MOBILE WIMAX: PRE-HANDOVER

OPTIMIZATION USING HYBRID BASE

STATION SELECTION PROCEDURE

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by Arpan Mandal

University of Canterbury

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Abstract

A major consideration for mobile WiMAX is seamless handoff. The British English term for transferring a cellular call is **handover** whereas the Americans prefer to call it **handoff**. Cellular-based standards have the advantage of many years experience in handover for voice calls, while for broadband mobility in itself is no mean feat, and handover is still a challenge. Mobile IP, with "slow" handover, will be fine for web-browsing but not good enough for decent voice quality. Many services require the appearance of seamless connections (VoIP, VPNs, etc). Much of the complexity (and latency) in the cellular network is from maintaining these connections across cell boundaries. Handovers in wireless technologies have always been a challenging topic of discussion.

According to the mobility framework of IEEE 802.16e, a Mobile Station (MSS) should scan the neighbouring Base Stations (BSs) for selecting the best BS for a potential handover. However, the standard does not specify the number of BSs to be scanned leaving room for unnecessary scanning. Moreover, prolonged scanning also interrupts data transmissions thus degrading the QoS of an ongoing connection. Reducing unnecessary scanning is an important issue. This thesis proposes a scheme to reduce the number of BSs to scan, thus improving the overall handover performance. Simulation results show that the proposed hybrid predictive BS selection scheme for potential scanning activities is more effective than the

conventional IEEE 802.16e handover scheme in terms of handover delay and resource wastage.

Before the actual handover process, there is scope of reducing the total number of iterations of message exchanges occurring between the mobile MSS, the SBS and the neighbouring BSs which are potential targets for handover. Simulations prove that it takes upto 700 ms to decide the target BS before initiating the handover process with it. There are multiple message exchanges to choose a set of potential target BSs from all the neighbouring BSs. A few more messages flow between the MSS, SBS and potential target BSs to choose the best candidate BS for handover. The many stages and messages waste time and could be reduced. This thesis discusses some ways to reduce them and backs it up with simulation results.

Acronyms

ASN	Access Services Network
ASN-GW	Access Services Network - Gateway
BE	Best Effort
BS	Base Station
CBR	Constant Bit Rate
CPE	Customer Premise Equipment
CSN	Connectivity Services Network
DCD	Downlink channel descriptor
DL	Down Link
FBSS	Fast base station switching
IPv4	IP
IPv6	IP
LOS	Line of Sight
MAC	Medium Access Control
MDHO	Macro diversity handover
MSC	Mobile Switching Centre
MSS	Mobile Subscriber Station
NLOS	Non Line Of Sight
NWG	Network Working Group (WiMAX Forum)
OFDMA	Orthogonal Frequency Division Multiple Access
PHY	Physical
QoS	Quality of Service
RSSI	Received Signal Strength Indication
SBS	Serving Base Station
SS	Subscriber Station
TBS	Target Base Station
UCD	Uplink channel descriptor
UL	Uplink

1 Introduction

1.1 Background

Since the inception of the telephone, service providers have staved off competition by relying on the exorbitant capital investment necessary to deploy a telephone network. The cost of deploying copper wires, building switches, and connecting the switches created an insurmountable barrier to entry for other competitors. In most of the world, the high cost of this infrastructure limited telephone service to the wealthy and the fledging middle class.

The Public Switched Telephone Network (PSTN) was the earliest example of traffic engineering to deliver Quality of Service (QoS) guarantees. It consists of three major components: access, switching and transport. Each element has evolved over the hundred years plus history of the PSTN. This network was designed originally to handle voice; later, data was introduced. As data traffic on the PSTN grew, high capacity users found it inadequate, so these subscribers moved their data traffic to data specific networks. Many data users then found themselves limited to an infrastructure that was dependent on wires, either fiber optic cable, coaxial cable or twisted pair copper wire. Using wireless means to bypass wired monopolies is now a practicality for subscribers of both voice and data services. The primary form of bypass is the use of cellular phones.

A cellular network is a radio network made up of a number of radio cells (or just cells) each served by a fixed transmitter, known as a cell site or base station. These cells are used to cover different areas in order to provide radio coverage over a wider area than the area of one cell. Cellular networks are inherently asymmetric with a set of fixed main transceivers each serving a cell and a set of distributed (generally, but not always, mobile) transceivers which provide services to the network's users. Cellular networks offer a number of advantages over alternative solutions such as increased capacity, reduced power usage, better coverage etc.

The use of multiple cells means that, if the distributed transceivers are mobile and moving from place to place, they also have to change from cell to cell. The mechanism for this differs depending on the type of network and the circumstances of the change. For example, if there is an ongoing continuous communication and we don't want to interrupt it, then great care must be taken to avoid interruption. In this case there must be clear coordination between the base station and the mobile station.

WiMAX, the Worldwide Interoperability for Microwave Access, is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways, from point-to-point links to full mobile cellular type access. It is based on the IEEE 802.16 standard, which is also called WirelessMAN. The name "WiMAX" was created by the WiMAX Forum, which was formed in June 2001 to promote conformance and interoperability of the standard. The forum describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL" (and also to HSPA).

WiMAX will change telecommunications, as it is known throughout the world today. As this technology enables a lower barrier to entry, it will allow true market based competition in all of the major telecommunication services: mobile and static voice, video and data.

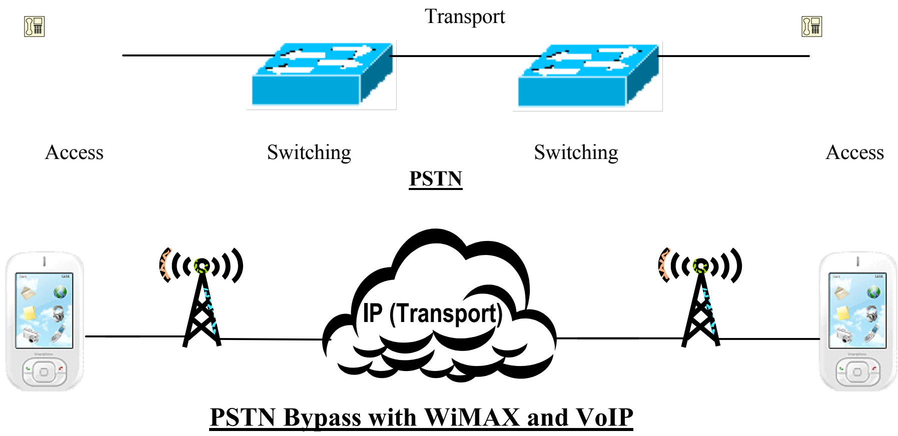


Figure 1. PSTN and WiMAX

1.2 Motivation

In IEEE 802.16e standard, the total handover occurs in phases. Network Topology Acquisition Phase (NTAP) and the Actual Handover Phase (AHOP) are the two main phases.

During the NTAP, the MSS performs scanning and downlink synchronization activities with the advertised neighboring BSs to select a new target BS to perform the handover activity.

During the AHOP, the MSS releases its connection with the current SBS and performs synchronization, registration procedures with the newly selected target BS to successfully complete the handover process. However, the entire procedure is not free from ambiguities. Excessive scanning and synchronization activities may result in unwanted handover delays along with wastages of valuable resources. Hence, limiting the extent of scanning activities remains a challenging task in the IEEE 802.16e systems.

During the scanning procedure all uplink and downlink traffic is stalled or buffered. For delay sensitive traffic like VoIP and video bitstream, such a phenomenon is disruptive. On careful analysis, it takes a few hundred milliseconds of time to decide the best candidate BS for handover. There is scope of improvement of the steps involved in both the phases of the BS selection procedure.

1.3 Research Objectives

- Survey problem areas in handover schemes in Mobile WiMAX (IEEE 802.16e)

- Focus on time consuming processes

- Analyze the performance of the standard procedure

- Introduce an innovative Base Station selection procedure for handover considering other factors apart from the standard.

- Optimize the target BS decision phases and reduce the overall time taken

- Survey a host of WiMAX simulators widely used in academic and industrial areas and select one for procurement.

- Simulate the standard WiMAX handover procedure and the proposed algorithms.

- Present analysis results.

1.4 Structure

This section provides an overview of the thesis structure and discusses the main points of each chapter briefly.

Chapter 2 presents an overview of different communication methods and introduces the topic of WiMAX. It presents a bird's eye view of the technology and performance metrics. It ends with a broad introduction of the research area.

Chapter 3 provides more detail about wireless handovers in general. It discusses the types, stages and the need for handover

Chapter 4 discusses the handover procedure as described in the IEEE 802.16e standard. It describes the WiMAX mobility management architecture.

Chapter 5 describes the proposed scheme against the backdrop of the existing standard procedure. It describes the implementation, the simulation scenario, the assumptions considered to simulate and the results.

Chapter 6 draws conclusion from the results achieved in the last chapter. It also presents ideas that might help the reader to carry out future research work in the area.

2 WiMAX Technology

2.1 Background of WiMAX

WiMAX (also known as IEEE 802.16) is a wireless digital communications system that is intended for wireless "metropolitan area networks" (WMAN). It can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations. In contrast, the WiFi/802.11 wireless local area network standard is limited in most cases to only 100 - 300 feet (30 - 100m).

WiFi-like data rates are easily supported in WiMAX, but the issue of interference is less. Operating on both licensed and non-licensed frequencies, it provides a regulated environment and a viable economic model for wireless carriers.

WiMAX can be used for wireless networking in much the same way as the WiFi protocol. WiMAX is a second-generation protocol that allows for more efficient bandwidth use, interference avoidance, and is intended to allow higher data rates over longer distances.

The IEEE 802.16 standard defines the technical features of the communications protocol. The WiMAX Forum offers a means of testing manufacturer's equipment for compatibility, as well as an industry group dedicated to fostering the development and commercialization of the technology. Soon, WiMAX will be a very well recognized term to describe wireless Internet access all over the world.

The IEEE 802.16 group was formed in 1998 to develop an air-interface standard for wireless broadband. The group's initial focus was the development of a LOS-based point-to-multipoint wireless broadband system for operation in the 10GHz–66GHz millimeter wave band. The resulting standard—the original 802.16 standard, completed in December 2001—was based on a single-carrier physical (PHY) layer with a burst time division multiplexed (TDM) MAC layer. Many of the concepts related to the MAC layer were adapted for wireless from the popular cable modem DOCSIS (data over cable service interface specification) standard.

The IEEE 802.16 group subsequently produced 802.16a, an amendment to the standard, to include NLOS applications in the 2GHz–11GHz band, using an orthogonal frequency division multiplexing (OFDM)-based physical layer. Additions to the MAC layer, such as support for orthogonal frequency division multiple access (OFDMA), were also included. Further revisions resulted in a new standard in 2004, called IEEE 802.16-2004, which replaced all prior versions and formed the basis for the first WiMAX solution. These early

WiMAX solutions based on IEEE 802.16-2004 targeted fixed applications, and these will be referred to as fixed WiMAX [19]. In December 2005, the IEEE group completed and approved IFEEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support. The IEEE 802.16e-2005 forms the basis for the WiMAX solution for nomadic and mobile applications and is often referred to as mobile WiMAX [18].

Note that these standards offer a variety of fundamentally different design options. For example, there are multiple physical-layer choices: a single-carrier-based physical layer called WirelessMAN-SCa, an OFDM-based physical layer called WirelessMAN-OFDM, and an OFDMA- based physical layer called Wireless-OFDMA. Similarly, there are multiple choices for MAC architecture, duplexing, frequency band of operation, etc. These standards were developed to suit a variety of applications and deployment scenarios, and hence offer a plethora of design choices for system developers. In fact, one could say that IEEE 802.16 is a collection of standards, not one single interoperable standard.

With the completion of the IEEE 802.16e-2005 standard, interest within the WiMAX group has shifted sharply toward developing and certifying mobile WiMAX[18] system profiles based on this newer standard. All mobile WiMAX profiles use scalable OFDMA as the physical layer. At least initially, all mobility profiles will use a point-to-multipoint MAC. It should also be noted that all the current candidate mobility certification profiles are TDD based. Although TDD is often preferred, FDD profiles may be needed for in the future to comply with regulatory pairing requirements in certain bands.

For the reminder of this chapter, the focus is solely on WiMAX and therefore only aspects of IEEE 802.16 family of standards that may be relevant to current and future WiMAX certification are discussed. It should be noted that the IEEE 802.16e-2004 and IEEE 802.16-2005 standards specifications are limited to the control and data plane aspects of the air-interface. Some aspects of network management are defined in IEEE 802.16g. For a complete end-to-end system, particularly in the context of mobility, several additional end-to-end service management aspects need to be specified. This task is being performed by the WiMAX Forums Network Working Group (NWG). The WiMAX NWG is developing an end-to-end network architecture and filling in some of the missing pieces.

2.2 WiMAX basics

2.2.1 Introduction

Internet is the preferred mode of communication today. There are basically three different options of accessing the internet:

Broadband access - In your home, you have either a DSL or cable modem. At the office, your company may be using a T1 or a T3 line.

WiFi access - In your home, you may have set up a WiFi router that lets you surf the Web while you lounge with your laptop. On the road, you can find WiFi hot spots in restaurants, hotels, coffee shops and libraries.

Dial-up access - If you are still using dial-up, chances are that either broadband access is not available, or you think that broadband access is too expensive.

All of these options have got their own problems as well. Broadband access is pretty expensive and it doesn't reach all areas. The main trouble with WiFi access is that hot spots are very small, so thin coverage.

What if there was a new technology that solved all of these problems? This new technology would provide:

- The high speed of broadband service
- Broad coverage like the cell phone network (against small WiFi hotspots)
- Wireless rather than wired access, so it would be a lot cheaper than cable or DSL and much easier to extend to suburban and rural areas

This system is actually being developed and tested right now in various parts of the world, and it is called WiMAX (short for Worldwide Interoperability for Microwave Access, and it also goes by the IEEE name 802.16).

The smallest-scale network is a personal area network (PAN). A PAN allows devices to communicate with each other over short distances. Bluetooth is the best example of a PAN.

The next step up is a local area network (LAN). A LAN allows devices to share information, but is limited to a fairly small central area, such as a company's headquarters, a coffee shop or your house. Many LANs use WiFi to connect the network wirelessly.

WiMAX is the wireless solution for the next step up in scale, the metropolitan area network (MAN). A MAN allows areas the size of cities to be connected.

WiMAX has the potential to do to broadband Internet access what cell phones have done to phone access. In the same way that many people have given up their "land lines" in favor of cell phones, WiMAX could replace cable and

DSL services, providing universal Internet access just about anywhere you go. WiMAX will also be as painless as WiFi -- turning your computer on will automatically connect you to the closest available WiMAX antenna.

Metropolitan Area Network (MAN)	IEEE 802.16	Connects devices upto 50 km radius (approx)
Local Area Network (LAN)	IEEE 802.11	Connects devices upto 300 ft radius (approx)
Personal Area Network (PAN)	IEEE 802.15	Connects devices upto 33 ft radius (approx)

Figure 2. Types of networks

2.2.2 Operating Principles

A WiMAX system consists of two parts:

- A WiMAX tower, similar in concept to a cell-phone tower - A single WiMAX tower can provide coverage to a very large area -- as big as 8,000 square kilometers (~3,000 square miles).
- A WiMAX receiver - The receiver and antenna could be a small box or PCMCIA card, or they could be built into a laptop the way WiFi access is today.

A WiMAX tower station can connect directly to the Internet using a high-bandwidth, wired connection (for example, a T3 line). It can also connect to another WiMAX tower using a line-of-sight, microwave link. This connection to a second tower (often referred to as a backhaul), along with the ability of a single tower to cover up to 3,000 square miles, is what allows WiMAX to provide coverage to remote rural areas.

What this means is that WiMAX actually can provide two forms of wireless service. There is the non-line-of-sight (NLOS), WiFi sort of service, where a small antenna on your computer connects to the tower. In this mode, WiMAX uses a lower frequency range -- 2 GHz to 11 GHz (similar to WiFi). Lower-wavelength transmissions are not as easily disrupted by physical obstructions -- they are better able to diffract, or bend, around obstacles.

There is line-of-sight service (LOS), where a fixed dish antenna points straight at the WiMAX tower from a rooftop or pole. The line-of-sight connection is stronger and more stable, so it's able to send a lot of data with fewer errors. Line-of-sight transmissions use higher frequencies, with ranges reaching a possible 66 GHz. At higher frequencies, there is less interference and lots more bandwidth.

WiFi-style access will be limited to a 4-to-6 mile radius (perhaps 25 square miles or 65 square km of coverage, which is similar in range to a cell-phone zone). Through the stronger line-of-sight antennas, the WiMAX transmitting station would send data to WiMAX-enabled computers or routers set up within the transmitter's 30-mile radius (2,800 square miles or 9,300 square km of coverage). This is what allows WiMAX to achieve its maximum range.

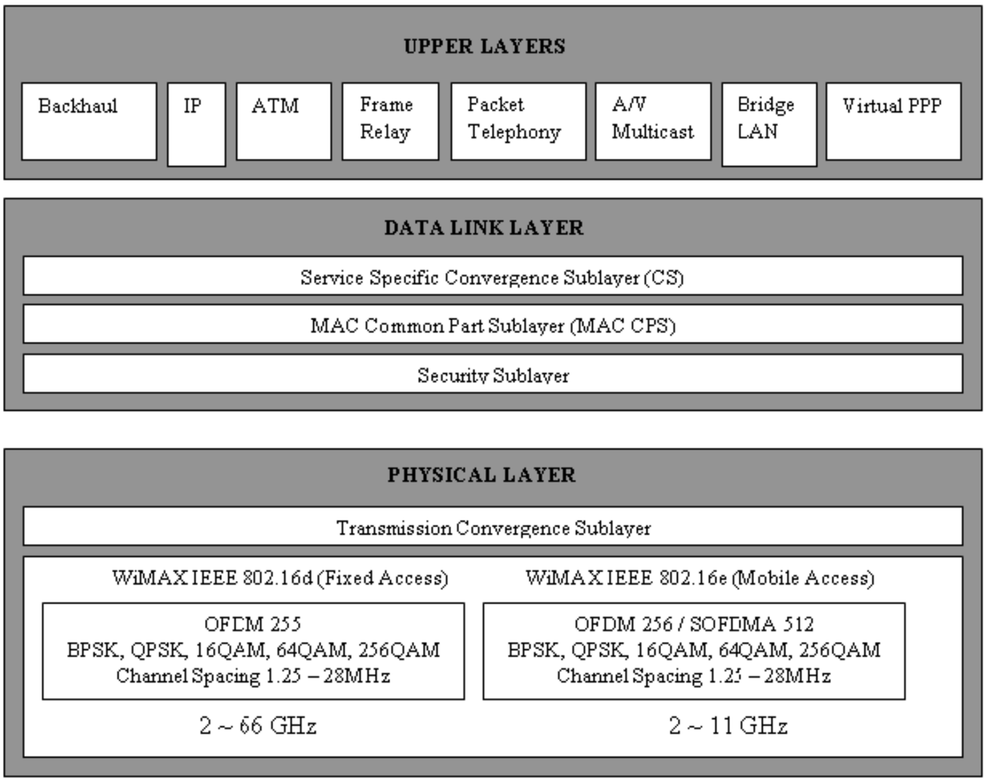


Figure 3. WiMAX Protocol Stack

2.2.3 Usage

WiMAX operates on the same general principles as WiFi -- it sends data from one computer to another via radio signals. A computer (either a desktop or a laptop) equipped with WiMAX would receive data from the WiMAX transmitting station, probably using encrypted data keys to prevent unauthorized users from stealing access.

The fastest WiFi connection can transmit up to 54 megabits per second under optimal conditions. WiMAX should be able to handle up to 70 megabits per second. Even once that 70 megabits is split up between several dozen businesses or a few hundred home users, it will provide at least the equivalent of cable-modem transfer rates to each user.

The biggest difference isn't speed; it's distance. WiMAX outdistances WiFi by miles. WiFi's range is about 100 feet (30 m). WiMAX will blanket a radius of 30 miles (50 km) with wireless access. The increased range is due to the frequencies used and the power of the transmitter. Of course, at that distance, terrain, weather and large buildings will act to reduce the maximum range in some circumstances, but the potential is there to cover huge tracts of land.

In an emergency, communication is crucial for government officials as they try to determine the cause of the problem, find out who may be injured and coordinate rescue efforts or cleanup operations. A gas-line explosion or terrorist attack could sever the cables that connect leaders and officials with their vital information networks.

WiMAX could be used to set up a back-up (or even primary) communications system that would be difficult to destroy with a single, pinpoint attack. A cluster of WiMAX transmitters would be set up in range of a key command center but as far from each other as possible. Each transmitter would be in a bunker hardened against bombs and other attacks. No single attack could destroy all of the transmitters, so the officials in the command center would remain in communication at all times.

2.2.4 Applicability

It depends how it will be used. There are two ways WiMAX can be implemented -- as a zone for wireless connections that single users go to when they want to connect to the Internet on a laptop (the non-line-of-sight "super WiFi" implementation), or as a line-of-sight hub used to connect hundreds of customers to a steady, always-on, high-speed wireless Internet connection.

Under the "super WiFi" plan, cities might pay to have WiMAX base stations set up in key areas for business and commerce and then allow people to use them for free. They already do this with WiFi, but instead of putting in a bunch of WiFi hot spots that cover a few hundred square yards, a city could pay for one WiMAX base station and cover an entire financial district. This could provide a strong draw when city leaders try to attract businesses to their area.

Some companies might set up WiMAX transmitters and then make people pay for access. Again, this is similar to strategies used for WiFi, but a much wider area would be covered. Instead of hopping from one hot spot to another, WiMAX-enabled users could have Internet access anywhere within 30 miles of the WiMAX base station. These companies might offer unlimited access for a monthly fee or a "pay as you go" plan that charges on a per-minute or per-hour basis.

The high-speed wireless hub plan has the potential to be far more revolutionary. If you have high-speed Internet access now, it probably works something like this: The cable (or phone) company has a line that runs into your home. That line goes to a cable modem, and another line runs from the modem to your computer. If you have a home network, first it goes to a router and then on to the other computers on the network. You pay the cable company a monthly fee, which reflects in part the expense of running cable lines to every single home in the neighborhood.

WiMAX doesn't just pose a threat to providers of DSL and cable-modem service. The WiMAX protocol is designed to accommodate several different methods of data transmission, one of which is Voice Over Internet Protocol (VoIP). VoIP allows people to make local, long-distance and even international calls through a broadband Internet connection, bypassing phone companies entirely. If WiMAX-compatible computers become very common, the use of VoIP could increase dramatically. Almost anyone with a laptop could make VoIP calls.

2.3 Broad Introduction to Research Area

Mobility is the most important feature of a wireless cellular communication system. Usually, continuous service is achieved by supporting handover (or handover) from one cell to another. The IEEE standard 802.16e-2005 provides enhancements to IEEE standard 802.16-2004 to support subscriber stations (SS) moving at vehicular speeds. It thereby specifies a system for combined fixed and mobile broadband wireless access without compromising the capabilities of fixed IEEE 802.16 subscribers. Functions to support handover at higher layers between base stations are specified. Operation is limited to licensed bands suitable for mobility below 6 GHz.

Vertical handover refers to handover from one technology to another in order to maintain communication. This involves changing the data link layer technology used to access the network. Thus it is different from a horizontal handover between different wireless access points or base stations (BS) that use the same technology.

In traditional handoffs, such as a handoff between cellular networks, the handoff decision is based mainly on RSS (Relative Signal Strength) in the border region of two cells, and may also be based on call drop rate, etc. for resource management reasons. In vertical handoff, the situation is more complex. Two different kinds of wireless networks normally have incomparable signal strength metrics, for example, WLAN compared to UMTS. In, WLAN and UMTS networks both cover an area at the same time. The Handoff Metrics in this situation should include RSS, user preference, network conditions, application types, cost etc.

One of the most challenging research issues of investigating broadband wireless access (BWA) technologies such as WiMAX is how to support mobility smoothly and seamlessly. It is essential to provide continuous services of multimedia streaming data when a mobile subscriber station (MSS) undergoes handover. Although the IEEE 802.16e standard proposes to tackle this problem, the disruption time (DT) of handover is still too long to overcome the maximum delay time of real-time services such as VoIP and video bit streaming.

2.4 Summary

WiMAX™ is based upon the IEEE 801.16 standard enabling the delivery of wireless broadband services anytime, anywhere. WiMAX products can accommodate fixed and mobile usage models. The IEEE 802.16 standard was developed to deliver non-line-of-sight (LoS) connectivity between a subscriber station and base station with typical cell radius of three to ten kilometers. All base stations and subscriber stations claiming to be WiMAX compliant must go through a rigorous WiMAX Forum Certified™ testing process. WiMAX Forum Certified systems can be expected to deliver capacity of up to 40 Mbps per channel. This is enough bandwidth to simultaneously support hundreds of businesses with T-1 speed connectivity and thousands of residences with DSL speed connectivity. The WiMAX Forum expects mobile network deployments to provide up to 15 Mbps of capacity within a typical cell radius of up to three kilometers.

3 Handover in Wireless Technologies

3.1 Why Handover?

In cellular telecommunications, the term handover refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another.

There may be different reasons why a handover might be conducted:

- when the phone is moving away from the area covered by one cell and entering the area covered by another cell the call is transferred to the second cell in order to avoid call termination when the phone gets outside the range of the first cell;

- when the capacity for connecting new calls of a given cell is used up and an existing or new call from a phone, which is located in an area overlapped by another cell, is transferred to that cell in order to free-up some capacity in the first cell for other users, who can only be connected to that cell;

- in non-CDMA networks when the channel used by the phone becomes interfered with by another phone using the same channel in a different cell, the call is transferred to a different channel in the same cell or to a different channel in another cell in order to avoid the interference;

- again in non-CDMA networks when the user behaviour changes, e.g. when a fast-travelling user, connected to a large, umbrella-type of cell, stops then the call may be transferred to a smaller macro-cell or even to a micro-cell in order to free capacity on the umbrella cell for other fast-travelling users and to reduce the potential interference to other cells or users (this works in reverse too, when a user is detected to be moving faster than a certain threshold, the call can be transferred to a larger umbrella-type of cell in order to minimise the frequency of the handovers due to this movement);
- in CDMA networks a soft handover may be induced in order to reduce the interference to a smaller neighbouring cell due to the "near-far" effect even when the phone still has an excellent connection to its current cell;

3.2 Types of Handover

Handovers are broadly classified into two categories—**hard** and **soft handovers**. Usually, the hard handover can be further divided into two different types—**intra-** and **inter- cell** handovers. The soft handover can also be divided into two different types—**multiway soft handovers** and **softer handovers**. In this thesis work, the focus is primarily on the hard handover.

A hard handover is essentially a “break before make” connection. Under the control of the MSC (Mobile Switching Centre), the BS hands over the MSS’s call to another cell and then drop the call. In a hard handover, the link to the prior BS is terminated before or as the user is transferred to the new cell’s BS; the MSS is linked to no more than one BS at any given time. Hard handover is primarily used in FDMA (frequency division multiple access) and TDMA (time division multiple access), where different frequency ranges are used in adjacent channels in order to minimize channel interference. So when the MSS moves from one BS to another BS, it becomes impossible for it to communicate with both BSs (since different frequencies are used). The figure below illustrates hard handover between the MSS and the BSs.

Intra cell/domain handover refers to handover occurring when a MSS moves from the vicinity of one BS to another BS within the same operator or backbone (referred to as (A) in the next figure). Inter cell/domain handover refers to a similar activity where the BSs are from different operators or backbones (referred to as (B) in the figure 4).

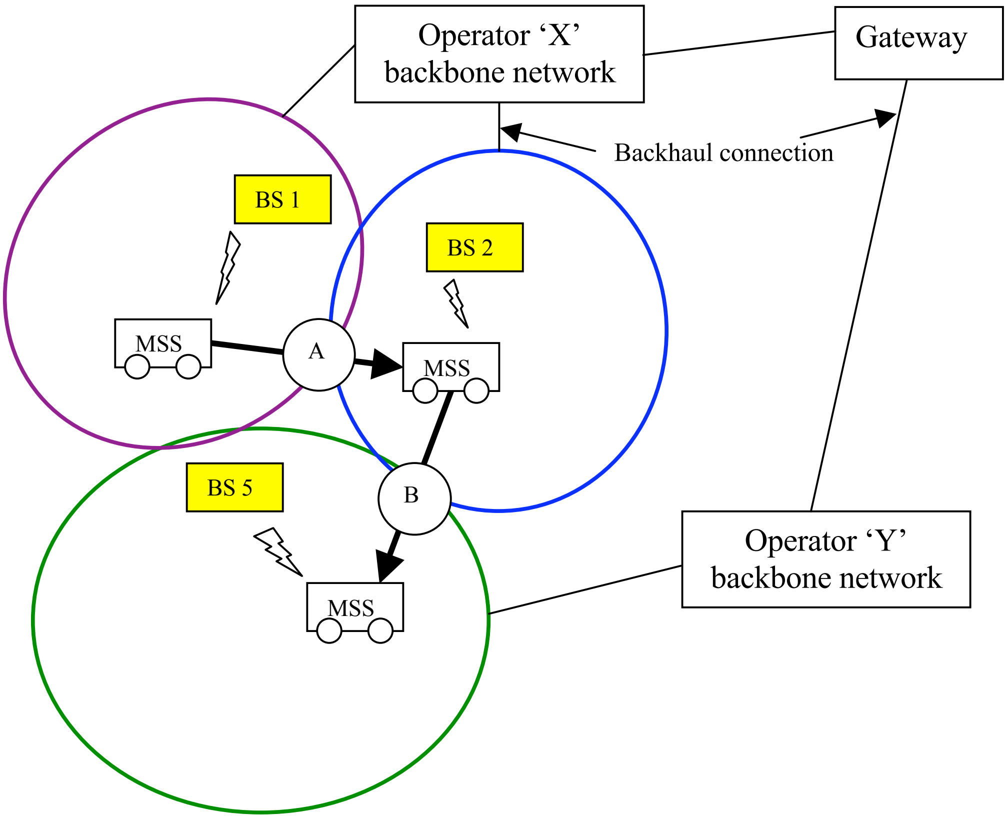
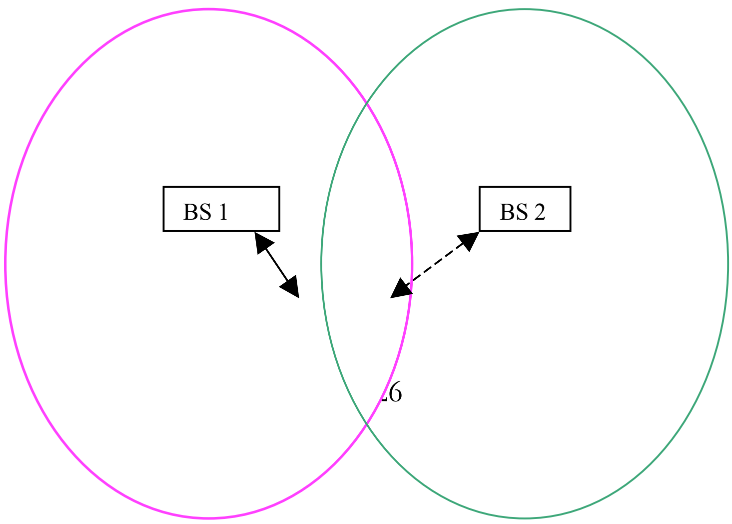


Figure 4. Inter-cell and Intra- cell handover

An advantage of the hard handover is that at any moment in time one call uses only one channel. The hard handover event is indeed very short and usually is not perceptible by the user. In the old analog systems it could be heard as a click or a very short beep, in digital systems it is unnoticeable. Another advantage of the hard handover is that the phone's hardware does not need to be capable of receiving two or more channels in parallel, which makes it cheaper and simpler. A disadvantage is that if a handover fails the call may be temporarily disrupted or even terminated abnormally. Technologies, which utilize hard handovers, usually have procedures which can re-establish the connection to the source cell if the connection to the target cell cannot be made. However re-establishing this connection may not always be possible (in which case the call will be terminated) and even when possible the procedure may cause a temporary interruption to the call.

One advantage of the soft handovers is that the connection to the source cell is broken only when a reliable connection to the target cell has been established and therefore the chances that the call will be terminated abnormally due to a failed handover are lower. However, by far a bigger advantage comes from the mere fact that simultaneously channels in multiple cells are maintained and the call could only fail if all of the channels are interfered or fade at the same time. Fading and interference in different channels are unrelated and therefore the probability of them taking place at one the same moment in all channels is very low. Thus the reliability of the connection becomes higher when the call is in a soft handover.



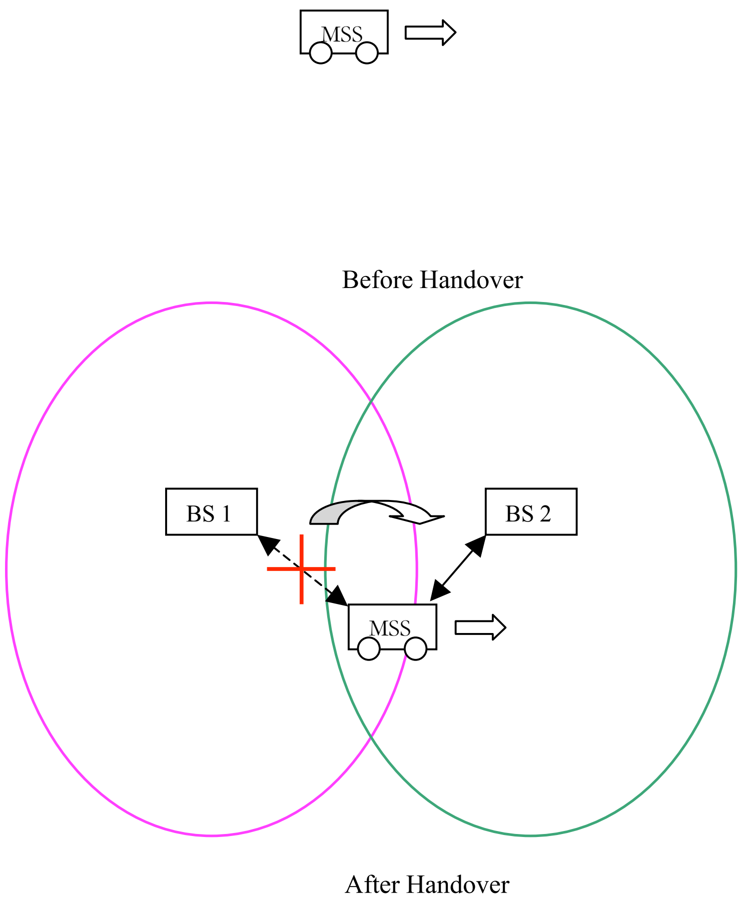


Figure 5. Hard Handover between the MSS and BSs

Because in a cellular network the majority of the handovers occur in places of poor coverage, where calls would frequently become unreliable when their channel is interfered with or fading, soft handovers bring a significant improvement to the reliability of the calls in these places by making the interference or the fading in a single channel not critical.

This advantage comes at the cost of more complex hardware in the phone, which must be capable of processing several channels in parallel. Another price to pay for soft handovers is the use of several channels in the network to support just a single call. This reduces the number of remaining free channels and thus reduces the capacity of the network. By adjusting the duration of soft handovers and the size of the areas, in which they occur, the network engineers can balance the benefit of extra call reliability against the price of reduced capacity.

3.3 Stages of Handover

3.3.1 Handover Initiation

A hard handover occurs when the old connection is broken before a new connection is activated. The performance evaluation of a hard handover is based on various initiation criteria. It is assumed that the signal is averaged over time, so that rapid fluctuations due to the multipath nature of the radio environment can be eliminated. Numerous studies have been done to determine the shape as well as the length of the averaging window and the older measurements may be unreliable. The next figure shows a MSS moving from one BS (BS1) to another (BS2). The mean signal strength of BS1 decreases as the MSS moves away from it. Similarly, the mean signal strength of BS2 increases as the MSS approaches it. This figure is used to explain various approaches described in the following subsection.

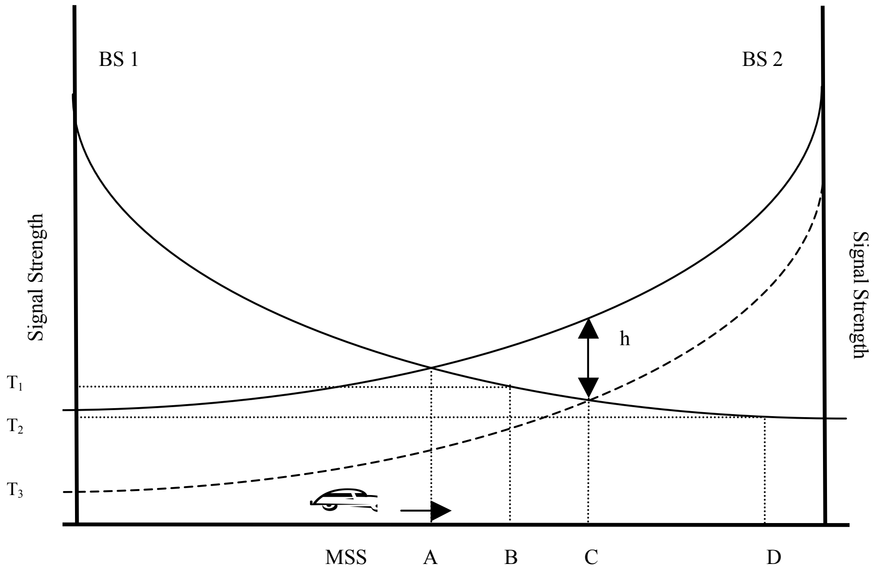


Figure 6. Signal strength and hysteresis between two BSs (potential handover)

3.3.1.1 Relative Signal Strength

This method selects the strongest received BS at all times. The decision is based on a mean measurement of the received signal. In Figure 6, the handover would occur at position A. This method is observed to provoke too many unnecessary handovers, even when the signal of the current BS is still at an acceptable level.

3.3.1.2 Relative Signal Strength with Threshold

This method allows a MSS to hand off only if the current signal is sufficiently weak (less than threshold) and the other is the stronger of the two. The effect of the threshold depends on its relative value as compared to the signal strengths of the two BSs at the point at which they are equal. If the threshold is higher than this value, say T1 in Figure 6, this scheme performs exactly like the relative signal strength scheme, so the handover occurs at position A. If the threshold is lower than this value, say T2 in Figure 6, the MSS would delay handover until the current signal level crosses the threshold at position B. In the case of T3, the delay may be so long that the MSS drifts too far into the new cell. This reduces the quality of the communication link from BS1 and may result in a dropped call. In addition, this results in additional interference to co-channel users. Thus, this scheme may create overlapping cell coverage areas. A threshold is not used alone in actual practice because its effectiveness depends on prior knowledge of the crossover signal strength between the current and candidate BSs.

3.3.1.3 Relative Signal Strength with Hysteresis

This scheme allows a user to hand off only if the new BS is sufficiently stronger (by a hysteresis margin, h in Figure 1.2) than the current one. In this case, the handover would occur at point C. This technique prevents the so-called ping-pong effect, the repeated handover between two BSs caused by rapid fluctuations in the received signal strengths from both BSs. The first handover, however, may be unnecessary if the SBS is sufficiently strong.

3.3.1.4 Relative Signal Strength with Hysteresis and Threshold

This scheme hands a MSS over to a new BS only if the current signal level drops below a threshold and the target BS is stronger than the current one by a given hysteresis margin. In the last figure, the handover would occur at point D if the threshold is T3.

3.3.1.5 Prediction Techniques

Prediction techniques base the handover decision on the expected future value of the received signal strength. A technique has been proposed and simulated to indicate better results, in terms of reduction in the number of unnecessary handovers, than the relative signal strength, both without and with hysteresis, and threshold methods.

3.3.2 Handover Decision

There are numerous methods for performing handover, at least as many as the kinds of state information that have been defined for MSSs, as well as the kinds of network entities that maintain the state information [4]. The decision-making process of handover may be centralized or decentralized (i.e., the handover decision may be made at the MSS or network).

From the decision process point of view, one can find at least three different kinds of handover decisions.

3.3.2.1 Network-Controlled Handover

In a network-controlled handover protocol, the network makes a handover decision based on the measurements of the MSSs at a number of BSs. In general, the handover process (including data transmission, channel switching, and network switching) takes 100–200 ms. Information about the signal quality for all users is available at a single point in the network that facilitates appropriate resource allocation. Network-controlled handover is used in first-generation analog systems such as AMPS (advanced mobile phone system), TACS (total access communication system), and NMT (Nordic Mobile Telephony).

3.3.2.2 Mobile-Assisted Handover

In a mobile-assisted handover process, the MSS makes measurements and the network makes the decision. In the circuit-switched GSM (global system mobile), the BS controller (BSC) is in charge of the radio interface management. This mainly means allocation and release of radio channels and handover management. The handover time between handover decision and execution in such a circuit-switched GSM is approximately 1 second.

3.3.2.3 Mobile-Controlled Handover

In mobile-controlled handover, each MSS is completely in control of the handover process. This type of handover has a short reaction time (on the order of 0.1 second). MSS measures the signal strengths from surrounding BSs and interference levels on all channels. A handover can be initiated if the signal strength of the SBS is lower than that of another BS by a certain threshold.

3.4 Summary

Handover is the process of transfer of connectivity from one base station to another. There may be various reasons for it to occur. Inter and Intra domain handovers are the two broad classifications of handover. Handover initiation and decision are the two stages of handover. Soft and hard handovers are the two methods or types of handovers. A hard handover occurs when the old connection is broken before a new connection is activated. The decision-making process of handover may be centralized or decentralized depending whether it is made at the MSS or the network. There are three different kinds of handover decisions.

4 Mobile WiMAX Handover

4.1 Mobility Management Architecture

The WiMAX mobility management architecture was designed to

- Minimize packet loss and handover latency
- Maintain packet ordering to support seamless handover at vehicular speeds
- Supporting macro diversity handover (MDHO) and fast base station switching (FBSS)
- Minimize signaling to execute handover (number of round trips)
- Support IPv4 and IPv6 based mobility management
    - Accommodate multiple IP addresses and simultaneous connections
- Maintain the possibility of vertical or inter-technology handovers and roaming between network service providers (NSPs).

The WiMAX network supports two types of mobility:

4.1.1 ASN-anchored mobility (intra-ASN mobility or micro mobility)

It supports handover situations in which the mobile moves its point of attachment from one BS to another within the same ASN (Access Services Network). This movement activity is unknown to the CSN (Connectivity Services Network) and has no impact at the IP layer or network layer level.

The WiMAX standard defines three functions that provide ASN anchored mobility management.

The **data path function** (DPF) is responsible for setting up and managing the bearer paths needed for data packet transmission between the functional entitites (BSs and ASN gateways) involved in a handover. This includes setting up appropriate tunnels between the entities for packet forwarding, ensuring low latency, and handling special needs (such as multicast and broadcast).

The **handover function** is responsible for making the handover decisions and performing the related signaling procedures. It supports both mobile and network initiated handovers (FBSS and MDHO). Like the DPF, this function is also distributed among many entities.

Context function is responsible for the exchange of state information among the network elements impacted by handover. It is implemented using a client/server model.

4.1.2 CSN-anchored mobility (inter-ASN mobility or macro mobility)

It refers to mobility across different ASNs (across multiple foreign agents [FAs]). WiMAX specification (Release 1) limits CSN anchored mobility to between FAs belonging to the same network access provider (NAP). CSN anchored mobility involves mobility across different IP subnets (therefore requiring IP layer mobility management). As a WiMAX network supports IPv4 and IPv6, the CSN anchored mobility management for IPv6 is different from IPv4 case (mobile IPv4 is different from mobile IPv6).

4.2 Standard Procedure in IEEE 802.16e

4.2.1 Explanation

In WiMAX, the handover procedure requires support from layers 1, 2, and 3 of the network. Although the final decision for the handover is determined by layer 3, the MAC and PHY layers play a crucial role by providing information and triggers required by layer 3 to execute the handover.

In order to be aware of its dynamic radio frequency environment, the BS allocates time for each MSS to monitor and measure the radio condition of the neighbouring BSs. This process is called scanning, and the time allocated to each MSS is called the scanning interval. Each scanning interval is followed by an interval of normal operation, referred to as the interleaving interval. The scanning process starts when the BS issues a MOB_SCN_REQ message that specifies to the MSS the length of each scanning interval, the length of the interleaving interval and the number of scanning events the MSS is required to execute.

4.2.2 Phases

The total handover procedure in Mobile WiMAX comprises of the following distinct phases. As mentioned in [11], firstly, network topology acquisition is carried out before a HO request. Then, the actual HO process including HO decision, initiation, ranging and re-entry process is performed.

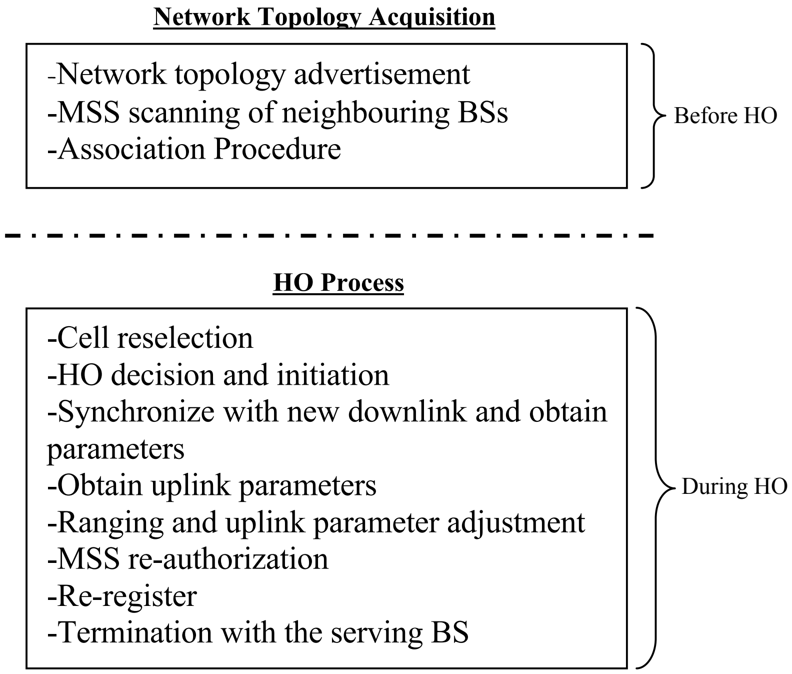


Figure 7. MAC Layer Handover Procedure

4.2.2.1 Network Topology Acquisition Phase (NTAP)

During the NTAP, shown in figures 8, 9 and 11, the MSS and the SBS, jointly with the help of the backbone network, gathers information about the underlying network topology. Using MOB_NBR-ADV messages, the SBS periodically broadcasts the network topology information or channel information of the available neighbouring BSs for a potential handover. Then the MSS is able to synchronize with neighbouring BSs without listening to their DCD/ UCD (downlink / uplink channel descriptor) broadcast messages.

Next step is scanning of neighbouring BSs. A MSS initiates the scanning process by transmitting the Scanning Interval Allocation Request (MOB_SCN-REQ). The message contains the estimated scan duration and, for scanning multiple times, the interleaving interval and the number of iterations.

Additionally, the MSS indicates the intended scanning of one or several neighboring BSs. Like this, the BS can negotiate over the backbone a unicast ranging opportunity (instead of contention-based ranging) for the intended neighboring BSs. The unicast opportunity will be granted to the MSS at a specific rendezvous time.

The SBS responds to the scanning request with the Scanning Interval Allocation Response (MOB_SCN-RSP), which either grants or denies the request. If the scanning interval is granted, the response contains the start time of the interval and the rendezvous time for each of the recommended neighboring BSs. The scanning can be either MSS or BS initiated. If it is BS initiated, the BS indicates the scanning interval to the MSS by only transmitting the MOB_SCN-RSP message.

Following the response message granting the request, a MSS may scan for one or more BSs during the time interval. Beside the recommended BSs, the MSS can look for any other BS during the scanning interval. When a neighboring

BS is identified through scanning, the MSS attempts to synchronize with its downlink transmissions.

The MSS scans the advertised BSs to select suitable candidates for the potential handover activity. The scanning is done within specific periods (frames) allocated by the SBS on request of the MSS. During the scanning process, data transmission is paused and all incoming data to the MSS is buffered by the SBS. Thus, scanning intervals should be assigned carefully so that the MSS's throughput is not degraded more than necessary. The MSS can terminate the scanning by transmitting any PDU, e.g., a BW request during the contention interval, to the BS.

For a proper selection of a target BS, the MSS needs to acquire and record meaningful service availability information. Beside the quality of the DL channel, the MSS can optionally associate to the neighbor BSs by performing initial ranging (contention / non-contention-based). By setting and storing the initial ranging values during the scanning interval, the MSS may be able to reuse them for future HO.

The BS's ranging response (RNG-RSP) further contains a service level prediction, which indicates the available services and the expectable level of QoS. There are three types of association during which the MSS obtains information of the PHY channel characteristics of the selected BSs. The scanning type is negotiated during the MOB_SCN-REQ / MOB_SCN-RSP message exchange.

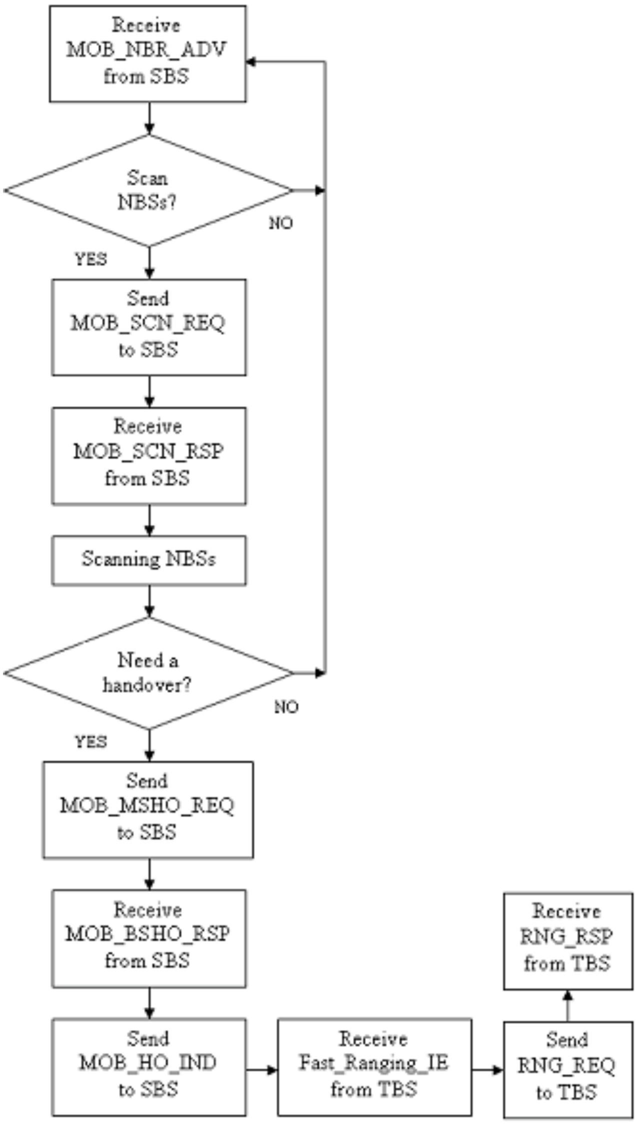


Figure 8. MSS initiated HO as seen by MSS

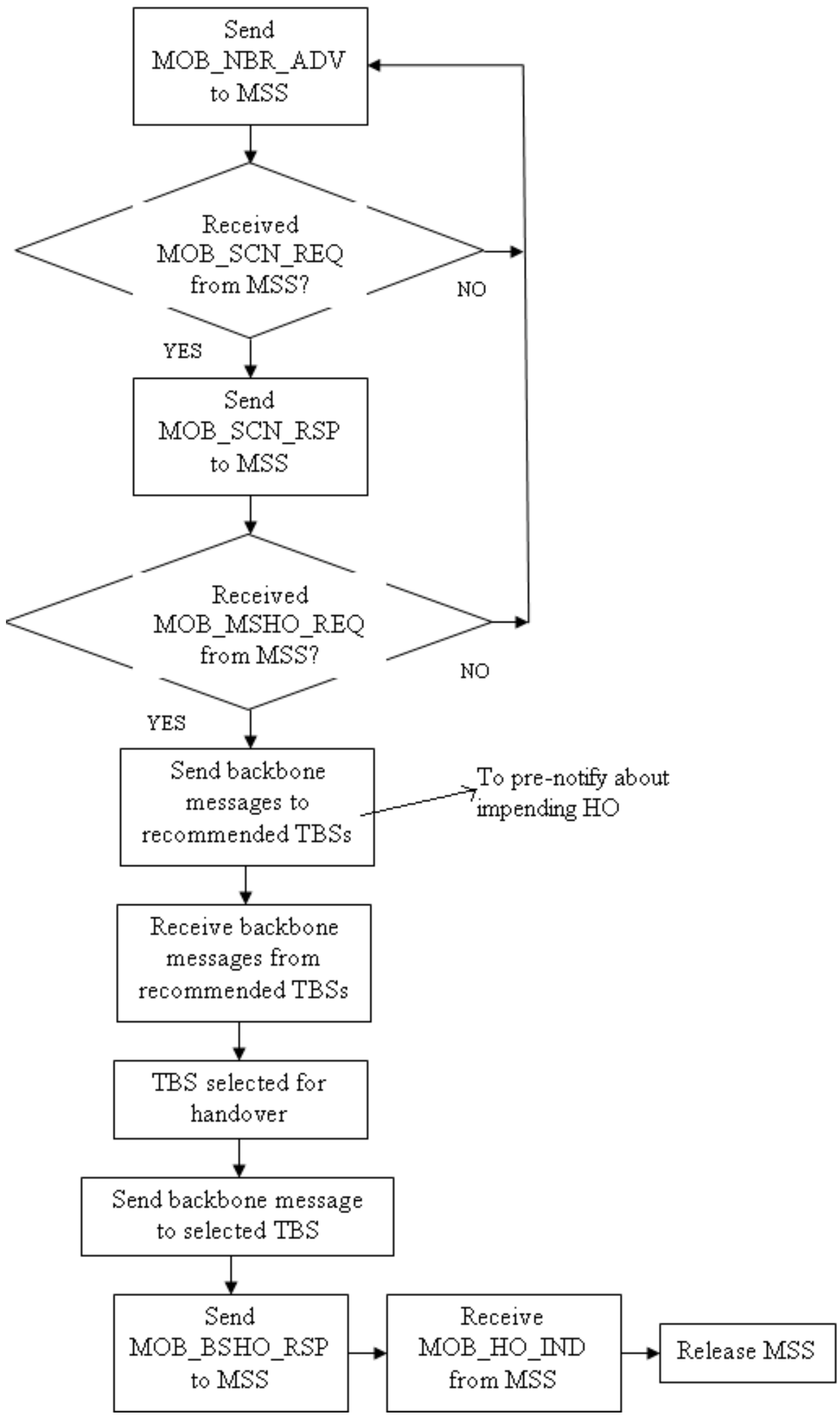


Figure 9. MSS initiated HO as seen by the SBS

4.2.2.2 Actual Handover Phase

When MSS migrates from the SBS to the target BS HO process is performed as follows. Figure 11 shows a detailed diagram of this phase.

4.2.2.2.1 Cell reselection

MSS conducts cell reselection with information obtained from network topology acquisition stage. Since it refers the same operation with network topology acquisition, this stage can be abbreviated.

4.2.2.2.2 Handover decision and initiation

The handover process begins with the decision for the MSS to migrate its connections from the SBS to a new target BS. This decision can be taken by the MSS, SBS, or some other external entity in the WiMAX network (dependent on the implementation).

When the handover decision is taken by the MSS, it sends a MOB_MSHO_REQ to the SBS, indicating 1 or more BSs as handover targets. The SBS then sends a MOB_BSHO_RSP message back to the MSS indicating the target BSs to be used for this handover process. The MSS sends a MOB_MSHO_IND message indicating which of the BSs indicated in MOB_BSHO_RSP will be used for handover.

When the handover decision is taken by the BS, it sends a MOB_BSHO_REQ message to the MSS, indicating 1 or more BSs for handover target. The MSS then sends a MOB_MSHO_IND message indicating receipt of the handover decision and its choice of target BS.

After the handover process has been initiated, the MSS can cancel it at any time.

4.2.2.2.3 Synchronization to the target BS

Once the target BS is determined, the MSS synchronizes with its DL transmission, beginning with processing the DL frame preamble of the target BS. The DL frame preamble provides the MSS with time and frequency synchronization with the target BS. The MSS then decodes the DL-MAP, UL-MAP, DCD and UCD messages to get information about the ranging channel. *This stage can be shortened* if the target BS was notified about the impending handover procedure and had allocated unicast ranging resources for the MSS.

4.2.2.2.4 Ranging with target BS

The MSS uses the ranging channel to perform the initial ranging process to synchronize its UL transmission with the BS and get information about initial timing advance and power level. This initial ranging process is similar to the one used during network entry. The MSS can skip or shorten this stage if it performed association with the target BS during the cell reselection stage.

4.2.2.2.5 Terminating serving BS

After establishing connection with the target BS, the MSS may decide to terminate its connection with the SBS, sending a MOB_HO_IND message to the BS. On receipt of this message, the SBS starts the resource-retain timer and keeps all the MAC state machines and buffered MAC PDUs associated with the MSS until the expiry of this timer. Once the timer expires, the BS discards all the MAC state machines and MAC PDUs and the handover process is assumed to be complete.

A call drop during a handover process is defined as the situation when an MSS has stopped communication with its SBS in either DL or UL before normal handover sequence has been completed. When the MSS detects a call drop, it attempts a network reentry procedure with the target BS to reestablish its connection with the network.

4.2.3 Scanning

The operation of an MSS can be assumed as follows. Although, it can be an implementation issue to decide when an MSS starts to scan neighbor BSs and performs handover to other BSs.

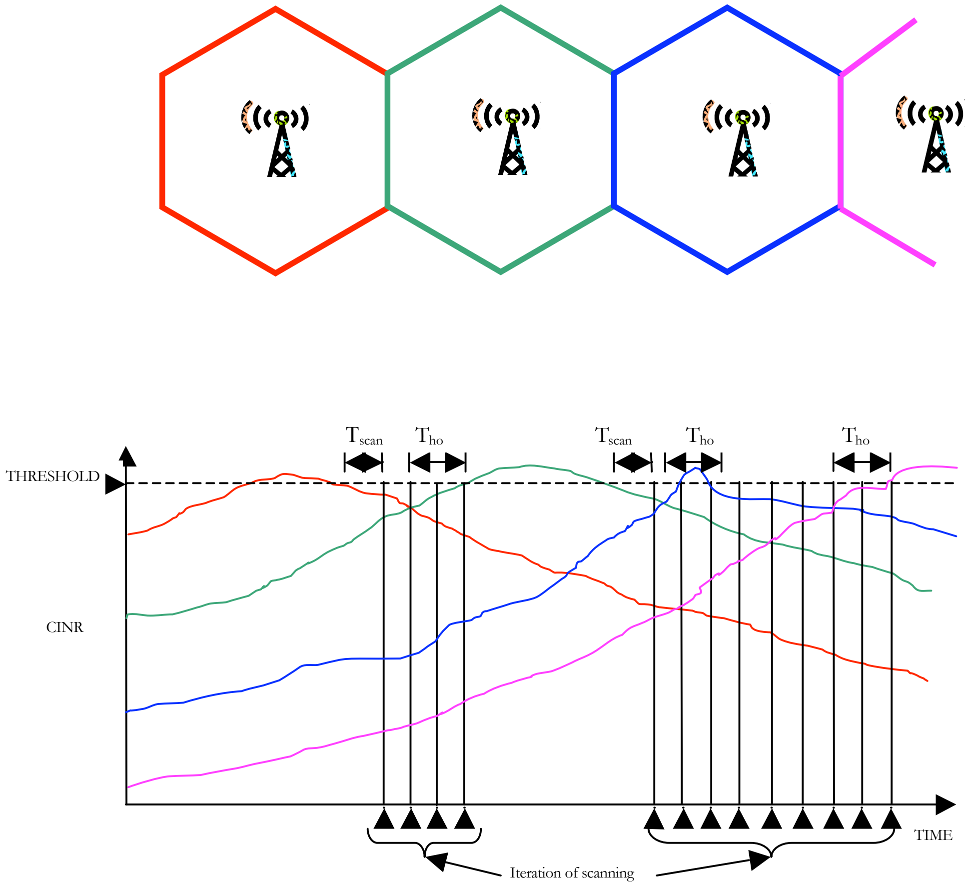


Figure 10. Example of Scanning

- An MSS can measure the signal power from the SBS without any scanning request message.
- An MSS starts to scan neighbor BSs, if the signal power from the SBS is lower than a given threshold for T_{scan} time.
- The handover procedure will be started, if the signal power of other BS is higher than that of SBS for T_{ho} time.

As shown figure 10, an MSS should scan neighbor BSs frequently in handover region. The MSS or the SBS may request periodic scanning if the MSS is considered in the handover region.

4.2.4 Ranging

Since each MSS has a unique distance from the BS, it is critical in the uplink to synchronize the symbols and equalize the received power levels among the various active MSS. This process is called ranging. When initiated, ranging requires the BS to estimate the channel strength and the time of arrival for the MSS in question. Downlink synchronization is not needed.

In WiMAX, four types of ranging procedures exist: initial ranging, periodic ranging, bandwidth request and handover ranging. If the ranging procedure is successful, the BS sends a ranging response (RNG-RES) message that instructs the MSS on the appropriate timing-offset adjustment, frequency-offset correction and power setting. If unsuccessful, the MSS increases its power level and sends a new ranging message, continuing this process until success.

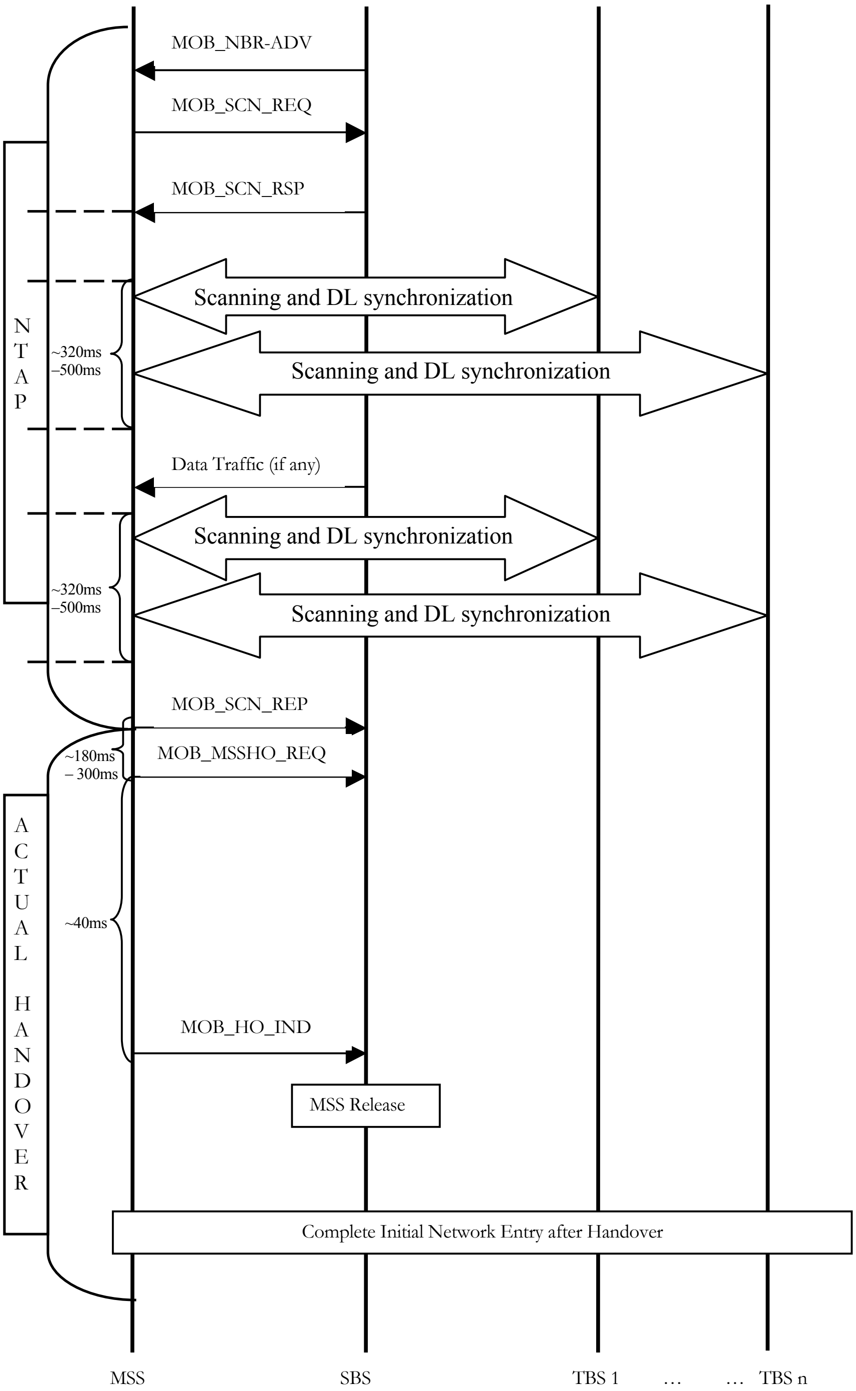


Figure 11. Hard Handover in WiMAX

4.2.5 Performance and Inference

Considerable literature has been searched looking for analysis results of the handover procedure in IEEE 802.16e. However, none of the published results were extensive enough to clearly figure out exactly which of the various stages were taking the lion's share of the total handover time. Hence considerable effort was required to study, simulate and analyze the performance of the standardized WiMAX handover. This was done through simulations on a commercial WiMAX simulator called Qualnet.

4.2.5.1 Simulation Environment

A moderately populated environment (6 BSs and 18 SSs in a small area) scenario was simulated on Qualnet 4.0 as shown in fig. 10. The scanning time and the total handover operation time were studied with the help of IEEE 802.16e OFDMA model implemented using QualNet 4.0. The speed of SSs was varied uniformly from 0-120 kmph, which means that both pedestrian and vehicular movements of SSs were considered. As described in Figure 11, association is optional. In this thesis it has been excluded from the study and analysis.

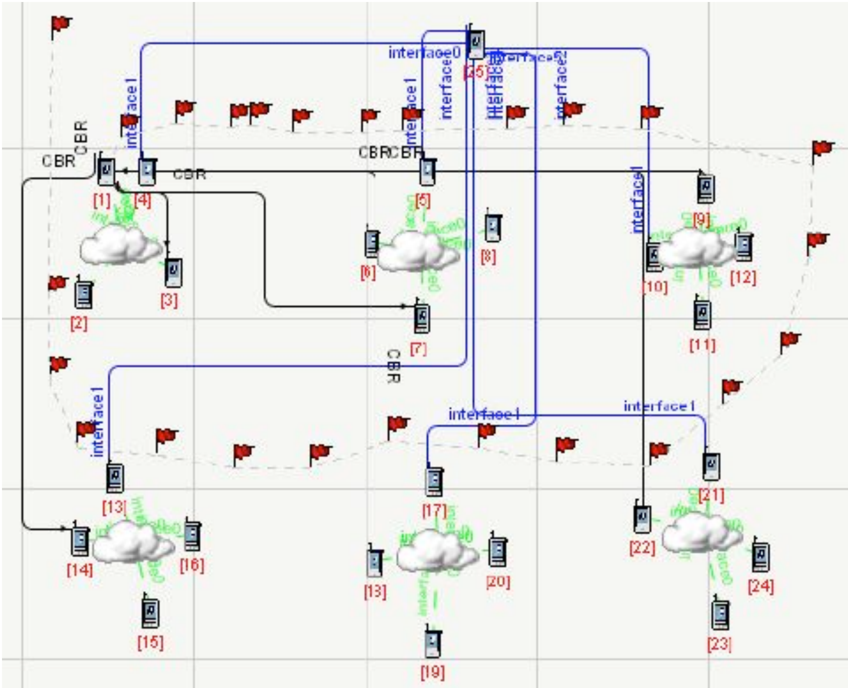


Figure 12. Simulated Network Topology (6BSs, 18 SSs)

In the last figure, nodes 4, 5, 9, 13, 17 and 21 are the BSs and the remaining are the SSs at a particular instance under each of the BSs. Node 25, connected to all the BSs, indicates the ASN-GW. Non-random movement of a single MSS (MS1) has been considered which performs six consecutive handovers. Simulation scenarios consisting of simultaneous random movements of multiple SSs are currently not considered. The flagged path shows the movement direction of the MS1 starting from BS4, which is the initial SBS. The handover sequence of MS1 is BS4 → BS5 → BS9 → BS21 → BS17 → BS13 → BS4.

Table 1 below shows the key simulation parameters.

Parameters	Value
Number of BSs	6
Number of SSs under each BS	3
Inter BS distance	400m
Channel Frequencies	2.4 - 2.45 GHz
PHY 802.16-FFT-Size	2048
MAC Propagation Delay	1ms
Simulation Time	240secs
Traffic	Constant Bit Rate

Table 1. Simulation Parameters

While some protocols are used directly as applications, such as FTP and Telnet, others are used to simulate real network applications. Applications such as CBR (Constant Bit Rate) can be configured to simulate a large number of real network applications by mimicking their traffic pattern. For example, audio traffic and video codecs (time critical traffic types) infuse traffic at a constant rate into the network and can be accurately simulated by appropriately configuring the CBR application in QualNet. In this simulation scenario, the MSS (executing handover) sent and received 200 half kilobyte items of CBR traffic to and from different other nodes at a rate of one half kilobyte item every second.

The figures of various stages have been tabulated in Table 2 in seconds.

Network Topology Acquisition Phase			Handover Phase		
MOB_SCN_REQ	MOB_SCN-RSP	MOB_SCN-REP	MOB_MSHO-REQ	HO_IND	Time taken
34.91743154	34.92745092	35.27761165	35.57776174	35.61778176	0.70035
58.00897154	58.01899093	58.36915167	58.58926174	58.62928175	0.62031
110.3551316	110.365151	110.7153116	111.0174617	111.0574817	0.70235
122.6412715	122.6512909	123.0014517	123.1815417	123.2215618	0.58029
149.3746315	149.3846509	149.7348117	149.9349117	149.9749318	0.6003
174.8873816	174.8974009	175.2475622	175.2575813	175.2875823	0.400201

Table 2. Total time taken for NTAP and handover (seconds)

4.2.5.2 Analysis

Analytical results of typical 802.16e are not available at the time of this research work. Hence a comparison of the simulated results with typical values is not possible at the time of writing this thesis.

Analyzing the simulation results (and presuming that it is comparative to typical values of 802.16e), it is observed that the process before actual handover (authentication, synchronization etc) takes upto 700 msec (CBR implementation specific with moderate traffic environment). This time is quite high considering the fact that this process only decides the final BS to do the handover before the MSS disconnects from the SBS. The actual handover happens after this. For each handover such a long time for the BS selection procedure is a waste of time. It must be noted that during most of this time, all uplink and downlink traffic is stalled. This is highly detrimental to delay sensitive traffic such as VoIP or bit streaming video.

Similar to its contemporary technologies like WLAN and third generation (3G) systems, 802.16e too suffers from large handover delays and resource wastages. Lengthy and blind scanning activities are one of the primary reasons. However, in 802.16e such blind scanning is partially avoided with the SBS periodically gathering and broadcasting information about the neighboring BSs. A MSS that needs a handover then scans the advertised BSs to select the potential new target BS. However, as the standard does not specify anything regarding the number of advertised BSs, hence chances of unnecessary and excessive scanning activities are always there.

Ranging and association activities follow scanning. For multiple neighboring BSs, these activities are repeated for each of the BS. As stated, a MSS might need all these activities including scanning to be performed in multiple iterations. Also, the standard does not clearly specify the number of iterations. The scanning duration (measured by the number of frames) depends on the number of BSs scanned. Therefore, more the number of BSs scanned more is the scan duration and more is the time required for the associated activities, which would increase the overall handover delay. Moreover, since during the scanning interval, all kinds of transmissions between the MSS and the SBS are paused, it leads to significant throughput degradation and particularly hampers the QoS of delay-sensitive real-time traffics [11].

Further, before the final selection of the new target BS, the MSS selects multiple potential candidate BSs from the advertised list of all neighboring BSs through scanning and synchronization activities. Each of the selected BSs then allocates individual ranging slots for probable future synchronization activities. When the new target BS is finally decided, all the allocated slots (except those of the newly selected target BS) are wasted. This adds to the volume of resource wastages during handover [11]. Limiting the number of BSs scanned can reduce such resource wastages and unnecessary slot allocations.

Additionally it is believed that a single BS gives the best performance in terms of resource wastage. Once a BS has been selected for handover, the number of steps taken for the handover can be drastically reduced. The sooner this decision is taken the better. Ideally, if the BS selection procedure is done before the Network Topology Advertisement Phase, it gives enough room to optimize the steps that follow. It is envisaged that a joint optimization of the Network Topology Advertisement Phase and the Actual Handover Phase will reduce the total handover time quite significantly.

Looking at the analysis results, it can be seen that the Scanning Activity takes about 350ms during which all other uplink and downlink activities at the MSS is stalled. Reducing this scanning duration can greatly reduce the overall time to select the final BS for handover. Also the 200ms of time between the MOB_SCN_REP message and MOB_MSSHO_REQ should be targeted to be reduced. Other messages across the two stages (NTAP and AHOP) can be combined together in order to optimize and reduce the overall handover time.

4.3 Summary

Mobile WiMAX (IEEE 802.16e) hard handover process comprises two stages. Network Topology Acquisition Phase (NTAP) involves the MSS acquiring the neighbouring base station (NBS) information from the SBS. It scans all the suggested neighbouring base stations for a considerable amount of time (denoted in frames). It decides on a couple of neighbouring base stations and generates reports. In the Actual handover Phase (AHOP), the SBS gets pre-notification information from these two base stations where it negotiates with each of them on band width, QoS etc required by the MSS seeking a handover.

All these activities consume a considerable amount of time. It is felt that unnecessary scanning occurs in the standard procedure that can be reduced if the target base station is chosen before the scanning activity. MSS's past movement history (current location, speed and direction of movement with respect to the serving and potential target base stations) will help predict the future movement and therefore the potential target base station(s) that are closest to that direction. A few past research activities on location predication algorithms have been cited.

The simulation scenario comprised of a sequence of six handovers which forms the basis of all the simulations in this thesis. Such a system was chosen in order to average the results and prove the consistency of the algorithm without using stochastic simulations. Since CBR traffic can be used to mimic a large variety of real network applications, it has been used in all simulations in this thesis. The simulation results have been tabulated and analyzed.

5 Proposed BS Selection Procedure and Simulation Results

5.1 Analysis Deductions

Based on the analysis results at the end of the last chapter, it can be deduced that:

- Some of the stages in the standard handover that takes long time need to be reduced.
- If the target BS for handover is decided prior to scanning, some of these stages may need less time.
- The overall iterations in the standard procedure can be reduced. Optimizing the number of steps through removal of some steps and combining a few other steps can be investigated.

5.2 Proposed Scheme

The scheme addresses all the derivatives of the analysis done so far. It involves a two pronged approach comprising of a BS station selection procedure and optimization in the steps before the MSS finally terminates from the SBS. It is denoted in the next figure.

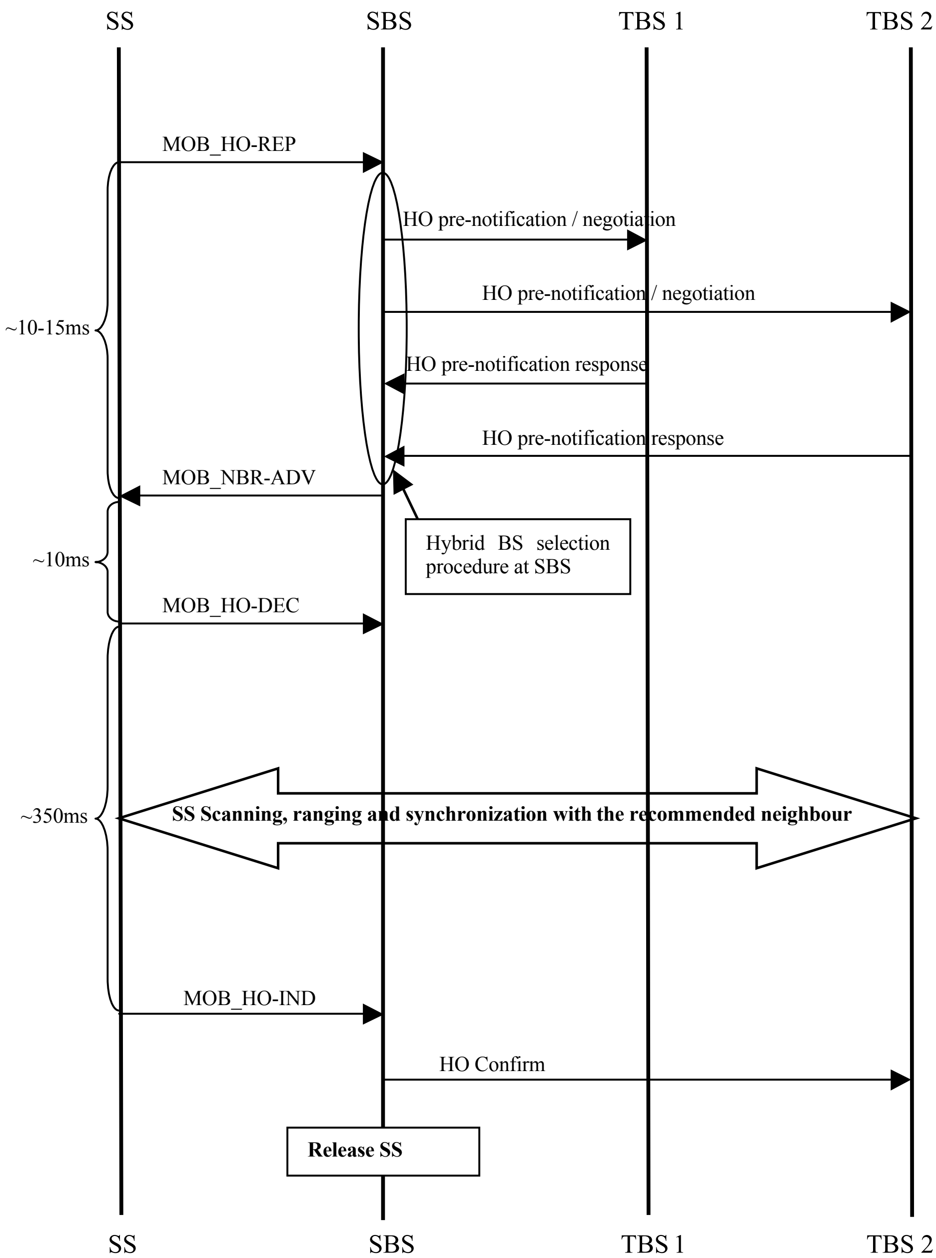


Figure 13. Proposed optimization along with Hybrid BS selection procedure

5.2.1 Hybrid BS station selection procedure

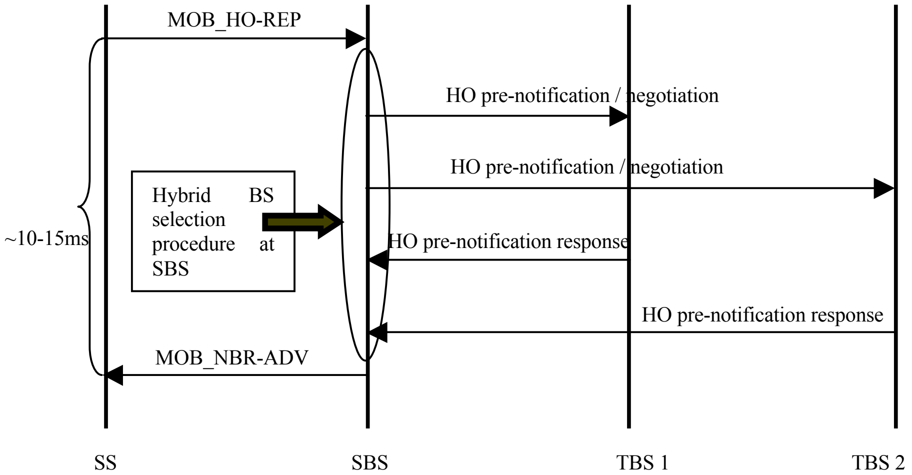


Figure 14. Hybrid BS selection procedure

5.2.1.1 Background

Over the last few years, much research has been focused on limiting and / or reducing the disruptive effects of excessive scanning activities during selection of the new SBS for a potential handover. An Adaptive Channel Scanning Algorithm (ACSA) [16] is used in IEEE 802.16e to estimate the total scanning time required by an MSS and to allocate scanning intervals to multiple SSs by interleaving them with the data transmission intervals. However, instead of minimizing excessive scanning activities, this scheme actually focuses on minimizing the disruptive effects of excessive scanning activities on the different application traffics. Selection of the target BS based on the mean

CINR and Arrival Time Difference (ATD) information of each neighbouring BSs (before any kind of synchronization and association activities are performed) was proposed in [11]. According to that scheme, an IEEE 802.16e-supported MSS can get this neighbouring BSs-related information from the broadcasted advertisements of the SBS. As the scheme does not consider the MSS's direction of motion as well as the current load of the selected BS, it might lead to unwanted ping-pong activities as well as call drops.

In a paper [15], presented by the author, a fast and hybrid BS selection procedure has been proposed for IEEE 802.16e systems that can result in significant reduction of unnecessary scanning activities. Selection of the new target BS for a potential handover not only depends on the signal strength but also on other parameters like the MSS's direction of motion, current load of the neighbouring BSs and the location of the neighbouring candidate BSs with respect to the current SBS. Simulation studies have shown that in comparison to the standardized IEEE 802.16e handover approach, the proposed scheme has the capabilities of reducing both the overall handover latency and the wastage of channel resources.

5.2.1.2 Location Prediction algorithms

In [17], a new approach for system integration of future wireless networks have been presented, based on the evaluation of foreign party based measurements to support (vertical) handover. For the new proposal, referred to as Hybrid Information System (HIS), it is suggested to collect information about the current state within the covered cell to provide this information to other mobiles that are willing to handover. The presented approach offers a great potential since scanning procedures can be minimized or even avoided.

In [10], mobility prediction has been reported as an effective means to decrease call dropping probability and to shorten handover latency in wireless cellular networks. They have proposed a new mobility prediction algorithm, which stores and uses the history of the user's positions within the current cell to predict the next cell.

In [22], a User Mobility Profile (UMP) framework is developed for estimating service patterns and tracking mobile users, including descriptions of location, mobility, and service requirements. UMP is a combination of historic records and predictive patterns of mobile terminals, which serve as fundamental information for mobility management and enhancement of quality of service (QoS) in wireless multimedia networks. For each mobile user, the service requirement is estimated using a mean square error method. Moreover, a new mobility model is designed to characterize not only stochastic behaviors, but historical records and predictive future locations of mobile users as well. Therefore, the approach incorporates aggregate history and current system parameters to acquire UMP. In particular, an adaptive algorithm is designed to predict the future positions of mobile terminals in terms of location probabilities based on moving directions and residence time in a cell. The proposed schemes are effective on mobility and resource management by evaluating blocking/dropping probabilities and location tracking costs in wireless networks.

5.2.1.3 Scheme

The SBS along with the MSS and the backbone network will jointly predict and decide a specific neighboring BS as the most suitable candidate for a potential handover activity before the starting of the scanning and related activities. The scanning activity is thus limited to the selected BS only (instead of the MSS scanning all the advertised BSs). This would result in reduced scan duration along with significantly minimized ranging and association activities. The prediction of the neighboring BS (suitable for a particular handover activity) depends on the following key parameters:

(i) direction of the MSS's movement
(ii) average time interval between each hop of the MSS
(iii) current load of a neighboring BS
(iv) position and coverage of a neighboring BS with respect to the current SBS

Selecting the ideal BS for the scanning activity is a joint decision of the SBS and the concerned MSS with the SBS taking the majority of the 'decision-making responsibilities'. The decision-making activities performed by the MSS and the SBS have been described below.

5.2.1.3.1 MSS module

The various location prediction algorithms either consider the history of the MSS's direction of movement over a scheduled time-period or consider the MSS's mobility parameters like velocity, angle or direction to select the future BS. The MSS's future movement direction is evaluated depending on the MSS's movement history over a small sample of time. All these data required to correctly locate the current position of a mobile MSS and predict the future location is captured at the MSS and regularly fed to the SBS at periodic intervals.

5.2.1.3.2 BS Module

The BSs can coordinate among themselves with the help of the underlying backbone network. In the scheme, it is assumed that the SBS keeps track of its different neighboring BSs up to a certain distance. Apart from the location and coverage information of the individual neighboring BSs with respect to the SBS, at any particular instance, information of the current load of the neighboring BSs, are also stored dynamically in the SBS (through the backbone). Load factor plays a critical role in selecting the new target BS for a potential handover activity [2]. In order to avoid incorrect 'link-ups', the proposed scheme considers only those neighboring BSs as potential candidates for becoming an 'ideal target BS', whose current available wireless resources are sufficient to sustain the requirements for the on-going connection. This is unlike the current 802.16e scenario [18] where the load factor is overlooked while selecting the candidate BSs. It is assumed that the BSs with the help of the backbone network exchange load information periodically. To accurately measure the amount of traffic load per BS, the mechanism used in [8][9] is being considered, based on the MAC state diagram showing data transmission occurrences in 4G mobile systems [7].

The SBS does all the mathematics to evaluate the ideal BS for the handover as stated in [15]. The exact course of events and mathematics involved is explained below.

5.2.1.3.3 Explanation

Each MSS maintains a Temporary Movement Database (TMDB), which is updated periodically. It contains the coordinates of the current location of the MSS. It communicates the TMDB information to the SBS through the MOB_HO_REP message (a new message introduced here), which is sent periodically similar to MOB_NBR-ADV.

The SBS maintains a Potential Handover Database (PHDB), which is also updated periodically. On receiving the MOB_HO-REP message, the SBS, based on the received TMDB information, computes the future mobility pattern of the MSS over the next T_{MS} secs. Based on this, out of the total number of neighboring BSs, N_{NBS}, the SBS discards those BSs that do not match the mobility pattern and only selects the remaining N number of BSs (N << N_{NBS}), which are likely to be visited by the MSS.

Further selections of M probable BSs, out of these N short-listed BSs (M << N), are made based on the integration of the load and the coverage factors. Let us assign W_{LF} and W_{CF} as the individual weight values to the load and the coverage factors respectively. The function to predict the probability of a BS (P_{TBS}) to be the next target BS is given by

$$P_{TBS} = \sum_{i=1}^{N} CiWi = C_{LF} * W_{LF} + C_{CF} * W_{CF}$$

where $0 \leq W_{LF}, W_{CF} \leq 1$ and Ci, Wi and N indicates the individual factors, assigned weights and the number of factors, respectively.

Then the M neighboring BSs are sorted with the two most suitable BSs coming to the top.

A small optimization is introduced at this point, where a message from the NTAP phase and a message from the AHOP phase are combined into one. Handover pre-notification and negotiation processes are carried out by the serving base station with the best two BSs. This involves sending a pre-notification / negotiation request to each of the two BSs containing the MSS ID, the required bandwidth and the QoS requirement of the MSS (information contained in the pre-notification message that follows after the SBS receives a MOB_MSSHO_REQ message from the MSS during the AHOP phase). It also contains information contained in the negotiation message that follows after SBS receiving MOB_SCN_REQ message from the MSS during the NTAP phase. The SBS knows of the MSS requirements from its communication with it.

Each of these two BSs replies with a pre-notification / negotiation response message which contains success or failure information of the two particular target BSs confirming if they meet the requirements of the MSS. This is primarily the same as the pre-notification response message in the standard AHOP phase. The SBS finally decides the single best candidate BS for handover and communicates the same through the MOB_NBR-ADV message to the MSS. It also includes information that is normally contained in a

MOB_HO_RSP message and the BSID of the most suitable neighboring BS for the potential handover.

5.2.1.4 Simulation

In the initial stages of the research work, the performance of the proposed scheme of reducing the scanning time (by hybrid BS selection procedure) without any pre-handover optimization was tested. The simulation environment was the same as mentioned in Section 4.2.5.1.

An improvement has been achieved in the total scanning latency in case of each handover performed by the SSs. Fig. 15 compares the overall scanning time of the proposed scheme with that of the 802.16e conventional scheme [2]. In the simulation scenario, the SBS selects only one BS and passes its information to the MSS through the MOB_NBR-ADV. According to the conventional scheme, MOB_NBR-ADV broadcasts the information about N number of neighboring BSs where N is unspecified. In this work, the number of BSs to be scanned has been reduced to one and hence this has significantly reduced the total length of the MOB_NBR-ADV message. The scanning duration mainly depends on the number of BSs to be scanned and the number of processed frames during scanning iteration. So, using the proposed algorithm, prior to any scanning and association related activities, the number of neighboring BSs to be scanned has been reduced to only one.

This strategy also significantly reduced the number of scanning iterations and the number of processed frames. MS1 sends MOB_SCN-REP messages to the SBS regularly to report the outcome of the ongoing scanning activity. The time duration between the start of a neighboring BS scanning and the end of the Network Topology Acquisition Phase (MOB_SCN-REP message) has been tracked. This duration is four frames. This value was reduced by one frame because of less scanning required as per this algorithm. In figure 15, each of the eight instances of MOB_SCN-REP message shows a significant reduction in the total scanning time by the proposed scheme. It must be noted that only six of the eight scanning instances culminated in a successful handover. Whereas in the conventional scheme it took 320 ms to complete a scanning activity, in the proposed scheme the time reduced to 300 ms, which implies a 20 ms overall improvement in the scanning time and the handover delay. In the simulation, this improvement was found to be consistent for all the handover activities performed.

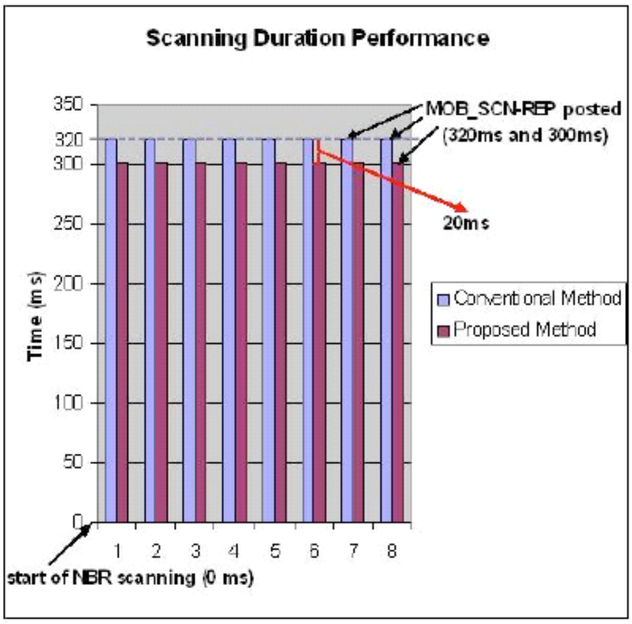


Figure 15. Scanning Time Vs Instances of MOB_SCN_REP messages

5.2.2 Pre-handover optimization

A part of the optimization already takes place during the BS selection procedure as explained in the last section. Once the BS has been decided, things become easier for the SBS and the MSS. With reference to the standard procedure in IEEE 802.16e (Fig 11), it can be seen that it takes upto 700ms for the MSS to decide upon a BS for a potential handover. Using a location based decision making process for selecting a BS, unnecessary scanning activity can be reduced. This has been described in the last section. Furthermore, it is felt that a few steps more can be curtailed and the total pre-handover steps can be optimized prior to SBS-MSS disconnection.

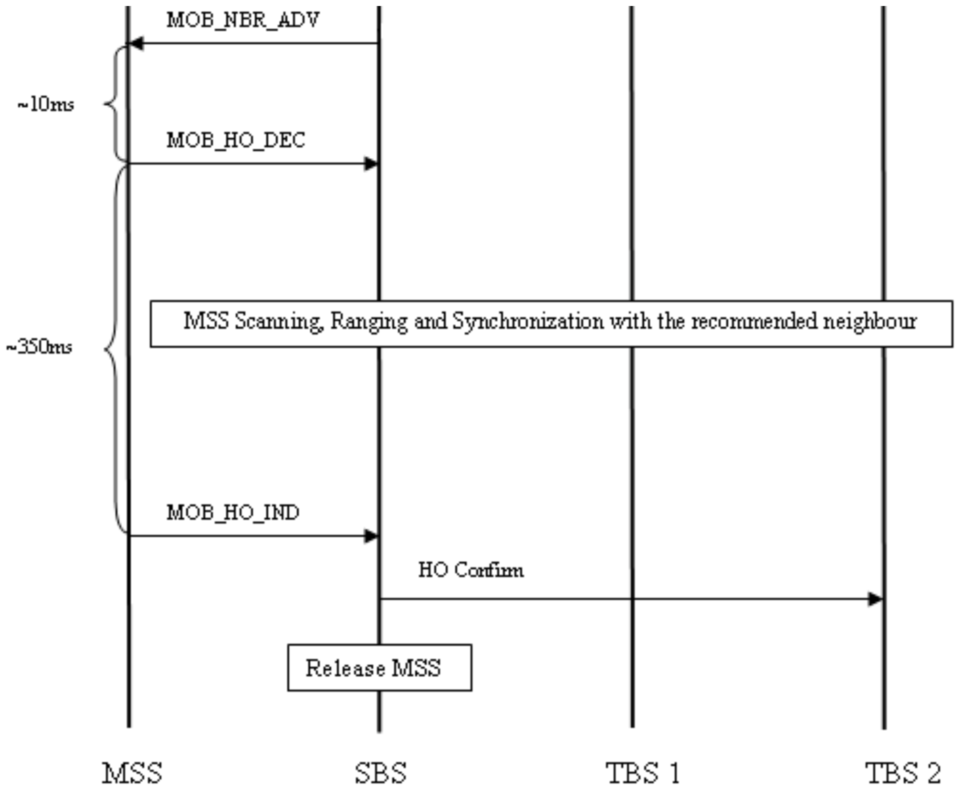


Figure 16. Further optimization prior to MSS release

5.2.2.1 Explanation

This process can be achieved by two methods: combining multiple messages and rearranging the sequence of certain other messages.

MOB_NBR-ADV contains information about the BS to be scanned by the MSS. However, in [5] it has been claimed that scanning procedure can be totally removed if the channel information is obtained by BS-to-BS backbone communication. Thus it was felt that whatever the situation, the decision is taken by the SBS whether a scanning is required or not. This decision can be passed on to the MSS by setting a flag in the MOB_NBR-ADV message. Thus, the purpose and structure of the MOB_NBR-ADV message is significantly changed in this proposal. It thus contains not only information about the target BS but also a flag that tells the MSS of a requirement of scanning.

It is assumed that the scanning type is being exchanged between the MSS and SBS through the MOB_HO-REP / MOB_NBR-ADV message pair. It is also assumed that scan duration, interleaving interval and scan iteration are already allotted to the MSS and are generally a constant value because the number of BSs that need to be scanned is only one (BS is already decided). Both the messages MOB_HO-REP and MOB_NBR-ADV are exchanged periodically (~30msec).

A new message MOB_HO-DEC is being introduced which the MSS sends to the SBS to signify the start of the scanning for measuring Received Signal Strength Indication (RSSI), which is important for ranging. This serves as an indication that the MSS has decided to carry on the handover starting with optional initial ranging and optional scanning. Without receipt of this message, all the steps following MOB_HO-DEC does not materialize. If the MSS decides against the handover it does not send the MOB_HO-DEC to the SBS. The SBS waits for a predefined time (timer dependent) after MOB_NBR-ADV for receipt of a MOB_HO-DEC.

As mentioned in [1], transmit power level for initial ranging is denoted by:

$P_{TX} = \mathrm{EIR}x\mathrm{P}_{\mathrm{IR,\,MAX}} + \mathrm{BSEIRP} - \mathrm{RSSI}$,

where the parameters EIRxPIR, MAX, MAX and BSEIRP are provided by the BS over the DCD message, and RSSI is the received signal strength at the MSS. EIRxPIR, MAX is the maximum equivalent isotropic received power computed for a simple single antenna receiver as RSSIR,MAX – GANT_BS_Rx, where RSSIR,MAX is the received signal strength at antenna output and GANT_BS_Rx is the received antenna gain. The BSEIRP is the equivalent isotropic radiated power of the BS, which is computed for a simple single-antenna transmitter as PTx + GANT_BS_Tx, where PTx is the transmit power and GANT_BS_Tx is the transmit antenna gain. Hence now the scanning and ranging of the decided BS is done at this point of time (if decided by the SBS). In the standard procedure, based on the range-response message (RNG-RSP) from the BS, the SS can adjust its transmission power and timing. However, in the current proposed algorithm such a process is not considered.

Downlink synchronization will also take place between the single BS and the MSS (instead of multiple BSs in the standard procedure) where the channel information exchange and contention resolution of the lone target BS takes place.

Once the scanning, ranging and synchronization is completed, the MSS sends MOB_HO-IND to the SBS to mark the beginning of the termination process with the SBS. The SBS then sends a HO confirmation message to the new target BS with which the MSS is executing the handover. Both these messages are similar to the standard WiMAX procedure and serve the same purpose.

5.2.2.2 Simulation

The simulation was again carried out on Qualnet 4.0. The same model as described in Section 7.2.5.1 was used to test the proposed technique. Each of the 6 different handovers gave results as described in the graphs. The y-axis shows the time taken to execute. The x axis shows the stages where the time has been measured.

On the graph stage 1 is the instance of MOB_NBR-ADV message in a standard procedure and Hybrid BS selection procedure. However, in the proposed algorithm it is the instance of the new periodic message MOB_HO-REP.

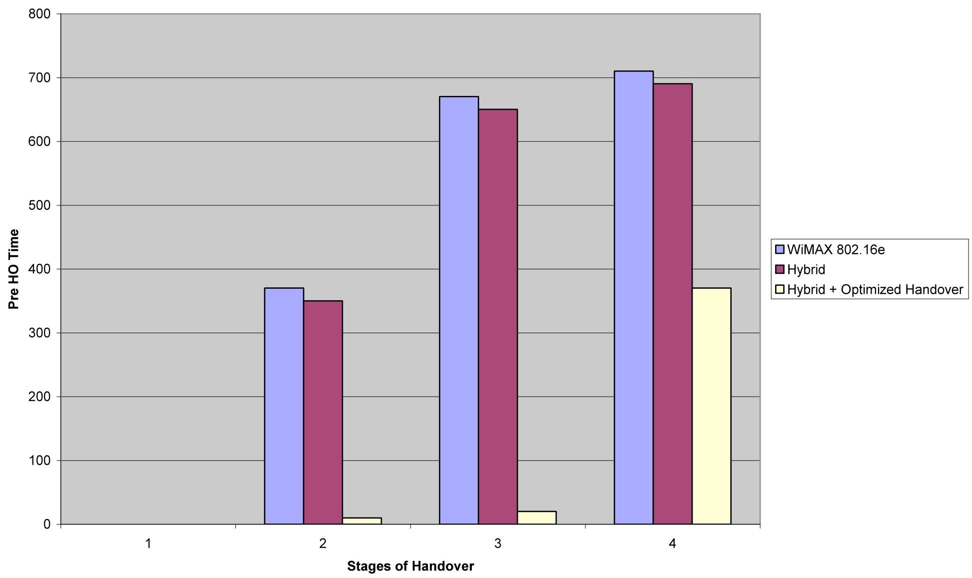
Stage 2 is the instance when the BS selects suitable candidates for the potential handover activity. In the standard procedure it may be one or multiple numbers of BSs selected. In our proposed algorithm it is always one.

Stage 3 denotes the stage when the MSS sends the MOB_MSSHO_REQ message to the SBS to get further recommendation for the best candidate BS for handover. However, in the proposed algorithm, with the absence of such a stage, this denotes the instance of the MOB_HO-DEC message.

Stage 4 is the instance of MOB_HO-IND where the MSS gives the signal to SBS for termination.

With reference to Section 4.2.5.1, this simulation was carried out wherein six handovers take place and the results obtained for each of them are shown in the graphs.

(1)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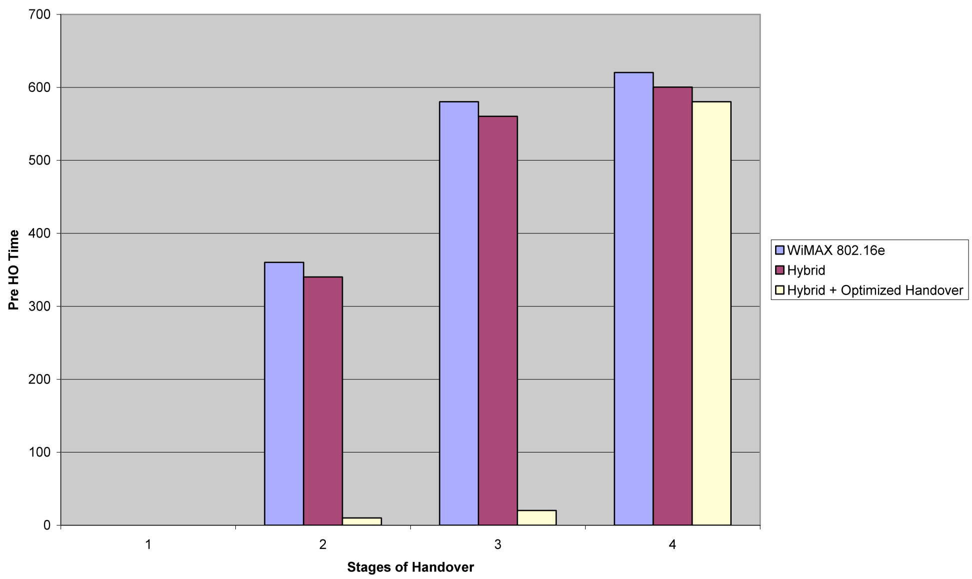
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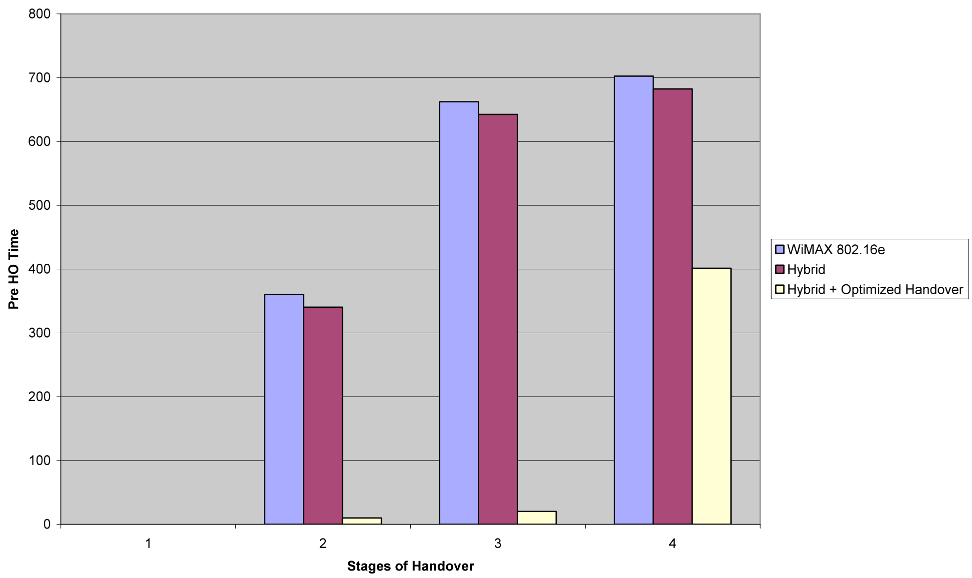

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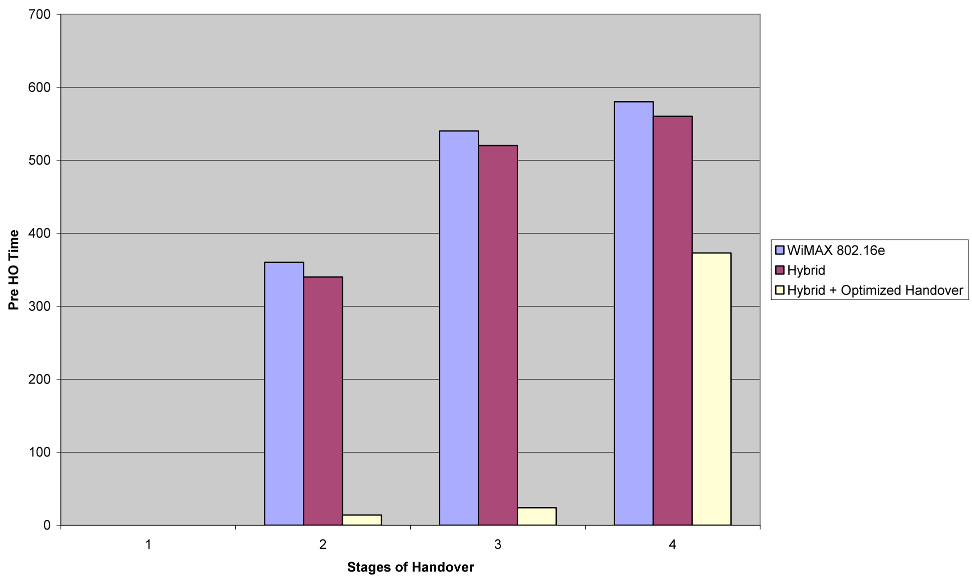

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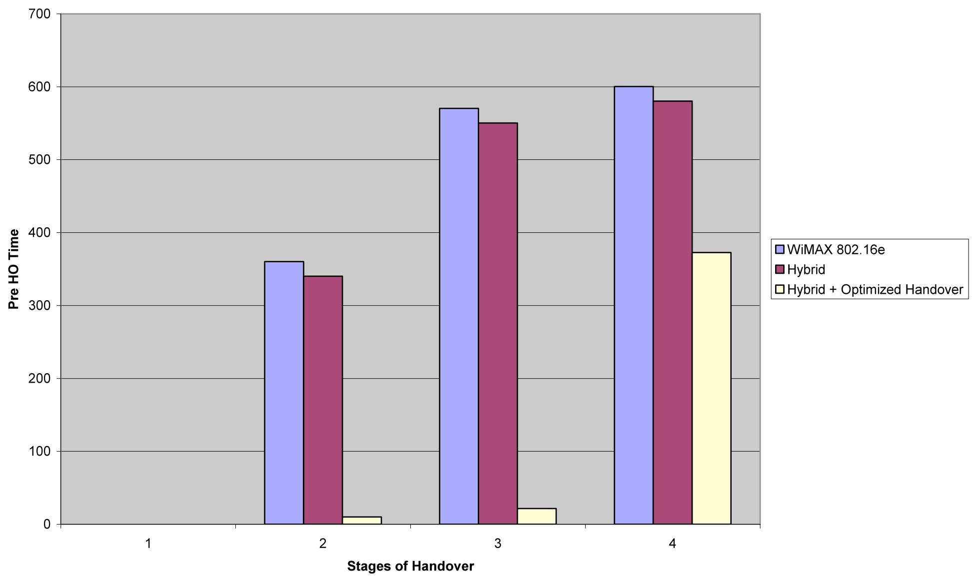
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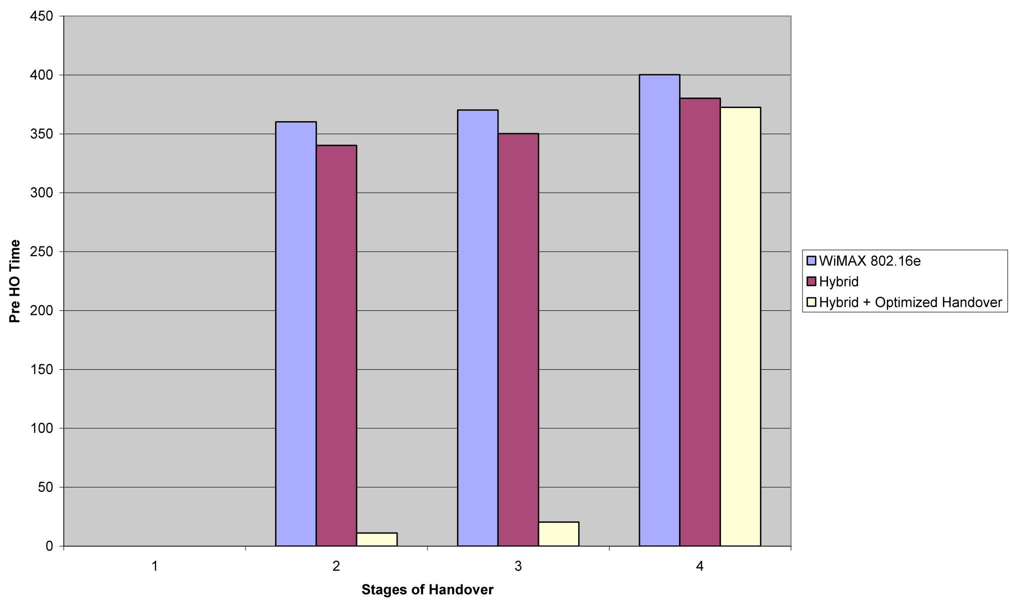
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WiMAX 802.16e
Hybrid
Hybrid + Optimized Handover

5.3 Summary

Based on the analysis done in the last chapter, this chapter begins with some important deductions. It is beyond doubt that some of the stages during the network topology acquisition phase take a significantly long time that needs to be reduced in order to support time-critical traffic like VoIP and video bit streaming. The current target BS selection procedure is primarily based on scanning all the neighbouring BSs which takes the lion's share of the total handover time. If the target BS is selected prior to scanning, the number of BSs scanned is reduced. This will also help reduce the number of iterations of message exchanges occurring between the mobile MSS, the SBS and the neighbouring BSs which are potential target BSs for handover.

Based on these observations, this chapter presents a two pronged approach of the proposed method of the total handover process. One targets the BS selection process based on using location prediction algorithms and the other optimizes all the iterations of message exchanges in order to achieve a substantial improvement.

6 Conclusion and Future Work

This chapter gives an overall conclusion of the work documented in this thesis. Potentially interesting issues that could be addressed in future work to extend this thesis are also presented.

6.1 Conclusions

The purpose of this research work was to address the handover issue of WiMAX with focus on time. Currently the WiMAX standard states that hard handover is compulsory. Macro diversity handover and fast base station switching are both optional. Hence hard handover is the focus of this work.

Extensive analysis was done using the Qualnet 4.0 simulator to determine the total time taken for the initial process from handover initiation and decision making (for target BS). The total time was found to be over 700 milliseconds. It was believed that this time could be reduced. Alternative methods of selecting the base station for handover were investigated. It was found that location and direction of movement based base station selection approach can help reduce the number of unnecessary scanning activities. Scanning takes the lion's share (>350ms) of the total time and hence unnecessary scanning should be reduced.

It is felt that the unnecessary scanning occuring in the standard procedure can be reduced if the target base station is chosen before the scanning activity. MSS's past movement history (current location, speed and direction of movement with respect to the serving and potential target base stations) will help predict the future movement and therefore the potential target base station(s) that are closest to that direction.

A research paper has been published by the author where a simple location prediction algorithm applied to select the target BS produces a 20ms reduction in the total scanning time. Subsequent investigation led to the belief that once a BS has been selected in the above method, many subsequent steps in the total handover process can be reduced by sheer handover optimization. Such optimization can be achieved by a mixture of combining multiple messages and rearranging the sequence of certain other messages. These led to a substantial reduction of the total time.

6.2 Future Work

Since handover optimization can lead to a significant reduction in the total pre-handover time, it can be further extended to post HO_IND message (core handover stage) where the steps involving termination with the SBS, authorization and registration with the target BS takes place. Such a view has been expressed in [5], where it states that the message exchange during re-entry can be shortened by means of backbone network assistance. Thus in the current work scenario, this can take place immediately after the target BS has been decided.

Also, the current work is restricted to hard handover only. Possibilities of extending this work to macro-diversity and fast base station switching (soft handover techniques) can be worthy of an investigation. Although these are soft handover techniques and currently optional in the WiMAX standard, the BS selection procedure based on location prediction algorithms and current load factors of the target BSs give an alternative way of deciding the target BS. WiMAX is a technology wherein there are a relatively small number of BSs (inter BS distance can be tens of kilometers). It makes better sense to predict BSs based on a user's direction of movement rather than just the RSSI. It is believed this will lead to fewer handovers for a user moving from A to B. From a system perspective, reducing the number of handovers is highly desirable. However, this needs to be investigated in more detail.

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8 Appendix

<u>Implemented Features in Qualnet 4.0</u>

The MAC802.16 model of QualNet 4.0 has implemented features defined in both IEEE 802.16 and IEEE 802.16e. The detailed list of features:

- Point to Multi-Point (PMP) mode.
- Time Division Duplex (TDD) mode.
    - MAC frame is equally 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.

- Dynamic flow management including service flow addition, deletion and change.

- Bandwidth management.

    - Five service types: UGS, ertPS, rtPS, nrtPS and BE.

    - Polling for bandwidth requests.

    - Both contention based and polling based bandwidth requests.

    - Bandwidth allocation based on request and service types.

- 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.

- 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 (please refer to the user's guide of PHY802.16 for details).
  - Dynamic switch of burst profiles based on CINR.
  - Supporting 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.
- Interface other networks such as ATM, 802.3, 802.11 at network layer.
- Support 802.16 OFDMA PHY.
- Assumes balanced link budget for downlink and uplink.

Omitted Features in Qualnet 4.0

- Mesh mode.
- Frequency Division Duplex (FDD) mode.
- PDU packing/unpacking, fragmentation/reassembly and CRC.
- Transmission power adjustment during ranging.
- CDMA based ranging and bandwidth request of OFDMA PHY.
- 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 application has been modified to provide correct QoS parameters. Other applications will use some default QoS parameters only based on their service types. No explicit admission control.
- No support for association level 1, 2 and soft handoff.
- No support for sleep/idle mode.