10-29-2009

Handover Performance in the Mobile WiMAX Netrworks

Yongxue Yu
University of South Florida

Handover Performance in the Mobile WiMAX Netrworks

by

Yongxue Yu

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering
Department of Electrical Engineering
College of Engineering
University of South Florida

Major Professor: Ravi Sankar, Ph.D
Richard D, Gitlin, Sc.D
Jing Wang, Ph.D

Date of Approval
October 29, 2009

Keywords: Hysteresis, Handover Threshold, Handover Latency,
Mobility Management, Power Management

ACKNOWLEDGMENTS

This Master's thesis was carried out in the *i*CONS group of the University of South Florida.

I would like to thank Prof. Ravi Sankar for his supervision, knowledge, support and persistent encouragement during my graduate studies at the Department of Electrical Engineering, University of South Florida. My studies would not have been completed without the help and the friendship of others including iCONS group members: Kun Li, Ismail Butun and Murad Khalid.

Finally, I want to express my deepest gratitude to my wife, Zhe, for the endless support and understanding throughout my studies and during this thesis process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

3GPP/2	3rd Generation Partnership Project /version 2
AAA	Authentication, Authorization and Accounting
AAS	Advance Antenna System
AC	Access Concentrator
ACK	Acknowledgment
AES	Advanced Encryption Standard
AK	Authorization Key
AMC	Adaptive Modulation and Coding
ASN	Access Service Network
ASN-GW	Access Service Network Gateway
BE	Best Effort
BPSK	Binary Phase Shift Keying
BS	Base Station
CCI	Co-Channel Interference
CDMA	Code Division Multiple Access
CID	Connection Identifier
CP	Cyclic Prefix
CN	Corresponding Node
CRC	Cyclic Redundancy Check
CSN	Connectivity Service Network
DCD	DL Channel Descriptor
DL	Downlink
DoA	Direction of Arrival
DP	Decision Point
DSL	Digital Subscriber Line
ertPS	Extended Real-Time Polling Service
FBSS	Fast Base Station Switching
FCH	Frame Control Header
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
GPRS	General Packet Radio Service

GSM	Global System for Mobile communication
HA	Home Agent
HARQ	Hybrid Automatic Repeat Request
HHO	Hard Handover
HO	Handover/Handoff
HSDPA	High Speed Downlink Packet Access
HSOPA	High Speed OFDM Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IP (IPv4 or IPv6)	Internet Protocol (version 4 or 6)
ISI	Inter Symbol Interference
ITU	International Telecommunication Union
LTE	Long Term Evolution
MAC	Medium Access Control
MAP	Mapping
MBWA	Mobile Broadband Wireless Access
MDHO	Macro Diversity Handover
MIH	Media Independent Handover
MIMO	Multiple Input Multiple Output
MPEG	Moving Picture Experts Group
MS	Mobile Station
NACK	Negative Acknowledge
NAP	Network Access Provider
ND	Neighbor Discovery
NIST	National Institute of Standards and Technology
NRM	Network Reference Model
nrtPS	Non Real-Time Polling Service
NS-2	Network Simulator version 2
NSP	Network Service Provider
NWG	Network Working Group
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PDU	Protocol Data Unit
PSTN	Public Switched Telephone Network
QAM	Quadrature Phase Shift Keying
RA	Router Advertisement
RRA	Radio Resource Agent

RRC	Radio Resource Controller
RRM	Radio Resource Management
RTG	Receive/Transmit Transition Gap
rtPS	Real-Time Polling Service
SAP	Service Access Point
SDMA	Space-Division Multiple Output
SDU	Service Data Unit
SIM	Subscriber Identity Module
SIMO	Single Input Multiple Output
SM	Spatial Multiplexing
SNR	Signal-to-Noise Ration
S-OFDMA	Scalable OFDMA
SS	Subscriber Station
TCP/IP	Transmission Control Protocol/Internet Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UCD	UL Channel Descriptor
UGS	Unsolicited Grant Service
UL	Uplink
UMTS	Universal Mobile Telecommunication System
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Network
VR-RT	Variable-Rate Real Time

HANDOVER PERFORMANCE IN THE MOBILE WIMAX NETWORKS

YongxueYu

ABSTRACT

Mobile terminals allow users to access service while on the move. This unique feature has driven the rapid growth in the mobile network industry, changing it from a new technology into a massive industry in less than two decades.

In this thesis, an in-depth study of the handover effects of mobile WiMAX networks is carried out. The mobile WiMAX technology is first presented as literature study and then the technologies of handovers for previous generations are introduced in detail. Further, the hard handover of the mobile WiMAX is simulated by Network Simulator-2 (NS-2). In addition, the “ping-pang” effect of handover was investigated and the call blocking and dropping probabilities are implemented using MATLAB. The goal is to find out which parameters have the significant impact on the handover performance.

The results showed that the threshold and hysteresis margin of the handover should be selected by considering the tradeoff between the “ping-pang” effect and the extra interference causing to neighboring cells due to the poor quality link. The handover latency of mobile WiMAX is below 50 ms with the traveling speed of mobile station up to 20 m/s.

CHAPTER 1

INTRODUCTION

1.1 Background

The growing demand for mobile Internet and wireless multimedia applications has motivated the development of broadband wireless-access systems in recent years. Mobile WiMAX was the first mobile broadband wireless-access solution based on the IEEE 802.16e-2005 standard [1] that enabled convergence of mobile and fixed broadband networks through a common wide-area radio access technology and flexible network architecture. The mobile WiMAX air interface is using orthogonal frequency division multiple access (OFDMA) [2] as the preferred multiple access method in the downlink (DL) and uplink (UL) for improved multipath performance and bandwidth scalability.

Depending on the available bandwidth and multi-antenna mode, the next-generation mobile WiMAX will be capable of over the air data transfer rates in excess of 1 Gb/s and support a wide range of high-quality and high capacity IP-based services and applications while maintaining full backward compatibility with the existing mobile WiMAX systems to preserve investments and continuing to support first-generation products [3]. There are distinctive features and advantages such as flexibility and the extensibility of its physical and medium access layer protocols that make mobile WiMAX and its evolution more attractive and more suitable for the realization of ubiquitous mobile Internet access.

The next-generation mobile WiMAX will build on the success of the existing WiMAX technology and its time-to-market advantage over other mobile broadband wireless access technologies. In fact, all OFDM-based, mobile broadband access technologies that have been developed lately exploit, enhance and expand fundamental concepts that were originally used in mobile WiMAX.

The IEEE 802.16 Working Group [1] focuses on Broadband Wireless Access standards. The current ongoing amendments of Working Group are including six extensions of the IEEE 802.16 as following.

The 802.16m is currently in predraft stage and being designed to focus on advanced air interface to meet the cellular layer equipments of International Mobile Telecommuncations (IMT)-Advanced next generation mobile networks. It is an amendment to air interface for fixed and mobile broadband wireless access services to push data rates up to 100 Mbps for mobile and 1 Gb/s for fixed while maintaining backware compatibility with existing WiMAX radios. The 802.11m is designed to fully utilize MIMO technology with OFDMA-based radio system.

The 802.16h is in draft stage and being designed to focus on improving coexistence mechanisms for license-exempt operation as an amendment to air interface for fixed and mobile broadband wireless access systems. The goal is to ensure that multi-vendor WiMAX systems can be readily deployed in the non-licensed bands with regard to minimum interference to other deployed 802.16 based non-license deployment. The 802.16i is in draft stage and being designed to focus on mobile management information base for MAC, PHY, and associated management procedures. The aim of the standard is to develop protocol independent methodologies for network management for multi-vendor operation.

The 802.16j is in draft stage and being designed to focus on providing multi-hop relay specification as an amendment to air interface for fixed and mobile broadband wireless access systems. The standard specifies OFDMA PHY and MAC enhancement to enable the operation of relay stations in licensed bands.

The 802.16g is an active standard and being designed to provide conformant 802.16 equipments with procedures and services and to enable interoperable and efficient management of network recourses, mobility.

The 802.16f is an active standard and being designed to focus on providing management information base as an amendment to air interface for fixed broadband wireless access systems.

The 802.16k is published standard and designed to focus on bridging of 802.16 as media access control bridges for local and metropolitan area networks.

1.2 Motivation

In the context of ubiquitous connectivity, a mobile station equipped with an IEEE 802.16 interface is likely to roam across multiple base stations in order to maintain connectivity. However, as in most mobility scenarios, finding the target base stations that best fits the mobility path and application requirements is far from being trivial. Generally the mobile device needs to scan multiple channels in order to find neighboring base stations (BSs) and select an appropriate target. This selection can be based on different criteria, for example, measured signal strength, packet delay, error ratio, throughput, and security levels. Furthermore, since channel scanning can be relatively time consuming and causes quality of service (QoS) to degrade, it is preferable for the mobile station (MS) to perform this scanning and obtain a list of neighboring BSs before it is ready to perform a handover. In fact, the IEEE 802.16e extension standard supports temporarily suspending the communication between the BS and MS in order to perform channel scanning. During this scanning period both upstream and downstream packets are buffered at the MS and BS, respectively. Recently, Rouil [4] proposed a handover mechanism, link-going down, which implements channel scanning depending on the level 2 association. The link-going down trigger predicts that the MS will be leaving the coverage area within a certain period of time. The generation of this trigger is based on a measurement algorithm used of link layer performance parameters, such as Signal-to-Interference-and Noise Ratio (SINR), received signal strength indicator (RSSI) and MAC delay. The MS in association level 2 predicts the channel quality and scans channel before the link down. Using link-going down dramatically reduces the handover latency and shows major improvements. In this research, we are going to implement this algorithm to study the influence of velocity of MS to the handover latency and predict what velocity of MS can be supported by the algorithm.

1.3 Objectives of the Research

The goals of this research involve several aspects of the handover in the mobile WiMAX.

- Study the handover technologies in cellular networks from both foundational and advanced aspects, such as the types of handovers, the handover decision, and handover optimization, etc.
- Understand the underlying technologies in the WiMAX network in terms of physical layer and MAC layer, and some advanced topics, for example, Multi-Input Multi-output (MIMO) and beamforming are introduced.
- Analyze the strength-based handover and signal-to-interference-based handover using MATLAB. In addition, the call blocking and dropping probabilities in the handover are studied. Furthermore, the impact of the speed of mobile station on the handover latency for the mobile WiMAX has been investigated.

1.4 Organization of the Thesis

Chapter 2 introduces the fundamental technologies of mobile WiMAX based on an amendment of the IEEE 802.16 standard (IEEE 802.16e) [1] for physical (PHY) and medium access control (MAC) layers.

Chapter 3 mainly introduces the technologies of WiMAX IEEE 802.16e. The features of the physical and MAC layers in WiMAX are presented.

Chapter 4 begins with the introduction of basic handover concepts for the cellular networks. The procedure and features of handover in the mobile WiMAX are thoroughly discussed.

Chapter 5 presents the simulation resultsfor the handover performance in the mobile WiMAX, based on the signal strength of handover between the two BSs. The call blocking and dropping probabilities are then discussed.

Chapter 6 sums up the conclusions based on the previous chapters and suggests topics to investigate as extension to this research.

CHAPTER 2

MOBILE COMMUNICATION NETWORKS

2.1 Evolution of Mobile Networks

Wireless access technologies have followed different evolutionary paths aimed at unified target: performance and efficiency in high mobile environment. The first generation (1G) has fulfilled the basic mobile voice, while the second generation (2G) has introduced capacity and overage. This is followed by the third generation (3G), which has quest for data at higher speeds to open the gates for truly “mobile broadband” experience [5]. Broadband refers to an Internet connection that allows support for data, voice, and video information at high speeds, typically given by wired-based high speed connectivity such as DSL (Digital Subscriber Line) or cable services. It is considered broad because multiple types of services can travel across the wide band, and mobile broadband integrates these services to mobile devices.

The IEEE 802.16, a solution to broadband wireless access commonly known as Worldwide Interoperability for Microwave Access (WiMAX) [6, 7], is a wireless broadband standard that is first published in 2001. It may be followed by Long Term Evolution (LTE), Ultra Mobile Broadband (UMB), and others. These standards are developed by partnership organizations and Internet Engineering Task Force (LETF, http://www.ietf.org). The third Generation Partnership Project (3GPP, http://www.3gpp.org) is responsible for LTE, while Third Generation Partnership Project 2 (3GPP2, http://www.3gpp2,org) deals with UMB. WiMAX is the developed by WiMAX Forum (http://www.wimaxforum.org) and Institute of Electrical and Electronics Engineers (IEEE, http://www.ieee.org). Figure 2.1 shows the wireless standard landscape, which are seen to be target and be researched and investigated further for feasible implementation.

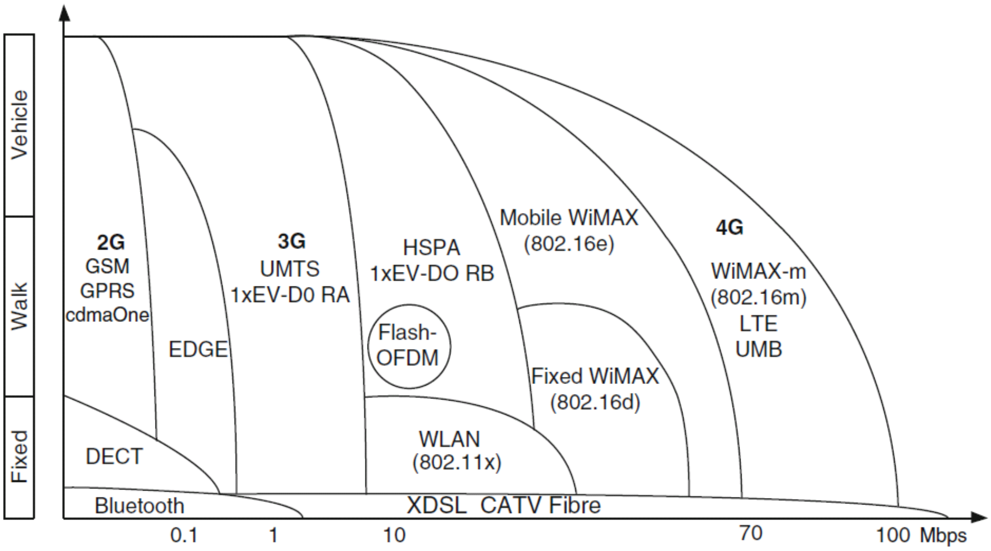

Figure 2.1: Wireless Standard Landscape [7]

2.1.1 3G Cellular Systems

Around the world, mobile operators are upgrading their networks to 3G technology to deliver broadband applications to their subscribers. Mobile operators using GSM (global system for mobile communications) are deploying UMTS (universal mobile telephone system) and HSDPA [8] (high speed downlink packet access) technologies as part of their 3G evolution. Traditional CDMA operators are deploying 1xEV-DO [9] (1x evolution data optimized) as their 3G solution for broadband data. In China, several operators look to TD-SCDMA (time division synchronous CDMA) as their 3G solution. All these solutions provide data throughput capabilities on the order of a few hundred kilobits per second to a few megabits per second.

HSDPA is a downlink-only air interface defined in the 3GPP (three generation partnership project) UMTS release 5 specifications. HSDPA is capable of providing a peak user data rate of 14.4 Mbps, using a 5 MHz channel. In practice, the average rages that users obtain are in the range of 250 kbps to 750 kbps. Enhancements, such as spatial processing, diversity reception in mobiles, and multi-user detection, can provide significantly higher performance over basic HSDPA systems. An uplink version, HSUPA [9] (high speed uplink packet access), supports peak data rates up to 5.8 Mbps and is standardized as part of the 3GPP Release 6 specifications. HSDPA and HSUPA together are name to HSPA (high speed packet access).

1xEV-DO is a high speed data standard defined as an evolution to second-generation IS-95 CDMA systems [10] by the 3GPP2 standard organization. The standard supports a peak downlink data rate of 2.4 Mbps in a 1.25 MHz channel. Typical user-experienced data rate are in the order of 100 kbps to 300 kbps. Revision A of

1xEV-DO supports a peak rate of 3.1 Mbps to a mobile user whereas Revision B will support 4.9 Mbps.

It should be noted that 3GPP is developing the next major revision to the 3G standards. The objective of this long-term evolution (LTE) [9] is to be able to support a peak data rate of 100 Mbps in the downlink and 50 Mbps in the uplink, with an average spectral efficiency that is three to four times that of Release 6 HSPA. In order to achieve these high data rates and spectral efficiency, the air interface will likely be based on OFDM/OFDMA and MIMO technologies.

Similarly, 3GPP2 also has long term plans to offer higher data rates by moving to higher bandwidth operation. The objective is to support up to 70 Mbps to 200 Mbps in the downlink and up to 30 Mbps to 45 Mbps in the uplink, using 20 MHz of bandwidth. It should be noted that neither LTE nor EV-DO Rev C systems are expected to be available until 2010.

2.1.2 Wi-Fi Systems

In addition to 3G, Wi-Fi based systems may be used to provide broadband wireless. Wi-Fi is based on the IEEE 802.11 family of standards and is primarily a local area networking (LAN) technology designed to provide in-building broadband coverage. Current Wi-Fi systems based on the 802.11 a/b/g support a peak data rate of 54 Mbps and typically provide indoor coverage over a distance of 100 feet. Wi-Fi has become the practical standard for “last feet” broadband connectivity in homes, offices and hotspots.

Metro-area Wi-Fi deployments rely on high power transmitters that are deployed on lampposts or building tops. Even with high power transmitter, Wi-Fi systems can typically provide a coverage range of only about 1000 feet from the access point. Consequently, metro Wi-Fi applications require dense deployment of access points, which makes it impractical for large-scale ubiquitous deployment. Wi-Fi offers remarkably higher peak data rates than do 3G systems, primarily since it operates over a large 20 MHz bandwidth. The inefficient CSMA (carrier sense multiple access) protocol used by Wi-Fi, along with the interference constraints at non-licensed band, is likely to significantly reduce the capacity of outdoor Wi-Fi systems. Furthermore, Wi-Fi systems are not designed to support high speed mobility. The one advantage of Wi-Fi over WiMAX and 3G is the wide availability of terminal devices. As with 3G, the capabilities of Wi-Fi are being enhanced to support even higher data rates and to provide better QoS support. The IEEE 802.11n will support a peak layer 2 throughput of at least 100 Mbps, by using multiple antenna spatial multiplexing technology.

2.1.3 Comparison WiMAX with 3G and Wi-Fi

Unlink 3G systems, which have a fixed channel bandwidth, WiMAX [9] defines a selectable channel bandwidth from 1.25 MHz to 20 MHz, which allows for a very flexible deployment. When deployed using the more likely 10 MHz TDD (time division duplexing) channel, 3:1 downlink-to-uplink split, and 2×2 MIMO, WiMAX offers 46 Mbps peak downlink throughput and 7 Mbps uplink. The application of OFDM modulation in WiMAX and Wi-Fi systems allows them to support very high peak rates. In addition, the OFDM physical layer used by WiMAX is more suitable to MIMO implementation than are CDMA systems from the standpoint of the required complexity over the gain. Therefore, compared to 3G, WiMAX offers higher peak rates, greater flexibility, and higher average throughput and system capacity. As mentioned before, Wi-Fi systems are not designed for high speed mobility. The new amendment of WiMAX supports the vehicle speed mobility and can be a backhaul for Wi-Fi hotspots. Most Wi-Fi hotspot operators currently use wired broadband connections to connect the hotpots back to a network access point. WiMAX could serve as a faster and cheaper alternative to wired backhaul for these hotspots. Similarly WiMAX could serve as 3G cellular backhaul.

2.2 Evolving WiMAX Standards

At the beginning, the IEEE 802.16 standard specified a frequency range of 10-66 GHz with a theoretical maximum bandwidth of 120 Mb/s and maximum transmission range of 50 km [11]. However, the initial standard only supports line-of-sight (LOS) transmission and thus does not seem to favor deployment in urban areas. A variant of the standard, IEEE 802.16a-2003, approved in April 2003, can support non-line-of-sight (NLOS) transmission and adopts OFDM at the PHY layer. It also adds support for the 2-11 GHz range. One of the main problems in the earlier draft of IEEE 802.16 is that it covers too many profiles and PHY layers, which can lead to potential interoperability problems. This has been largely recognized in the community, and now focuses on several main profiles and defines interoperability testing for WiMAX equipment. Gradually, the IEEE 802.16 standard has undergone several amendments and evolved to the 802.16-2004 standard (also known as 802.16d) [12]. The standard provides technical specification for the PHY and MAC layers for fixed wireless access. Since mobility support is widely considered one of the key features in wireless networks, the IEEE 802.16e -2005 is released with mobility support. This is generally refereed to as mobile WiMAX. Mobile WiMAX adds significant enhancements:

- It improves NLOS coverage by utilizing advanced antenna diversity schemes and hybrid automatic repeat request.
- It adopts dense subchannilzation, thus increasing system gain and improving indoor penetration.
- It uses adaptive antenna system (AAS) and multiple-input multiple-output (MIMO) technologies to improve coverage.
- It introduces a downlink subchannelization scheme, enabling better coverage and capacity trade-off.

Since January 2007, the IEEE 802.16 working Group has been developing a new amendment of the IEEE 802.16 standard as an advanced air interface to meet the requirements of the International Telecommunication Union — Radiocommunication/ International Mobile Telecommunications (ITU-R/IMT)- advanced for fourth-generation

(4G) systems [13, 14]. It will enable roaming and seamless connectivity across IMT-advanced and IMT-2000 systems through the use of appropriate interworking functions. The next-generation mobile WiMAX will be capable of 1 Gbps and support a wide range of high-quality and high-capacity IP-based service. Figure 2.2 demonstrate the evolutionary path of cellular technology.

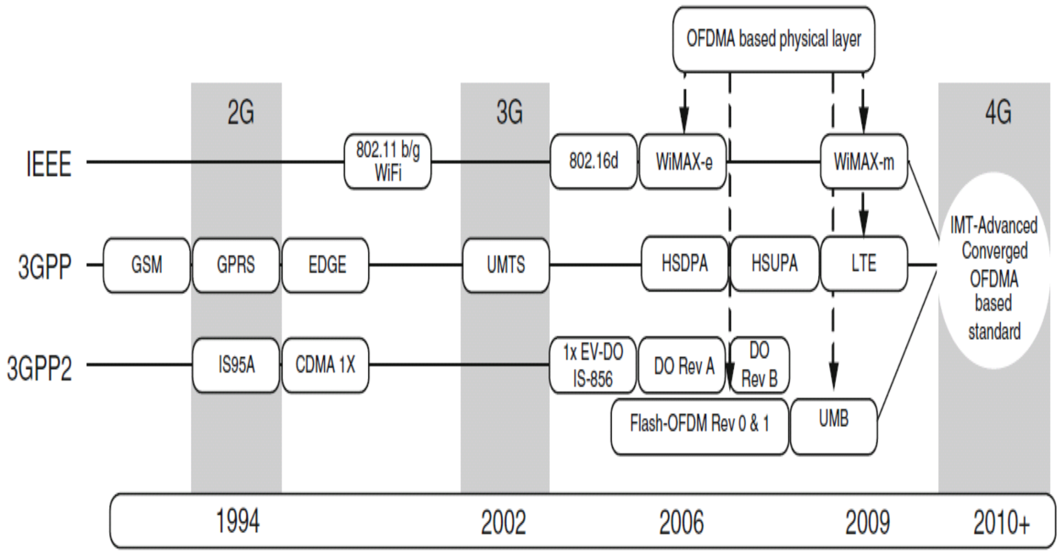

Figure 2.2: Evolutionary Path of Cellular Technology [11]

2.3 Key Features of WiMAX

From technical perspective, the fundamental goal of mobile broadband is to offer higher data rates with reduced latency. The key characteristics of mobile WiMAX system are following [15, 16]:

- Increased data rates: OFDMA based air interface is the key technology to offer higher data rates with higher order modulation schemes such as 64 QAM, and sophisticated FEC (Forward Error Correction) schemes such as convolutional coding, turbo coding, and radio echniques like MIMO and beamforming.

- High spectral efficiency: Operators seek to increase the number of customers within their existing spectrum allocations, with reduced cost of per bit.
- Flexible radio planning: Deployment flexibility gives operators to change the cell six depending on the demand.
- All-IP architecture: All-IP based core network will enable PC-like services such as voice, video, data and improves the interworking to other fixed and mobile networks.
- Spectral flexibility: Scalable bandwidths give operators flexibility to reuse their exiting spectrum allocations.

CHAPTER 3

TECHNOLOGIES OF MOBILE WIMAX 802.16e

3.1 Physical Layer

The IEEE 802.16-2004 and IEEE 802.16e-2005 [17, 18] standards construct the basis of Mobile WiMAX Physical (PHY) Layer and Medium Access Layer (MAC). 802.16 series defines five Wireless Metropolitan Area Networks (Wireless MAN) PHY layers and any of them can be combined with the MAC layer, which is described in the next section. In Figure 3.1, a detailed view of the construction of the mobile WiMAX system profile [19] is presented from the air interface perspective.

WirelessMAN-SC is the first standard that is introduced by the 802.16 working group. It employs a single-carrier (SC) line-of-sight (LOS) modulation for point-to-point communication to operate in the 10-66 GHz spectrum. This standard is to address network access support to buildings with data rates that is comparable to those offered by high-speed fiber optic networks

WireelssMAN-SCa is the second amendment to the 802.16 standard. LOS communication in SC is ratified with 802.16a-2003 amendment to address low-frequency

2-11 GHz spectrum with non-line-of-sight (NLOS) point-to-multipoint communication for fixed broadband wireless access.

The 802.16a-2003 added an OFDM PHY, which is called WirelessMAN-OFDM, with 256 subcarriers to accommodate NLOS fixed access for frequencies in 2-11 GHz. Later, it is finalized in 802.16-2004 standard. This is the approved WiMAX fixed access standard by WiMAX Forum

Wireless High-Speed Unlicensed MAN (WirelessHUMNA) is similar to OFDM PHY but dynamic frequency selection is mandatory for license exempt bands.

The 802.16a-2003 also introduced up to 2048-carrier OFDMA PHY to accommodate NLOS point-to-multipoint communication, which is WirelessMAN-OFDMA. This is ratified in 802.16-2004 and revisited in 802.16e-2005 for mobile access.

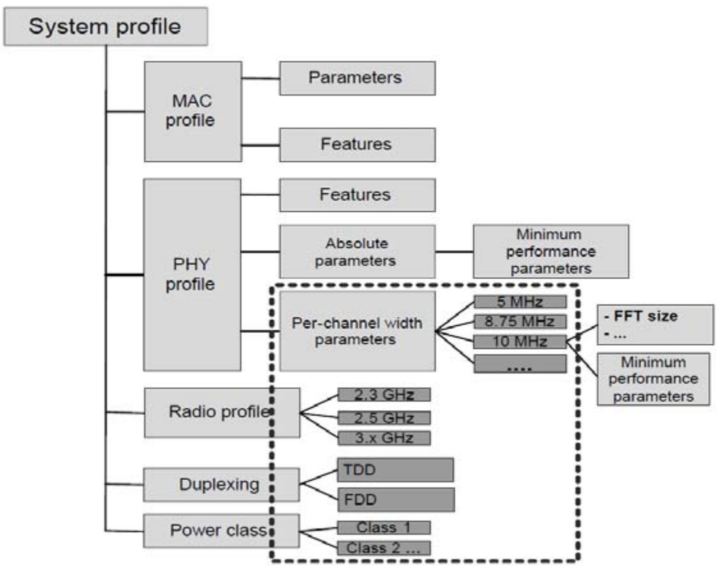

Figure 3.1: Structure of the Mobile WiMAX System Profile [19]

3.1.1 Scalable OFDMA

OFDMA is the multiple access technique for mobile WiMAX. OFDMA [20] is the Orthogonal Frequency Division Multiplexing (OFDM) based multiple access scheme and has become the single choice for modern broadband wireless technologies adopted in other competing technologies such as 3GPP’s Long Term Evolution (LTE) and 3GPP2’s Ultra Mobile Broadband (UMB). OFDMA demonstrates superior performance in non-ling-of-sight (NLOS) multi-path channels with its relatively simple transceiver structures and allows efficient use of the available spectrum resources by time and frequency subchannelization. The simple transceiver structure of OFDMA also enables feasible implementation of advanced antenna techniques such as MIMO with reasonable complexity. Last, OFDMA employed in mobile WiMAX is scalable in the sense that by flexibly adjusting FFT sizes and channel bandwidths with fixed symbol duration and subcarrier spacing, it can address various spectrum needs in different regional regulations in a cost competitive manner. The bandwidth adjustment can be chosen between 1.25-20 MHz as demonstrated in Table 3.1. The scalability is realized with FFT size variations and the frequency spacing of sub-carriers is defined to be 10.94 kHz.

Table 3.1 OFDMA Scalability Parameters [20]

Parameters	Values			
System Channel Bandwidth (MHz)	1.25	5	10	20
Sampling Frequency (MHz)	1.4	5.6	11.2	22.4
FFT Size	128	512	1024	2048
Number of Sub-channels	2	8	16	32
Sub-carrier Frequency Spacing	10.94 kHz			
Useful Symbol Time (μs)	91.4			
Guard Time (μs)	11.4			
OFDMA Symbol Duration (μs)	102.9			
Number of OFDMA Symbol	48			

3.1.2 Time Division Duplex (TDD) Frame Structure

The mobile WiMAX Release 1 (WiMAX R-1) [13] Profile has only TDD as the duplexing mode even though the baseline IEEE standards contain both TDD and Frequency Division Duplex (FDD). Even though future WiMAX Releases will have FDD mode as well, TDD is in many ways better positioned for mobile Internet services than FDD.

First of all, Internet traffic is asymmetric typically with the amount of downlink traffic exceeding the amount of uplink traffic; thus, conventional FDD with the same downlink and uplink channel bandwidth does not provide the optimum use of resources. With TDD products, operators are capable of adjusting downlink and uplink ratios based on their service needs in the networks.

In addition, TDD is inherently better suited to more advanced antenna techniques such as Adaptive Antenna System (AAS) or Beamforming (BF) than FDD due to the channel reciprocity between the uplink and downlink. Mobile Internet with increased multimedia services naturally requires the use of advanced antenna techniques to improve capacity and coverage.

As shown in Figure 3.2, the downlink subframe begins with a downlink preamble that is used for PHY layer procedures, such as time and frequency synchronization and initial channel estimation. The downlink preamble is followed by a frame control header (FCH), which provides frame configuration information, such as the MAP message length, the modulation, and coding scheme, and the usable subcarriers. Multiple users are allocated data regions within the frame, and these allocations are specified in the uplink and downlink MAP messages (DL-MAP and UL-MAP) that are broadcast following the FCH in the downlink subframe. MAP messages include the burst profile for each user, which defines the modulation and coding scheme used in that link. Since MAP contains critical information that needs to reach all users, it is often sent over a very reliable link, such as binary phase shift key (BPSK) with rate 1/2 coding and repetition coding. Although the MAP messages are an elegant way for the base station to inform the various users of its allocations and burst profiles on a per-frame basis, it could form a significant overhead, particularly when there are a large number of users with small packets for which allocations need to be specified. To mitigate the over head concern, mobile

WiMAX systems can optionally use multiple sub-MAP messages where the dedicated control messages to different users are transmitted at higher rates, based on their individual Signal-Interference-Noise Ratio (SINR) conditions. The broadcast MAP messages may also optionally be compressed for additional efficiency.

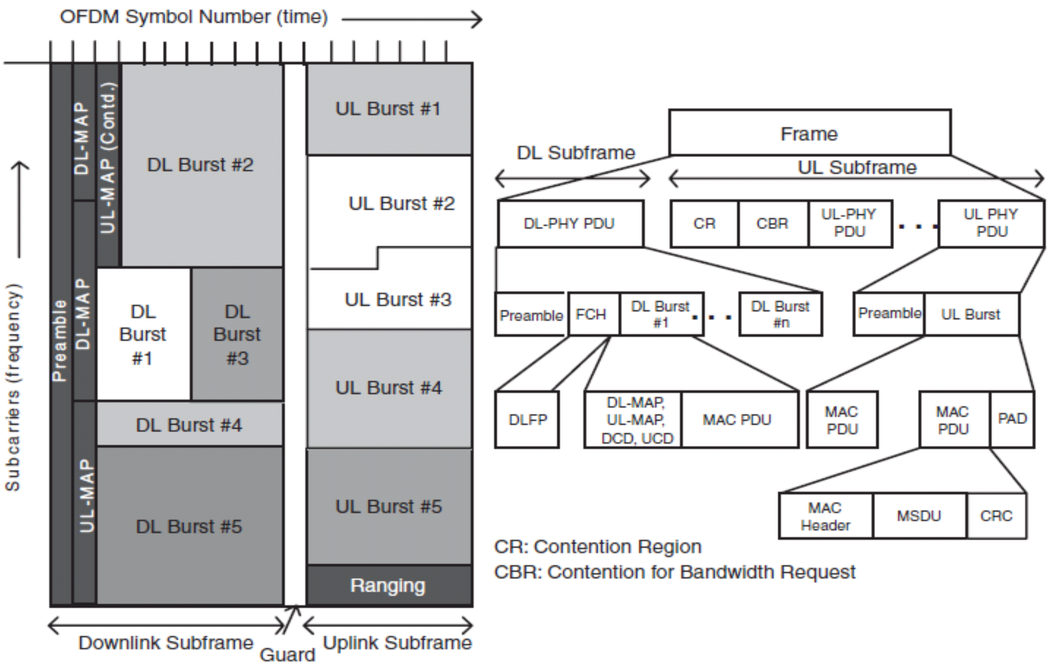

Figure 3.2: OFDMA Frame Structure in TDD [11, 13]

3.1.3 Advanced Antenna Techniques (MIMO and BF)

Various advanced antenna techniques have been implemented in the mobile WiMAX R-1 [13] profile to enable higher cell and user throughputs and improved coverage. As a matter of matter of fact, mobile WiMAX was the first commercially available cellular technology that actually realized the benefits of MIMO techniques [21] promised by academia for years. With its downlink and uplink MIMO features, both operators and end-users enjoy up to twice the data rates of Single-Input Single-Output (SISO) rate, resulting in up to 37 Mbps for downlink and 10 Mbps for uplink sector throughput using just 10 MHz TDD channel bandwidth.

Mobile WiMAX also enhances the cell coverage with its inherent beamforming [21] (BF) techniques. Coupled with TDD operation, its powerful BF mechanism allows base stations to accurately form a channel matching beam to a terminal station so that uplink and downlink signals can reach reliably from and to terminals at the cell edge, thus effectively extending the cell range.

3.1.4 Full Mobility Support

Full mobility support is another strength of the mobile WiMAX products. The baseline standard of mobile WiMAX was designed to support vehicles at highway speed with appropriate pilot design and Hybrid Automatic Repeat Request (HARQ) [22], which helps to mitigate the effect of fast channel and interference fluctuations. The systems can detect the mobile speed and automatically switch between different types of resource blocks, called subchannels, to optimally support the mobile user. Furthermore, HARQ helps to overcome the error of link adaptation in fast fading channels and to improve overall performance with its combined gain and time diversity.

3.1.5 PHY Layer Data Rates

Because the PHY layer of WiMAX is quite flexible, data rate performance varies based on the operating parameters. Parameters that have a significant impact on the PHY layer data rate are channel bandwidth and the modulation and coding scheme used. Other parameters, such as number of subchannals, OFDM guard time, and oversampling rate, also have an impact.

Table 3.2 shows the PHY layer data rate at various channel bandwidths [14], as well as modulation and coding schemes. The rates shown are the aggregate PHY layer data rate that is shared among all users in the sector for the TDD case, assuming a 3:1 downlink-to-uplink bandwidth ratio.

Table 3.2 PHY Layer Data Rate at Various Channel Bandwidths [14]

Channel bandwidth	3.5 MHz		1.25 MHz		5 MHz		10 MHz		8.75 MHz	
PHY mode	256 OFDM		128 OFDMA		512 OFDMA		1024 OFDMA		1024 OFDMA	
Oversampling	8/7		28/25		28/25		28/25		28/25	
Modulation and Code Rate	PHY-Layer Data Rate (kbps)									
	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL
BPSK, 1/2	946	326	Not applicable							
QPSK, 1/2	1882	653	504	154	2520	653	5040	1344	4464	1120
QPSK, 3/4	2822	979	756	230	3780	979	7560	2016	6696	1680
16 QAM, 1/2	3763	1306	1008	307	5040	1306	10080	2688	8928	2240
16 QAM, 3/4	5645	1958	1512	461	7560	1958	15120	4032	13392	3360
64 QAM, 1/2	5645	1958	1512	461	7560	1958	15120	4032	13392	3360
64 QAM, 2/3	7526	2611	2016	614	10080	2611	20160	5376	17856	4480
64 QAM, 3/4	8467	2938	2268	691	11340	2939	22680	6048	20088	5040
64 QAM, 5/6	9408	3264	2520	768	12600	3264	25200	6720	22320	5600

3.2 MAC Layer

The primary task of the WiMAX MAC layer [13, 18] is to provide an interface between the higher transport layers and the physical layer. The MAC layer takes packets from the upper layer that is called MAC service data units (SDU) and organizes them into MAC protocol data units (PDU) for transmission over the air. For received transmissions, the MAC layer does the reverse. The IEEE 802.16-2004 and IEEE 802.16e-2005 MAC design includes a convergence sublayer that can interface with a variety of higher layer protocols, such as ATM, Ethernet, IP, and adaptable for future protocol. The WiMAX MAC uses a variable length PDU and offers a lot of flexibility to allow for their efficient transmission. For example, multiple PDUs of same or different lengths may be aggregated into a single burst to save PHY overhead. Similarly, multiple SDUs from the higher layer service may be concatenated into a single PDU to save MAC header overhead. Conversely, large SDUs may be fragmented into smaller PDUs and sent across multiple frames.

3.2.1 Channel Access Mechanisms

In WiMAX, the MAC layer [13, 18] at the base station is fully responsible for allocating bandwidth to all users, in both the uplink and the downlink. The only time the MS has some control over bandwidth allocation is when it has multiple sessions or connections with the BS. In that case, the BS allocates bandwidth to the MS in the aggregate, and it is up to the MS to allocate it among the multiple connections. All other scheduling on the downlink and uplink is done by BS. For the downlink, the BS can allocate bandwidth to each MS, based on the needs of the incoming traffic, without involving the MS. For the uplink, allocations have to be based on requests from the MS.

The WiMAX standard supports several mechanisms by which an MS can request and obtain uplink bandwidth. The BS allocates dedicated or shared resources periodically to each MS, with which it can use to request bandwidth. This process is called polling. There are two types of polling: multicast polling and unicast polling. Multicast polling is done when there is insufficient bandwidth to poll each MS individually. When polling is done in multicast, the allocated slot for making bandwidth request is a shares slot, which every polled MS attempts to use. WiMAX defines a contention access and resolution mechanism for the case when more than one MS attempts to use the shared slot.

3.2.2 Quality of Service (QoS)

Support for QoS is a fundamental part of the WiMAX MAC layer design [18]. WiMAX defines a concept of a service flow. A service flow is a unidirectional flow of packets with a particular set of QoS parameters and is identified by a service flow identifier (SFID). The QoS parameters could include traffic priority, maximum sustained traffic rate, maximum burst rate, scheduling type, ARQ (automatic repeat request) type, maximum delay, tolerated jitter, and so on. Service flows may be provisioned through a network management system or crated dynamically through defined signaling mechanisms in the standard. The base station is responsible for issuing the SFID and mapping it to unique connection identifier (CID). Figure 3.3 demonstrates the process of connection between BS and MS with service flows.

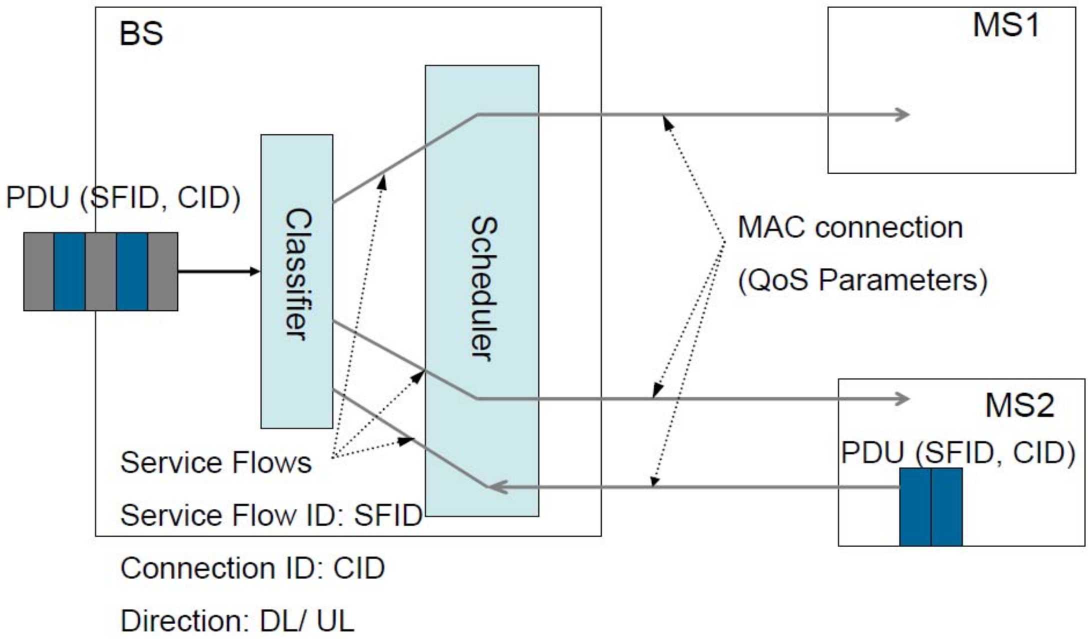

Figure 3.3: Mobile WiMAX QoS Support [18]

When some type of data service (voice, data) is wanted to be offered, a connection has to be created between the BS and the MS. This is done by a unidirectional logical link between the peer MACs. The service flow has certain QoS parameters that give the scheduler a chance to do decisions for transmission priorities.

To support a wide variety of applications, mobile WiMAX defines five scheduling services listed in Table 3.3 [13, 18], which are discussed in detail as follow.

Table 3.3: Service Flows Supported in Mobile WiMAX [18]

Service Flow Designation	Defining QoS Prameter	Application Examples
Unsolicited grand service	Maximum sustained rate Maximum latency tolerance Jitter tolerance	Voice over IP (VoIP) without silence suppression
Real-time Polling service	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Traffic priority	Steaming audio and video, MPEG (Motion Picture Expert Group) encoded
Non-real-time polling service	Minimum reserved rate Maximum sustained rate Traffic priority	File Transfer Protocol (FTP)
Best-effort service	Maximum sustained rate Traffic priority	Web browsing, data tranfer
Extended real-time Polling service	Minimum reserved rate Maximum sustained rate Maximum latency tolerance Jitter tolerance Traffic priority	VoIP with silence suppression

3.2.2.1 Unsolicited Grand Services (UGS)

This is designed to support fixed-size data packets at a constant bit rate (CBR). Example of applications that may use this service is voice over IP (VoIP) without silence suppression. The mandatory service flow parameters that define this service are maximum sustained traffic rate, maximum latency, tolerated jitter, and request/transmission policy.

3.2.2.2 Real-time Polling Services (rtPS)

This service is designed to support real-time service flows, such as MPEG video, that generate variable-size data packets on a periodic basis. The MS has a possibility to request for a needed bandwidth based on the size of the transmission. Resulting from the variable need of bandwidth, the rtPS requires more overhead than the previous UGS.

3.2.2.3 Non-real-time Polling Service (nrtPS)

This service is designed to support delay-tolerant data streams, such as an FTP, that require variable-size data grants at a minimum guaranteed rate. The intervals between polls are not constant but they are short enough to provide sufficient service for the MS.

3.2.2.4 Best Effort (BE)

This service is designed to support data streams, such as Web browsing, the do not require a minimum service-level guarantee. The BE service is intended for traffic without strict requirements for latency or QoS in genral.

3.2.2.5 Extended Real-time Variable Rate (ERT-VR)

This service is designed to support real-time applications, such as VoIP with silence suppression, that have variable data rates but require guaranteed data rate and delay. ERT-VR is a combination of the two previous services, UGS and rtPS.

It should be noted that the implementation of an effective scheduler is critical to the overall capacity and performance of a mobile WiMAX system.

3.2.3 Power Saving Features

To support battery-operated portable devices, mobile WiMAX has power saving features [23] that allow portable subscriber stations to operate for longer durations without having to recharge. Power saving is achieved by turning off some parts of the MS in a controlled manner when it is not actively transmitting or receiving data. Mobile WiMAX defines signaling methods that allow the MS to retreat into a sleep mode or idle mode when inactive. Sleep mode is a state in which the MS effectively turns itself off and becomes unavailable for predetermined periods. The periods of absence are negotiate with the serving BS. WiMAX defines three power saving classes, based on the manner in which sleep mode is executed. When in power save class 1 mode, the sleep window is exponentially increased from a minimum value to a maximum value. This is typically done when the MS is doing best-effort (BE) and non-real-time traffic. Power save class 2 has a fixed-length sleep window and is used for UGS service. Power save class 3 allows for a one-time sleep window and is typically used for multicast traffic or management traffic when the MS knows when the next traffic is expected. In addition to minimizing MS power consumption, sleep mode conserves BS radio resources. To facilitate handoff while in sleep mode, the MS is allowed to scan other base stations to collect handover information.

Idle mode allows even great power savings, and support for it is optional in WiMAX. Idle mode allows the MS to completely turn off and to not be registered with any BS but receive downlink broadcast traffic. When downlink traffic arrives for the idle mode MS, the MS is paged by a collection of base stations that form a paging group. The MS is assigned to a paging group by the BS before going into idle mode, and the MS periodically wakes up to update its paging group. Idle mode saves more power than sleep mode, since the MS does not have to register or do handovers. Idle mode also benefits the network and BS by eliminating handover traffic from inactive MSs.

3.2.4 Mobility Support

Handover procedures include numerous means of optimization. In particular, to reduce time expenses for the mobile to find the central frequency and acquire parameters of the neighbor base station, the mobile can apply a scanning process when the mobile is away from the serving base station to scan the wireless media for neighbor base stations. Information collected during scanning such as central frequencies of the neighbor base stations can then be sued in actual handover. In some deployment scenarios, scanning can be performed without service interruption. For this purpose, information about the central frequency and parameters of the neighbor base stations is periodically advertised by the serving base station. The specific handover techniques and optimization scheme used in mobile WiMAX will be introduced in the next chapter in details.

3.2.5 Security Functions

The security sublayer provides Extensible Authentication Protocol (EAP) –based mutual authentication between the mobile and the network. It protects against unauthorized access to the transferred data by applying strong encryption of data blocks transferred over the air. Basic security mechanisms are strengthened by adding digital-certificate-based Subscriber Station (SS) device authentication to the key management protocol. Security of mobile WiMAX is handled by a privacy sublayer within the MAC layer. The key aspects of WiMAX security [24] are as follow.

3.2.5.1 Support for Privacy

User data is encrypted using cryptographic schemes of proven robustness to provide privacy. Both AES (Advanced Encryption Standard) and 3DES (Triple Data Encryption Standard) are supported. Most system implementations will likely use AES, as it is the new encryption standard approved as compliant with Federal Information Processing Standard (FIPS) and is easier to implement. The 128 bits or 256 bits key used for deriving the cipher is generated during the authentication phase.

3.2.5.2 Device and User Authentication

WiMAX provides a flexible means for authenticating subscriber stations and users to prevent unauthorized use. The authentication framework is based on the Internet Engineering Task Force (IETF), which supports a variety of credentials, such as username/password and smart cards. WiMAX terminals come with built-in X.509 digital certificates for device authentication and use a username/password or smart card authentication for user authentication.

3.2.5.3 Support for Fast Handover

To support fast handovers, WiMAX allows the MS to use pre-authentication with a particular target BS to facilitate accelerated reentry. A three-way handshake scheme is supported to optimize the reauthentication mechanisms for supporting fast handover.

3.2.6 Advanced Antenna Systems

The WiMAX standard provides extensive support for implementing advanced multiantenna solutions to improve system performance. Significant gains in overall system capacity and spectral efficiency can be achieved by deploying the optional advanced antenna systems (AAS) defined in WiMAX [25, 26]. AAS includes support for a variety of multiantenna solutions, including transmit diversity, beamforming, and spatial multiplexing.

3.2.6.1 Transmit Diversity

WiMAX defines a number of space-time block coding schemes that can be used to provide transmit diversity in the downlink. For transmit diversity, there could be two or more transmit antennas and one or more receive antennas. The space-time block code (STBC) used for the 2×1 antenna case is the Alamouti codes [27], which are orthogonal and amenable to maximum likelihood detection. The Alamouti STBC is quite easy to implement and offers the same diversity gain as a 1×2 receiver diversity with maximum ratio combining, although with a 3dB penalty owing to redundant transmissions.

3.2.6.2 Beamforming

Multiple antennas in WiMAX may also be used to transmit the same signal appropriately weighted for each antenna element such that the effect is to focus the transmitted beam in the direction of the receiver and away from interference, thereby improving the received SINR. Beamforming can provide significant improvement in the coverage range, capacity and reliability. To perform transmit beamforming, the transmitter needs to have accurate knowledge of the channel, which in the case of TDD is easily available owing to channel reciprocity but for FDD requires a feedback channel to learn the channel characteristics.

3.2.6.3 Spatial Multiplexing

WiMAX also support a spatial multiplexing [27], where multiple independent streams are transmitted across multiple antennas. If the receiver also has multiple antennas, the streams can be separated out using space-time processing. Instead of increasing diversity, multiple antennas in this case are used to increase the data rate or capacity of the system. Assuming a rich multipath environment, the capacity of the system can be increased linearly with the number of antennas when performing spatial multiplexing. A 2×2 MIMO system therefore doubles the peak throughput capacity of WiMAX. If the mobile station has only one antenna, WiMAX can still support spatial multiplexing by coding across multiple users in the uplink. This is called multiuser collaborative spatial multiplexing. Unlike transmit diversity and beamforming, spatial multiplexing works only under good SINR conditions.

3.2.7 Improved Frequency Reuse

Although it is possible to operate WiMAX systems with frequency reuse of one, doing so can cause severe outage owing to interference, particularly along the intercell and intersector edges. To mitigate this, WiMAX [28] allows for coordination of sub-channel allocation to users at the cell edges such that there is minimal overlap. This allows for a more dynamic frequency allocation across sectors, based on loading and interference conditions, as opposed to traditional fixed frequency planning. Those users under good SINR conditions will have access to the full channel bandwidth and operate under a frequency reuse of one. Those in poor SINR conditions will be allocated non-overlapping sub-channels such that they operate under a frequency reuse of 2, 3 or 4, depending on the number of non-overlapping sub-channel groups that are allocated to be shared among these users. This type of sub-channel allocation leads to the effective reuse factor taking fractional values greater than 1. Obviously, the downside is that cell edge users cannot have access to the full bandwidth of the channel, and hence their peak rates will be reduced.

3.2.8 Reference Network Architecture

The WiMAX Forum's Network Working Group (NWG), is responsible for developing the end-to-end network requirements, architecture, and protocols for WiMAX, using IEEE 802.16e-2005 as the air interface [29].

The WiMAX NWG has developed a network reference model to serve as an architecture framework for WiMAX deployments and to ensure interoperability among various WiMAX equipment and operators. Figure 3.4 shows a simplified illustration of an IP-based WiMAX network architecture. The overall network may be logically divided into three parts:

- Mobile stations used by the end user to access the network.
- The access service network (ASN), which comprises one or more base stations and one or more ASN gateways that form the radio access network at the edge.
- The connectivity service network (CSN), which provides IP connectivity and all the IP core network functions.

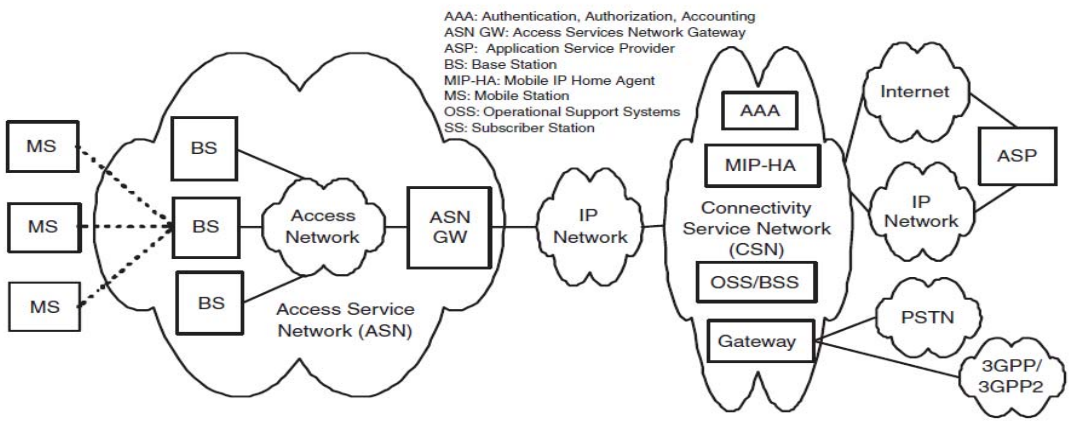

Figure 3.4: IP-Based WiMAX Network Architecture [33]

The network reference model developed by the WiMAX Forum NWG defines a number of functional entities and interfaces between those entities. Figure 3.4 shows some of the more important functional entities.

The BS is responsible for providing the air interface to the MS. Additional functions that may be part of the BS are micromobility management functions, such as handover triggering and tunnel establishement, radio resource management, QoS policy enforcement, DHCP (Dynamic Host Control Protocol) proxy, key management, session management, and multicast group management.

Access service network gateway (ASN-GW) typically acts as a layer 2 traffic aggregation point within an ASN. Additional functions that may be part of the ASN gateway include intra-ASN location management and paging, radio resource management and admission control, caching of subscriber profiles and encryption keys, AAA client functionality, establishment and management of mobility tunnel with base stations, foreign agent functionality for mobile IP, and routing to the selected CSN.

Connectivity service network (CSN) provides connectivity to the Internet, ASP, other public networks, and corporate networks. The CSN is owned by the network service provider and includes AAA servers that support authentication for the devices, users, and specific services. The CSN also provides per user policy management of QoS and security. The CSN is also responsible for IP address management, support for roaming between different NSPs, location management between ASNs, and mobility and roaming between ASNs. Further, CSN can also provide gateways and interworking with other networks, such as public switched telephone network (PSTN), 3GPP, and 3GPP2.

In addition to functional entities, the reference architecture defines interfaces, called reference points, between function entities. The interfaces carry control and management protocols in support of several functions, such as mobility, security, and QoS, and so on.

The WiMAX network reference model defines reference points between:

- MS and the ASN, called R1, which in addition to the air interface includes protocols in the management.
- MS and CSN, called R2, which provides authentication, service authorization, IP configuration, and mobility management.
- ASN and CSN, called R3, to support policy enforcement and mobility management.
- ASN and ASN, called R4, to support inter-ASN mobility
- CSN and CSN, called R5, to support roaming across multiple NSPs.
- BS and ASN-GW, called R6, which consists of intra-ASN bearer paths and IP tunnels for mobility events.
- BS to BS, called R7, to facilitate fast, seamless handover.

CHAPTER 4

HANDOVER AND POWER MANAGEMENT

4.1 The Fundamental Handover of Cellular Networks

Because of scarcity of frequency spectrum, cellular systems deploy smaller cells in order to achieve higher system capacity. The spectrum band is divided into some fixed bandwidth frequencies and these frequencies are reused in non-interfering cells [30, 31]. Smaller cells make an active mobile station (MS) to cross several cells during an ongoing conversation. This active call should be transferred from one cell to another cell in order to achieve call continuation during boundary crossings. Handover process is transferring an active call from one cell to another. The transfer of current communication channel could be in terms of time slot, frequency band, or code word to a new base station (BS), which leads to different techniques of handover. If new BS has some unoccupied channels then it assigns one of them to the handover. If all of the channels are in use at the handover time there are two possibilities: to drop the call or delay it for a while. In order to evaluate the efficiency of handover, two of the most important metrics for evaluating a handover technique are forced termination (call dropping) probability and call blocking probability. The forced termination probability is the probability of dropping an active call due to handover failure and the call blocking probability is probability of blocking a new call request. The aim of a handover procedure is to decrease forced termination probability while not increasing call blocking probability significantly.

4.1.1 Initialization of a Handover

Handover initiation is the process of deciding when to request a handover. Handover decision is based on received signal strengths (RSS) from current BS and neighboring BSs [32]. Figure 4.1 shows the RSSs of current BS1 and one neighboring BS2. The strengths of received signal are varying in according with the distance the MS traveling between them. The RSS gets weaker as MS goes away from BS1 and gets stronger as it gets closer to the BS2 as a result of signal path loss. The received signal is averaged over time using an averaging window to remove momentary fadings due to geographical and environmental factors. The figure is useful in explaining various handover strategies that have been used to determine the instant of handover.

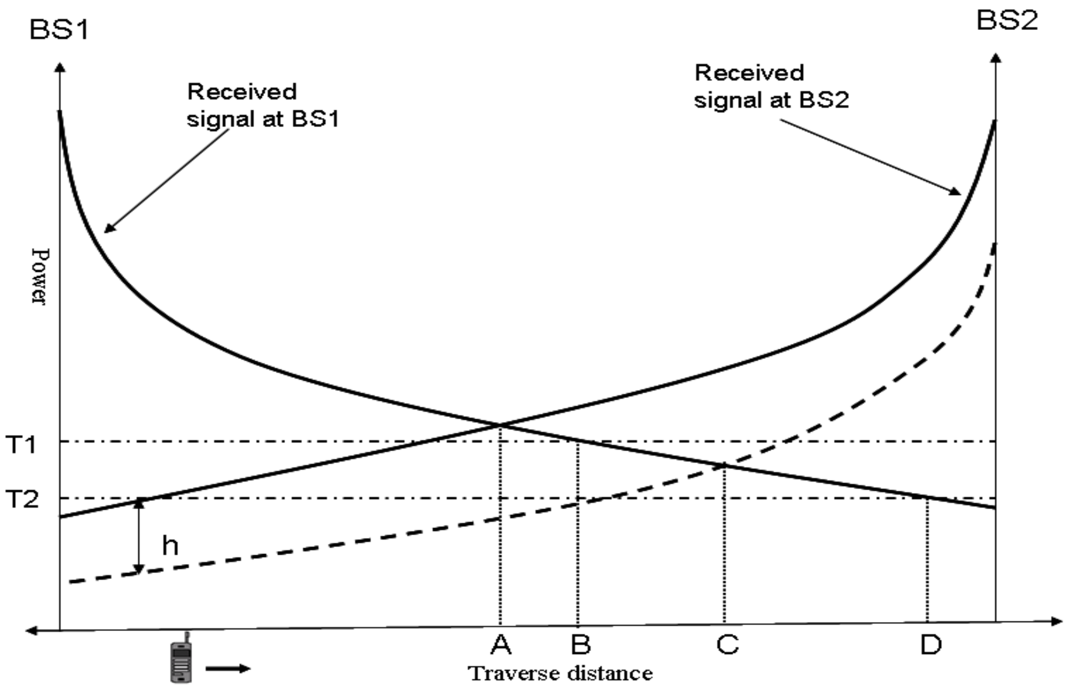

Figure 4.1: Handover Decision as a Function of Handover Scheme

4.1.1.1 Relative Signal Strength

The mobile station is handed off from BS1 to BS2 when the signal strength at BS1 first exceeds that at BS2. In Figure 4.1, BS2's RSS exceeds RSS of BS1 at point A and handover is requested. Due to signal fluctuations, several handovers can be requested while BS1's RSS is still sufficient to serve MS. There unnecessary handovers are known as ping-pang effect. As the number of handovers increase, forced termination probability also increases. So handover techniques should avoid unnecessary handovers.

4.1.1.2 Relative Signal Strength with Threshold

Handover only occurs if first, the signal at the current BS is sufficiently weak and second, the other signal is the stronger of the two. The intention is that as long as the signal at the current BS is adequate, handover is unnecessary. So the relative signal strength with threshold introduces a threshold value (T1 in Figure 4.1) to overcome the ping-pang effect. The handover is initiated if BS1's RSS is lower than the threshold value and BS2's RSS is stronger than BS1's. The handover request is issued at point B at Figure 4.1.

4.1.1.3 Relative Signal Strength with Hysteresis

This technique uses a hysteresis value (*h* in Figure 4.1) to initiate handover. Handover is requested when the BS2's RSS exceeds the BS1's RSS by the hysteresis value *h* at point C in figure 4.1.

4.1.1.4 Relative Signal Strength with Hysteresis and Threshold

This technique combines both the threshold and hysteresis margin to come up with a technique to reduce the number of handovers. Handover occurs only if first the current signal level drops bellow a threshold, and second the target base station is stronger than the current one by a hysteresis margin *h*. In our example, handover occurs at point C if the threshold is T1 and at D if the threshold is at T2.

4.1.2 Handover Decision

There are three types of handover decision protocols used in various cellular systems: network controlled handover (NCHO), mobile assisted handover (MAHO), and mobile controlled handoff (MCHO) [33, 34].

Network controlled handover (NCHO) is used in first generation cellular systems such as Advanced Mobile Phone System (AMPS) where the mobile telephone switching office (MTSO) is responsible for overall handover decision. In NCHO, the network handles the necessary RSS measurements and handover decision.

In Mobile assisted Handover (MAHO), the load of the network is high since network handles the all process itself. In order to reduce the load of the network, MS is responsible for doing RSS measurements and send them periodically to BS in MAHO. Based on the received measurements, the BS or the mobile switching center (MSC) decides when to handover. MAHO is used in Global System for Mobile Communications (GSM).

Mobile controlled Handover (MCHO) extends the role of the MS by giving overall control to it. Both MS and BS make the necessary measurements and the BS sends them to the MS. Then the MS decides when to handover based on the information gained from the BS and itself. Digital European Cordless Telephone (DECT) is a sample cellular system using it.

4.1.3 Handover Types

There are two types of handovers used in cellular network systems: hard handover and soft handover. The hard handover is used when the communication channel is released first and the new channel is acquired later from the neighboring cell. For real-time users it means a short disconnection of communication. Thus, there is a service interruption when the handover occurs reducing the quality of service. Hard handover is used by the systems which use time division multiple access (TDMA) and frequency division multiple access (FDMA) such as GSM and General Packet Radio Service (GPRS) [35].

The soft handover, in contrast to hard handover, establishes multiple connections with neighboring cells. Soft handover is used by the code division multiple access (CDMA) systems where the cells use same frequency band using different code words. Each MS maintains an active set where BSs are added when the RSS exceeds a given threshold and removed when RSS drops below another threshold value for a given amount of time specified by a timer. When a presence or absence of a BS to the active set is encountered soft handover occurs. The systems using soft handoff are Interim Standard 95 (IS-95) and Wideband CDMA (WCDMA).

The objectives of handover can be summarized as follows:

- Guaranteeing the continuity of wireless services when the mobile user moves across the cellular boundaries.
- Keeping required QoS.
- Minimizing interference level of the whole system by keeping the mobile linked to the strongest BS or BSs.
- Roaming between different networks.
- Distributing load from hot spot areas.

4.1.4 System Optimization for Handover

When a BS has an idle channel, it is assigned due to first-come first-serve basis regardless of whether the call is new or handover. But forced termination of an active call is less desirable by the users in contrast to new call blocking. In order to provide lower forced termination probability, prioritization schemes assigns more channels to the handover calls. The two prioritization techniques are: guard channels and queuing handover calls [36-38].

The guard channel scheme reserves some fixed or adaptively changing number of channels for handover calls only. The rest of the channels are used by new and handover calls. So the handover calls are better served and forced termination probability is decreased. The cost of such a scheme is an increase in call blocking probability and total carried traffic.

Queuing handover calls is another prioritization scheme. It queues the handover calls when all of the channels are occupied in a BS. When a channel is released, it is assigned to one of the handover calls in the queue. A new call request is assigned a channel if the queue is empty and if there is at least one free channel in the BS. This technique queues new calls to decrease call blocking probability. The time interval between handover initiation and receiver threshold makes it possible to use queuing handover calls. Queuing handover calls can be used either with the guard channel scheme or not.

4.2 Handover in Mobile WiMAX Systems

In mobile WiMAX, the handover process is defined as the set of procedures and decisions that enable an MS to migrate from the air interface of one BS to the air interface of another and consists of several stages. Figure 4.2 shows the procedures of initial network entry (encircled in dashed line) and handover for the mobile WiMAX. It can be seen that the two procedures [39] are vary similar to each other.

Generally, the decision for a handoff can be determined based on various properties and values. The decision attribute is a combination of network conditions, system performance, application types, power requirements, MS conditions, user preferences, and security. The network conditions and system performance can be improved by balancing the load of heavily occupied BSs to less active BSs, assuming possible within other requirements. Different applications in the mobile device can set requirements to the currently serving BS and it might be that it does not support all the needed technologies. Additionally, if a new BS can provide sufficient service with better power saving or security properties than the currently serving BS, it can be useful for the MS to perform a handover to the new one. The user preference can define that the network of the own service provider is used from several available networks.

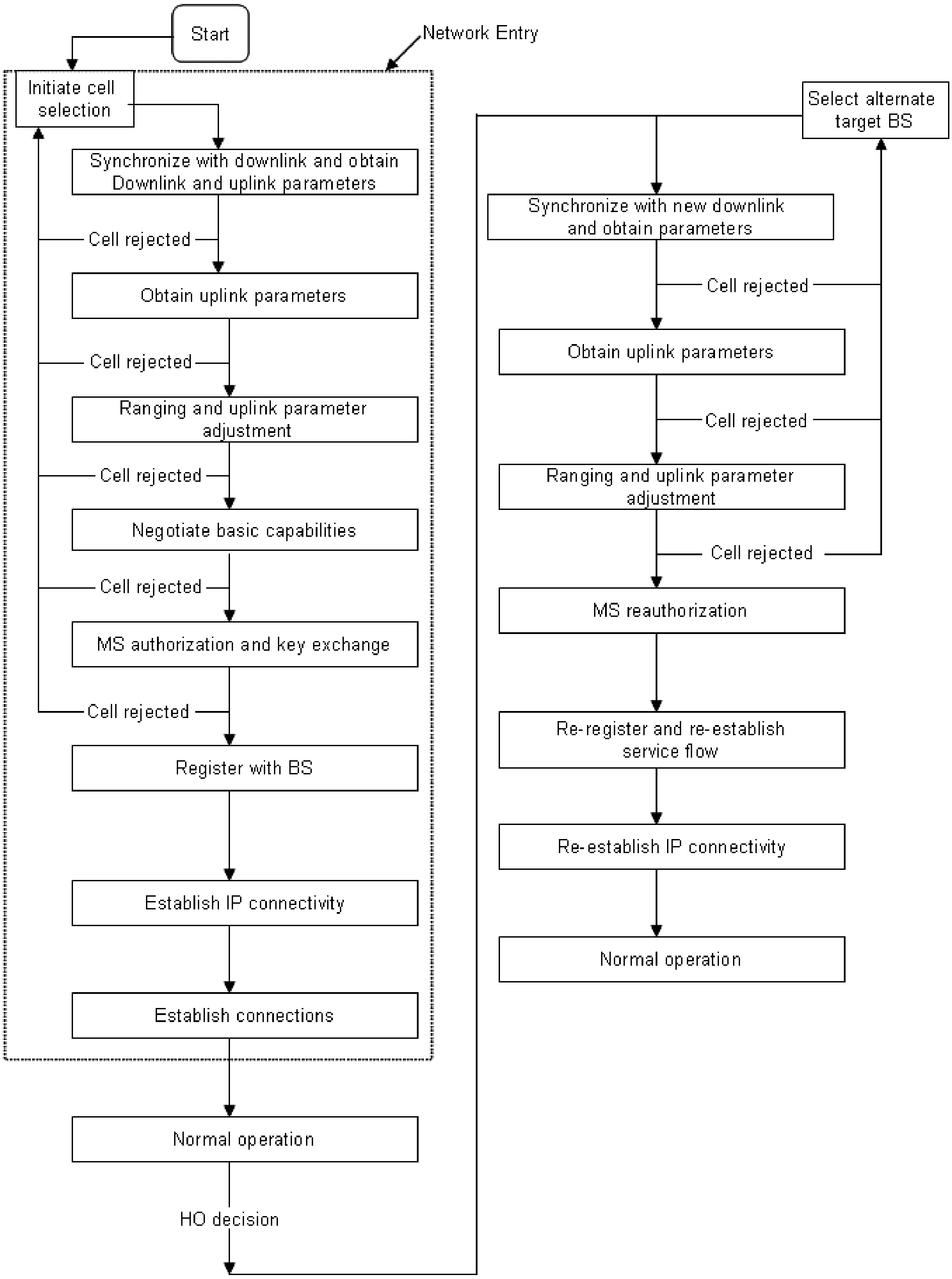

Figure 4.2: Initial Network Entry and Handover [39]

4.2.1 Handover Process and Cell Reselection

In Figure 4.3, the handover process of mobile WiMAX is demonstrated that consists of several stages: cell reselecting, handover decision and initiation, synchronization to the target BS, ranging with target BS, and termination of context with previous BS.

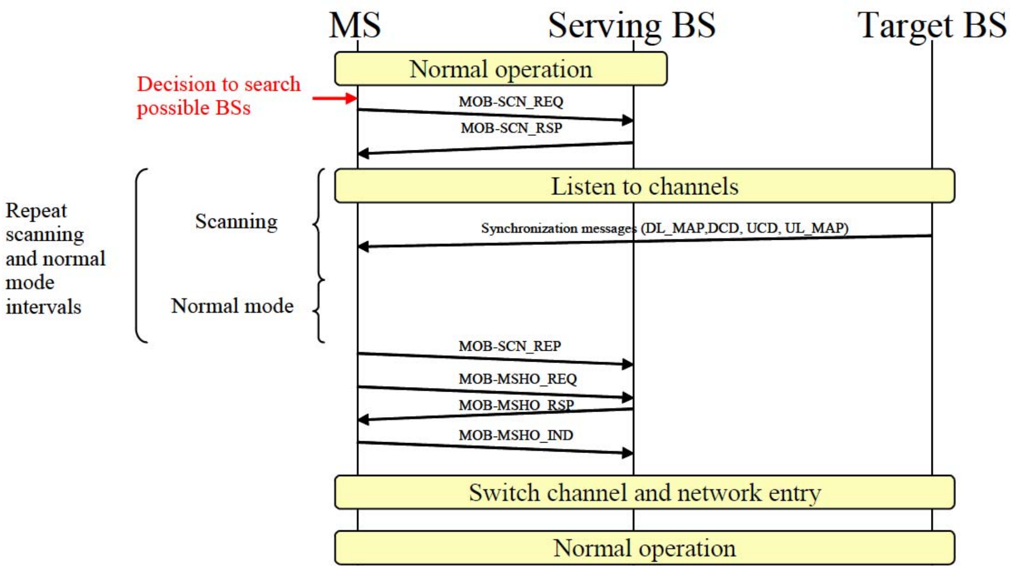

Figure 4.3: Process of Handover in Mobile WiMAX System [39]

4.2.1.1 Cell Reselection

During this stage, the MS performs scanning and association with one or more neighboring BSs to determine their suitable as a handover target. After performing cell reselection, the MS resumes normal operation with the serving BS.

4.2.1.2 Handover Decision and Initiation

The handover process begins with the decision for the MS to migrate its connections from the serving BS to a new target BS. This decision can be taken by MS, BS, or some other external entity in the mobile WiMAX network and is dependent on the implementation. When the handover decision is taken by the MS, it sends MOB-SCN_REQ message to the BS, indicating one or more BSs as handover targets. The BS then sends a MOB-SCN_RSP message indicating the target BSs to be used for this handover process. When the handover decision is taken by the BS, it sends a MOB_BSHO_REQ message to the MS, indicating one or more BSs for the handover target. The MS in this case 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 MS can cancel it at any time.

4.2.1.3 Synchronization to the Target BS

Once the target BS is determined, the MS synchronizes with its DL transmission. The MS begins by processing the DL frame preamble of the target BS. The DL frame preamble provides the MS with time and frequency synchronization with target BS. The MS then decodes the DL-MAP, UP-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 MS.

4.2.1.4 Ranging with Target BS

The MS 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 MS can skip or shorten this stage if it performed association with the target BS during the cell reselection stage.

4.2.1.5 Termination of Context with Previous BS

After establishing connection with the target BS, the MS may decide to terminate its connection with the serving BS, sending a MOB-HO_IND message to the BS. On receipt of this message, the BS starts the resource retain timer and keeps all the MAC state information and buffered MAC PDUs associated with the MS until the expiry of this timer. Once the resource retain timer expires, the BS discards all the MAC state information and MAC PDSs belonging to the MS, and the handover is assumed to be complete.

4.2.2 The Types of Handover in Mobile WiMAX

Mobile WiMAX provides three handover mechanisms: hard handover (HHO), fast base station switching (FBSS), and macro-diversity handover (MDHO). HHO is mandatory, while FBSS and MDHO are optional [40].

During hard handover (HHO) the MS communicates with only just one BS in each time. Connection with the old BS is broken before the new connection is established.

Handover is executed after the signal strength from neighbor's cell is exceeding the signal strength from the current cell. Hard handover is more bandwidth-efficient than soft handover, but it causes longer delay.

When macro-diversity handover (MDHO) is supported by MS and BS, the diversity set is maintained by MS and BS. Diversity set is a list of the BS's, which are involved in the handover procedure as shown in Figure 4.4. There is always one BS in the diversity set that is defined as an anchor BS. The HHO is a special case of MDHO when there is only one BS in the diversity set.

There might be also BSs that can be reached with the MS, but the signal is too weak for real traffic. These BSs are kept outside the diversity set and named as neighbor BSs. Naturally, while moving towards a neighbor BS, at some moment the signal is strong enough and the BS can be included in the diversity set, or if the signal strength is too weak the BS will be removed off form the diversity set.

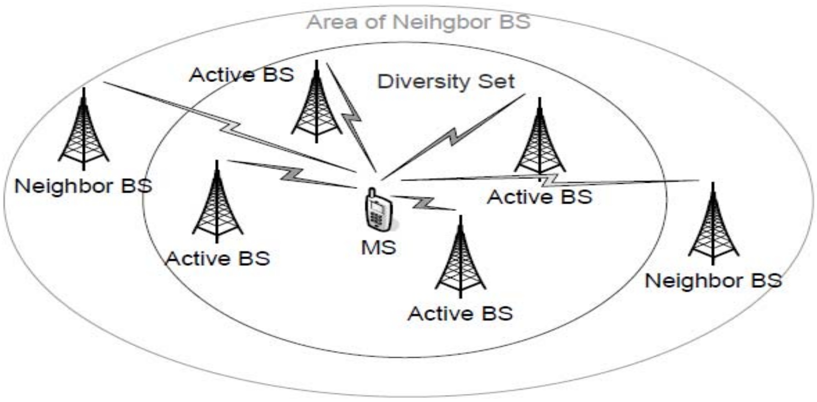

Figure 4.4: Macro-diversity Handover

In fast base station switching (FBSS), the MS and BS diversity set is maintained similar as in MDHO. MS continuously monitors the base stations in the diversity set and defines an anchor BS. Anchor BS in only one base station of the diversity set that MS communicates with all uplink and downlink traffic (Figure 4.5). This is the BS where MS is registered, synchronized, performs ranging and also
monitoring downlink channel for control information. The adding/dropping of members of the diversity set is similar to the one with MDHO above.

In fact, all the BSs in the diversity set receive the data addressed to the MS, but only one of them transmits the data over the air interface while the others eventually drop the received packets. The anchor BS can be changed from frame to frame depending on BS selection scheme. This means every frame can be sent via different BS in diversity set.

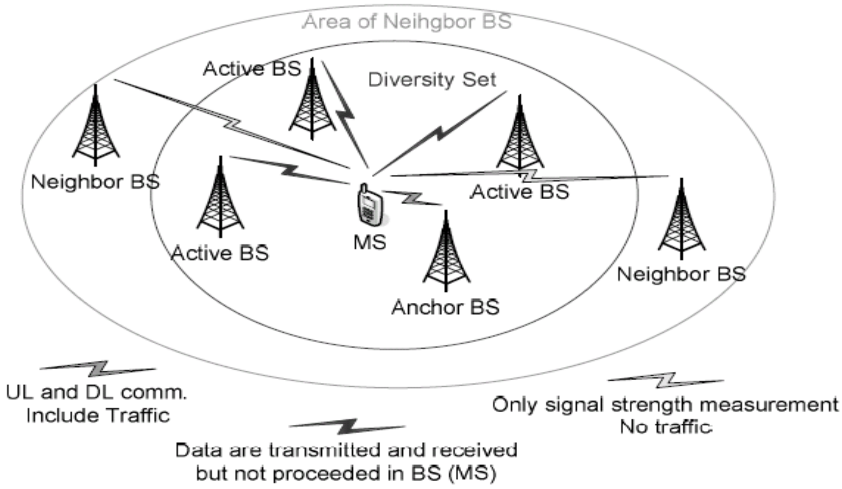

Figure 4.5: Fast Base Station Switching

4.3 Power Management

The mobile WiMAX standard introduces several new concepts related to power management, one of the most fundamental requirements of a mobile wireless network. Power management enables the MS to conserve its battery resources, a critical feature required for handheld devices.

4.3.1 Sleep Mode

Sleep mode [41] is an optional mode of operation in mobile WiMAX. An MS with active connections with connection identification (CID) negotiates with the BS to temporarily disrupt its connection over the air interface for a predetermined amount of time, called the sleep window. Each sleep window is followed by a listen window. As shown in Figure 4.6, the MS goes through alternating sleep and listen windows for each connection. The length of each sleep and listen window is negotiated between the MS and BS and is dependent on the power saving class of the sleep mode operation. There are three power saving classes defined in mobile WiMAX.

4.3.1.1 Power Saving Class One

Each listen window of fixed length is followed by a sleep window such that its length is twice the length of the previous sleep window but not greater than a final sleep window size. Class 1 is intended for Best Effort (BE) or Variable-Rate Non-Real-Time (VR-NRT) type of traffic. Before entering power saving class 1, the BS indicates to the MS the initial sleep window size and the final sleep window size. Once the final sleep window size is reached, all the subsequent sleep windows are of the same length. At any time during the sleep mode operation, the BS can reset the window size to the initial sleep window size, and the process of doubling sleep window sizes is repeated.

4.3.1.2 Power Saving Class Two

All the sleep windows are of fixed length and are followed by a listen window of fixed length. Before entering power saving class 2 mode, the BS indicates to the MS the sleep and listen window sizes. Power saving class 2 is the recommended sleep mode for Unsolicited Grant Service (UGS) connections.

4.3.1.3 Power Saving Class Three

It only consists of a single sleep window. The start time and the length of the sleep window are indicated by the BS before entering this mode. At the end of the sleep window, the power saving operation becomes inactive. This power saving class operation is recommended for multicast traffic or for MAC management traffic. The length of the sleep period can be adjusted according to the needed time for the ranging.

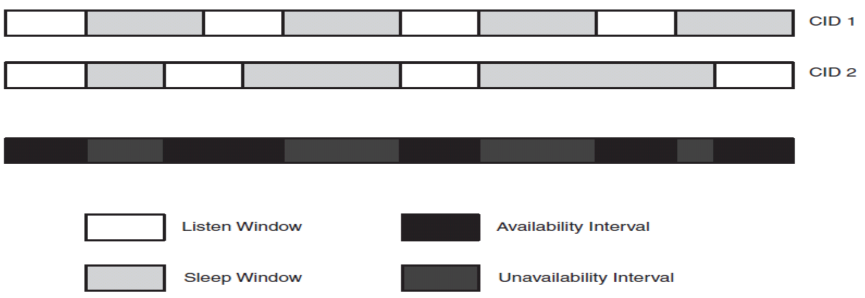

Figure 4.6: Sleep Mode Operation in Mobile WiMAX

4.3.2 Idle Mode

In mobile WiMAX, idle mode [41] is a mechanism that allows the MS to receive broadcast downlink (DL) transmission from the BS without registering itself with network. Support for idle mode is optional in WiMAX and helps mobile MS by eliminating the need for handover when it is not involved in any active data session. Idle mode also helps the BS to conserve its PHY and MAC resources, since it doesn't need to perform any of the handover-related procedures or signaling for MSs that are in idle mode.

For idle mode operation, groups of BSs are assigned to a paging group, as shown in Figure 4.7. An MS in idle mode periodically monitors the DL transmission of the network to determine the paging group of its current location. When detecting that it has moved to a new paging group, an MS performs paging group update. When the network needs to establish a connection with an MS in idle mode, the network needs to page the MS only in all the BSs belonging to the current paging group of the MS. Each paging area should be large enough so that the MS is not required to perform a paging area update too often and should be small enough so that the paging overhead associated with sending the page on multiple BSs is low enough.

During idle mode operation, the MS can be in either MS paging-unavailable interval or in MS paging-listen interval. During the MS paging-unavailable interval, the MS is not available for paging and can power down, conduct ranging with a neighboring

BS, or scan the neighboring BS for the received signal strength. During the MS paging-listen interval, the MS listens to the DCD and DL MAP message of the serving BS to determine when the broadcast paging message is scheduled.

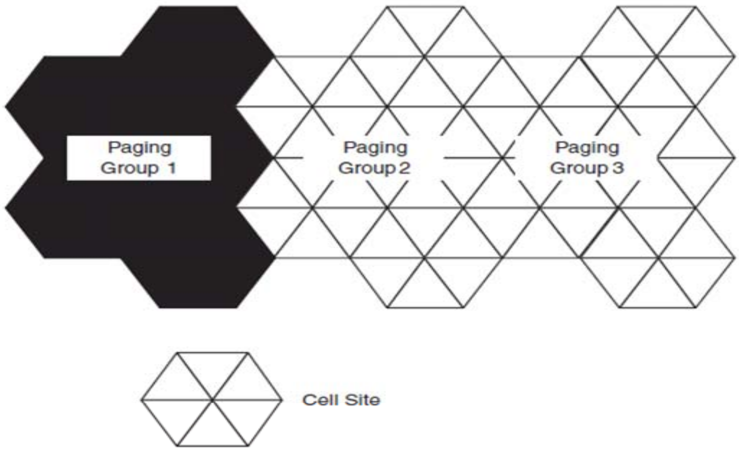

Figure 4.7: Paging Area Example [41]

4.4 Related Works for Handover in Cellular Networks

The simulation approach is the most commonly used handover evaluation mechanism. Several simulation models suitable for evaluation of different types of handover algorithms under different deployment scenarios have been proposed and used in literature. Usually, the analytical studies of handover algorithms consider handover between two BSs. However, the simulation approach considers incorporation of many features of cellular systems and a cellular environment into the evaluation framework. This approach provides a common testbed for comparison of different handover algorithms.

Several references [42-46] used a two-BS model that is simple and widely used for evaluating signal strength based algorithms. This model is suitable for small macrocells and LOS handovers in microcells. In this model, an MS travels from one BS to anther in a straight line at a constant velocity. The path loss was calculated using a single slope formula, and shadow fading was assumed to be log-normal with an exponential correlation function.

Chuah [47] used an SIR-based model that can be used for integrated dynamic resource management tasks. Twenty BSs were uniformly spaced on a ring. The new calls were uniformly distributed throughout the ring.

A comprehensive simulation model suitable for macrocellular and microcellular environments was described in [48]. The conventional macrocellular environment [48] was modeled by a 49-cell terrestrial structure that has seven-cell clusters with 1 km radius cells. The simulation model systems consider both the transmission and traffic characteristics. Such combined analysis of transmission and traffic characteristic provides a more realistic scenario for performance evaluation of a cellular system.

The performance of an SHO algorithm suitable for a CDMA system was analyzed in [49, 50]. Simmonds [51] studied the application of soft handover (SHO) in wideband direct sequence CDMA (DS-CDMA) systems. Exploitation of diversity in the cell overlap region provides better handover performance but requires additional resources. A compromise between diversity usage and resource utilization was analyzed. The handover performance is quantified by the performance measures such as active set updates, number of BSs involved in SHO, and outage probability.

Rouil and Golmie [4] proposed an algorithm to analyze the IEEE 802.16e mobile WiMAX that supports application quality of service requirements and determines the handover duration. In [4], the handover was associated with adaptive channel scanning depending on the link condition. With association level 2, the handover duration can be reduced dramatically. Our simulation is based on this algorithm by modifying scanning duration, contention window size, scan request timeout, and the velocity of MS to analyze the impact on the handover latency.

CHAPTER 5

MOBILE WIMAX HANDOVER SIMULATIONS AND DISCUSSION

The goal for simulation is to test the performance of handover in PHY layer and the properties of mobile WiMAX in practice. In this chapter, we first implement the handover concept using MATLAB with RUNE Toolkit [52] and later on a very basic scheme is planned with the Network Simulator [55] (version 2.29 with additional WiMAX and mobility packets from NIST project [53, 54]).

5.1 Simulation in PHY Layer

5.1.1 Signal Strength Base Algorithm

The frequencies used in mobile communications are normally above 30 MHz and the maximum link lengths do not exceed 25 to 30 km. Macrocells in current 2G (second generation) or 3G (third generation) systems are much smaller. It must be taken into account that mobile communications are two-way and that the uplink (MS to BS) is power limited. This is especially so in the case of regular portable, handheld terminal. This makes frequency reuse possible at relatively short distances. This is also important feature in mobile networks which require a great spectral efficiency for accommodating larger number of users.

Generally, the transmitted signal, as it propagates away from the transmitter, experiences three different rates of variation, namely, very slow variations, also known as path loss, which are distance dependent, slow variations, mainly due to shadowing effects, and fast variations, due to multipath. The received signal is averaged over time using an averaging window or by means of filtering to remove out fast variations due to the geographical and environmental factors. So the received signal by MS can be suitably considered to be containing only two components: path loss and shadowing variations.

In our project, the path loss follows the well-known Hata model [56]. Hata model is a version of Okumuar et al. model [57] developed for use in computerized coverage predicting tools. Hata obtained mathematical expressions by fitting the empirical curves provided by Okumuar. Expressions for calculating the path loss, L (dB) for urban, suburban and rural environments are provided. For flat urban areas,

$$\begin{aligned} L(dB) = {} & [69.55 + 26.16\log(f) - 13.82\log(h_t) - a(h_m)] \\ & + [44.9 - 6.55\log(h_t)]\log(d) \end{aligned} \tag{5.1}$$

where f is in MHz, h_t and h_m are in meters and d in km. Parameter h_t is the BS effective antenna height and h_m is the MS height, and d is the radio path length. For an MS antenna height of 1.5 m, $a(h_m)=0$. For a medium-small city,

$$a(h_m) = [1.1\log(f) - 0.7]h_m - [1.56\log(f) - 0.8] \tag{5.2}$$

For a large city,

$$
\begin{aligned}
a(h_m) &= 9.29[\log(1.54h_m)]^2 - 1.1 \qquad f \le 200MHz \\
a(h_m) &= 3.2[\log(11.75h_m)]^2 - 4.97 \qquad f \ge 400MHz
\end{aligned}
\tag{5.3}
$$

In order to accommodate the need to deploy higher frequency systems, such as the GSM at 1800 MHz or PCS at 1900 MHz, a new revision of Hata model (COST 231-Hata [58]) was developed using similar method to those used by Hata. The COST 231-Hata model follows the express,

$$
\begin{aligned}
L(dB) = {} & [46.3 + 33.9\log(f) - 13.82\log(h_t) - a(h_m)] \\
& + [44.9 - 6.55\log(h_t)]\log(d) + C_m
\end{aligned}
\tag{5.4}
$$

where $a(h_m)$ has the same expression as in the original model and C_m is equal to 0 dB for medium-size cities and suburban centers, and equal to 3 dB for metropolitan centers.

The very slow variations, shadowing variation can be modeled as a power law, i.e., $1/d^n$, where the exponent, n in typical cellular applications is close to 4. The slow variations, can be represented by the expression

$$
P(d) = P_{1km} - 10n\log(d_{km}) + N(0, \sigma_L) \tag{5.5}
$$

where P(d) is the received power at a distance d(km), P_{1km} is the received power at 1 km, n is the power decay law and N is a Gaussian random variable of zero mean and standard deviation, σ_L, called the location variability. It should be pointed out that P_{1km} is used in macrocell scenarios, In other cases where radio paths are shorter, e.g., indoor or urban microcells, other reference distances such as 1 m or 100 m are used.

We performed simulations for a frequency of 2 GHz, the larger area mean is −70 dBm, location variability is 7 dB, and the correlation length is set to 30 m. The simulation scenario is like: MS is assumed to travel from BS1 to BS2 which are 6 km apart. Somewhere halfway between both BSs, the averages of the received signals are very similar in level. A threshold and a hysteresis margin are defined so that two HO algorithms, HO based on relative signal strength with threshold and HO based on Relative signal strength with threshold and hysteresis margin, can be simulated. Figure 5.1 illustrates the two received signals by the MS and the HO threshold and hysteresis margin above it. The smooth lines are the path loss of signal with distance increased from BSs. The fluctuation is due to the shadowing variations. The HO based on relative signal strength with threshold just performs the switch whenever the received signal is below the threshold and the alternative signal is larger. Figure 5.2 demonstrates the numerous switches handover flip-flops that take place if you only set the threshold level. If a margin is taken into consideration in the HO algorithm so that, in order to switch back to the former BS, the difference between received signals must be above such margin. From Figure 5.3, not only the number of BS changes is drastically reduced but also the time of the HO occurrence is delayed, so the load is reduced for the whole networks system. Figure 5.4 shows the actual power the MS receiving during the HO taking place. System parameters: frequency: 2.0 GHz, large area mean: −70 dBm, local variability: 7 dB, correlation length is 30 meters, threshold: −85 dBm, hysteresis margin: 15 dB.

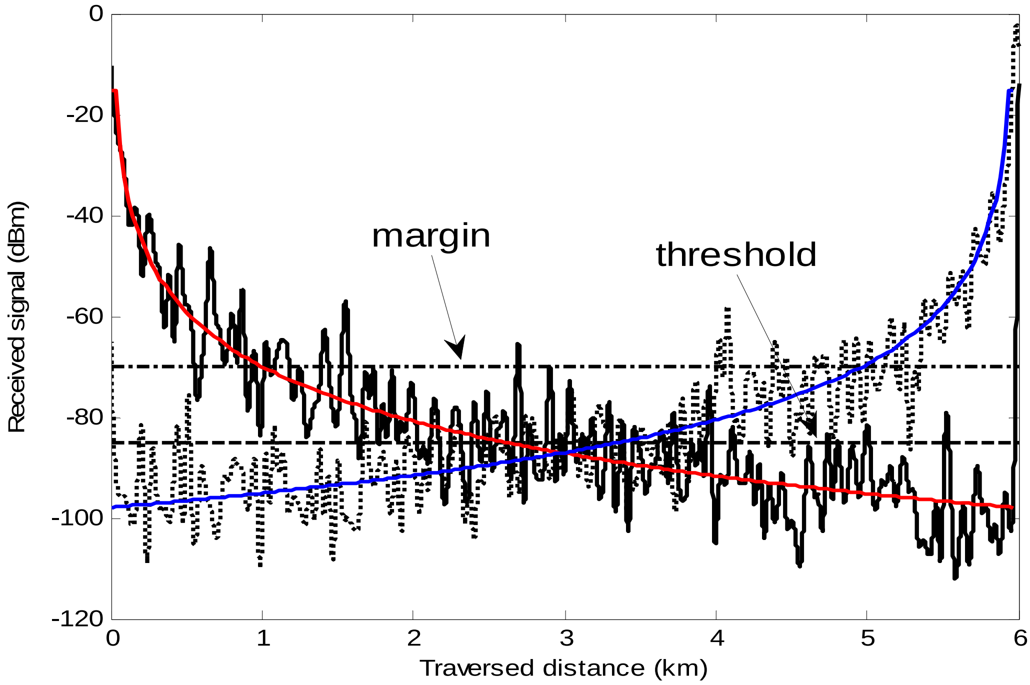

Figure 5.1: Signals from Two BSs, and HO Threshold and Hysteresis margin

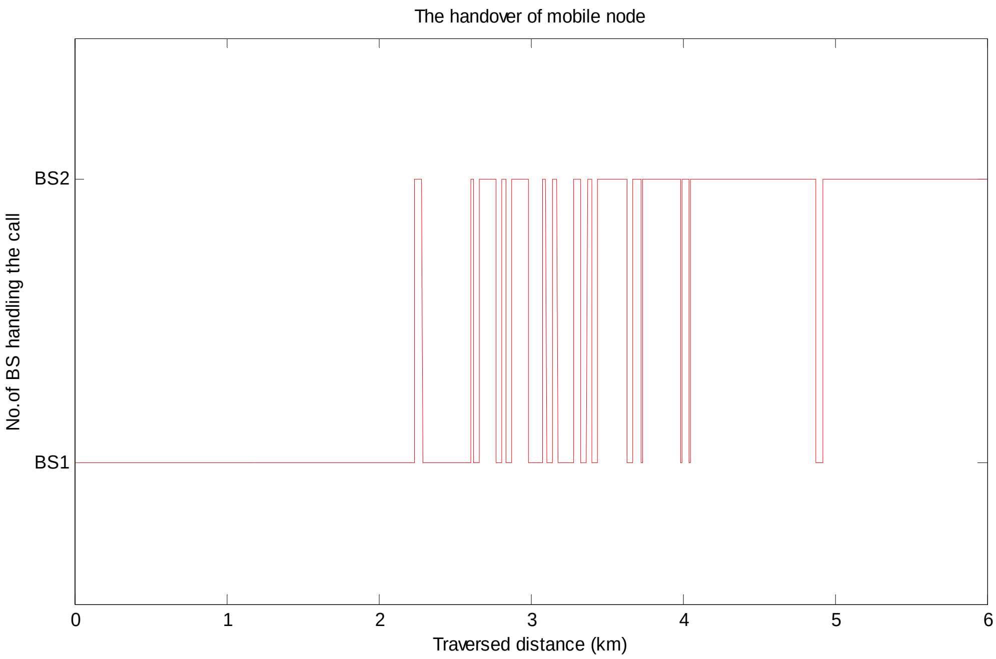

Figure 5.2: HO Based on Relative Signal Strength with Threshold

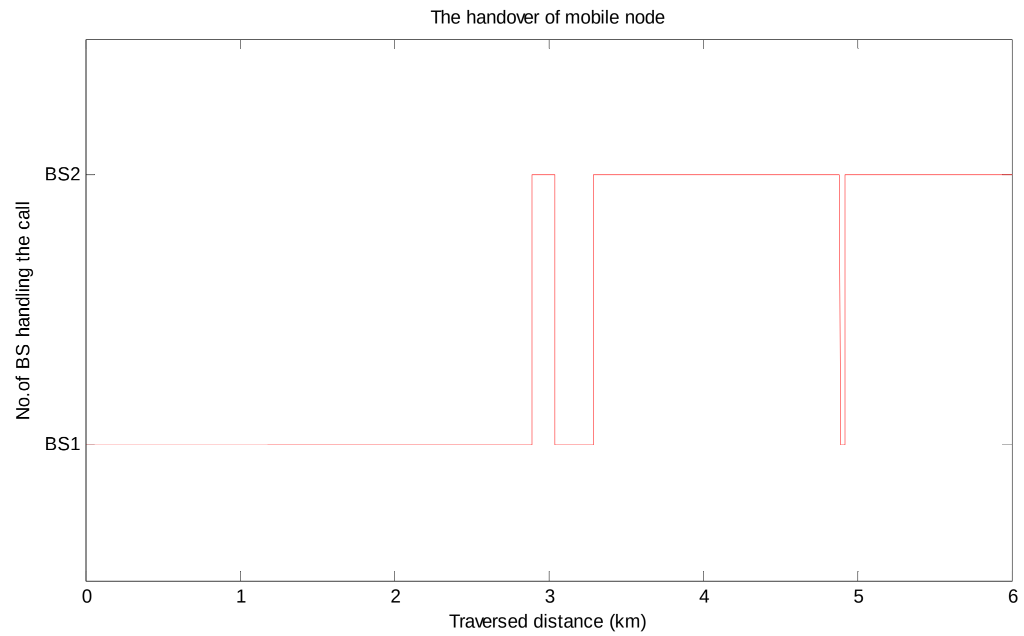

Figure 5.3: HO Based on Relative Signal Strength with Threshold (–80 dBm) and Hysteresis Margin (15 dB)

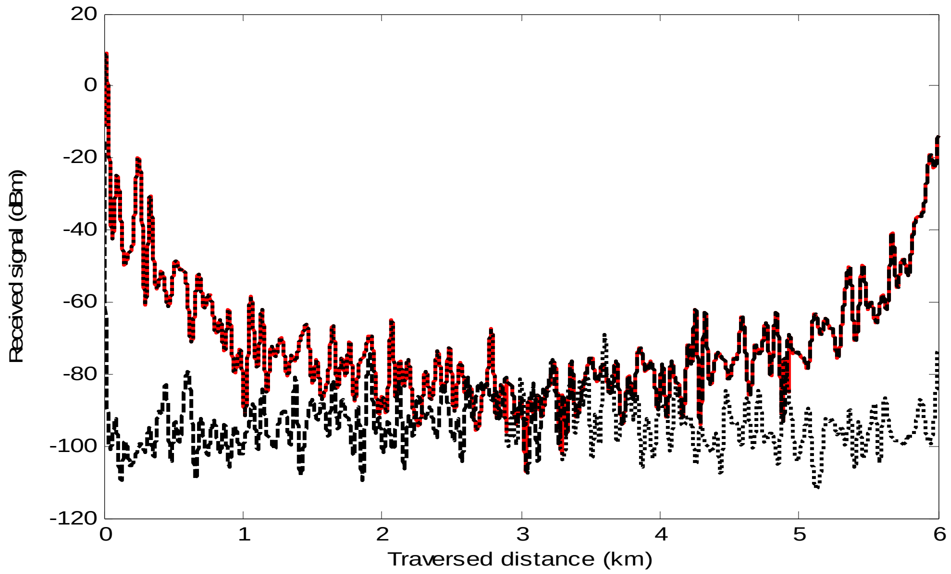

Figure 5.4: Received Signal by the MS during HO

5.1.2 SIR Based Algorithm

In order to maintain the Quality of Service (QoS), signal-to-interference ratio (SIR) at the cell boundary should be relatively high, such as 18 dB for Advanced Mobile Phone System (AMPS) and 12 dB for GSM. However, a low SIR may be used for capacity reasons since co-channel distance and cluster size are small for lower SIR and channels can be reused more frequently in a given geographical region. SIR is a measure of communication quality. This algorithm makes a handover when the current BS's SIR drops below a threshold and another BS can provide sufficient SIR. The simulation scenario is set up with reused factor equal to 3, and with 3 sectors for each cell as shown in Figure 5.5. The signal level decays with the 4^{th} power of the distance and the shadow fading has a standard deviation of 8 dB and a correlation distance of 50 meters. The coverage area of one BS is 1000 meters. The red circles in the Figure 5.4 are the BS and the dot-line is the trajectory of MS with the speed of 20 m/s.

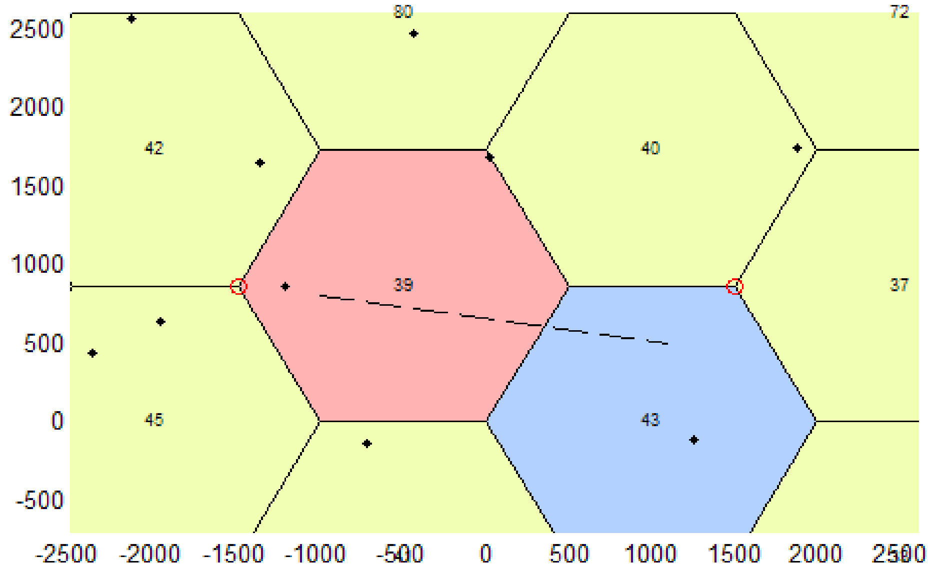

Figure 5.5: Geometrical Cell Arrangement

Figure 5.5 shows the results of a mobile station moving from one cell to another. A SIR-based (Fig. 5.8) scheme would make one handoff at around 600 meters whereas the signal strength based algorithm (Fig. 5.6) would probably make several handover back and forth. Figure 5.7 shows the interferences sensed by the MS in the different cells. The signal strength base algorithm have several disadvantages: (1) when received signal strength (RSS) is high due to high interference, the handover will not take place, although ideally, handover is desirable to avoid interference; (2) when RSS is low, handover takes place even if voice quality is good and such a handover is not required. Thus, the SIR-based algorithm is much more reliable and it also reduces the unnecessary handovers to mitigate the handover processing loads and poor communication quality.

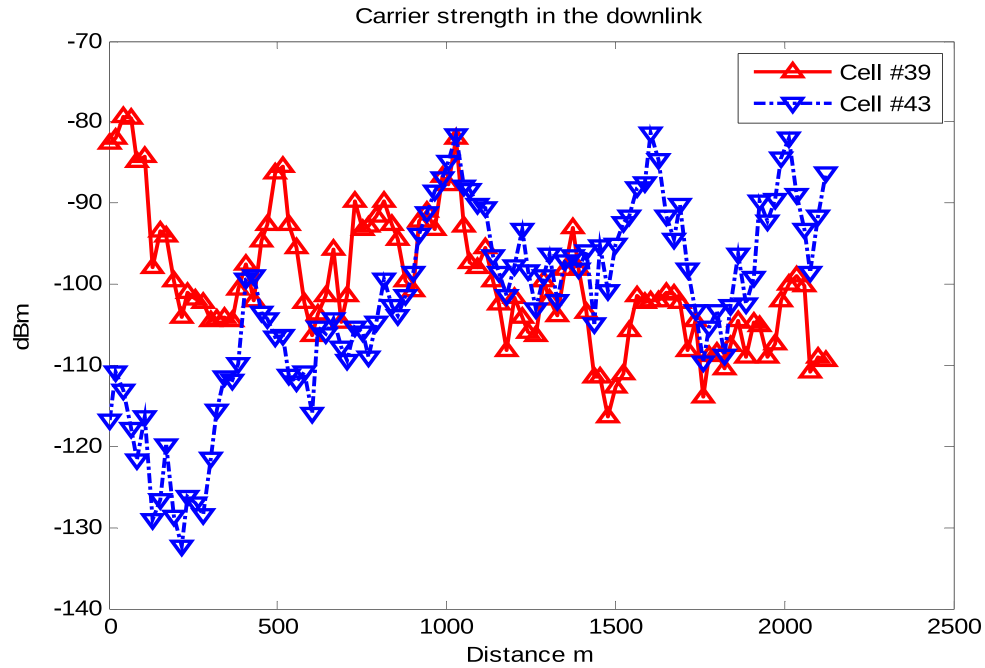

Figure 5.6: Signal Strength Based Algorithm, Received Signal Level in the Downlink

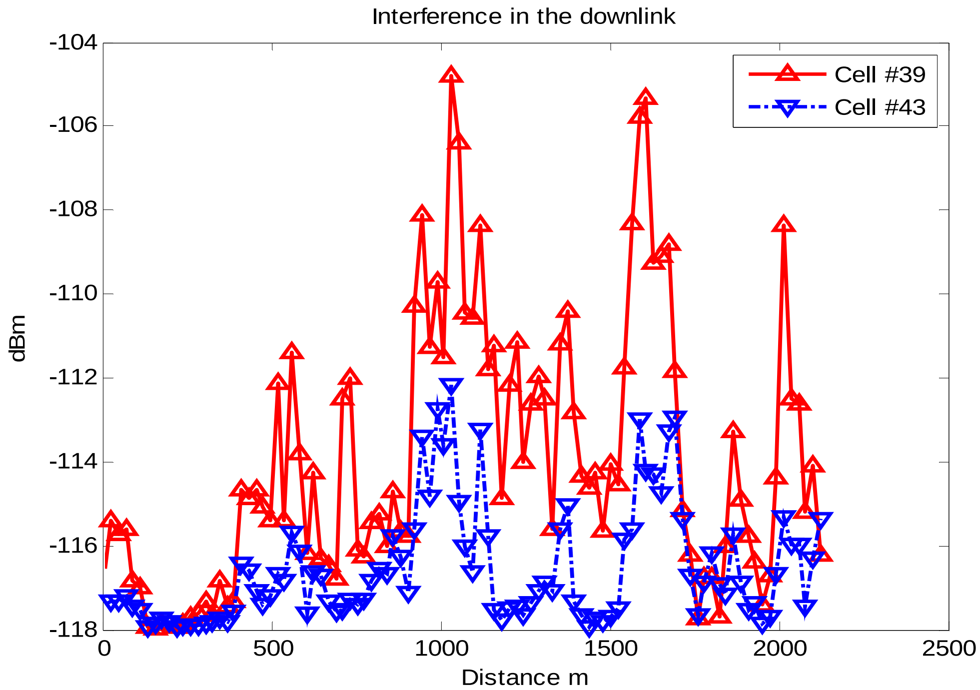

Figure 5.7: Interference Level in the Downlink

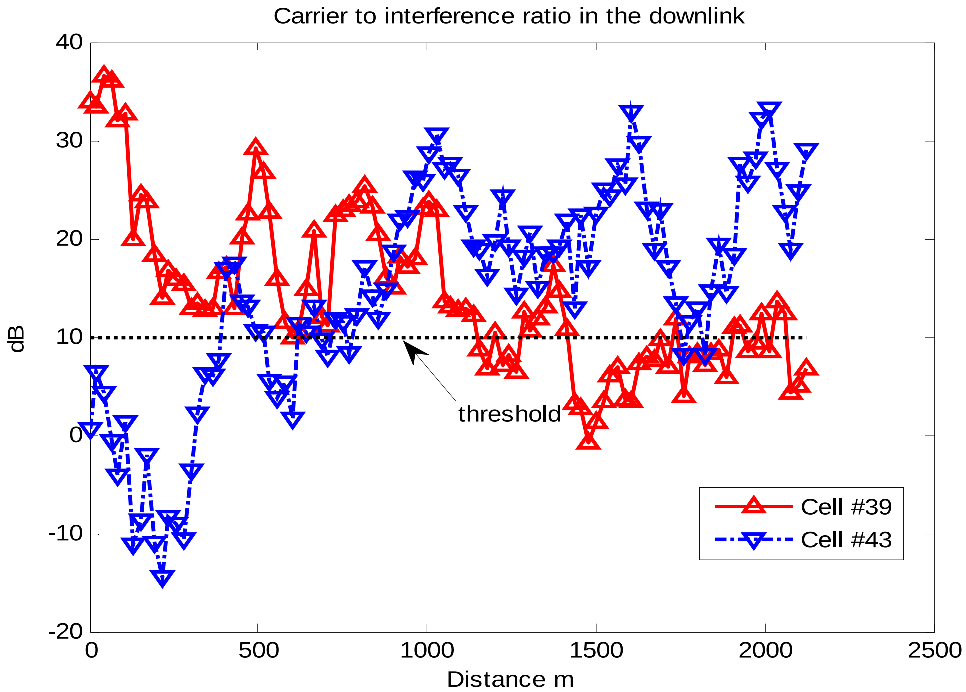

Figure 5.8: SIR Based Algorithm, Received Signal Level in the Downlink

5.1.3 Handover Prioritization: Guard Channels

In order to reduce the handover failure rate, the handover prioritization should be used as mentioned in Chapter 4. There are two basic methods of handover prioritization, guard channels and queuing. In this section, we only implement the guard channels method to investigate the new call blocking and handover dropping probability.

In a cellular telephone system, each cell reserves N_h channels for handover traffic so that no new calls are admitted when the number of channels in use is larger or equal to $N_0=N-N_h$, where N is the total number of channels for each cell. New calls and handover calls can be assumed to arrive as independent Poisson processes with intensities λ_N and

λ_H respectively. Calls have a lifetime in the cell, that is, they are terminated or leave the cell within a time interval that is exponentially distributed with an average $1/\mu$.

Denote the total number of calls in progress in the cell at time *t*, N(*t*). Due to the memory-less properties of the Poisson arrivals and the exponential distribution of the call life time in the cell, N(*t*) will be a Birth-Death Markov chain with the state –transition diagram as shown in Figure 5.9.

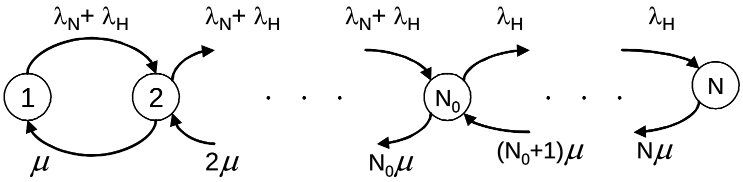

Figure 5.9: Birth-Death Markov Chain

We denote the probability of k channels in use is:

$$p_k = \Pr(N(t) = k) \tag{5.6}$$

By means of the flow-cut equations:

$$\begin{aligned} (\lambda_N + \lambda_H) p_{k-1} &= k\mu p_k & 1 \le k \le N_0 \\ \lambda_H \, p_{k-1} &= k\mu p_k & N_0 < k \le N \end{aligned} \tag{5.7}$$

Iteratively solving these equations yields

$$p_k = \begin{cases} p_0 \dfrac{(\lambda_N + \lambda_H)^k}{\mu^k k!} & k \le N_0 \\ p_0 \dfrac{(\lambda_N + \lambda_H)^{N_0} \lambda_H^{k-N_0}}{\mu^k k!} & N_0 < k \le N \end{cases} \tag{5.8}$$

Using the fact that all p_k add up to unity, we can solve for p_0 by using the notations:

$$\rho_{Tot} = \frac{\lambda_N + \lambda_H}{\mu} \qquad \rho_H = \frac{\lambda_H}{\mu} \tag{5.9}$$

We get [59]

$$p_k = \begin{cases} \dfrac{\dfrac{(\rho_{Tot})^k}{k!}}{\sum_{j=0}^{N_0} \dfrac{(\rho_{Tot})^j}{j!} + \sum_{j=N_0+1}^{N} \dfrac{(\rho_{Tot})^{N_0} (\rho_H)^{j-N_0}}{j!}} & k \le N_0 \\ \dfrac{\dfrac{(\rho_{Tot})^{N_0} (\rho_H)^{k-N_0}}{k!}}{\sum_{j=0}^{N_0} \dfrac{(\rho_{Tot})^j}{j!} + \sum_{j=N_0+1}^{N} \dfrac{(\rho_{Tot})^{N_0} (\rho_H)^{j-N_0}}{j!}} & N_0 < k < N \end{cases} \tag{5.10}$$

Now, the blocking and handover dropping probabilities can be derived as:

$$P_{block} = \sum_{k=N_0}^{N} p_k \qquad P_{drop} = p_N \tag{5.11}$$

Further, the relative mobility, a, is defined as:

$$a = \frac{\lambda_H}{\lambda_N + \lambda_H} \tag{5.12}$$

If we set the number of available channels for each cell as 12, and the relative mobility as a=0.50, we can plot the blocking and dropping probabilities as function of total traffic load with reserved channels for handover for N_h equal to 2, 4, and 6 in Figure 5.10. From the figure, we can find that if there is a requirement to keep the dropping probability low, more channels for handover calls have to be reserved. It also shows that if the number of reserved channels dedicated to the handover increase, the blocking probability of new calls is increasing correspondingly.

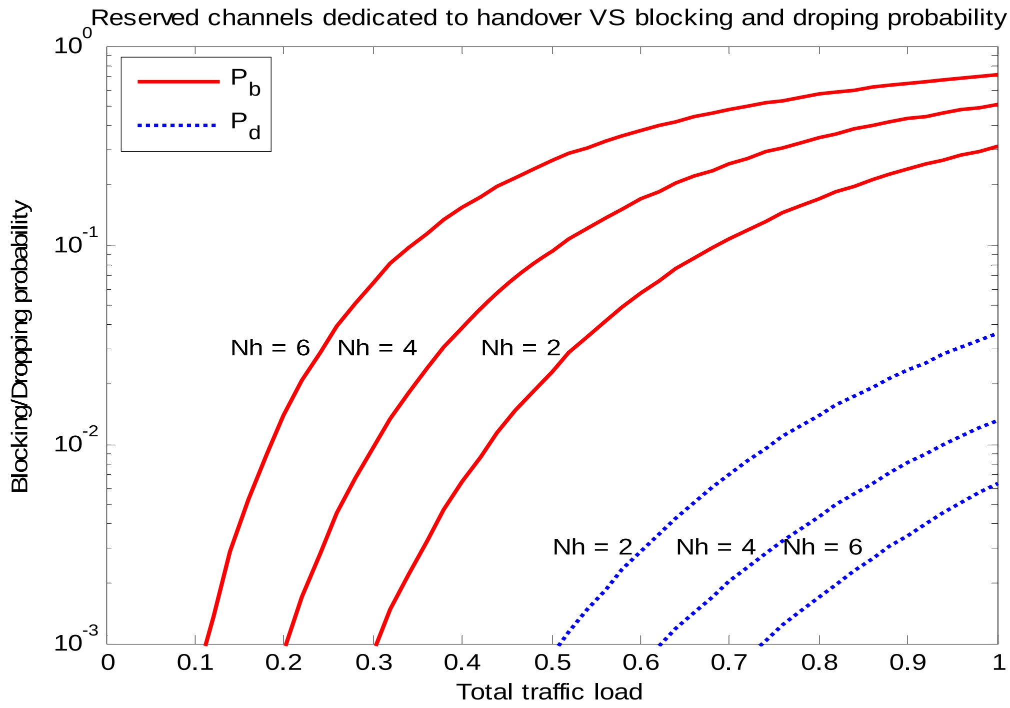

Figure 5.10: Blocking/Dropping Probabilities as Function of Traffic Load

5.2 Handover Latency with NS2

In the context of ubiquitous connectivity, a mobile station (MS) equipped with an IEEE 802.16 interface is likely to roam across multiple base station (BS) in order to maintain connectivity. However, as in most mobility scenarios, finding the target BS that best fits the mobility path and application requirements is far from being trivial. The IEEE 802.16e standard supports temporarily suspending the communication between the BS and the MS in order for the mobile to perform channel scanning. It is preferable for the MS to perform this scanning and obtain a list of neighboring BSs before it is ready to perform a handover because channel scanning can be a relatively time consuming activity. During this scanning period, both upstream and downstream packets originating at the mobile and destined to it are buffered at the MS and BS, respectively.

The IEEE 802.16 standard defines the mechanisms for a user equipment to connect to a BS. Figure 5.11 shows the so-called network entry phase, which consists of both synchronization and association operations. During the synchronization step, the MS received broadcast messages, which are sent by the BS and contain information about how and when to access the channel. The downlink (DL_MAP) and upling (UL_MAP) messages contain burst allocation for each frame. The downlink channel descriptor (DCD) and uplink channel descriptor (UCD) contain transmission parameters of each burst. The synchronization phase is followed by the association operation, where the MS adjusts its timing and transmission power to communicate with BS. During this step, also known as initial ranging, the MS randomly picks a ranging slot according to a truncated exponent algorithm [37, 38]. It then waits for a contention slot in an uplink frame in order to transmit its ranging request. The next steps following the network entry phase include basic capability negotiation, authentication, and registration. Finally, the MS is connected to the BS and an IP connection is established. Therefore, if an MS needs to perform a network entry operation each time it performs a handover, any ongoing connections could be disrupted severely.

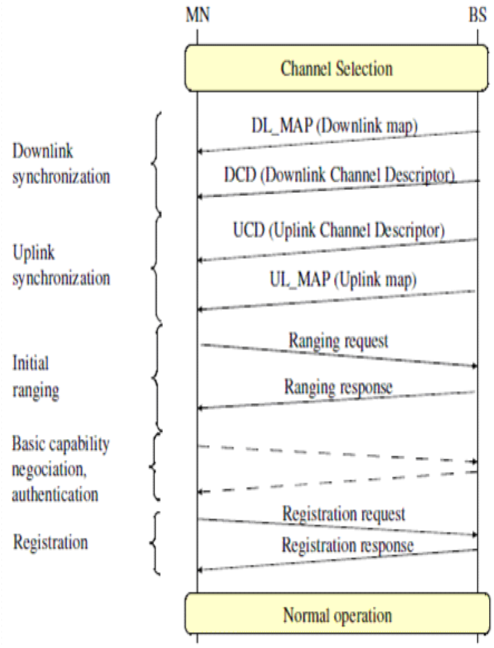

Figure 5.11: Network Entry in the Mobile WiMAX

In order to reduce the period of channel scanning time, the IEEE 802.16e defines the mechanisms related to BS communication and channel scanning in order to facilitate neighbor discovery and handovers. Regarding BS communication, the assumption in IEEE 802.16e is that neighboring BSs exchange DCD and UCD messages over the backbone. The information is then embedded in messages sent periodically by the serving BS to the MSs. This allows an MS to acquire channel information prior to any scanning. Mechanisms related to channel scanning are in the form of requests by the MS seeking to maintain information about neighboring BSs as shown in Figure 5.12. The MS sends a MOB-SCN_REQ message to the serving BS that processes the information and returns the scanning interval information using a MOB-SCN_RSP message.

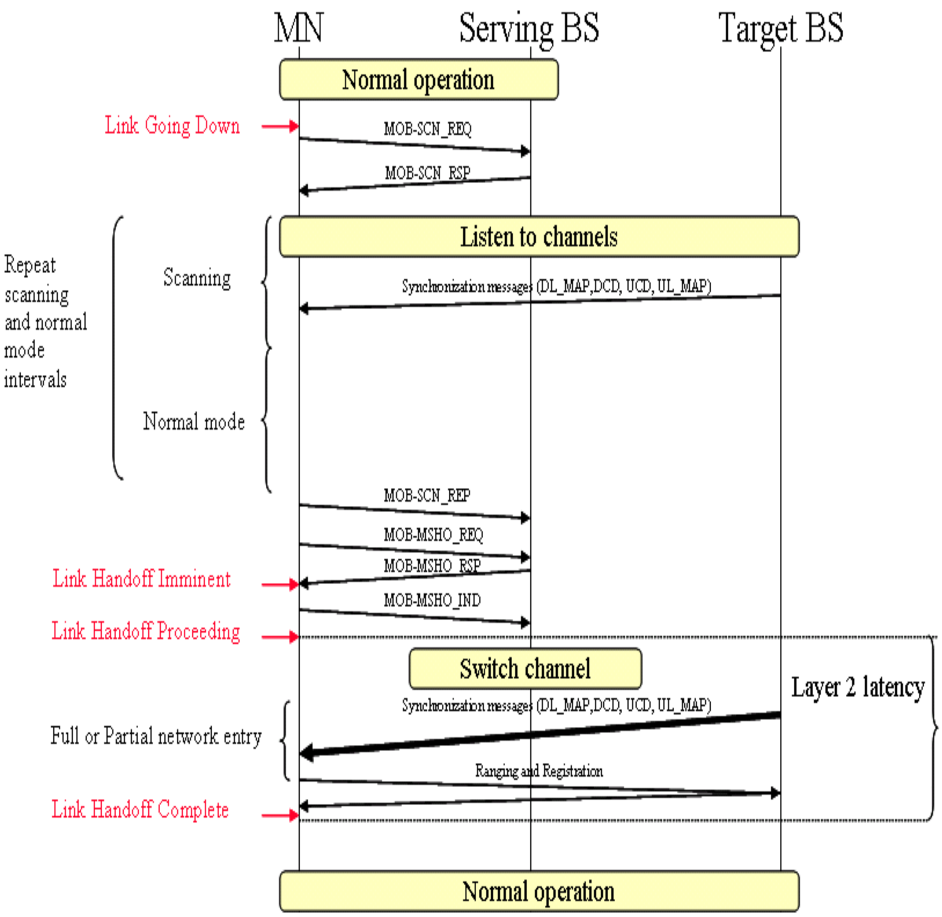

Figure 5.12: The Handover in the Mobile WiMAX.

5.2.1 Simulation Scenario

The all-in-one package of the NS-2 did not include support for mobile WiMAX and therefore additional components are required. Two packages from NIST (http://w3.andtd.nits.gov/seamlessandsecure.shtml), the WiMAX and the mobility modules, are installed to achieve simulations of mobile scenarios.

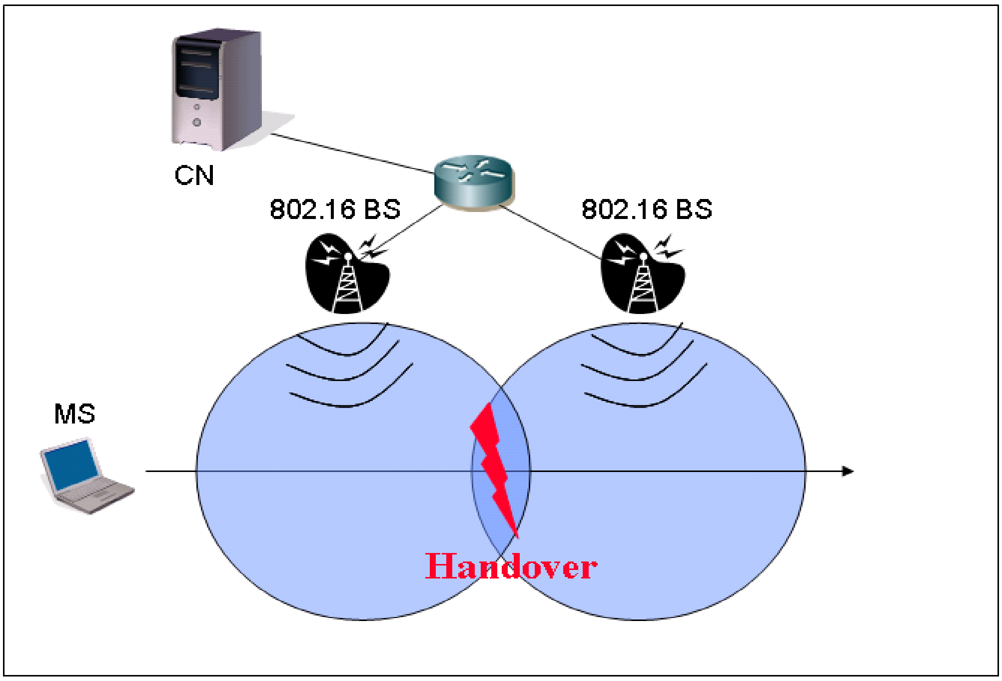

Figure 5.13: The Handover between Two IEEE 802.16e Networks.

There is an example scenario in the provided modules, which is taken as a basis for our simulations. The basic idea of a MS traveling through the coverage areas of two 802.16e BSs is shown in Figure 5.13. Each BSs' coverage areas have a radius of 1 km. The channel scanning interval is set up to 2 frames and the contention probability is 5 times per frame.

5.2.2 Simulation Result

After the adjustments of NS-2 and WiMAX-module parameters, the influence of velocity of the MS is investigated. The simulations were done with MS speeds between 1 and 32 m/s with 1 m/s step. For each speed, the start time for the MS is set up randomly and the simulation with corresponding speed runs 10 times. For many applications, such as VoIP, handover should be performed seamlessly without perceptible delay or packet loss. To support these applications, WiMAX requires that for the full mobility, up to 120 km/h, handover latency be less than 50 ms with an associated packet loss that is less than 1 percent. The 32 m/s equals to 115 km/h, which is a little bit below the mentioned 120 km/h for a seamless handoff.

The handoff latencies first vary in the region of 40 ms and stayed nicely below the 50 ms limit until the MS reached the velocity of 20 m/s, apart from few exceptions that exceeded the limit by only few milliseconds. After this, the times show a more or less steady growth up to 150 ms region with the 32 m/s MS speed. The average handover latencies are drawn as the velocity of 1-32 m/s in Figure 5.14. Figure 5.14 also shows that the handover latency with threshold level equal to 7 dB and the one with threshold level 3 dB. It seems that in order to maintain high SNR, the MS needs more time to scan channels.

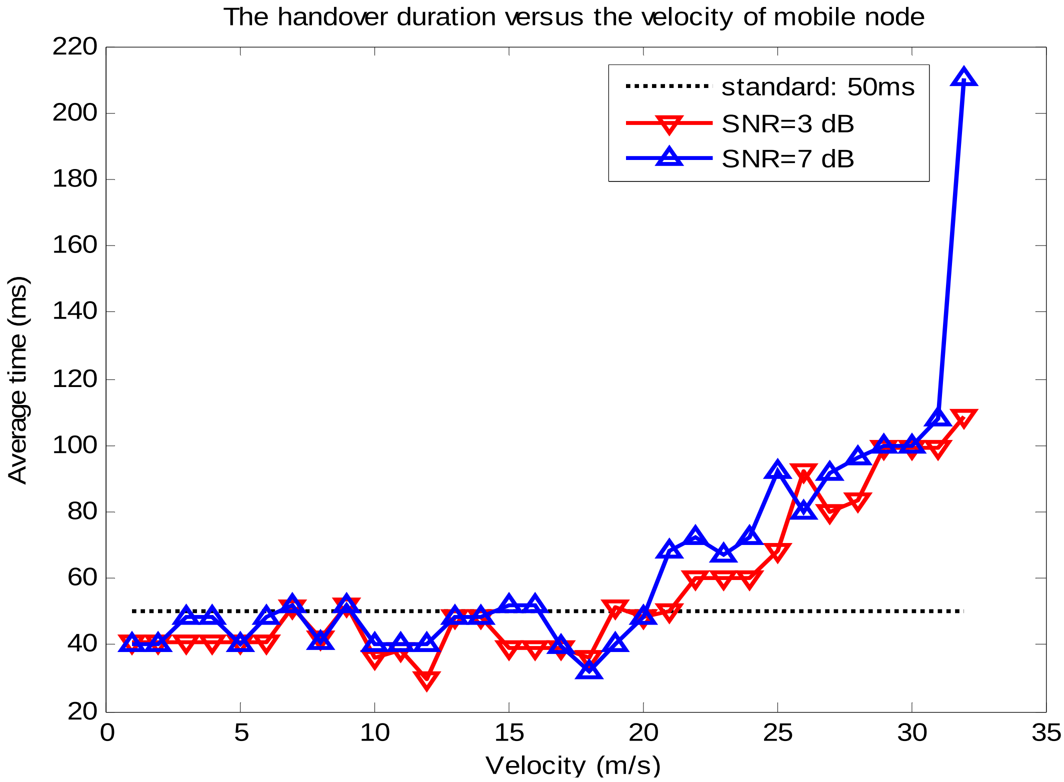

Figure 5.14: The Handover Latency with the Velocity of MS

Figure 5.15 shows the average packet loss varying with the velocity of MS for different threshold level. The packet loss steadily increases with the velocity increasing. The packet loss is also proportional to the SIR; the higher SIR, the more packet loss can be caused.

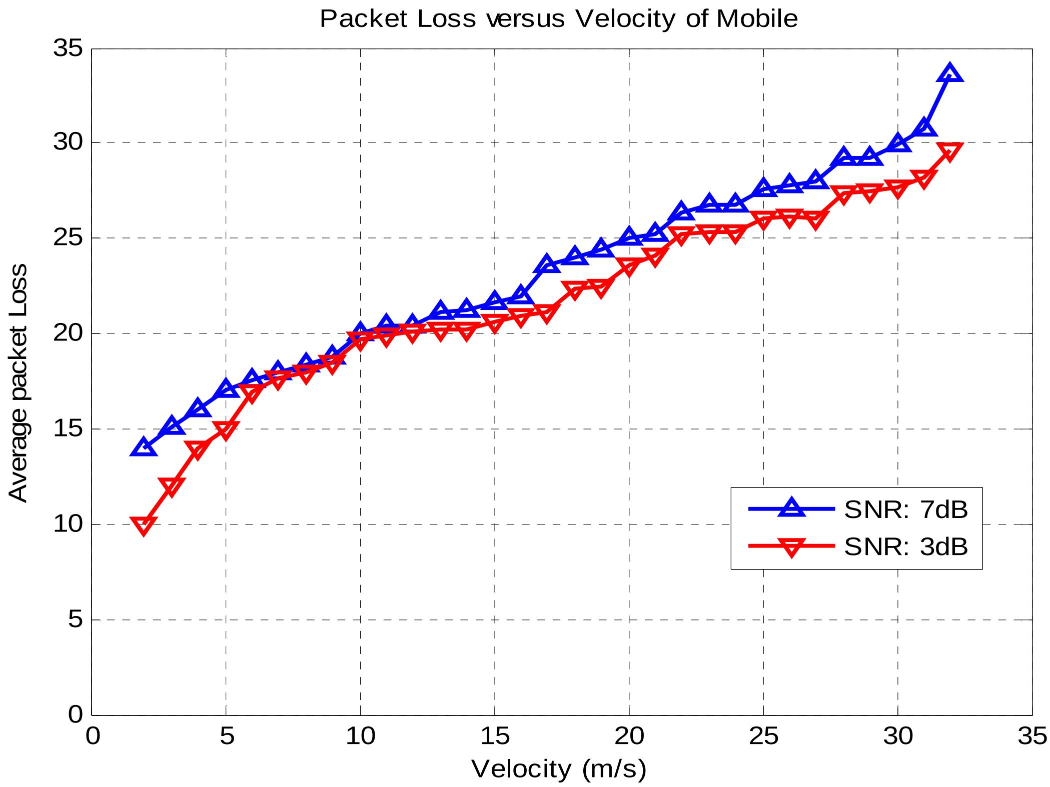

Figure 5.15: The Packet Loss with the Velocity of MS

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS FOR RESEARCH

The purpose of this research work is to study the basic concepts of cellular handover and the handover latency with the traveling speed of mobile station in mobile WiMAX networks. 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.

First, we simulated the handover in the physical layer using MATLAB. Two handover scenarios have been studied. One is the handover only considering the threshold that causes numerous handover switching between serving base station and target base station, which puts some load to the system and reduces the performance of the whole network. The other is the handover considering both the threshold and hysteresis margin that tremendously reduces the unnecessary handover at the price of increased handover latency.

Secondly, we also simulated the more realistic handover in the mobile WiMAX using NS-2 with WiMAX and mobility modules. The goal of this simulation is to find out the relationship between the handover latency and the velocity of mobile station. It can be seen that the current handover mechanics used in the NS-2 module meets the requirement of seamless handover in mobile WiMAX when the mobile station travel at the speed of 20 m/s. Although, using link-going down mechanism will dramatically reduce the handover latency, it is still a challenge to achieve the full mobility: up to 120 km/h, handover latency of less than 50 ms with an associated packet loss that is less than 1 percent.

As extension to this research work, two topics for future research investigations are suggested. Since there is a tradeoff between handover threshold and margin, an adaptive threshold window could be used to balance the load of base station and the QoS of the mobile. If the handover happens early before mobile entering the coverage of the target base station, the target base station has to allocate some resources to the call entry and it also causes unnecessary handovers. But, if the handover happens too late, the QoS will be hard to maintain due to the low SINR and interference from other cells. This is a potential research topic by selecting the threshold window (the gap between threshold and hysteresis margin) adaptively according to the SINR of the mobile station senses.

Also, the current work is restricted to hard handover only. Possibilities of extending this work to macro diversity and fast base station switching 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 predication algorithms and current load factors of the target BSs give an alternative way of deciding the target BS. Further, reducing the number of handovers is highly desirable from a system perspective.

REFERENCES

[1] IEEE Std 802.16e-2005. Amendment to IEEE Standard for Local and Metropolitan Area Network-Part 16: Air Interface for Fixed Broadband Wireless Access System –Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, February, 2006.

[2] J. H. Stott, “The how and why of COFDM”, http://www.ebu.ch/en/technical/trev_278-stott.pdf, January, 1999.

[3] Sassan Ahmadi, “An overview of Next-Generation Mobile WiMAX Technology”, *IEEE communications Magazine*, pp.84, June 2009.

[4] Richard Rouil and Nada Glomie, “Adaptive Channel Scanning for IEEE 802.16e”, *IEEE MILCOM 2006*, pp. 1-6, 2006.

[5] Informa Telecoms and Media: “Mobile industry outlook”, http://shop.information.com/, 2006.

[6] Thinkquest, “Wireless Communication Technologies- WiMAX”, http://library.thinkquest.org/040i/01721/wireless/wimax.htm.

[7] J.G. Andrews, A. Ghosh, R. Muhammed, “Fundametals of WiMAX”, Prentic Hall, 2007.

[8] C.S. Kang, J. Kim, D. K. Sung, “A Dynamic Downlink load control Scheme for WCDMA and HSDPA Systems”, *IEICE Trans. On Comm.* Vol. 92b, pp.2327-2331, 2009.

[9] K. Balachandran, Q. Bi, and A. Rudrapatna, “Performance Assessment of Next-Generation Wireless Mobile Systems”, *Bell Labs Technical Journal*, vol. 13, pp. 35-38, 2009.

[10] CDMA2000 Technologies, CDMA Development Group. http://www.cdg.org/

[11] A. Goldsmith, “Wireless Communications”, Cambridge University Press, Cambridge, 2005.

[12] L.M. Correia, “Mobile Broadband Multimedia Networks: Techniques, Models and Tools for 4G”, Academic Press, 2006.

[13] WiMAX Forum, “Executive Summary: Mobile WiMAX performance and Comparative Summary”, Sept. 2006. http://www.wimaxforum.org/.

[14] Mustafa Ergen, “Mobile Broadband –including WiMAX and LTE”, Springer Science, 2009.

[15] WiMAX Forum, “Mobile WiMAX Part I: A Technical Overview and Performance Evaluation”, 2006. http://www.wimaxforum.org/.

[16] WiMAX Forum, “Mobile WiMAX Part II: A Comparative Analysis”, 2006. http://www.wimaxforum.org/.

[17] IEEE. Std. 802.16-2004. Part16: Air interface for fixed broadband wireless access systems. October 2004.

[18] IEEE. Std. 802.16e-2005. Part16: Air interface for fixed and mobile broadband wireless access systems-Amendment for physical and medium access control layers for combined fixed and mobile operation in licensed band. December 2005.

[19] WiMAX Forum, WiMAX Forum Mobile System Profile. 2006-07.

[20] R. Fantacci, D. Marabissi, and D. Tarchi, “Adaptive Modulation and Coding Techniques for OFDMA Systems”, *IEEE Trans. On Wireless Comm.* vol.8, pp. 4876-4882, 2009.

[21] E. Biglieri, “MIMO Wireless Communications”, Cambridge University Press, Cambridge 2007.

[22] J. C. Fricke and P. A. Hoeher, “Reliability-Based Retransmission Criteria for Hybrid ARQ”, *IEEE Trans. On Comm.* vol. 57, pp. 2181-2184, 2009.

[23] S. L. Tsao, and Y. L. Chen, "Energy-efficient packet scheduling algorithms for real-time communications in mobile WiMAX system", *Computer Communications*, vol. 31, pp. 2350-2359, 2008.

[24] A. Steffen, "Secure Network Communication Part III", http://www.strongsec.com/zhw/ksy_auth.pdf.

[25] D. Gesbert, A. Naguib, M. Shafi, D.S. Shiu, P, Smith, "Theory to practice: an overview of MIMO space-time coded wireless systems", *IEEE Journal on Selected Areas in Communication*, vol.21, pp.281, 2003.

[26] G.L. Stuber, "Principles of Mobile Communication", 2nd edition, Kluwer, Boston, 2001.

[27] Y. F. Chen and N. C. Beaulieu, "Maximum Likelihood Receivers for Space-Time Coded MIMO Systems with Gaussian Estimation Errors", *IEEE Trans. on Comm.* vol. 57, pp. 1712-1720, 2009.

[28] S. M. Alamouti, "A simple transmit diversity technique for wireless communication", *IEEE Journal on Selected Areas in Communication*, vol.8, pp.1451-1458.

[29] WiMAX Forum, WiMAX Forum Network Architecture (Stage 2: Architecture Tenets, Reference Model and Referenc Points) [Part 1], http:// www.wimaxforum.org/technology/documents/WiMAX_End-to-End_Network_systems_Architecture_stage_2-3_Release_1.1.0.Zip.

[30] S. Tekinary and B. Jabbari, "Handover and Channel Assignment in Mobile Cellular Networks", *IEEE Communication Magazine*, Vol.29, pp.42-46, 1991.

[31] Gregory P. Pollioni, "Trends in Handover Deisng", *IEEE Communication Magazine*, vol.34, pp.82-90, 1996.

[32] W. Stallings, "Wireless Communications & Networks", 2nd version, Pearson Education, Inc. 2005.

[33] P. Marichamy, S. Chakrabati and S. L. Maskara, "Overview of handoff schemes in cellular mobile networks and their comparative performance evalution", *IEEE VTC'99*, vol.3, pp.1486-1490, 1999.

[34] Y. Kim, K. Lee and Y. Chin, “Analysis of Multi-level Threshold Handoff Algorithm”, *Global Telecommunications Conference (GLOBECOM’96)*, vol.2, pp.1141-1145, 1996.

[35] J. L. Chen, S. W. Pan, and M. C. Chen, “Adaptive radio resource management in an integrated GPRS/UMTS service network”, *European Trans. on Telecomm.* vol.19, pp. 837-845, 2008.

[36] Alexe E. Leu and Brian L. Mark, “Modelling and Analysis of Fast Handoff Algorithms for Microcellular Networks”, *Proceedings of the 10th IEEE MASCOTS’2002*, pp.321-328, 2002.

[37] N. D. Tripathi, J. H. Reed and H. F. Vanlandinoham, “Handoof in Cellular Systems”, *IEEE Personal Communications*, vol.5, pp. 26-37, 1998.

[38] D. Munoz-Rodriguez and K. W. Cattermole, “Multicriteria for Handoff in Cellular Mobile radio”, *IEEE Proc.*, Vol. 134, pp. 85-88, 1987.

[39] M. A. Ben-Mubarak, B. M. Ali, and N. K. Noordin, “Review of Handover Mechanisms to Support Triple play in Mobile WiMAX”, *IETE TECH REVIEW*, vol. 26, pp. 258-267, 2009.

[40] A. B. Pontes and J. Jailton, “Handover Management in Integrated WLAN and Mobile WiMAX networks”, *IEEE Wireless Communications*, vol. 15, pp. 85-95, 2008.

[41] M. G. Kin, J. Choi, and M. Kang, “Trade-off guidelines for power management mechanism in the IEEE 802.16e MAC”, *Computer Communications*, vol. 31, pp. 2063-2070, 2008.

[42] R. Vijayan and J. M. Holtzman, “Adaptive Averaging Methodology for handoffs in Cellular Systems”, *Proc. 2nd IEEE ICUPC*, vol. 1, pp. 158-162, 1993.

[43] O. E. Kelly and V. V. Veeravalli, “A Framework for Optimal Scheduling of Handoffs in Wireless Networks”, *Proc. IEEE Globecom*, pp.1669-1673, 1994.

[44] R. Rezaiifar, A. M. Makowski, and S. Kumar, “Optimal Control of Handoffs in Wireless Networks”, *Proc. 45th IEEE VTC*, pp. 887-891, 1995.

[45] M. Gudmundson, “Analysis of Handover Alogrithms”, *Proc. 41st IEEE VTC*, pp. 537-547, 1991.

[46] R. Viayan and J. M. Holtzman, “Analysis of Handover Algorithm Using Nonstationary Signal strength Measurements”, *Proc. IEEE Globecom*, vol. 3, pp. 1405-1409, 1992.

[47] Chen-Nee Chuah and D. J. Goodman, “Integrated Dynamic Radio Resource Management”, *Proc. 45th IEEE VTC*, pp.584-588, 1995.

[48] H. Panzer and R. Beck, “ Adaptive Resource Allocation in Metropolitan Area Cellular Mobile Radio Systems”, *Proc. 40th IEEE VTC*, pp.638-645, 1990.

[49] D. Giancristofaro, M. Ruggieris, and F. Santucci, “Queuing of Handover Requests in Microcellular Network Architectures”, *Proc. IEEE VTC*, pp.1846-1849, 1994.

[50] C. M. Simmonds and M. A. Beach, “Network Planning Aspects of DS-CDMA with Particular Emphasis on Soft Handoff”, *Proc. 43rd IEEE VTC*, pp. 846-849, 1993..

[51] N. Zhang and J. Hotlzman, “Analysis of a CDMA soft handoff Algorithm”, *Proc. IEEE PIMRC*, pp. 819-823, 1995.

[52] RUNE (Rudimentary Network Emulator), J. Zander and S.-L. Kim, “Radio Resource Management for Wireless Networks”, ARTECH House, INC, 2001.

[53] R. Rouil, “The Network Simulator NS-2 NIST add-on –IEEE 802.16 model (MAC+PHY) –Draft 1.1.

[54] NIST Seamless and Secure Mobility –project, http://w3.andtd.nits.gov/seamlessandsecure.shtml.

[55] The Network Simulator- NS-2, Internet home page, http://www.isi.edu/nsnam/ns/.

[56] M. Hata, “Empirical formula for propagation loss in land mobile radio services”, *IEEE Trans. Veh. Tech.*, vol.3,pp.317-325, 1980.

[57] Y. Okumuar et al. , “Field strength variability in VHF and UHF land mobile service”, *Rec. Elec. Comm. Lab.*, 1968.

[58] J. Walfisch and H. L. Bertoni, "A theoretical model of UHF propagation in urban environments", *IEEE Trans. Anten. Propag.*, vol.36, pp.1788-1796, 1988.

[59] L. L. Peterson, B. S. Davie, "Computer Networks: A systems approach ", Academic Press, 2nd edition 2000.