# Handoff Performance for Voice over IP in WiMAX Networks

BY

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## Dedication

*To My Beloved Parents*

*To my wife*

*To my kids*

*To my brother and sisters*

# Acknowledgements

I would like to thank my thesis supervisor Dr. Tarek for his guidance, enthusiasm and commitment to this thesis. Without his tireless reviews of my drafts and continuous feedback this document would not have been possible. Also I would like to thanks my thesis committee members.

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## Thesis Abstract

Full Name : Nayef Fawaz Mendahawi

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High data rate, mobility, QoS, vendor independence and interoperability are very important characteristics for the next generation of wireless communication networks. For example mobility support within a homogenous network and between networks of different technologies is a must to have feature for the next generation of wireless networks.

The standardization allows vendor independence and interoperability. A technology which was developed to fulfill these characteristics and standardized by IEEE is 802.16, also referred to as WiMAX. The WiMAX is the latest technology aims to have the above characteristics with low deployment costs. WiMAX architecture aims to have high data rates, QoS, long range and low deployment costs to a wireless access technology.

In the first phase the standard (802.16d) was released to support fixed terminal but the second release to support mobility. Different releases of the standards specify media access control (MAC) layer and physical (PHY) layer of the WiMAX technology. [14,35].

WiMAX supports different scenarios of handoff such as hard handover, soft handover and fast base station switching [6,8,14]. However, only certain handovers are possible for certain frequency reuse scenario.

This thesis is focused on the technology and architecture of WiMAX; more specifically, on its mobile capabilities (handover delay time). To illustrate, there are many types of handover, however this thesis focuses on hard handover with various application such as FTP and VoIP. Results demonstrate there are differences in HO time delay by means of different schedule services. Nonetheless, simulator confirms the WiMAX HO has long time delay in comparison to others technology such as GSM, UMTS and LTE. Finally, the thesis proposes idea towards developing the HO capabilities.

## ملخص الرسالة

**الاسم** : نايف فواز نايف مندحاوي

عنوان الدراسة :**كفاءة نظام VoIP في شبكات WiMAX في حالات التنقل**

**الدرجة** : ماجستير علوم

**التخصص**: هندسة الحاسبات

تاريخ التخرج:**في أكتوبر** 2009

**ارتفاع معدل** البيانات ، والتنقل ، و جودة الخدمة والتوافقية الخدمة هي خصائص مهمة جدا للجيل المقبل من شبكات الاتصالات اللاسلكية. على سبيل المثال مسانده التنقل داخل شبكة متجانسة وبين شبكات من التكنولوجيات المختلفة لا بد أن يكون ميزة للجيل القادم من الشبكات اللاسلكية.

التجانس في البروتكول يسمح للمصنعين في الاستقلال و التوافق بينهم. والتكنولوجيا التي تم تطويرها لتحقيق هذه الخصائص موحدة ايضا من قبل IEEE 802.16 ، كما يشار إلية WiMAX. و تعتبر تكنولجية WiMAX هي أحدث التكنولوجيا التي تهدف الى الوصول الى الخصائص المذكورة أعلاه مع انخفاض تكاليف النشر.**شبكة** WiMAX تهدف الى الوصول الى معدلات عالية للبيانات ، جودة الخدمة ، طويلة المدى ومنخفضة التكاليف لنشر التكنولوجيا الاسلكية.

**في المرحلة الأولى على مستوى** (802.16d) نشر لدعم محطة ثابتة ولكن النشرالثاني منه يهدف لدعم التنقل. **إصدارات** مختلفة من المعايير لتحديد MAC **و طبقة** (PHY) من تكنولوجيا WiMAX. [14،35].

WiMAX يدعم سيناريوهات مختلفة من عمليتي التحول مثل soft handover ,hard handover **وكذلك** fast base station switching [8،14].

هذه الرساله هي التي تركز على التكنولوجيا والهندسة المعمارية WiMAX ؛ على نحو أكثر تحديدا ، على قدراتها المتنقلة. لتوضيح ذلك ، هناك أنواع عديدة من التنقل ، ولكن هذه الرساله تركز على hard handover مع مختلف التطبيقات مثل **بروتوكول نقل الملفات و**VoIP. النتائج تظهر أن هناك اختلافات في وقت HO و تأخير في وقت HO عن طريق الخدمات **الجدول الزمني**. و تؤكد الرساله على WiMAX HO طويلة بالمقارنة مع غيرها مثل GSM ، UMTS و LTE. أخيرا ، تقترح الرسله فكرة نحو تطوير قدرات HO

# Literature Review

With the wide deployment of wireless networks, there has been tremendous interest in designing smoothly HO procedure for multimedia application and especially VoIP.

802.16e design to support HO from BS to BS, while SS has VoIP or data session. The main feature  for successful HO is that HO should be happened with minimal latency and without disturbance in real time application.

In summary 802.16e refer as WiMAX network; WiMAX has many challengeable in implementation as HO and reliability of VoIP while SS HO from BS to BS.

One problem which has caught my attention during literature review is that the behavior of SS while HO in WiMAX network is not considered. QoS for SS consider as a critical criteria for acceptance device from side, service provider and end user. A well known MOB manufacture company as RIM , Nokia, Apple spend a lot of time and effort and research in this domain. Different kind of scenarios and test cases were created and executed with simulator or live network.

Another problem is HO methodology, spec doesn't consider a specific methodology for implementation HO criteria, and it is related to implementation specification; spec only mention different HO scenario as I will mention later. Different parameters can be used to trigger HO step,  which attract me to investigate with simulator.

QoS and HO, to the best of my knowledge, both have not been studied in detail up till now.  So I hope to look into this problem in more details and come up with different performance metrics which can be implementing in SS.  BS performance investigated by many researcher, so that there are many published papers on this subject.  From my side I will work on continue the effort which have been done and extend the view to investigate SS.

In [47] hard handover is a mandatory in specification; FBSS and soft HO are optional. Papers present that hard HO allows only in low speed mobility. For higher speed mobility was FBSS and soft HO implemented.

Network scan has long latency in HO procedure as reference to some papers. Scanning time around 350 ms. A research paper has been published by the author where different approach in scanning to reduce latency are implement and significant results able to produce.

In [45] present that HO would not be observable if HO was only to occur once or twice during a conversation. And the speed doesn't have as speed main effect on HO but can cause a conversation to become unworkable.

Related to VoIP application, papers show that the data loss is still quite low, but will be more noticeable to the user. And that why this application should be consider as a core during investigation from SS side. Other results show a different packet losses are observed depend on application, and this comes down to the difference in data rates in the traffic types.

Some papers claimed that break-before-make handover system, an SS is not able to transmit or receive data before handover process is completed. And so the SS which has delay sensitive traffic as VoIP, might bring out the packet loss due to the transmission delay during the handover process. And so this paper proposed to have enhanced link-layer handover scheme in which mobile station can receive real-time downlink service from base station during handover process. As a result, SS can ignore the network re-entry processing time.

In [9] show the efficiently of using scheduling algorithm in manage resource.

It worth to point that the ertPS algorithm can support more 21% and 35% voice users compared with the UGS and rtPS algorithms, respectively.

In [49] demonstrated that the ertPS algorithm can save a lot of downlink and uplink resources compared with the UGS and rtPS algorithms. In addition, with the simulation

results of packet transmission delay for voice packets, result shown that the UGS, rtPS, ertPS algorithms can support 68, 76, 92 voice users, respectively. Consequently, through

the performance analysis of resource utilization efficiency and VoIP capacity, results have proven that the ertPS algorithm has number VoIP users the best resource utilization efficiency and the largest VoIP capacity among the various scheduling algorithms in IEEE 802.16e systems. The ertPS algorithm could be used efficiently in any wireless communication systems that support VoIP services with variable data rates and silence suppression.

In [48] it worth to mention that ertPS could be used efficiently in any wireless communication systems that support VoIP services with variable data rates and silence suppression.

HO topology is not specified and it is according implementation specific. Some papers suggest an idea to implement a methodology for HO as in [60].

Most of papers were published and results collect by using Qualnet simulator, which has WiMAX module and most of the core feature for WiMAX specifications. NS2 and Qualnet is the recommend simulator for investigate WiMAX module.

Papers show that the maximum attainable MOS score is 4.33 for G.711 during HO. In [50] measure the handoff latency when SS sends an ASCONF (Address Configuration Change) message to CN(core network ) until the CN modified the primary address and transmit an acknowledgment message is 17 ms. In [50] shows that -80 the trigger threshold for HO. Also it shows that jitter around 13 ms all above result in case a call support and for BS. In [51, 40] present total time was found over 700 ms by using Qulnet simulator (from the time MOB_NBR-ADV message is sent to the time message HO_IND is received) which I see is long time. In [40] the author suggests an optimization for HO and he could able to simulate the new algorithm and to decrease scan time to 20 ms.

**Thesis Contribution**

The first contribution is to study behavior of device with different type of services while HO and with VoIP application. All Literature Review results were collected for BS mainly and related to one aspect may be HO with VoIP or HO alone, in my case many scenarios were created to evaluate the integrity for different type class of services and HO and VoIP for device side. Different metrics were collected and results present that ertPS has and consider the first option for real time application even incase HO at device side.

The second contribution is to study the HO protocol which can be implemented. Different value used as the trigger for HO procedure as example RSSI and CINR.

Finally, HO latency time was measured with different scenario, after investigation, it found that BS scan period has the long latency time.  So, a HO optimization procedure was suggested by using a center data base and track system to decrease the scan time by SS. Because the most of the time spend by SS during HO related to scan BSs.

# Chapter 1: Introduction

With modern communication technology there is more and more demand on different kind of application such as multimedia, streaming and high-speed internet access with location reliability. Wide band services as Asymmetric Digital Subscriber Line (ADSL) which address these services attract many users and many internet service provider. Wireless technology provides a lot of business due to the consumer's attraction of interest. One of the most attractive wireless technology is WiFi. WiFi has many implementation world-wide. Thus, before the initiation the WiMAX discussion topic, it is of significance to mention a quick introduction of WiFi.

WiFi refer to IEEE standard which is 802.11 and has the following release 802.11 a/b/g. These releases are the most famous. It provides the following data rates 54 Mbps, 11 Mbps and 54 Mbps. A typical range of such WiFi system is ~up to 100 m for 802.11g indoor. [37]

Another attractive factor to wireless technology is the wide implementation of 2G and 3G wireless communications; as well as, the wide coverage of these technologies but the implementation of this technology is costly compared to WiFi. So the lower cost of WiFi attracts many researchers to seek for technological possibilities lower rate cost and wide range area coverage.

Another interesting point is most of recent applications have requirements for high data rate as real time applications like video, streaming and voice over IP (VoIP). So vendors are looking for a better solution to meet client's necessities.

High data rate, QoS and seamless of mobility will be the objectives for the next generation of wireless technology. The IEEE 802.16 specified the standard of technology which meets the above requirements [11,27]. The IEEE 802.16 is also known as WiMAX, which is a certification mark for products that pass conformity and interoperability tests for IEEE 802.16 standards.

WiMAX and WiFi appear to be compliments to each other. The main motive behind WiMAX implementations are area coverage, backhaul and rate wise. WiMAX has the advantage in large-area coverage, as in Metropolitan Area Networks (MAN's), the WiMAX system has coverage of 5km for non-Line of Sight operation and 15km for Line of Sight operation, even though up to 50km is achievable in ideal conditions at lower data rates. It appears reasonable to presume that WiMAX systems may be used as a backhaul network to serve a WiFi LAN's. Another possibility of WiMAX is the backhaul networks of 3G networks. The reasoning behind this interest in WiMAX as backhaul systems is due to their great capacities. [1]

A WiMAX system is sponsored by an industry consortium called WiMAX Forum. WiMAX is an abbreviation for Worldwide Interoperability for Microwave Access. The WiMAX Forum is committed to provide an optimized solution for fixed and nomadic, portable and mobile broadband wireless access. The main two versions of WiMAX are the following [5,17]:

- **802.16-2004 WiMAX.** This is based on the 802.16-2004 version of the IEEE 802.16 standard. It uses Orthogonal Frequency Division Multiplexing (OFDM) and supports fixed and nomadic access in Line of Sight (LOS) and Non Line of Sight (NLOS) environments.
- **802.16e WiMAX.** Optimized for dynamic mobile radio channels, this version is based on the 802.16e amendment and provides support for mobility. It uses Scalable Orthogonal Frequency Division Multiplexing Access (SOFDMA), a multi-carrier modulation technique that uses sub-channelization. Service providers that deploy 802.16e can also used the network to provide fixed service.

Handover indicates the maintenance of the connection while moving across cell borders. WiMAX 802.16e supports mobility which implies the SS will do handover while moving across cells borders. This is also accomplished by using base station to provide network access to subscribe stations based on 802.16 standards. [38]

WiMAX introduces several interesting advantages, and one of them is the support for QoS at the MAC level. Several different types of applications and services can be used in the WiMAX networks and the MAC layer is designed to support this convergence. The basic approach for providing the QoS guarantees in the WiMAX network is that the BS does the scheduling for both the uplink and downlink directions. To demonstrate the point, an algorithm at the BS has to translate the QoS requirements of SSs into the appropriate number of slots. The algorithm can also account for the bandwidth request size in which specifies size of the SS input buffer. When the BS makes a scheduling decision; it informs all SSs about it by using the UL-MAP and DL-MAP messages in the beginning of each frame. These special messages define explicitly slots that are allocated to each SS in both the uplink and downlink directions. [39]

IEEE 802.16 BWA systems support four uplink scheduling algorithms, such as unsolicited grant service (UGS), real-time polling service (rtPS), non-real-time polling service (nrtPS), and best effort (BE) service. [39]

During the past years WiMAX became a fascinating topic for many research projects, nonetheless, the devotion to this technology by many thesis papers, documentation and reports.

This thesis is organized as follows: The second chapter provides the background topic of the WiMAX technology. The third chapter presents the diverse handover types with illustrative schemes. Subsequently, the simulation environment is discussed; this includes simulation parameters, assumptions as well as simulator utility. Lastly, the simulator results, analysis and conclusions are covered.

# Chapter 2: The WiMAX Technology

## 2.1 The Background of WiMAX

WiMAX is a wireless technology designed to provide broadband wireless access up to 50 km for fixed stations and (5 – 15 km) for mobile stations. The standard operates in both license and unlicensed frequency.

IEEE released the first 802.16 standard in 2001, as IEEE 802.16-2001 which is also recognized as 802.16a. The 802.16a was a plain PTP- technology without OFDM or OFDMA and was solely meant for frequency rang 10-66 GHZ. In 2004 IEEE released 802.16d. The important technical aspect of this change was the new support for NLOS frequency range 2-11 GHZ and support of OFDM, OFDMA, AMC and HARQ. These modifications permitted the release to become the wireless DSL-alternative. In 2005 IEEE 802.16e scalable OFDMA and mobility support, this set of technical amendments enables WiMAX to address and deter the cellular. Later, IEEE released the following standard amendments which are not covered with proposals of this thesis: [40]

- IEEE 802.16f-2005
- IEEE 802.16g-2007
- IEEE 802.16k-2007

## 2.2 WiMAX Architecture

The basic components of an 802.16 network are Base Stations (BS) and Subscriber Stations (SS) (or Mobile Stations (MS) in 802.16e). Each of the components has specific functions as following: [41]

**Base Station:** The Base Station is capable of transmitting and receiving high speed data from subscribes stations (SS) or from another BS.

**Subscribe Station:** The subscriber station is capable of transmitting and receiving data from base station. It is considered as Customer Premise Equipment (CPE).

The standard specified two modes of operation:

In the *(PMP) mode* subscriber station obtain access to network through one or more powerful base station. Refer to figure number 2.1.

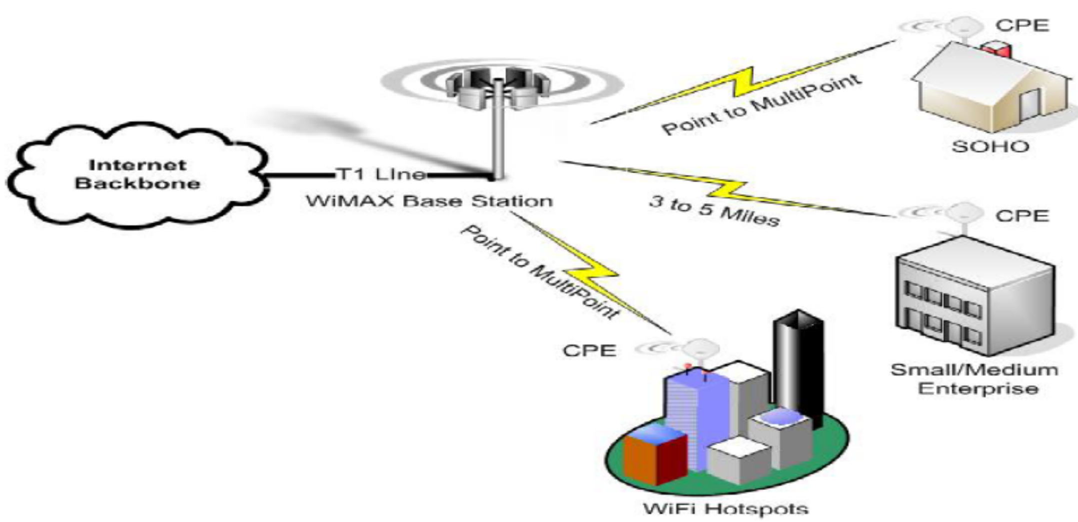


Fig. 2.1. “Point to multipoint”

In *mesh mode* and also called multipoint to multipoint, there is no centralized BS, as more SS join network. Mesh network allows subscribe stations to directly communicate to each other and thus traffic can be route through subscribe stations. See figure number 2.2.

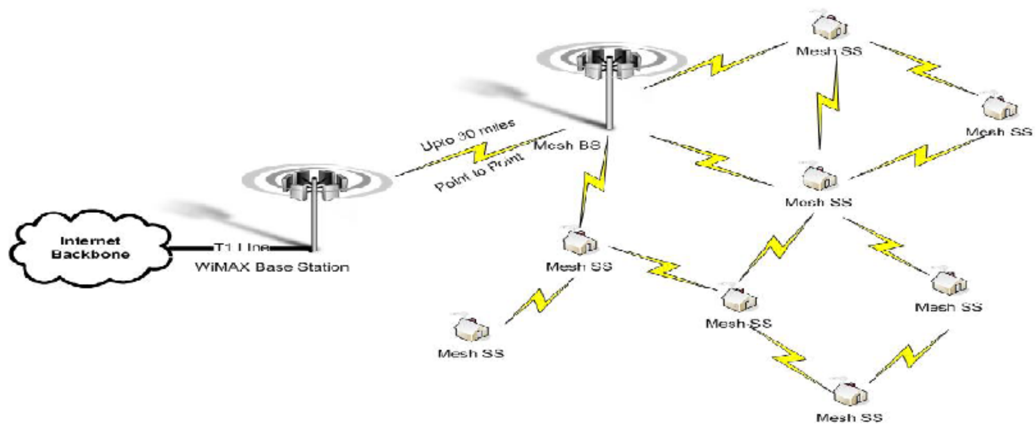


Fig.2.2. "Mesh Network"

## 2.3 Network Architecture

The WiMAX consists of entities such as Mobile Subscriber Stations (MSS), Access Service Network (ASN) and Connectivity Service Network (CSN) [2], figure number 2.3 depict infrastructure.

It also contains a reference point which is a protocol or procedure between entities.

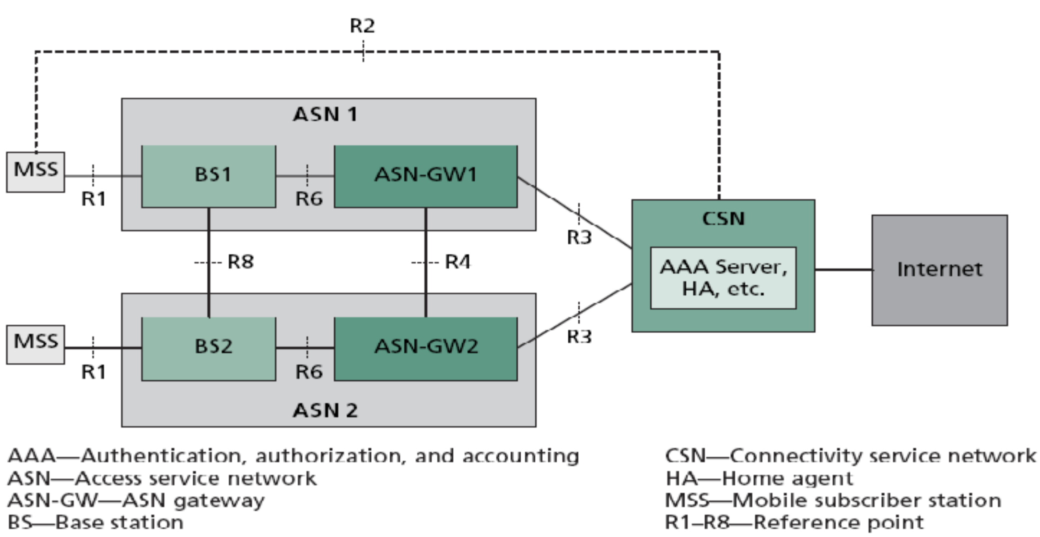


Fig.2.3. "WIMAX Network Architecture"

The ASN consists of a base station, an Access Service Network gateway (ASN-GW) as well as define a set of network functions that provides radio access to a WiMAX subscriber. The main functions provided by the ASN include:

• The mobile subscriber station Layer 2 connectivity to the BS

• Radio resource management at the ASN-GW

In addition, the ASN also needs to support intra-ASN mobility when a MSS moves from one ASN to another; paging and location management of a MSS; and tunneling of packets between the ASN and the CSN.

CSN has different function as AAA proxy service and it works as hosting mobile IP home address (HA).

Reference to figure number 3:

- R1 is the air-interface (PHY and MAC) protocols and procedures between the MSS and the BS.
- The R6 reference point defines the set of control and bearer plane protocols between a BS and an ASNGW.
- The R3 reference point defines the set of control for interworking between the ASN-GW and the CSN.
- The R8 reference point defines the protocols between the BSS in order to ensure fast and seamless handover.
- The R4 reference point defines the set of control and bearer protocol for inter-ASN-GW mobility.

## 2.4 WiMAX Protocol Stack

Figure number 2.4 shows IEEE 802.16 protocol stack. The IEEE has defined many different options within the MAC protocol like ATM, 802.3 or IP. It also shows the Security layer and a whole series of PHY –implementation options for WiMAX like single carrier, OFDM and OFDMA. [41]

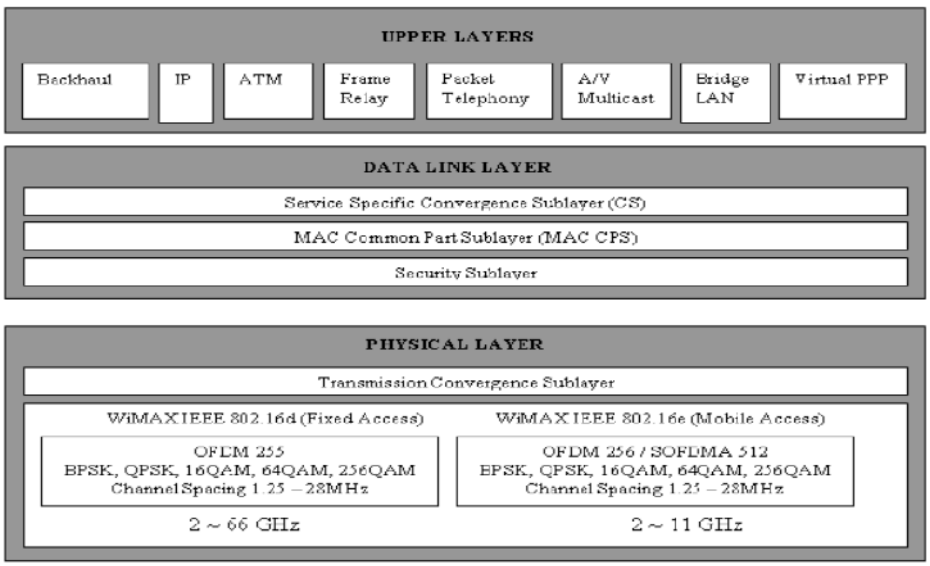


Fig.2.4. “WiMAX Protocol Stack”

### 2.4.1 Physical Layer

The following are important assets:

- Use of OFDMA ( Orthogonal frequency division multiple access):
    1. With support for FDD and TDD operation.
    2. Support various bandwidths of 1.25 MHZ operation.
- Adaptive modulation and Coding:
    1. QPSK, 16 QAM and 64 –QAM
    2. Coding techniques: ( Turbo coding TC, Convolution Coding CC and Bit repetition

- Sub-channelization
- HARQ ( Hybrid automatic repeat request)
- Support of Multiple Antenna technique (TX/RX – diversity operation, beam forming and MIMO techniques)
- Power control

### 2.4.2 Overview of MAC Layer

The MAC layer is built to support IP, ATM and others. The standard is supported both TDD, full/half FDD.

The MAC layer is divided into convergence –specific and common part sub-layer. The convergence is used to map the transport – layer traffic to MAC layer which enables it to efficiently carry any type of traffic. The common sub-layer is response for segmentation and fragmentation of MAC SDU into PDU.

MAC Packet Data Units (PDU) can be of variable length, with support for concatenation and fragmentation, which is also available to internal MAC-layer Service Data Units (SDU). This helps save overhead in headers as well as utilizes bandwidth and meet QoS demands through packet resizing. Redundant header information can also be omitted with use of Package Header Suppression (PHS). Figure number 2.5 shows MAC layer. [41,42]

Fig.2.5. “MAC layer”

Each of the MAC sub-layers as shown in figure 5 performs a specific function as following:

- Service – Specific Convergence Sub-layer: it present at the top of the MAC CPS. It accepts higher layer protocol data unit (PDU) from higher layer and makes classified and delivers to appropriate MAC SAP. CS are two specification defined which are (ATM CS and packet CS).

Fig.2.6. “Service – Specific Convergence Sub-layer”

- Common Part Sub-layer : the function of this layer are ( Mobility feature, HARQ, ARQ, Connection management and network entry and initialization)

Fig.2.7. “Common Part Sub-layer”

- Security Sub-layer: the function of this layer is protection from theft of service, PKMv2 and data encryption.

Fig.2.8. “Security Sub-layer”

#### 2.4.2.1 MAC Connection

There are different kind of connection the main three connections are basic, primary and secondary. The purpose of basic is for short and more urgent MAC message. Also it use with RLC for control power and ranging, in addition to changing burst profile. The primary connection is responsible for longer management message as in security message. The secondary connection allows particular protocol to run at higher layer, such as routing. In addition there are transport connection to transfer data and broadcast connection for transmission of broadcast MAC message and initial ranging connection.

#### 2.4.2.2 MAC Management Messages

A set of MAC management message are defined, these message shall be carried in the payload of MAC PDU. There are 49 MAC management messages [43] which list in table number 2.1.

Table 2.1. “MAC Management Messages”

# Chapter 3: WiMAX Handover Technology

The handover means to move SS with call or data session from one network to another network successfully without a call drop or stop session. There are many reasons to have handover, but this thesis will not cover these reasons.

The most important features in handover are to make it with minimum latency and without deficiency in performance or disruption for user.

802.16e standard, enable this feature and make this technology to compete with cellular in market.

## 3.1 Handover Type:

802.16e stander is highly flexible and there are three types for handover,[14,6,1] which are:

### 3.1.1-Hard handover:

The default is the “break before make” handover that requires no communication between BS’s. In this mode the BS broadcast uplink channel descriptor (UCD) and downlink channel descriptor (DCD) information of neighbor BSs. The MS negotiates with BSs about scanning period, just it got the scanning period, it estimates downlink signal quality of neighbor BSs. [1]

### 3.1.2-Soft handover

In soft handover the MS will listen to around BSs at the same time. The MS will perform diversity combining on signal from the BSs and the BSs will in turn perform diversity combining among them to get the uplink PDUs. [1,43]

### 3.1.3-Fast base station switching

In this scenario there is no need to network reentry, The MS communicates with anchor BS, in which all the BSs should be an active set and should use the same frequency. [1,43]

Both the soft handover and the fast BS switching are optional in the standard and can be disabled.

## 3.2 MAC layer handover procedure

This section will describe the process from which the mobile migrate from air – interface provides by BS to air interface provide by another BS. It consists from the following stages: [43]

- Cell reselection: MS can use information from MOB_NBR_ADV message or may be schedule scanning intervals and possibly range for the purpose of evaluation MS interest in HO or potential target BS.
- HO decision and initiation: the decision may be originate at MS or serving BS. These happen through MOB_MSHO-REQ or MOB_BSHO-REQ message.
- Synchronization to target BS DL and UL: MS should synchronize to DL transmission of target BS and obtain DL and UL transmission parameters. If MS had received a MOB_NBRADV message including target BSID, physical frequency, DCD and UCD, this process may be shortened.
- Ranging: MS and target BS shall conduct initial ranging, if MS RNG-REQ include BSID then target BS may make a request to serving BS for information on the MS over the backbone.
- Termination of MS Context: this is the final step in handover. Termination of MS context. Which means that serving BS terminate of context of all connections belong to MS and the context associate with them as (counter, timer etc.).

- HO Cancellation: MS may cancel HO prior to expiration of Resource_Retain_Time interval after transmission of MOB_HO-IND message.

Handover process and initial network entry process [43], is depicted in figure number 3.1

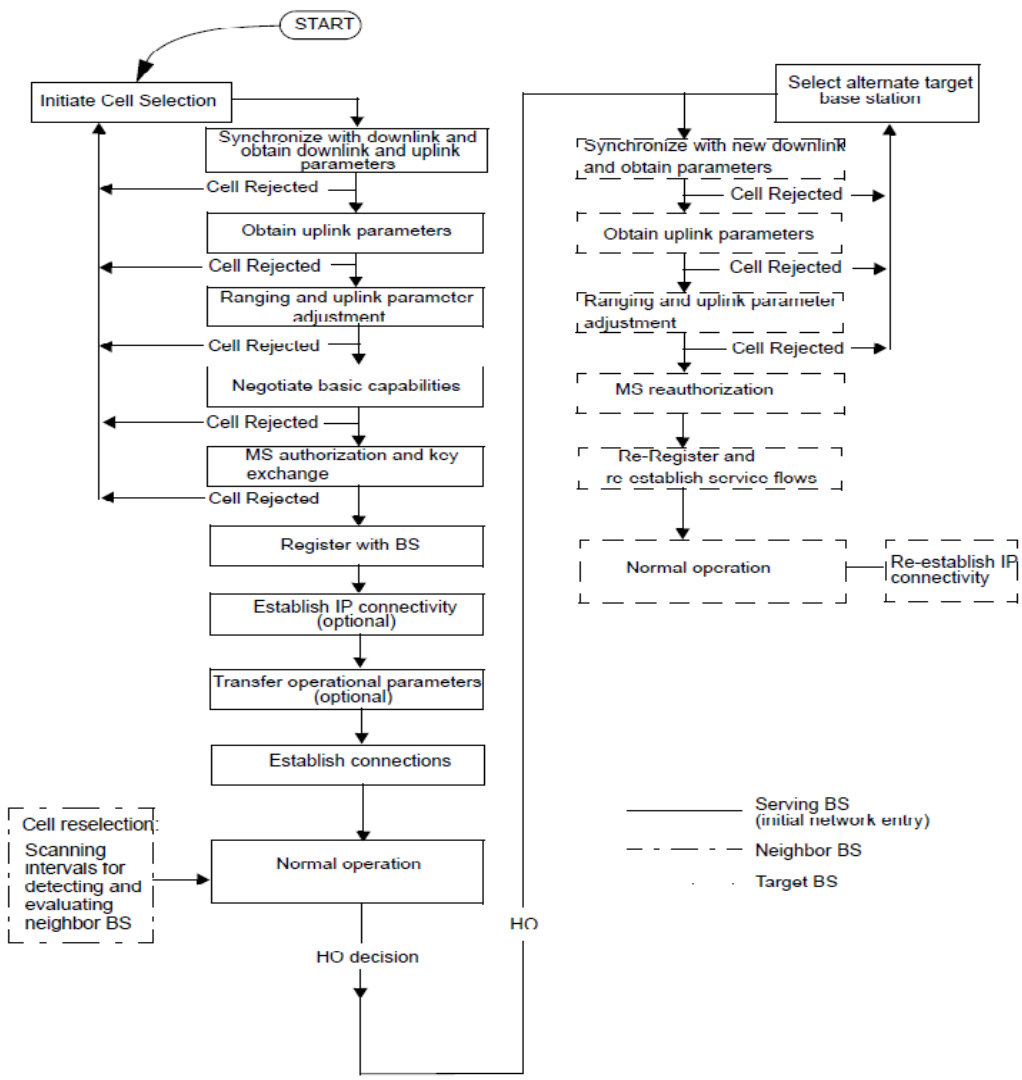


Fig. 3.1"Handover process and initial network entry process"

To better understand how handover is performed in WiMAX, we discuss different HO scenarios below:

## 3.3 MS initiated HO

MS can initialize handover for different reasons, as example when an MS has bad signal quality with serving BS, it may wish to move to another BS or a MS wish to move to another BS to get better QoS at another BS, the standard doesn't specified the methodology of HO. The standard provides means to gain information and exchange messages to make the HO decision. Handover initiated by MS as seen by MS and BS [43], is depicted in figure number  Fig. number 3.2 and Fig. number 3.3

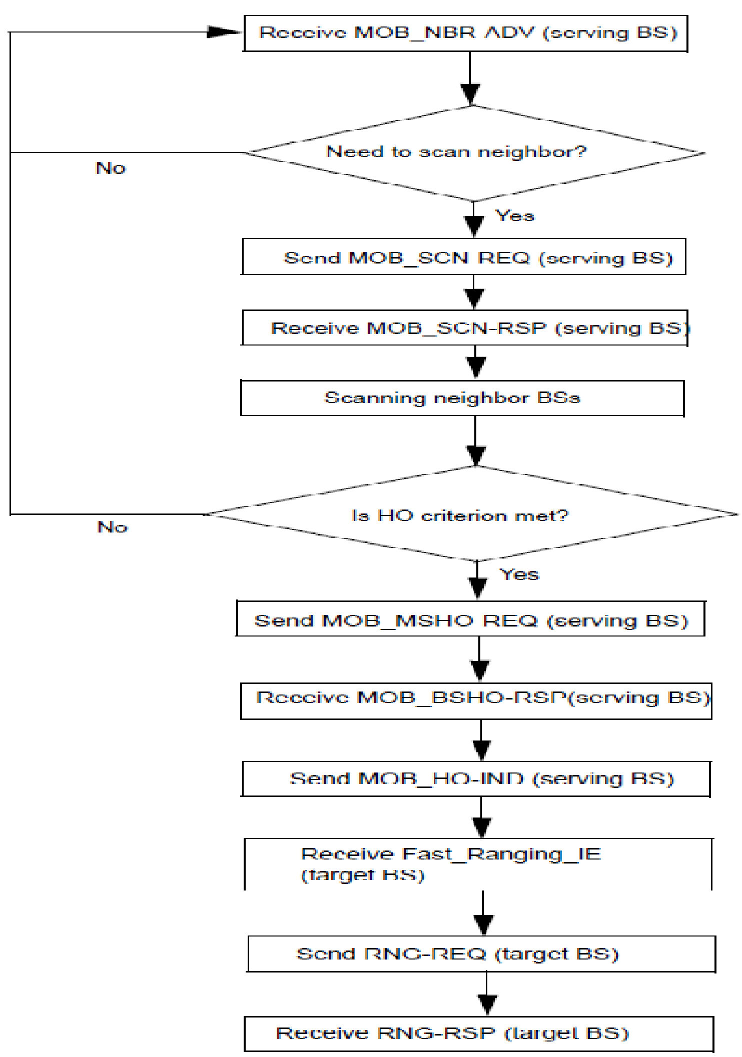

Fig.3.2 “MS initiated HO process as seen by MS”

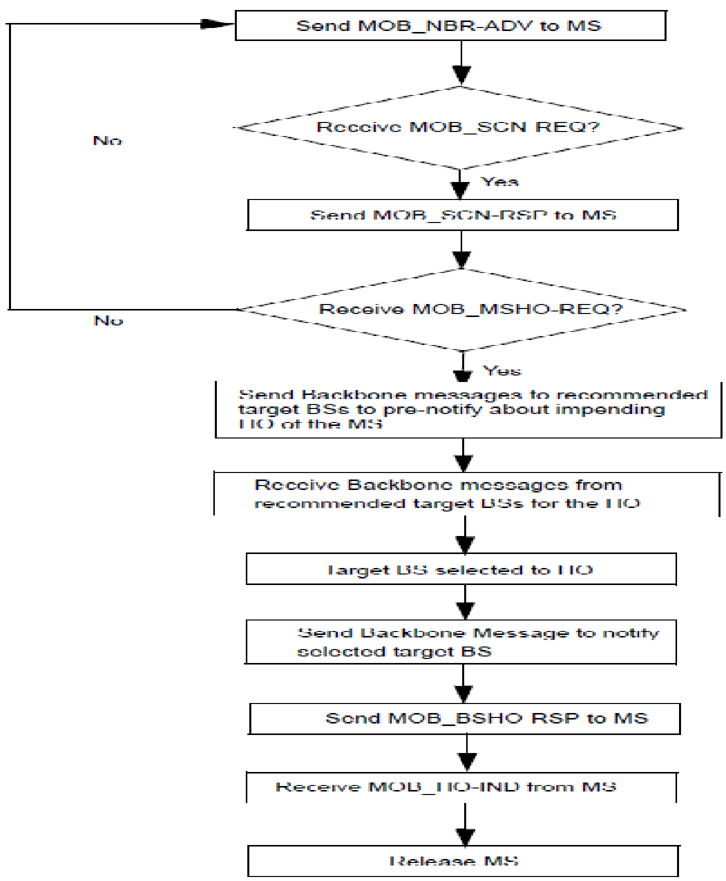


Fig.3.3 “MS initiated HO process as seen by serving BS”

## 3.4 BS initiated HO

The next scenario should be considered when the BS decide to move a MS to another BS. When BS can’t serve MS with the required QoS, BS can decide to move the MS to another BS [43]. Handover initiated by BS as seen by MS and BS, is depicted in figure number3.4 and figure number3.5

Fig.3.4 “BS initiated HO process as seen by serving MS”

Fig.3.5 “BS initiated HO process as seen by serving BS”

## 3.5 MAC – HO Messages

Finally, it is worth to discuss some MAC messages that are exchanged during handover, these messages are:

### 3.5.1 RNG-REQ, Ranging Request (Transmitted on Basic or Initial Ranging connection)

This message is transmitted periodically to determine network delay and to request a power or burst profile change.

| Syntax | Size | |
|---|---|---|
| RNG-REQ_Message_Format() { | | |
| Management Message Type = 4 | 8 bits | |
| Reserved | 8 bits | |
| TLV Encoded Information | variable | TLV specific |
| } | | |

Table number 3.1" RNG-REQ"

### 3.5.2 RNG-RSP, Ranging Response (Transmitted on Basic or Initial Ranging connection)

This message contains the response to the RNG-REQ message, containing such

Parameters in which are relevant to the request. If the RNG-REQ was sent on the initial ranging connection, this message then also contains the connection identifier for the basic and primary connection assigned to this SS.

Table number 3.2" RNG-RSP"

### 3.5.3 REG-REQ, Registration Request (Transmitted on Primary connection)

Sent by a SS in order to register with the BS and to negotiate the SS's capabilities, such as its IP version, ARQ parameters and convergence layer capabilities.

Table number 3.3" REG-REQ"

### 3.5.4 REG-RSP, Registration Response (Transmitted on Primary connection)

Sent by BS in response to a REG-REQ; it contains the connection identifier for the SS's secondary connection, in addition to relevant parameters for the SS's capabilities.

Table number 3.4" REG-RSP"

REG-RSP includes a timer called System Resource_Retain_time, this timer indicates the duration for MS's connection that will be retained in serving.

Table number 3.5" HO system Resource_Retain_time"

### 3.5.5 DSA-REQ, Dynamic Service Addition Request (Transmitted on Primary connection)

Sent by SS to create a new service flow.

Table number 3.6" DSA-REQ"

### 3.5.6 DSA-REQ, Dynamic Service Addition Response (Transmitted on Primary connection)

Sent by BS in response to a DSA-REQ; it contains the connection identifier of the transport connection assigned to this service flow, if this has been approved.

Table number 3.7” DSA-RSP”

### 3.5.7 Downlink-MAP, DL-MAP:

The purpose of the downlink map is to define the access to the downlink information. It tells each SS at what time changes in modulation and coding will occur. The subscriber station listens to all the data it is able to until it reaches data for itself.

Table number 3.8" Downlink-MAP, DL-MAP"

### 3.5.8 Uplink-MAP, UL-MAP

The purpose of the UL-MAP is to define access to the uplink channel. It specifies a burst profile and a time for each SS to transmit its data.

| *Syntax* | *Size* | *Notes* |
|---|---|---|
| UL-MAP_Message_Format() { | | |
| **Management Message Type = 3** | *8 bits* | |
| Reserved | *8 bits* | Shall be set to zero |
| **UCD Count** | *8 bits* | |
| **Allocation Start Time** | *32 bits* | |
| Begin PHY Specific Section { | | See applicable PHY subclause. |
| If (wireless MAN-OFDMA){ | | |
| No. OFDMAsymbols | *8 bits* | Number of OFDMA symbols in the UL subframe |
| } | | |
| for(i =1; i < = *n*: i++ ){ | | For each UL-MAP element 1 to *n* |

| | | |
|---|---|---|
| UL-MAP_IE() | *variable* | See corresponding PHY specification. |
| } | | |
| } | | |
| if! (byte boundary){ | | |
| **Padding Nibble** | *4 bits* | Padding to reach byte boundary. |
| } | | |
| } | | |

Table number 3.9” Uplink-MAP, UL-MAP”

### 3.5.9 Downlink Channel Descriptor, DCD

The purpose of the DCD is to specify the characteristics of a given downlink physical channel. The BS transmits it at a given interval, which can have a maximum value of 10 seconds.

| Syntax | Size | Notes |
|---|---|---|
| DCD_Message_Format() { | | |
| **Management Message Type = 1** | 8 bits | |
| Reserved | 8 bits | Shall be set to zero |
| Configuration Change court | 8 bits | |
| TLV Encoded information for the overall channel | *variable* | TLV specific |
| Begin PHY Specific Section { | | See applicable PHY subclause. |
| for(i =1; i < = *n*: i++ ){ | | For each downlink element 1 to *n* |
| Downlink_Burst_Profile | | PHY specific |
| } | | |
| } | | |
| } | | |

Table number 3.10” Downlink Channel Descriptor”

### 3.5.10 Uplink Channel Descriptor, UCD:

The purpose of this is similar to the DCD, in that it specifies the characteristics of the uplink channel and is transmitted at a given interval, which cannot exceed 10 seconds. This message also contains required information for initial ranging contention.

Table number 3.11" Uplink Channel Descriptor"

The simulator by default used "MS initiated HO" scenario. So in this thesis this scenario used to simulate HO scenario and collect results.

# Chapter 4: The QualNet Network Simulator

## 4.1 Simulator Background

The scenario implemented by using QualNet simulator which is a wireless simulator version of GloMoSim software. The simulator is C++ based. All C++ files are called by simulator kernel. The simulator is scalable, efficiency will not effected by number of nods running. QualNet has a GUI which is built in Java and it consists of [44]:

1. Scenario Designer: is a network design tool that allows setting up terrain, network connections, subnets, mobility patterns of wireless users and other functional parameters of network nodes.
2. Animator offers in-depth visualization and analysis of a network scenario designed in Scenario Designer.
3. 3D Visualizer is a tool for advanced visualization of network scenarios and simulations.
4. Analyzer is a statistical graphing tool that displays hundreds of metrics collected during simulation of a network scenario.
5. Packet Tracer is a packet-level visualization tool for viewing the contents of a packet as it goes up and down the network stack.

QualNEt architecture is depicted in figure number 4.1

Fig. 4.1. “QualNet architecture “

The simulator is built on OSI model [44], OSI model references is depicted in figure number  4.2

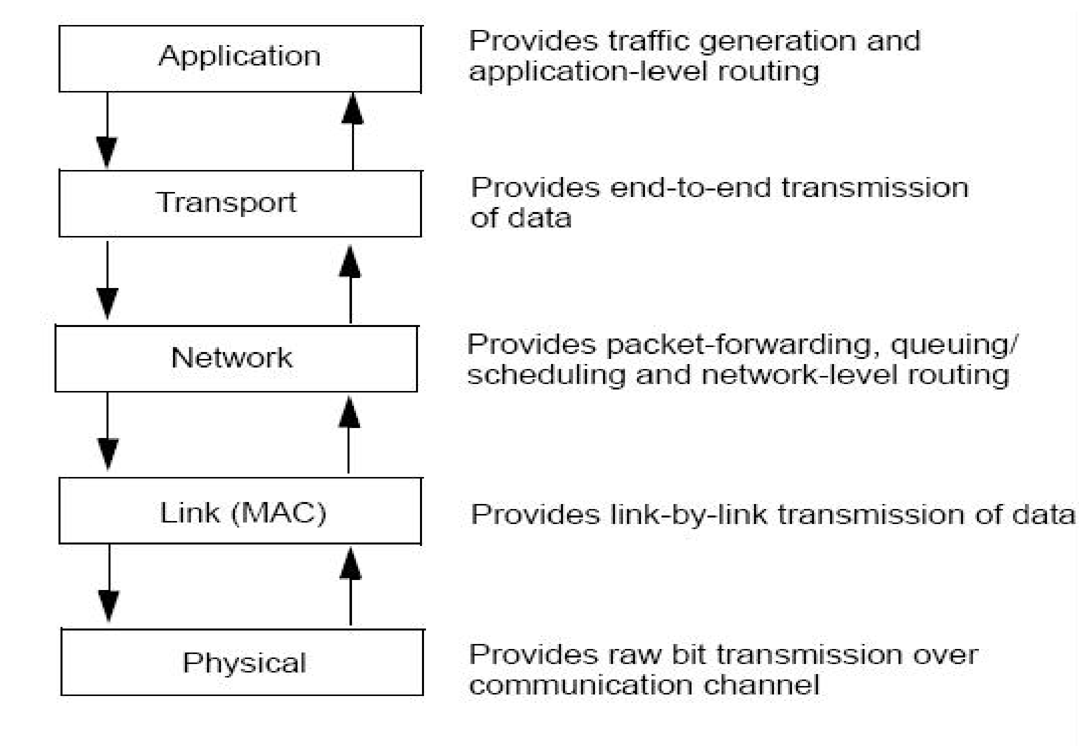


Fig. 4.2. “OSI Model“

Simulator supports both UNIX and Windows OS. The minimum hardware /software requirements to have stable installation on Windows XP OS are:

- **Memory requirements**

- 512 MB for simulations of networks with up to 100 nodes.

- 768 MB for simulations of networks with up to 250 nodes.

- 1 GB for simulations of networks with up to 1000 nodes.

- **Software pre requirements are**

•Sun Java™ 2 SDK, Standard Edition, version 1.4.2

•VC++ or higher (see attachment for a list of supported C++ compilers).

## 4.2 802.16 MAC and 802.16e MAC models

The WiMAX models are part of the advance wireless library. The MAC of IEEE 802.16 model of QualNet 4.5 has implemented features defined in both IEEE 802.16 and IEEE 802.16e. The detailed lists of implemented features are:

- Point to Multi-Point (PMP) mode.
- Time Division Duplex (TDD) mode:
  - •MAC frame is divided into downlink subframe and uplink subframe.
  - •DL-MAP and UL-MAP supporting subchannels of OFDMA PHY.
- Network entry and initialization:
  - •Channel scan and synchronization with DL channel. Channel lost detection and network re-entry.
  - •DCD and UCD messages for obtaining and maintaining DL/UL parameters.

  - Initial (contention) ranging and periodical ranging.
  - Negotiation of basic capability and registration.
  - CDMA-based ranging.

- Dynamic flow management including service flow addition, deletion and change.
- Bandwidth management:
  - Five service types: UGS, ertPS, rtPS, nrtPS and BE.
  - Polling-based bandwidth requests.
  - Contention-based bandwidth requests.
  - CDMA-based bandwidth requests.
- Scheduling service at the base station:
  - Strict priority-based scheduling for different service types where management messages > UGS > ertPS > rtPS > nrtPS > BE.
  - Within each service type, WFQ scheduling is used for fairness.
- MAC frame construction:
  - Downlink(DL) subframe construction.
  - Uplink(UL) burst construction.
  - PDU concatenation, fragmentation, and packing.
- Adaptive Modulation and Coding (AMC):
  - Signal strength monitoring (UL/DL) and reporting (DL).
  - Seven burst profiles for both downlink and uplink transmissions using different coding and modulation combinations.
  - Dynamic switch of burst profiles based on CINR.

•Support for broadcast and multicast flows.

- Convergence Sublayer (CS):

  •Classify flows to different service types based on their priority.

  •Retrieve accurate QoS parameters of UGS flows.

  •Support both IPv4 and IPv6.

- IEEE 802.16e Mobility Support:

  •Neighbor information exchange among configured BSs.

  •Neighbor BS scanning at SS.

  •MS initiated and BS initiated hard handoff.

  •Flow disconnection and reconnection.

  •Idle mode and paging.

  •Sleep mode.

- Interface other networks such as ATM, 802.3, 802.11 at network layer.
- Support 802.16 OFDMA PHY.
- Simple admission control.
- ARQ.

## 4.3 Omitted Features

The 802.16 MAC features omitted in QualNet 4.5 are:

- Mesh mode.
- Frequency Division Duplex (FDD) mode.
- Transmission power adjustment during ranging.

- PKM security feature.
- Convergence sublayer doesn't support ATM. No packet header compression.
- No support to SC, SCa and OFDM 802.16 PHYs.
- Only CBR and VBR traffic generators have been modified to provide correct QoS parameters. For other types of traffic generators, some default QoS parameters are used.
- Association level 1, 2 and soft handoff.

# Chapter 5: Implementation

The basic scenario consists of two BSs connected by background infrastructure figure 5.1.

A HO trigger while a SS move from BS to BS under certain condition. Different scenario of HO with different class of service for VoIP and CBR, were simulated. The simulator has been running over than 50 times with different options.

To have more accurate results another scenario is similar to the one above, but with increasing number of BSs and SSs as in figure 5.2.

Many scenarios were developed for three purposes. The first purpose was to evaluate class of services as rtPS, nrtPS, ertPS, BE and UGS by measure different metrics as delay Jitter, throughput, MOS and  RTP average end to end delay. The second purpose to come up with HO protocol by evaluate CINR , RSSI and burst profile. The third one is measure HO delay time and other parameter as SS velocity.

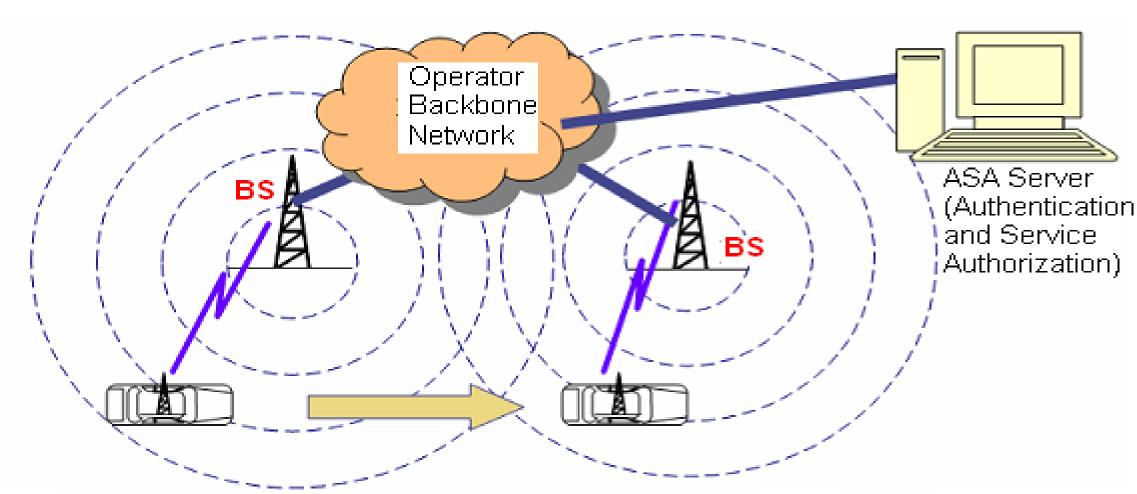


Fig. 5.1. “HO Scenario“

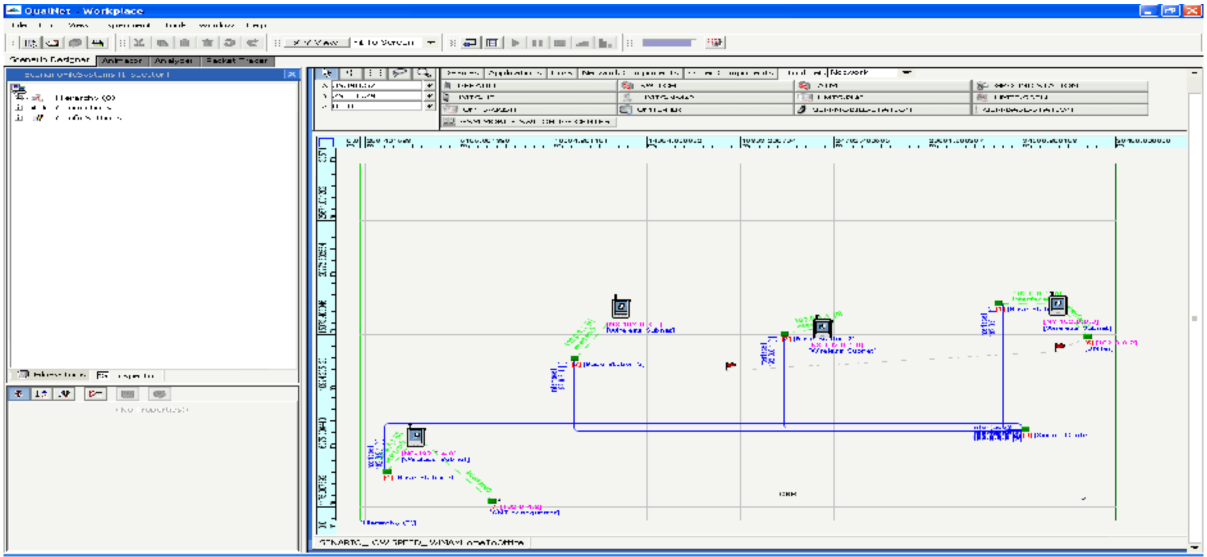

Fig. 5.2. “HO Simulator Scenario “

### 5.1 The scenario supports:

**1.** Neighbor BS information: periodically the serving BS periodically broadcasts information about neighbor BS, this information as (HO threshold) will used by MS to trigger HO process.

**2.** Neighbor BS scanning: MS will look for serving BS RSSI signal when the signal below threshold, the MS starts the neighbor BS scanning, looking for BS during neighbor BS scanning.

**3.** Handover: A MS may perform handover under two conditions, a) when the signal quality of the serving BS is below threshold, and b) when the QoS capability of the serving BS cannot fulfill requirements. Both MS and BS can initiate the handover.

**4.** Idle mode/ Sleep mode: A MS can go into idle mode or sleep.

**5.** Authentication and Service Authorization (ASA) server: to provide access control of MS.

**6.** Backbone functionalities: BSs can use the backbone to communicate with each other to exchange some information for services.

In our scenario MS will monitor BS signal strength, when the signal strength decreases HO process will start.

## 5.2 Simulation Parameters

The parameters which are considered in implementation:

<table>
<tr><th>Parameter</th><th>Our Value</th></tr>
<tr><td>MAC-802.16-STATION-TYPE [BS | SS]</td><td>The value “BS” means that it is a Base Station, while “SS” means it is a Subscriber Station (or Mobile Station).</td></tr>
<tr><td>MAC-802.16-BS-FRAME-DURATION <Time></td><td>This parameter defines the duration of the MAC frame. The BS schedules transmission each MAC frame by MAC frame. A MAC frame is then divided into downlink (DL link) and uplink (UL link) under TDD. This parameter specifies the length of a MAC frame. The value in our scenario is 20MS.</td></tr>
<tr><td>MAC-802.16-BS-TDD-DL-DURATION <Time></td><td>This parameter specifies how long the DL part of a MAC frame is. Basically, it indicates how the MAC frame is divided between downlink transmissions and uplink transmissions. The value scenario is 10MS.</td></tr>
<tr><td>MAC-802.16-BS-TTG <Time></td><td>This parameter specifies the Transmit/receive Transition Gap. The scenario value is 10US.</td></tr>
<tr><td>MAC-802.16-BS-DCD-BROADCAST-INTERVAL <Time></td><td>This parameter specifies the interval of DCD packets. The scenario value is 5S.</td></tr>
<tr><td>MAC-802.16-BS-UCD-BROADCAST-</td><td>This parameter specifies the interval of UCD</td></tr>
</table>

| | |
|---|---|
| INTERVAL <Time> | packets. The scenario value is 5S. |
| MAC-802.16-BS-RANGING-BACKOFF-MIN <integer> MAC-802.16-BS-RANGING-BACKOFF-MAX <integer> | These two parameters specify the minimum and maximum backoff counter used for contention-based ranging (initial ranging). The scenario value for MAC-802.16-BS-RANGING-BACKOFF-MIN is 3. The scenario value for MAC-802.16-BS-RANGING-BACKOFF-MAX is 15. |
| MAC-802.16e-NEIGHBOR-SCAN-RSSTRIGGER <RSS in dBm> MAC-802.16e-HANDOVER-RSSTRIGGER <RSS in dBm> MAC-802.16e-HANDOVER-RSSMARGIN <RSS in dBm> | These three parameters are for SS to perform neighbor BS scanning or handover. The scenario value for MAC-802.16e-NEIGHBOR-SCAN-RSS-TRIGGER is 76 dB. The scenario value for MAC-802.16e-HANDOVER-RSS-TRIGGER is -76 dB. The scenario value for MAC-802.16e-HANDOVER-RSS-MARGIN is 1 dB. |
| MAC-802.16e-SS-SUPPORT-IDLEMODE [YES \| NO] | This parameter specifies whether or not SS supports idle mode. Paging would only be enabled if value of this parameter is configured as YES. The default value for this parameter is NO. |
| MAC-802.16-BS-BANDWIDTH-REQUEST-BACKOFF-MIN <integer> MAC-802.16-BS- | These two parameters specify the minimum and maximum backoff counter used for contention-based bandwidth requests. |

| | |
|---|---|
| BANDWIDTH-REQUEST-BACKOFF-MAX <integer> | The default value for MAC-802.16-BS-BANDWIDTH-REQUEST-BACKOFF-MIN is 3. The default value for MAC-802.16-BS-BANDWIDTH-REQUEST-BACKOFF-MAX is 15. |
| MAC-802.16-BS-MAX-ALLOWED-UPLINK-LOAD-LEVEL <double> MAC-802.16-BS-MAX-ALLOWED-DOWNLINK-LOAD-LEVEL <double > | This parameter specifies the upper limit of the load that BS can handle in the uplink/downlink direction.The default value is 0.7. |
| MAC-802.16-SS-WAIT-DCD-TIMEOUT-INTERVAL <Time> | This parameter specifies how long SS will wait for the DCD message before it decides that it has lost the synchronization of the downlink channel.<br>The default value is 25 seconds, which is 5 times of the default value of DCD interval. |
| MAC-802.16-SS-WAIT-UCD-TIMEOUT-INTERVAL <Time> | This parameter specifies how long a SS will wait for the DCD message before it decides that it has lost the synchronization of the downlink channel.<br>The default value is 25 seconds, which is 5 times of the default value of DCD interval |
| MAC-802.16-SERVICE-FLOW-TIMEOUT-INTERVAL <Time> | This parameter specifies how long that the BS or SS will wait before it times out a service |

| | |
|---|---|
| | flow.<br>The default value is 15 seconds. |
| MAC-802.16-ARQ-ENABLED [YES \| NO] | This parameter is used to send request for ARQ enabled connection.<br>The default value is NO. |
| MAC-802.16-BS-NEIGHBOR <neighbor BS list> | This parameter specifies the neighboring BS of this BS. The neighbor BS list could be in the form of {nodeId1,nodeId2…} or {nodeId1 thru nodeId2} or a combination. This parameter is used for 802.16e feature where neighbor BS defined by this parameter will exchange information among themselves. |
| MAC-802.16e-SS-SUPPORT-IDLEMODE [YES \| NO] | This parameter specifies whether or not SS supports idle mode. Paging would only be enabled if value of this parameter is configured as YES. The default value for this parameter is NO. |
| MAC-802.16e-SS-SUPPORT-SLEEPMODE [YES \| NO] | This parameter specifies whether or not SS supports sleep mode. The default value for this parameter is NO. |

Table number 5.1” Simulation Parameters”

**QualNet and classes of service**

QulNet has five classes to support real time and non real time. which are:

- Unsolicited Grant Service (USG): UGS supports real-time service flows that generate a fixed-size data packet on a periodic basis, e.g., VoIP without silence suppression.
- Extended Real-time Polling Service (ertPS): ertPS supports features of UGS with variable-size data packets, such as Voice over IP with silence suppression.
- Real-Time Polling Service (rtPS): rtPS supports real-time service flows that generate variable-size data packets on a periodic basis, such as MPEG video or Voice over IP with silence suppression.
- Non-real-time Polling Service (nrtPS): nrtPS supports delay-tolerant data streams consisting of variable-sized data packets for which a minimum data rate is required, such as FTP or HTTP (web browsing).
- Best Effort (BE): BE service supports data streams for which no minimum service level is required and which may therefore be handled on a space-available basis.

By using IP precedence filed the, application can direct traffic to a specific service class. Table number 5.2 specifies the mapping between precedence values and service classes.

| **MAC Layer Services** | **Precedence** |
|---|---|
| Unsolicited Grant Service | 7, 5 |
| Extended Real-time Polling Service | 4 |
| Real-Time Polling Service | 3 |
| Non-real-time Polling Service | 6,2,1 |
| Best Effort | 0 |

Table number 5.2" The mapping between precedence values and service classes"

## 5.4 GUI interface:

QualNet supports GUI interface, the following screenshots help present the powerfulness of this tool.

1- 802.16 Radio Setup

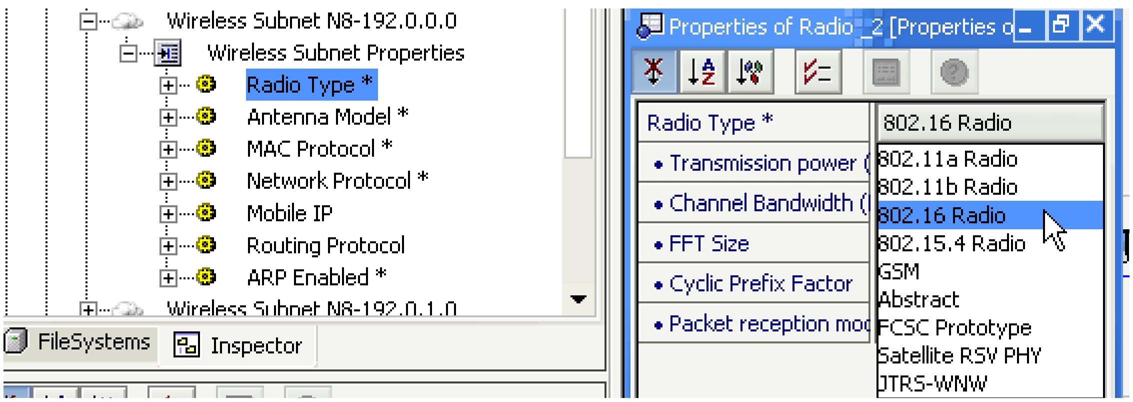


Fig. 5.3. "802.16 Radio Setup "

2-BS node setup

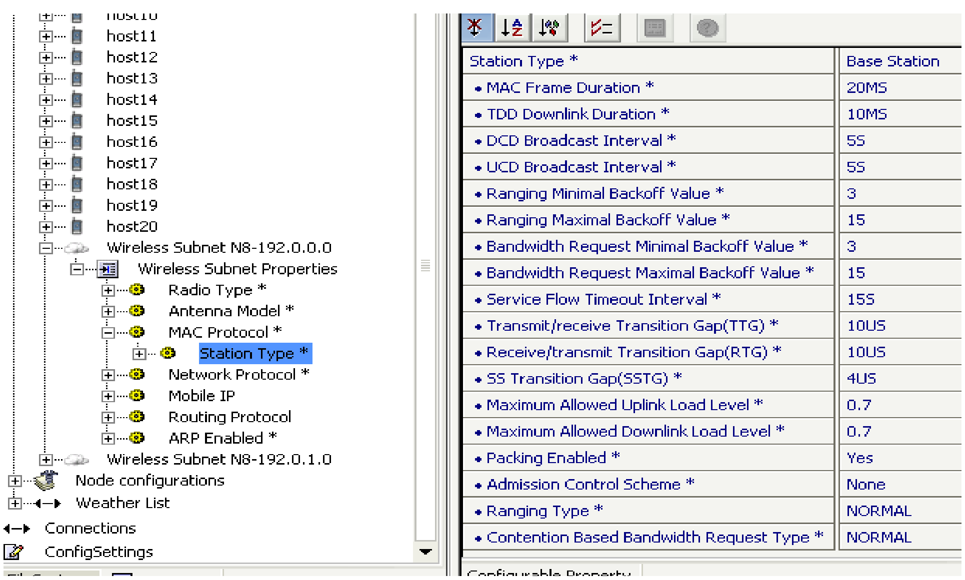


Fig. 5.4. "BS node setup "

3- SS node Setup:

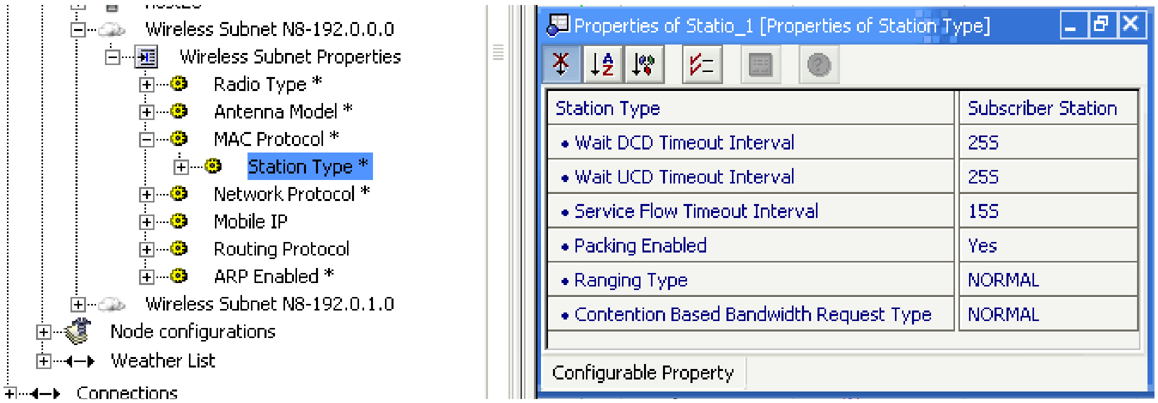


Fig. 5.5. “SS node Setup “

4-Mobility option:

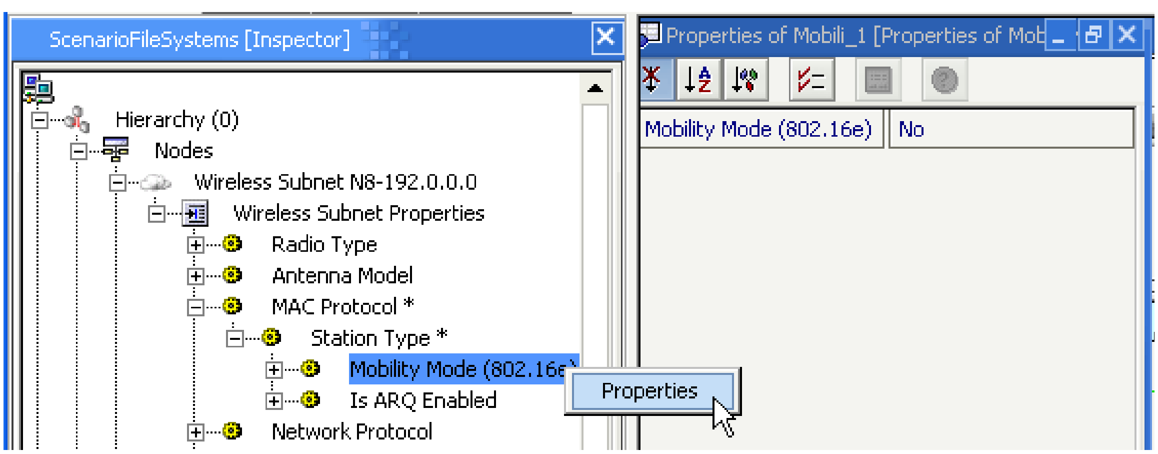


Fig. 5.6. “Mobility option “

5-Service class:

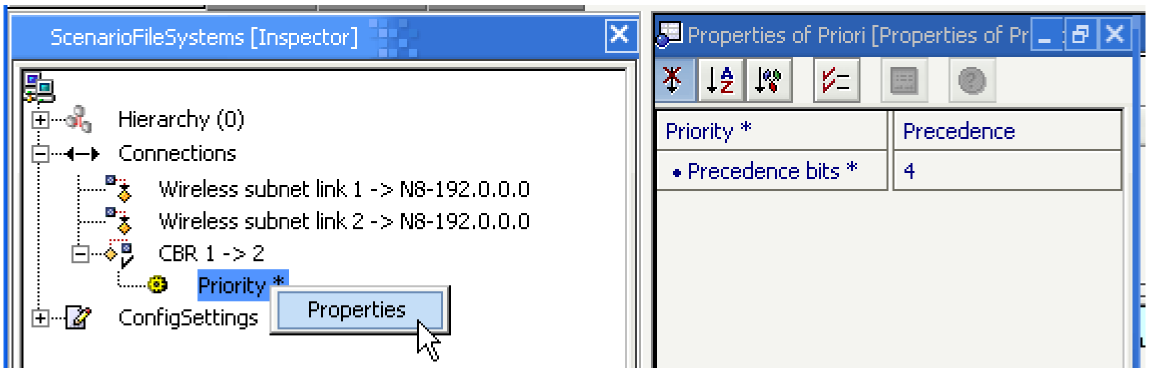


Fig. 5.7. “Service class“

6- Application setup:

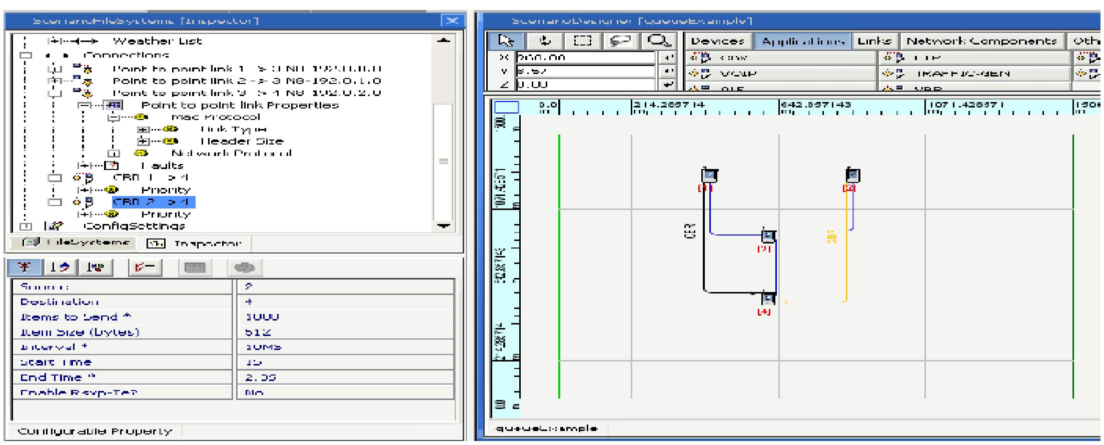

Fig. 5.8. “Application setup“

7- The methodology used for collecting simulation is based on using a tracing tool and 3D Developer tool to compare the result. Simulator used the following tools for presenting result:

- Analyzing Statistics, figure number 5.10
- Tracing Packets
- Developer 3D Visualization

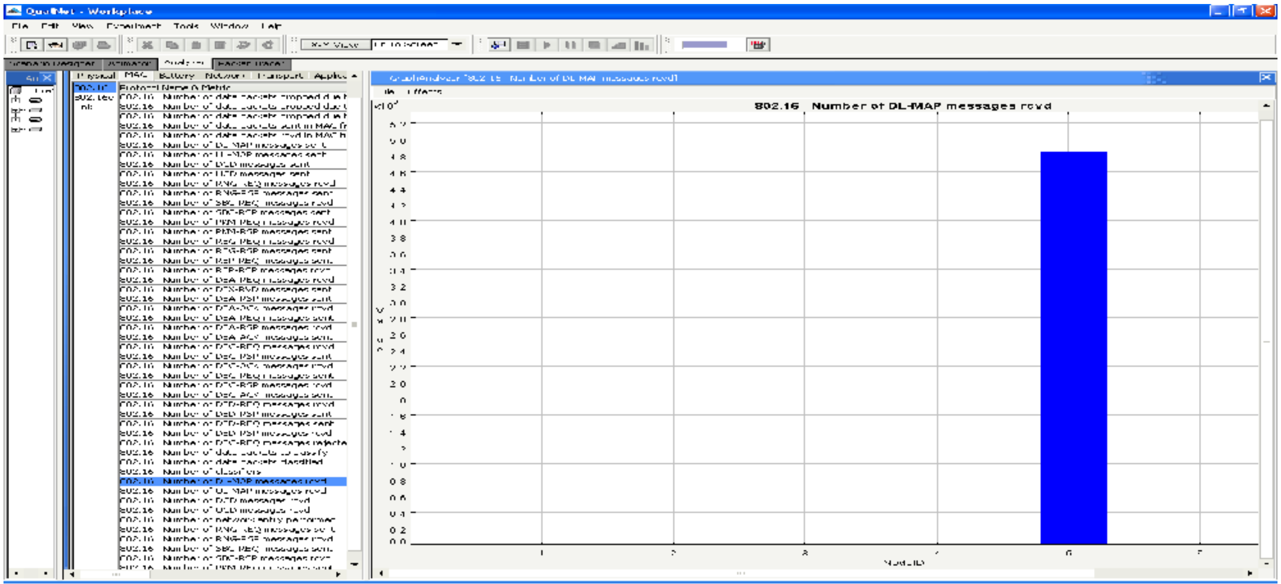


Fig. 5.9. “Analyzing Statistics “

# Chapter 6: Results

As mentioned earlier, WiMAX  support different type class of service as in table number 6.1:

| Qos in WiMAX | Application |
|---|---|
| Real Time Packet Services (rtPS) | Video Conferencing, Audio Streaming, Telemedicine, E-Learning |
| Extended Real Time Packet Services (ErtPS) | Voice over IP with Silence Detection, Retrieval of Multimedia |
| Non Real Time Packet Services (nrtPS) | FTP, Document Sharing |
| Best Effort Services (BE) | E-Mail, Web Browsing |
| Unsolicited Grant Service (UGS) | VoIP without silence |

Table number 6.1" class of service"

## Traffic Model and Mobility Model:

For traffic both kind of traffic were used depend on scenario case, as example to evaluate MOS VoIP application considered but CBR  used for throughput , as following:

- VoIP  application which setup with a CODEC  G.711.

| Codec & Bit Rate (Kbps) | Codec Sample Size (Bytes) | Codec Sample Interval (ms) | Mean Opinion Score (MOS) | Voice Payload Size (Bytes) | Voice Payload Size (ms) | Packets Per Second (PPS) |
|---|---|---|---|---|---|---|
| G.711 (64 Kbps) | 80 Bytes | 10 ms | 4.1 | 160 Bytes | 20 ms | 50 |

- CBR which generate a traffic  every 20ms, the default packet size is 512 kb

For mobility model, Qulnet support directional Random Waypoint mobility model. The directional Random waypoint model is a random-based mobility model used in mobility management schemes for mobile communication systems. This model considers individuals moving on straight walk segments with constant speed.

### Scenario 1: Delay Jitter and  Class of Service while HO

In this scenario, a large 40 x 30 km terrain with four base stations that provide coverage along a freeway path. A mobile station moves along the freeway path and maintains a VoIP call with SS during this period. As many papers work on evaluate SS performance while HO within one BS, in this scenario the SS faces many times of HO while SS moves from BS to BS. Different type classes of services are configured and the delay Jitter as fist parameter is considered in this scenario. To have more accurate results each BS pressure by 35 SS.

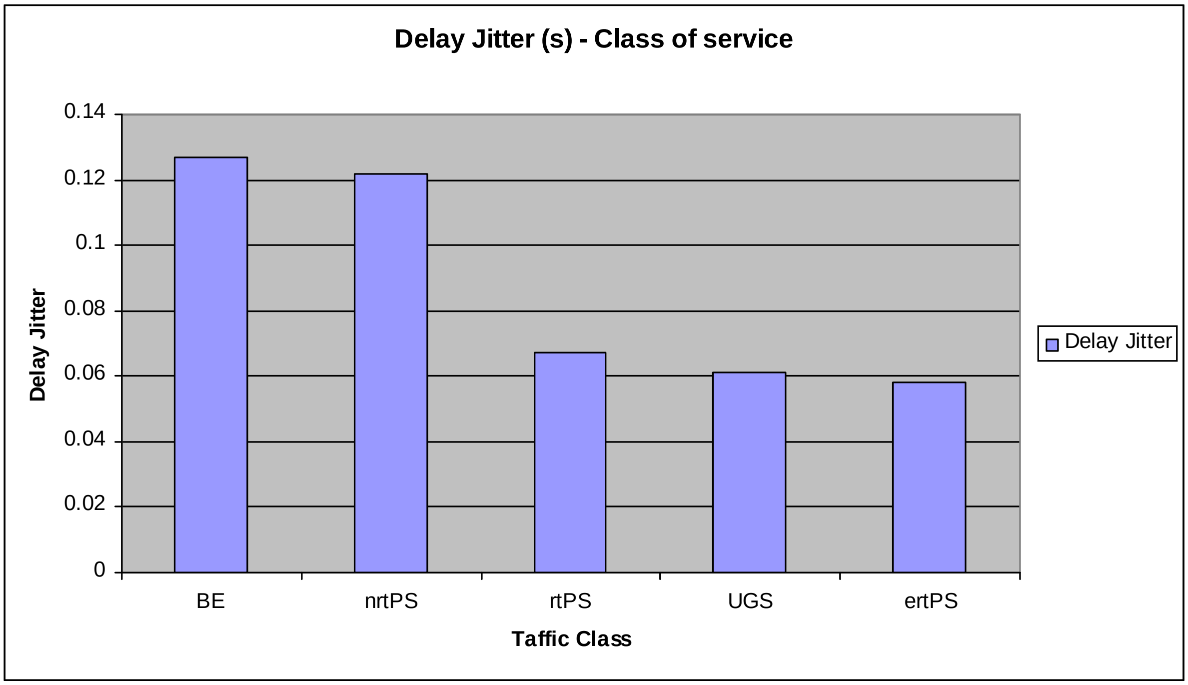


Fig. 6.1 “Delay Jitter”

**Analysis and comments:**

In figure 6.1, x axis represent class of service (BE, nrtps, rtPS , UGS and ertPS).

Fig 6.1 shows the relation between the delay jitter and class of service. As seen in the figure 6.1 and comparing these results with table number 6.1, ertPS has the minimum delay of jitter time while BE and nrtPS have the maximum delay jitter time.

## Scenario 2: Throughput and Class of Service while HO

This is the same scenario in scenario 1, but this time CBR traffic session sending  every 20 ms

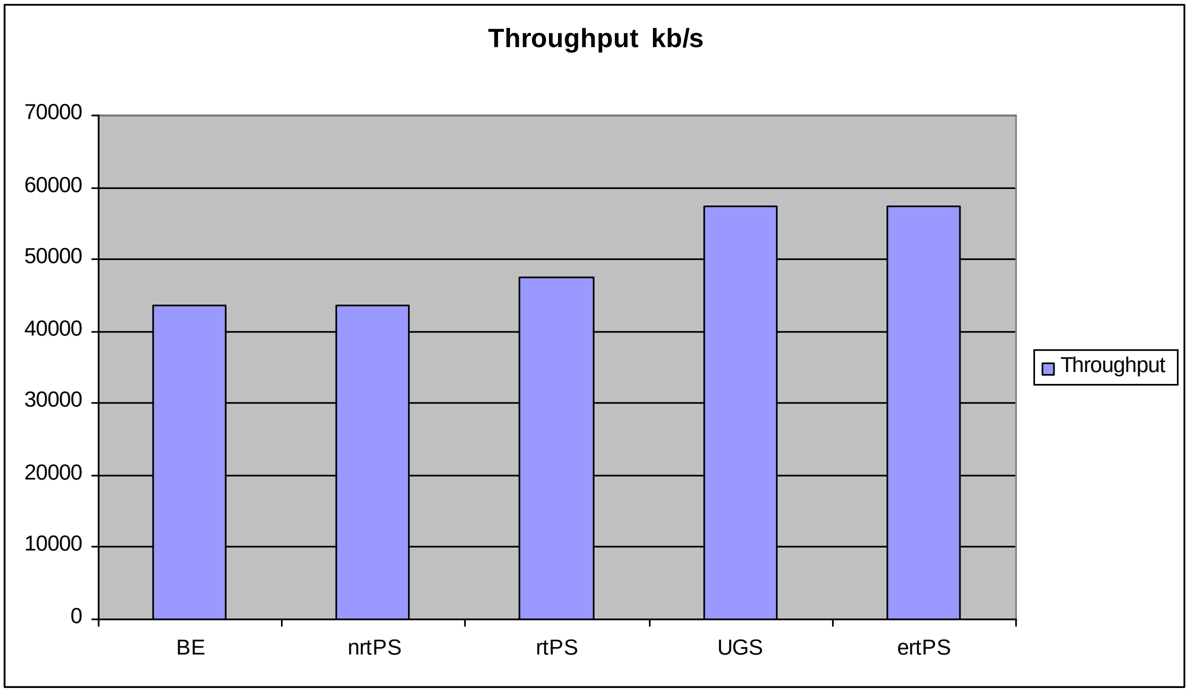


Fig. 6.2 “Throughput”

### Analysis and comments:

In figure 6.2, x axis represent class of service (BE, nrtps, rtPS , UGS and ertPS).

Fig 6.2 shows the relation between the throughput and class of service.  As seen in the figure 6.2 and comparing these results with table number 6.2, ertPS has the maximum throughput while BE and nrtPS have the minimum throughput.

## Scenario 3 : MOS and Class of service while HO

This is the same scenario in scenario 1 but the BS is not under pressure which mean only one SS , but in this scenario VoIP session between movable SS and fixed SS were configured; the following parameter were considered with VoIP application as CODEC name is G.711 and interval 20 ms.

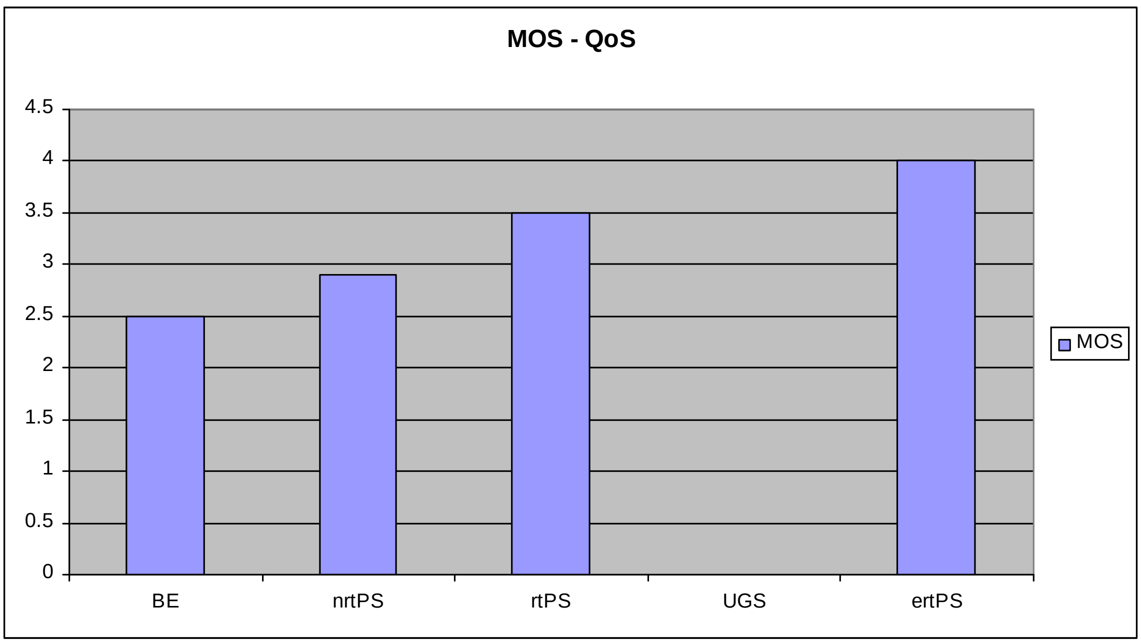


Fig. 6.3 “MOS”

**Analysis and comments:**

In figure 6.3, x axis represent class of service (BE, nrtps, rtPS , UGS and ertPS).

Fig 6.3 shows the relation between the MOS and class of service.  As seen in the figure 6.3 the ertPS  MOS close to 4 and this is good value for VoIP application.

### Scenario 4: RTP average End to End Delay and Class of Service

This is the same scenario in scenario 1, and VoIP session between movable SS and fixed SS were started.

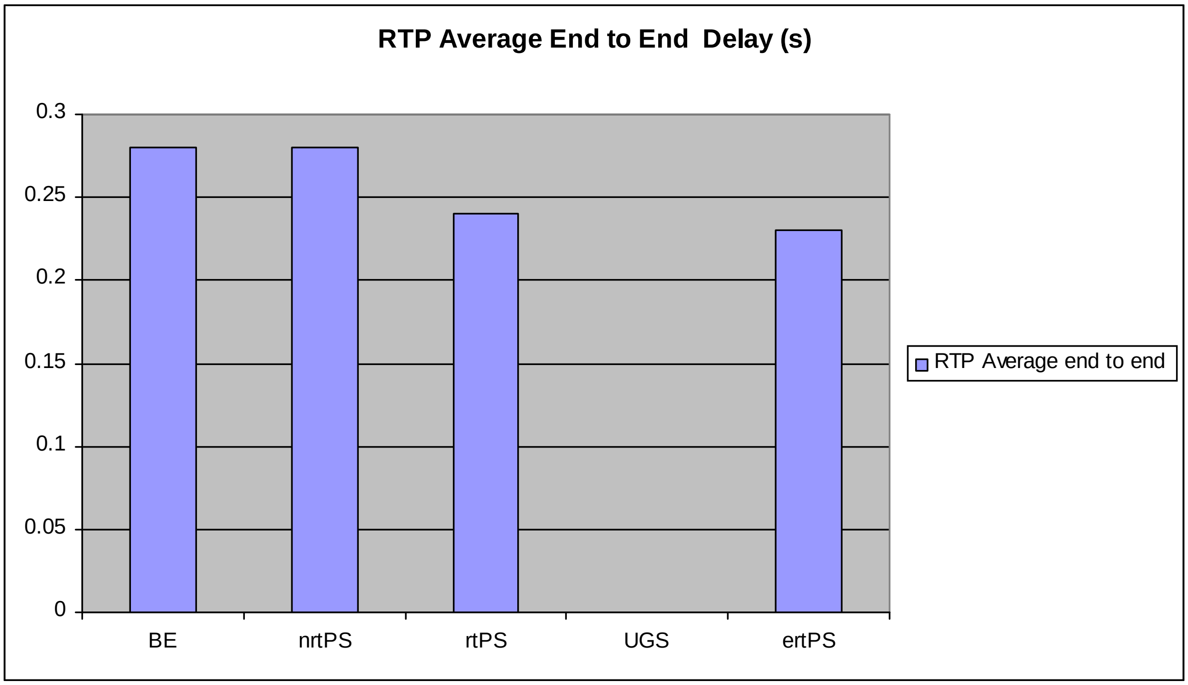


Fig. 6.4 “RTP average End to End Delay”

**Analysis and comments:**

In figure 6.4, x axis represent class of service (BE, nrtps, rtPS , UGS and ertPS).

Fig 6.4 shows the relation between the RTP average end to end delay time and class of service.

As seen in the figure 6.4 the ertPS has the minimum end to end delay and BE and nrtPS have maximum end to end delay.

From above scenario numbers 1, 2, 3 and 4 we can conclude that ertPS is the recommended class of service for VoIP while HO of SS.

The rest of these scenarios in this chapter consider ertPS as the main choice for SS for VoIP application.

The HO protocol investigated from different aspect as below scenario.

### Scenario 5 : CINR and HO

The same scenarios in scenario 1 without add more SS around BS .CINR result investigated while HO trigger.

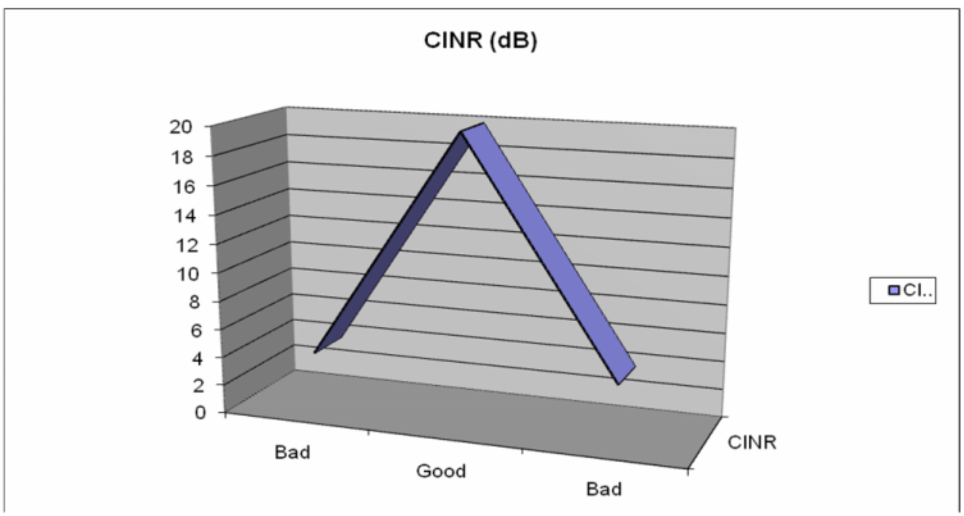


fig.6.5 “CINR”

**Analysis and comments:**

In figure 6.5, y axis represent the value of CINR while HO trigger. By analysis the CINR graphic which collected from simulator, the results show that HO trigger when CINR = 4 dB and when the SS close to AP CINR = 20 dB. Estimation for this behavior represented by figure 6.5. Fig 6.5 shows that when CINR = 4 dB the HO trigger and the SS enjoy the connection with BS when CINR = 20 dB.

Depend on the above results for CINR behavior; the following algorithm can be implemented for HO and CINR:

If CINR = 4 dB then trigger HO schema.

### Scenario 6: RSSI and HO

The same scenarios in scenario 1 without add more SS around BS .CINR and RSSI results investigated while HO triggers.

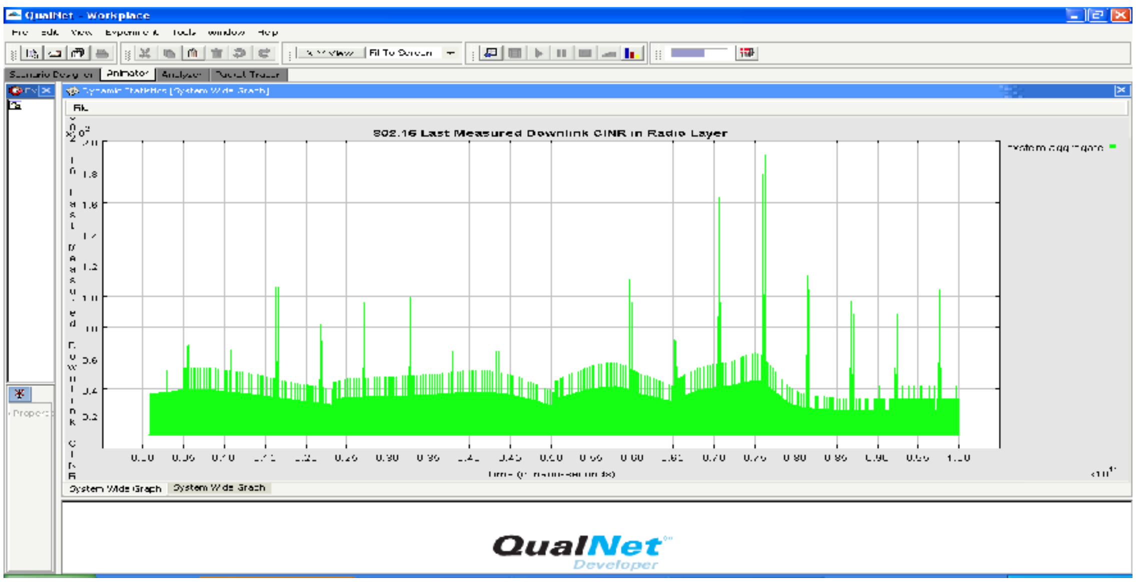


fig.6.6“CINR”

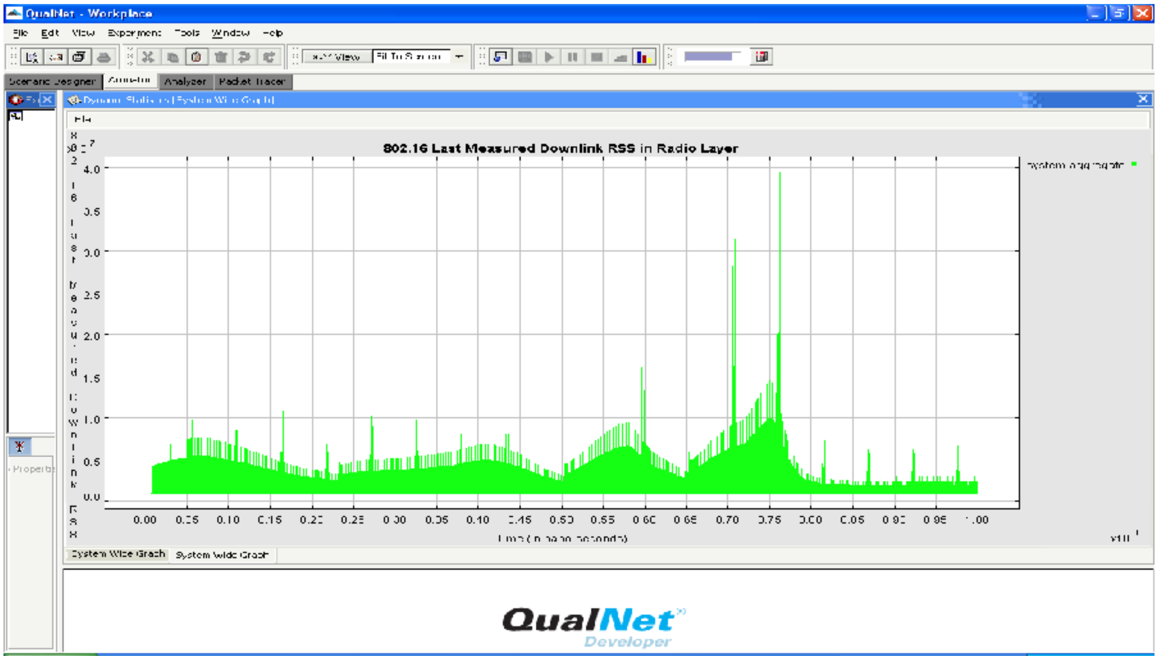


fig.6.7 “RSSI”

**Analysis and comments:**

Figure 6.6 and 6.7 demonstrate a close relation between CINR and RSSI.

## Scenario 7: RSSI and HO

The same scenarios in scenario 1 without add more SS around BS. This time different values of RSSI were configured. The results show in table 6.2 and the number of HO which passed consider as in table number 6.2.

| | | | | | |
|---|---|---|---|---|---|
| RSSI | -90 | -85 | -80 | -60 | -50 |
| Number Of HO Passed | 1 | 2 | 3 | 3 | 3 |

Table number 6.2 “ RSSI and HO”

**Analysis and comments:**

In figure 6.7 shows that HO failed when RSSI more then - 80, HO should trigger before RSSI > - 80 dBm .

Looking to above the following algorithm can be implemented for HO and RSSI :

If RSSI > - 80 dBm then trigger HO schema.

Finally the HO protocol can be implemented as following:

If RSSI > - 80 dBm or CINR = 4 then

trigger HO procedure.Scenario 8: Call establishment Time:

Scenario as scenario 1 were evaluated for call establishment time, results show that:

VoIP session initiated at 80 s and Session established at 95 , that mean

**Call establishment Time = 95 - 60 = 35s**

This value consider too much and wasting a time, VoIP application has better value as 5 s and some time 20 s, so may be the delay in simulator performance .

### Scenario 9: Burst Profile

In this scenario one SS and two BS, the SS move to BS at the end of simulator. Number of Burst is collect from this scenario.

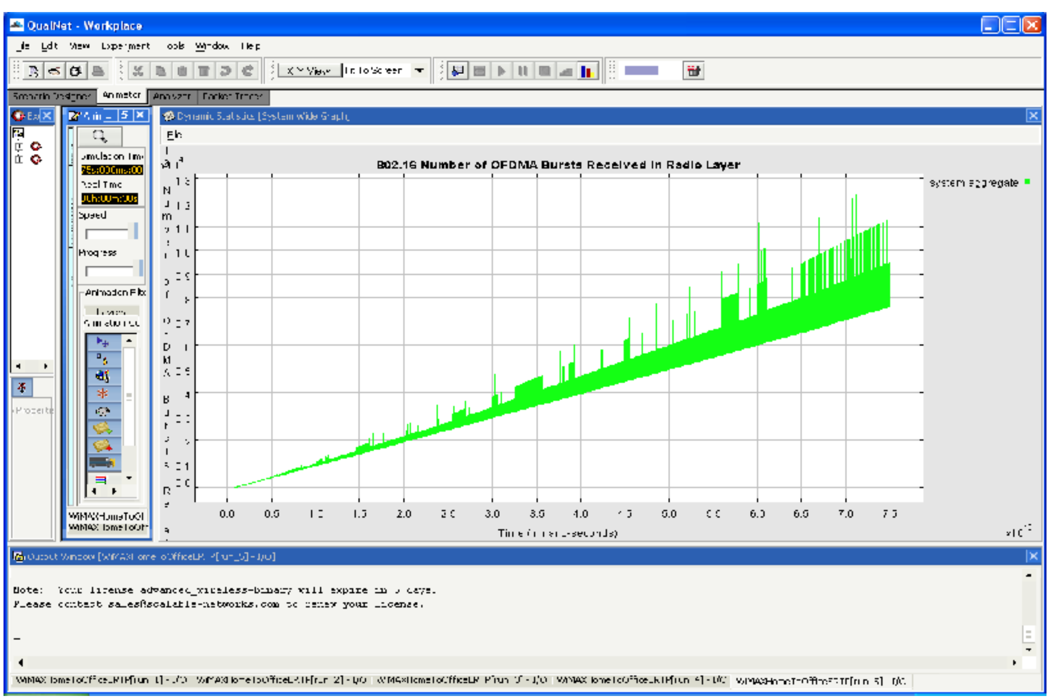

fig 6.9 “Burst Profile”

**Analysis and comments:**

Figure number 6.9 shows the burst while the SS move toward BS, when the SS move close to BS which mean that RSSI and CINR have high value the rate adaptation is high. Simulator support modulation scheme as in table number 6.3 .

| Modulation Scheme | Encoding Rate | Raw Data Rate (Mbits/s) |
|---|---|---|
| QPSK | ½ | 14.2857 |
| QPSK | ¾ | 21.4285 |
| 16QAM | ½ | 28.5714 |
| 16QAM | ¾ | 42.8570 |
| 64QAM | 1/2 | 42.8470 |
| 64QAM | 2/3 | 57.1428 |
| 64QAM | 3/4 | 64.2857 |

Table number 6.3 “Modulation Schema”

**Scenario 10: HO Delay time:**

The same scenario as in scenario 1 and this time HO delay time is measured from the time MOB_NBR-ADV message is sent to the time message HO_IND is received. During this time the BS has normal operation except the re-entry phase and scan operation.

ertPS HO taken time = 580 ms

MOB_SCN_REQ = 9.984217 s

MOB_HO_IND = 10.548652 s

The MOB scan time = 350 ms.

But the simulator showed fewer packets were dropped.

**Analysis and comments:**

The time spent by MS during scanning depends on all BSs that need to be scanned. As a result, all kinds of transmissions between the MSS and the serving BS are paused. This leads to a significant throughput degradation and particularly hampers the QoS of delay-sensitive real-time traffics.

The reason why the packet drop with VoIP application is few that because VoIP has higher priority and lower data so fewer packets were dropped. Additionally voice packets are smaller in size.

Finally standard allow from 200 to 400 ms for delay in HO.

### Scenario 11: HO vs Mobility (speed):

In this scenario, scenario 1 has been run with different speeds, by using time variable for node within X, Y location. In figure 6.1, x axis represent MS speed , as example number 2 mean that the experiment 2 had higher speed compared to experiment 1.

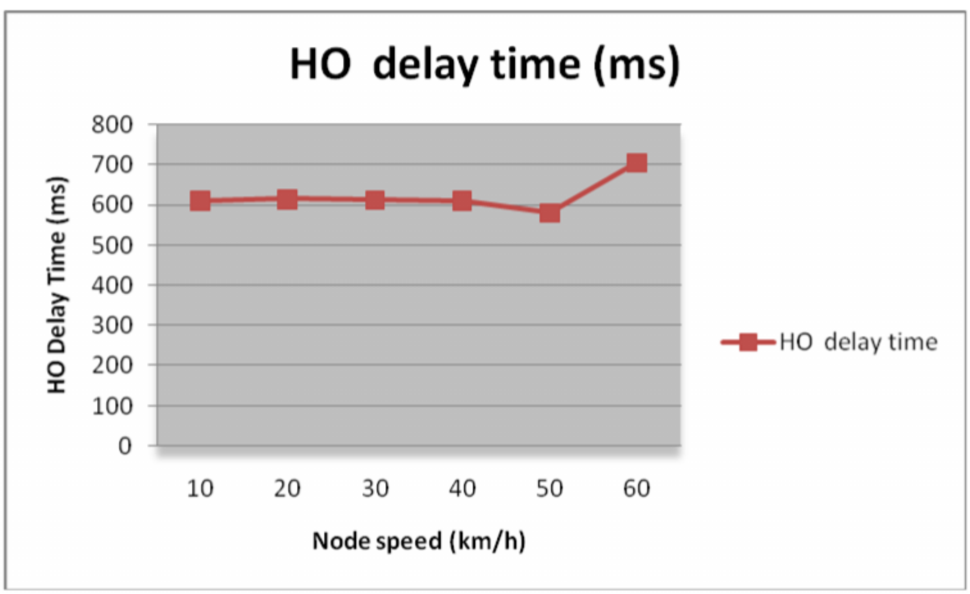


Fig. 6.10. “Mobility option“

### Analysis and comments:

Fig 6.11 shows the relation between the MS speed and HO delay time, as seen, there is no effect for speed on HO. For example if the information needed for uplink synchronization is sent via management messages or through periodic neighbor scanning, the handover could be completed faster.

In theory there is no effect for mobile speed on HO, but when mobile speed increases, more HO will happen because the probability is high for MS to move across the boundaries of more BSs and this will affect QoS.

If HO was only to occur once or twice during a call, this will not affect the end-user. However, if we have a node moving at vehicular speeds (as the standard was designed for) it may move through several BS, and HO may occur several times. This may cause a degradation of the service quality perceived by end-user.

Last point, the figure shows that there is degradation in HO delay time when speed around 50 km/h, this happen may be because the MS spend more time in scan BS because SS missed NBR_ADV message. Or may be delay in network from BS side to response.

## Scenario 12 :Delay Time vs Numbers of SSs:

Lastly, we performed experiments to better study the performance impact that number of SSs may have on HO completion time.

Different number of SSs per BS for each scenario were used (10, 40,60,80). Figure number depicted the result

| | | | | |
|---|---|---|---|---|
| Number of SS per BS | 10 | 40 | 60 | 80 |
| HO delay time (ms) | 580 | 602 | 701 | 705 |

Table number 6.4" **Delay Time vs. Numbers of SSs**"

## Analysis and comments:

We can notice that the HO delay time increases as more SSs are considered in simulation. This is because it increases contention time back off and UCD response time.

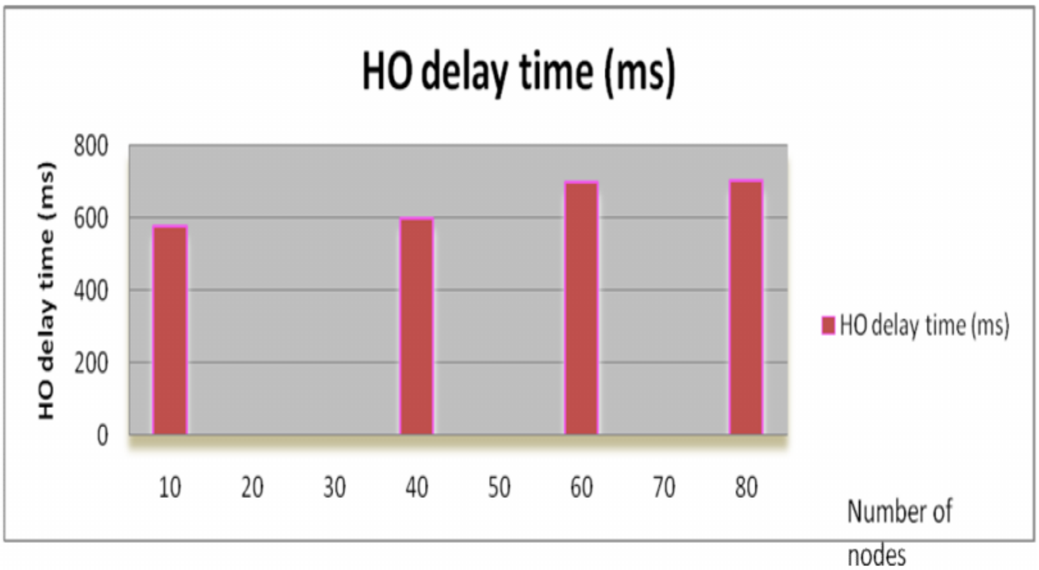


Fig. 6.11. "**Delay Time vs Numbers of SSs** "

## 6.7 Optimize HO

WiMAX infrastructure is designed to be the wireless replacement for DSL, which covers wide area. HO delay time will be the main challenge for WiMAX implementation. From the results which have been collected from simulator, in this study we can recognize that WiMAX has a longer HO delay time compared to other technology such as UMTS and GSM has.

For example the delay time when MS scans BSs equal to 350 ms. So one main approach, for optimization HO is to decrease delay time because of exchanging messages.

A center DB which has information about each BSs location can be used. Each MS will keep updating the DB about its location and direction of movement by sending update message.

So when MS decide to do HO, it will first send update message so the system can update the serving BS about the closest target BS to MS.

The basic idea is that both target BS and serving BS can exchange information to mobile from the center DB from backbone. These will help in the following scenario:

- MS will conduct cell reselection from information obtained from DB.
- This will decrease the number of steps for HO because one BS has been selected for HO.
- Decrease the scanning process for all BSs. This is true because MS knows about the target BS from serving BS.
- If the target BS had previously received HO notification from serving BS over the backbone, then target BS may allocate a non-contention-based Initial Ranging opportunity.

- MS shall synchronize to downlink transmissions of Target BS and obtain DL and UL transmission parameters.

# Chapter 7: Conclusion and Further Work

## 7.1 Conclusion

As we can see the WiMAX technology has implementation difficulty and challenges to cover wide area and serve many subscribers. Implementation of WiMAX will replace wired cable especially in rural area. WiMAX will continue to grow and become widely spread because of its cheap implementation cost.

Our purpose of this research is to evaluate class of services and to study WiMAX HO delay time. There are different types of HO, our focus on this research is at hard HO.

Extensive analysis was done by using QulNet 4.5 as a simulator. Result show that the total HO time is ~ 500ms, including HO initiation and decision making. We believe this long time and can be reduced.

Improving of HO process especially for mobile users will attract many subscribers and operator. However, several technical challenges must be overcome first, including mobility & data loss.

There are different losses of data which can be observed. As we notice, the lost of voice data is too low and not visible by the user. However, our concern is when the user has multiple HOs while moving. This particular case should be handled and well supported by the protocol.

To have a good implementation of WiMAX, HO delay time should be considered as a high priority improvement issue to meet user expectations.

Another important issue is the routing of data in proper way during HO. This is especially important during an ongoing voice call.

## 7.2 Further Work:

Several areas for improvement have been identified for the simulator as generate traffic in simulator, generate a noise and using traffic trace as wirshark. Other features should be implemented to help wireless network researchers and professionals in their job. Modifications in simulation nodes should be more flexible. Some parameters as propagation models should be added.

Other types of HO should be investigated, to figure out the proper type of HO for implementation. Enhance HO implementation should consider to able WiMAX to compete with other technologies as UMTS and LTE, and these technologies have better HO latency.

VoIP is also a changeable technology, especially when integrate with wireless technologies such as WiMAX. IMS technology which recommended by 3GPP should consider with WiMAX.

## References:

[1] **WiMAX - A Study of Mobility and a MAC-layer Implementation in GloMoSim**
Michael Carlberg Lax and Annelie Dammander, April 6, 2006 Master's Thesis in Computing Science, 2*20 credits Supervisor at CS-UmU: Thomas Nilsson

[2] **System Aspects and Handover Managementfor IEEE 802.16e**
Suman Das, Thierry Klein, Ajay Rajkumar, Sampath Rangarajan, Michael Turner, and Harish Viswanathan

[3] **Broadband Wireless Access with WiMax/8O2.16: Current Performance Benchmarks and Future Potential**
Arunabha Ghosh and David R. Wolter, SBC Laboratories Inc.
Jeffrey G. Andrews and Runhua Chen, The University of Texas at Austin

[4] Wireless MAN Working Group, **http://WirelessMAN.org/**

[5] **Design and Implementation of a Simulator Based on a Cross-Layer Protocol between MAC and PHY Layers in a WiBro Compatible IEEE 802.16e OFDMA System**
Taesoo Kwon, Howon Lee, Sik Choi, Juyeop Kim, and Dong-Ho Cho,
Korea Advanced Institute of Science and Technology
Sunghyun Cho, Sangboh Yun, Won-Hyoung Park, and Kiho Kim,
Samsung Advanced Institute of Technology

[6] **Fast Handover Scheme for Real-Time Downlink Services in IEEE 802.16e BWA System**

[7] **IEEE P802.16-REVd/D5-2004, "Draft IEEE Standard for Local and Metropolitan Area Networks—Part 16:** Air Interface for Fixed Broadband Wireless Access Systems," May, 2004

[8] **IEEE 802.16e System Performance, analysis and simulations,**
Fan Wang, Amitava Ghosh, Robert love, Rapeecat Ratasuk, Raja Bachu, Yakun Sun, Qing Zhao, Advance Radio Technology, GTSS Motorola Inc.600 North U.S.Hwy45.

[9]**Performance Analysis of Scheduling Algorithms for VoIP Services in IEEE 802.16e Systems**
Howon Lee*, Taesoo Kwon*, Dong-Ho Cho*, Geunhwi Limt and Yong Changt*Department of Electrical Engineering and Computer Science
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[10]

[11] **Fixed, nomadic, portable and mobile applications for 802.16-2004 and 802.16e WiMAX networks November 2005** Prepared by Senza Fili Consulting on behalf of the WIMAX Forum

[12] **THE COMPETITION AND COOPERATION OF WiMAX, WLAN AND 3G Liangshan** Ma Beijing Consulting and Design Institute of P&T, P.R. China
Email: maliangshan(bcdi.com.cn Dongyan Jia Beijing Consulting and Design Institute of P&T, P.R. ChinaEmail: jiadongyan(bcdi.com.cn

[13] **IEEE Standard for Local and metropolitan area networks**
**Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems**
Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands

[14]**Hard Handoff Scheme Exploiting Uplink and Downlink Signals in IEEE 802.16e Systems**
Sunghyun Cho, Jonghyung Kwun, Chihyun Park, Jung-Hoon Cheon, Ok-Seon Lee, and Kiho Kim Communication Lab. Samsung Advanced Institute of Technology
Suwon, Korea

[15]**Quality Of Service Issues In Voice Over Internet Protocoal ,** Athesis Mubashir Uddin F.MohammedTexasA&M University – Kingsville

[16] **WIMAX POTENTIAL COMMERCIAL OFF – THE – SHELF SOLUTION FOR TACTICAL MOBILE MESH COMMUNICATIONS by** BRYON KEITH HARTZOG B.S., Appalachian State University, 1992

[17]**The Design and Implementation of WiMAX Module for ns-2 Simulator** Jenhui Chen∗ , Chih-Chieh Wang†, Frank Chee-Da Tsai§, Chiang-Wei Chang,Syao-Syuan Liu, Jhenjhong Guo, Wei-Jen Lien, Jui-Hsiang Sum, and Chih-Hsin HungDepartment of Computer Science and Information Engineering
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[18]**WiMAX Channel - PHY Model in Network Simulator 2, Leonardo Betancur** Universidad PontificiaBolivariana, Facultad de Inform´ atica y Telecomunicaciones
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[19]**ns-3 Project Goals**, Thomas R. Henderson and Sumit Roy

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[20]**A Module-Based Wireless Node for NS-2** Laurent Paquereau laurent.paquereau@q2s.ntnu.no Bjarne E. Helvik bjarne@q2s.ntnu.no
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[21]C. Eklund et al., **"IEEE Standard 802.16: A Technical Overview of the WirelessMAN Air Interface for Broadband Wireless Access**," IEEE Commun. Mag., June 2002, pp. 98–107.

[22] **A. Ghosh et al., "Broadband Wireless Access with WiMAX/ 802.16: Current Performance Bandchmarks and Future Potential**," IEEE Commun. Mag., Feb. 2005, pp. 129–36.

[23]: http://www.voip-info.org/wiki-What+is+VOIP

[24]: http://www.cse.ohio-state.edu/~jain/cis788-99/ftp/voip_products/index.html#intro

[25]: http://www.packetizer.com/voip/papers/understanding_voip/voip_protocols.html

[26]http://www.wi-lan.com/

[27]http://www.eionwireless.com/

[28]http://www.redlinecommunications.com/news/pressreleases/2006/092106.html

[29]http://www.dailywireless.org/2005/09/16/canadian-wimax-network/

[30]http://www.marport.com/

[31]http://www.wimax.com/commentary/news/wimax_industry_news/news8-16-2005marport

[32]http://www.proxim.com/products/landing_wimax.html?type=GoogleAdWordsSearch&gclid=CLSO4aCNyYoCFSQ8XgodlGMoew

[33]http://www.radioplan.com/_vti_bin/shtml.exe/download.html

[34] **PROTOCOL AND CONTROL MECHANISMS TO SAVE TERMINAL ENERGY IN IEEE 802.16 NETWORKS**
Sayandev Mukherjee†, Kin K. Leung* and George E. Rittenhouse†

[35] **WiMAX Forum News** Weekly Clip Report July 28 – August 3

[36] **Considerations for VoIP Services in IEEE 802.16 Broadband Wireless Access Systems**, Seung-Eun Hong and Oh-Hyeong Kwon ,Broadcasting System Research Group Electronics and Telecommunications Research Institute Daejeon, Korea {iptvguru, ohkwon} ietri.re.kr

[37] http://en.wikipedia.org/wiki/WiFi

[38] **MOBILITY IMPROVEMENT IN IEEE 802.16, KUMAR** MRINAL (2007SIY7509), CHETAN ANEJA(2007SIY7510), VIKRAM GUPTA, SWATI SHARMA

[39] **Ensuring the QoS Requirements in 802.16 Scheduling**,Alexander Sayenko, Olli Alanen, Juha Karhula, Timo H¨am¨ al ¨ainen, Telecommunication laboratory, MIT department ,University of Jyv¨askyl¨ a, Finland {sayenko,opalanen,jkarhula,timoh}@cc.jyu.fi

[40] **MOBILE WIMAX: PRE-HANDOVER OPTIMIZATION USING HYBRID BASE STATION SELECTION PROCEDURE**, Arpan Mandal, the University of Canterbury University of Canterbury 2008

[41] **an efficient QoS Scheduling Architecture for IEEE 8052.16 Wireless MANs**, Supriya Maehwari

[42] **WiMAX Management Frame Vulnerabilities and Comparative Analysis of Authentication Techniques** , Krishna Bakthavathsalu , Dalhousie University

[43]**802.16e-2005**

[44] **http://www.scalable-networks.com/products/developer/new_in_45.php**

[45] **A Cross-Layer Optimization Mechanism for Multimedia Traffic over IEEE 802.16 Networks**

[46] **MOBILE WIMAX: PRE-HANDOVER OPTIMIZATION USING HYBRID BASe STATION SELECTION PROCEDURE.**

[47] **Handovers in the Mobile WiMAX** Zdenek Becvar, Jan Zelenka Czech Technical University Department of Telecommunication Engineering Technicka 2, Praha 6, 166 27,

[48] **Performance Analysis of Scheduling Algorithms for VoIP Services in IEEE 802**.16e Systems

[49] Vertical handover criteria and algorithm in IEEE 802.11 and 802.16 hybrid networks

[50] **ECHO - A Cross Layer, Terminal Oriented Handover Solution for VoIP** by John Fitzpatrick, B.Eng

[51] **Development of IEEE 802.16e Functionality in QualNet , Stephen Roberts**

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  Administration: EnsemblePro 6 Contact Flow Scripting Essentials (Course 0082)

  Administration: EnsemblePro 6 Historical Reporting Essentials (Course 0082)

- **UNIX: AIX , SBM**

  AIX 5L System Administration I: IBM Education center.

- **Oracle/ J.D.Edwards courses:**

  J.D.Edwards® Human Resource and Payroll modules.

  OneWorld Development Tools: basic and advance training.

  Enterprise Report Writing basic and advance.

Installation and Configuration (OneWorld® Xe).

IBM WebSphere ® 5.0.2 Application Server installation and configuration.

CNC Foundation and J.D.Edwards® System Administration.

Package Management and Administration Net Change

Financial and Distribution modules.

Workflow Management.

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