

VERTICAL AND HORIZONTAL HANDOVER IN HETEROGENEOUS WIRELESS NETWORKS

*Thesis submitted in partial fulfillment of the requirements for the award of the
degree of*

MASTER OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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THAPAR UNIVERSITY

(Established under the section 3 of UGC Act, 1956)

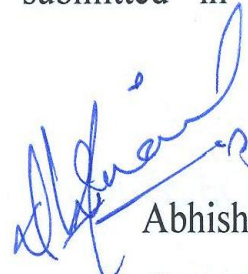
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CERTIFICATE

I, Abhishek Dhiman, hereby certify that the work which is being presented in this thesis entitled “**Vertical and Horizontal Handovers in Heterogeneous Wireless Networks**” by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of *Mr. Karamjit Singh Sandha*.

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ACKNOWLEDGEMENT

I would like to express my deepest gratitude to **Mr. Karamjit Singh Sandha**, Assistant Professor, Electronics and Communication Engineering Department, Thapar University, Patiala, under whose guidance I had the privilege to complete this thesis. I wish to express my deep gratitude towards him for providing individual guidance and support throughout the thesis work.

I am also thankful to **Dr. Rajesh Khanna**, Head of Department, ECED, **Dr. Kulbir Singh**, Associate Professor and PG Coordinator, ECED, and entire faculty and staff of Electronics and Communication Department for the encouragement and cooperation.

I am also very thankful to **Mr. Ankush Kansal**, Assistant Professor, ECED, for his continuous guidance and support.

My greatest thanks are to all who wished me success especially my parents. Above all that I render my gratitude to the Almighty who bestowed self-confidence, ability and strength in me to complete this work for not letting me down. I do not find enough words with which I can express my feelings of thanks to my dear friends for their help, inspiration and moral support which went a long way in successful competition of the present study.

Finally, I would like to extend my gratitude to all those persons who directly or indirectly helped me in the process and contributed towards this work.

At last but not the least, I am thankful to the authors, whose work I have consulted and quoted in my thesis report.

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ABSTRACT

Nowdays all Enterprises, Internet Service Providers, and Mobile Network Operators are all looking for cost-effective ways to move data ,voice and video amongst multiple, separate locations at broadband speeds. Fiber optics solutions often fall short due to up-front costs, recurring leases from telecommunications companies, and a lack of flexibility to scale with the operating organization. Broadband Wireless has emerged as a means to fill these gaps and to provide a lower total cost of ownership than wired solutions, while maintaining or exceeding the reliability and performance of those technologies. The IEEE 802.11 and IEEE 802.16 family of standards and its associated industry consortium, Wi-Fi and WiMAX, promises to deliver high data rates over large areas to a large number of users in the near future. This exciting addition to current broadband options such as DSL, Cable, and Wi-Fi promises to rapidly provide broadband access to locations in the world's rural and developing areas where broadband is currently unavailable.

The last decade has seen the exponential growth in the development of mobile applications. This has increased the demand on the wireless communication services. The capability to achieve wireless access anywhere, anytime, and anyplace has become common expectation as it provides significant flexibility and freedom in mobility. But to achieve global mobility in heterogeneous networks for any mobile device requires seamless connectivity using vertical handoff. Since none of the existing wireless frameworks provide practical solutions for vertical handoff. End-to-End Vertical Handoff or Always Best Connected concept proposed in this thesis offers a new concept to perform vertical handoff between heterogeneous wireless networks. To deliver network services without interruption, this concept present a novel design to monitor the network availability, it then picks the best accessible network for application layer. Since this approach relies only on existing technologies, deployed protocols, our approach can be easily implemented. In this thesis all the simulation results are obtained using OPNET Modeller 14.5. The results for different tested scenarios indicate the effectiveness of the proposed approach. Future research activities will integrate several wireless technologies that are discussed in the thesis.

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ABBREVIATIONS

3GPP/2	3 rd Generation Partnership Project /version 2
AAA	Authentication, Authorization and Accounting
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
BS	Base Station
CCI	Co-Channel Interference
CDMA	Code Division Multiple Access
DL	Downlink
DoA	Direction of Arrival
DP	Decision Point
DSL	Digital Subscriber Line
ertPS	Extended Real-Time Polling Service
FBSS	Fast Base Station Switching
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
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
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
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
NACK	Negative Acknowledge
NAP	Network Access Provider
ND	Neighbour Discovery
NIST	National Institute of Standards and Technology
NRM	Network Reference Model
NSP	Network Service Provider
NWG	Network Working Group
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPNET	Optimized Network Engineering Tools
PDU	Protocol Data Unit
PSTN	Public Switched Telephone Network
QAM	Quadrature Phase Shift Keying
RA	Router Advertisement
RTG	Receive/Transmit Transition Gap
rtPS	Real-Time Polling Service

SAP	Service Access Point
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
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Network

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 very flexible network architecture. The mobile WiMAX air interface used 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.

Next-generation wireless networks have been envisioned as an Internet Protocol (IP) based infrastructure with the integration of various wireless access networks such as IEEE 802.11 wireless local area networks (WLANs), IEEE 802.16 wireless metropolitan area networks (WMANs), General Packet Radio Service (GPRS), and Universal Mobile Telecommunications System (UMTS). Heterogeneous

wireless networks need to cooperate to provide users with seamless mobility and required quality of service (QoS). Mobile nodes (MNs) can automatically switch the connectivity between different types of networks. Such future mobile communications calls for reconfigurable and efficient systems [4]. It is expected that wireless mesh networks (WMNs) will become a key technology as an economically viable solution for wide deployment of high speed, scalable, and ubiquitous wireless Internet services.

Mesh routers and mesh clients are the two types of nodes in WMNs. A mesh router not only has gateway/bridge functions, but also has routing functions to support mesh networking. It is usually equipped with multiple wireless interfaces built on either the same or different wireless access technologies to improve the flexibility of mesh networking. Mesh routers have minimal mobility, form a multi-hop network topology, and can self-configure a wireless broadband mesh backbone for local communication and information delivery to/from a wired Internet backbone via wired gateways. The wireless backbone provides multi-hop connectivity between a mobile client and a gateway.

Moreover, the integration of WMNs with various existing wireless networks such as cellular, wireless-fidelity (Wi-Fi) [5], and worldwide inter-operability for microwave access (WiMAX) networks can be accomplished through the gateway/bridge functionalities in mesh routers. With the integration of multiple wireless access technologies, the wireless mesh backbone provides a viable solution for users to access the Internet anywhere anytime. Compared to wired networks, e.g., cable or optical networks, the wireless mesh backbone is an economic alternative to broadband networking, especially in underdeveloped regions. Existing WLANs can provide low-cost data services and have been widely deployed in traffic hotspots such as offices, hotels, shopping malls, schools, university campus, and airports. On the other hand, IEEE 802.16 can provide high speed wireless services in wide areas. As a result, the integration between a wireless mesh backbone (based on IEEE802.16 standards) [5] and WLANs can create a complete wireless solution for delivering broadband Internet services to the hotspots instead of cable, DSL, and T1 level services.

The typical Wi-Fi setup contains one or more Access Points (APs) and one or more clients. An AP broadcasts its SSID (Service Set Identifier, Network name) via packets that are called beacons which are broadcasted every 100ms. Now the beacons are transmitted at 1Mbps speed, and are relatively short and therefore are not of influence on

performance. Since 1Mbps is the lowest rate of Wi-Fi and that assures the client who receives the beacon can communicate at least 1Mbps based on the settings (i.e. the SSID), the client may decide whether to connect to an AP. If we have two AP's of the same SSID are in range of the client, the firmware may decide based on signal strength (Signal-to-noise ratio) to which of the two AP's it will connect [6]. The Wi-Fi standard leaves connection criteria and roaming totally open to the client. This is the strength of Wi-Fi, but also means that one wireless adapter may perform substantially better than the other. Since Windows XP there is a feature called zero configuration which makes the user show any network available and let the end user connect to it on the fly. In the future wireless cards will be more and more controlled by the operating system. Microsoft's newest feature called *SoftMAC* will take over from on-board firmware. Having said this, roaming criteria will be totally controlled by the operating system. Wi-Fi transmits in the air, it has the same properties as a non-switched ethernet network. Even collisions can therefore appear like in non-switched ethernet LAN's.

The IEEE 802.16 Working Group [7] focuses on Broadband Wireless Access standards. The current on-going 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 equipment's of International Mobile Telecommunications (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 backward 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 equipment's with procedures and to enable interoperable and efficient management of network resources, 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 WiMAX physical layer (PHY) is based on orthogonal frequency division multiplexing, a scheme that offers good resistance to multipath, and allows WiMAX to operate in NLOS conditions. WiMAX is capable of supporting very high peak data rates. In fact, the peak PHY data rate can be as high as 74Mbps when operating using a 20MHz wide spectrum. More typically, using a 10MHz spectrum operating using TDD scheme with a 3:1 downlink-to-uplink ratio, the peak PHY data rate is about 25Mbps and 6.7Mbps for the downlink and the uplink, respectively.

IEEE 802.16-2004 and IEEE 802.16e-2005 supports both time division duplexing and frequency division duplexing, as well as a half-duplex FDD, which allows for a low-cost system implementation.

1.2 Wireless Network Topologies

There are basically three ways to setup a wireless network[7].

- **Point-to-point Bridge:** As you know a bridge is used to connect two networks. A *point-to-point bridge* interconnects two buildings having different networks. For example, a wireless LAN bridge can interface with an Ethernet network directly to a particular access point.
- **Point-to-multipoint Bridge:** This topology is used to connect three or more LANs that may be located on different floors in a building or across buildings.
- **Mesh or ad hoc network:** This network is an independent local area network that is not connected to a wired infrastructure and in which all stations are connected directly to one another.

1.3 IEEE 802.16 Standards

Standard	Description	Status
802.16-2001	Fixed Broadband Wireless Access (10–63 GHz)	Superseded
802.16a-2003	Physical layer and MAC definitions for 2–11 GHz	Superseded
802.16.2-2004	Recommended practice for coexistence	Current
802.16e-2005	Mobile Broadband Wireless Access System	Superseded
802.16g-2007	Management Plane Procedures and Services	Superseded
802.16j-2009	Multihop relay	Current
802.16h-2010	Improved Coexistence Mechanisms for License-Exempt Operation	Current
802.16m-2011	Advanced Air Interface with data rates of 100 Mbit/s mobile and 1 Gbit/s fixed. Also known as <i>Mobile WiMAX</i> or <i>Wireless MAN-Advanced</i> .	Current
802.16n	Higher Reliability Networks	In Progress
802.16p	Enhancements to Support Machine-to-Machine Applications	In Progress

1.4 Motivation

For the seamless connectivity, a mobile station equipped with an IEEE 802.11 and 802.16 interfaces are 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 neighbouring 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 neighbouring 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, in a paper [8] author has been discussed about the different type of handovers in various heterogeneous wireless networks i.e. in Wi-Fi and WiMAX and 3G. He discussed and simulated vertical as well as horizontal handover for different networks to calculate the throughput and delays of the systems. In this research we are going to simulate the same scenario and try to improve the delay and throughput of the different wireless networks. We are also finding out the best way to connect networks for the seamless connectivity and to get maximum coverage area by link quality concept.

1.5 Organization of the Thesis

Chapter 2 gives literature survey about the topic. In order to start the thesis, the first step is to study the papers that have been already published by other researchers. Paper related to this work are chosen and studied. With the help of literature review, it becomes easier to perform this work.

Chapter 3 introduces the different wireless technologies like 3G, LTE, Wi-Fi and WiMAX. In this chapter we also find out the basic difference between these technologies and the evolution of different technologies. This will really help us to get the basics clear from the starting of the technologies.

Chapter 4 introduces the fundamental technologies of Wi-Fi and mobile WiMAX based on an amendment of the IEEE 802.11 and IEEE 802.16 standard for physical (PHY) and medium access control (MAC) layers. This chapter includes various characteristics of Wi-Fi and WiMAX technologies.

Chapter 5 begins with the introduction of basic handover concepts for the cellular networks. This chapter also introduces the different types of handover in different technologies. The procedure and features of handover in Wi-Fi and the mobile WiMAX are thoroughly discussed.

Chapter 6 explains the Vertical and Horizontal handover thoroughly. It also

introduces the procedure time, delay time and different pros and cons of both the handovers. It also explains different parameters of these handovers.

Chapter 7 presents the simulation results for the handover performance in the Wi-Fi and mobile WiMAX system, based on the signal strength of handover between the two BSs. In this chapter always best connected concept is also explained.

Chapter 8 includes the Conclusion and Future scope of the work.

CHAPTER 2

LITERATURE SURVEY

Iyad Alkhayat *et al.* [8] According to this paper from the last decade there is a rapid growth has been seen in the development of mobile applications. This has increased the demand on the wireless communication services. The capability to achieve wireless access anywhere, anytime, and anyplace has become common expectation as it provides significant flexibility and freedom in mobility. But to achieve global mobility in heterogeneous networks for any mobile device requires seamless connectivity using vertical handoff. Since none of the existing wireless frameworks provide practical solutions for vertical handoff. End-to-End Vertical Handoff (E2EVH) proposed in this paper offers a new concept to perform vertical handoff between heterogeneous wireless networks. To deliver network services without interruption, E2EVH present a novel design to monitor the network availability, it then picks the best accessible network for application layer. Since this approach relies only on existing technologies, deployed protocols and lightweight calculations, our approach can be easily implemented. In this paper, they present a proof-of-concept of E2EVH, and preliminary simulation results using OPNET Modeller 14.5. The results for different tested scenarios indicate the effectiveness of the proposed approach. Future research activities will integrate several additional wireless technologies that are presented and discussed in the paper.

In E2EVH approach, they search for the best affordable link using a simple method to avoid adding complexity to the hand set or the MS. On the other hand E2EVH simplifies the problem by hiding the network handover by using server/ client design so the application running on the MS will be un-aware about the used service. Single login will save a lot of time due of the central authentication at the communication server; also the MS will be represented by the MIP Master IP address which may help in the design to use private IPs for the delivering IPs which will save IPs pool.

Daan Pareit *et al.*[9] According to this paper the working group responsible for this topic has shifted over time from 10-66GHz spectrum to 2-11GHz and other amendments were added for mobility, relaying, etc. Being open minded and including multiple physical layer options (Wireless MAN-SC, Wireless MAN-OFDM, Wireless MAN-OFDMA), while maintaining a single MAC protocol. New features are still continuously being

developed and added. The applicable standard today, May 2011w is IEEE Std 802.16-2009, amended by IEEE Std 802.16j-2009, IEEE Std 802.16h-2010 and IEEE Std802.16m-2011. Further enhancements that are being developed concern higher reliability (P802.16n) and machine to-machine communications (P802.16p). The WiMAX Forum is the organization that derives system profiles, most notably Fixed WiMAX and Mobile WiMAX. The Mobile WiMAX profile is being further developed and has currently reached Release 1.5. A lot of preparations are being made by the WiMAX Forum to incorporate IEEE Std 802.16m-2011 into new Release 2.0 specifications. Most products today are being certified or deployed for the 2.5GHz and 3.5GHz.

Zeyad T. Sharef, *et al.* [10] In this paper, a detailed link level simulation has been studied and optimized to investigate the physical layer performance of Worldwide Interoperability for Microwave Access (WiMAX) IEEE 802.16e over AWGN and multipath Rayleigh fading channels, in which ITU-Reference channel models have been used. Moreover, the effect of fading channel, Doppler shift and cyclic prefix on the system design performance has been analyzed and investigated. The bit error rate (BER) vs. bit energy-to-noise density ratio (E_b/N_0) curves was used to evaluate and compare the performance of QPSK modulation technique. The outcomes of simulation results clarified how the use of channel estimation improves the system performance, whereas obviously, the investigated system suffers from severe performance degradation and high probability of error whenever channel estimation is not applied.

Sewon Jung *et al.* [11] In this paper, they analyze handoff procedures and IEEE 802.11 part of OPNET Modeller 9.0 in detail and explain the modules. Using this simulator, they assessed performance such as delay and packet loss of WLAN during handoff. They used TCP and UDP traffic to analyze how applications are affected by their traffic types. They implemented a handoff module to the OPNET simulator and assessed the performance of TCP and UDP during handoff.

Using the simulator, when they assess the performance of TCP, they observed that packet loss did not occur at the buffer of AP. However, small number packet losses in the wireless connection. This is because AP does not know that the handoff of MS, it tries to send packets to MS until it is notified by NAP after the handoff is completed. The number of packet losses depends on the handoff delay. Because of the packet losses in the wireless medium, TCP always timeouts and restarts in our simulation. For UDP, they

observed that its performance is directly related to the handoff delay, the buffer size, and the transmission speed. In general large buffer results lower packet loss. However, as the buffer size becomes large the delay does too. They observed that as the number of neighbour BSSs increases the handoff delay also increases. This is because most of handoff delay is due to the time spent in the Scanning Phase in which MS spends 3 hrs once it finds signal in a given channel, whether it has received information on APs or not.

L. Nithyanandan *et al.* [12] According to this paper heterogeneous mobile network such as WLAN, LTE and WiMAX require efficient handoff mechanisms to guarantee seamless connectivity. In this work four different types of interworking architectures were designed between WLAN, LTE and WiMAX networks namely: tightly coupled integration, loosely coupled integration, tight coupling with neighbour reservation and with gateway relocation. Consideration of vertical handover is made by locating the mobile node in a region where WLAN, LTE and WiMAX coverage coexist. It was found that tight coupling with neighbour reservation and with gateway relocation provides better handover performance. The network simulation also shows that interworking architecture with gateway relocation outperforms the other coupling methodologies due to the reason that a secondary path is established prior to handover and it results in less handover delay, lesser packets dropped and high signal to noise ratio. It was found that handover delay is lesser than the voice inactivity time with neighbour reservation and with gateway relocation and hence we can assure that seamless connectivity can be achieved.

Nadia Qasim, Muhammad Saleem Sheikh [13] In this paper the main focus is on vertical handover to preserve mobile nodes connections in spite of its movement from one network to another heterogeneous network and also provide quality of service factors utilization. This vertical handover involves procedures of registration, binding, route optimization, and bi-directional tunnelling mode so that transition between heterogeneous access technologies is transparent to user. In this paper they have proposed an algorithm for vertical handover in multi-homed mobile node that relies on received signal strength and threshold along with quality of services factors, where QoS mapping is carried out, and in traffic conditioning block four classes are differentiated and assigned various weights to improve performance and QoS provision. After simulation network topology with novel multihomed mobile node, then the results shows good network performance where throughput is improved and delays are reduced during vertical handover where it

switches all traffic between heterogeneous networks at once. In our vertical handover algorithm, its decision is based on link quality measurements such as received signal strength with threshold and QoS through traffic conditioner block where classes are assigned various weights for prioritization of ingress traffic in differentiated service's manner to improve network efficiency. The simulation results show that there is good network performance in terms of throughput and end-to-end delay. It is observed that there is fair increase in network throughput as it has acquired quality of service and maintains connectivity in wireless overlay networks. There is reduction in end-to-end delay based on quality of transmission in real-time traffic such as voice and video and non-real-time traffic over heterogonous networks. Hence, the overall performance of wireless overlay networks has improved during vertical handover.

Bhaskar Ashoka *et al.* [14] According to this paper, Mobile WiMAX has the key advantage of serving large coverage areas per base station it has become a popular emerging technology for handling mobile clients. However, serving a large number of Mobile Stations (MS) in practice requires an efficient handover scheme. Currently, mobile WiMAX has a long handover delay that contributes to the overall end-to-end communication delay. Recent research is focusing on increasing the efficiency of handover schemes. In this paper, they analyse the performance of the two standardised handover schemes, namely the Mobile IP and the ASN-based Network Mobility (ABNM), in mobile WiMAX using simulation. The results are promising for the applicability of network-based handover technology, and encouraging for network-based handover research. Mobile WiMAX network providers are particularly satisfied with the ASN anchored protocol because of the fact that it is their own protocol, and also the changes to the protocol will not affect the mobile devices of their users. Most other protocols for mobility management tend to require modifications to the MS software stack. With the MS being independent of mobility management, vendors can design mobile phones for mobile WiMAX without needing to cater for frequent software updates. Vendors can manufacture mobile devices irrelevant of the handover protocol used in the network. Overall in this paper they have demonstrated that the ABNM handover scheme can strengthen the capability of mobile WiMAX network operators to manage and control their networks more efficiently.

2.1 Gaps in Study

Numerous works have been done on the performance analysis of IEEE 802.11 and IEEE 802.16 and a lot of work has been done to reduce the delay in Horizontal Handover that means handover took place in the same technology but a very little work is done in the field of Vertical Handover where the handover occurred in different technology.

In this thesis we have done a lot of work to reduce the delay and increase the throughput of the system in Vertical as well as Horizontal handover. Also the proposed model helps us to reduce the complexity to the MS. It will also reduce the connection time between hard handover and soft handover process.

2.2 Objectives of the Research

The goals of this research involve several aspects of the handover in Wi-Fi and mobile WiMAX.

- Study the handover technologies in wireless networks from both foundational and advanced aspects, such as the types of handovers, the handover decision, and handover optimization, etc.
- Understand the various technologies like Wi-Fi and WiMAX network in terms of physical layer and MAC layer, and some advanced topics, for example, Vertical handovers and Horizontal handovers are introduced.
- Analyse and simulate vertical and Horizontal handover using OPNET 14.5 simulator. In addition, we are also going to study Always Best Connected scenario for the seamless connection between various wireless networks. Furthermore, the delay and throughput of Wi-Fi and WiMAX networks are also investigated.

CHAPTER 3

MOBILE COMMUNICATION NETWORKS

3.1 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 coverage. 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 [15]. 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) [16, 17], 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. Figure 3.1 shows the wireless standard landscape, which are seen to be target and be researched and investigated further for feasible implementation.

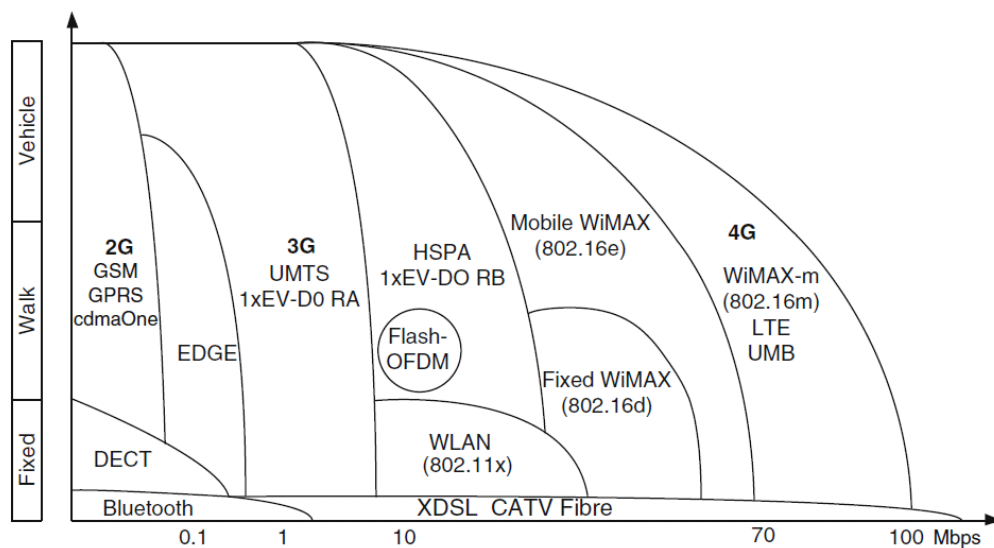


Figure 3.1: Wireless Standard Landscape [17]

3.1.1 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 [18] (high speed downlink packet access) technologies as part of their 3G evolution. Traditional CDMA operators are deploying EV-DO [19] (evolution data optimized) as their 3G solution for broadband data. 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 rates 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 [13] (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).

It should be noted that 3GPP is developing the next major revision to the 3G standards. The objective of this long-term evolution (LTE) [19] 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 OFDMA 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.

3.1.2 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 54Mbps and typically provide indoor coverage over a distance of 100 feet. Wi-Fi has become the practical standard for –last feetll broadband connectivity in homes, offices and hotspots.

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 [20]. 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.

3.1.3 Comparison WiMAX with 3G and Wi-Fi

Unlink 3G systems, which have a fixed channel bandwidth, WiMAX [20] 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 hotspots 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.

3.2 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 [20]. However, the initial standard only supports line-of-sight (LOS) transmission and thus does not seem to favour 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) [21]. 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 referred 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 sub channelization, 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 sub channelization 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 — Radio communication/ International Mobile Telecommunications (ITU-R/IMT)- advanced for fourth-generation (4G) systems [22, 23]. 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 3.2 demonstrate the evolutionary path of cellular technology.

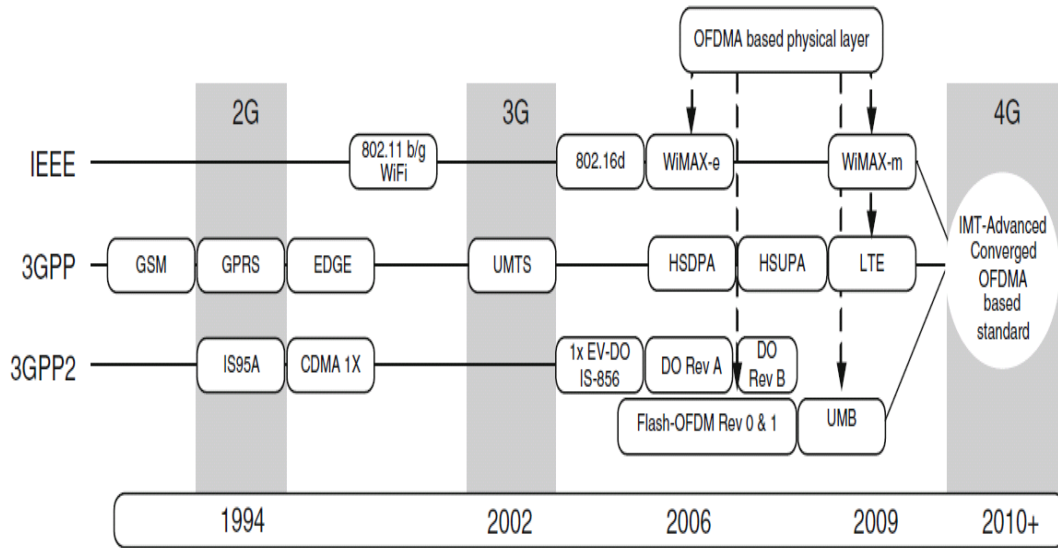


Figure 3.2: Evolutionary Path of Cellular Technology [20]

3.3 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 [24, 25]:

- 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 techniques like MIMO and beam forming.
- 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 size 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 existing spectrum allocations.

CHAPTER 4

DIFFERENT WIRELESS TECHNOLOGIES

4.1 Wi-Fi Technology

The Market for wireless communication has grown rapidly since the introduction of 802.11b wireless local area networking (WLAN) standards, which offer performance more nearly comparable to that of Ethernet. WLAN (or WiFi) was created specifically to operate as a wireless Ethernet. It is an open-standard technology that enables wireless connectivity between equipment and local area networks. Public access WLAN services are designed to deliver LAN services over short distances, typically 50 to 150 meters. In these cases, WLANs are connected to a local database, and give the end user access through portable device.

Internet access through public WLANs is a new and very hot trend, providing many benefits and conveniences over other types of mobile Internet access. Its performance is 50 to 200 times faster than dial-up Internet connections or cellular data access [26]. And users do not have to worry about cords, wires or sharing an access point, such as a phone jack.

Coverage extends over a 50 to 150 meter radius of the access point. Connection speeds range from 1.6 Mbps, which is comparable to fixed DSL transmission speed, to 11 Mbps. New standards promise to increase speeds to 54 Mbps. Today's WLANs run in the unlicensed 2.4 GHz and 5 GHz radio spectrums. The 2.4 GHz frequency is already crowded—it has been allocated for several purposes besides WLAN service. The 5 GHz spectrum is a much larger bandwidth, providing higher speeds, greater reliability, and better throughput.

4.1.1 Interoperability and Compatibility

The first, and most important job of any network manager, is to insure that any WLAN products conform to wired infrastructure interconnection standards. Standards based interoperability makes the wireless portion completely transparent to the rest of the network, and is generally based on Ethernet or Token Ring.

Also, older WLAN systems from different vendors may not always interoperate, even if they are using the same technology and the same frequency band.

A wireless NIC from one vendor may have difficulty connecting to an access point from another vendor, because vendors may adjust their hardware or software to meet their own customization requirements and quality standards [26].

However, the Wireless Ethernet Compatibility Alliance (WECA) now certifies WLAN vendors whose products are interoperable. The WECA seal (Wi-Fi Certification) guarantees that WLAN products from different vendors will work together.

4.1.2 Proprietary versus Standard

Although WLANs that follow the 802.11 standards are now widely supported and will likely continue to be so. However, there are actually a few situations today in which a proprietary WLAN is a choice. May be to add stations to an existing WLAN, however, replacing a proprietary WLAN with one that follows the IEEE standard is a more forward-looking choice. Another reason, to implement an Infrared WLAN the Infrared WLAN doesn't interfere with other communication systems, which makes it the choice to be deployed near sensitive scientific or medical equipment. Also, because infrared signal doesn't penetrate walls, so an infrared WLAN may be suited for a network that handles a sensitive data, such as in government or military applications.

4.1.3 Peer-to-Peer versus Infrastructure Mode

The decision regarding whether to configure the WLAN for peer-to-peer or infrastructure mode should be based upon the purpose of the network. Peer-to-peer mode should be used when wireless stations need to communicate only with each other. This mode is good for a temporary network. Also it's advisable to connect the peer-to-peer network as a first setup before installing the infrastructure mode.

For users that need to access the internet or intranet, or for covering a larger area, the infrastructure mode is deployed.

4.1.4 Range and Coverage

Product design and RF and IR propagation determine the distance over which a signal can transmit information. Objects including walls, metal, desks, and people can affect how signals propagate, and, therefore, the range a signal can travel. As we have mentioned before, IR waves cannot travel through opaque objects and have

shorter wavelengths, making them more susceptible to interference, shortening the distance over which they can transmit and receive information. The RF systems will provide the most range, but sacrifice data rates, while Infrared will support high data rates with limited range [26].

4.1.5 Throughput

WLAN throughput rates are a constant source of debate, and invariably come down to product and setup choices. IR, as we have mentioned, supports the highest overall data rates, but implementation is difficult. Between the two RF technologies, it is often quoted that DS systems support a higher data rate than FH systems on the order of 5:2. While this is true in low usage systems, FH systems are capable of dividing the allotted spectrum into more channels than DS systems, and, while supporting slower speeds, can actually support more users and, therefore, experience fewer bottlenecks.

4.1.6 Interference

WLANs can experience interference from other devices operating on the same frequencies. The ISM bands, set aside for free usage by most governments, often have other devices using these same frequencies in close proximity to WLANs. The 2.4 GHz band, for instance, must compete with microwave ovens for spectrum [26]. While most WLAN technologies are designed to resist these types of interference, it is sometimes unavoidable. In addition, FH and DS systems most often cannot be implemented in the same environment despite the different characteristics of transmission; networks of the same type, yet different vendors, can often interfere with one another.

4.1.7 Licensing

The regulator of the countries governs radio transmission, including those used by WLANs. WLANs are most often operated in the ISM bands we mentioned previously as they do not require the end user to obtain a license to use the airwaves. Most countries have declared it is important, when choosing a vendor, to make sure that they can deliver a product that will conform to the 2.4 GHz portion of radio spectrum as ISM, but some have not. Products must conform to the spectrum

requirements of the country in which they operate.

4.1.8 Battery Life

Battery life for end-user products varies from vendor to vendor and technology to technology and can be an extremely important consideration when designing a wireless network. All vendors typically employ design techniques to maximize the host computer's battery life, and some are more successful than others. Between DS and FH systems, the battery life issue is tilted in favour of FH systems as they have less bandwidth requirements. Generally, the more bandwidth it takes to transmit a signal, the greater degree of battery drain.

4.1.9 Safety And Health Concerns

WLAN system output is even less than that of cellular phones and no illness has ever been attributed to WLANs. Yet, there are concerns in hospitals when it comes to WLANs as monitoring devices and some medical devices (heart monitors and pacemakers) [27] operate in the same frequency range. Hospital network administrators must make sure that any products they purchase have a sufficient track record of avoiding interference with these types of devices.

4.2 WiMAX Technology

4.2.1 How Does WiMAX Work?

Think of WiMAX as taking the best part of cellular network access—the part that allows you to easily connect anywhere within your service provider's wide coverage area and taking the best part of your Wi-Fi experience—the fast speeds and a familiar broadband Internet experience and combining them into a new wireless standard. WiMAX is a Wide Area Network (WAN) technology [28]. Service providers will deploy a network of towers that will enable access over many miles. Internet access is instantly available anywhere within coverage areas. And like Wi-Fi, WiMAX is a standards-based technology that will unleash the benefits of open markets and global economies of scale to deliver the devices and services that consumers want.

The WiMAX network uses an approach that is similar to that of cell phones. A user sends data from a subscriber device to a base station mounted on a tower or

tall building to broadcast the wireless signal in a channel called an uplink, and the base station transmits to the same or other user in a channel called a downlink. Unlike the user, who traditionally has limited resources, i.e. very limited transmission power, limited number of antennas, and limited computation capabilities, the base station can use higher transmission power, more antennas, and enhanced computation algorithms. WiMAX service providers deploy a network of towers that enable access over many miles and the WiMAX broadband service will be available anywhere within coverage areas. Coverage for a geographical area is divided into a series of overlapping areas called cells. When the user travels from one cell to another, the wireless connection is transferred from one cell to another.

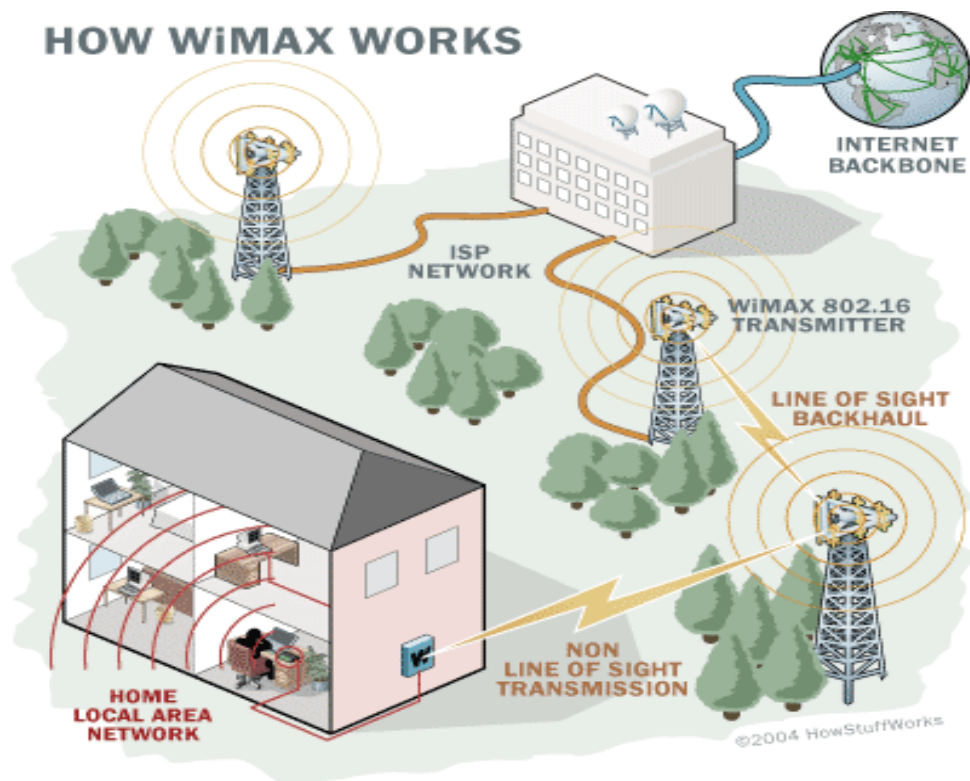


Figure 4.1 Working of WiMAX [29]

The signal transmitted from the base station to the user or from the user to the base station through wireless channel faces attenuation in space, fraction, refraction, reflection from objects on the propagation path, and shadowing from walls or other barriers. As a result, the transmitted signal is distorted and sometimes splits into different replicas called multi-paths. The transmitted signal is commonly described by its structure in time, frequency (its frequencies and its bandwidth), and space [30]. The receiver's target at both uplink and downlink is to combat the signal's distortion

in order to perfectly recover the transmitted signal and enable reliable data transmission.

4.2.2 Physical Layer

The IEEE 802.16-2004 and IEEE 802.16e-2005 [31, 32] 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. In Figure 4.2, a detailed view of protocol layer structure of mobile WiMAX system profile [33] is presented from the air interface perspective.

Wireless MAN-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 fibre optic networks

Wireless MAN-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.

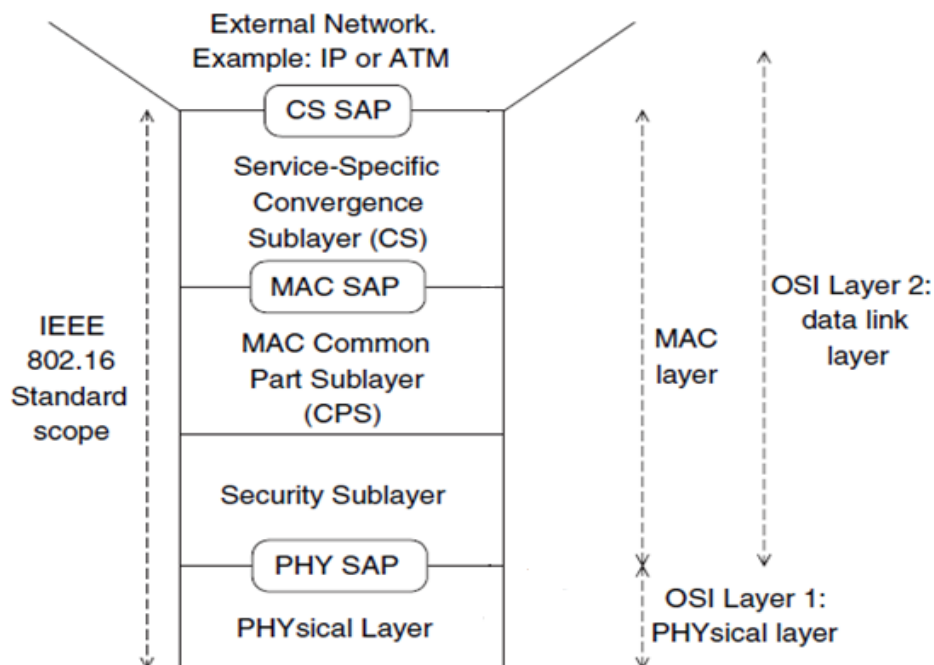


Figure 4.2: Protocol layer structure of WiMAX System Profile [33]

The 802.16a-2003 added an OFDM PHY, which is called Wireless MAN-

OFDM, with 256 subcarriers to accommodate NLOS fixed access for frequencies in 2-11 GHz. Later, it is finalized in 802.16-2004 standards. This is the approved WiMAX fixed access standard by WiMAX Forum

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

4.2.2.1 Scalable OFDMA

OFDMA is the multiple access technique for mobile WiMAX. OFDMA [34] is the Orthogonal Frequency Division Multiplexing (OFDM) based multiple access schemes 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-line-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 sub channelization. The simple transceiver structure of OFDMA also enables feasible implementation of advanced antenna techniques such as MIMO with reasonable complexity [35]. 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 1.25-20MHz. The scalability is realized with FFT size variation and the frequency spacing of sub-carriers is defined to be 10.94 kHz.

4.2.2.2 Time Division Duplex (TDD) Frame Structure

The mobile WiMAX Release 1 (WiMAX R-1) [22] 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 Beam forming (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.

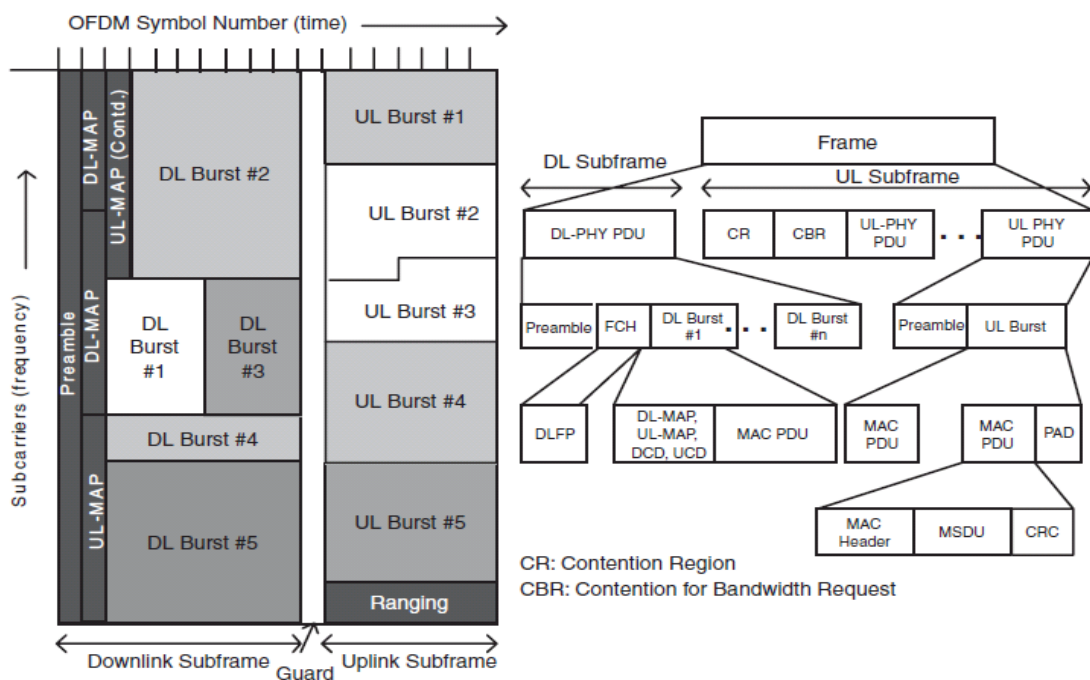


Figure 4.3: OFDMA Frame Structure in TDD [20, 22]

As shown in Figure 4.3, the downlink sub frame 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 sub frame. 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 overhead 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.

4.2.3 MAC Layer

The primary task of the WiMAX MAC layer [22, 32] 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 sub layer 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.

4.2.3.1 WiMAX Reference Model

Various sub-layers of MAC layer and corresponding issues are clear from figure 4.4

(1) Service Specific Convergence Sublayer

The IEEE 802.16 standards are very much connection oriented. Each service is assigned a connection with a varying level of quality of service, QoS. There are three management connections, coupled with transport connections for transmission of data. The purpose of the Service Specific Sublayer, is to accept higher layer PDUs and classify them. Based on this classification, they are assigned

to a given connection, with a given QoS. The Service Specific Sublayer supports ATM services as well as packet based IP services.

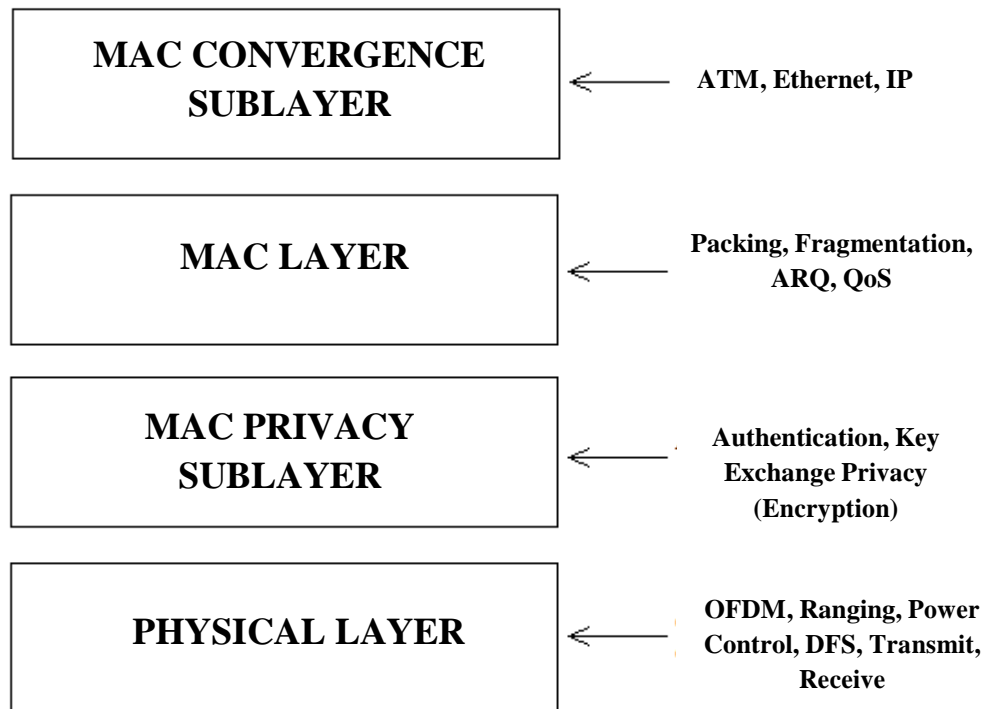


Figure 4.4: WiMAX Reference Model [36]

(2) Common Part Sublayer

The purpose of the Common Part Sublayer is to facilitate the sharing of the transmission medium. The system works on a PMP basis, where every station hears the same downlink transmission. The BS grants access to the uplink. This access is very much driven by the class of service and the QoS provisions such a service requires.

4.2.3.2 MAC Management Messages

In total, there are 49 MAC management messages. The most important ones as regarding this thesis are illustrated below:

RNG-REQ, Ranging Request (Transmitted on Basic or Initial Ranging connection) This message is transmitted periodically to determine network delay and to request a power or burst profile change.

RNG-RSP, Ranging Response (Transmitted on Basic or Initial Ranging connection) This message contains the response to RNG-REQ message, containing such parameters that are relevant to the request. If RNG-REQ was sent on the initial ranging connection, this message also contains the connection

identifier for the basic and primary connection assigned to this SS.

REG-REQ, Registration Request (Transmitted on Primary connection) This message sent by a SS in order to register with the BS and to negotiate the SS's capabilities, such as its IP version, ARQ parameters and convergence layer capabilities.

REG-RSP, Registration Response (Transmitted on Primary connection) This message sent by BS in response to a REG-REQ. It contains the connection identifier for the SS's secondary connection, in addition to relevant parameters for the SS's capabilities.

4.2.4 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 [33].

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 4.5 shows a simplified illustration of IP-based WiMAX network architecture.

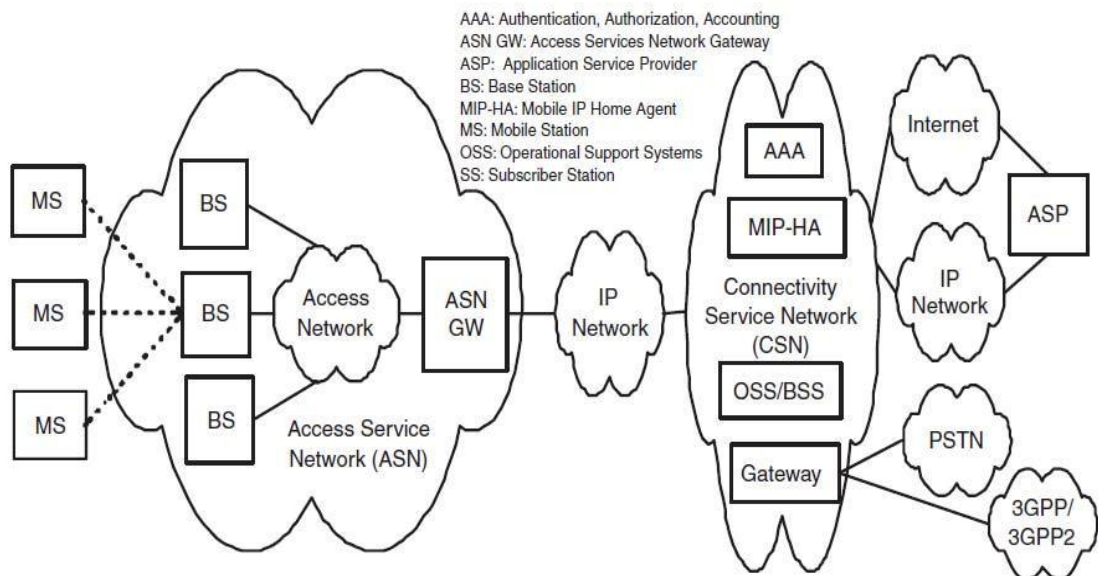


Figure 4.5: IP-Based WiMAX Network Architecture [36]

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.

The network reference model developed by the WiMAX Forum NWG defines a number of functional entities and interfaces between those entities. Figure 4.5 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 micro mobility management functions, such as handover triggering and tunnel establishment, 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 [36]. 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 [36]:

- 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 5

HANDOVER PERFORMANCE

5.1 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 [35, 36]. 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 [37]. 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.

5.1.1 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 neighbouring BSs [38]. Figure 5.1 shows the RSSs of current BS1 and one neighbouring 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 fading 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.

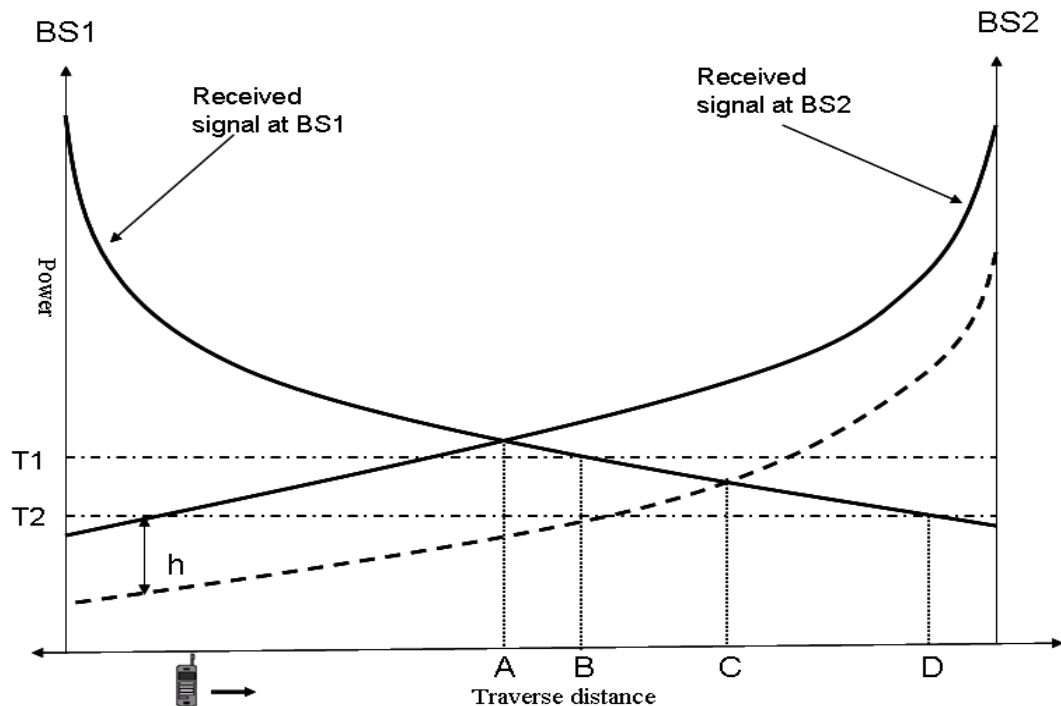


Figure 5.1: Handover Decision as a Function of Handover Scheme [38]

5.1.1.1 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. These 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.

5.1.1.2 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 5.1) 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 5.1.

5.1.2 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) [35,40].

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 centre (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.

5.1.3 Different types of Handovers

There are different types of handovers used in different wireless network systems:

- Hard Handover
- Soft Handover
- Horizontal Handover
- Vertical Handover

5.1.3.1 Hard Handover

The hard handover is used when the communication channel is released first

and the new channel is acquired later from the neighbouring 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) [41].

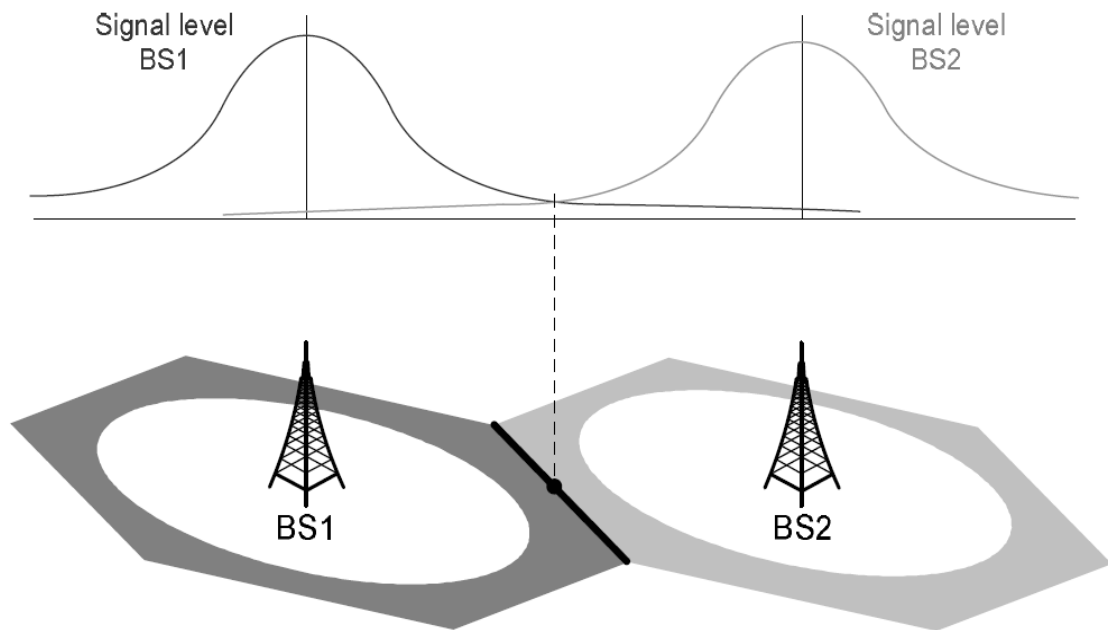


Figure 5.2: Hard handover realization [41]

Pros and Cons of Hard Handovers

There are many pros and cons of hard handovers which are discussed in detail in the below section.

Pros

- The hard handovers are simple and economical as the cellular phone hardware is not able to make connection with the two or more channels at the same time.
- Only one channel is used at any interval of time which makes it simple and easy.

Cons

- If the handover process is not successfully executed then call may be terminated or ended.

5.1.3.2 Soft Handover

The soft handover, in contrast to hard handover, establishes multiple connections with neighbouring cells. Soft handover is used by the code division

multiple access (CDMA) systems where the cells use same frequency band using different code words [42]. 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).

Pros and Cons of Soft Handovers

There are also some pros and cons of the soft handover which are explained in the following section

Pros

- Sophisticated handover type in which the call dropping probabilities are low as compared to hard handovers.
- The connection to the target cell are more reliable as compared to the source connection at which the user equipment is connected first and after the handover procedure the target connection are more reliable.

Cons

- More than one radio links are used so the more complex hardware is needed for it in order to cope with the existing situation.
- More than one channel is used parallel in a single call so the handover process should be done in such a way that the dropping probabilities' should be low as possible.

5.1.3.3 Horizontal Handovers

The transformation of an ongoing session from one cell to another cell having the same access technology is called Horizontal Handover [41]. For example if user equipment is connected with the radio link with the GSM network the horizontal handover must be from GSM to GSM. Similarly the handovers between two UMTS network is the horizontal handover.

5.1.3.4 Vertical Handovers

The transformation of an ongoing session or call from one cell to another cell having different access technologies is called Vertical Handover. For example when

a mobile user is moving from GSM based network to the UMTS network, here the access technologies are changed so the handover in this case is the vertical handover.

Loose coupling and tight coupling are the two architectures' used in the vertical handovers between UMTS and WLAN.

5.2 Handover Process and Cell Reselection

In Figure 5.3, 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.

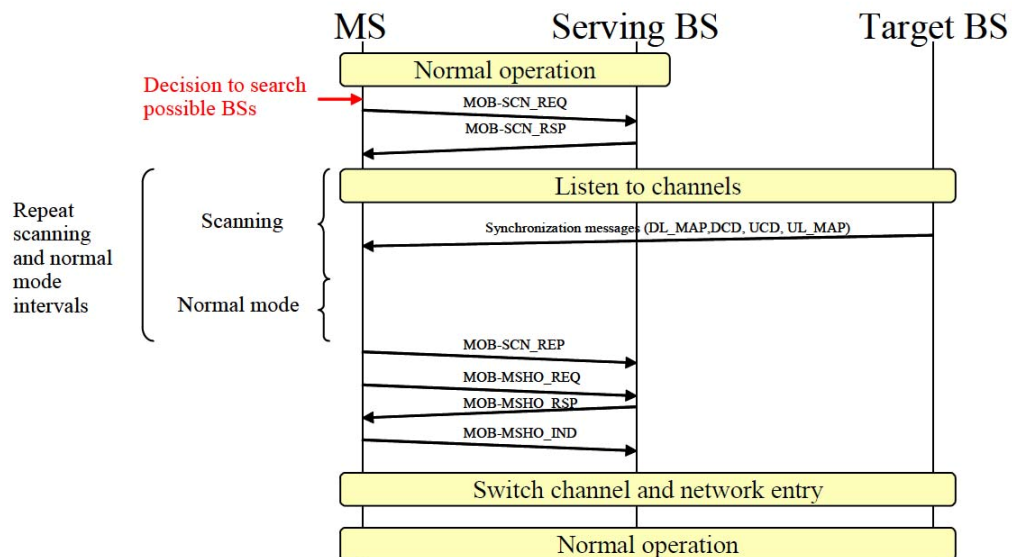


Figure 5.3: Process of Handover in Mobile WiMAX System [42]

5.2.1 Cell Reselection

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

5.2.2 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.

5.2.3 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 [42]. 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.

5.2.4 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.

5.2.5 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.

CHAPTER 6

VERTICAL AND HORIZONTAL HANDOVER

6.1 Vertical handover

The exploitation of wide-area wireless network such as 3G and GPRS and the growing esteem of Wi-Fi (802.11b based Wireless LAN) show the strapping expansion of Mobile Internet. Various types of mobile campaign such as Wireless LAN-GPRS PC cards are becoming inexpensive due to which hand held devices (e.g. laptops, PDAs) are ready to connect with dissimilar networks [43]. Basically Wireless networks diverge in medium access layer, physical layer and link-layer mechanism. To meet diverse wireless medium various methods are used.

The cellular networks use the complicated signal processing, channel evaluation techniques to manage the harsh-outdoor mobile atmosphere. Through deep fading and handover process, the cellular link endure from variable and high round trip time, burst losses and link outages because of net effect. Thus the end user familiarity in 802.11 based Wireless LAN is relatively different from cellular atmosphere.

Between the heterogeneous wireless networks the handover process can be set apart in to handover execution and handover decision process. In handover decision process both the mobile node and network decides that when the handover process will be occur. After taken handover decision, the handover execution process continues. The handover decision process involves supplementary network information such as replica address detection time in Mobile IPv6, when handover decision and detection process overlaps. The handover delay can be alienated in to three main mechanisms.

6.1.1 Discovery Time (t_d)

In this process via link layer beacon, the mobile terminal perceive that it is in the under the range of new wireless network from where it get the Router Advertisement (RA) of new access router [43]. Through the RA and triggered-based router solicitation from access router in the visited network, the MT detects the coverage on new network.

6.1.2 Address Configuration Period (t_c)

In this period the MT receive the Router Advertisement (RA) and updates its routing table and assign the new Care of Address (CoA) to all its interfaces. This new CoA based on new access router accessible form RA.

6.1.3 Network Registration Period (t_r)

In this period the binding updates are transmit to Home Agent (HA) as well as correspondent node and collect the acknowledgement from correspondent node. As binding acknowledgement from correspondent node is elective, so we consider the situation when mobile node accept packet from correspondent.

Thus an IP level handover consist of t_d , t_c and t_r . This recommended that by optimizing IP-level vertical handover delay would really involve minimizing the discovery time and network registration period, whereas address configuration period based on mobile device computing potential.

6.1.4 Causes of Vertical Handover

1. The mobility of Mobile Host (MH) from WiMAX coverage area to WLAN Access Point Coverage area is the major cause of Vertical Handover.
2. System Load Control
3. Interference
4. Power Emission (PE)

6.1.5 Problems in Vertical Handover

Wireless network is the major medium of communication between the people in today's tremendously growing world of Telecommunication. The demand of this type of communication is increasing day by day, therefore to handle this demand more wireless networks have to establish to obtain the high data rate requirement [44]. In case of Vertical Handover (VHO) due to symmetric nature Received Signal Strength (RSS) is not compatible with Vertical Handover (VHO). When Mobile Terminal discovers the WLAN coverage area its starts the MI process because MI decision depends upon the availability of preferred network. Now if more than one Wireless LAN Access Point (AP's) are present in the coverage area then the MT establishes the connection with the AP from which it receives the strongest Received Signal Strength (RSS).

Now in Mobile Out (MO) scenario the Mobile Terminal MT performs only one handoff at the end of Wireless LAN, where network is expected to unavailable. So according to scenario discuss the above the Vertical Handover (VHO) faces the following problems.

1. To minimize the number of surplus handover processes to reduce the network load.
2. To maximized the underlay network resources.
3. To assure the required degree of Quality of Services (QoS).
4. To reduce the congestion of the network in case of Mobile in (MI).
5. To prefer the handover in case of Mobile Out (MO) in the underlay network[44].

6.1.6 Vertical Handover Strategies

In case of Vertical Handover (VHO) normally three strategies are used to resolve the problems. These techniques are basically the extension to the common handover strategies. In these strategies we use vertical handover algorithms in required three dimensions.

6.1.6.1 Dwelling Timer Strategy

The dwelling timer strategy is basically the traditional strategy of measuring Received Signal Strength (RSS) with the combination of network overload parameters. The dwelling timer handover initiation technique is used to optimize the Wireless LAN resources.

In this technique the association of Mobile Terminal (MT) with Wireless LAN enhances the user throughput, even in case of transition of period. The maximum value of dwelling timer depends upon the difference between the rates of both networks. However the handover delay phenomena is even dominant here with dwelling timer strategy. Hence the dwelling timer technique is an appropriate method of Vertical Handover (VHO) to maximize the network resources but due to large dwelling timer there will be some surplus interruptions during real time applications. Therefore to handle the interruption problems we use specific signal threshold phenomena according to the requirements [45].

6.1.6.2 Artificial Intelligence (AI) Strategy

In this technique Artificial Intelligence (AI) is used with network parameters in case of mobility and handover decision. Fuzzy Logic and neural network criteria are implemented to detect the signal delay and the making of handover decision. These Artificial Intelligence (AI) approaches are very complex and difficult to apply on practical system.

6.1.6.3 Power Consumption Strategy

In Power Consumption technique the power consumption and bandwidth for the available networks are calculated and according to these measurements the Mobile Terminal (MT) decide to handover, since the power consumption and bandwidth parameters are different in case of Heterogeneous Networks [45]. Therefore a specific policy for these parameters has to be defined for each network. In this technique the Mobile Terminal (MT) frequently measures these parameters and then decides to handover for optimal value of the parameter. There is a difficulty in this approach because all the parameters not easy to measure especially in case of large Cellular Network the available bandwidth and the channel conditions are changed dynamically.

6.1.6.4 Definitions and Characteristics of vertical handoff

The exchange of connection between different wireless technologies is referred to as vertical handoff, while the horizontal handoff is referred to as the switching between points of attachment in the same network. The hand off mechanism can be implemented in two ways: hard handoff and soft handoff methods. During the hard handoff some packets may be lost during the connection transfer to different points of attachment [46]. While soft hand off minimizes the packet loss by sending the traffic on the old path and the new path until the full handoff is done, but this increases the design complexity and the bandwidth usage. Nowadays mobile stations (MS) are equipped with multiple radio interfaces for connecting to different wireless networks. Existing technologies offers different wireless connection capability where each technology has different characteristics. Wi-Fi offers the highest wireless speed, but Wi-Fi covers a limited area. This requires frequent horizontal handoff if the MS is in motion. WiMAX offers less wireless speed than Wi-Fi, but has significant bigger footprint coverage than Wi-Fi.

Finally UMTS/GSM has the lowest speed when compared with Wi-Fi and WiMAX but has the biggest footprint covered area. In vertical handoff the MS need to switch the current service between Wi-Fi to WiMAX or UMTS/GSM. Since LQ evaluation algorithm will calculate the quality of the available connections and sort the priority order for their use. The authentication procedure for the MS will be done one time at the server for all the available interfaces. This information will be used to represent the MS and the highest LQ interface card will be on the top of the priority list so that the server will forward the data to MS. To avoid unnecessary handovers, the handover decision is based on the LQ calculation of handover events and delay timer. Later predictive system will be added to improve the connection selection and the overall system. Since handover initiation is based on the current LQ values at different network interfaces at the MS, the updated LQ calculation of individual links are collected. These values are then sorted to identify the best link for communication and the best link is placed on the top of the table. This information will be sent periodically to the server, so the server will keep track of the wireless connectivity status at the MS interface cards.

6.2 Horizontal Handover

A mobile node moves with the single technology network from one access point to the other one in a horizontal handover. For example, if a mobile user moves from on base station to base station of other area, then the mobile user of GSM network makes a horizontal handover. A horizontal handover is a traditional handover. In other words, the difference between vertical and horizontal handover is that the vertical handover changes the access technology and the latter does not change [46].

In comparison with micro and macro mobility, they are differentiated into subclasses such as vertical and horizontal micro mobility, vertical and horizontal macro mobility. Vertical micro mobility is the handover within the same domain using different wireless technologies. Horizontal micro mobility is the handover among the same domain using the same wireless technology [47]. Vertical macro mobility is handover among different domains using different wireless technologies and horizontal macro mobility is handovers within various domains, using same wireless technology.

The handoff process can be characterized as hard handoff or soft handoff. Before making a handoff if there is a break in the communication, it is referred as a hard handoff (brake before make) and whereas in soft handoff, there is a connection to both of the base stations for some time before making the handoff (make before break).

To enhance the capacity and QoS of cellular systems, efficient handoff algorithms are cost effective ways. In a horizontal handover, the main concern is to maintain the ongoing service even if the IP address changes because of the movement of the mobile node. The ongoing service is done either by dynamically updating the changed IP address or by hiding the change of IP address. Vertical handover takes place when the mobile node moves over heterogeneous access networks. The used access technology is also changed along with the IP address in the vertical handover, as the mobile nodes moves across different networks which use different access technology. In such cases, the main issue is to maintain the on-going service even when there is a change not only in IP address but also in network interfaces, QoS characteristics etc.[47]

Table 6.1: Parameters in Horizontal and Vertical handover

Parameter	Horizontal handover	Vertical Handover
IP address	Changed	Changed
Access Technology	No change	Changed
Network Interface	No change	Can be changed
QoS Parameter	No change	Can be changed

The main capabilities of Vertical handovers over Horizontal handovers are:

1. Vertical handovers use different access technology.
2. Vertical handovers use multiple network interfaces.
3. Multiple IP addresses are used in Vertical handovers.
4. QoS parameters can be changed in Vertical handovers and multiple parameters are used.
5. Multiple network connections are used in Vertical handovers.

CHAPTER 7

RESULTS AND DISCUSSION

7.1 INTRODUCTION TO OPNET MODELLER

Optimized Network Engineering Tools (OPNET) is a very powerful network simulator. Performance, availability and optimizing cost are the major purposes of it. OPNET Modellers offers various tools for designing the model, simulating the model, data mining and various analysis, considering the different alternatives. In OPNET Modeller, simulation of a wide variety of various networks that are linked to each other can be done. Simulation using OPNET gives an experience to build networks in the real world and helps in understanding various layering techniques and protocols. OPNET simulates the behaviour of the system as it models each event occurring in it and processes the event as defined by the user. A hierarchical strategy is employed by OPNET to organize the models to build the desired network [48]. It provides programming tools to define various types of packet formats used in protocols.

7.1.1 OPNET MODELLER Tools

OPNET supports model specification with a number of tools, called editors. These editors handle the required modelling information in a manner that is similar to the structure of real network systems. Therefore, the model-specification editors are organized hierarchically. Model specifications performed in the Project Editor rely on elements specified in the Node Editor [48]. The rest of the editors are used to define various data models, new links and nodes, etc. This organization is described below:-

Project Editor

Project Editor is used to develop network models. Network models are made up of subnets and node models. This editor also includes basic simulation and analysis capabilities. The Project Editor is the main staging area for creating a network simulation. From this editor, you can build a network model using models from the standard library, choose statistics about the network, run a simulation and view the results. It is also possible to create node and process models, build packet formats, and create filters and parameters, using specialized editors that you can access from the Project Editor.

Node Editor

Node Editor is used to develop node models. Node models are objects in a network model. They are made up of modules with process models. The Node Editor lets you define the behaviour of each network object. Behaviour is defined using different modules, each of which models some internal aspect of node behaviour such as data creation, data storage, etc. A network object is typically made up of multiple modules that define its behaviour.

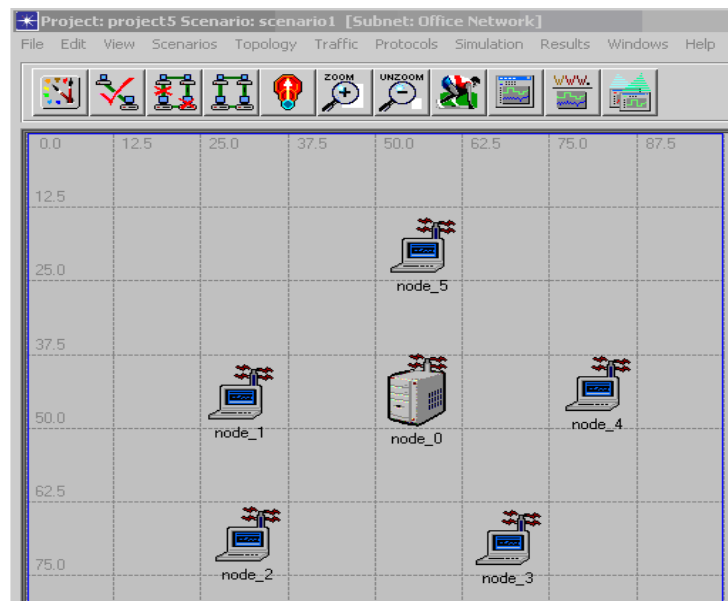


Figure 7.1 Project Editor - view of a Wireless Network

Process Editor

Process Editor is used to develop process models. Process models control module behaviour and may reference parameter models. This editor lets you create process models, which control the underlying functionality of the node models created in the Node Editor[48]. Process models are represented by finite state machines (FSMs), and are created with icons that represent states and lines that represent transitions between states. Operations performed in each state or for a transition are described in embedded C or C++ code blocks.

Link Model Editor

Link Model Editor creates new types of link objects. Each new type of link can have different attribute interfaces and representation. It is also possible to edit and view link models already created.

Packet Format Editor

Develop packet formats models are created by using Packet Format Editor. This editor defines the internal structure of a packet as a set of fields. A packet format contains one or more fields, represented in the editor as colored rectangular boxes. The size of the box is proportional to the number of bits specified as the field's size.

Path Editor

The Path Editor defines path models; each path object's underlying model determines its attribute interfaces, presentation, and behaviour.

Link Editor

The Link Editor supports the definition of reusable link models that are used to create link objects in the Project Editor [49]. Each link object's attribute interfaces, presentation, and behaviour, are determined by the link model that it relies upon.

Once all the different interfaces are shown, it is necessary to describe the different steps to build a network model and to simulate it. For the purposes of this thesis work, it's only necessary to work with the project.

7.1.2 The Modeller Workflow

This section outlines the workflow when using OPNET.

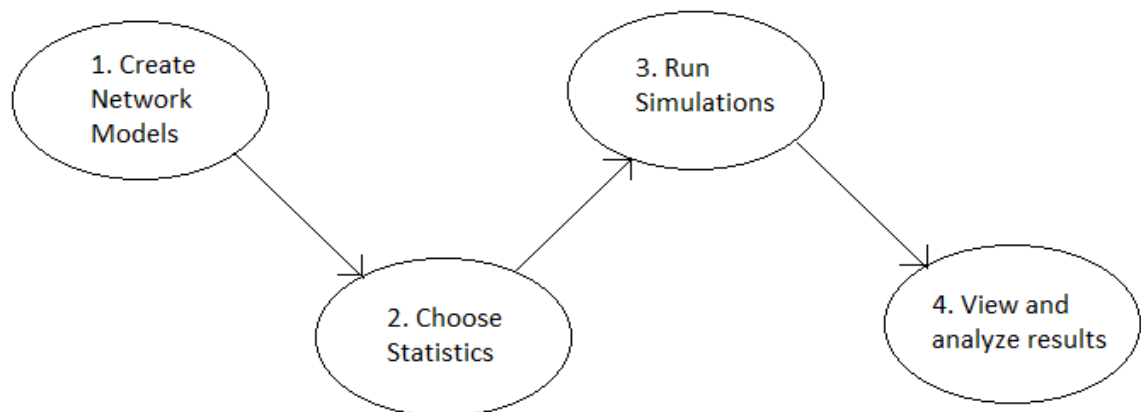


Figure 7.2 Workflow Model

7.1.2.1 Create Network Model

The first step is to create the networks models. It is necessary to generate the network to simulate in any of the following three ways:

- Placing individual nodes from the object palette into the workspace.
- Using the rapid configuration tool.
- And/or importing the network from an external data.

Furthermore, you have to introduce the traffic you want to run through the network.

There are two main ways of putting traffic in the model:

- a) Importing
- b) Manually specifying

7.1.2.2 Choose Statistics

Afterwards and before running a simulation, it is necessary to choose the statistics we want to collect. OPNET does not automatically collect all statistics in the system because there are so many available that you may not have enough disk space to store them. Specifying statistics is a straightforward task which is performed through the GUI.

7.1.2.3 Run Simulation

The third thing to set is configuring the parameters of the simulation and running them. Running simulations is typically thought of as the next-to-last step in the simulation and modelling process, the last step being results analysis. However, simulation is typically done many times in the modelling process to check the rightness of the generated network. There are different kinds of analysis that can be done in OPNET MODELLER.

1. Discrete Event Simulation
2. Flow Analysis
3. Failure Impact Analysis
4. NetDoctor Validation

Discrete event simulation provides the most detailed results but has the longest running times. This is because it does a more thorough analysis than the others, handling explicit traffic, conversation pair traffic, and link loads. The other types answer specific types of questions and generate results much faster than a discrete event simulation. A flow analysis, for example, handles only conversation pair traffic (flows) and a NetDoctor validation does not consider traffic at all. Licenses for generating Discrete Event Simulations (DES) are available for this studies and analysis.

7.1.2.4 View and Analyze Results

It is the last step of simulation. The results can be watched from the Project Editor or from the Analysis Tool. The Analysis Tool provides the capability to extract data from simulation output files, and to manipulate and display it according to various plotting methods. Data can be manipulated through built-in operations in a different way to get wanted information.

Hence, the final workflow of a project could be as follows:

- Create project
- Create baseline scenario
 - Import or create topology
 - Import or create traffic
 - Choose results and reports to be collected
 - View results and analyze them

Iterate by duplicating the scenario and changing parameters.

OPNET uses a project and scenario approach to model networks. Project is a collection of related network scenarios in which each explores a different aspect of network design.

A project contains at least one scenario and a scenario is a single instance of a network containing all the information. It is possible to run all the scenarios of the network at the same time and compare the results of each one. This allows the scenarios to check if a server will support and increment of the traffic, the effect of the increment of the traffic in a link in the response of a service, etc.

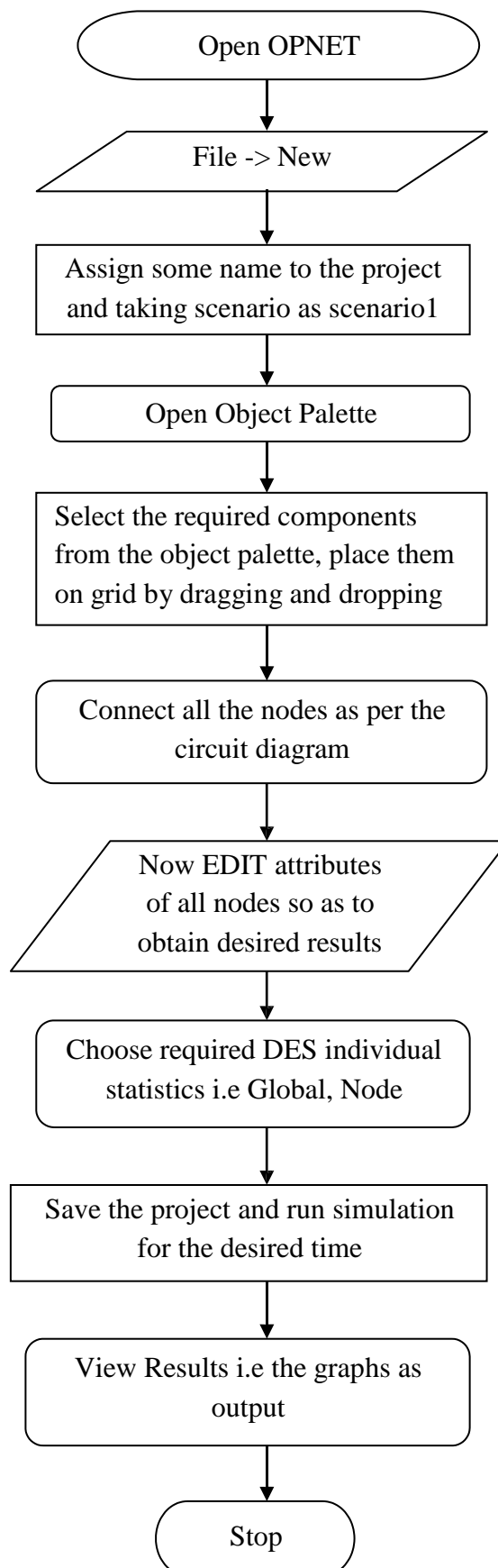
7.1.3 Advantages of OPNET:

OPNET has a number of advantages over analytical modelling for analyzing performance of the system.

1. The basic concept of simulation is easy to comprehend over analytical methods.
2. Simulation in OPNET is more credible because the behaviour is compared to that of the real system.
3. Once the OPNET model is ready and validated, one can run it on various different sets of parameter values to generate the performance measures in each of the cases.

7.1.4 SIMULATION PROCEDURE

The simulation of Wi-Fi, WiMAX network is done using OPNET MODELLER.



7.2 Connection design and Proposed Model

7.2.1 Server/MS Connections design

An MS in 4G networks will be ready with multimode interface UMTS/GSM, WiMAX, and Wi-Fi. Since different wireless networks may co-exist in the same coverage area, and these technologies are connected to the Internet with their respective gateways [52]. The gateways will grant the MS limited connectivity by providing an IP address to interact with the server for proper authentication. At the server the authentication procedure will be performed for the MS. Since each gateway will assign an IP address for each NIC at the MS. So the MS will have more than one IP address, as those IP addresses will be used to deliver the flow from/ to the server. At the server a table for each authenticated MS will be created with their respective connected IPs address. The server will assign one distinguishing IP address for each of the connected MS. A MS will be identified by this address called the Master IP (MIP) address, and all the traffic for the server will be routed via the MIP address. The remaining IPs address will just work as temporary addresses from the MS to the server and vice versa. These addresses could be changed during the MS mobility if the gateway is changed. The MS will execute a simple algorithm to measure the link quality decide which network interface card has better quality to reach to the server.

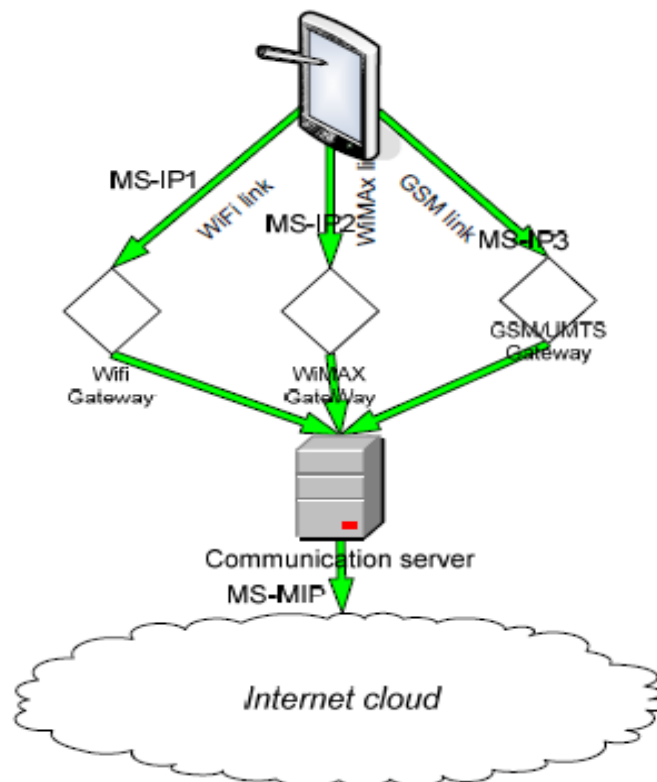


Figure 7.3 : Server/MS architecture[8]

Above figure shows the network flows between Client/Server through different gateways. The Link Quality algorithm will continuously work and get the updated results. These results are sent to the server periodically. This interaction between the MS and the server is required to keep the connection active between the server and MS.

7.2.2 Proposed Model using Always Best Connected (ABC) concept

In this Model different wireless services will be accessible (GSM/UMTS, WiMAX/802.16e, and Wi-Fi/802.11), and these services share the same physical locations. Different Points of Attachment (PoA) will be available to access this service [52]. These PoA include BSs or APs and they will offer different ways to connect the MS to the communication server. At the beginning when the MS is turned on; the wireless network cards NIC at the MS will do active scanning, then the MS will wait for the probe request. The probe request will return the available AP or BS. Since the Authentication process in the proposed model is centrally located at the communication server. The reply gateway will grant a delivery IP address to the wireless NIC. In this manner the MS will be able to reach the communication server, and then the MS will go through the authentication process.

This process will run only one time for all wireless interfaces, and the gateway will be just a delivery medium between the MS and communication server. At the MS all the traffic need to flow through an -Agent. This agent is an application which has full control over all the available wireless interfaces. The agent will evaluate the LQ for every available connection and the agent will pick the best affordable service. At the server the incoming traffic from the MS will be encapsulated with MIP address and forward it to the destination address. When the Communication server receives the data destined for the MS. The communication server will decapsulate the received packet and replaces the MIP with one of the available delivery IP addresses.

The communication server will pick the last updated best link available. This mechanism will provide simple vertical Handoff. The best available QoS will be chosen since the system mechanism proactively keeps periodically updating the LQ for all available links without affecting the performance and without user interaction. In our future research, we will consider ways to enhance connection selection by adding predictive decision making based on MS location.

This proposed model will optimize all the parameter thresholds in order to deliver the best affordable QoS with seamless connectivity. One of the key features of this is that it will not add complexity to the hand set or MS.

7.3 Simulation and Results

7.3.1 Horizontal handover in Wi-Fi network

This scenario shows the mobile station performance during horizontal handover between eight APs while the MS is moving in clock wise direction. This scenario shows Wi-Fi wireless technology. This scenario also comprise one video conferencing server, one client connected to the server via L3 switch and WLAN stations surrounding the access points. All the stations of AP_0 and AP_6 are roaming at a speed of 30 m/s around the access points. All the links used here are 100 BASE T links. The mobile_node_2 is roaming from AP0 to AP7 at the speed of 1 m/sec in Figure 7.4. Figure 7.5 shows the throughput of the MS that is stable between 10k – 20k bit/sec. When the delay is increased throughput decreases. Figure 7.6 shows the delays during the handoff. The maxim delay points are 0.017 sec., which is considered to be tolerable for most applications.

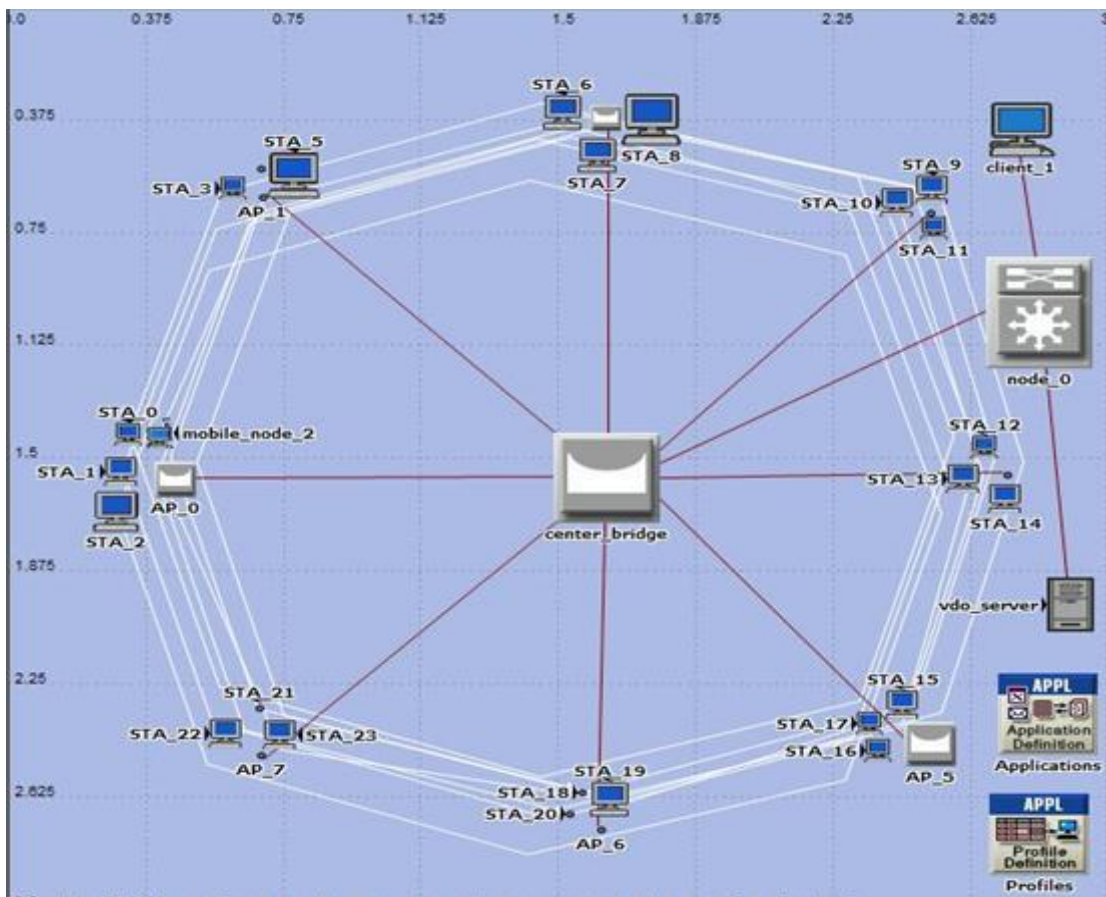


Figure 7.4: Set-up of Wi-Fi Handoff

Table 7.1: Wireless LAN Parameters (for mobile node)

BSS Identifier	0
Access Point Functionality	Disabled
Physical Characteristics	Direct Sequence
Data Rate (bps)	11 Mbps
Transmit Power (W)	0.002
Packet Reception-Power Threshold (dBm)	-95
CTS-to-self Option	Enabled
Short Retry Limit	7
Long Retry Limit	4
AP Beacon Interval (sec)	0.02
Max Receive Lifetime (sec)	0.5
Buffer Size (bits)	256000
Roaming Capability	Enabled
Large Packet Processing	Drop

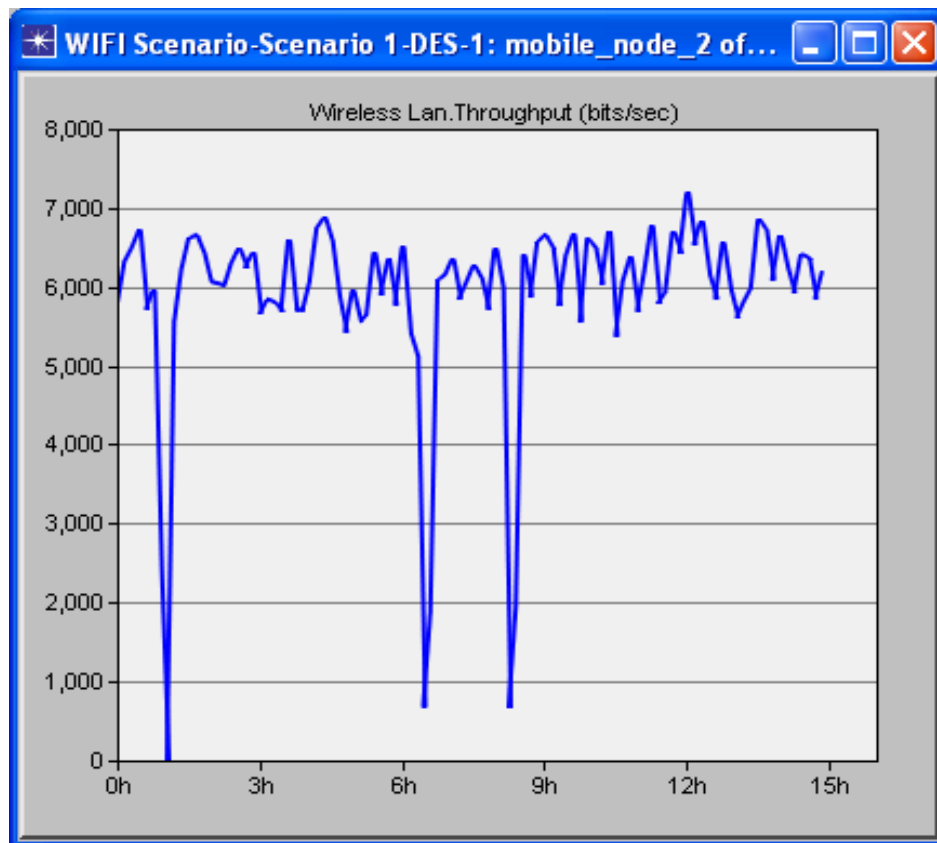


Fig 7.5: Throughput of Wi-Fi set-up

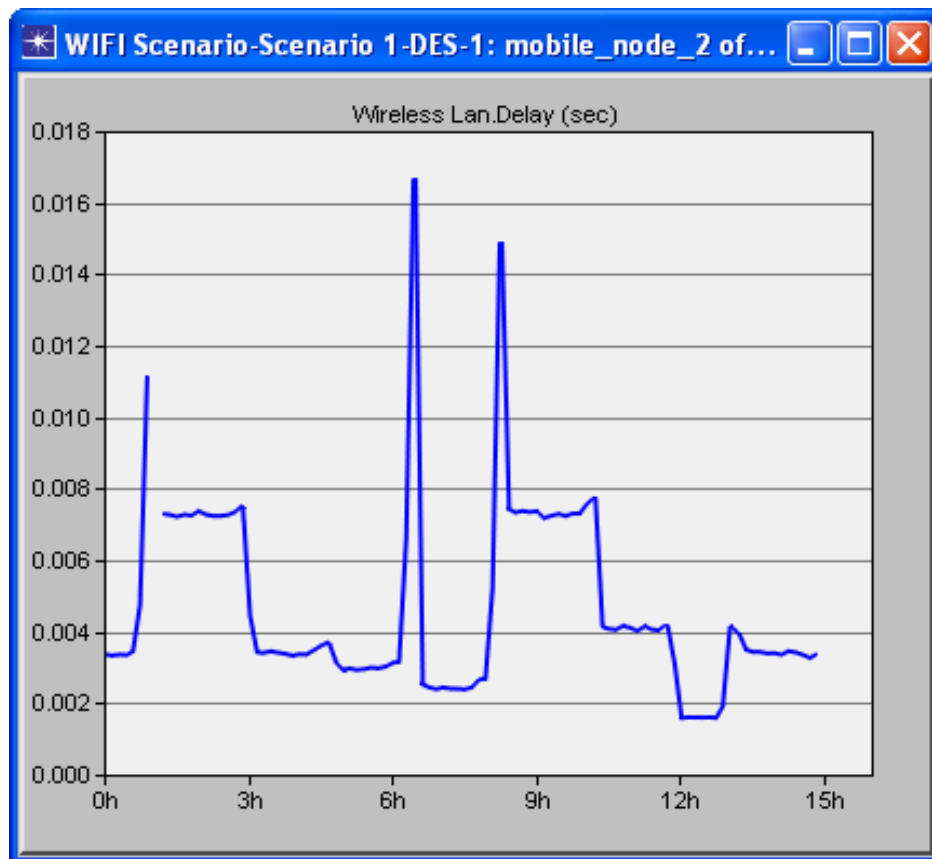


Fig 7.6: Delay of Wi-Fi set-up

This setup compares the data traffic received by different APs in the network. All APs have their own traffic from station STA_0 to STA_23. Since the initial stations of AP_0 are mobile ones, AP_0 receives data traffic only at the beginning and then at end of simulation when its stations start their tour and come back. Additionally, it receives data traffic when the stations started to get connected to it. In contrast to AP_0, AP_2 has stable stations, so the data traffic received by it does not drop to 0 like AP_0's traffic. As expected, its received data traffic doubles when the moving stations from west and south cross its section. AP_3 is visited by all moving stations at the same time. Hence, its received data traffic is tripled when this happens during simulation and the throughput and delay for the WLAN MS is obtained. Here in the Fig 7.6 we can see that initially the delay is more due to the set up time. Then the mobile node and the stations start roaming around the access points and hence the delay is almost constant. Then after 6 hrs there is small increase in the delay which is again due to the non-availability of stations. (bits/sec). The simulation time is 15 hrs. The throughput drops during handoff.

7.3.2 Horizontal handoff in WiMAX network

This scenario demonstrates the mobile station performance during horizontal handoff in WiMAX network. This set-up has eight BS, these BSs support WiMAX technologies. The MS roaming from BS0 to BS7 with the mobility speed of 29 m/sec. Figure 7.7 shows the set-up of the WiMAX. All the links used are 100 BASE T links. Figure 7.8 shows the throughput of the MS during the movement that is around 65k bit per sec. The drop points represent the connection time during the handoff. The curve in Figure 7.8 shows the delays during the handoff. The maximum delay point is 0.025 sec. This value is acceptable delay for most applications.

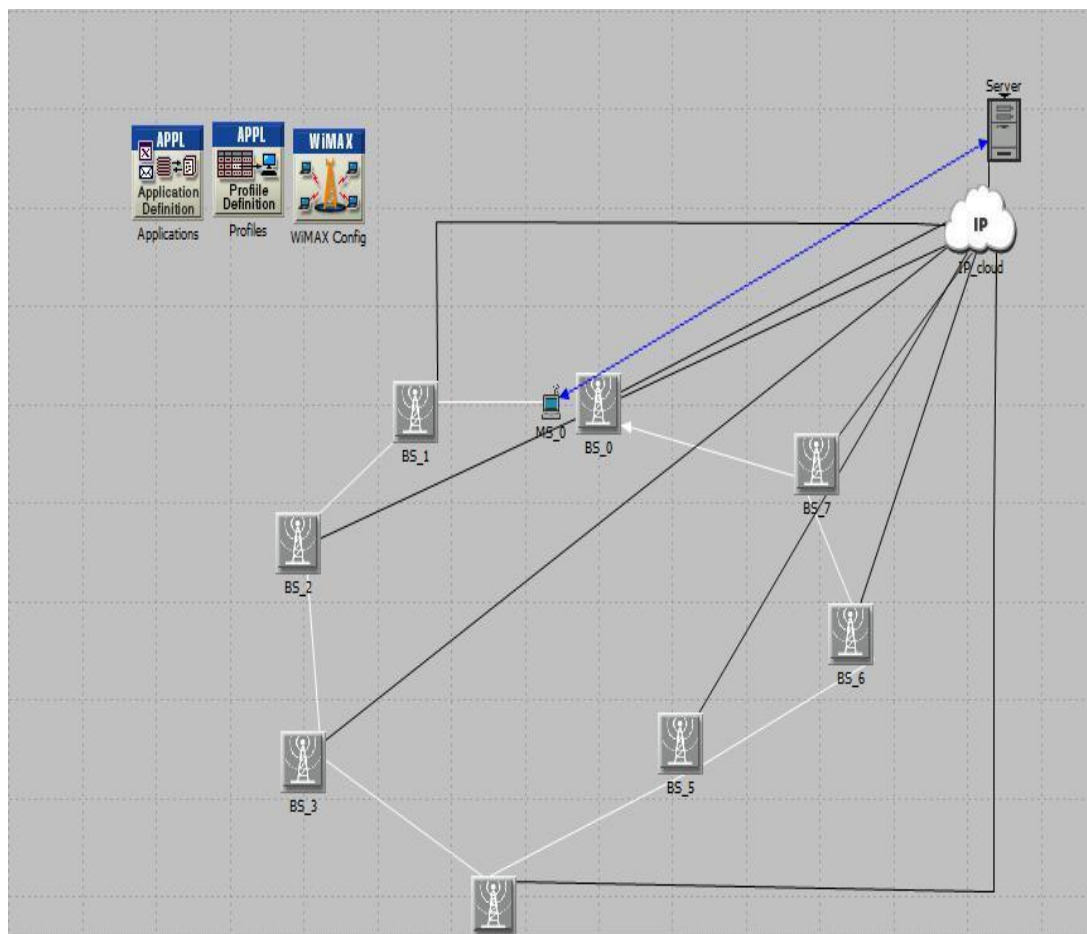


Figure 7.7: set-up of WiMAX Handoff

The throughput and handover delay graphs are obtained for the mobile station as shown below. Throughput drops during handoff. Throughput is total data traffic in bits/sec successfully received and forwarded to the higher layer by the WiMAX MAC.

In the WiMAX handoff setup the MS node moves away from the Home Agent and visits 7 Foreign Agent BS nodes, before returning back to the care of the Home

Agent. As it moves away from BS_0, it attaches itself with the BS_1 and so on etc. All the BSs are connected to IP cloud that provides and maintain the IP for each base station When MS_0 starts roaming around different BS horizontal handoff takes place and the throughput, delay, scanning BS ID graphs are obtained.

Table 7.2: WiMAX Parameters for MS

Antenna Gain (dBi)	-1 dBi
MAC Address	Auto Assigned
Maximum Transmission Power (W)	0.5
PHY Profile	Wireless OFDMA 5 MHz
PHY Profile Type	OFDM
BS MAC Address	Distance Based
Pathloss Parameters	Vehicular
Ranging Power Step (mW)	0.25
Scanning Threshold (dB)	27
Scan Duration (N) (Frames)	4
Interleaving Interval (P) (Frames)	240
Scan Iterations (T)	10
MS Handover Retransmission Timer(ms)	30
Maximum Handover Request Retransmissions	6
Handover Threshold Hysteresis (dB)	0.4

Initially the mobile station starts moving from BS_0 to BS_1 and so on. Hence there is throughput for some duration of time for BS_0. As the mobile node leaves its area the throughput is 0. And then after some time it again increases and becomes nearly constant when the mobile node reaches back to BS_0. Simulation time is 15 minutes. Delay here represents the end-to-end delay of all the data packets that are successfully received by the WiMAX MAC and forwarded to the higher layer.

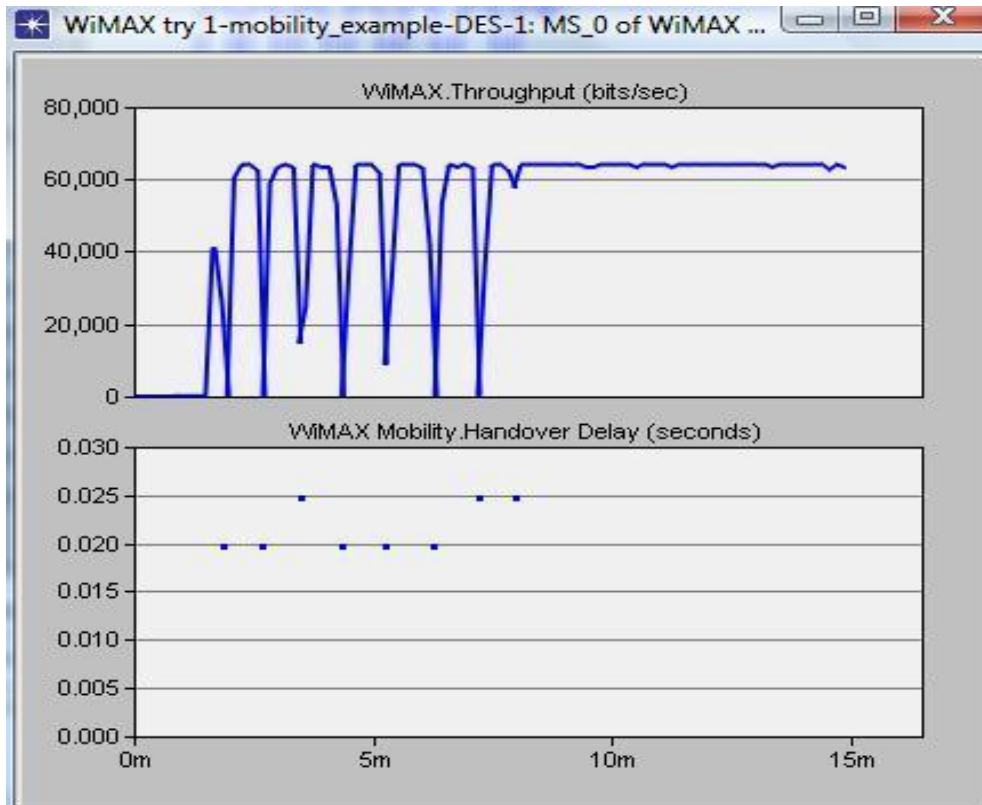


Figure 7.8 Throughput and handover delay of WiMAX set-up

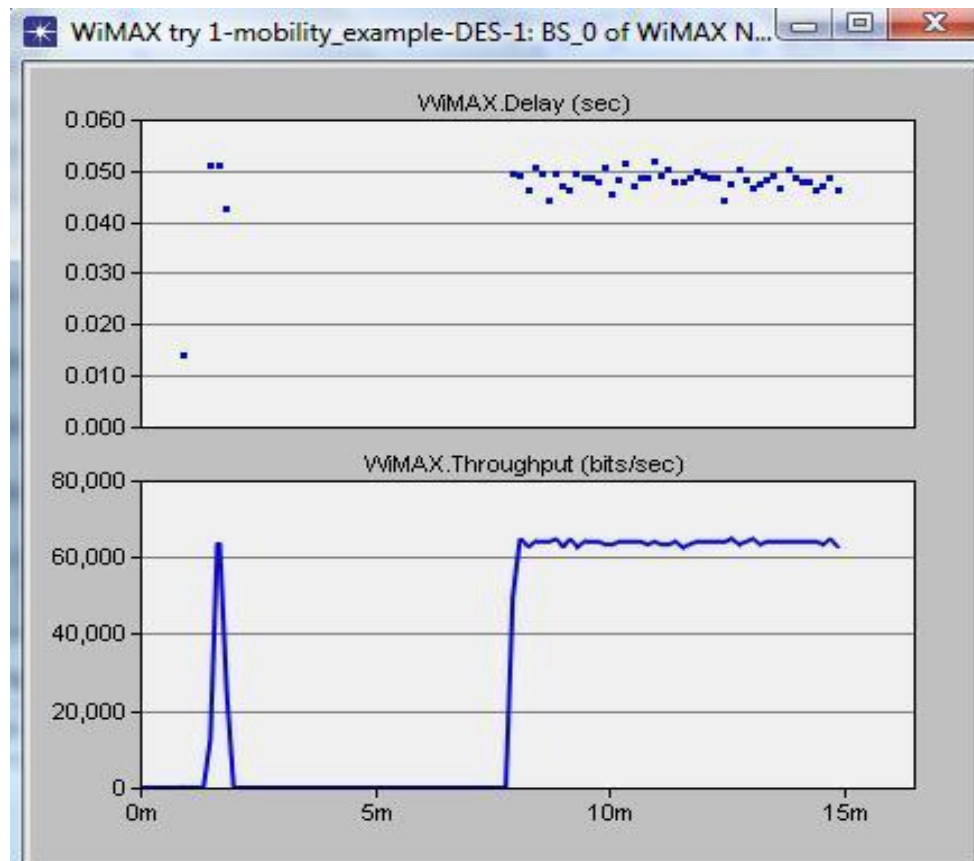


Figure 7.9: Delay and throughput for a WiMAX BS_0

7.3.4 Vertical Handoff in Heterogeneous Wireless Networks

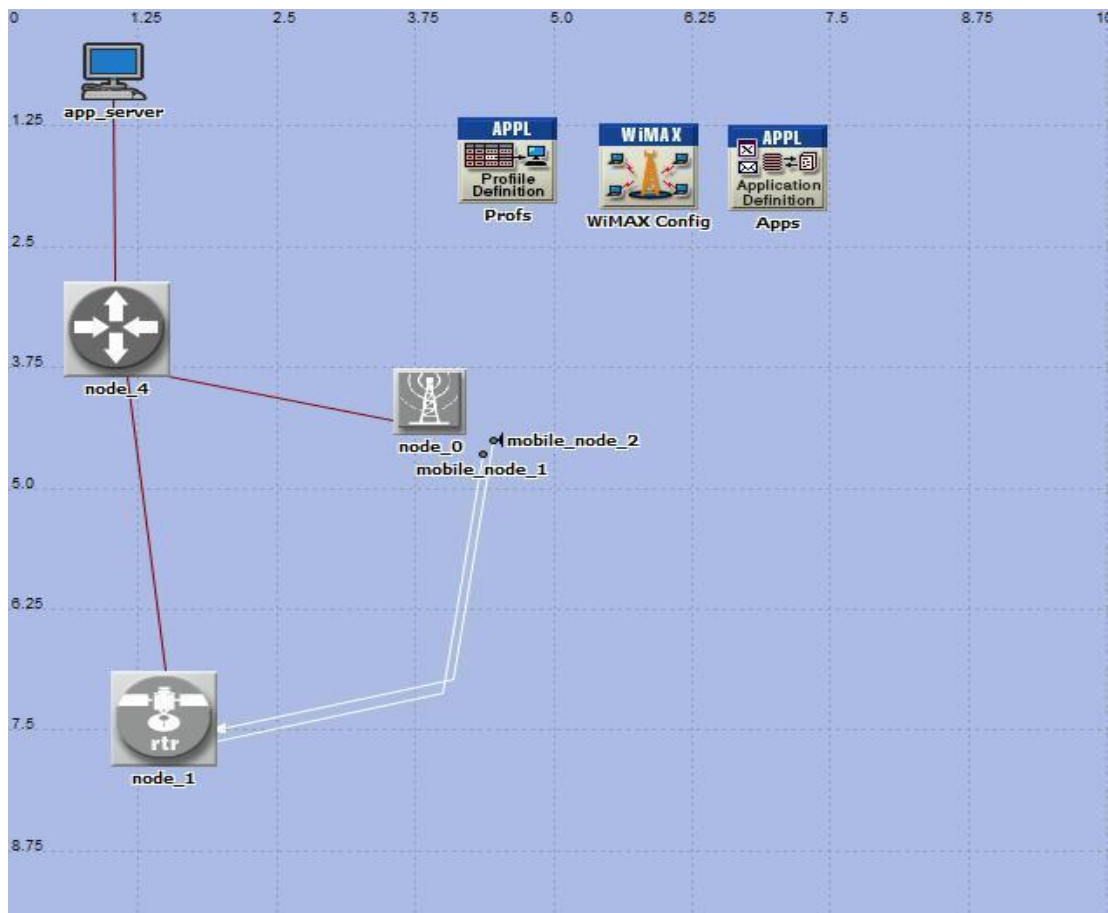


Figure 7.10: Set-up for vertical handoff

The vertical handover setup consists of a gateway, application server providing voice service to the WiMAX BS and to the WLAN router. Initially both the mobile nodes are placed near the WiMAX BS from where they start roaming towards the WLAN router. As they reach near the router, the WiMAX throughput is reduced and the WLAN throughput starts increasing which depicts vertical handoff triggering properties.

The above set-up comprises of an ethernet_wkstn (app_server) node model, ethernet4_slip8_gtwy node model (node_4), router (node_1), MS for WLAN as well as for WiMAX, WiMAX BS, Application config, Profile Config, WiMAX Config. MS for WLAN is mobile_node_1 and for WiMAX is mobile_node_2. Both the MS roam in some desired trajectory with the speed of 24 m/s.

Initially both the mobile_node_1, mobile_node_2 are placed near to the WiMAX BS from where they start roaming towards the WLAN router.

So the throughput for WLAN MS is 0 for some time while WiMAX MS depicts some throughput (bits/sec). And that some time is the time in which both the

mobile nodes reach in close vicinity or the range of the WLAN router. And then the throughput of WiMAX MS is reduced to 0, while throughput for WLAN MS starts increasing and becomes almost constant after some time. Simulation time for calculating this scenario is 500 sec.

Hence we observe that the Communication server performed hard handoff. The application running on the MS will stay connected to the application/communication server(GSM quality voice). The throughput is affected but one of the two MS stays connected.

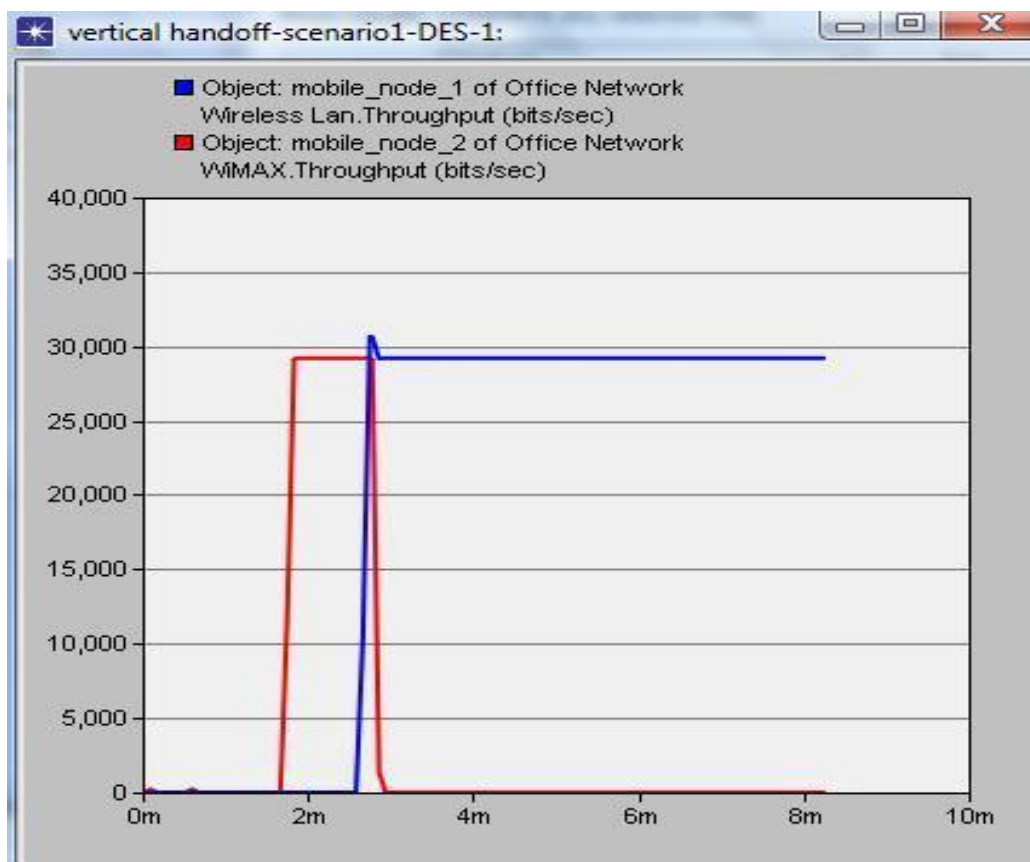


Figure 7.11: Throughput (bits/sec) for WLAN MS and WiMAX MS

The below figure depicts the relations between the delay and the throughput for WLAN MS.

It is clearly visible that when the WLAN MS reaches in the range of the router, throughput starts increasing and hence delay drops to zero. And as the WLAN MS stops after reaching close to router the throughput becomes almost constant.

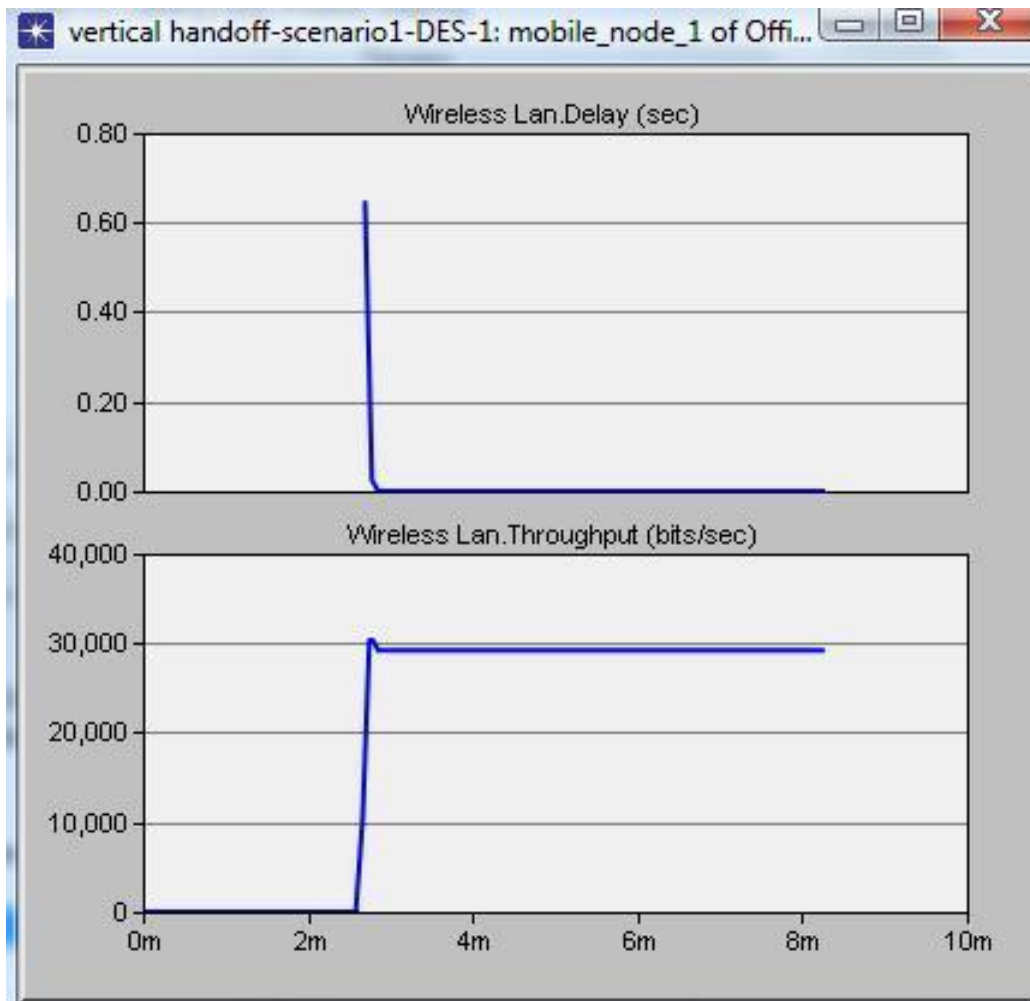


Figure 7.12: Delay (sec) and throughput (bits/sec) for WLAN MS

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 CONCLUSION

The purpose of this research work is to study the basic concepts of different handovers in heterogeneous wireless networks. There are different types of wireless technologies such as LTE, Wi-Fi and WiMAX. To maintain the QoS and seamless connectivity between different technologies we need to reduce the delay while shifting to another technology. And if delay is reduced, throughput will be increased. For better services we have to increase the throughput of the system.

In the context of ubiquitous connectivity, a mobile station (MS) equipped with IEEE 802.11 and IEEE 802.16 interface is likely to roam across multiple base stations (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 neighbouring 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.

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 the interference from other cells.

In the first scenario we have Wi-Fi handover setup. In this setup we compare the data traffic received by different APs in the network. All APs have their own traffic from station STA_0 to STA_23. AP_0 receives data traffic only at the beginning and then at end of simulation when its stations start their tour and come back. Initially there is increase in a delay when mobile station starts to roam around

all APs but after that it remains constant. Maximum delay we got is 0.017 sec which is considered to be tolerable for most applications.

In the second scenario we have WiMAX handover setup. In this setup the MS node moves away from the Home BS and visits 7 Foreign BS nodes, before returning back to the care of the Home BS. As it moves away from BS_0, it attaches itself with the BS_1 and so on etc. All the BSs are connected to IP cloud that provides and maintain the IP for each base station. When MS_0 starts roaming around different BS horizontal handoff takes place and the throughput, delay, scanning BS ID graphs are obtained.

In the third scenario we have a vertical handoff setup. In The vertical handover setup consists of a gateway, application server providing voice service to the WiMAX BS and to the WLAN router. Initially both the mobile nodes are placed near the WiMAX BS from where they start roaming towards the WLAN router. As they reach near the router, the WiMAX throughput is reduced and the WLAN throughput starts increasing which depicts vertical handoff triggering properties. The graphs for throughput and delay are obtained as expected.

8.2 FUTURE WORK

Vertical mobility has been a topic of research for over a decade now, and it is deployed in commercial products. Yet, the popularity of seamless services has not taken its place in the everyday life of consumers in the same way that talking to a mobile phone or using Internet from a home PC. While there is some doubt if vertical mobility will ever have significant enough revenue creating ability for operators, the future challenge is to –put into action|| services and applications that utilize vertical roaming with both technical and economical excellence. These services need to be enabled and introduced in mobile handsets with viable and tailored applications in order to see their full benefits. The challenge is about enabling better mobile applications through holistic plug-and-play connectivity and –always best connected|| paradigms.

The vertical handover is a very important capability in the future wireless communication era, where an integrated network grouping multiple technologies will try to offer a global broadband access to mobile users. However, compared to the horizontal handover, the signal strength metric is sometimes not suited and often not

sufficient to appropriately trigger the vertical handover: as heterogeneous networks have different system characteristics, their performance cannot be simply compared using the signal strength of two cells.

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