobile WiMAX.
- Mobility support should extend to 350 km/h
- Single user and multi user MIMO for throughput enhancement

- New and enhance RS which provides better throughput capability with MIMO
- It support multi cast and broadcast services
- Enhanced energy efficiency enabled for power savings
- It supports femtocells which are low power base station (BS) to enhance the coverage.

1.2 Relay Station in WiMAX

Relay stations enhance the capacity, throughput and coverage area of BS (Base station) in the technologies like WiMAX and LTE. At early stages, relay stations were used to work as repeaters, and their primary task was to boost the signals received from BS. However, the booster did not have the capability to remove errors, increase throughput for long distance communication and also cause inter cell interference. But, after the introduction of IEEE 802.16j which is the first standard for relay station, various new features are added in RS to enhance the functionality of the relay stations making them much more intelligent devices to work well with BS and provide better performance to end users. The RS is capable of boosting the signal and also it has some extra features like compression and decompression, error correction, and DF (decode and forward). In WiMAX relay stations are either deployed at the cell edge to extended coverage area or they are deployed within the cell to relay the BS signal into coverage holes. Relay stations provide a cost effective, low coverage and easy to install solution for coverage area extension and to eliminate coverage holes [5]. Multi-hop wireless networks use two or more relays to provide services to the users which are out of the range of BS. Instead of installing multiple BS, use of multiple relay stations is a very cost effective solution. Relay stations are very useful to ensure QoS in WiMAX as they increase coverage area, eliminate coverage holes, increase throughput and capacity of the network [8].

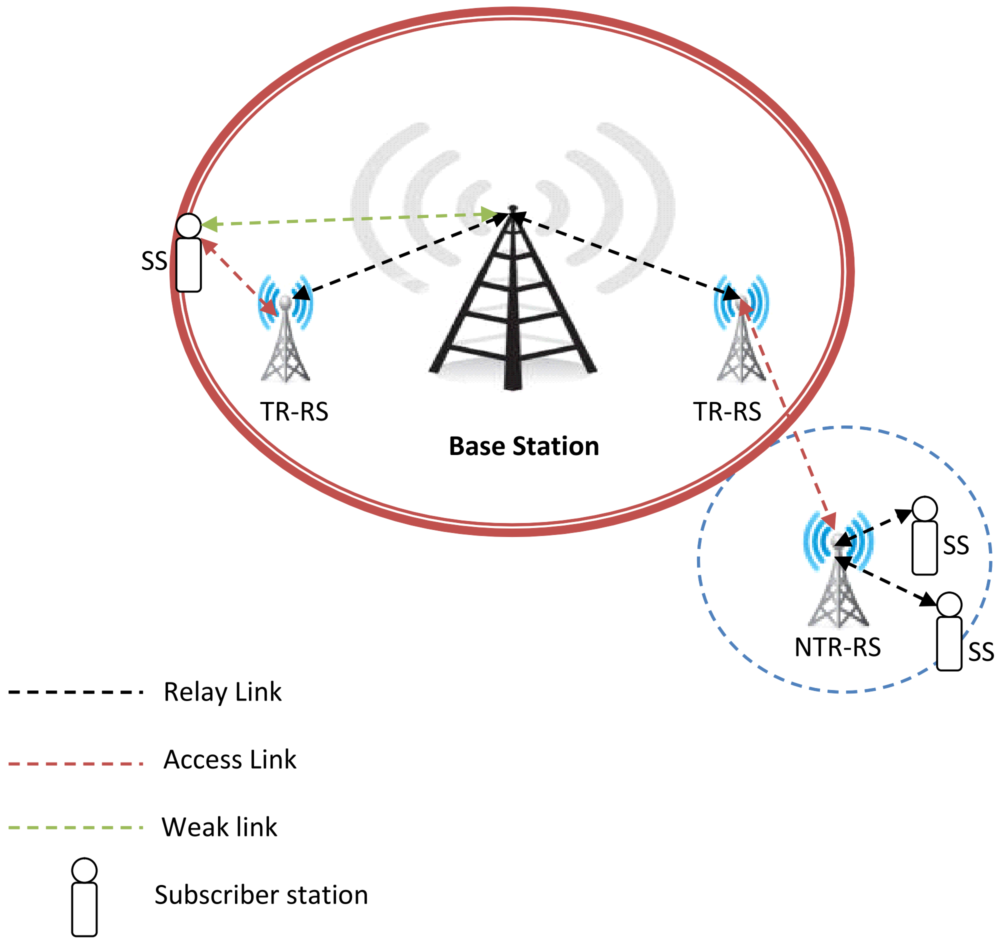


Figure 1.1 Different types of relay stations

The figure above shows the operation of relay stations in a WiMAX network. Here RS of NTR-RS (non transparent relay station) is used to extend the coverage are as it installed at the edge of the cell and relay stations of TR-RS (transparent relay station) are used to eliminate the coverage hole as they are deployed within the cells where signal are obstructed, possibly by tall building or mountains or base signal signals are not strong enough to communicate. The link from BS to Rs called relay link and from SS (subscriber station) to RS called access link.

1.3 Problem Statement

In a WiMAX network there are two main entities involved in communication which are Subscriber Station (SS) and a BS. A BS is typically a service provider which has backhaul connectivity and SS subscribes to the BS for the service. A BS exchange control messages and negotiate the connection parameters with SS before setting up the communication link with it. These parameters may vary during the communication depending on the requirements and availability of resources between the two entities. When a BS try to create link with a SS and if the SS is within the range then BS communicate directly with SS. Otherwise, if SS station is out of the range of the BS or there is coverage limitations or no LOS (line of sight) between the BS and SS then RS is a cost effective solution to overcome this problem.

There are two approaches applied in the research towards improving the WiMAX network performance. Firstly the placement method should need to be determined in order to cut down the cost as well as maintain the QoS standard. The second scenario is based on the performance evaluation of WiMAX2 network using relay station with in depth analysis of how to increase throughput and reduce delay parameters to improve overall network performance. The QoS class’s comparison also will be included for network flow and its resource usage. In the course of research, various issues have been addressed by providing solutions based on selection of RS and using different modes of RS. WiMAX nodes are incorporated to produce useful functionalities; communication models, antennas and other devices are technically enhanced. And using these ideas and products WiMAX communication is brought to an advanced level, where multi-hop scenarios were successfully simulated and studied.

OPNET Modeller, version 16.0 is used for simulations and all the models used in this research are based on features available or added to OPNET Modeller. The performance of a WiMAX communication system is also based on some assumptions as IEEE 802.16m relay station which support advance antenna technology like MIMO (Multiple input multiple output) and directional antennas and it also will have the capability to work as full fledge BS (Base Station). These enhanced features are not supported by OPNET Modeller 16.0. To make the WiMAX relay system more competitive and applicable to meet the QoS demands, WiMAX RS has been considered as a promising solution for throughput and coverage enhancement. As relay based architectures are quite new, there are many open questions which are of concern to network operators regarding how best to design IEEE 802.16j and IEEE 802.16m to provide better performance to the users. There are many open issues regarding cost effective deployment and enhanced QoS need to be considered including:

- The main responsibility of RSs to work as middle node and regulate the data transmission between the BS and Subscriber Stations (SSs). As discussed earlier, RS are used to extend coverage of BS by placing RS at cell edge or boundary where BS signals start to fades and there is no direct link between BS and SS or link quality for the user out of the boundary is not very strong to communicate. To cover the cell area, normally four relay stations are used to provide services to the users out of the range of BS, however four relay stations can provide better QoS but overall cost also increase. In order to get better QoS as well minimize overall cost, RS should need to be placed at in cost effective manner so better results could be achieved as well as save the overall cost.

- Another important aspect should need to consider for network performance evaluation measurement by improving the QoS standards in different RS usage scenarios such as multihop, with three and with four RS in order to compare the performance with throughput and delay parameters to maximise the overall system capacity.

1.4 Aim and Objectives

The aim and objectives of the thesis are described below.

1.4.1 Aim

The aim of the thesis is to cost effectively deploy the RS in a WiMAX network and also to takes measures to enhance the QoS and conduct an analysis

1.4.2 Research Objectives

- To acquire detail knowledge of WiMAX and WiMAX2 technology
- To investigate different methods and techniques for RS deployment in order to cut down the costs.
- To understand the different problems in maintaining cost effective deployment of RS.
- To investigate and analyse different QoS characteristics such as throughput, delay, SNR (signal to noise ratio) and network load.
- To investigate and evaluate different techniques to improve overall system performance which provides guaranteed QoS.
- To assess published major approaches (through literature review) on WiMAX RS planning and optimization.
- To investigate advance antenna technology and MIMO to further improve coverage and throughput in WiMAX2.
- To investigate and implement an efficient way to reduce delay and enhance throughput to meet the QoS standard in 802.16m

1.5 Thesis Structure

This section represents how the chapters of this report are organised.

Chapter 1: This chapter includes the introduction of WiMAX technology, RS in WiMAX, problem statement and aim and objectives of the research.

Chapter 2: The purpose of this chapter is to present an overview of RS characteristics, cost analysis and QoS parameters in order to evaluate and differentiate with other researcher. In this chapter existing relevant research is analysed with respect to the problem. Extensive study is carried out for cost effective placement of RS and QoS metrics for performance evaluation.

Chapter 3: This chapter comprises of through knowledge on WiMAX technology and RS. This chapter is divided into two sections where first sections described in detail about WiMAX technology and its physical layer and some other key technologies like modulation schemes, QoS and advance antenna technologies. The second section is all about the background of WiMAX and RS where different techniques on RS, RS modes, paring schemes and MIMO technology are discussed in detail.

Chapter 4: This chapter contains the simulation design and setup using OPNET version 16, RS deployment using modulation schemes and cell sectoring. Then, comparison of QoS class's is also made in order to compare and evaluate different class's types and their usage. Finally, a detailed performance analysis based on throughput and delay also made to check the performance metrics with throughput and delay aspects.

Chapter 5: This chapter critically comments and analyses the approaches and methodologies towards RS deployment, QoS classes comparisons and detailed performance analysis based on throughput and delay designed and simulated in chapter four. This chapter gives a purposeful knowledge about cost effective deployment of RS to decrease the cost but maintain the QoS standard. The comparison on QoS classes is also discussed to check and measure the allocation of resources. The delay and throughput parameters are also discussed and compared in order to check the overall network performance.

Chapter 6: This chapter concludes the thesis with cost effective deployment of RS, QoS classes and QoS performance metrics with delay and throughput. The suggestions for future work are also addressed.

Chapter 2

Literature Review

2 Literature Review

The RS helps to improve coverage and throughput for better performance of WiMAX network. Relay is cost effective technology to achieve high data rate, enhance performance and throughput and increase cell coverage. The RS may be deployed in the following scenarios

- Signal reception is not very good such as in dense urban areas
- The BS deployment cost is too much
- During mobility, the power requirement at subscriber stations with high speed communication and at distance.

RS also plays vital role to enhance throughput and coverage for better performance of WiMAX system [13 – 16]. All the above mentioned scenarios depends on the deployment and relay usage type as there are three types of relay usage which can be classified as fixed, nomadic or mobile. The fixed RS are deployed at fixed locations to enhance the throughput and coverage and the nomadic RS can be deployed temporarily but at fixed location. However, the mobile RS are deployed at trains, buses or any other moving objects for the users to access the service while on move [25, 27].

2.1 Cost effective Deployment of Multi-hop Relay Networks

There are different types of challenges in planning and optimization of RS in order to get better QoS with cost effective deployment [32]. The cost is the main factor for any type of technology. Therefore a cost effective deployment solution could provide better performance results as well as save the overall deployment cost.

2.1.1 Cost Analysis of Relay station

Generally four RS cover the territory of the BS [67] in order to get guaranteed QoS for the users out of the range of BS. However, BS planning and placement is another major factor in wireless industry [26, 32, 49]. Generally a site can be divided into three parts consist of backhauling, BS equipment and overall site infrastructure [37]. The backhauling is the connection of BS to the core network with point to point or leased line. The BS equipment can be antennas, material for tower height and infrastructure can consist of number of equipments like back up power units. The RS does not have any connection with backhaul as it connected with nearest BS to provide services to EN (end nodes). The position of the RS is also an important issue for RS placement in the area where SNR (signal to noise ratio) is high and link budget is good. The table below [31] shows the elements needs to be considered as CAPEX (Capital Expenditure) and OPEX (Operational Expenditure) for BS and RS deployment. In the table the one of cost for spectrum licence, research and marketing has not been considered. The CAPEX and OPEX may be different dependent on the scenario type such as urban, dense urban or in rural areas.

CAPEX	**OPEX**
Cost of BS (Three sector site)	Power supply Cost
Cost of RS	Site rent and maintenance cost
Civil works cost for BS and RS	Rent for RAN connectivity
New tower or rooftop deployment	Power supply cost (BS – RS)
Wire line or microwave connectivity	Network Operations
Centralized radio resource management	Terminal device cost and subscription
Initial network optimisation	Software upgrade

Table 2.1 General CAPEX and OPEX for BS and RS deployment [31]

However, the costs of base station (estimated $120,000) and relay station (estimated $40,000) are approximate cost from typical supplier [69]. The authors of [31] developed a model to minimize the installation cost of base station and relay station, which does not minimize path loss.

The author [31] also did the analysis of cost of RS deployment where the RS deployment cost can be compared with BS as shows in table below.

CAPEX	**Cost**
Three sectored BTS Tx + Rx + Antenna + Cables	$70000
Site acquisition + preparation + cabling + power	$50000
Backhauling with core network	$30000
New tower deployment	$80000
Total BS CAPEX	$23000
Total RS CAPEX	40% of BS
OPEX	
Backhauling cost (T1/E1) per year	$6000
Site lease expense per year	$13200
Maintenance cost per year	$9200
Installation and commissioning	$2500
Power per year	$2400
Total BS CAPEX	$333000
Total RS OPEX	40% of BS
Summary CAPEX + OPEX	
Per BS CAPEX + OPEX per year	$263300
Per RS CAPEX + OPEX per year	40% of BS

Table 2.2 Comparison of CAPEX and OPEX for RS with BS [31]

2.1.2 Relay station Placement

The design and implementation of WIMAX2 relay station model based on non transparent modes. The approaches and techniques used can improve the operation of non transparent mode. Whether WiMAX operators could provide better services to end users depends on available resources. The more capacity which is made available within cell or region, the large amount of data can be delivered. The critical aspect of this drawback is the type of services the end users can access e.g. video, voice or data. This could be more complex in multihop scenarios where more than one RS connected and providing services to the users out of the range of BS and primary RS. Therefore, to satisfy end users requirements and meet QoS standard, it is very important to determine some key issues like the end users requirements, overall load and what type of requirements end users are demanding e.g. video streaming, audio or data as the applications like online gaming or video streaming consume too much bandwidth when compared with voice and data applications. In order to achieve better QoS standards, the placement of RS should be carefully examined with site location, placement methods and area zone where RS can perform better.

In [59], writer deployed RS with AMC (adaptive modulation and coding) by dividing into zone based on QPSK (Quadrature phase shift keying), 16QAM (Quadrature amplitude modulation) and 64 QAM. The writer explained the advantages of AMC scheme with deployment of RS and differentiated the deployment in three zones. The available SNR and useful bits per symbol can be calculated by modulation scheme and its coding rate [64]. The BS nearside zone can be assumed on higher modulation and coding rate where SNR is high and high data rate can be sent and receive. However, the area nearside cell edge can be defined as QPSK and depending on the coding rate data rate is not as much as in higher modulation schemes.

SNR	**Modulation**	**Coding**	**Useful bits per symbol**
6.0	QPSK	½	192*2*1/2=192
8.5	QPSK	¾	192*2*3/4=288
11.5	16 QAM	½	192*4*3/4=384
15.0	16 QAM	¾	192*6*3/4=576
19.0	64 QAM	2/3	192*6*2/3=768
21.0	64 QAM	¾	192*6*3/4=864

Table 2.3 Adaptive Modulation and Coding Scheme example [64]

As an extension for PMP (point to multipoint) mode the MMR (mobile multi hop relay) mode in IEEE 802.16j was introduced to fill the communication gaps. As far as the better performance, coverage, capacity and considering some other major advantages of RS but we also need to bear in mind some critical aspects of RS. For example it also cause interference and if deploy more relays then it also exceeds the cost compare to BS as in [49, 51], the RS deployment in cost effective manner and also by simulated work showed the reduction of cost. The authors in [49] mentioned in detail and analyse the cost of BS and RS in order to achieve the guaranteed QoS. The QoS standard is based on better throughput less delay and packet loss

The location or placement of relays station is also another problem as the network operators will always like to have cost effective solution to provide satisfactory service. RS at the cell edges are better for coverage extension and relays between the BS and the cell edge are better for capacity enhancement,

2.1.3 Placement and Capacity Requirements for Relay station Deployment

Before the deployment of BS and RS, it is very important to measure the overall system capacity then specify the capacity requirement as it’s good to investigate the target city or region based on population density, population growth rate and customer distribution etc [48]. Different user demand different applications and some applications require large bandwidth and spectrum in order to fulfil the user requirement such as voice applications, video streaming, video conferencing and all other multimedia applications require more bandwidth as compare to users who just require only simple applications like emailing and surfing internet. Also it depends on the zone where of RS based on AMC [59]. As compare with other multi-hop networks routings issues of relay based networks are less challenging because of that if has purpose full effects on achievable throughput of such type of systems. System capacity is been reduced during transmission through RS in two different transmission phases comparing with a data duplication over RS which may affect the capacity of system. In relay based system may be higher delay will be occurred because of use of multi-hop networks as comparing with single-hop network. The DF (decode and forward) has studied widely and has much research done on this technique as the writer in [53]. In this paper the author developed an Omni-directional relay scheme with multiple sources using DF relay scheme, in this scheme every node can transmit multiple messages in different directions by combining them into a single signal. However by applying this Omni-directional relay technique it can cause interference and also can cause week signal strength by spreading the signal around.

In [18], the authors present a method for effective post processing processes for throughput at the receiver, but some other factors should be taken in consideration in addition to the previously mentioned issues. To sum up, the planning process in

WIMAX can be modelled as a multi objective optimization problem. The cost functions also to be considered [68, 69]:

- Cost
- Coverage
- Performance (Throughput)
- Interference

Using the multi-objective optimization framework, the time used for simulation may be a little long. A combination of both analytical study and simulation could be used to improve the speed of optimization, for example, theoretical analysis on network relay. Also new simulation techniques using OPNET can be considered to increase the simulator efficiency.

2.2 Adapted Approaches to Improve WiMAX Relay station Performance

There are so many key techniques used to improve the performance of WIMAX based RS included radio resource allocation, Advance antenna techniques, relay protocols, link adaptation, MIMO and frequency reuse etc.

2.2.1 QoS with Delay Minimization and Throughput Enhancement

AMC schemes used network for better performance [10, 11, 13]. The error correction techniques can be applied to UL (uplink) and DL (downlink) transmission which is adjustable as the higher modulation constellations can provide better throughput. However, the BS assigned higher modulation constellations to the users allocated nearside of the BS.

There are other physical medium like advanced antenna systems can be uses to improve throughput and link reliability [12]. WiMAX especially WiMAX2 allows multiple antennas to be used at the transmitter and the receiver. In order to get enhanced results IEEE 802.16m use new antennas technologies including MIMO, frequency reuse and Comp (Coordinated multipoint) etc.

The frequency planning and frequency reuse are another techniques used in WiMAX2. These techniques reduce the interference and therefore increasing the capacity. [11]

- Optimum frequency assignments can be applied by considering

- Site locations
- Power levels
- User distribution
- Spectrum availability
- Geography and building characteristics.

In OFDMA (Orthogonal frequency division multiple access) based technologies, hexagonal cell is used to denote the area covered by BSs and RS. The RS cluster in the following includes single RS or several adjacent RS; the frequency reuse method follows four rules [8]:

Each RS cluster has an isolation band [9].

- All the users are served by the BS except those within the coverage of RS cluster.
- The RS in each RS cluster could reuse the resource out of its isolation band.
- RS in each RS cluster could reuse the resource in its isolation band selectively depending on the interference measurement or throughput decreasing.

2.2.2 Coverage and Capacity Enhancement Using Relay station

In WIMAX, most efforts have been aimed to improve spectral efficiency. This can be achieved using one or more of the following approaches: MIMO large increase in signals bandwidth and cross-layer optimizations.

In [15] they present results for different simulation scenarios and show that RS can provide an improvement in SINR coverage and spectral efficiency. In [16] results for the coverage extension and capacity enhancement of RS in a realistic scenario are presented. In [17], the writers introduce the algorithm of coverage angle and coverage range to establish the relation between the coverage extensions achieved with RS. In [18], the writers present an analysis of coverage extension with mobile relays and in [19] they propose dynamic load balancing schemes based on the integrated cellular and using point to multipoint point relaying systems. The BS and RS transmit signals with a certain power so that the average received power at the border of the cell is reaching to the end users without path loss and shadowing. The main factors in path loss are the frequency band and the distance from source to destination as the path loss and attenuation caused by higher frequencies used by neighbouring cell. Also shadowing is caused by obstacles between the source and the destination which cause reflection and scattering. The increase in the required received power results in the decrease of the coverage. As more users increase in the cell or in the case of load, the coverage area decreases. The coverage and the capacity in a cell have both advantage and disadvantage as higher frequencies are a disadvantage for coverage, but it’s an advantage when it comes to capacity.

Capacity is another important factor which affects the WIMAX performance. In general term we can determine capacity by the amount of data that can be delivered to the user and from the user [26]. In a WIMAX system, user normally access internet for surfing net, video streaming and voice applications and these applications or user requirements applies or request different demands on the system depending on the applications type. Different applications require a higher data rate and need more bandwidth for downloading purpose but not on upload. The authors of [47] evaluate the performance of WiMAX using RS for the purpose of cost effective coverage extension with link capacity model for 802.16 MMR and also address the scheduling schemes for EN. However, they mentioned that with good RS antenna gain and power, RS can be deployed further away from the cell coverage to increase the cell coverage but it is not mentioned about the BS and RS link quality as placing the RS out of the cell where signal strength normally very week can result in poor link or delay.

2.2.3 Optimisation of Radio Resource Management in Relay station

The RRM (Radio Resource Management) in WiMAX network covers the management and optimization of the radio resource utilization. The new developing standards like 802.16m require better spectral efficiency with high data rates to fulfil user and QoS requirements [23]. There are so many ways to achieve better performance in IEEE 802.16m such as Link adaptation techniques where different types of modulation scheme applied to get better results. Link adaptation can be useful if before transmission the BS as transmitter has the knowledge about channel state. To utilize the radio resources in WiMAX link adaptation plays an important role. There are different approaches which help in good link adaptation. In [70], uplink scheduling algorithm has been proposed for RS. The purposed algorithm enhances system capacity, bandwidth efficiency and improves delay performance for real time applications. AMC (Adaptive Modulation and Coding) plays an important role in wireless communication technology for both fixed and mobile environments. The authors of [66] clearly defined and implemented AMC scheme and its effects on QoS performance of WiMAX network. all the new upcoming technology like LTE and 802.16m using advance antenna technologies such as MIMO and directional which help to utilization of resources efficiently.

MIMO has more than four streams which are used in IEEE 802.16m [60, 52, 55]. In IEEE 802.16m, the enhanced MIMO plays an important role for increasing the throughput [55]. The previous link adaptation techniques based on MIMO can be classified into two general categories which are analytical and heuristic which explain limitations of packet error rate. In [52], authors explain error rates for link adaptation which is bit error rate (BER) or packet-error rate (PER) against SNR.

2.3 The QoS with Relay stations

The QoS based on MAC layer of IEEE 802.16m on the concept of connections as unidirectional data flow from each side (from source to destination and from destination to source). The flow is assigned a four bit flow ID also called FID. To generate the network-unique 16 bit identifier, the FID can be combined with a 12 bit station ID (STID). As compare to IEEE 802.16m the existing legacy model allowed full 16 bit connection ID for each connection which means almost 216 users can be connected per BS. But the disadvantage is, each of these connection IDs had to be re-establish on handover which cause more overhead. Not much work is done on QoS in WiMAX2 or IEEE 802.16m as compare to existing WiMAX networks. There has been related work such as in [15], where the IEEE 802.16 QoS was simulated but mostly on BE (Best Effort) services with limited scope and scenarios. Our research includes simulation and detailed analysis of all the five service classes in varied conditions and scenarios. In [13] the authors, worked on both physical and MAC layer and used NS-2 to simulate the scenario. However, the work is only simulated for packet loss whereas there are different types of QoS characteristics such as delay, network load and throughput to be pin pointed in order to improve the performance. In contrast, the writers in [40] calculate the throughput to improve the performance of WiMAX non transparent mode. The parameters chosen by writers in this work were very basic. However, the idea was just based on non transparent mode where average throughput inside and outside the coverage area of the BS is calculated.

The simulation was made for UGS (unsolicited grant service, BE (best effort) and rtPS (real time polling service) scheduler in [21], in order to compare the results of all the mentioned above QoS scheduler, writer investigated and implemented a new module to get and compare the results of all three QoS classes. In [42], the writers present the flow management framework for multi-hop mobile systems and apply it to QoS scheduling with different priorities. The writers mentioned that application sessions on the Data Link Layer, flows are assigned priorities to distinguish QoS requirements and simulated results are based on single and multihop scenarios.

Writers in [43] evaluated on-demand bandwidth allocation in RS. They develop new algorithm for spectrum efficiency based adaptive resource allocation. The writers have in detail look and simulated the results of available throughput, packet loss and delay but here it is needed to consider network load which the writers did not mentioned. Because when the network load increases the QoS automatically decreases [16]. The authors further describe in the paper about QoS and their problems in which they considered the centralized scheduling using UL scheduling. They proposed an architecture named as SQSA named as scheduling QoS scheduling architecture to ensure QoS and to find a specific request for the quality of request.

WiMAX forum worked on IEEE 802.16m bandwidth request protocol for better performance [1]. Because in existing legacy system a five message request was needed for bandwidth request but in 80.16m three messages grant request is available by knocking off two to decreasing the latency. WiMAX channel bandwidth is 20MHz and WiMAX2 bandwidth has doubled and varying bandwidth is used based on the traffic. WiMAX uses OFDMA to allocate sub carriers or modulated carrier to the users. The available sub carriers to allocate in the UL and DL (down link) are based on UL and DL transmits power ratio, frame structure and size and available bandwidth as utilisation of resources in OFDMA relay network relay on BS. The efficient and simple resource algorithm proposed in [65] for relay network to maintain the fairness among users while maximized data rate.

2.3.1 Relay stations Applications

RS can be used for different applications in WiMAX networks but it most commonly used for three aspects which are coverage extension, capacity enhancement and throughput enhancement [42]. The WiMAX2 have very challenging requirements for transmission rates and there is a growing demand in WiMAX networks for coverage and capacity enhancement.

RS have been designed to meet these requirements with guarantee QoS support. The QoS in relay technology can be:

- Better throughput with less delay
- Coverage Extension for the user out of the coverage of BS
- Reduce signal overhead/Latency
- Higher bandwidth efficiency
- Less delay and packet loss during mobility

Together with all mentioned above better performance and QoS results in relay networks can be achieved. In RS communication, the SS or EN can receive the signal from the BS or via RS through different paths depends on the end user location. It can be through the multihop relay link (transparent) and the multi hop (non transparent) where direct link from BS is also possible. IEEE802.16j and IEEE802.16m define two different types of modes in relay technology called transparent mode and non transparent mode [9, 16, 25]. The transparent mode can provide better QoS demands for end users as compared to non transparent mode because the transparent mode basically works to extend the capacity of BS not coverage because the end users may access the service directly from BS or through RS depending on the link quality. Also, it enhances the throughput within the cell. However, covering end users QoS demands we need to enhance the throughput and minimize the delay in order to WiMAX RS work well. The performance can be improved in RS by taking all the necessary QoS characteristics such as delay, throughput, pack loss and network load. Most of the work has been done on individual factor by focusing on single term to show the improvement by enhancing the system performance in that specific parameters like in [18], the writers focus on throughput and packet loss but delay has not been simulated as it is clear from the title but there is no simulation found for delay analysis.

The writers done simple simulation with only one BS and one RS connected with mobile node out of the range of BS. The critical aspect in this paper is the antenna height mentioned in simulation parameters which is 10 meters. The normal antenna height of both BS and RS should be above 25 meters to get better performance and signal strength.

2.3.2 Performance of Relay stations

WiMAX like other wireless systems suffers from different propagation characteristics and resource allocation in reasonable manner. The performance of RS can be affected by different characteristics such as antenna height, distance from BS and distance from SS as the SNR (signal to noise ratio) decreases when distance increase. Also NLOS (non line of sight) communication where signal reflects with objects like tall buildings, forest and mountains can affect the signal quality. Throughput enhancement, capacity and reliability can be achieved if the users have better SNR especially in the area where BS signal fades at the edge of the cell. The RS enhance the link quality, throughput and coverage extensions. There are two approaches defined by IEEE 802.16 standard which are centralized and distributed [10]. In centralized approach, the BS can cover the cell radius where RS also deployed and the second approach called distributed scheme, where RS coordinates the performance of the SSs.

RS is also very useful in load balancing. During congestion or high load within same cell RS transfers the traffic of one cell to neighbouring cell. The RS extends the coverage where there is no direct link between the BS and the destination node.

2.3.3 Relay stations Selection in WiMAX System

In wireless networks such as IEEE 802.16m or 3GPP (Third Generation Partnership Project) LTE, there are typically several fixed RS in the region deployed depending on the user’s access. If source A as MS (mobile station) wants to send a message to Z (MS) as destination node and there are several nodes (RS) in between A and Z then relay selection determines the best suited RS for this communication. The selection process will operate in distributed manner in terms of message complexity and delay.

In the first step relay estimates the channel quality between itself and source and itself and destination. For example A is source and z is destination and R is relay. So it can be R and A and R and Z respectively.

Source A send ready to send message to destination Z or destination received this message. Also, all other neighbours of source A received this message. When destination Z receives the RTS (request to send) message it then send CTS (clear to send message) back to source A. When relay receive RTS message from source a, it check or determine the channel state information (CSI) from source A to R (relay and R (relay to destination Z. The main point we need to keep in mind on this stage that the Relay (R) assumes the channels are the same from forward source (A) to relay(R) and backward relay(R) to destination (Z) then each nodes or RS determines the best channel state information (CSI) value and worst channel state information (CSI) value should served as relay.

Relay selection plays an important role in WIMAX network [29 – 30]. As discussed above, in congested wireless networks there are different RS deployed in the region to fill the transmission gap and user requirements. Determining from different relays which one should be selected for communication is a difficult problem, because some RS may have a strong channel link or link quality to the destination, but it may also be heavily loaded with traffic from other SS. In [29] the authors proposed a relay selection algorithm to meet the QoS standard. However the writer did not mention about the available throughput for each end user and their algorithm improved the performance in accordance with signal to noise ratio and latency. Also the writer chooses very simple services like HTTP and voice to be checked and meet the demand of user. The writer suggests through effective relay selection algorithm, RS can play an important role by considering the QoS parameters in order to get better performance. There are different types of relay selection methods mentioned in by the writer.

The main relay selection methods are:

- RS selection with physical distance
- RS selection with path loss
- RS selection based on SINR
- RS based on transmission power

However, there are some disadvantages of above mentioned selection's methods e.g. Delay can cause while selection suitable relay for communication, also path loss transmission's delay can occur. In [30] the author proposes a cross-layer design relay selection algorithm for two hop relay networks. The authors introduce a novel function for relay and proposed algorithm by considering both channel state information on physical layer and queue state information at data link layer. As compare to this, the authors of [34] proposed a method based on geographical information, aiming to minimize the symbol error probability (SEP). Also the suitable relay is determined with the aim of minimizing the symbol error probability so the proposed scheme can achieve better performance in selection process.

Relay mainly works as half duplex and DF technique can be applied for error free communication through RS. However, the half duplex DF, the transmission of RS can be divided into two time slots. In the first attempt, the source transmits the data to the RS where it demodulates and decodes received information. In the second phase, the RS encode again the received data and retransmit it to the EN.

There is also an important factor in the selection process which is that when relay send a message to the end users with signalling message indicating his availability. Then the pilot sequence used by BS estimate the instantaneous SNRs of that RS for selection process but this type of scenario can cause time delay.

2.4 Proposed Solution

The overall goal of the research is to propose the solution to deploy the RS in a manner to minimize the overall cost and maintain the QoS standard. Secondly, the two important QoS parameters which are throughput and delay has been taken to further investigate to improve the QoS standard using RS as well as improve overall network performance. A careful study is carried out to develop and design a solution to achieve the aim and objectives of the thesis. OPNET modeller will be used to simulate WiMAX RS networks and analyse its various parameters.

In order to provide guaranteed QoS to the users out of the range of BS, four RS are used in rural areas to cover the territory of the BS. Each RS cover additional cell radius to boost the BS signals to the end users which are out of the range

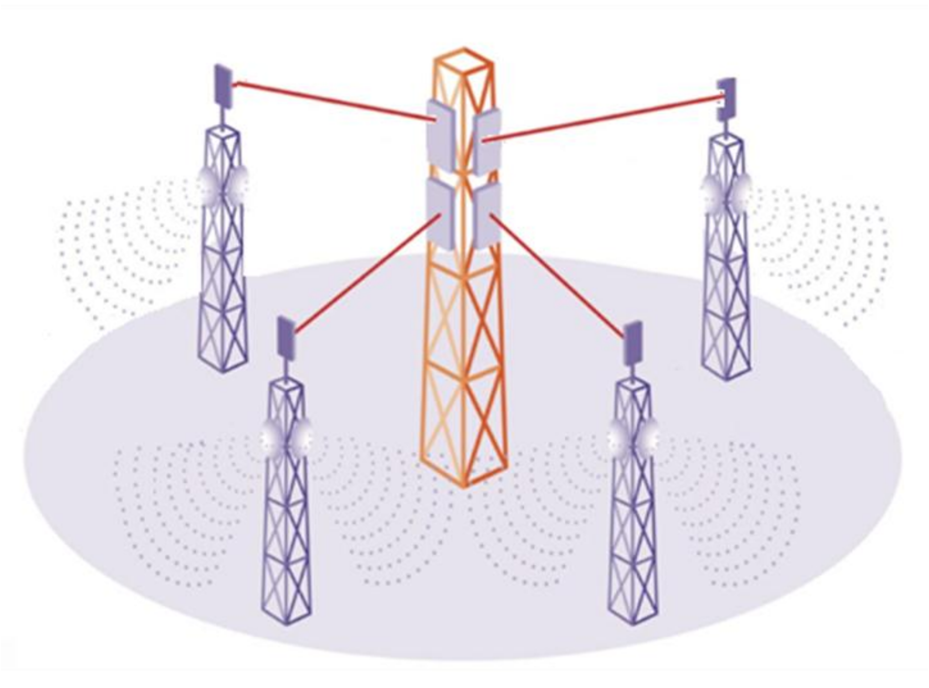


Figure 2.1 Four RS covering territory of BS

However, the increase of RS within cell can provide better QoS and SNR but it also increases the cost. There has been a solution propose to deploy three RS in efficient manner instead four to cover the territory of BS as well as maintain QoS standard and also using of three RS will result in saving costs by cutting down the deployment, installation and maintenance costs for RS. To provide better QoS and minimizing the cost can be achieved by dividing the cell into three sectors and deploying a RS in each sector at QPSK ¾ zones which can be inside the boundary of the cell. As in other cases, the RS placed at the edge of cell where the BS signal fades or less powerful. But by deploying RS at QPSK ¾ zone, the signal strength and SNR will be more as compare to cell edge area or QPSK ½ zones. However, three RS can consider not enough to cover all of the territory of the BS as compare to four RS. This can be solved by directional antenna at BS and it is important that the lobe of the directional antenna on the BS should be set towards the RS of the corresponding cell. So it could cover each sector with main and side lobes and suitable for throughput enhancement.

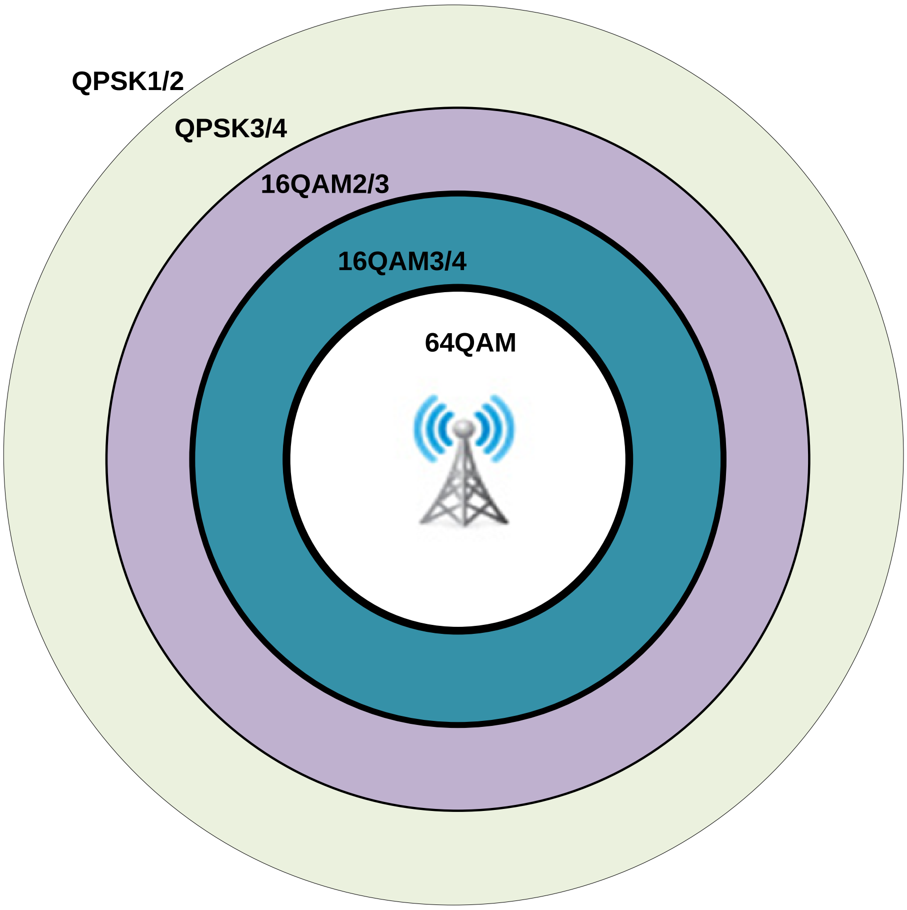


Figure 2.2 Adaptive modulation and coding scheme zones

Above mentioned network arrangement will be simulated in OPNET version 16.0 and various performance parameters will be collected. A comparison of performance parameters of three relay and four relay arrangements will be carried out to decide if the three relay arrangement is efficient enough to take place of four relay network and if this is a true case than it can be said that three relay arrangements is cost effective and QoS standard can be achieved with directional antenna and AMC scheme.

Secondly, QoS classes' comparison will be carried out by comparing the performance parameters of different classes. To achieve a simulation will be created in OPNET and QoS parameters collected from the simulation will be used for analysis.

Thirdly, a different network will be simulated with different RS arrangements. In this network there will be four cells where as one cell will have no RS, one cell will have three RS configuration, one cell will have multihop RS configurations and one cell will have four RS configurations. Later performance parameters will be taking for varying no of antennas and frame sizes. Based on those parameters an analysis will be carried out to decide which combination is most efficient. The Opnet version 16.0 does not support 4 * 4 MIMO antennas, so an assumption can be made upon the third scenario using advance RS with 4*4 antennas. It is important to mention that all the RS will operate in non transparent mode.

Chapter 3

Background

3 Background

IEEE 802.16m also called WiMAX2 is new and enhanced version of existing WiMAX with the new and enhanced features. It works on peak rates of its capacity that is 300 Mbps that increase VoIP capacity with low latency to meet the requirement of 4G (International telecommunication union). IEEE 802.16m uses the OFDM and MIMO to achieve the performance, importance to support advance services in featuring for emerging broadband mobile communication applications. The main purpose of IEEE 802.16m WiMAX standard is to improve spectral efficiency, improve VoIP capacity, and improve handover and coverage range. WiMAX physical layer support both TDD (time division duplexing) and FDD (frequency division duplexing) modes in to optimized multipoint application. The architecture of IEEE 802.16m works with the radio frequency which ranges at same standard from 2 to 6 GHz as well as it also supports scalable bandwidth of range 5 to 20MHz.

3.1 WiMAX Physical Layer

WiMAX2 or IEEE 802.16m is compatible with IEEE 802.16e 2005 specification and it's define three different physical layers characteristics

Single carrier transmission

- OFDM ("Orthogonal frequency division multiplexing")
- OFDMA ("Orthogonal frequency division multiple access")
- SCOFDMA ("Scalable orthogonal frequency division multiple access")

Now we will discuss them one by one.

3.1.1 Frequency Division Multiplexing (FDM)

As the name suggest, In FDM signal transmitted over different frequencies at the same time slot or carrier and each sub carrier is modulated separately by different data stream. Figure 3.1 shows five FDM carriers.

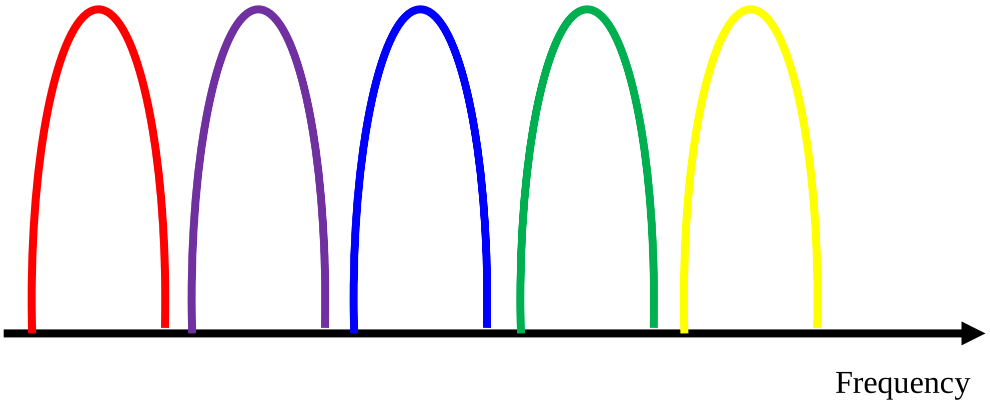


Figure 3.1 FDM (Frequency Division Multiplexing)

3.1.2 Orthogonal Frequency Division Multiplexing (OFDM)

To better understand OFDM or OFDMA technologies, it is useful to know FDM (frequency division multiplexing) as discussed above. In OFDM the frequencies are combined and are orthogonal with each other for data to be transmitted over a radio resource. The Figure 3.2 showing the multiple overlapped subcarriers combined with each other without causing interference. The main advantage of using OFDM is the data stream can be divided into low rate streams then each stream is converted to sub carrier with the help of adaptive modulation scheme.

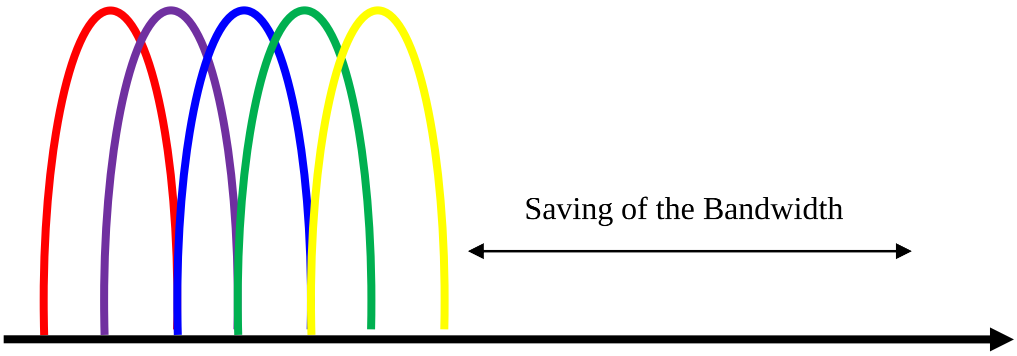


Figure 3.2 OFDM modulation techniques

Figure 3.3 below shows where five subcarriers are overlapped and not interfering with each other at peak where it carries data.

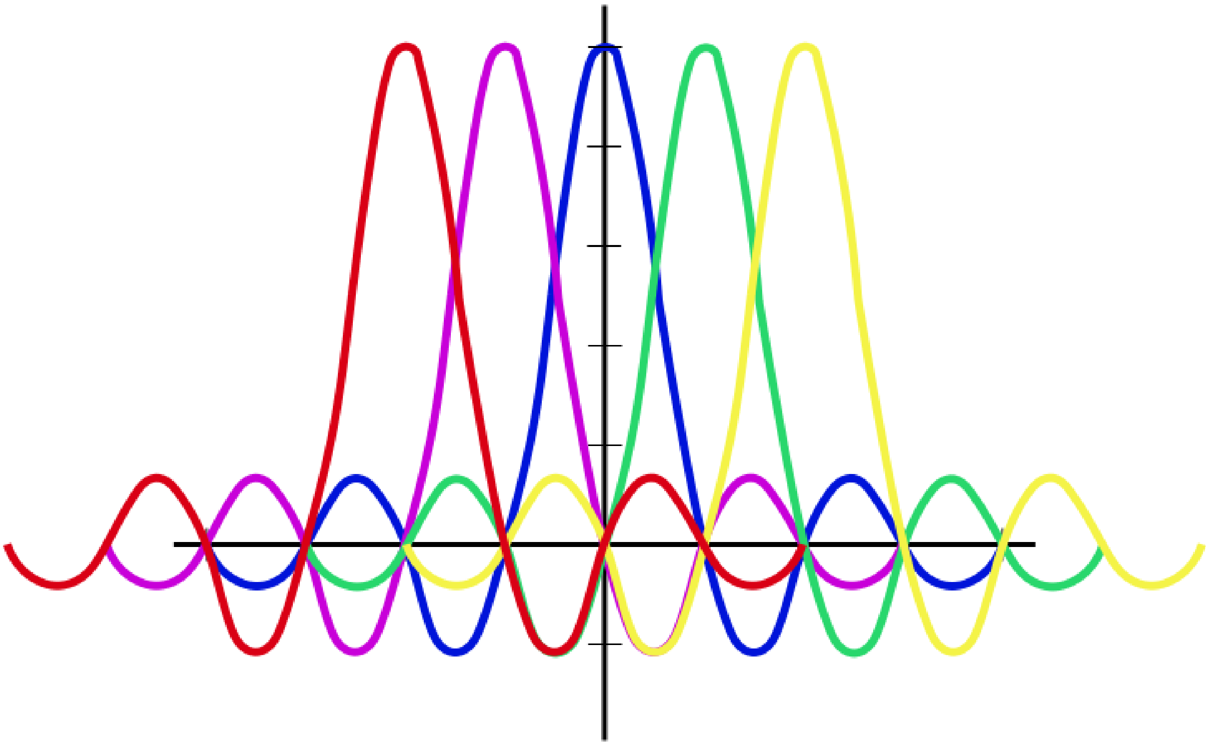


Figure 3.2 OFDMA five carriers

3.1.3 Orthogonal Frequency Division Multiple Access (OFDMA)

As compare to OFDM, the OFDMA combined subcarriers into groups of sub carriers which is also called sub channel and using sub channel all the user can send and receive data at same time and all the users can be accommodated at the same channel. WiMAX uses OFDMA as different FFT (fast Fourier transform) modes used in different standards of WiMAX e.g. WiBRO uses 1024 FFT whereas IEEE802.16d support 256 FFT.

3.1.4 Scalable OFDMA (SOFDMA)

Scalable OFDMA is widely used in new technologies like IEEE802.16m and LTE advance as it has the extra features compared to OFDM and OFDMA. In this scheme there are multiple FFT sizes supported such as 128 FFT, 512FFT and 2k FFT to address bandwidth up to 20MHz. From all of the mentioned above technologies, WiMAX forum selected OFDMA, because as compare to TDMA (time division multiple access) based technology, OFDMA based system leads to cell range extension on the UL, however cell range extension can also be achieved and enhanced on the DL if we allocate extra power to the carrier group assigned to users with high distance.

3.2 Modulation Scheme in WiMAX

In wireless communication system, the selection of modulation scheme that includes both modulation and channel schemes depends on radio resource management. The WiMAX use OFDM which is most efficient schemes used by advance wireless technologies [22]. One of the major advantages of OFDM is frequency signals with data can be transmitted by using different modulation schemes depending on available resources and SNR As it depends on SNR like if the value of SNR is high then the powerful modulation can be used, however when the SNR is low then the lower type of modulation scheme can be used.

In WiMAX, there are four different modulation schemes used which are as follows:

QPSK, 16-QAM and 64 QAM [22].

3.2.1 Quadrature Phase Shift Keying (QPSK)

It uses four different possible phases, making it possible to send two bits for every symbol. The QPSK is popular scheme where two bits accommodate one symbol. These two bits send information by changing the phase of the radio wave. In the constellation diagram of QPSK, we have four different points showing in the figure 3.4 [23]. QPSK efficiently used spectrum as compared to BPSK, however it cannot guarantee against noise.

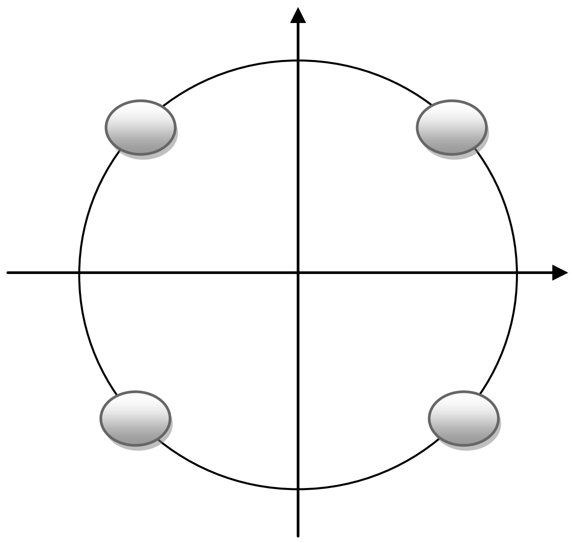


Figure 3.3 QPSK constellation diagram [23]

3.2.2 Quadrature Amplitude Modulation (QAM)

WiMAX also uses QAM which is combination of phase shift keying and amplitude modulation is the efficient and reliable scheme. In QAM, the amplitude and phase by adjusting signal wave and by combining these two phases a symbol can be generated. In WiMAX, the area where have high SNR, the QAM can be utilize for better performance and throughput... The figure 3.5 shows the different region of AMC scheme as we can see the area near to BS can have better capacity but less coverage and in area in 16QAM have less capacity and more coverage as compare to 64QAM. And in QPSK represent where it has large coverage area but less capacity.

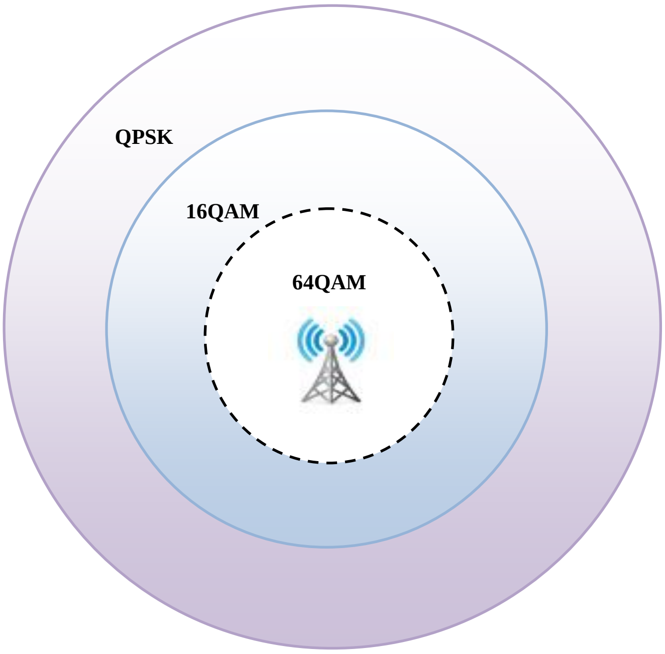


Figure 3.4 Adaptive modulation and coding transmission of BS

3.3 Quality of Service in WiMAX and Relay Station

WiMAX allows the network operators to provide better services which differentiate them from operators using other technologies; this edge attracts a range of subscribers. It provides flow types which allow the provider to provide optimised data, video and voice services. In WiMAX traffic can be prioritised via four services classes, each class prioritises specific traffic such as voice, video or data. These classes are listed below

- UGS (Unsolicited Grant Service)
- rtPS (real-time Polling Service)
- nrtPS (non-real-time Polling Service)
- BE (Best Effort)

The second phase of WiMAX with the support of mobility has added fifth class which is extended real time polling service (ertPS);

Unsolicited Grant Service (UGS)

The UGS scheduling service is suitable when the constant data stream is required hence it is suitable for VoIP. In UGS, fixed size packets are sent with as low jitter and latency as possible. It is important to mention that in UGS, packets are sent at persistent intervals. UGS packets have higher priority over BE and nrtPS and system first transmit the UGS packets and then transmit the BE or nrtPS packets.

Real-Time Polling Service (rtPS)

This service supports real time service flows where variable size data packets are generated. It is important to mention that these packets are generated periodically. This service is suitable for video transmission, such as MPEG (Moving Pictures Experts Group) videos.

Non-Real-Time Polling Service (nrtPS)

The nrtPS supports data streams which consist of variable size packets tolerate delay. This service guarantees minimum data rate. This service is suitable for FTP.

Best Effort (BE)

The basic service class of QoS does not guarantee minimum data rate, meaning at one instance data rate can be very low or idle and as soon as network becomes less congested data rates increases allowing the traffic to move faster. This type of service is not suitable for voice and video as at low data rates it cause interruptions. It is more suitable for data streams which can be dealt on best available basis. BE packets have lowest priority over the network and these packets are only transmitted if no packets of UGS, rtPS, nrtPS and ertPS are waiting for transmission.

Extended Real-Time Polling Service (ertPS)

The ertPS scheduling service is hybrid class and it possesses the combination of best features of UGS and rtPS [2]. This transmits the variable size data packets at periodic intervals. This class is reserved for real-time data that generates variable size packets such as VoIP with silence suppression.

Table 3-1 shows the QoS classes and their features.

Service Class	**Applications**	**QoS Specification**
Unsolicited Grant Services (UGS)	VoIP, fixed size packets on periodic basis	Maximum rate, latency and jitter tolerance,
Best-effort service (BE)	Web browsing, data transfer	Maximum sustained rate, Traffic priority
Real-time Polling service (rtPS)	streaming audio and video	Minimum reserved rate, Maximum sustained rate, Maximum latency tolerance, Traffic priority
Non-real-time Polling service (nrtPS)	FTP	Minimum reserved rate, Maximum sustained rate, Traffic priority
Extended real-time Polling service (ErtPS)	VoIP (voice with activity detection)	Minimum reserved rate, Maximum sustained rate, Maximum latency tolerance, Jitter Tolerance, Traffic priority

Table 3.1 QoS classes with application specified

3.4 Advance antenna technology

WiMAX2 supports advanced antenna technology including enhanced MIMO, directional antenna with diversity techniques.

3.4.1 Directional Antennas

An antenna gives three fundamentals in WiMAX technology which are based on direction of antenna, antenna gain and polarization. The antenna gain can be measure by increasing the power to boost the signal and making the antenna direction in the shape where it directs the antenna lobe for signal power and cover large area as shown in figure 3.6. The larger the beam width can decrease the area and smaller beam width can increase area. The beam width power can be measured in dBm where it increase or decrease the power with 3 or -3 dBm.

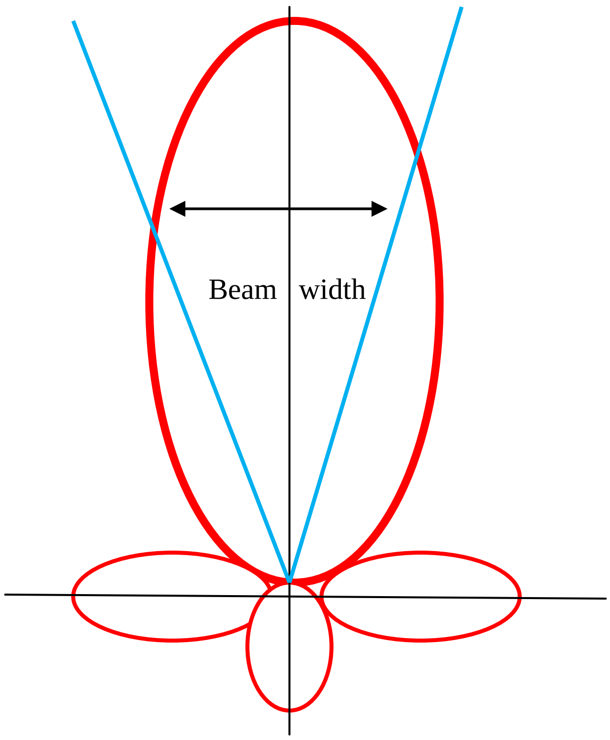


Figure 3.5 Beam width of directional antenna

A directional can enhance the throughput as it radiates power in one or more directions as compared to an Omni directional antenna that radiates equal power in all direction.

The main Advantages of a directional antenna are

- Less interference
- Higher gain
- Higher adaptive modulation coding(AMC)

3.5 Overview of WIMAX Relay station

The RS technology works as middle node as it transmits the BS data to SS which is can be out of the range of BS or in the area where signal strength is very low. The RS are widely used in all the main today’s wireless technologies such LTE advance and WiMAX2

A RS does not have backhaul connectivity as it get the signal from BSs in line of sight connectivity and it can be connected with a BS through a wired, leased cable or radio link [2]. There are two types of connections in RS communication known as access link and relay link which can be further define as, the communication path between RS and BS is called a relay link where communication is possible from BS to RS or RS to BS. The second path can be described as the communication path between RS and EN is called access link.

The main advantage of RS is to extend the coverage, throughput and minimise the coverage gaps. The BS usually covered a cell territory, however in NLOS communication due to tall buildings, forest and mountains can cause in coverage gap where RS can be used to fill the gap and improve overall system performance.

There are different types of scenarios in wireless communication where RS plays vital role to overcome and provide better performance, some of the key factors are:

- Low coverage due to poor SNR at the cell boundary.
- Less coverage or very low signal reception in dense urban area
- Cost of BS deployment too high in rural area.

RS can be deployed at the edge of the cell to extend the coverage or top of the building in NLOS communication of BS for EN.

3.5.1 Multihop Communications

Multihop communications is a way where users get the services from BS through different hops. In IEEE 802.16a standard introduced multihop communication in

WiMAX as mesh mode and later in IEEE 802.16e in introduced mobile multihop relay topology. Figure 3.8 shows the difference between PMP, Mesh and relay topologies.

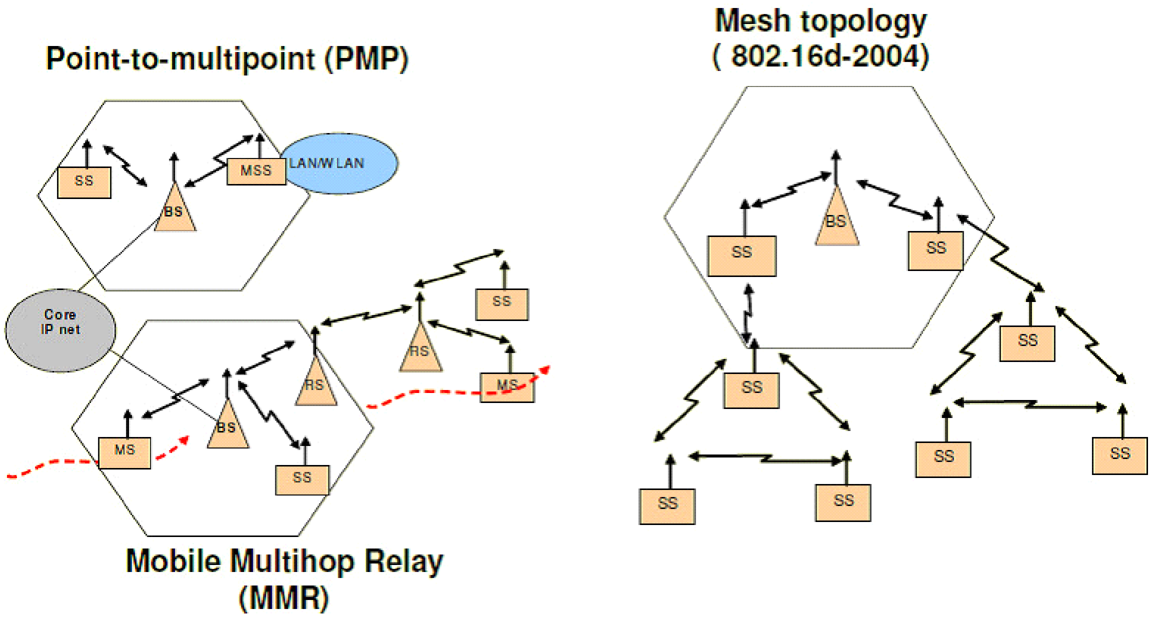


Figure 3.6 Different WiMAX topologies

Point to multipoint

In point to multi point communication is a topology where BS communicate with end users in LOS and NLOS environment. The typical range of BS in PMP topology can be up to 8km

Relay Topology

This is based on tree topology, where relay communicate as a middle node between BS and MS where one end is connected with BS and other with MS. The BS provides resources to RS for the MS out of the range of BS. Next generation mobile networks need very high data rates to enhance the overall network performance. So, therefore relay is a cost effective topology

Mesh Topology

In mesh topology, all the devices can be connected with each other within the same network. In mesh every node is connected to other nodes within the same topology or network. The mesh topology can further extend into two categories called as partial full mesh which can be described as if the all the nodes have a connection with each other then it will be full mesh.. However it is very expensive to implement. And the partial mesh topology which is less expensive to implement as in this mode some node are organized as full mesh and some are connected with one or two only in the network.

The different topologies above shows the different communication methods used in WiMAX system. Use of multi hop relays raises in MS of Routing or “Relay Selection”. Because the relays operate at baseband layer, so the Power, QoS and delay constraints should be taken into account for routing. The deployment of WiMAX technology without RS can be more expensive as BSs cost is almost three times more than a RS. The communications methods of RS are based on single hop or with multihop.

3.5.2 Relay stations Modes

RS can be further described in two different modes depends on its usage. The two modes are [2]

- Transparent mode
- Non-transparent mode

Transparent Relay

Transparent mode of RS can be used to extend the capacity of the network and to make the communication possible in NLOS environment. [3] The BSs initial ranging request can be possible due to BS coverage but still RS needed to cover the coverage gap within cell... However, in the multihop scenario where the number of relays increases to further boost the signal but it can decrease the overall system capacity. To maintain the QoS and end users demands satisfactory based on transparent mode then are several key features to be discussed in detail in order to understand the transparent mode which are

- In this mode single relays data traffic can be transmitted to the BS and vice versa
- Transparent mode only operate in centralized scheduling
- It can support multihop topologies
- Scheduling is not possible with transparent mode.
- Does not transmit preamble nor broadcast control message

- Transparent mode basically use for capacity enhancement and improve throughput
- This mode cannot allocate bandwidth to SS.

Non Transparent Relay

The non transparent RS can be used to extend the coverage of the cell by placing them on the cell boundary where BS signals fades and the signal quality is not very strong to cover the EN out of the cell. The EN cannot get the signal directly from BS as compared to transparent mode, so the RS has to send its control information to EN for connectivity. Following are the key features of non-transparent mode

- Non transparent RS can operate as a BS for EN
- Both distributed and centralized scheduling can be used in this mode
- Suitable for multihop scenario
- It can be used for scheduling
- Non transparent mode sends its own preamble, FCH and MAP messages to SS
- The purpose of this mode is to improve throughput and cell coverage enhancement.
- Communication using the same or different carrier frequencies
- Participate in bandwidth allocation in distributed scheduling mode

Multi-hop system where more than one RS is connected in non transparent modes can communicate with the EN out of the range of BS.

3.6 Relaying Techniques

Based upon relaying or forwarding schemes Relays can be broadly classified in three categories where each category have its own functionality depends on QoS demands and link adaptation. The main techniques widely used in RS are

3.6.1 Amplify and Forward

In this technique, relays receive the signal, amplify it and retransmit it. It is the simplest form of relaying and it requires minimum processing power at the RS. This is a non transparent technique which means BS has no knowledge of RS. One major demerit of this technique is that, since the relay amplifies the received signal, it also amplifies the noise received with the signal which can degrade its performance.

3.6.2 Decode and Forward

This technique overcome the noise amplification problem by decoding the received data and error correction before forwarding it hence only error free data is forwarded. This kind of relaying is good if there is a good channel between BS and RS. If the channel is not good then this causes ARQ overhead and degrades the performance.

3.6.3 Compress and Forward

In this technique RS compress the data before forwarding to EN or users. It is assumed that MS also have direct transmission from BS. This technique can perform better if there is direct transmission from BS to EN without using RS.

3.6.4 Adaptive Forwarding

This is additional technique used in new wireless standards such as 3GPP LTE and IEEE802.16m. In this technique the methods of transmission can be changed depends on the channel state information of both access link and relay link.

3.7 Pairing Schemes for Selection of Relay

There are two types of pairing schemes which can be used in selection process of RS when more than two RS exist in the same cell.

3.7.1 Centralized Pairing Scheme

The BS collects information from all the neighbouring RS and subscriber stations for paring of RS with mobile stations because BS have full access to all the RS and subscriber stations within the cell and range of BS. This scheme works with transparent RS mode and BSs updates pairing information frequently.

3.7.2 Distributed Pairing Scheme

In this scheme, RS used two mechanisms for pairing with subscriber stations which are

- Contention based mechanism
- Local channel information

In this pairing scheme BS has no fully access on all the subscriber stations because in this scheme paring scheme handled by non transparent RS for selection and communication.

3.8 Architecture of Relay Station

To understand the architecture of RS there are two basic fundamental can be used which are:

- Firstly, whether BS has awareness about nearest RS or not, if BS knows nothing about RS then RS integration with service area is simpler, no change to the BS and no special signalling between BS and RS are required. Here RS only act as a helper to the BS and it poses no burden over BS. Earlier cellular systems such as GSM (global system for mobile communication) used this kind of RS also called repeaters.
- Secondly, Two kinds of characteristics are popular in relay types which are DF and second one is amplify and forward (AF), each has their own merits and demerits and hence the use. Generally, AF equipment is less expensive than decode and forward.

3.9 MIMO in Relay Station

Multiple-input multiple-output (MIMO) technique can increase the spectral efficiency of wireless communication systems. MIMO can increase the throughput, capacity, extend the coverage and maintain the link reliability [55].

Relay stations with MIMO provide high capacity with coverage extension and throughput enhancement of relay transmission. The point to point MIMO channel or for the single antenna relay channel to the MIMO relay channel is complicated task in WiMAX communication networks and as compared to the single antenna relay channel, the MIMO relay channel introduces additional advantages to make it possible to perform more sophisticated encoding and decoding techniques to improve system performance. Figure 3.9 shows sending/receiving multiple MIMO antennas

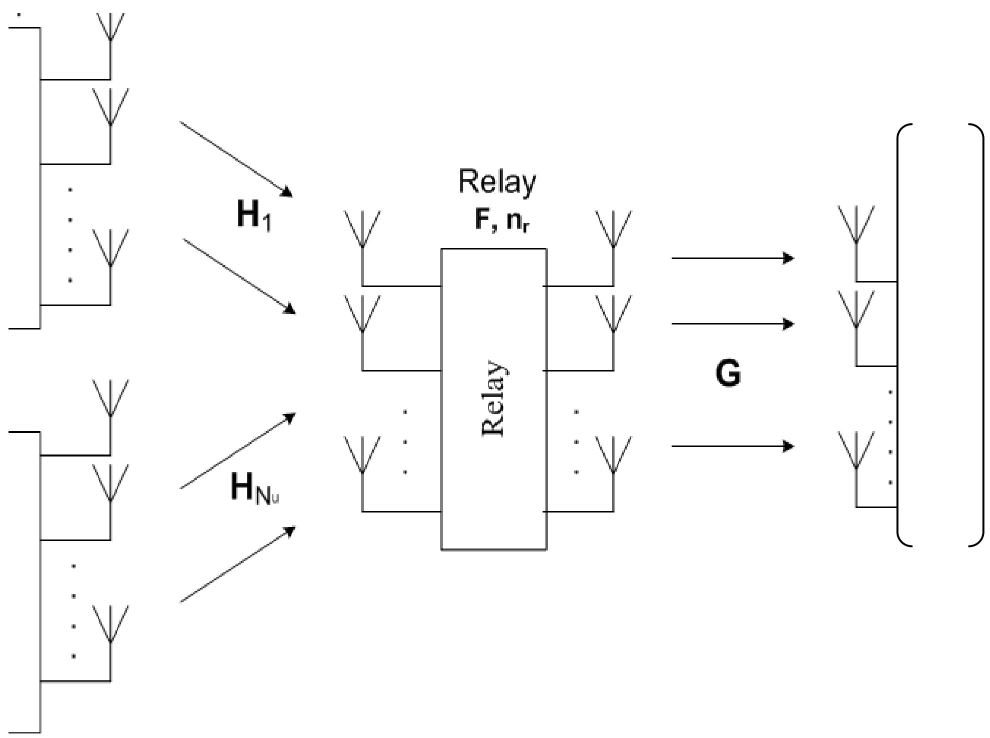


Figure 3.7 MIMO communication with multiple source antenna and designations [55]

Chapter 4

Design and Network Architecture

4 Design and Network Architecture

In this chapter detailed description of RS deployment with cost effective placement and QoS classes with throughput enhancement and delay minimization is discussed. The placement of RS based on AMC scheme replaces the four RS which covers the territory of BS with three RS to do the same job and save overall deployment cost and other expenditures. The relay itself a cost effective solution for BS as the deployment of BS is more expensive then RS whereas the RS can be worked as fixed, nomadic and mobility environments. The overall system performance based on deployment of RS and overall QoS can be depended on operators, cost and user requirements. The QoS also discussed in detail by having the QoS class's comparison to analyse the performance of real time applications, also different scenarios has been taken such as the performance without RS, multihop scenario where more than two RS used to reach at MS which is far from BS coverage, QoS with four RS and finally QoS with three RS.

IEEE 802.16j also called RS supports many options to enhance the overall system performance. In order to make some reasonable models to analyse the cost effective systems, it is necessary to make it clear that we are going to take those functionalities adapted by both IEEE 802.16m and IEEE 802.16j RS.

In this section the methodologies to determine the cell range, the relay position, the transmit power at the RSs and the number of relays deployed are described. The main step in the design of multi cell system is described. The main purpose in the dimensioning of the cell size is to ensure that all the SSs in a cell are able to receive the framing information from the BS. The SINR at the cell edge is analysed for different frequency reuse factors and by applying the direction antenna. This work focuses on the deployment of non transparent relays which can provide throughput capacity gain over WiMAX system and coverage extension.

4.1 System Description and OPNET Tool

The below is detail of system description and the model I use for the implementation of RS. As discussed earlier I use OPNET modeller version 16.0 to simulate the desire results. Now we will discuss it in detail.

4.1.1 Overview of Design in OPNET

OPNET is a powerful tool, which provides an excellent graphical user interface facility to user. Following are the steps required to construct the WiMAX network in OPNET Version 16.

- Creating the initial Topology
- Creating WiMAX deployment scenario
- Adding Traffic to the WiMAX Network Model
- Configuring, SS, BS and WiMAX Parameters
- Running and analysing results

In order to run the simulation, the service class, efficiency mode, and some other parameters need to be defined. To do the analysis of the WLAN and WiMAX network model, the statics can be collected individually and globally.

To create WiMAX topology several instructions need to be followed. The first is step to construct the subnet with mobile subnet and connect both with IP cloud. In subnet network, the server with router need to be placed which later connect with backbone through router. In subnet, where two voice and video servers connected with router in order to get the results based on voice and video profile. The application, profile definition and WiMAX tower tabs are also placed to set the parameters based on voice and video applications. After designing application process, the topology based on cost has been deployed using wireless network topology deployment where three cell topology draw and random set of SS nodes selected with three BS and the entire BS are connected to core network's router using IP backbone while PPP_Sonet cable is used for connectivity. Ethernet cable is used to connect router from server holding voice and video application. The second topology designed with four cells where each cell represent different environment such as multihop, without relay station, with three relay stations and with four relay stations. The comparison of QoS classes based on cost topology using 96Kbps codec is used for voice in each service class. After completing the deployment process then the traffic added to the three cells and nodes has been assigned to the voice application server.

4.1.2 Design of Directional Antenna Pattern in OPNET

This chapter also details the design of directional antenna customized in OPNET Modeller for simulating RS scenarios. Some special features of directional antennas were designed using OPNET antenna pattern. In the antenna pattern editor, the gain of an antenna can be edited and set to different values to provide directionality. The main high lobe gain directs towards RS and the remaining side lobes directions with low gain can directs towards sides to cover the sector of the cell. The antenna then directed towards its target RS. Directional antennas provide more power and signal strength in the direction of communication as compared to Omni directional antenna.

Directional antenna helps less interference, higher gain and higher adaptive modulation coding. Designing antenna pattern in OPNET is not very difficult task because there are 2 methods of creating antenna patterns in OPNET. Figure 4.1 shows the directional antenna design pattern in OPNET.

- Using Antenna Pattern Editor (APE)
- External Model Access (EMA)

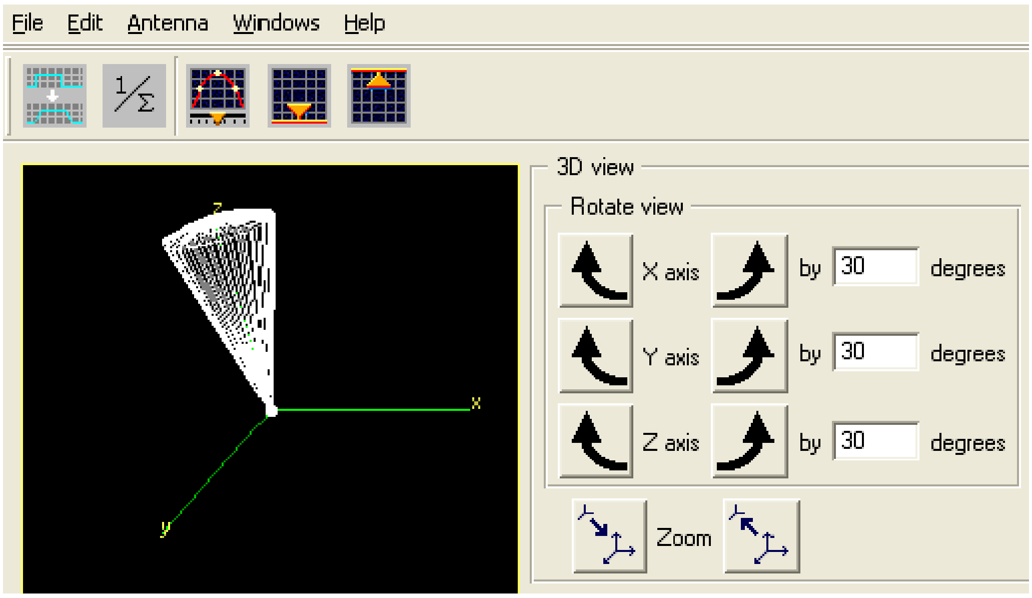


Figure 4.1 OPNET Antenna Pattern editor

4.1.3 Approaches and Methodologies Based on Application

In this chapter, different approaches based on cost analysis with relay deployment and QoS analysis topologies designed and required results set to global and statists. A simulation topology has been designed using OPNET modeller and place three non transparent RS at QPSK ¾ zone to get better throughput and SNR. Two types of applications are defined for simulation model, video application and voice applications. Video application is of high-resolution video data and voice application is defined as PCM quality voice. All the application defined in the network using application definition utility

4.1.4 Cell Coverage and Sectorisation

For network operators the site of the BS can be much costly investment. The sectorisation can be useful for BS and RS placement for better performance as it evidently needs directional antennas to boost the signal in one direction so the users in that area can get better throughput. In wireless technology a cell normally in hexagonal shape which can be divided into three sectors [60]. Figure 4.2 shows cells and three sectors in each cell.

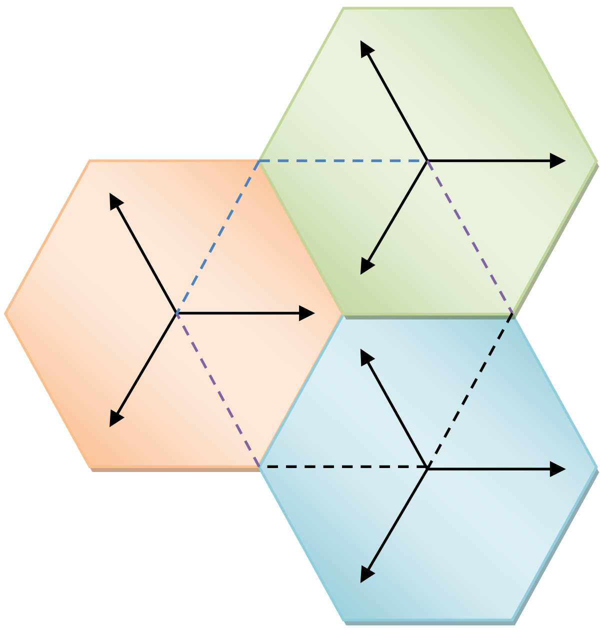


Figure 4.2 Hexagonal cells and three sectors in each cell.

The simulation emphasizes on the coverage of the system in general. Path loss is the term which is used to estimate the coverage of a cell as it is the loss in the signal power when it is transmitted through free space. It is the difference between the transmitted power and the received power. Different radio propagation models are adopted to find out the path loss between transmitter and receiver. One of the most commonly used models is free space path loss model.

4.1.5 Propagation Model for Cost and QoS

There are different types of propagation models available in wireless system. However free space propagation model has been selected in this work as supported by OPNET and the topologies based on free space with no or less obstacles. The free space propagation model defined the cost effective deployment and QoS as both topologies based on rural areas where no such obstacles are in between BS or RS. We also make some assumptions on transmitter power of both BS and RS and antenna Gains can be used to determine the received signal strength at a node.

4.2 Topology Design for Cost Effective Deployment

A three cell topology has designed where three BSs in each cell covering cell radius and each BS is connected with backbone. The coverage area of each cell is assumed without any coverage hole in which any RS within the cell can receive the framing information from the BS. Also we assumed that there is no direct communications between BS and SS. The directional antenna with 120 degree aperture used in order to make the three directions of each antenna lobe towards fixed RS for getting good throughput by dividing each cell into three sectors.

Different scenarios will be discussed in cost analysis section, in this scenario; the fixed RS is deployed in each sector at the modulation and coding rate of QPSK ¾. Obviously, the number of RNs and the way we drop them will greatly influence the system capacity. I only analyze one example, which has one RS per sector located at near cell edge by QPSK 1/2. The objective is to show this general analysis method.

4.2.1 Relay station Deployment Scenario

The main aspect of network planning is to estimate the number of users that each BS may serve and how the bandwidth is allocated to the user’s connections is typically left to operator configuration, which means it depends on the configuration of operators that how much bandwidth they allocate for each end user. Figure 4.3 shows three RS placed in each cell to cover the territory of the BSs. The topology based on the area neither rural and nor dense urban with free space path loss model. The placement of each RS is in QPSK ¾ where it is confirmed it's not on the cell edge as the RS supposed to be placed on cell edge in order to get more outer coverage. But in this topology, the placement of relay stations are at QPSK ¾ area where we can say the signal and received SNR is strong compared to QPSK 1/2 or at the cell edge.

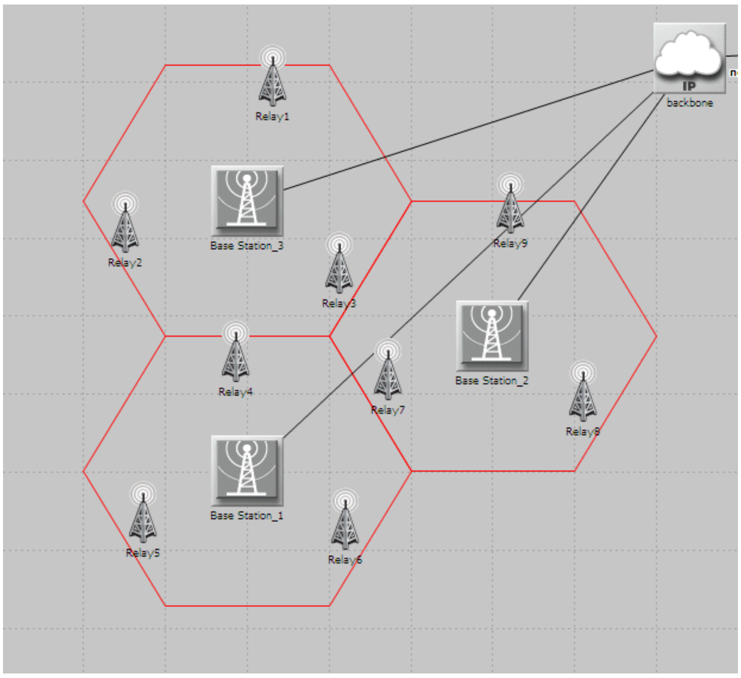


Figure 4.3 Deployment with three RS

The MS has been added to the topology and all the parameters of mobile nodes set to the same apart from few nodes which are placed out of the range of BS and a trajectory named IEEE802.16j assigned to those nodes. The arrow on nodes positioning up represents that the node is connected with RS and the arrow positioning to right shows that the nodes is connected with BS as vector.

4.2.2 Relay station Deployment with Adaptive modulation and coding

AMC based placement shows the results based in QPSK, 16QAM and 64QAM. As mentioned before we placed RS in QPSK ¾ and get the results based on this modulation level. Figure 4.4 shows the RS placement where we measure the distance in miles and calculate end to end distance by setting up trajectory by AMC as shows the lines in red shows the end to end distance of each RS which is connected through BS. Before placing the RS on this point we can assume the QPSK1/2 area can be near side boundary of the cell so we place the RS inside the boundary area where the signal is strong and better throughput is available for end users.

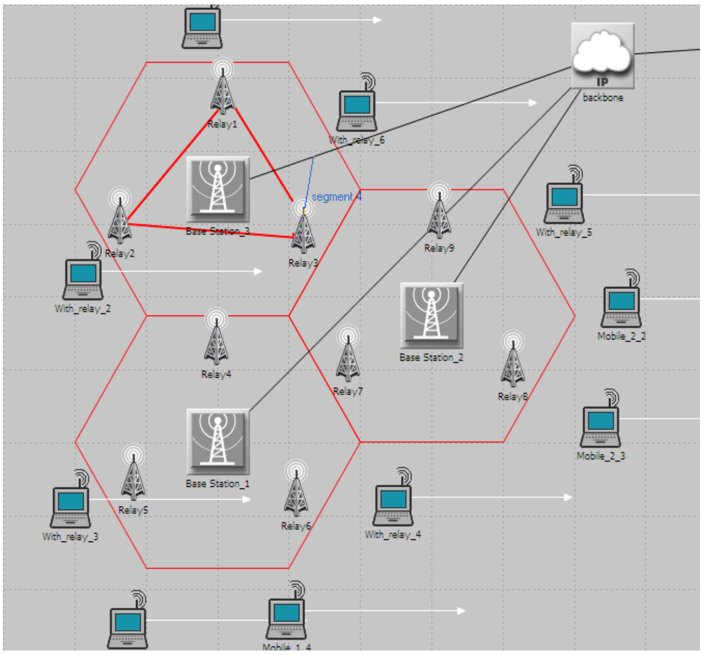


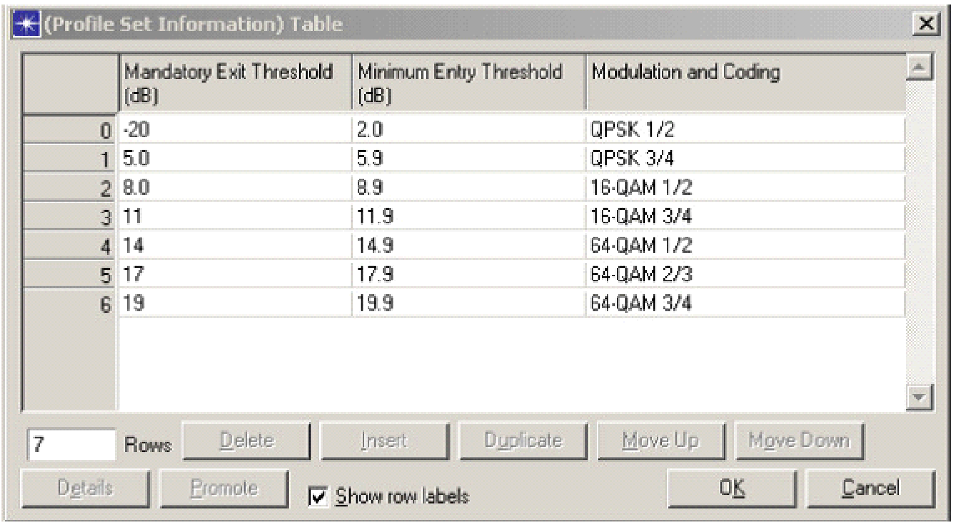
Figure 4.4 End to end Distance measure in AMC trajectory

In WiMAX, information bits are generally sent into symbols, if the end to end SNR is low, then only 1 bit will be transmitted per symbol. Table 4-1 shows the modulation schemes and bits per symbol. It all depends on the coding scheme applied as WiMAX supports QPSK, 16QAM and 64 QAM under different coding rate. QPSK area is usually near boundary side of the cell so fewer symbols can be transmitted and 64 QAM is close to the BS so more symbol can be transmitted.

Modulation	**Bits/symbol**
QPSK	2
16QAM	4
64 QAM	6

Table 4.1 Modulation and the number of bits per symbol

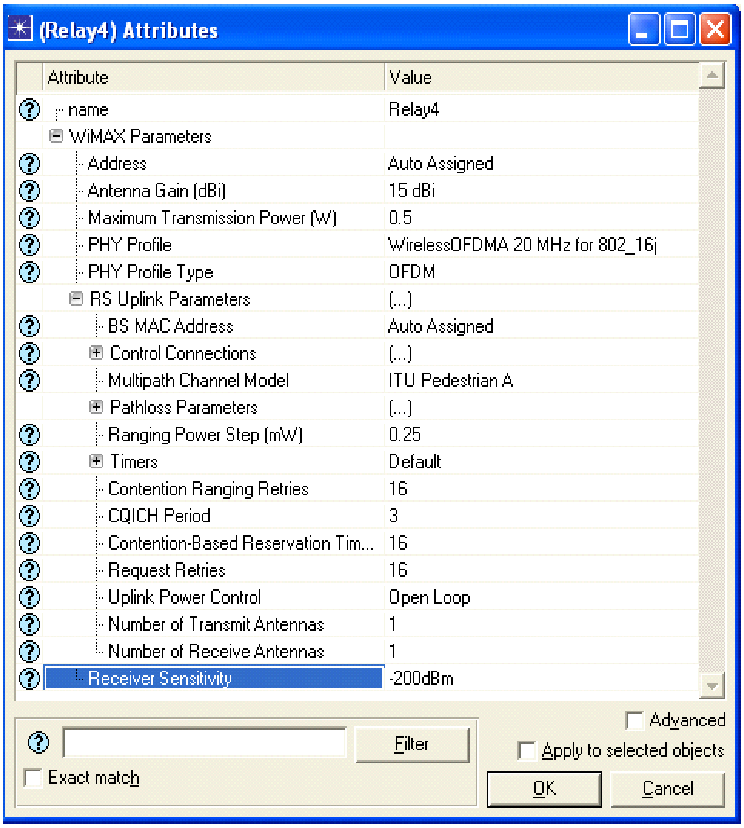
If we use a directional antenna, we can get higher gain, the end to end SNR will also be high, the end users will communicate with a high modulation index, so that mean the throughput automatically will be increased. Figure 4.5 shows the minimum entry threshold and maximum exit threshold for each modulation and coding.



	Mandatory Exit Threshold (dB)	Minimum Entry Threshold (dB)	Modulation and Coding
0	-20	2.0	QPSK 1/2
1	5.0	5.9	QPSK 3/4
2	8.0	8.9	16-QAM 1/2
3	11	11.9	16-QAM 3/4
4	14	14.9	64-QAM 1/2
5	17	17.9	64-QAM 2/3
6	19	19.9	64-QAM 3/4

Figure 4.5 Modulation and coding scheme and their threshold in OPNET

RS parameters shown in figure 4.6 are set to run the simulation and to get required results. The PHY tab set from wireless OFDMA 20MHz to wireless OFDMA 20MHz for 802_16j for RS for MS and RS communication.



Attribute	Value
name	Relay4
WiMAX Parameters	
Address	Auto Assigned
Antenna Gain (dBi)	15 dBi
Maximum Transmission Power (W)	0.5
PHY Profile	WirelessOFDMA 20 MHz for 802_16j
PHY Profile Type	OFDM
RS Uplink Parameters	(...)
BS MAC Address	Auto Assigned
Control Connections	(...)
Multipath Channel Model	ITU Pedestrian A
Pathloss Parameters	(...)
Ranging Power Step (mW)	0.25
Timers	Default
Contention Ranging Retries	16
CQICH Period	3
Contention-Based Reservation Tim...	16
Request Retries	16
Uplink Power Control	Open Loop
Number of Transmit Antennas	1
Number of Receive Antennas	1
Receiver Sensitivity	-200dBm

Figure 4.6 RS parameters

In the RS UL tab for RS and BS communication has been set for better RS connection as the figure 4.7 further explain the RS UL parameters where BS MAC address set as default to auto assigned.

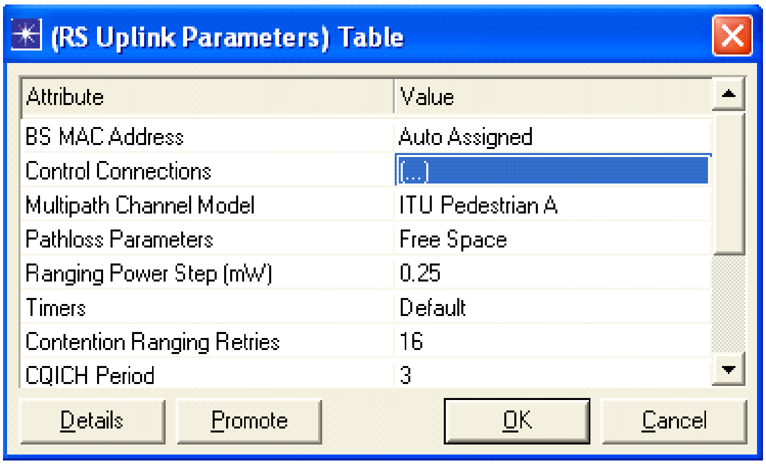


Figure 4.7 RS UL parameters

However the control connections window has been set to AMC scheme based in QPSK 1/2 and QPSK 3/4 connections shown in figure 4.8.

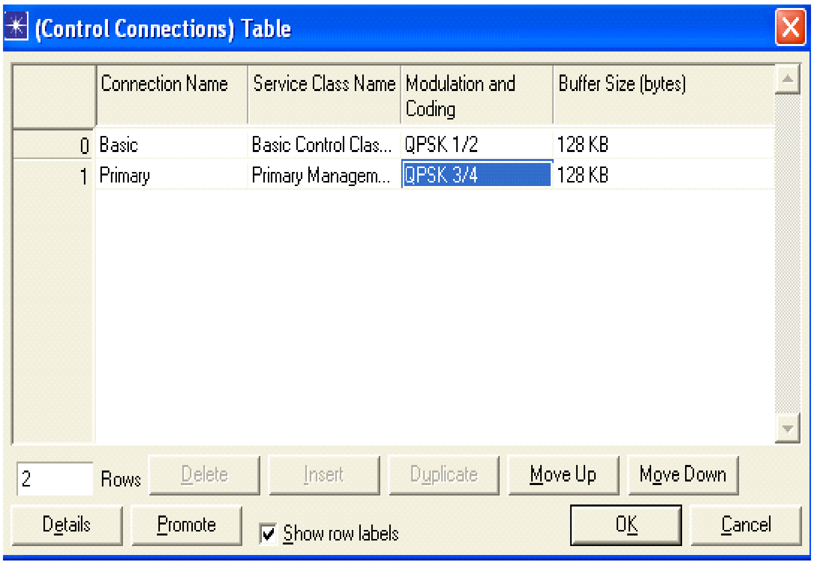


Figure 4.8 RS control connections with Modulation and coding

4.2.3 Relay Station parameters and their values for Cost

Table 4-2 shows the parameters set for relay deployment scenario:

Parameters	**Value**	**Parameters**	**Value**
No of Cell	3	Propagation model	Free Space
No of BS	3	Coding Rate	½, ¾
No of RS	12	Applications	Voice
No of SS	10	Cell type	sector
BS range	10km	No of sectors	3
RS range	3km	BS antenna gain	20dBi
BS height	40m	RS antenna gain	15dBi
BS transmit power	40dBm	BW bandwidth	20MHz
RS transmit power	35dBm	Overall Symbol Time (µs)	14.55
Fame duration	5ms	Data Subcarrier	192
At coding rate3/4, PHY OVERHEAD%	57.81	OFDM Subcarrier	256
At coding rate1/2, PHY OVERHEAD%	71.88	Antenna type	Directional
Simulation duration	400sec	DL/UL service class	Gold

Table 4.2 RS parameters and their values for relay deployment

This chapter gives a detailed description of QoS parameters like delay, throughput and network analysis in RS to analyze the performance of non transparent mode of wimax2 system. Firstly, we study and analyze the location of RS for better performance which also helps to decrease the cost of RS deployment.

4.3 Topology Design for QoS parameters

A four cell topology created to demonstrate different scenarios of using RS with four cells and one BS in each cell. RS deployments scenarios are shown in figure 4.9 are for QoS analysis.

- Based on multihop communication
- Based on three RS communication
- Based on without RS
- BSs four RS

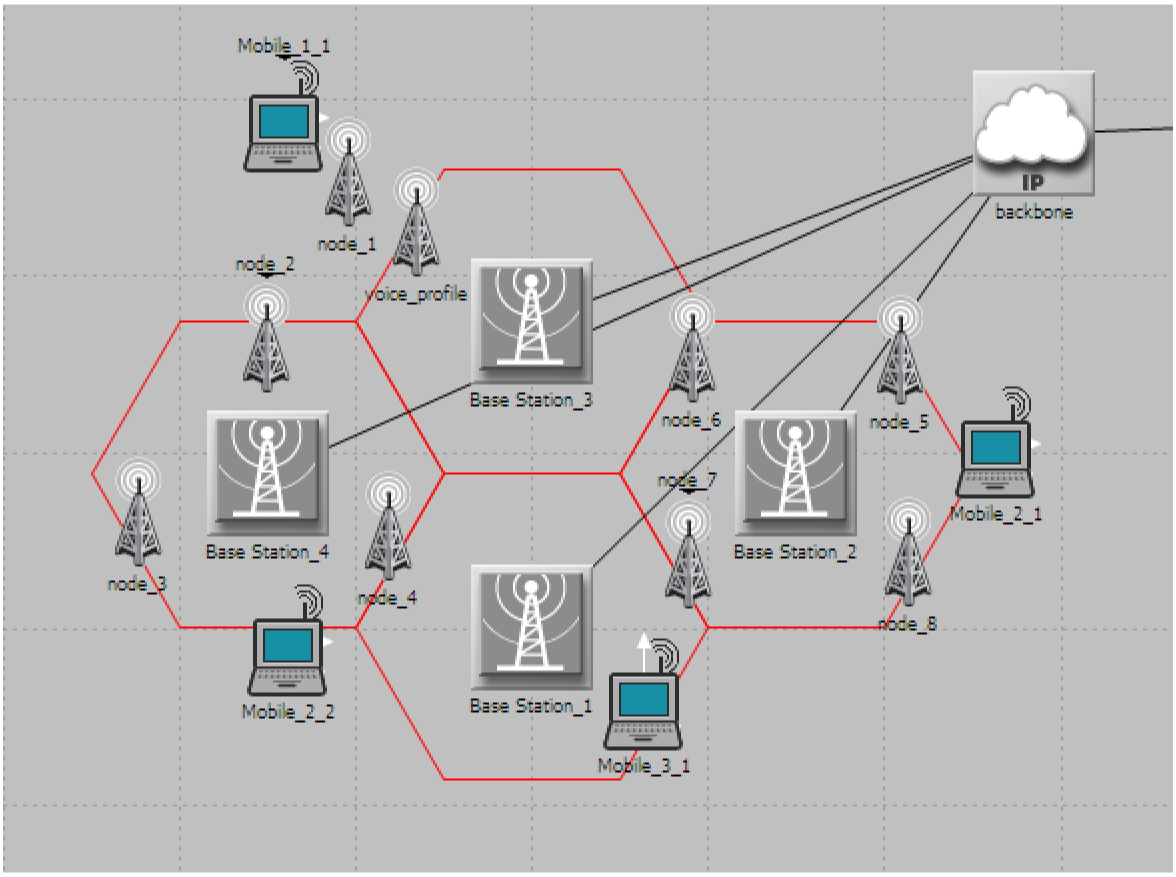


Figure 4.9 Topology based on different environments

The BS1 cell represents with one BS and three RS and nodes named QPSK 3/4 has been connected with BS1 and with relay 1 and node with relay 4 has been connected with relay 6. The QPSK ¾ node placed at the edge of the boundary where we can assume AMC scheme area of QPSK ¾. The arrows of each EN positioning right represents that the nodes is connected with RS not BS as we have set a trajectory for each node arrow positioning right to IEEE802.16j.

The BSs 2 showing with have one BS and four RS to cover the territory of the cell and two nodes named with relay and with relay four connected with RS.

The BS 3 showing above represents multihop environments where two RS have been placed in between the EN called multihop and BS3. Each topology in each cell will show comparatively results taken for EN. The multihop scenario designed in BS3 cell in order to get results for EN named multihop and to compare with other nodes within the topology.

4.3.1 Relay station positions for QoS

Figure 4.10 shows the RS positions represents different scenarios.

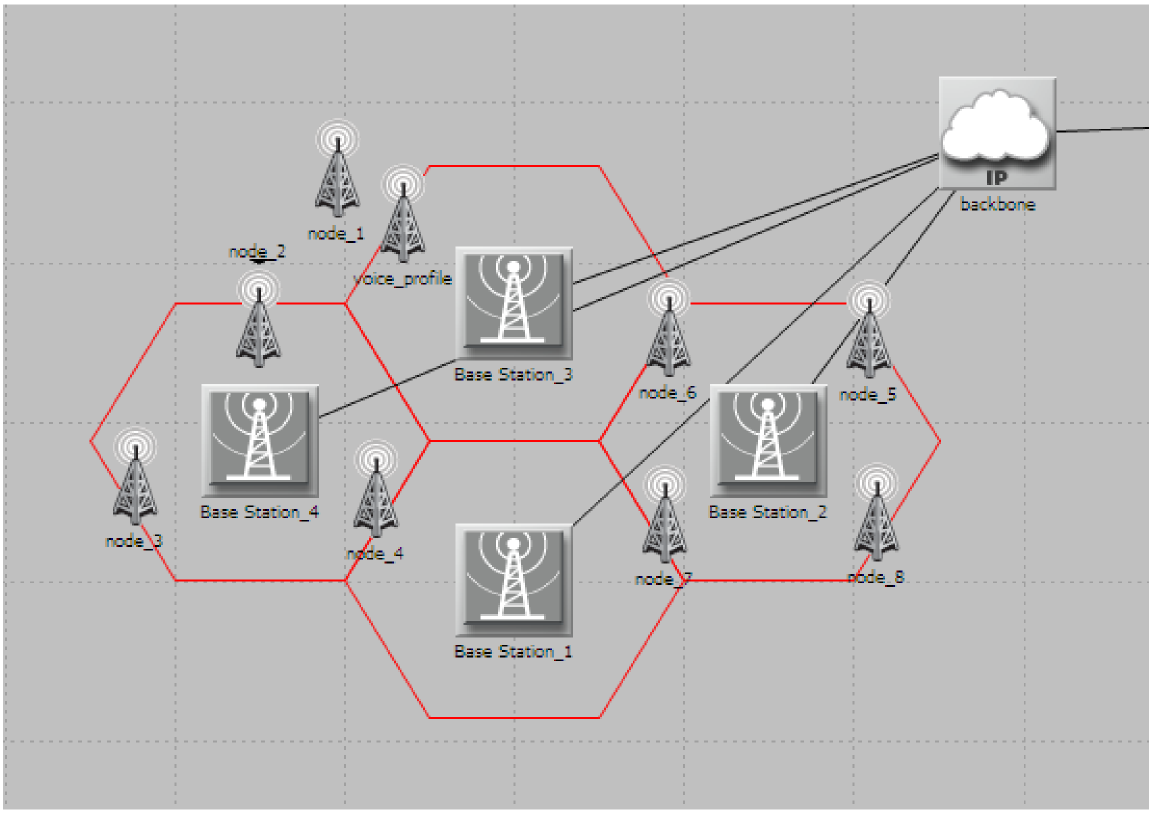
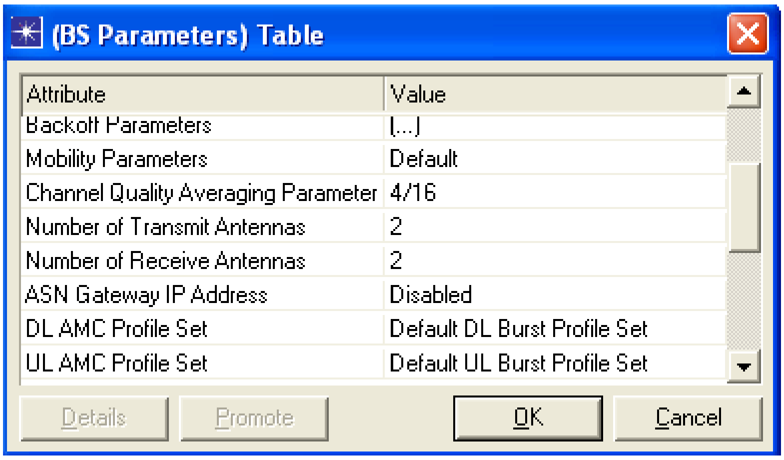


Figure 4.10 RS positions

4.3.2 Base Station and Subscriber Stations Parameters

The difference between previous topology parameters for BS which is based on cost effective placement of RS and QoS are the number of antenna increased for better throughput. The parameters are showing in figure 4.11 and 4.12.


(BS Parameters) Table

Attribute	Value
Backoff Parameters	(...)
Mobility Parameters	Default
Channel Quality Averaging Parameter	4/16
Number of Transmit Antennas	2
Number of Receive Antennas	2
ASN Gateway IP Address	Disabled
DL AMC Profile Set	Default DL Burst Profile Set
UL AMC Profile Set	Default UL Burst Profile Set

Details Promote OK Cancel

Figure 4.11 BS parameters with multiple antennas

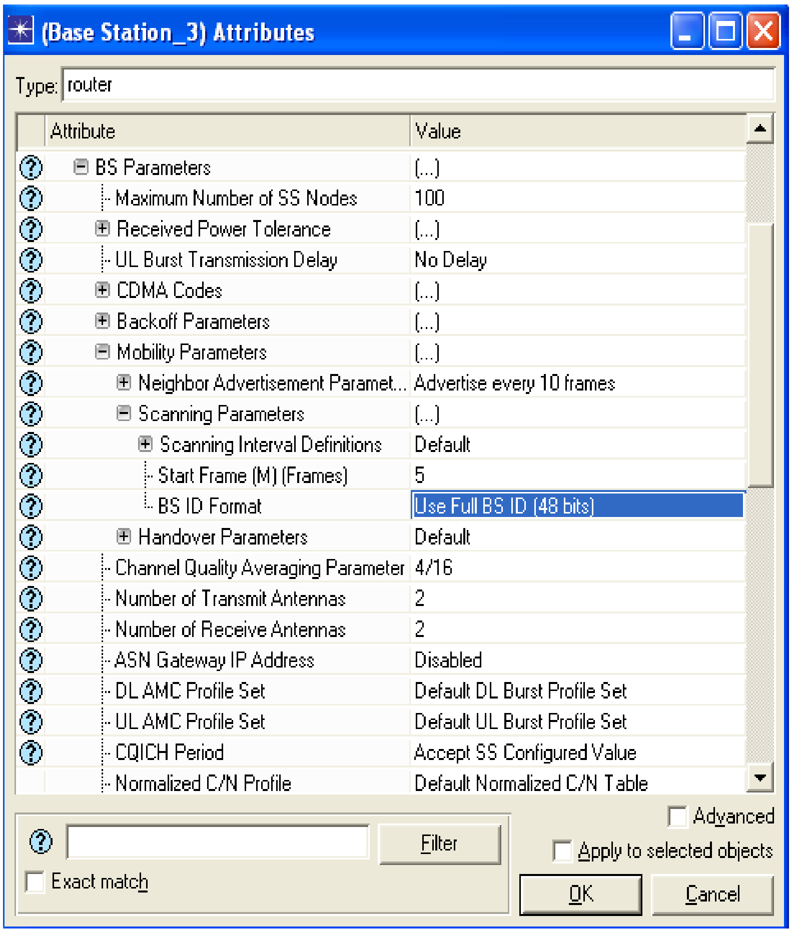


Figure 4.12 BS parameters

The SS parameters set for QoS topology for all the mobile nodes within four cells are shown in figure 4.13.

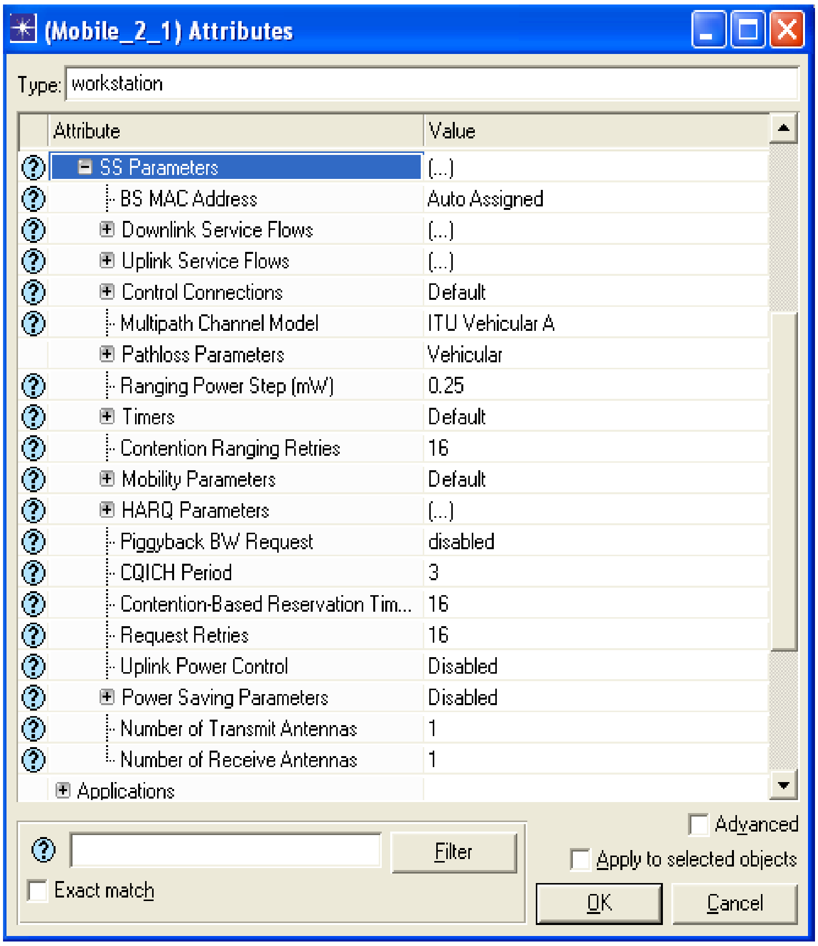


Figure 4.13 Subscribers parameters

4.3.3 RS parameters and their values for QoS

Table 4-3 shows the parameters set for QoS in RS:

Parameters	Value	Parameters	Value
No of Cell	4	Propagation model	Free Space
No of BS	4	applications	Voice and video
No of RS	9	BS antenna gain	40dBi
No of SS	4	RS antenna gain	15dBi
BS range	10km	BANDWIDTH BW	20MHz
RS range	3km	overall symbol time (µs)	14.55
BS height	40m	Data Subcarrier	192
BS transmit power	40dBm	Path loss parameters	Vehicular
RS transmit power	35dBm	Antenna type	Omni directional
Fame duration	5ms	Simulation duration	400sec
frequency band (GHz	5	MIMO at BS	2*2
MIMO at RS	2*2	UL/DL connections	Gold ertPS

Table 4.3 RS parameters and their values for QoS

Chapter 5

Analysis and Results

5 Analysis and Results

There are different scenarios and deployment possibilities with RS to maintain the overall network capabilities as well as user satisfaction. The main focus is based on two different contribution scenarios which are based on cost effective solution for RS deployment where overall cost can be reduced and maintain QoS standard. In the rural area with large distance to cover by BSs and where there RS are needed to be placed in order to provide the services to end users, in this type of scenarios usually four RS covers the territory of the BS. However, the new three RS placement scenarios have been proposed for cost effective solution for future WiMAX system.

The second scenario where throughput and delay parameters considered to measure the performance of RS with different deployment environments. QoS class's comparison has also been made to analyse the difference classes' like UGS, rtPS, ertPS and BE usage and their flow. There are also some assumptions made in scenario such as the future technologies are using advance RS which are supported by advance MIMO antennas and some other advance features where RS would be able to work as full fledge BSs. However, due to the limitations in OPNET version 16.0, is it not possible to demonstrate advance RS to work as full fledge BS and also 4*4 MIMO antenna usages.

The simulation results have been analyzed with different important performance parameters such as delay, load and Throughput as these are the main parameters which affect overall system performance. There are also a comparison have made which is in appendix chapter which shows the throughput and delay parameters with ertPS and BE class and also two performance parameters which are traffic sent and traffic received are analyzed. In both scenarios, free space path loss model is used supported by OPNET as the topologies based on rural areas. The transmission power is set to 40dBm in order to use directional antenna for better signal ratio towards the boundary of the cell where RS is located. The directional antenna use to target the RS as well as the users within the cell.

5.1 Relay Station Cost Analysis and Performance

Based on the simulated work it can be shown that the 25% of cost can be reduced by deploying three RS to cover the territory of BS and maintaining the QoS standard. However it also depends on the operators what type of service they would like to offer to end users as some user prefer to have better network connection which means they want to be safely connected to the internet but do not mind of available throughput but some user want to have better signal reception in order to access all the application easily.

To evaluate the overall QoS constraints we need also to be aware of certain figures like

- What type of applications end user demanding and how much traffic normally generated by users?
- How much channel bandwidth is available for each cell and how much throughput is assigned to an average subscriber.
- Finally, it depends on the location which makes a big difference where the RS deployment occurs. It also depends on the densities of the area e.g. London is obviously very different to rural areas.
- The performance based on LOS and in all the scenarios is assumed in LOS environment.

The proposed scenario is based on rural area where non transparent RS used to extend the coverage for remote sites or less populated area and the deployment in that area with extra BSs can be much costly. Therefore, RS perform almost the same task as BS with less coverage but the users and QoS can be achieved. However, in contrast with BS deployment and the less expensive deployment of RS where more than four RS used to cover the territory of the BS can also be an expansive solution, because the cost will increase when more RS deployed. In this proposed solution, three RS have been used to cover the territory of BS and provide coverage, capacity and throughput enhancement to the users at the QoS standard. The cost of each RS is $40,000 and BS Cost is $120,000 as shown in table 5-1 [68, 69]. The cost of BS is almost three times more than the RS, because it has extra functionality and connected through backhaul whereas RS works as repeaters to get the signal from BS and provide coverage and capacity to the users which are out of the range or cannot communicate directly with of BS.

Value	Cost
BS	$120000
RS	$40000
Site + Preparation and Cabling	$50000
Backhauling Connection	$30000
New Tower Deployment	$80000
Site Lease/year (expenses)	$13200
Maintenance cost/year	$9200
Additional Installation	$ 5000

Table 5.1 Cost comparison of RS with BS [69]

In order to compare overall cost with three cell topology, where each cell represent a geographical area of the BS territory. We have compared the same topology with four and three RS deployment. The table 5.2 represent the overall cost of deployment and approximate value shows for three RS deployment as compare to four RS.

Value	Four RS	Three RS
Three cell	12(4 in each cell)	9 (in each cell)
BS	$360000	$360000
RS	$160000	$120000
Site + Preparation and Cabling	$50000	$38000 (approx)
Backhauling Connection	$30000	$22000(approx)
Site Lease/year (expenses)	$13200	$13200
Maintenance cost/year	$9200	$8000(approx)
Additional Installation	$5000	$4000(approx)
Total	**$627400**	**$565200**

Table 5.2 Cost comparisons with four and three relay station

The hardware deployment cost difference for three RS when compare with four RS is approximate $62200, while similar performance could be achieved. However, there are some extra cost associated in this situation in order to achieved better QoS standard which can be possible by having directional antenna at the BS to enhance the throughput and AMC and coding scheme applied at the BS. These features can also be applied in four RS scenario but this solution is costly as compared to three RS. The main aspect of placing the RS in the area covered by BSs where better SNR and throughput available in order to achieve better performance for the SS out of the range of BS where signal strength is not very strong to communicate with mobile nodes. The topology has been designed with three cells which are consisting of three RS have been designed to cover the territory of BS in urban rural area. As mentioned in [56], normally four RS are used to cover the territory of BS in urban environment, because each RS can cover and enhance the performance of the designated area so that the users out of the range of BS can achieve coverage and throughput. Also the RS admission control is based on available SNR, QPSK zone with coding rate, 16QAM with coding rate and 64QAM with coding rate.

5.1.1 Coverage and Capacity Analysis with Relay Station

Coverage can be described as the area covered by a BS or RS where the SS station easily can communicate and send and receive data. In order to extend the coverage area of BS, non transparent RS are placed at the border of the cell where BS signal power reduces so it boosts the signal to cover more area. The WiMAX networks with relay enabled scenarios, three link budget are required.

- BS - SS
- BS - RS
- RS - SS

The strong link budget with better signal reception can make communication system reliable. This also depends on the operators what type of configuration they use and what type of service they would like to provide to their customers. The RS/SS battery power can be saved by improved signal strength at the QPSK ¾.

In the scenarios, the focus was three RS placements at the area within the range of QPSK ¾ not at the cell edge or the area zone of QPSK ½ where signal power decreases or the communication link is not very strong. The RS placement at this coverage area can cover majority of the cell area, however directional antenna also designed and used as it directs the main lobe towards the target or to cover the cell sector.

5.1.2 Network & Application Performance Parameters

Multimedia traffic often consists of long streams of data generated from digital video or audio sources. Even if these streams are broken up in to packets, they place a great demand on the network. However, to analyse these performance parameters in relation with cost effective deployment of relay station, some of the critical limitations need to be determined e.g. what the throughput difference is measured using four and three relay station s? What are the overall load impact using three relay stations instead four? How delay can be minimized when load increased and throughput decreased with three relay stations? There are many key performance parameters for multimedia networks. In [57] highlights the following as the most important network performance parameters:

- Throughput
- Load
- Delay
- Traffic sent

The throughput of a network is its effective bit rate. In high throughput networks, it is important that the receiving end-system have sufficient buffer capacity to receive the incoming multimedia traffic. The relay stations are placed using AMC scheme at QPSK ¾ zone where better throughput available depending on available resources as compare with at the cell edge or QPSK ½ zone.

Delay is the second main important parameter in any communication network and the QoS standards mainly derived from minimal delay and better throughput. Delay can be described as, the time it takes to transmit a block of data from the sending to the receiving end system, therefore more commonly known as end-to-end delay. End-to-end delay has many components including:

- Transit Delay- this is the physical parameter denoting the propagation time required to send a bit from one site to another.

-Transmission Delay – affected by the routing and buffering of the network. This is the time required to transmit a block of data end to end.

- Network Delay – this is composed of the transit and transmission delay components.

- Interface Delay - is the delay incurred between the time a sender is ready to begin sending a block of data and the time that the network is ready to transmit the data

5.2 Cost Scenario: Throughput Analysis

The throughput measured below is based on different RS deployment scenarios which are as follows.

5.2.1 Throughput Using Directional Antenna

The directional antenna beam can be useful for throughput enhancement and link budget as it directs its main lobe towards one direction and small side lobes to other directions to cover the cell area. The average throughput with Omni and directional antenna are shown in figure 5.1. In the scenarios, it looks a little difference but the number of bits send with directional and Omni directional and overall throughput increased. It also depends on the overall load on network, antenna height, antenna direction beam width, BS and RS link quality and preoperational model used. The RS deployed at QPSK3/4 zone and with the help of directional antenna, it can be evaluated that the link quality between BS and RS is strong as compared to the QPSK ½ area zone and with the help of Omni direction antenna.

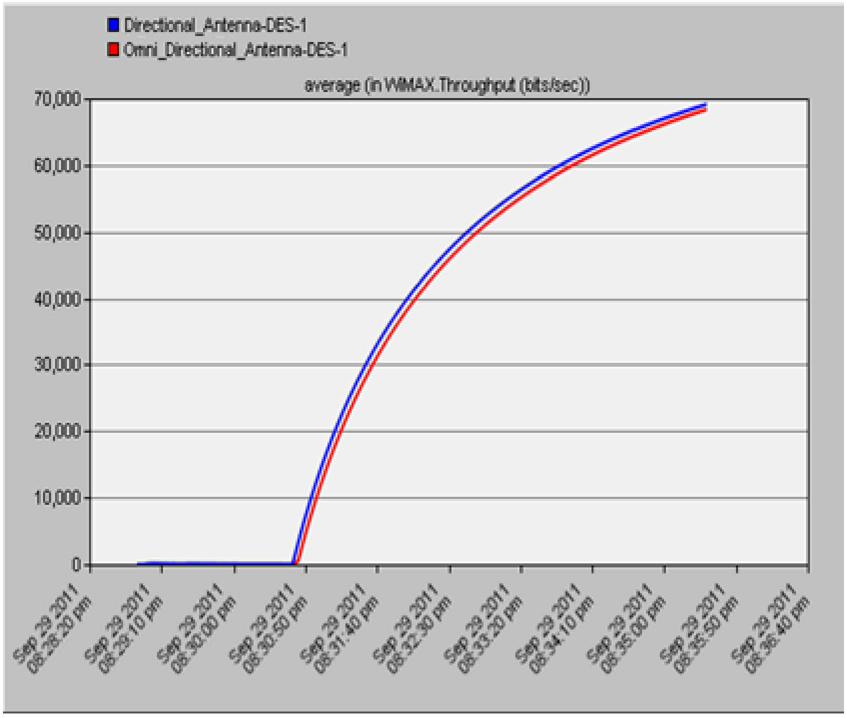


Figure 5.1 Results of throughput with Omni and directional Antenna

5.2.2 Throughput Comparison with Three and Four RS

The throughput measurement of three and four RS is shown in figure 5.2.

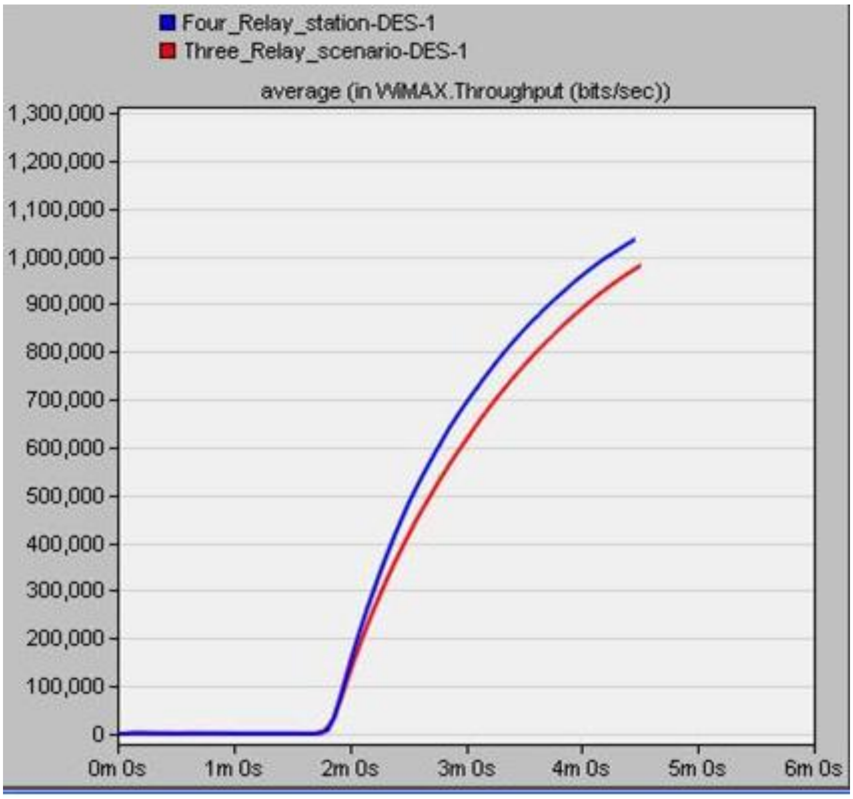


Figure 5.2 Throughput comparisons with four and three RS

However, when four RS deployed in the same topology then the throughput increased as the distance decreased from RS to EN. In the results, blue bar represents with four and red with three RS scenarios. The overall cost can be minimized by decreasing the number of RS. However, it affects QoS standards as the throughput parameter showing in the graph where overall throughput has been measured with four and three RS. But using AMC scheme and directional antenna at the BS can solve this problem. To compare throughput with four and three RS, we simulated both topologies. The simulation run time is 6 minutes. Figure 5.2 represents results obtained from both scenarios. It could be observed that the maximum throughput that is achieved with four RS is almost 976 kbps at 4 minutes and 30 seconds and with three RS deployment throughput of 957 kbps achieved in same time duration. If we compute the difference of both scenarios it is only almost 2kbps while on the other hand cost has been reduced so that it is a trade-off throughput and cost. If the users want better QoS in respect with throughput and willing to spend budget on the performance then four RS scenario could be considered. However, by comparing both scenarios there is a little difference of QoS parameter and RS cost is reduced.

5.2.3 Throughput measurement of End nodes

The results in figure 5.3 shows the average throughput of three nodes placed at different angles. The node two is near RS and have high throughput as compared to node five and node six. However, node five throughputs is also high compared to node six due to the distance of each individual node from RS But still the user at this point have throughput to access the services from RS. .

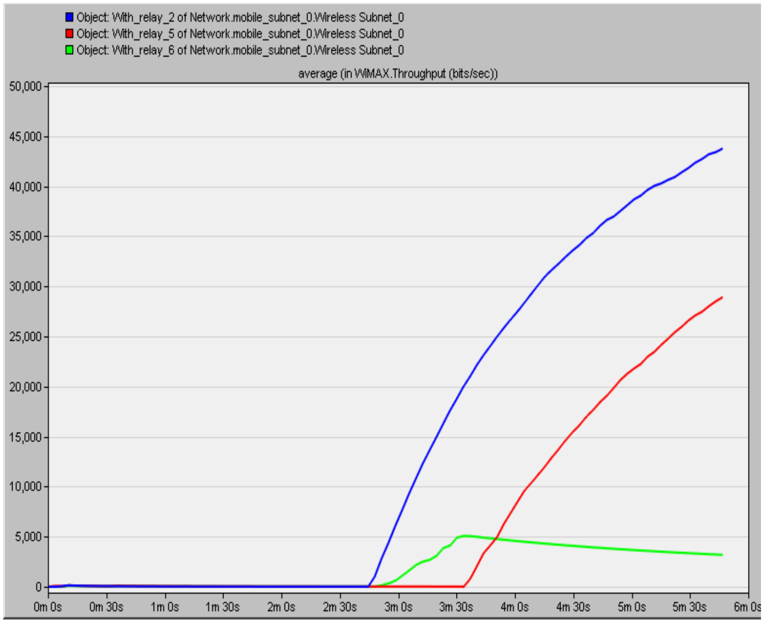


Figure 5.3 The average throughput of three nodes placed at different angles

The results show

That location of the RS is at close distance to the edge of the BS SS QPSK ½ areas. The optimal RS location is affected by two parameters:

- The number of user accessing service from BS or RS
- The signal strength between the RS and BS. The throughput can be increased based on link quality between the BS and RS

5.3 Cost Scenario: Delay and Load

To analyse the cost effective RS deployment analysis of load and delay is carried out.

5.3.1 Comparison of Load with Three and Four RS

The overall load will increase when three RS are used as the number of user randomly divided up with three relay stations. However, the load can be decreased by efficient use of resources. Figure 5.4 shows the average impact of load in three and four RS scenarios. The load with three relay stations is high as compared to four relay stations, because resource allocation, initial ranging process and data transmission with three relay stations can result load increase. However, the difference is not as much due to the usage and placement of relay station efficiently and use of directional antenna that provide better coverage and signal strength towards relay station and also improved link quality which means the resources can be utilized efficiently in order to maintain or reduce load, ultimately user can achieve better QoS.

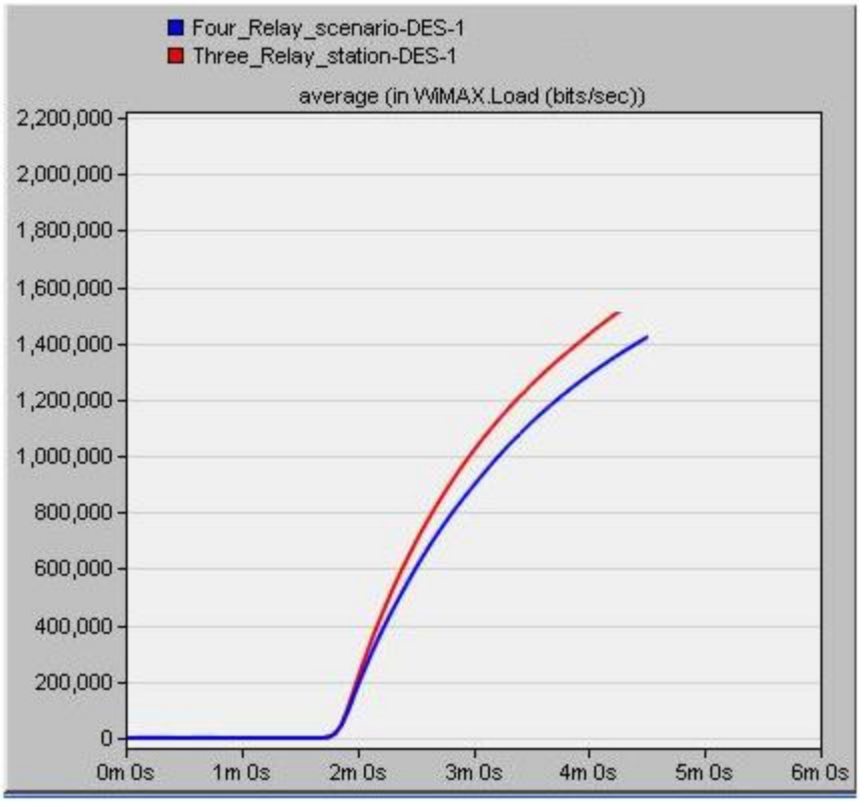


Figure 5.4 Average load using three and four RS

5.3.2 Comparison of Delay in Four and Three RS

Figure 5.5 shows the average delay using three and four RS. The average delay with three RS is increasing due to high overall load on the network. However, Overall delay is very difficult to calculate as there many different types of delays involved such as processing delay, propagation delay and transmission delay. It is also depending on the scenario type e.g. transparent mode, non transparent mode and multihop environment. The processing delay will increase in multihop environment because processing delay is the time where each hop takes time to process the received packets and forward it to destination nodes. In contrast to processing delay, propagation delay will be less as it is the type of delay where time it takes a signal change to propagate through the communication media and the hop distance. In this scenario the hop distance is decreased from BS to RS placed area which is QPSK ¾.

The delay with three RS starts increasing due to overall load on the network compare with four relay stations. But the difference is not as much it could be without AMC scheme and directional antenna which help to transmit more number of bits per second.

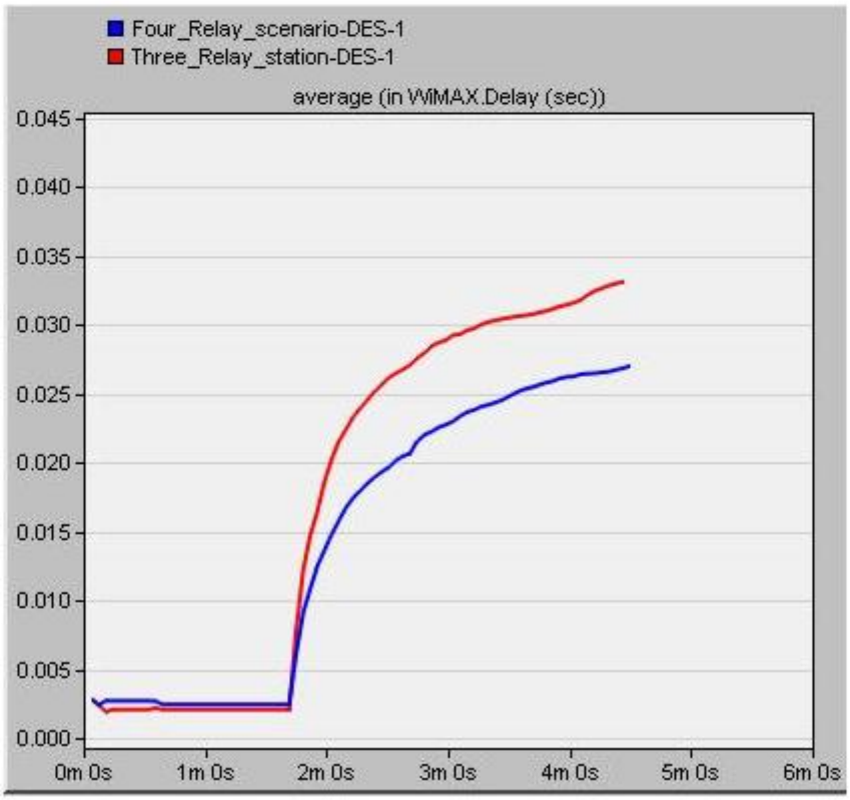


Figure 5.5 Average delay three and four RS

5.4 Cost Scenario: SNR Analysis

To analyse the cost effective RS deployment analysis of available SNR based on different scenarios is carried out.

5.4.1 SNR at QPSK ¾ zone

The figure 5.6 shows the SNR in QPSK ¾ of three RS placed at different angels. The blue bar represents the RS which is deployed at less distance from BS as compare to Relay 2 and 3. It is clear that the less the distance is the higher the SNR. To enhance the capacity and cover more geographically area, RS is normally placed at cell boundary. But in this scenario, RS placed at QPSK ¾ zones which are inside boundary area of BS. The higher SNR zones using AMC scheme are 64 QAM, 16 QAM and then QPSK. The overall SNR at QPSK ¾ zone is high as compare to QPSK ½.

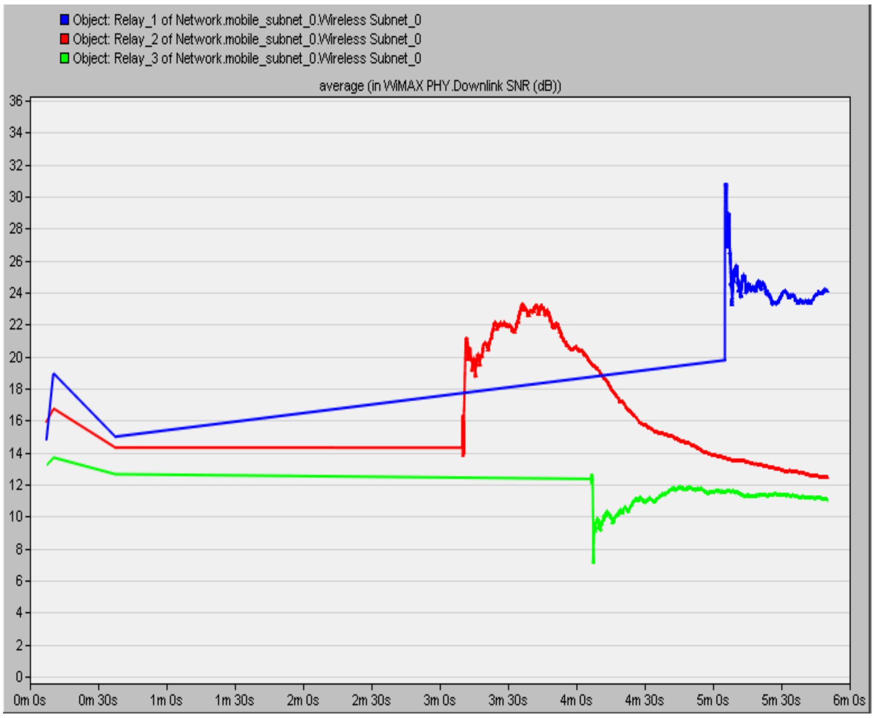


Figure 5.6 Three RS SNR comparison based in QPSK ¾

5.4.2 Comparison of SNR Based in QPSK ½ and ¾ Zone

The figure 5.7 shows object parameters of SNR whereas the above results are based on global parameters and can be compared with different scenarios. However, the SNR results shown are only for EN which is randomly placed within the range of RS but out of the range of BS. The two scenarios compared as QPSK ½ zone and QPSK ¾ zone.

The available SNR based on QPSK ½ zones for RS one is slightly less than QPSK ¾ zoned. Hence, it can be said that SNR is batter if relay is operating in QPSK ¾ zones.

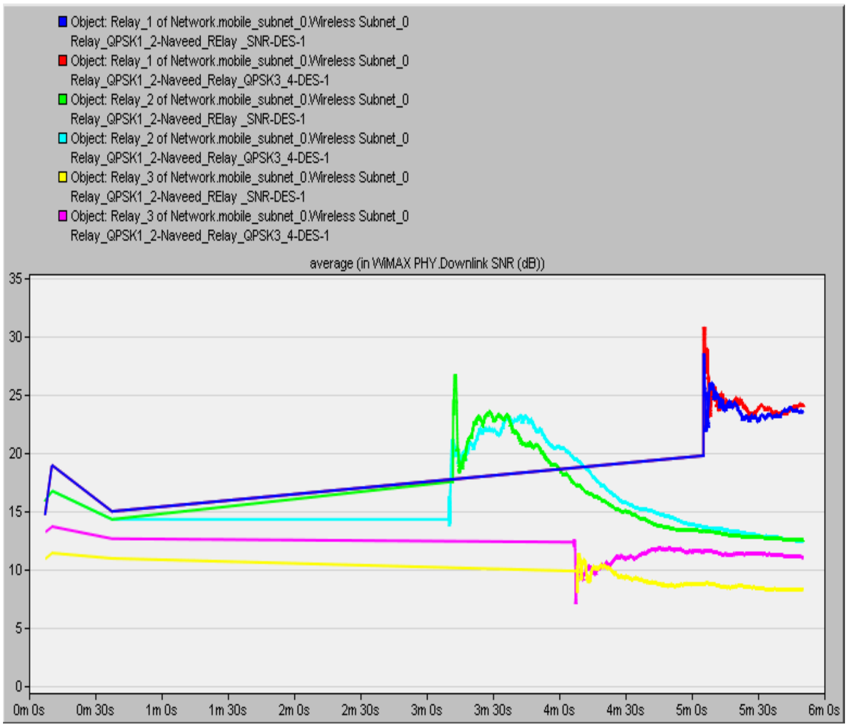


Figure 5.7 Comparison of SNR in QPSK ½ and in QPSK ¾

5.4.3 Comparison of SNR Based on Three and Four RS

Figure 5.8 shows the comparison of SNR based on three and four RS. The blue, green and yellow line in the figure 5.8 represents results based on three RS. The average available SNR with four RS is a bit high as compare to three RS. However, by placing the three RS in the QPSK ¾ zone, increase in SNR can be gained. This represents that there is a very slight performance decrease in three relay scenario whereas the cost difference is very high.

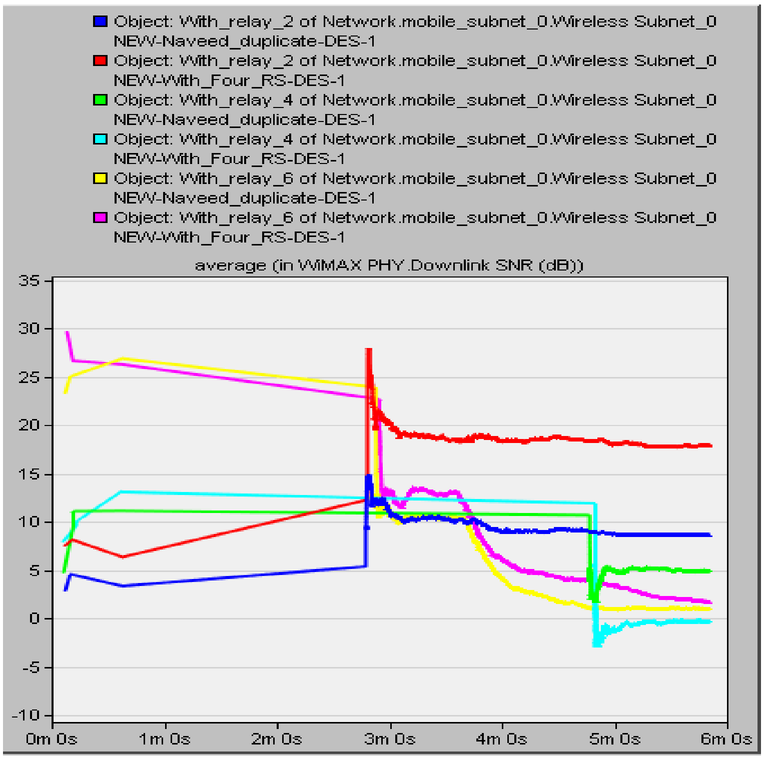


Figure 5.8 SNR with four and three RS

5.5 QoS Classes Comparison

The comparison of QoS gives in detail understanding of each class and its matrices such as throughput, delay, packet loss, traffic received and traffic sent with bandwidth request probability. In following scenario, throughput, load and traffic received parameters based on QoS classes compared to analyze the overall system performance for better performance. The video application defined as real time application to check the efficiency of each class. A network topology designed using wireless network deployment tool in the OPNET.

In this scenario three parameters (throughput, load, traffic sent) under real time application (voice) is compared in four QoS classes where voice application is configured and compared on each service class. In following scenario, topology is based on three cells and one BS in each cell with random users using 96Kbps codec is used for voice in each service class. BSs are connected to core network's router using IP backbone while PPP_Sonet cable is used for connectivity. Ethernet cable is used to connect router from server holding voice application.

5.5.1 Throughput with QoS classes

Each QoS class have its separate set of priority over different applications as discussed earlier. The figure 5.9 shows throughput for different QoS classes, amongst all other classes where UGS class has higher throughput as packet lost probability is low, because this class mainly use for real time applications and the packet data size are fixed in this service class and the BS grant maximum sustained rate flow. The ertPS also have high throughput but not as UGS, because this service class also support real time applications but it use the voice with suppression enabled mode. As compared with UGS and ertPS, the rtPS and BE has low throughput as it provide data with variable size and BE class has no guaranteed QoS because it is based on lowest priority

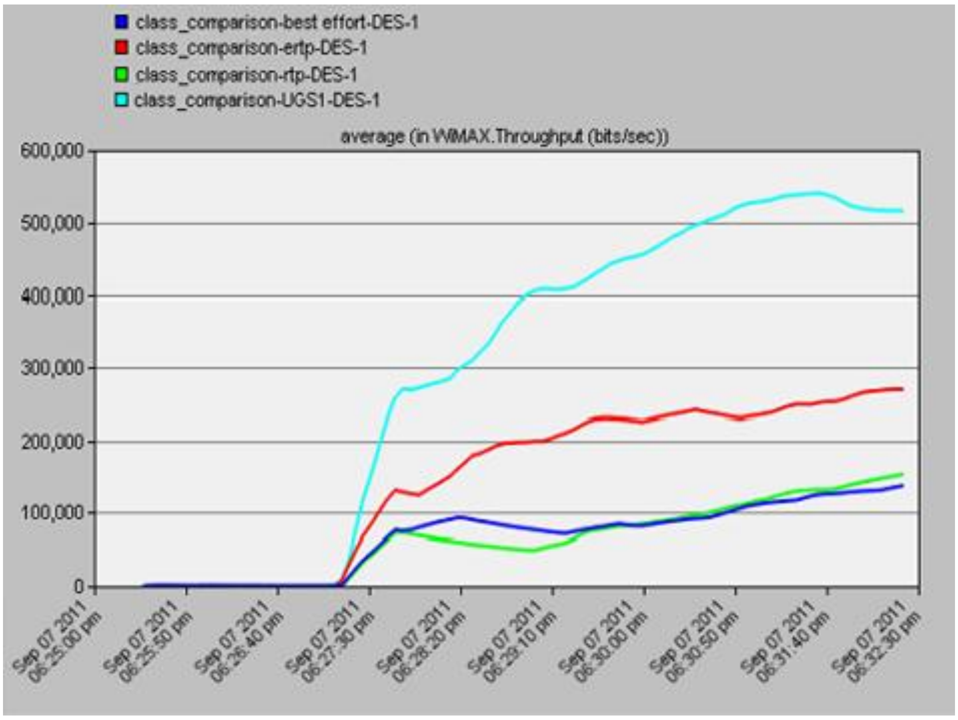


Figure 5.9 Throughput with QoS class's comparison

5.5.2 Load with QoS classes

The impact of load on all the service classes is almost the same as throughput. The figure 5.10 shows the impact of load on UGS class which is high then the same as UGS, ertPS class also have high load due to their application utilizations and sustained rate. The BE and rtPS have less load as these two classes works with no guarantees of traffic

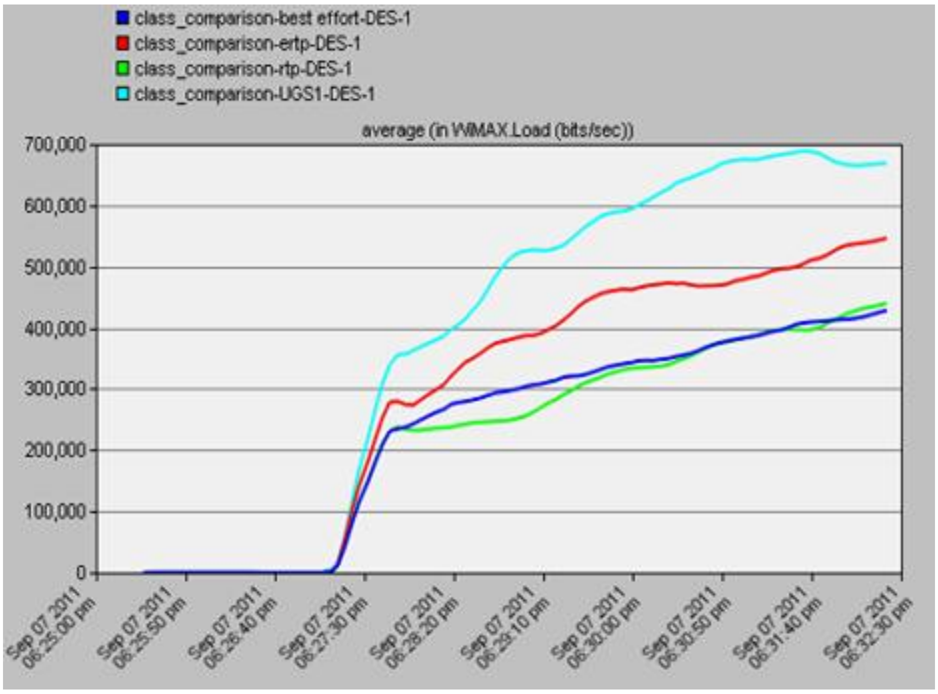


Figure 5.10 Average load with QoS classes' comparison

5.5.3 Traffic Sent with QoS Classes

The traffic sent parameter has been chosen to determine the number of packets sent successfully using each class. The BE class have very low data rate for transmission as compared to UGS, however ertPS also have better rate of traffic sent compared with rtPS and BE. Figure 5.11 shows traffic sent parameters in QoS comparison.

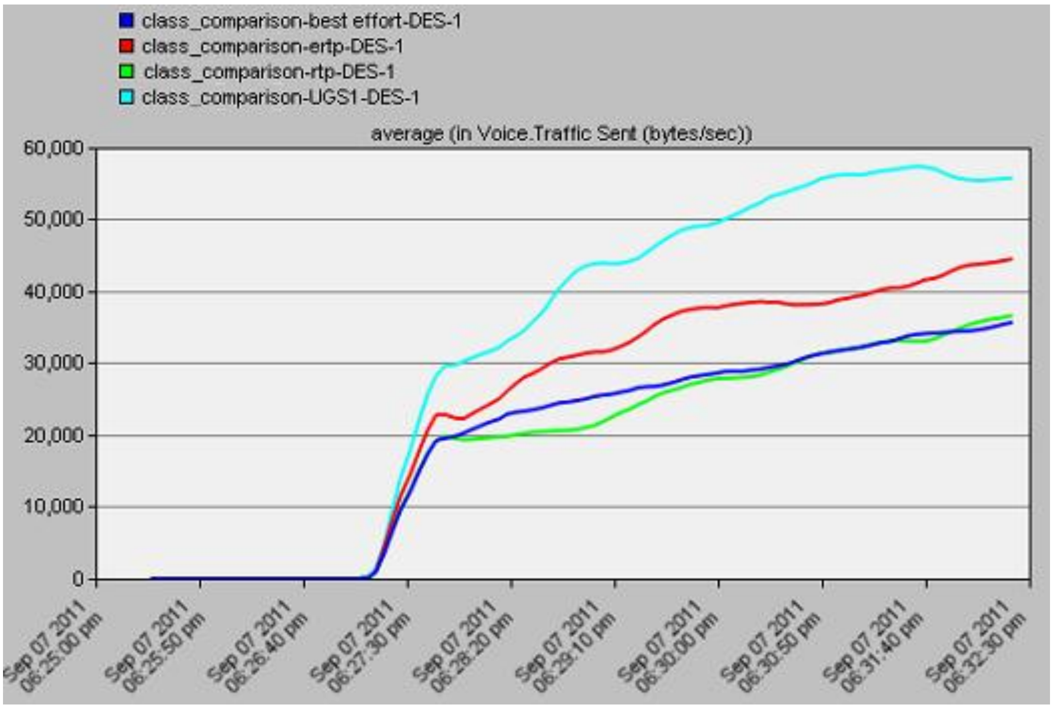


Figure 5.11 Average Traffic sent with QoS Classes comparison

5.5.4 QoS Classes Comparison Analysis

The above QoS classes comparison based on simple small WiMAX network design consist of four hexagonal cells topology with random RS and four mobile nodes are connected through BSs and RS. Each of the service class have not have load in order to get and compare service classes flows clearly. In the results above, the UGS and ertPS has high priority as they support real time applications and the available bandwidth allocated to each class would be high as compared to BE and rtPS class. The second scenario can be taken based on bandwidth request through RS. However, this would generate delay and overhead as RS cannot allocate bandwidth to mobile nodes, however it request bandwidth grant to BS for mobile station.

In the BSs and SS classifier parameters, the Gold class has been selected to get the best results, however silver and bronze also can be choose to perform the QoS comparison.

When mobile stations want to communicate or send data then it send a bandwidth allocation message to its connected RS or BS if it's directly communicating with BSs. If the communication is through RS which is in between BS and mobile station then the process will create delay and overhead, because the both parties contact RS as a middle node to pass messages which can cause delay and overhead by exchanging messages from mobile nodes to RS then BS and vice versa.

This situation can be more worst in big scenarios where the number of mobile stations are too many and they are requesting bandwidth same time through RS or in multihop communication scenarios showing in the network design topology where more than two RS are used to fill the communication gap of mobile node which is out of the range of BS and also out of the range of first RS. These types of scenarios are more complex in relay time application such as video streaming with high load and distance which can cause more delay and overhead.

The solution to these scenarios is to estimate the general overhead before start communication process start by using different length of frames from 2.5 ms to 20 ms according to [46]. And for getting enhanced performance, the length of frame should be large but it will cause errors, however the overall overhead will be decreased. The second solution to this scenario is decrease in distance of BS and RS and better AMC utilized with better channel quality.

5.6 Impact of Throughput and Delay

The most difficult task in wireless communication can be to measure accurate data of delay as there are different types of delay can occur for getting real time and simulation based results, because when a packet arrives at buffer and if the size of buffer is already full where packet loss probability is high for all the incoming data which can cause transmission delay.

First of all, to consider delay and throughput type of parameters, the distance between BS, RS and mobile stations need to be measured as with less distance of any node can have better SNR value and link budget. In contrast to short distance, the large distance can cause week signal quality which also increases delay. In direct transmission scenario, where the end user can communicate directly to BS in order to achieve better SNR due to single hop.

Figure 5.12 shows the performance of delay among four different scenarios. The AMC with coding rate ¾ has been chosen to reduce the distance and make the channel quality more reliable. The result is based on multihop scenario, using three RS scenarios, without RS scenario and using four RS scenarios by getting the single node results from each scenario. Also multiple antennas used to extend the throughput and link reliability. The DF technique can be assumed on cells with four and three relay and AF technique can be assumed for multihop scenario.

In AF mode, the traffic rate is increased with less delay as compare to DF technique but the error probability is less in DF mode, because it decodes the signal before transmitting to mobile station, however this technique can cause a little delay and that's why it has not been applied on multihop scenario. Because in multihop relay scenario, two RS communicating and get the signal from BS and through different hops to end users.

5.6.1 Impact of Delay with Different Scenarios

The figure 5.12 below shows the delay based on different scenarios which have been taken in the same cell with different scenarios. The node 1_1 represents multihop environment where two RS have been placed in between the BS and the mobile node1_1 to make BS and MS communication possible. The delay of node1_1 is increasing due to increase in number of hops. Because in multihop scenarios, delay can be increased as signals travels through different hops and when reach at the EN signal quality fades. However the advantage of this type of scenarios is to provide the services to the users out of the range of BSs and non transparent RS due to users demand and physical environment scenarios.

The 2_1 node which have less overall delay as four RS are covering the territory of BSs and the SNR is high in the area of node_2_1 and with three RS cell where node 2_2 have slightly less delay compared with node 2_1 due to distance and signal reception. And node 3_1 which is communicating directly with BS has less delay as there is single hop communication and distance is short.

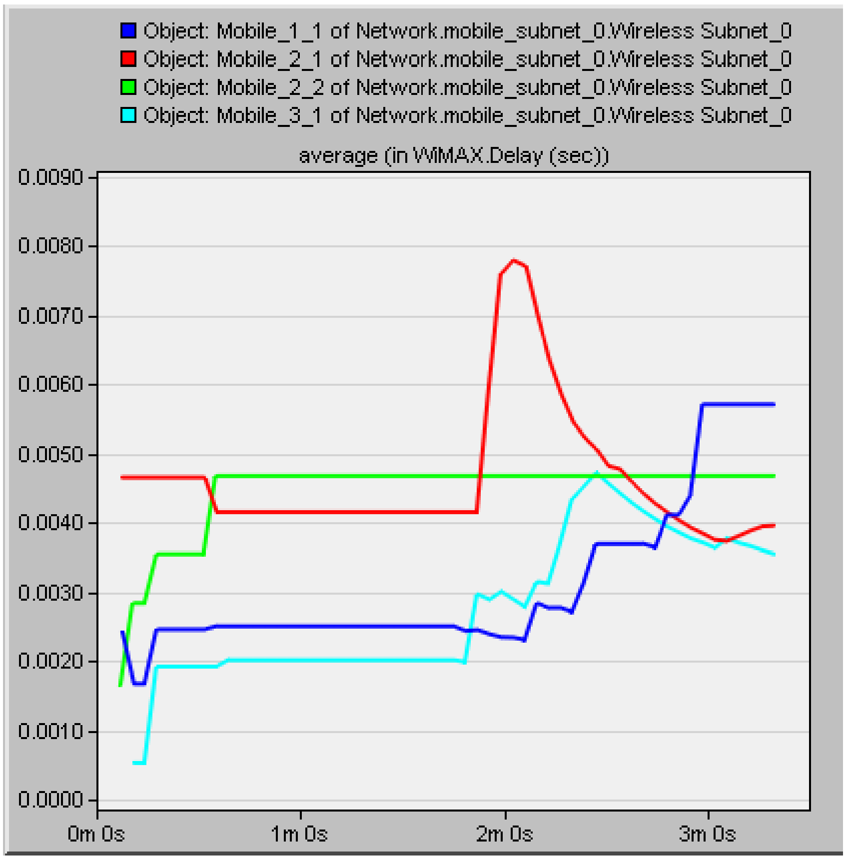


Figure 5.12 Average delays with end nodes

5.6.2 Impact of Frame Size with Different Scenarios

There are different types of delay such as propagation delay is the time where signal propagate through different hops. Transmission delay can be define as the time takes a packet to transmit through channel and processing delay can be define as the number of hops spends time to process the signal. This type of delay can be minimized by evaluating and defining suitable ways of communication. In the simulation using OPNET, free space model was selected so we can assume there is no propagation delay in this scenario. Transmission delay can be minimized by decreasing the distance of non transparent RS to BS as with the less distance better signal reception can achieved which can reduce transmission delay.

The processing delay can be reduce by estimating the general overhead before start communication process start by using different length of frames from 2.5 ms to 20 ms and for getting enhanced performance, the length of frame should be large but it will cause errors, however the overall overhead will be decreased. In WiMAX frames are divided into DL and UL sub frames, in initial ranging process, BS broadcast its control information which is consist of frame control header and MAC management message to all the relay and SS with the range.

The figure 5.13 shown for the scenario compared with frame length of 5ms and 10ms. The delay increased when 5 ms of frame length was used as multiple frames in the buffer generate delay but the 10 ms frame size have less delay but disadvantage of using 10ms frame is it increase errors. The overall system performance is depends on QoS requirements and demands.

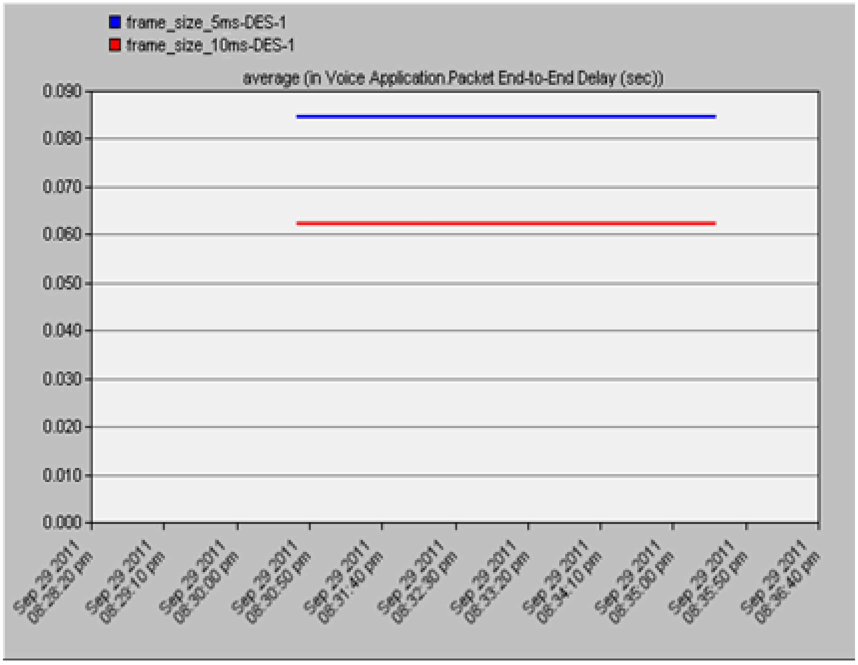


Figure 5.13 Average delays with different frame sizes

5.6.3 Impact of Throughput with Different Scenarios

The figure 5.14 shows the throughput based on different scenarios which have been taken in the same cell with different scenarios. The node 1_1 represents multihop environment where two RS communication hops are in between the BS and the mobile node1_1 to make BS and MS communication possible. The throughput of node1_1 is high as there are two RS are used to send the data rate to the user which is out of the range of BS and first RS.

The 2_1 node also have high throughput in the start as four RS are covering the territory of BSs and the SNR is high in the area of node_2_1. The three RS cell where node 2_2 have slightly less throughput compared with node 2_1 due to distance and signal reception by using four and three RS to cover the cell area. And node 3_1 which is communicating directly with BS have less throughput compared with all above as the node 3_1 is within the range of BS inside the boundary cell.

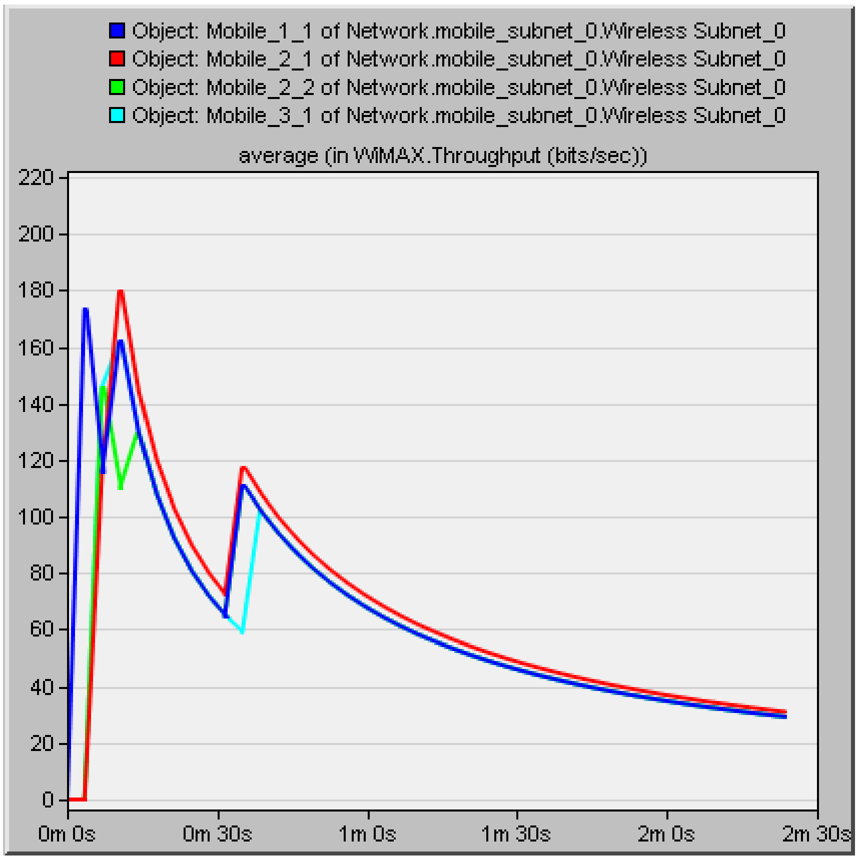


Figure 5.14 Average throughputs with different scenario

5.6.4 Impact of Load with different scenarios

The average load of each individual node is almost same as the network design is based on small network to measure the accurate results. Figure 5.15 shows average load with different scenarios.

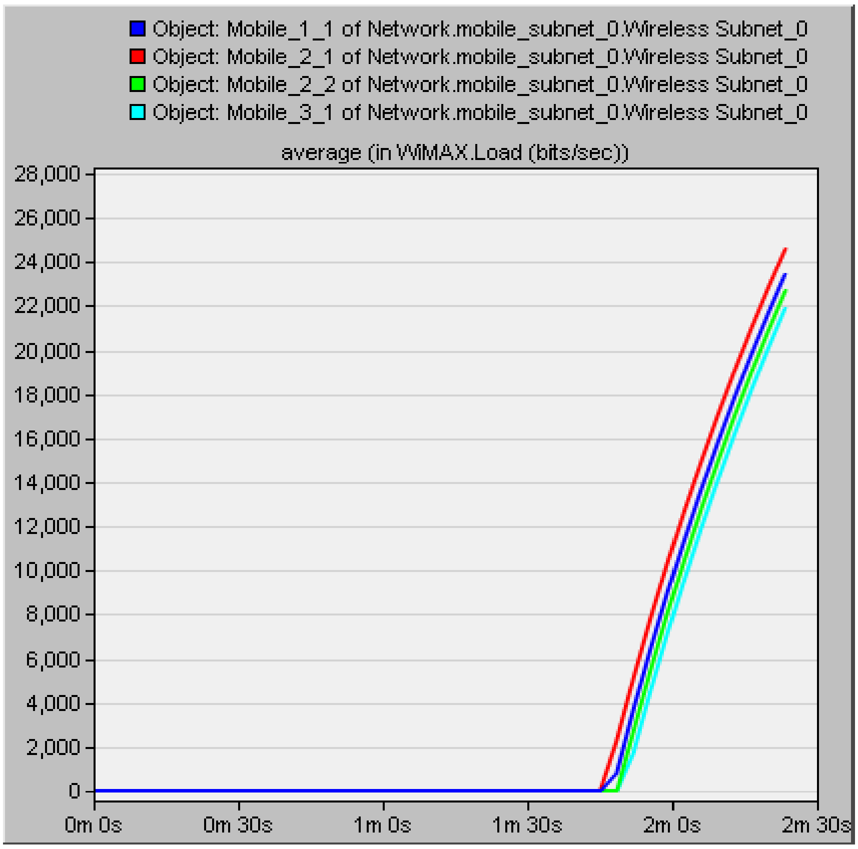


Figure 5.15 Average delays of QoS with different scenario

Chapter 6

Conclusion
And
Future work

6 Conclusion and Future Work

6.1 Conclusion

IEEE802.16m or WiMAX2 is 4th generation mobile and internet communications which offers better throughput, less delay, less latency for VOIP users and great speed. The other competitors like LTE advance also offering and getting a market place now, however WiMAX have the timing and market advantage over LTE as WiMAX already in the market since long and the upcoming new WiMAX2 emerge from its existing standard which means the compatibility and the usage will remain same and a very less changes can be made in deployment process. The IEEE 802.16m or WiMAX2 release will have significant number of the new technologies for better performance of overall network and for the end users, the new techniques like MIMO, AAS, Beam forming and advance RS which can make the new release to work well and provide better QoS.

During simulation of required results, where different types of scenarios have been taken to show the results based on cost effective deployment of RS on AMC rate of ¾ which can be inside of the boundary area of BS coverage territory and the signal strength is strong in this coding rate area as compare with ¾ coding rate. The cell is divided into three sectors in order to make direction of directional antenna lobe towards the RS as target area to provide better throughput. The results provided in chapter five where each QoS parameter has been compared with using four and three RS, It can be said that using three RS, the QoS standard can be achieved by dividing cell into sectors and placing RS at AMC coding rate of ¾ instead ½ which is inside of the boundary of BS coverage area and coverage and throughput can be extended using directional antenna.

Second scenario represents four cells and in each cell different environment has been taken to show the performance of using three RS in the cell, using four RS, without RS and multihop communication. There are several aspects need to be considered during RS deployment like BS and RS antenna height, available bandwidth, BS and RS power and data rate performance with respect to SNR and throughput. The antenna pattern such as sector antenna and advance antenna technologies, MIMO and AAS and beam forming as these technologies plays an important role in future wireless communication system.

In WiMAX network, the OFDM used as a transmission technique with QPSK, 16 QAM and 64QAM as modulation techniques for network to perform well. The RS obviously plays a key role in current and upcoming technology in terms of cost effective solution, range extension, capacity improvement and covering communication gaps in dense area and within the buildings. The work conducted in this project measures the impact cost effective placement and QoS in WiMAX network. The QoS can be measured and compared with different QoS parameters. The cell planning and sectoring, path loss model, BS and RS placement, cell size selection, BS and RS antenna height are the main concerns of wireless technology like WiMAX. In our simulation results which have been shown in chapter four and discussed in detail in later chapter, we have compared different scenarios and models for a WiMAX network based on different environment within the topology. After simulated the results, I found the main factors which affects the network performance can be distance from BS to RS and from RS to MS, cell size, the LOS and NLOS communication as it can cause propagation delay etc.

In this dissertation, we studied two aspects of RS

- Based on cost effective deployment of RS
- Based on QoS in RS.

Firstly, three RS deployed to cover the territory of the BS and also compared the simulated results with four RS topology. There were a small difference in throughput and SNR but compared with cost, we can conclude that the overall performance may be little bit decrease but we are saving cost for overall network. As mentioned before, it also depends on the operators and user demands as some user want better coverage but they don't mind of throughput and downloading speed, however, some user demand for better download speed but they don't consider cost. By comparing with both the operators and users demands, we need to focus on cost effective RS deployments for operator's perspectives and better QoS for end users satisfaction.

Secondly, The QoS parameters have been considered for better RS performance. The performance factor of any wireless technology depends on different aspects such as cell planning, cell size, antenna types, scheduling type applied to decrease the delay and improve the performance. It physical media like MIMO, SIMO, AAS and beam forming also play a vital role in QoS performance.

6.2 Future Work

The RS in WiMAX networks become an important research topic over the past couple of years. We studied the placement and QoS in relay enhanced WiMAX networks. However, to provide better high data rate coverage by using multihop relaying in practical, there are several issues can be investigated.

First of all, different applications and end users have different QoS requirements. Some delay sensitive applications such as video conferencing, VoIP, and online gaming have requirements on the maximum latency or the minimum bit rate. Non transparent relay can increase the data rate and coverage for cell edge and out of the cell users, however it increase the transmission delay simultaneously.

Last but not least, If we need to extend the coverage, enhanced throughput and capacity of the cell in order to provide better QoS for the users out of the range of BS and within the range of BS then we must have to place RS in a way to decrease overall cost and increase QoS support with end users satisfaction. Different resource algorithm needed for cost effective deployment and to improve QoS performance especially for delay sensitive applications as mentioned in previous chapters. Also resource allocation algorithm should be on high priority in RS deployment as we are well aware of better resource allocation can result better output and end user satisfaction.

Finally, the future wireless technologies depend on some new standards which help users to access the internet services anytime anywhere at a very good speed which is possible with proper use of available resources and provide better link quality, better throughput and guaranteed QoS. Advance RS which will be available in market in 2013 or 2014. The main idea behind the advance RS is, it support 4*4 MIMO antennas, it work as full fledge BS and also it will have the capability of sending and receiving its own preamble. If possible, I’ll try to carry on working with WiMAX technology with advance RS with added features like MIMO and other operational parameters.

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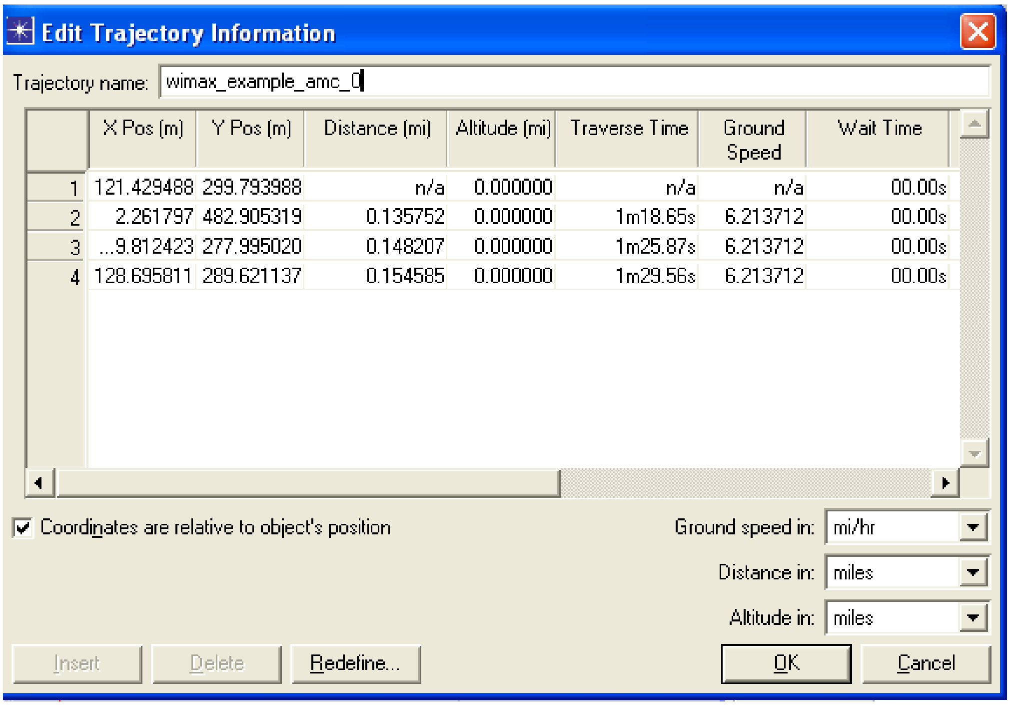
Appendix



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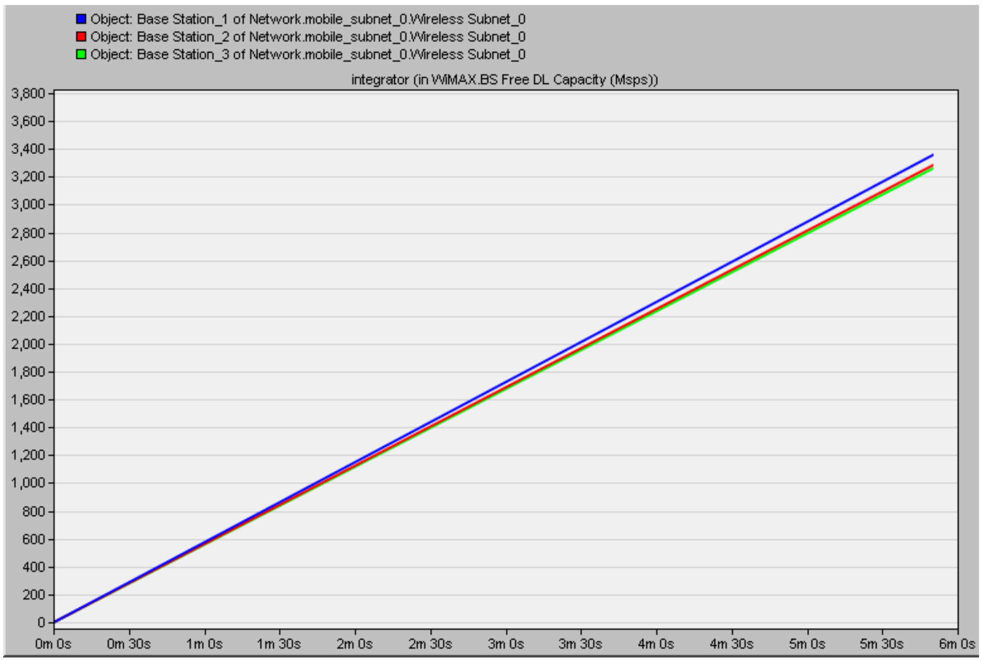
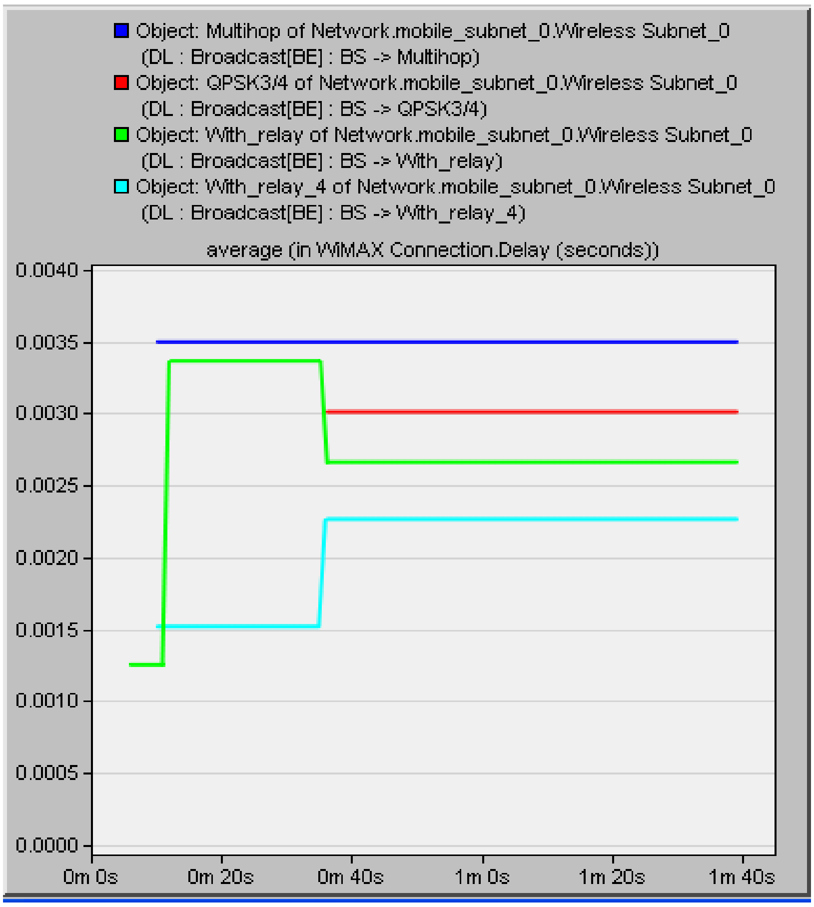


Average base DL capacity



Delay comparison of BE class

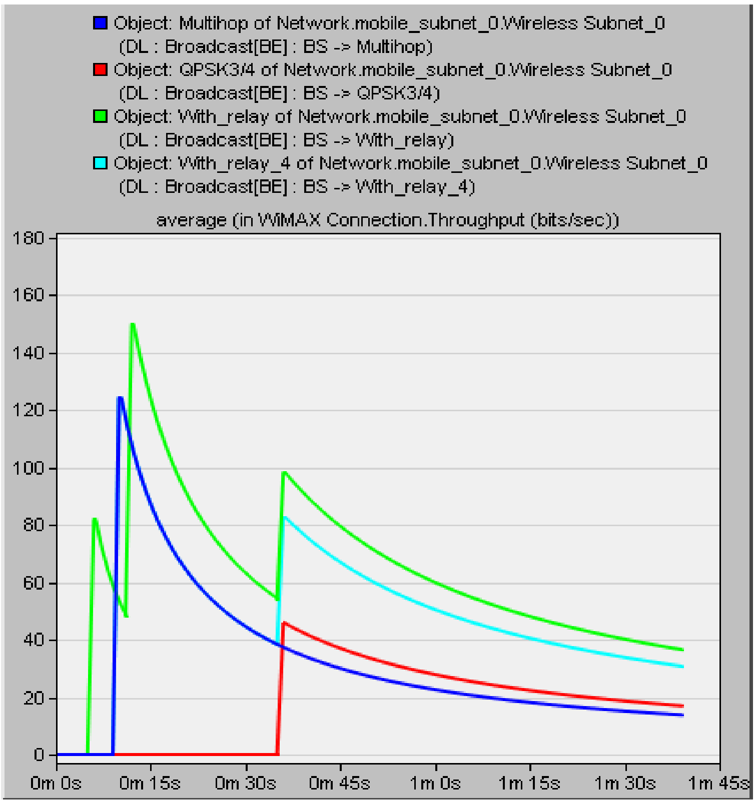


Fig: Available throughput