PERFORMANCE EVALUATION OF HANDOVER SCENARIOS IN MOBILE WIMAX NETWORKS

BY

AHAMEFUNA EUSEBIUS AGBO

REG. NO: PG/UD/MENG/05/11

DEPARTMENT OF ELECTRONIC ENGINEERING

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TITLE PAGE

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APPROVAL PAGE

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF ENGINEERING (M.ENG.) IN THE DEPARTMENT OF ELECTRONIC ENGINEERING, TELECOMMUNICATIONS OPTION, UNIVERSITY OF NIGERIA NSUKKA

AHAMEFUNA EUSEBIUS AGBO **SIGNATURE…………..DATE………………**
(STUDENT)

PROF. C. I. ANI **SIGNATURE…………..DATE………………**
(SUPERVISOR)

EXTERNAL EXAMINER **SIGNATURE…………..DATE……………..**

DR. M.A. AHANEKU **SIGNATURE…………..DATE……………..**
(Ag. HEAD OF DEPARTMENT)

PROF. W. I. OKONKWO **SIGNATURE…………..DATE…………….**
(CHAIRMAN, FACULTY

POSTGRADUATE COMMITTEE)

CERTIFICATION

Ahamefuna Eusebius Agbo, a masters' degree postgraduate student in the department of Electronic Engineering and with registration number

PG/UD/MENG/05/11 has satisfactorily completed the requirements for the award of Master of Engineering (M.ENG) in Telecommunications Engineering.

___________________________ ________________________________

PROF. C. I. ANI DR. M.A. AHANEKU (SUPERVISOR)

(Ag. HEAD OF DEPARTMENT)

____

PROF. W.I. OKONKWO

(CHAIRMAN, FACULTY POSTGRADUATE COMMITTEE)

DECLARATION

I, AHAMEFUNA EUSEBIUS AGBO, a postgraduate student in the Department of Electronic Engineering, University of Nigeria, Nsukka, declare that the work embodied in this thesis is original and has not been submitted by me in part or in full for any other diploma or degree of this or any other university..

AHAMEFUNA EUSEBIUS AGBO **DATE**

PG/UD/MENG/05/11

DEDICATION

This thesis is dedicated to the Almighty God

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AHAMEFUNA EUSEBIUS AGBO

SEPTEMBER 2014

ABSTRACT

Achieving seamless homogeneous handover in mobile WiMAX due to its low cost and state of the art technology will enable ubiquitous broadband access to high volume applications especially with the high global increase in mobile subscribers. Extending this seamless handover across network technologies-heterogeneous handover- like WiFi will further lower cost, improve battery life and enable high productivity for end users. In this project, ways of optimizing handover in mobile WiMAX network, and the design and evaluation of system-level performance of different select handover scenarios were analyzed. Modeled voice application on a mobile node at pedestrian and vehicular speeds was used for the analysis with the media independent handover (MIH) network simulator 2 (NS-2) as simulation tool. MATLAB-based Trace Graph and Microsoft excel were used as the MAC layer packet-level analysis tools. The average handover delay from the simulation result is found to be 46 msec in all the simulation which fell below the WiMAX forumôs recommended handover delay of 150 msec for VoIP. The average handover jitter of 47msec also fell under the standard value of 50 msec. It was determined that the

heterogeneous handover to WiFi network has acceptable throughput, delay, latency with no packet lost for voice packets. However, there were significant drop in throughput observed during WiMAX handover periods with highest drop of 5 packets/sec from 50 packets/sec at normal operation. This is due to packet loss caused by Doppler spread at vehicular speed and low SINR (signal-to-interference noise) at non overlapping cells and large base station distances. These throughput drops can be mitigated by appropriate channel modelling, adaptive sampling of Orthogonal Frequency Division Multiplexing (OFDM) symbols at high speed, antenna diversity, and also by making sure that all cells overlap during base station deployments.

TABLE OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION

1.1 Introduction to the Problem

WiMAX (Worldwide Interoperability for Microwave Access) is a certification that denotes interoperability of equipment built to the IEEE 802.16 or compatibility standard. It is based on the wireless Metropolitan Area Network technology, optimized for the delivery of IP centric services over a wide area.

This thesis introduces the IEEE 802.16e-2005 standard, also known as Mobile WiMAX, which defines the physical (PHY) and Medium Access Control (MAC) layers of it. The 802.16e-2005 [1] is the new, mobile version of the older WiMAX specification known as 802.16-2004 [2], which is a wireless but fixed, data transmission scheme for providing broadband connection to metropolitan areas. The traditional WiMAX has lacked the ability for the user to move during transmission. The importance of mobile WiMax becomes imperative, due to the need for a mobile user to change from one serving base station to another. The handover should be fast enough, so that the on-going video or voice call is not interrupted long enough for the user to notice. The support for *seamless* mobility in mobile broadband radio access network, will give opportunity for *anytime, anywhere, any network and any device* communication, especially for high bandwidth-hungry internet applications like online gaming, video and audio streaming, voice over IP, video conferencing and *location based services.*

Mobile WiMAX enjoys wide support from telecom industry leaders such that by creating a common platform, which addresses a wide range of market and business segments, it will be well placed to assume the global standard for mobile broadband wireless. Achieving seamless mobility across different wireless technologies like WiFi (wireless fidelity) or other 3G (third generation) broadband networks like UMTS (universal mobile telecommunication services) will further have a user advantage of keeping cost very low and productivity very high while saving battery life. In December 2005, the 802.16-2004 WiMAX standards was amended to the 802.16e-2005 and ratified by the IEEE (Institute of Electrical and Electronics Engineers). This amendment added the features and characteristics that makes it necessary to support mobility in the air interface [2, 3] [3]. The WiMAX Forum, which is pioneering this technology, defined system performance and certification profiles based on the IEEE 802.16e-2005 amendment to go beyond the air interface and identify network architecture necessary for implementing end-to-end mobile architecture [4]. This forum is making sure that WiMAX standard have benefits that cuts across equipment vendors, consumers, service providers and component makers.

1.2. Motivation

The motivation for this thesis is to determine how seamless mobility in WiMAX network can be achieved, keeping in mind the need to maintain tolerable system throughput, delay, jitter and packet lose during homogenous (horizontal), and heterogeneous (vertical) handover, between mobile broadband networks at pedestrian and vehicular speeds

1.3. Research Objectives

The aim of this project is to analyze the various mechanisms for optimizing handover in mobile WiMAX so as to achieve seamless handover session of broadband applications. Also different handover scenarios will be designed in an attempt to demonstrate possible real life deployment of WiMAX base stations, based on site logistics and existing infrastructure constraints. Performance metrics of throughput, delay, jitter and packet loss will be used to evaluate the performance of a mobile subscriber (MS) on a voice session with a user in a correspondent node (CN) during normal (interleaving) and homogenous handover intervals at different speeds using NS-2. Finally, the same performance metrics will also be used to analyze heterogeneous handover of voice session between a multimode MS and same user in the CN while traversing a WiFi and a WiMAX coverage area at various speeds and trajectory. This is an attempt to demonstrate the possibility of saving cost, battery life and achieving high productivity by a very busy business executive or telecoms professional that starts a voice session from home and finishes up in the office while communicating with his client or technical manager respectively

1.4. Organization of Thesis

The thesis starts with an overview and background of WiMAX Technology. Chapter two takes a look at the underlying technology and foundation of mobile WiMAX. Chapter three discusses handover types in detail, with current and ongoing research for optimizing handover techniques. Chapter four discusses different handover scenarios carried out and the methods used and results achieved, at the same time testing the performance of mobile WiMAX handovers. Chapter five analyses the trace file output from the simulation. Finally, chapter six concludes the report with standard comparisons and possible ways of improving handover issues with recommendation for further work.

2 WIMAX TECHNOLOGY AND IMPLEMENTATION

2.1 Introduction to Mobile Broadband Wireless Access

Network technologies are traditionally based on wireline solutions. The introduction of cellular networks has made mobility an important issue in communication. Although cellular networks provide mobility support for voice communication, they cannot support high bandwidth data transfer for numerous mobile users simultaneously. Wireline networks on the other hand excel in high bandwidth data communication, but they do not support mobility. The aim of emerging wireless data networks is to provide wireless service comparable to that of wireline networks for fixed and mobile users.

Wireless data networks can be categorized according to their coverage areas. Wireless Local Area Networks (WLANs) are designed to provide wireless access in areas with cell radius up to hundred meters and are used mostly in home and office environments. Wireless Metropolitan Area Networks (WMANs) cover wider areas, generally as large as entire cities. Wireless Wide Area Networks (WWANs) are designed for areas larger than a single city.

Different network standards are designed for each of these categories. However, some of these standards fit into several of these categories. As of today, WLAN is the most widely deployed wireless technology. The most notable WLAN standard is IEEE 802.11 family [18]. Another WLAN standard is the HiperLAN family by European Telecommunications Standard Institute (ETSI). These two technologies are united under the Wireless Fidelity (WiFi) alliance. Both technologies serve a local area with a radius of 50ï 100 m at most.

A typical WLAN network consists of an Access Point (AP) in the center and Stations (STAs) connected to this AP. Communication to/from a STA is always carried over the AP. There is also a decentralized working mode of WLAN, in which all STAs can talk to each other directly in an ad-hoc fashion. While WiFi initially provided an aggregate throughput of11 Mbps (per AP), the current standard provides a throughput of 54Mbps. Also, in the market there are WiFi devices that support data rates up to 108 Mbps using various additional techniques. With the emerging IEEE 802.11n standard, WiFi is expected to standardize these improvements and provide throughput values up to 540 Mbps. While not as widely deployed as WLAN, WMAN networks are becoming popular.

IEEE developed IEEE 802.16 [31] standard to provide Broadband Wireless Access (BWA) to fixed Line of Sight (LOS) Subscriber Stations (SSs) from a Base Station (BS). IEEE 802.16-2005, the current version, supports non-LOS (NLOS) SSs and Mobile Subscribers (MSs). IEEE 802.16 is a cell based technology, in which multiple cells are used to cover urban areas. Average throughput of IEEE 802.16 cell is expected to be between 75 and 100 Mbps.

On the other hand, ETSI established the Broadband Radio Access Networks (BRANs) project in 1997 to develop standards that provide broadband radio access to business and residential users. Two different WMAN standards are introduced under the BRAN project as of today; Hiper-ACCESS for LOS and HiperMAN for both LOS and NLOS user support. Furthermore, Wireless Broadband (WiBro) standard is developed by the Telecommunications Technology Association (TTA) of South Korea based on IEEE 802.16. A different approach for BWA support is High Altitude Platforms (HAPs). HAPs fill in the gap between WMANs and WWANs. In HAP systems, floating platforms (or air vehicles) serve as the BS over wide areas, and the cities are covered by multiple platforms. The most important aspect of HAP is the platformŝ ability to reach virtually all buildings within its LOS. Satellite systems provide the widest coverage for WWAN environments. The satellites in current use are mostly capable of one sided (only downlink) broadcast communication. Next Generation Satellite Systems (NGSSs) are expected to have Onboard Processing (OBP) and on-board routing capabilities. Coupled with upload channel support, these satellites will have greater versatility and are expected to play an important role in future broadband system. Another WWAN technology is the emerging IEEE 802.20 standard. This new technology targets highly mobile vehicles with speeds up to 250 kmph (e.g., high speed trains) for BWA access. IEEE 802.20 is expected to cover large areas and will have versatile mobility support. Thus, mobile users with different speeds and profiles may connect to the same IEEE 802.20 BS. The aggregate throughput of the system is not expected to be as high as a WLAN Access Point or a WMAN Base Station due to the high speed of the mobile users. Wireless data networks operating at different scales can be integrated to provide ubiquitous broadband access to users. In a simple integration environment, WLANs provide wireless access to indoor users. Traffic to/from multiple WLANs in the same building can be aggregated and transmitted over the local WMAN (e.g., through an IEEE 802.16 SS) to the Internet. WMANs covering different areas can be interconnected by a WWAN. Thus, a mobile user has ubiquitous connectivity in a wide area.

2.2 Brief Review of WiMAX Concept

2.2.1. Introduction

WiMAX is defined as Worldwide Interoperability for Microwave Access by the WiMAX Forum, formed in June 2001 to promote conformance and interoperability of the IEEE 802.16 standard, officially known as WirelessMAN. The Forum describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL".

2.2.2. Technical Overview

The definition: WiMAX is not a technology, but rather a certification mark, or 'stamp of approval' given to equipment that meets certain conformity and interoperability tests for the IEEE 802.16 family of standards [18]. A similar confusion surrounds the term Wi-Fi (Wireless Fidelity), which like WiMAX, is a certification mark for equipment based on a different set of IEEE standards from the 802.11 working group for wireless local area networks (WLAN). Neither WiMAX, nor Wi-Fi is a technology but their names have been adopted in popular usage to denote the technologies behind them. This is likely due to the difficulty of using terms like 'IEEE 802.16' in common speech and writing. WiMAX is a term coined to describe standard, interoperable implementations of IEEE 802.16 wireless networks, in a rather similar way to Wi-Fi being interoperable implementations of the IEEE 802.11 Wireless LAN standard. However, WiMAX is very different from Wi-Fi in the way it works. In Wi-Fi the media access controller (MAC) uses contention access ð all subscriber stations that wish to pass data through a wireless access point (AP) are competing for the AP's attention on a random interrupt basis. This can cause subscriber stations distant from the AP to be repeatedly interrupted by closer stations, greatly reducing their throughput. This makes services such as Voice over IP (VoIP) or IPTV, which depend on an essentially constant Quality of Service (QoS) depending on data rate and interuptibility, difficult to maintain for more than a few simultaneous users. In contrast, the 802.16 MAC uses a scheduling algorithm for which the subscriber station need compete once (for initial entry into the network). After that it is allocated an access slot by the base station. The time slot can enlarge and contract, but remains assigned to the subscriber station which means that other subscribers cannot use it. The 802.16 scheduling algorithm is stable under overload and over-subscription (unlike 802.11). It can also be more bandwidth efficient. The scheduling algorithm also allows the base station to control QoS parameters by balancing the time-slot assignments among the application needs of the subscriber stations. The original WiMAX standard (IEEE 802.16) specified WiMAX for the 10 to 66 GHz range. 802.16a, updated in 2004 to 802.16-2004 (also known as 802.16d), added specification for the 2 to 11 GHz range. 802.16d (also known as "fixed WiMAX") was updated to 802.16e in 2005 (known as "mobile WiMAX"). and uses scalable orthogonal frequency-division multiplexing (OFDM) as opposed to the OFDM version with 256 sub-carriers used in 802.16d. This brings potential benefits in terms of coverage, self installation, power consumption, frequency re-use and bandwidth efficiency. 802.16e also adds a capability for full mobility support.

The WiMAX certification allows vendors with 802.16d products to sell their equipment as WiMAX certified, thus ensuring a level of interoperability with other certified products, as long as they fit the same profile.

Most interest will probably be in the 802.16d and .16e standards, since the lower frequencies suffer less from inherent signal attenuation and therefore give improved range and in-building penetration. Already today, a number of networks throughout the World are in commercial operation using certified WiMAX equipment compliant with the 802.16d standard. The WiMAX specification improves upon many of the limitations of the Wi-Fi standard by providing increased bandwidth and range and stronger encryption. It provides connectivity between network endpoints without need for direct line of sight in favourable circumstances. The non-line-of-sight propagation (NLOS) performance requires the .16d or .16e revisions, since the lower frequencies are needed. It relies upon multi-path signals, somewhat in the manner of 802.11n.

2.2.3. Uses for WiMAX

A commonly held misconception is that WiMAX will deliver 70 Mbit/s, over 70 miles (112.6 kilometers). Each of these is true individually, given ideal circumstances, but they are not simultaneously true. WiMAX has some similarities to digital subscriber line DSL in this respect, where one can either have high bandwidth or long reach, but not both simultaneously. The other feature to consider with WiMAX is that available bandwidth is shared between users in a given radio sector, so if there are many active users in a single sector, each will get reduced bandwidth. The bandwidth and reach of WiMAX make it suitable for the following potential applications:

* Connecting Wi-Fi hotspots with each other and to other parts of the Internet

* Providing a wireless alternative to cable and DSL for last mile (last km) broadband access.

* Providing high-speed mobile data and telecommunications services (4G)

2.3 Overview of IEEE 802.11 Standard

In 1997 the IEEE adopted IEEE Standard. 802.11-1997, the first wireless LAN (WLAN) standard. This standard defines the media access control (MAC) and physical (PHY) layers for a LAN with wireless connectivity. It addresses local area networking where the connected devices communicate over the air to other devices that are within close proximity to each other. The standard specifically, addresses:

- Functions required for an 802.11 compliant device to operate either in a peer-to-peer fashion or integrated with an existing wired LAN
- Operation of the 802.11 device within possibly overlapping 802.11 wireless LANs and the mobility of this device between multiple wireless LANs
- MAC level access control and data delivery services to allow upper layers of the 802.11 network
- Several physical layer signaling techniques and interfaces
- Privacy and security of user data being transferred over the wireless media

2.3.1. Network Topology

The 802.11 architecture is comprised of several components and services that interact to provide station mobility transparent to the higher layers of the network stack.

Wireless LAN Station

The *station* (STA) is the most basic component of the wireless network. A station is any device that contains the functionality of the 802.11 protocol, that being MAC, PHY, and a connection to the wireless media. Typically the 802.11 functions are implemented in the hardware and software of a network interface card (NIC). A station could be a laptop PC, handheld device, or an Access Point.

Stations may be mobile, portable, or stationary and all stations support the 802.11 station services of authentication, de-authentication, privacy, and data delivery.

Basic Service Set (BSS)

802.11 defines the *Basic Service Set* (BSS) as the basic building block of an 802.11 wireless LAN. The BSS consists of a group of any number of stations. It defines the various topologies of the 802.11 standard. The different Network topologies are defined as follows:

Independent Basic Service Set (IBSS)

The most basic wireless LAN topology is a set of stations, which have recognized each other and are connected via the wireless media in a peer-to-peer fashion. This form of network topology is referred to as an *Independent Basic Service Set* (IBSS) or an *Ad-hoc* network. In an IBSS, the mobile stations communicate directly with each other. Every mobile station may not be able to communicate with every other station due to the range limitations. There are no relay functions in an IBSS therefore all stations need to be within range of each other and communicate directly.

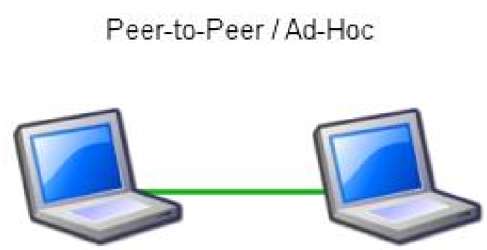


Figure 2.1 Peer-to-peer Network Topology

Infrastructure Basic Service Set

An Infrastructure Basic Service Set is a BSS with a component called an *Access Point* (AP). The access point provides a local relay function for the BSS. All stations in the BSS communicate with the access point and no longer communicate directly. All frames are relayed between stations by the access point. This local relay function effectively doubles the range of the IBSS.

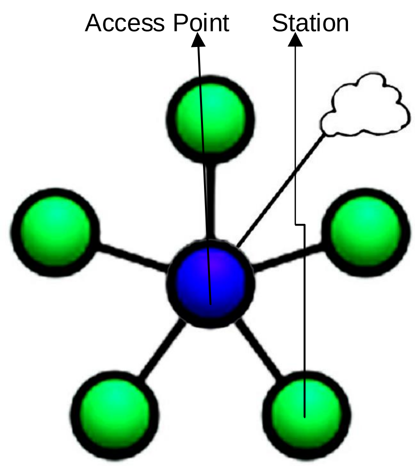


Figure 2.2: Infrastructure Topology

Distribution System (DS)

The *distribution system* (DS) is the means by which an access point communicates with another access point to exchange frames for stations in their respective BSSs, forward frames to follow mobile stations as they move from one BSS to another, and exchange frames with a wired network. As IEEE 802.11 describes it, the distribution system is not necessarily a network nor does the standard place any restrictions on how the distribution system is implemented, only on the services it must provide. Thus the distribution system may be a wired network like 803.2 or a special purpose box that interconnects the access points and provides the required distribution services.

Extending coverage via an Extended Service Set (ESS)

802.11 extends the range of mobility to an arbitrary range through the *Extended Service Set* (ESS). An extended service set is a set of infrastructure BSS's, where the access points communicate amongst themselves to forward traffic from one BSS to another to facilitate movement of stations between BSS's. The access point performs this communication through the distribution system. The distribution system is the backbone of the wireless LAN and may be constructed of either a wired LAN or wireless network.

Typically the distribution system is a thin layer in each access point that determines the destination for traffic received from a BSS. The distribution system determines if traffic should be relayed back to a destination in the same BSS, forwarded on the distribution system to another access point, or sent into the wired network to a destination not in the extended service set. Communications received by an access point from the distribution system are transmitted to the BSS to be received by the destination mobile station.

Network equipment outside of the extended service set views the ESS and all of its mobile stations as a single MAC-layer network where all stations are physically stationary. Thus, the ESS hides the mobility of the mobile stations from everything outside the ESS. This level of indirection provided by the 802.11 architecture allows existing network protocols that have no concept of mobility to operate correctly with a wireless LAN where there is mobility.

2.4 Comparison Between WiMax and WiFi

The features and characteristics of WiMAX and WiFi broadband networks are discussed below:

- **WiMAX**: WiMAX broadband is IP-based and designed from the ground up to provide high speed broadband access to subscribers with capability for seamless mobility at high pedestrian and vehicular speeds. WiMAX offers high data rate of between 10Mbps to 75Mbps, depending on modulation and coding, with a coverage area of about 30 miles or more. Its wider coverage area compared to WiFi gives it the opportunity of being considered for mobility. WiMAX Broadband was originally deployed for fixed application; its prospects will only be exploited when used for nomadic and mobile broadband applications [5].

- **WiFi**: WiFi, until the advent of WiMAX, had been the defacto standard for last mile broadband access to homes, offices and public hotspot areas. Deploying WiFi in large scale areas is impossible due to the required dense deployment of access points which is usually not practical. Moreover, the ineffective CSMA (carrier sense multiple access) protocol as well as the interference constraints of operating in the license exempt band and also for the fact that WiFi is not designed for high speed mobility, definitely has an effect in deploying WiFi as an outdoor system [11].

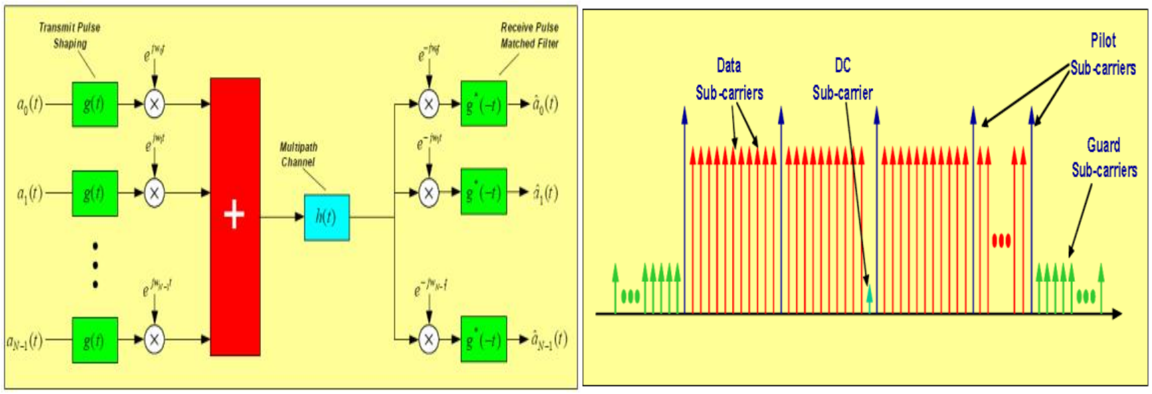
The IEEE 802.21 MIH, bringing together these broadband technologies, will have the advantage of:

1. a seamless handover across WiMAX and WiFi access technologies.
2. enhancing user experience during handover by optimizing layer 3 handover
3. providing QoS continuity across these technologies while minimizing service disruptions
4. providing ease of implementation with thin software client on terminals with no access network modification by just adding a single MIH server in the IP core network
5. supporting client-controlled or network controlled handover.

The IEEE 802.20 network working group (NWG) is under development to attain vehicular speeds up to 250 km/h with operations below 3.5GHz to deliver peak user data rates in excess of 4Mbps and 1.2Mbps in the DL and UL respectively [5].

2.5 Physical (PHY) Layer

The PHY layer of mobile WiMAX sits on OFDMA (orthogonal frequency division multiple access) which is a transmission scheme called multicarrier modulation. The principle is based on dividing a given high-bit-rate data stream into several parallel lower bit-rate streams and modulation of each stream on separate carriers called sub channels. This helps in eliminating or mitigating ISI by increasing the symbol time thereby making *delay spread* a negligible fraction of this symbol duration. Figure 2.3 (a) shows the basic architecture of an OFDM system while Figure 2.3 (b) shows the principle of sub channelization [14]. Mobile WiMAX uses scalable OFDMA, with Fast Fourier Transform (FFT) size varying from 128 bits to 2,048 bits.



(a) OFDM multicarrier (b) Subchannel structure

Figure 2.3: Basic architecture of an OFDM System [15]

This choice of transmission scheme enables high-speed data, video, real-time, and non real-time multimedia communications in NLOS environments. The scalable nature of OFDMA-PHY in mobile WiMAX works in the sense that when the available bandwidth increases, the FFT size increases through maintaining the subcarrier spacing at 10.94 kHz thereby keeping the OFDM symbol duration fixed. This makes scaling have minimal impact on higher layers as well as keeping the cost low. The delay spread and *Doppler spread* is also satisfied by this subcarrier spacing enabling it to function in both mobile and fixed scenarios. Delay spread of 20µs and vehicular mobility of up to 125 km/h can be supported by this 10.94 kHz subcarrier spacing [5]. Application traffic experiences *Pathloss, shadowing and multipath* in wireless channels. Empirical path loss models like the *Hata model* and *COST-231-Walfish-Ikegami model* are used to mitigate this effects [16]. In the PHY layer a reflected signal containing data and control information often experience 180^o phase shift. The reflection at relatively large distance creates a destructive interference causing Pathloss. The common *two-ray* approximation for Pathloss is:

$$P_r = P_t \frac{[illegible]}{d} \qquad 2.1$$

2.6 Media Access Control (MAC) Layer

The MAC layer is the core and foundation of mobile WiMAX technology. The primary function of the MAC layer is to provide an interface between the higher layers and the physical layer as well as controlling and multiplexing the various subchannels in transporting these higher layer traffics with minimum or no error. In the transmitting entity, the MAC layer takes packets called the MAC service data units (MSDU) from the upper higher layers and organizes them into MAC protocol data units (MPDU) for transmission in the air. The MAC layer of the receiving entity does the reverse. This MSDU can either be *fragmented* (when the radio link quality is bad) or several of them *packed* (when the radio link quality is good) forming a payload for the MPDU. For the MPDU to be transmitted over the wireless media, a unidirectional logical link called a *connection* - with associated connection identification (CID) - must be established between the peer MAC layer of the BS and a MS. The CID for UL and DL are different. In addition to the connection for MPDU, there are also three management connections known as: basic, primary and secondary connections. This makes WiMAX a *connection-oriented* wireless network. The MAC layer of mobile WiMAX also defines the *service flow* concept which is also a unidirectional flow of MPDU having a set of QoS parameters and identified by service flow identification (SFID). Figure 2.6 shows a MAC PDU frame. The MAC layer supports mobility management to upper layer as well as power management using sleep and idle mode [17].

2.7 Mobility Management

2.7.1 Frequency Reuse

Frequency reuse is the act of planning the reuse of scarce frequency allocated by a regulatory body in a manner that affords minimum or no interference between adjacent cells [19]. Achieving frequency reuse of one is possible if the adjacent coverage areas of a BS operate on the same frequency channel. This reuse pattern will affect signals of users at cell edges due to interference. This problem has been addressed in mobile WiMAX by *tweaking* the frequency reuse of one in what is known as *fractional frequency reuse.* The principle is in users at cell centre operating on all available sub-channels while those at cell edges operate on a fraction of all available sub-channels. See Figure 2.4. F1, F2 and F3 are different sets of subchannels fractions allocated to users at adjacent cell edges, while F being the sum of the fractional subchannels are allocated to users at the cell centres [12] such that:

$$F=F1+F2+F3 \qquad 2.2$$

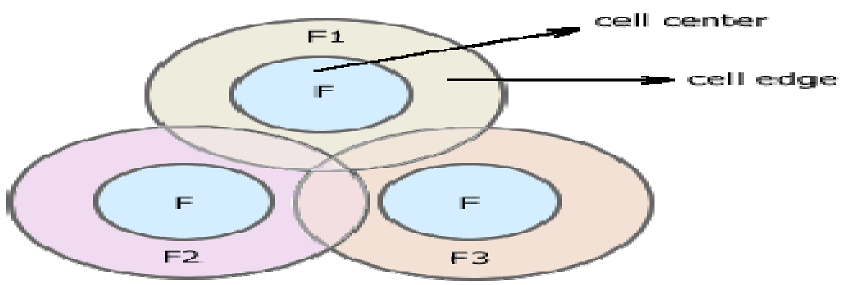


Figure 2.4: Fractional frequency reuse [12]

Therefore, fractional frequency reuse maximizes spectral efficiency for MSs at cell centres and improves signal strength and throughput for users at a cell edges.

2.7.2 Network Entry

On initial switch-on and during handover a MS needs to undergo network entry to the subscribed network. This basically involves the steps in Figure 2.5.

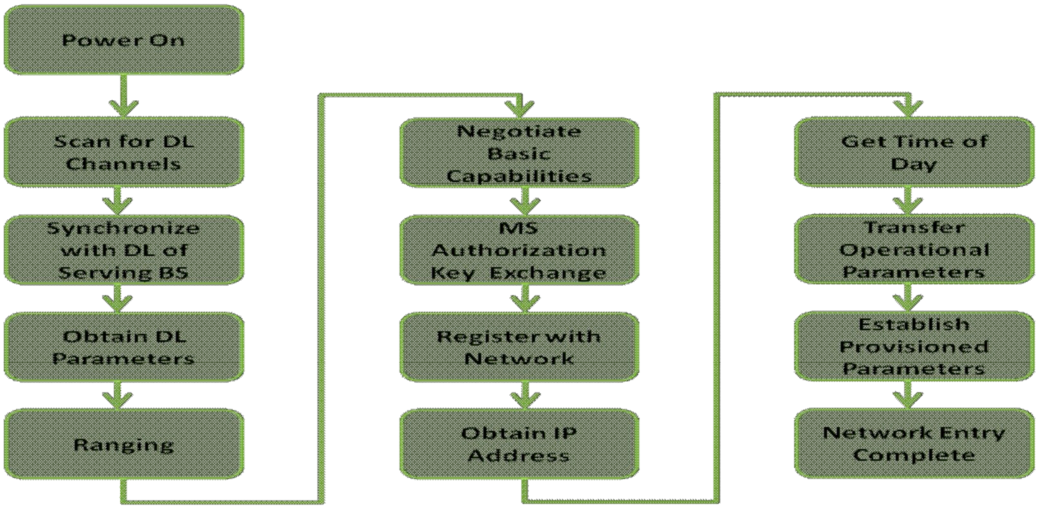


Figure 2.5: Network entry in mobile WiMAX

2.7.3 Location Management

This constitutes two processes namely: *location* update and *paging*. In location update MSs periodically informs the network of its current location making it possible for the network to authenticate and update location profile in user"s database. In Paging, the arrival of an incoming session in a network triggers a location database look-up to determine MS current location area and then pages all base stations in that area. The target MS then responds to the paging signal. Larger coverage area constitutes a greater paging resource causing operators to make trade-off decisions[20] [21].

2.7.4 Radio Resource Management

To achieve seamless mobility and to reduce dropping probability when a MS moves across different BSs, handover decision must take into account the availability of radio resources in the target BS, This can be achieved by reserving network resources to handover and given higher priority to handover session over new session. This makes dropping probability low but might increase blocking probability for new calls and sessions. This reservations and prioritization of handover session over new session consumes radio resources and causes lower spectral efficiency [22].

2.7.5 Power Management

In Mobile WiMAX, handover and battery life are two critical issues. Two modes for power efficient operation are supported: Sleep Mode and Idle Mode. The MS conducts pre-negotiated phases of absence from the Serving BS air interface in Sleep Mode state. These phases characterises unavailability of the MS, as observed from Serving BS, to DL or UL traffic. On the order hand, idle Mode provides mechanisms for MS to become periodically available for DL broadcast traffic messaging without authorized connection at a particular BS as the MS moves across multiple base stations [23].

2.7.6 Handover Management

Handover management is the adequate management of handover initiation, handover decision or preparation and handover execution at layer 1, layer 2 and layer 3 so as to minimize handover latency, packet loss and service disruption time. Handover can also involve be initiated in application layer using SIP (session initiation protocol) mobility. The next chapter looks at handover in full detail

3 HANDOVER IN MOBILE WIMAX

3.1 Introduction

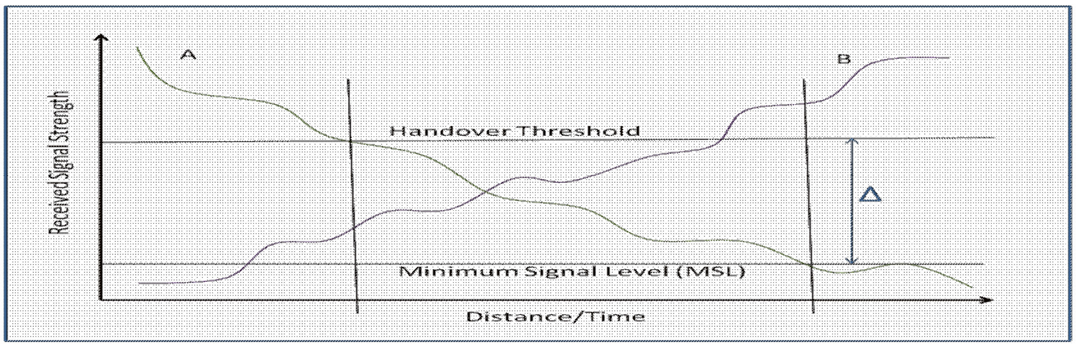
When is handover necessary? Ideally, handover (HO) becomes necessary due to external conditions like signal degradation, network congestion, discovery of a cheaper network, discovery of higher bandwidth network, or better energy efficiency. Seamless handover can be achieved by: periodic network monitoring, quick neighbour discovery, faster network selection, on-time link even triggers, proper connection setup and constant route update by the BSs and MSs. Handover can be classified as either horizontal or homogenous (within single network of same technology) and vertical or heterogeneous (across different network technology). A dual band multimode WiMAX-WiFi MS terminal should be capable of a seamless handover of application sessions when in the coverage area of a WiFi access point, if authorized, to reduce cost and save battery life. Proper frequency planning and cell overlapping is necessary for efficient handover [24].

3.2 Homogenous Handover

Handover in WiMAX network has more stringent real-time performance requirements. This is because VoIP and real-time multimedia sessions like video conferencing needs seamless handover without noticeable delay and packet loss [25]. For these applications to be supported in mobile WiMAX at full mobility of 120km/h, the delay should be less than 0.05 seconds (50msec) while the packet loss should be less than 1% [5].

Traditionally, handover usually involves three phases namely: *Initiation*, *Decision* and *Execution* [26]. In mobile WiMAX as well as other 3G cellular network handover procedure requires support from layer 1, layer 2 and layer 3 of the wireless network. The ultimate decision and final execution is done by layer 3. In the *initiation* stage, the PHY layer provides the information based on signal quality depending on either RSSI (received signal strength indicator), or SINR.

In the *decision* or preparation stage, based on information from the PHY layer, the MAC layer provides the triggering through scanning for time and frequency synchronization and controlling the flow of MPDU for buffering in the air interface queue and redirection through the backbone. In the *execution* stage new bearer and control planes are established and either same IP address is maintained, if on the same subnet or domain, or changed if going to a different subnet using an efficient mobile IP protocol version e.g. MIPv6 [27] [28]. Figure 3.1 shows the link going down in base station A with possible switch to B after reaching the handover threshold set by the link going down factorΔ"[5] .



Source: IEEE International Journal of Computer Applications (0975 – 8887) Vol.25 – No.9, July 2011

Figure 3.1: Handover detection based on signal strength

Under rapid fading conditions there could be a back and forth handover occurrence known as the *ping-pong effect.* This can be avoided by building a *signal quality hysteresis* in the handover algorithm. This is done by setting a higher value to the handover threshold after a handover from A to B to avoid an unwanted immediate handover from B to back to A [29]. The BSs usually allocates time for each MS to monitor, measure the radio condition and check for new connection availability on all possible target BSs so that they will be aware of its dynamic nature. This process is called *scanning.* The allocated time is called *scanning interval.* The scanning interval is usually followed by a period of normal operation known as *interleaving interval* while the number of times a scanning event should occur is known as *scan iteration or scan events*[30]. The handover decision can come from the BS or from the MS. Assuming the decision coming from MS, to initiate scanning, the MS sends a scan request message „MOB-SCN_REQ" to the serving BS which responds with a „MOB-SCN_RSP" message containing the scanning interval, interleaving interval and the scan iteration. Figure 3.2 illustrates the handover procedures. In other to avoid the number of times these messages are sent, the BS can direct the MS to perform multiple scan events. Channel scanning then takes over with different association levels [30]:

- Association level 0 (scan/association without coordination)
- Association level 1 (Scan/Association with coordination)
- Association level 2 (Network assisted association reporting)

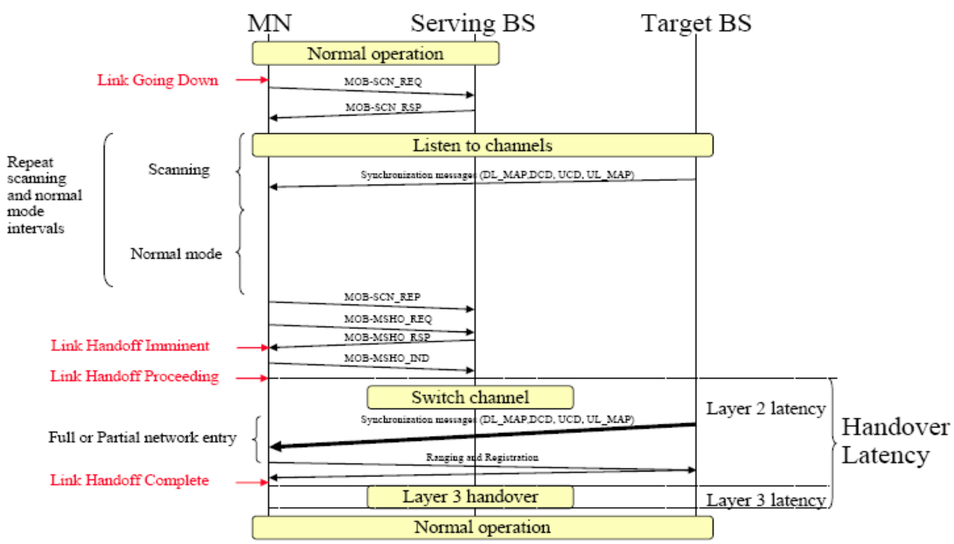


Figure 3.2: Layer 2 and layer 3 handover process [31]

The layer 2 handover procedure in IEEE802.16e-2005 standard [32] is stated below:

- **Cell reselection:** This refers to the process of an MS scanning with or associating with one or more BS in other to determine their suitability as a handover target. Neighbour BS information acquired from a decoded MOB_NBR-ADV message may be used by the MS to schedule scanning intervals.
- **Handover decision and initiation:** this process begins with the decision of the MS to change its connection from a serving BS to a target BS. This decision may originate either from the MS or from the BS. For MS initiated handover (HO) a MOB_MSHO-REQ (mobile MS initiated HO request) message is sent to the BS while indicating one or more BS as potential target BS. The BS then send a MOB_MSHO-RSP (mobile MS initiated HO

response) message to the MS indicating the considered target BS based on their signal strengths. If HO is mandatory, the MS sends a MOB_MSHO-IND (mobile MS initiated HO indication) indicating which of the BSs indicated in MOB_MSHO-RSP will be used for handover, else it will send a HO reject in the MOB_MSHO-IND message.

- **Synchronization to a target BS downlink:** This stage can be shortened if the BS has previously received a MOB_NBR-ADV (MAC management) message including a target BSID (BS identification), physical frequency, DCD (DL channel descriptor) and UCD (UL channel descriptor), and DL-MAP and UL-MAP through the backbone. The MS begins by processing the DL frame preamble of the target BS; this provides the MS with time and frequency synchronization with the target BS. The MS then decodes the UCD, DCD, DL-MAP and UL-MAP messages to get information about the ranging channel.

- **Ranging with target BS and network re-entry:** the MS and the BS must conduct handover ranging to synchronize its UL transmission with the BS and get information about initial timing advance and power levels. This is similar with the initial network entry process. This is followed by negotiating basic capabilities, authentication using key management and encryption. Network re-entry may be shortened if the target BS possesses the MS information obtained through the backbone from the serving BS. The target BS can also request this information if absent.

- **Termination of context with previous BS:** This is the final stage of the handover process. After connection has been established with the target BS, the MS may decide to terminate his connection with the serving BS by sending a MOB_HO-IND message to the BS. When this message is received, the BS starts the *resource-retain timer* keeping all the MAC state machines and buffered MPDU associated with the MS until the expiry of this timer. Once the resource retain timer expires, the BS discards all the MAC state machines and MPDU of the MS completing the handover process.

Handover types in mobile WiMAX can also be classified as hard handover (HHO) and soft handover (SHO). Homogenous handover in mobile WiMAX can further be classified as Intra-ASN (access service network), Intra-CSN (connectivity service network), or Inter-CSN handover. The sections below take a look at these handover types. Figure 3.3 illustrates the HHO and SHO types explained in [5].

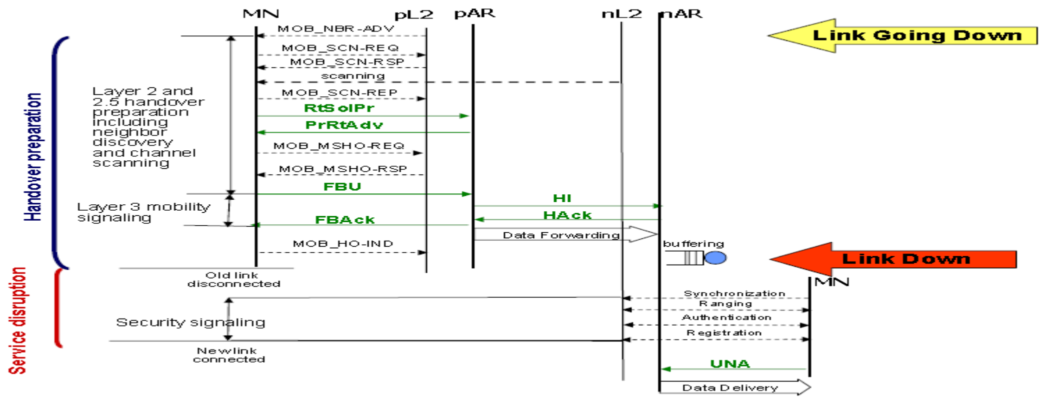


Figure 3.3: Horizontal handover signal and data flow [33]

3.2.1 Hard Handover

Hard handover is mandatory in the IEEE802.16e-2005 standard and is the only type required to be implemented in mobile WiMAX. It involves a *break-before-make* in which the MS only initiates a handover to a target BS when the link has gone down with the serving BS. This HO type will experience more latency and packet loss due to the fact that new CIDs and SFIDs would not have been setup on-time before handover.

3.2.2 Soft Handover

Soft handover involves a *make-before-break* in which new CIDs and SFIDs would have been created before connection is transferred to the target BS from serving BS. This HO is optional in the IEEE802.16e-2005 standard. It is of two types: fast base station switching (FBSS) and micro diversity handover (MDHO) [32]. These two methods involve the MS maintaining a valid connection simultaneously with more than one BS. FBSS and MDHO offer a greater performance to HHO. These HO type are further explained in the next subsection that follows.

3.2.2.1 Fast Base Station Switching

In FBSS, the MS maintains a list of BSs involved called the active *set.* This active set is continuously monitored by the MS while performing ranging and maintains a valid CID with each of them. The MS communicates with only one BS at a time called the *anchor BS* which often acts as the controlling entity for DL and UL allocations. When a change of anchor is required, the connection is switched from one BS to another without performing handover signalling. The selected anchor BS is reported by the MS on the channel quality indicator channel (CQICH) [20]. Figure 3.4 illustrates this process.

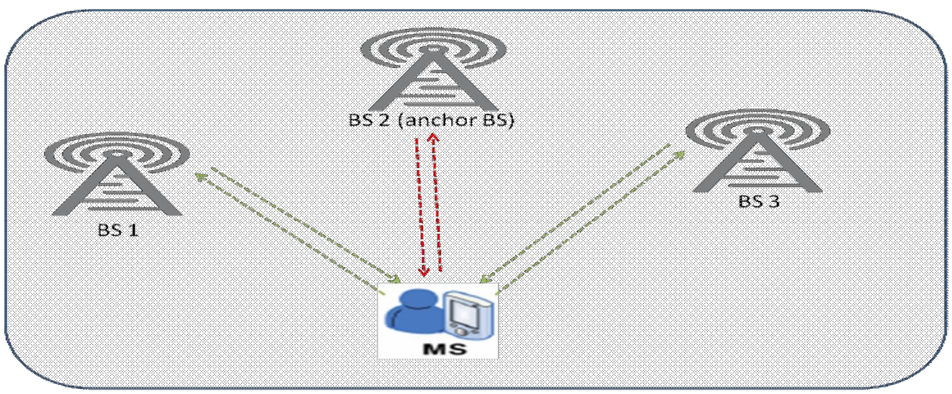


Figure 3.4: FBSS Handover process

3.2.2.2 Micro Diversity handover

This HO type is somewhat similar with FBSS except that the MS communicates simultaneously in the UL and DL channel with all the BSs in its own set of BSs called the *diversity set,* see Figure 3.5. Multiple copies of MPDU received by the MS in the DL are pooled together using a familiar micro-diversity combining techniques which includes *spatial demultiplexing*, *Beamforming* and *channel estimations* [14]. In UL where MS sends MPDU to multiple BSs, selection diversity is carried out to pick the best UL.

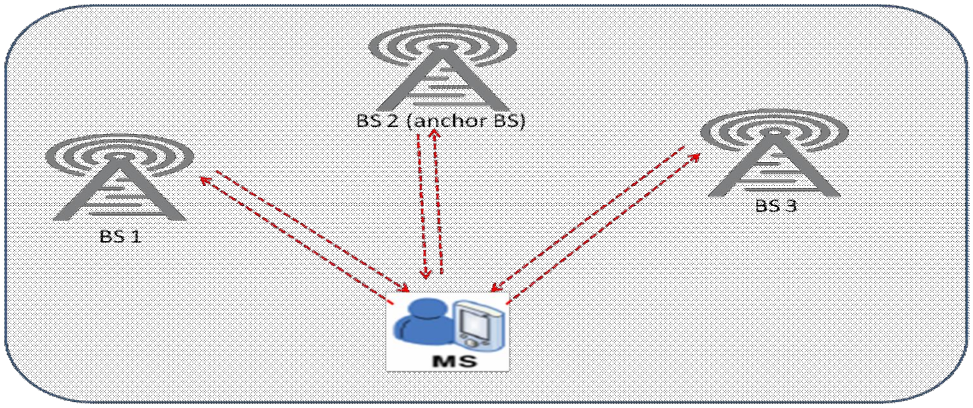


Figure 3.5: MDHO Handover process

There are two modes in which an MS involved in MDHO can monitor its DL and UL allocations: The first mode involves the MS monitoring only the DL-MAP and UL-MAP of the anchor BS which provides the DL and UL allocations of the MS for the anchor BS as well as the entire non anchor BSs. In the second mode the MS monitors the DL-MAP and UL-MAP of all the BSs in the diversity set separately for the DL and UL allocations, respectively. Figure 3.6 shows the combination of the DL signals from all the BSs in the diversity set before being decoded by the FEC stage. The combination of the signals from all the BSs in the diversity set is not mentioned in the MDHO standard. However, the most efficient way to combine the signals from different BSs would require the MS to demodulate them independently and then combine them at the baseband level before the FEC decoder stage [34] [5].

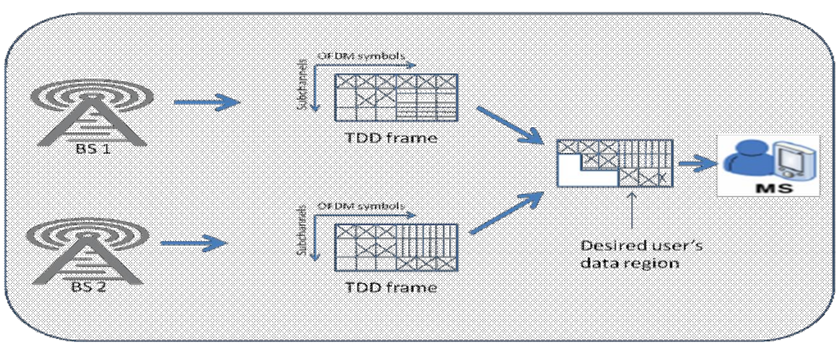


Figure 3.6: DL MDHO: Combining

Similarly in the UL each BS separately decodes the FEC blocks from the MS and forwards the decoded packet to the anchor BS which selects the copy that was received without errors. This process is very similar to the SHO mechanism in current CDMA systems. See Figure 3.7.

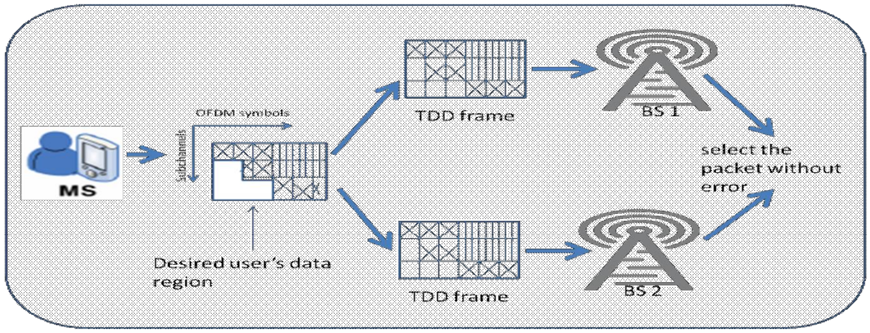


Figure 3.7: UL MDHO: Selection

Figure 3.8 shows the different handover scenarios from an architectural perspective. These can be classified as:

- Intra-ASN handover
- Intra-CSN handover
- Inter-CSN handover

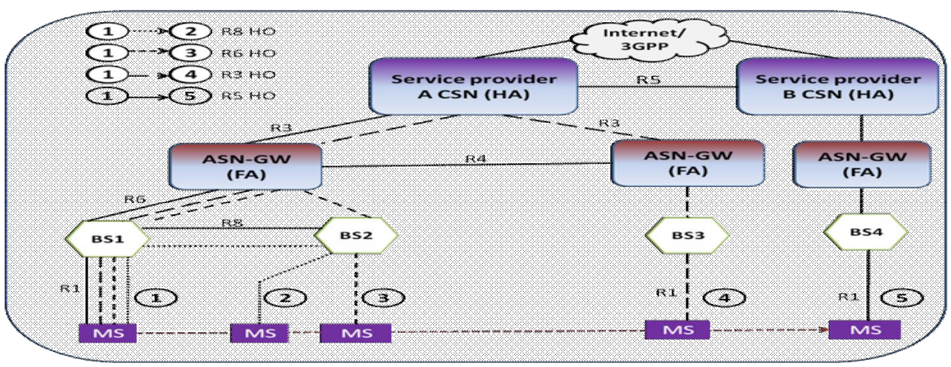


Figure 3.8: Architectural perspective of handover procedures

(A) Intra-ASN Handover

This handover type also known as micromobility or ASN anchored handover involves the MS moving between two data paths while maintaining same anchor foreign agent at the northbound edge of the ASN network. This occurs in the reference points as shown in Figure 3.9 in which R6 is used for migration while R8 is used for transferring undelivered MAC PDU after handover. It is also possible to keep the layer 3 connection to the same (anchor BS) through the handover and have data packet move from the anchor to the serving BS throughout the session[30].

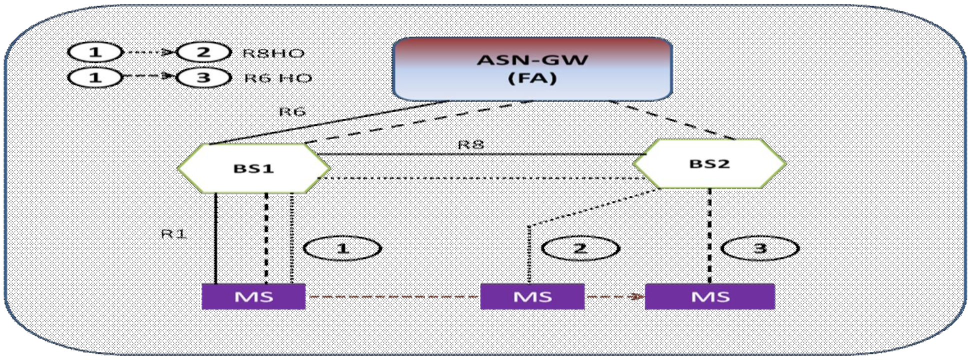


Figure 3.9: Intra ASN handover

Three functions are involved in Intra-ASN handover and are defined in WiMAX standard. This functions are known as: (1) *data path function* (2) *handover function* and (3) *context function* [5].

- **Data path function (DPF):** This function is in charge of the setup and management of bearer paths or tunnels essential for MPDU transmissions between BSs and ASN-GWs involved during handover to ensure low handover delay. There are four DPF defined in WiMAX: (a) *anchor DPF,* which is at one end of the data path that anchors the data path associated with the MS across handover; (b) *serving DPF,* which is the one associated with the BS that currently has the IEEE802.16e link to the MS; (c) *target DPF*, which is the one that has been chosen as the target for the handover; and (d) *relaying DPF*, which arbitrate between anchor, serving and target DPF in delivering the information.
- **Handover function:** This function sees to all decisions and signalling procedures associated with handovers. This function supports both MS and network initiated handovers including FBSS and MDHO. Handover functions are also distributed among many entities, i.e.: *serving handover function*, *target handover function* and *relaying handover functions*: the serving HO function controls the decision and signalling procedures, signalling the target HO to prepare for handover and informing the MS. Signalling between the serving and target HO function may be through the relay function. The content of HO messages maybe modified by the relay HO function.

- **Context Function:** This function is responsible for exchanging state information among the network elements affected by handover. During a handover execution, there might be network or MS related information"s that needs to be exchanged, updated or transferred between these entities. I.e. the target BS needs to have an update of the security context of the MS before being registered to it. The context function is implemented using a client/server model. The *context server* keeps the updated session context information while the *context client* retrieves it during handover. A relaying context function could occur between the server and the client. Some of this information exchanged between the context server and client include: CID, SFID, MS network access identifier, MS MAC address, anchor ASN-GW associated with the MS, HA IP address, CoA, DHCP server, AAA server and other security information, and MIP [15] [5].

(B) Intra-CSN Handover

This is also known as inter-ASN handover or micro-mobility which occurs within the network of a service provider designated as „A" in Figure 3.10. In this scenario the MS changes to a new anchor foreign agent (FA) in the ASG-GW and the new FA and CSN exchange signaling messages to establish the MPDU paths. This HO type happens across R3 with undelivered MPDU tunneled over R4.

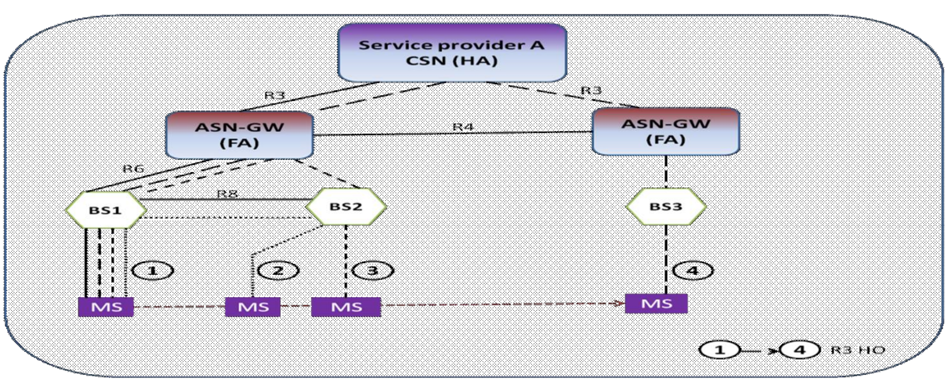


Figure 3.10: Intra CSN handover

Intra CSN handover requires mobility across different subnets or domain which means a change in IP address. This implies mobility using MIPv4 or MIPv6 in the R3 reference point. MIPv4 in

Intra-CSN handover involves two types of MIP implementations: (1) MIP-enabled client at the MS, which is based on the IETF mobile IP standard (RFC 3334), involves getting a CoA from an FA within the ASN. While moving across the FA boundaries, the client becomes aware of the movements through agent advertisements, does a MIP registration with the new FA and gets a new CoA from it. (2) Proxy MIP in the network involves implementing MN in the ASN on behalf of the MS. With Proxy MIP there is no IP address change when the MS traverse the subnets of BSs. The functional entity in the network that runs proxy MIP instances on behalf these clients is called the *proxy MIP mobility manager*. For MIPv6 in Intra CSN handover, client MIPv6 (CMIPv6) is supported. The support for route optimization and absence of FA in IPv6 implies that the CMIPv6 operates using a *collocated CoA* (CCoA), which is typically obtained by the MS using stateless auto-configuration (RFC 2462) or DHCPv6 (RFC 3315). The CCoA is communicated to the HA through a binding update (BU), and also to the corresponding node (CN). Intra-CSN handover through the R3 reference point is initiated by the network and may be triggered by an MS mobility event, by an MS waking up from idle mode, or by a network resource optimization need [27] [35].

(C) Inter-CSN Handover

This scenario is technically supported by mobility management and involves two CSN belonging to different service providers. It is known as *roaming* based on agreement between the service providers involved. It involves a MS leaving his home network service provider (NSP) A and entering a visited NSP B due to his home network not having a coverage area in the visited location see Figure 3.11. All calls or sessions destined to the MS is routed (through the R5 reference point) to the visited network through the home network [5].

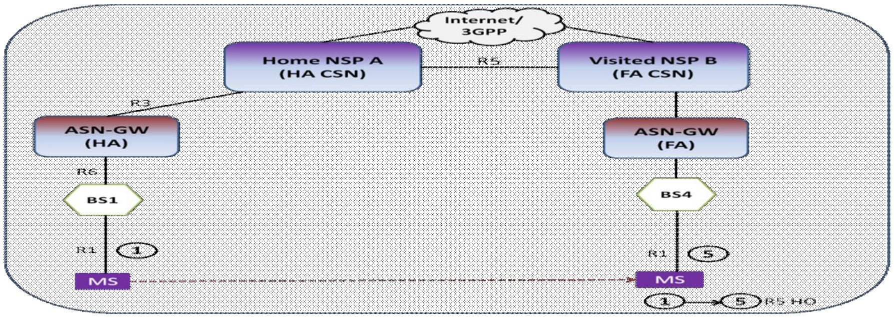


Figure 3.11: Inter CSN handover

3.3 Heterogeneous Handover

Heterogeneous or vertical handover occurs between two or three mobile network with different technologies, standards and protocols. This could be between WiMAX and WiFi networks, between WiMAX and UMTS, between UMTS and WiFi or between WiMAX and UMTS. The handover in these networks should have an interworking mechanism for operating between the different technologies, standards and protocols especially in layer 1 and layer 2. For layer 3 an all IP network with MIPv6 will be most appropriate because of its numerous advantages and can leverage the different interface technologies involved using a stateless auto configuration or a DHCPv6 server in the network [28] [36]. For a vertical handover between WiMAX and WiFi the MS should operate in dual band multimode (MM) with 802.11 and 802.16 interfaces switching when in the coverage area of a WiFi access point (AP) or WiMAX BS. See Figure 3.12. An adaptive schemes has been proposed by [37] [38] to optimize heterogeneous handover.

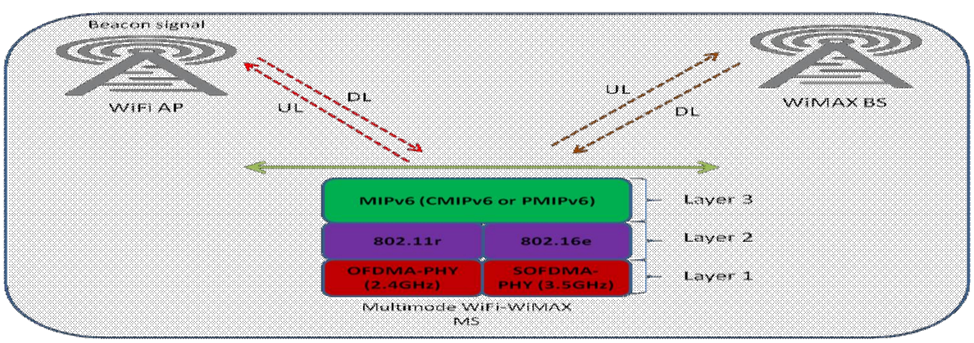


Figure 3.12: Heterogeneous HO with of MM terminal

The IEEE 802.21 media independent handover (MIH) working group is collaborating with the IEEE 802.16e, IEEE 802.11r, as well as the Internet Engineering Task Force (IETF) working group to accomplish Heterogeneous handover. Figure 3.13 this illustrates these standards.

Figure 3.13: Handover standards for the IEEE802.21 MIH project [39]

The architecture of MIH as proposed by IEEE802.21 is given in Figure 3.14. It is based on an intelligent *media independent handover function* (*MIHF)* abstraction layer that interworks access networks with different link-layer technologies. This MIHF interacts with upper application layer via connections and handover policies, based on mobility and handover management protocols. On the lower layer, it interacts with multimode devices, depending on the point of attachment (PoA) and point of service (PoS), by responding to layer 2 trigger events and communicates handover messages through the information services from the 802.21 information server. The MIHF runs in the MM terminal as well as the BSs and APs and helps applications to adjust to changing network conditions while abstracting so as to achieve ubiquitous seamless connection to different network technologies. In the NIST NS-2 model, the MIHF is implemented as an agent that sends layer 3 packets to remote MIHF in the MM terminals. A MM MIH user makes use of this MIHF functionality to enhance performance thereby optimizing handover. [39] [40].

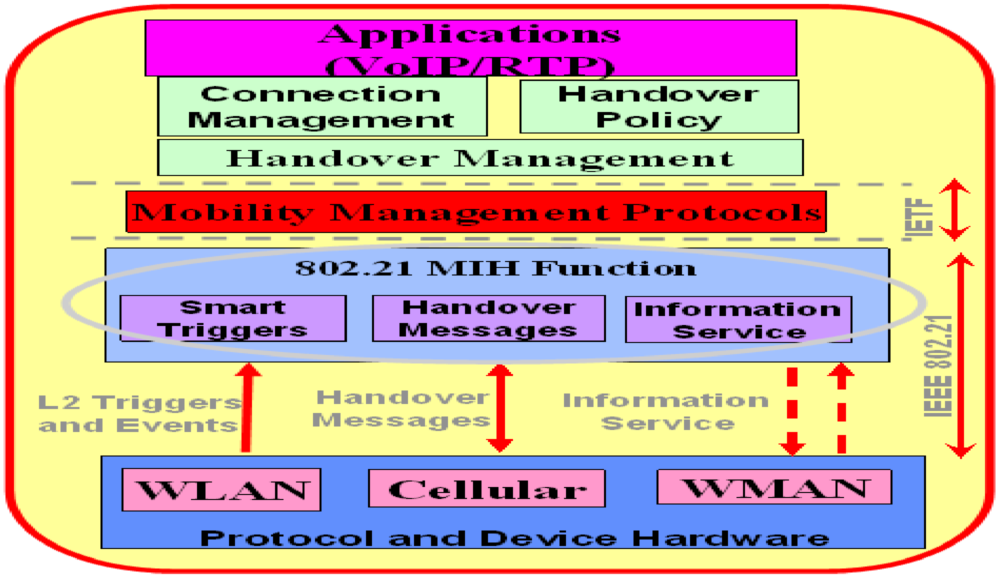


Figure 3.14: The IEEE 802.21 MIH functional architecture [39]

In the work of [33], achieving seamless vertical or horizontal handover with very low service disruption time can be achieved by implementing cross-layer mobility management mechanism. This involves cross-layer settings and timely configuration of link triggers. The mechanism involves four layered network architecture as shown in Figure 3.15. The network layer uses FMIPv6 for faster network discovery, faster IP address acquisition and faster binding update (FBU). The handover decision engine takes care of handover parameter configuration, required handover time estimation and handover decisions. The PHY/MAC layer is responsible for link measurement, and link going down trigger for vertical or horizontal handover execution. These mechanisms are all managed by the signalling and control of the MIHF kernel using network layer information and link events from the lower MAC and PHY layers.

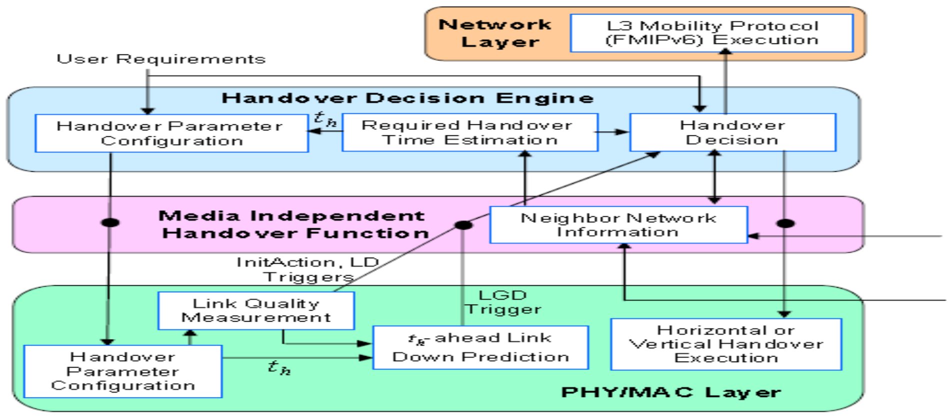


Figure 3.15: Predictive cross-layer mobility architecture

For a vertical handover from WiMAX to WiFi coverage are, The MIHF enabled WiFi interface of the MM MS terminal picks up a beacon signal (containing MIHF negotiation capabilities) sent at periodic (100 msec) interval by a WiFi access point on entering the AP coverage area. This beacon signal is used for movement detection and for synchronization with WiFi interfaces. On receiving this beacon signal the MM terminal send a request-to-send (RTS) message to the AP. The AP receives it and sends a clear-to-send (CTS) message back to the MM terminal. The 802.11 interface then sends association request, and upon being accepted, receives an associated response from the AP. After the various acknowledgements (ACK), the MM terminal obtains IP address and gets a binding update through the help of the 802.21 information server on the core network. Afterwards, the normal interface switching, handover and packet redirections then takes place ending the vertical handover. An interface manager (IFMNGMT) in the IEEE 802.21 information server provides flow management functions. See Figure 3.16. In the NIST mobility module, users can register the flow that is being used in the node thereby facilitating the handover module in finding the flows that need to be redirected. Also it receives actions from the neighbour discovery (ND) agent when a new network prefix is detected or expires. The MIPv6 agent adds the redirection capability to the MIH user. In redirecting a flow, a message can be sent to the source node informing it of the new address or interface to use. The handover class then provides a template for handover modules making available a new address when the handover is successful. Virtual nodes, in the MM terminal, link nodes of similar or different technologies. Layer 3 movement detection is possible due to the ND (neighbour discovery) agent residing in each node. New and expired prefix are usually sent to the IFMNGMT [41].

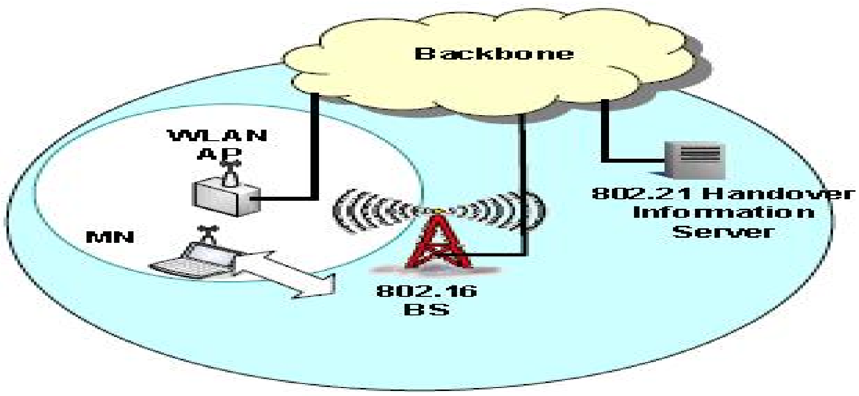


Figure 3.16: Heterogeneous HO between WiFi and WiMAX network

The interworking of a WiFi and WiMAX interface during vertical handover is shown in handover flow diagram of Figure 17 (a), (b) and (c) [42]. It involves a multimode terminal with initial point of attachment (PoA) and point of service (PoS) of its WiFi interface on a WiFi access point. At this point the WiMAX interface is in sleep mode to conserve power. Due to low signal, network congestion, or cheaper network the WiMAX interface on the MM terminal wakes up and scans for better network (WiMAX BS) checking resource availability. See Figure 3.17 (a).

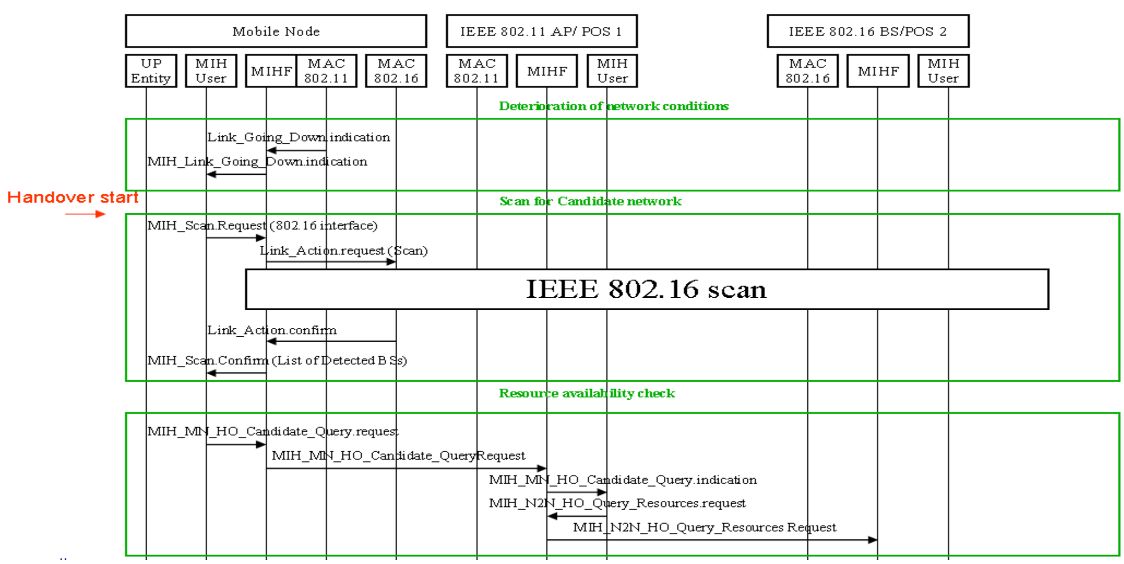


Figure 3.17: (a) MIH start

After discovery of a stronger and cheaper link with authenticatication and authorization based on the MIHF algorithm running on both the MM terminal and the BS, a handover request is made to the BS. See Figure 3.17 (b). When a response is granted, a vertical handover is then executed with traffic redirection and the WiFi interface on the MM terminal goes into sleep mode, which ends the vertical handover process. See Figure 3.17 (c).

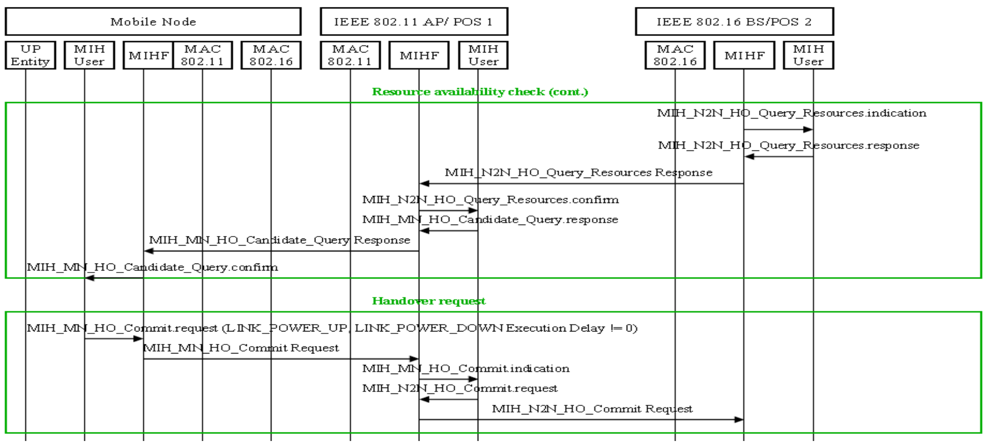


Figure 3.17 (b) : MIH continued

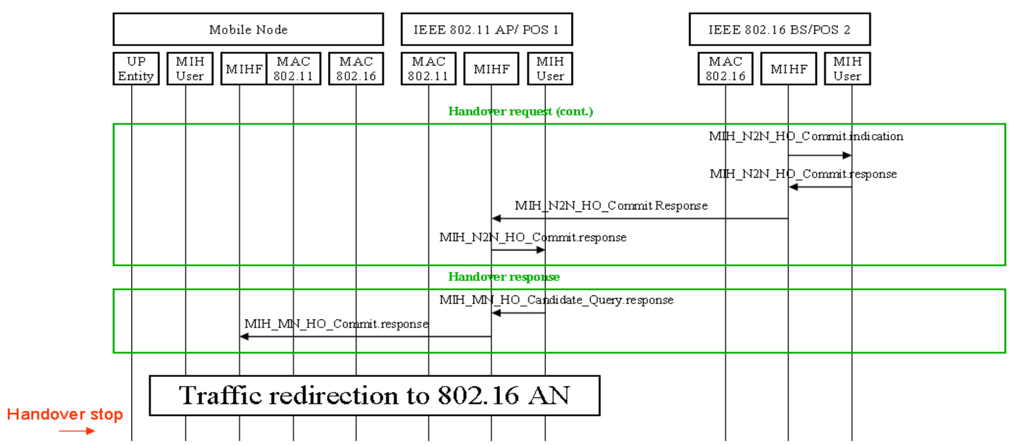


Figure 3.17: (c) MIH end

Figure 3.17: Interworking and HO flow in 802.16e and 802.11r networks

Instead of using the conventional RSSI for layer 2 triggering which may cause too late or too early handover execution, a *predictive link triggering mechanism* using least mean square (LMS) linear prediction for proper handover decision and execution has been proposed by [43] for seamless handover in heterogeneous and homogeneous networks. This uses neighbour network information to generate a timely link triggers so that required handover procedures can properly finish before the current link goes down [44]. Figure 3.18 shows the concept with a receive power versus time for measured and predicted sample while Figure 3.19 (a) and (b) shows the simulation result of the predictive mechanism during a vertical handover between a WiMAX and WiFi network.

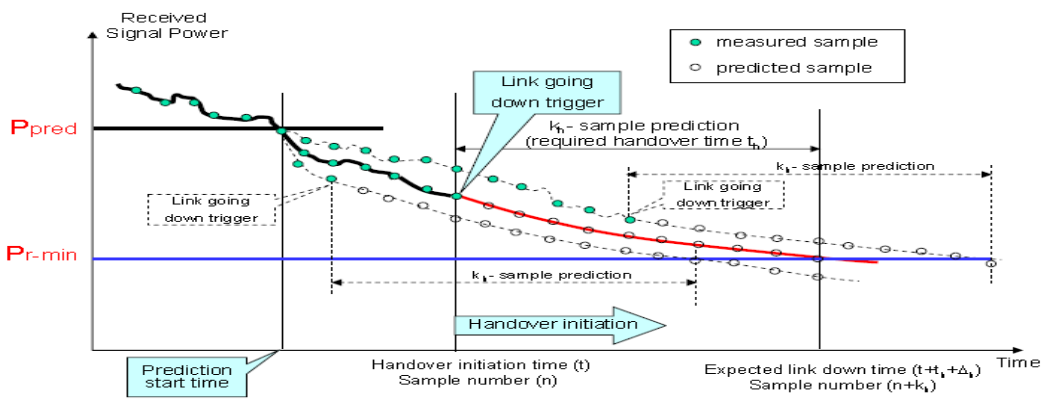
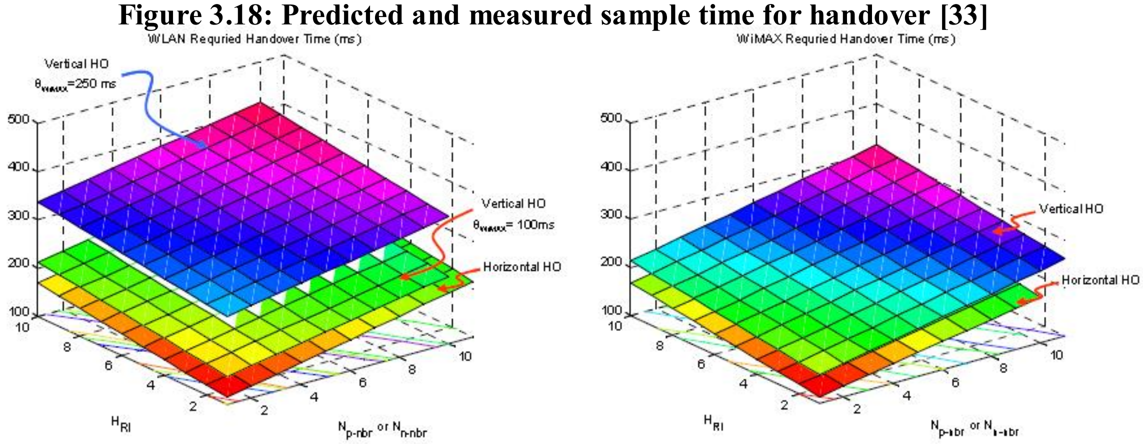


Figure 3.18: Predicted and measured sample time for handover [33]



(a) WiFi **(b) WiMAX Figure**

3.19: Predicted HO time results for WiFi and WiMAX network [43]

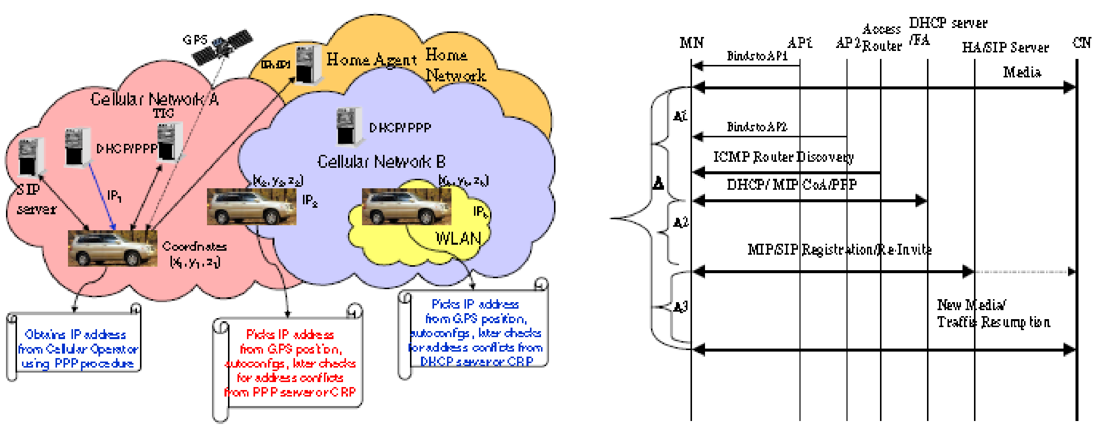
3.4 Handover Optimization Mechanisms

3.4.1 GPS-based Handover

GPS-based handover was proposed by [45] and [21]. It is more like using layer 7 SIP protocol to reduce handover latency in layer 2 and layer 3. It is based on using GPS coordinates of a MS to achieve fast IP address discovery on a high vehicular speed. It involves registering with a SIP (session initiation protocol) server for location management and update and being assigned a globally routable IP address almost instantly based on the GPS (X, Y, Z) coordinate on the entry of a new subnet. See Figure 3.20. This proposal breaks down handover latency into Δ1, Δ2 and Δ3 such that

$$\Delta = \Delta 1 + \Delta 2 + \Delta 3 \qquad 3.1$$

Where Δ is the total latency, Δ1 is layer 2 latency, Δ2 is IP address acquisition and configuration latency and Δ3 is latency due to registration and media redirection. The implementation on the proposed test bed reduced the Δ2 and Δ3 latency.



(a) Architecture (b) Flow diagram

Figure 3.20: GPS-IP based handover

3.4.2 Smoothening Prediction and Trend Analysis of Signal

In the work of [46], a mechanism of smoothening of signal using exponential averaging, straight lining of signal for predictions and fast Fourier transform for trend analysis has been proposed for optimizing handover between WiMAX and WiFi. Figure 3.21 below illustrates this proposal.

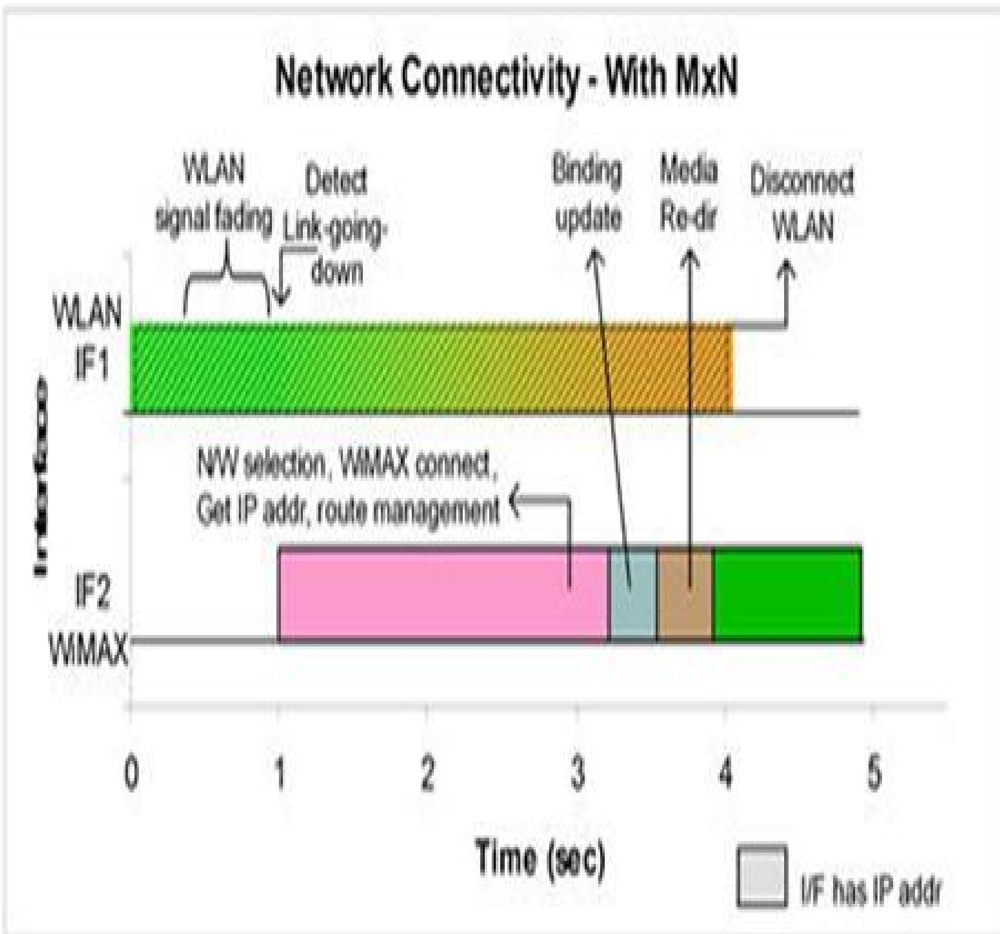
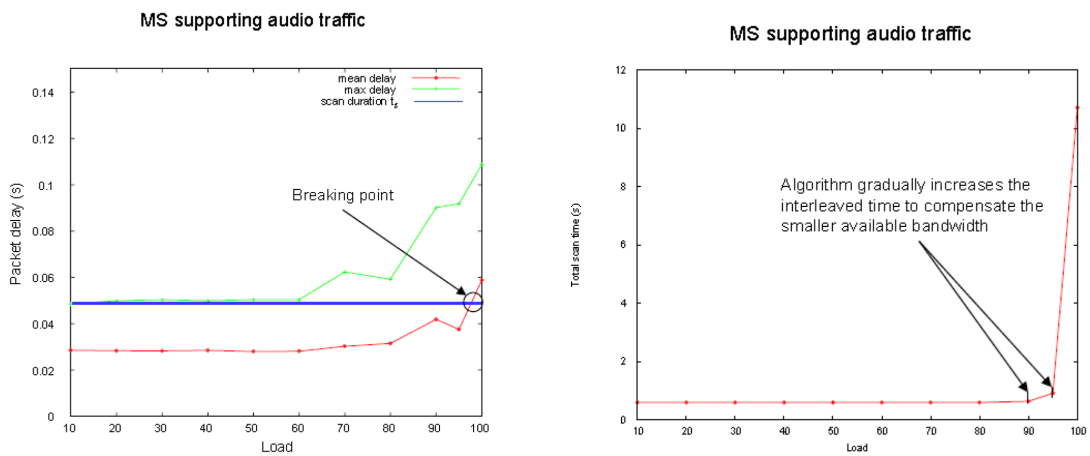


Figure 3.21: vertical handover with predictive trigger timing [46]

3.4.3 Adaptive Channel Scanning

Adaptive channel scanning algorithm is proposed by [47] for reducing overall channel scanning time thereby reducing handover latency. It is based on the IEEE 802.16e specification of performing channel scanning while keeping current connection by interleaving of channel scanning and transmission intervals. This algorithm is based on the assumption that neighbouring BSs exchange information in the backbone and the messages should be extended to fit the information required by the algorithm. The ACS algorithm uses configuration information shared by the BSs to estimate the scanning time required by a MS. Figure 3.22 (a) and (b) shows the simulation result of the algorithm.



(a) Packet delay with a single MS

(b) Total scanning time with single MS

Figure 3.22: Adaptive channel scanning algorithm simulation output [47]

3.4.4 Integration of layer 2 and layer 3 Handover

In [48] a two design cross layering approach was used by interleaving the handover procedure in layer 2 and layer 3, while the concept of Last Packet Marking (LPM) was proposed by [49]. In both approaches, the handover procedures of 802.16e and mobile IPv6 (MIPv6) are reconstructed to achieve a better transmission performance. This idea is adopted to refine the existing handover procedures specified in 802.16e-2005 MAC layer and MIPv6. Two things were involved for the cross layer design in their approach. First, the handover procedures of layer 3 were interleaved with that of layer 2 synchronizing the process of both layers. Secondly, the handover performance was improved through the integrated design. In addition to studying the handover latency affected by the frame duration of 802.16e and connection dropping rate caused by handover, the proposed scheme was compared with a scheme proposed in IETF draft. The simulation results show that their scheme is superior to the compared scheme. See Figure 3.23.

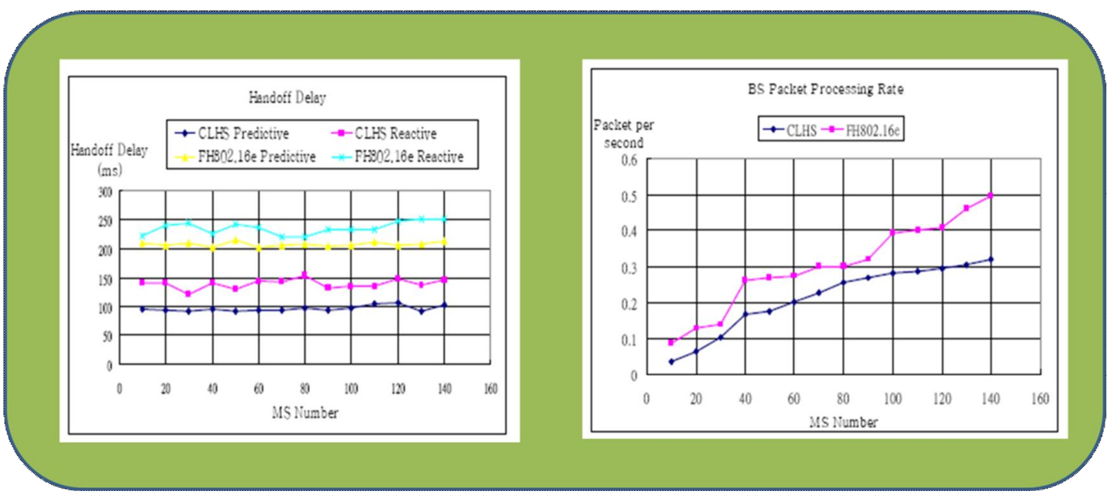


Figure 3.23: Proposed cross layer and standard scheme result [48]

Handover delay was minimized and packet losses eliminated during handover by integrating MAC and network layer handovers efficiently in the work of [50]. The results shows loss-free packet delivery without packet duplication and the system throughput significantly increased. Figure 3.24 shows the simulation results for throughput and packet sequence against simulation time on the proposed scheme and the standard hard HO scheme. The graph shows that the proposed scheme has a better performance compared to the standard scheme [51].

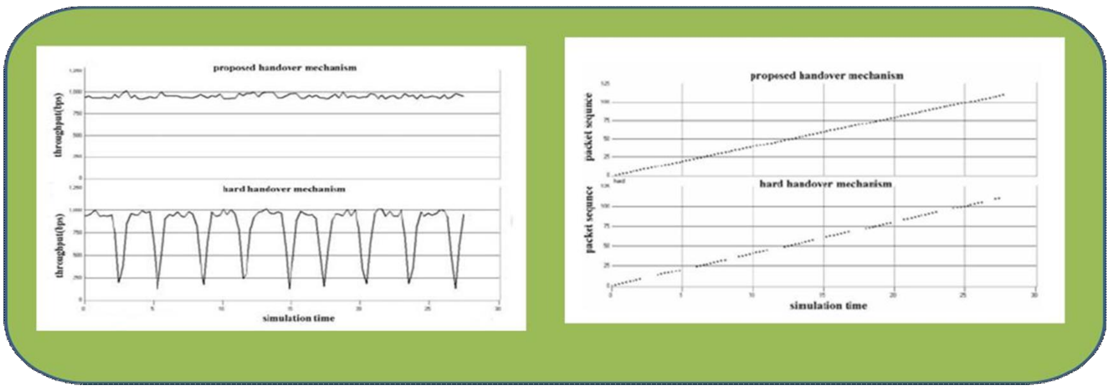


Figure 3.24: Results showing throughput versus time for the proposed solution [50]

3.4.5 Handover Decision based on Fussy Logic

In this research finding a fuzzy logic based handover decision is used to optimize handover in IEEE802.16e broadband wireless network [52]. It is based on three criteria:

- Geographical data
- Received power level, and
- Used bandwidth of each base station

Fuzzy Logic and Neural Networks will allow quick decision as a result of changing channel conditions in layer 1 and the QoS requirement in the layer 2 to harmonize with the IP functionalities in layer 3 for an efficient overall system performance during handover in WiMAX network. This concept has been proposed by [53], [9] and [54] promising to make handover decisions faster which will reduce delay and packet loss and also remove the ping pong effect in mobile WiMAX. See Figure 3.25. Since most handover optimization mechanisms outlined so far involves operations in the IEEE802.16e MAC layer, it then follows that handover performance in layer 3 will depend largely on the performance of the MAC layer.

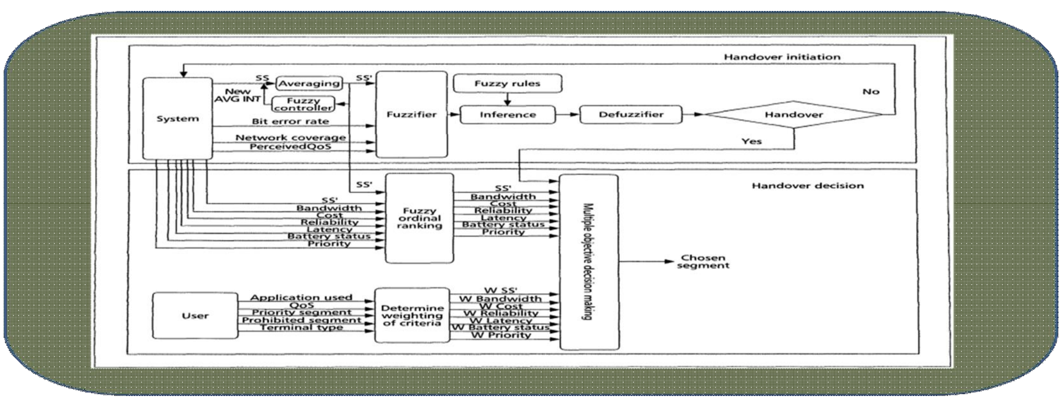


Figure 3.25: Block diagram of fuzzy logic concept in HO algorithm [54]

3.5 Handover Performance Metrics

Lots of performance metrics can be used in handover analysis but for the purpose of the NS-2 simulation in the next chapter, throughput, delay, jitter and packet loss will be considered. The performance metrics in the subsections that follows is based on [35] and [55].

3.5.1 Handover Throughput

This is the effective transmission rate based on system and channel conditions. In NS-2, system throughput (S_{TH}) is calculated as:

$$\mathbf{S_{TH}} = \frac{\times \text{ Packet sent or received (packet sequence number)}}{\text{Simulation time}} \qquad \mathbf{3.2}$$

Figure 3.26 shows a typical graph of throughput versus simulation time.

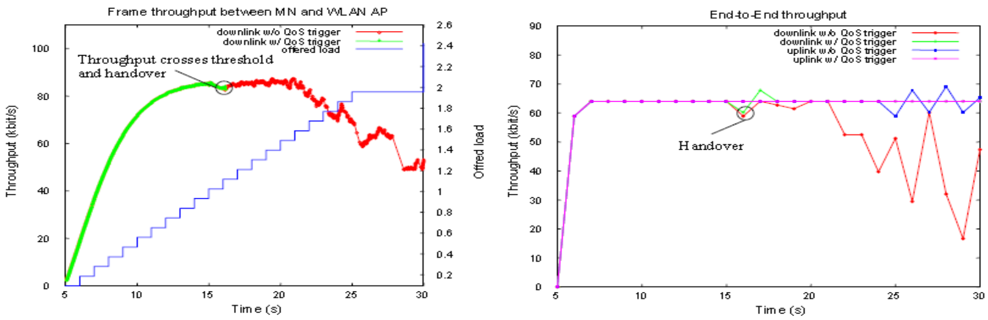


Figure 3.26: Handover and E2E throughput [33]

3.5.2 Handover Delay or Latency

The delays involved during handover are: (1) PHY layer latency; which is the time instant $T_{1,\,i}$ that a MS transmits to a serving BS its intention to HO and the time instant $T_{2,\,i}$ that the MS achieves the success of PHY layer synchronization (i.e. frequency and DL timing synchronization due to handover occurrence i (2) Network entry latency; which represents the delay between an MS"s PHY layer synchronization at $T_{2,\,i}$ and its completion of a MAC layer network entry procedure at $T_{3,\,i}$ due to HO occurrence i (3) and Connection setup latency; which represent the time for the completion of MAC layer network entry procedure at $T_{3,\,i}$ and the transmission of the first data packet at the target BS at $T_{4,\,i}$ due to HO occurrence i. These delays are given in (5a), (5b) and (5c) below [35].

Average PHY layer latency = $\frac{\sum_{i=1}^{N_{HO\,SS}} (T_{2,i} - T_{1,i})}{N_{HO\,SS}}$ **3.3a**

Average network entry latency = $\frac{\sum_{i=1}^{N_{HO\,SS}} (T_{3,i} - T_{2,i})}{N_{HO\,SS}}$ **3.3b**

Average Connection setup latency = $\frac{\sum_{i=1}^{N_{HO\,SS}} (T_{4,i} - T_{3,i})}{N_{HO\,SS}}$ **3.3c**

Where $N_{HO\_success}$ is the total number of successful HO during a simulation time or real life scenario. The delay for the simulation is on the MAC layer i.e. using (3.3b).

Figure 3.27 shows a graph of delay versus simulation time

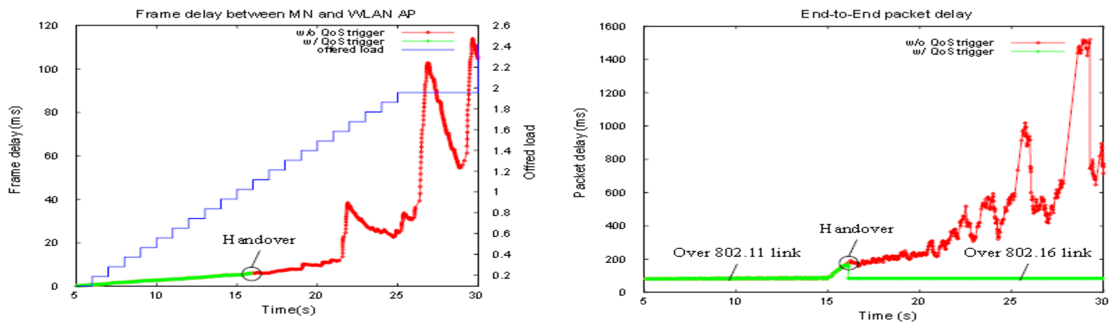


Figure 3.27: Handover and E2E delay [43]

3.5.3 Handover Jitter

Handover jitter is delay variation during handover period. If $S_{(i)}$ is the time a packet i is sent from the MS, and $R_{(i)}$ is the time it is received by the CN, then jitter is given as

$$\mathbf{Jitter_{(i)} = \{[R_{(i+1)}-S_{(i+1)}]-[R_{(i)}-S_{(i)}]\}} \qquad \mathbf{3.4}$$

Figure 3.28 shows a graph of handover jitter with respect to the simulation time.

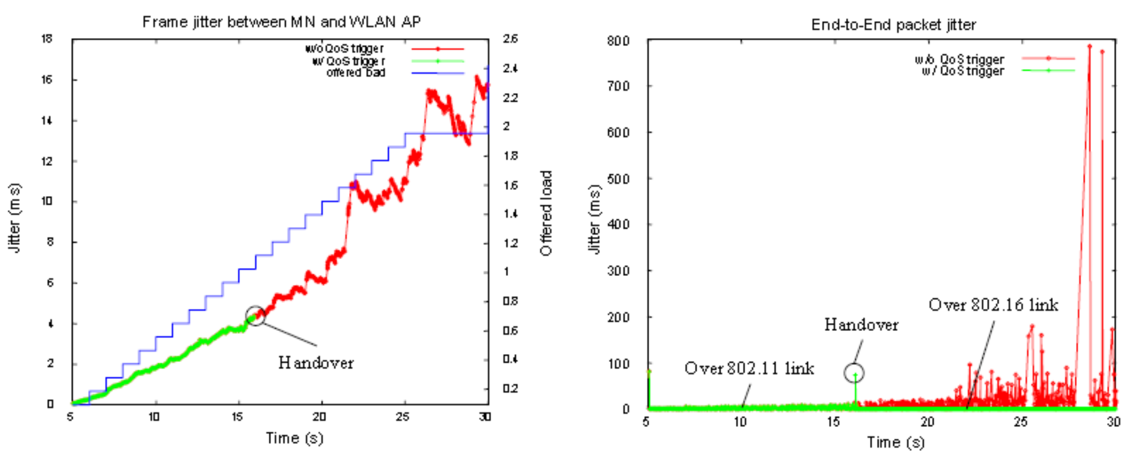


Figure 3.28: Handover and E2E jitter [43]

3.5.4 Packet loss

Packet or data loss represents the total number of dropped or lost packets during a HO process, If $D_{RX,i}$ and $D_{TX,i}$ represents the number of the received packets by the MS and the number of total packets transmitted by the serving and target BSs during the MS performing HO occurrence i respectively, then packet data loss is given as [35]. NS-2 uses sequence numbers for UDP packets for purpose of analysis. Packet loss is given as:

$$\text{Packet data loss} = \frac{\sum_{i=1}^{N_{HO\_success}} (D_{TX,i} - D_{RX,i})}{N_{HO\_success}} \qquad \textbf{3.5}$$

Table 3.1: Wimax applications class [35]

Class	Application	Bandwidth Guideline		Latency Guideline		Jitter Guideline	
1	Multiplayer Interactive Gaming	Low	50-85 kbps	Low	< 150 msec	Low	<100 msec
2	VoIP & Video Conference	Low	4-384 kbps	Low	< 150 msec	Low	<50 msec
3	Streaming Media	Low to High	5 kbps to 2 Mbps	N/A		Low	<100 msec
4	Web Browsing & Instant Messaging	Moderate	10 kbps to 2 Mbps	N/A		N/A	
5	Media Content Downloads	High	> 2 Mbps	N/A		N/A	

These performance metrics are going to be used for the analysis in chapter 5 at the end of the simulation in the next chapter. These analyses will be compared with the values in Table 3.1.

4 DESIGNS AND SIMULATION WITH NS-2

4.1 Introduction

In this section various handover scenarios will be designed and simulated. Voice, video and FTP data traffic applications will be modelled. A MS at a pedestrian speed of 5km/h, low vehicular speed of 60km/h, and high vehicular speed of 120km/h will communicate with a correspondence node in the CSN to test the performance of these scenarios using NS-2 simulator. A vertical handover scenario between a WiMAX and a WiFi network will also be designed and tested with this MS, at various speeds and trajectories within the same scenario. The simulation trace file will be analysed in the next chapter using MATLAB-based *Trace Graph* and Microsoft excel-for packet loss analysis. A brief introduction of the NS-2 simulator follows in the Section below.

4.2 The NS-2 Simulator

NS-2 is an open source discrete event simulation (DES) tool used for simulating wired or wireless networks with trace file analysis possible at the MAC layer, network layer or transport layer. NS-2 uses C++ standard or third party libraries as the backend simulator engine and OTcl (object oriented tool command language) as its front end interpreter. It was developed at University College, Berkeley and widely used worldwide for research-based network simulation purposes. Users create new Application Programme Interface (API) scripts which are instantiated within the front end interpreter, and are closely mirrored by a corresponding object in the compiled hierarchy (C++ source code) during the running of the programme. Upon the completion of the simulation, trace files that capture events occurring in the network are produced and analysed using in-built X-Graph or other external trace analyser tools like GNU plot or race graph. The inbuilt X-Graph tool has its limitations and is still under development. Although NS-2 is open source, which is why it is being used in this project, its installation and version is mostly tailored to a third party implemented module which the simulation is based on. Most times, it requires the debugging of the C++backend source code and modifications to suit a purpose and compiler platform. NS-2 runs on UNIX or Linux Operating System (OS) or, for a windows based system, on Cygwin which is a UNIX/Linux emulation shell that runs in windows OS [55]. Figure 4.1 shows the block diagram of the simulation process.

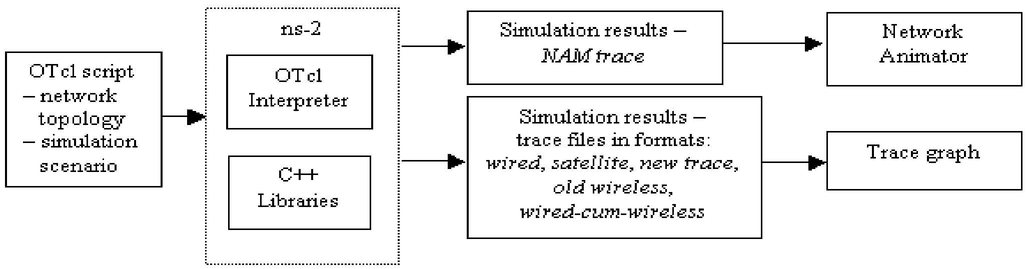


Figure 4.1: NS-2 block diagram [56]

4.3 Debugging of the NIST Mobile WiMAX Module

To run the NIST mobility module on Linux Fedora 9 OS, a total of nine C++ header files and seven C++ files in the ns-2.29 subfolder where debugged. A typical case was a double argument in the „static int interference" function with variable name *pktRx_start* which was erroneously declared twice. This function is in the interference.h file inside the subfolder „*interference*" which is in the ns-2.29 folder of the mobility module. This was corrected by declaring one of them as *pktInt_start* in the proper position of this „static int" function in line with the structure of the other functions where the value of this argument variable will usually be passed for proper two-way communication between these function. After this was done the error was corrected. Other corrections include removal of extra qualifications in some functions and moving some functions to the beginning of the C++ header files. For example the *void XmitFailureCallback* and the *void XmitFlowFailureCallback* functions in the dsragent.cc file were moved to the beginning of the file so that the objects that depend on these functions can always call them thereby masking loads of extra qualifications that would have been removed. Other files that where debugged with their path names in the ns-2.29 folder include: sctp/sctp.h; /mobile/god.h; mac-802_11.h; sscheduler.h; /diffusion/diffusion.h; /diffusion/omnicast.cc; /tcp/tcp-sack-rh.cc; /pgm/pgm-agent.cc; /pgm/pgm-sender.cc; /pgm/pgm-reciever.cc; ucbt-0.9.8.2a/Imp-link.h; bt-node.h; /tora/tora-bt.h; dsr-bt.h; and umts/rlc.h.

4.4 Handover Scenario Designs

The handover scenarios are designed with Power point. The MS traverses five BSs with different overlapping cell orientation scenarios: full cell overlap (FCO); half cell overlaps (HCO); no cell overlap (NCO), and finally a no cell overlap with a distance of 10 metres (10m-NCO). The MS will move at pedestrian speed (PS) of 5 km/h, low vehicular speed (LVS) of 60 km/h and then at a high vehicular speed (HVS) of 120km/h at these cell orientations. The subsection that follows illustrates these scenarios.

4.4.1 Scenario 1: Full Cell Overlap

The full cell overlap scenario, ideally, should give a cumulative high uniform receive signal strength and a high SINR from the cell centre of one BS to the other due to the proximity of the two BSs. This scenario at pedestrian speed serves as a baseline for comparison. It is meant to ensure minimum packet loss, less throughput drop, lower handover delay and jitter. This scenario automatically sets the lgd trigger higher, because of the closeness of the BSs, thereby making the handover threshold higher. Figure 4.2 shows the FCO scenario.

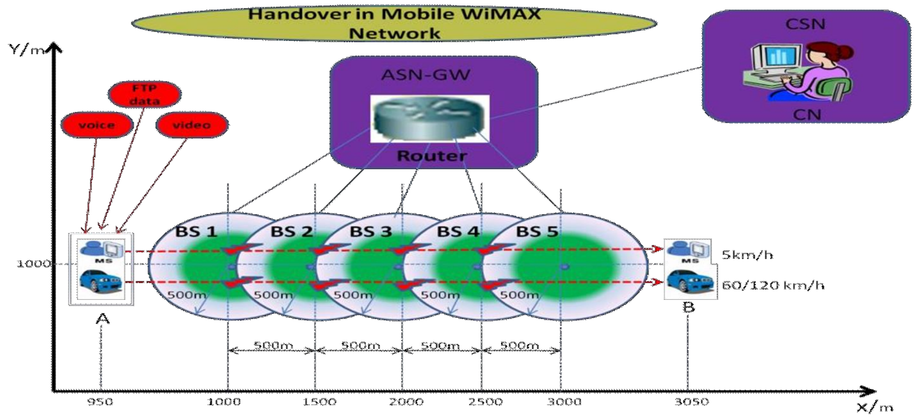


Figure 4.2: Full cell overlap

4.4.2 Scenario 2: Half Cell Overlap

The half cell overlap will automatically set the lgd trigger or threshold lower than that of the FCO. The number of MAC layer scan iteration will be less in this case and the MS will experience decreasing SINR at the cell edges. See Figure 4.3.

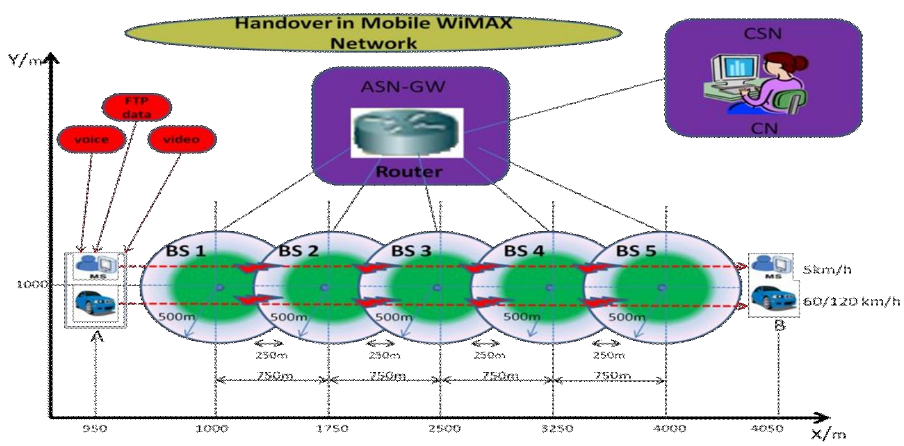


Figure 4.3: Half cell overlap

4.4.3 Scenario 3: No Cell Overlap with Zero Distance

This scenario will test the effect of having the coverage areas not overlapping with each other. This is possible in real network deployment due to the inability to site a BS at the appropriate location after frequency planning owing to logistics of immovable utility infrastructures like power substations or road networks. The MS will experience a longer time in the cell edge in pedestrian speed with more interference and decreased SINR. Half way between any two BSs at pedestrian speed, the power level of the received packets at the CN might be severely degraded due to interference on the packet sent by the MS. The MAC layer of the MS will scan for a longer time causing packet loss at pedestrian speed. This will also cause the RSSI from the target BS to be low due to none overlapping of the cell edges where the SINR is very low. Figure 4.4 illustrate this scenario.

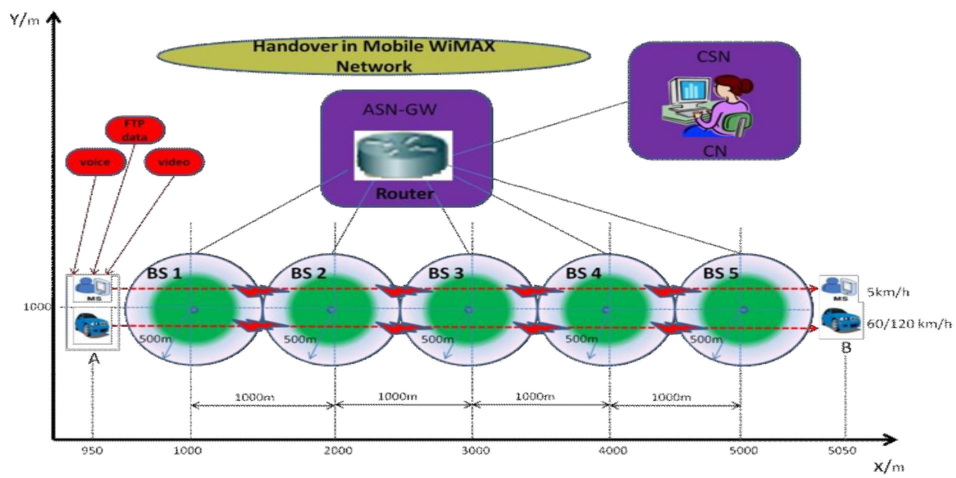


Figure 4.4: No cell overlap

4.4.4 Scenario 4: 10 metre Distance No Cell Overlap

This scenario is a severe case of the previous scenario in which the cell neither touches nor overlaps. In pedestrian speed there will be a period of complete call drop owing to lack of synchronization with the serving or target BS. However, in vehicular speed, it is possible for the MS to traverse this gap quickly while anchoring to the target BS with few packet loss and handover delay. See Figure 4.5.

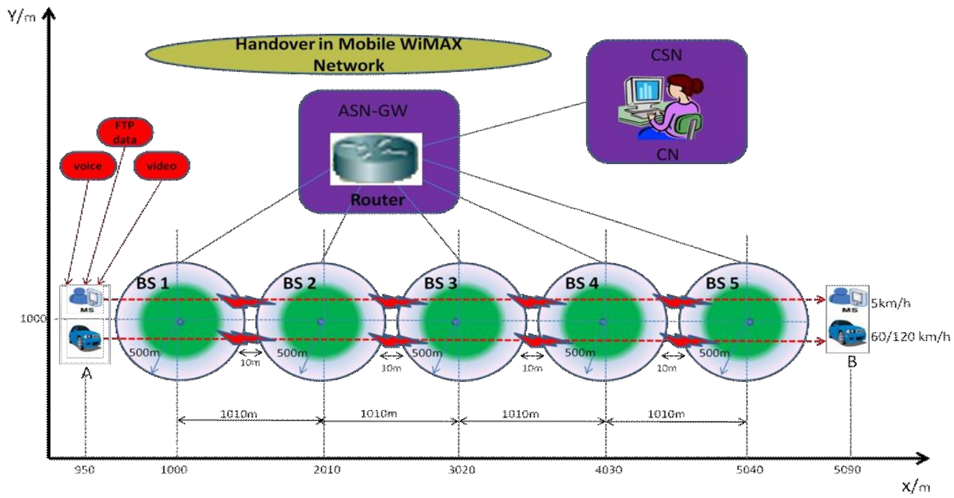


Figure 4.5:10 metre no cell overlap

4.4.5 Scenario 5: Vertical WiFi-WiMAX-WiFi handover

This scenario illustrates the busy life of a mobile business executive or telecoms engineer who might always be on the phone. At point A, within the coverage area of a WiFi access point (AP1) in his home, he starts a voice session with a user in CN using a multi mode terminal. He moves to his car at a pedestrian speed of 5km/h at point B and experiences a handover to a WiMAX network in BS1. He enters his car and moves at a speed of 60km/h to point C handing over to BS2. Afterwards he accelerates to point D at 120km/h handing over to BS3 and maintains the same speed to point E in BS4. The MS then moves to point F (having been handed over to BS5) at 60 km/h. He then alights from the car and made his way to his office at 5km/h to point G handing over to the office access point (AP2). See Figure 4.6. All the way from home to the office the idea is to have a seamless connection all through at a low cost with high productivity and low battery power consumption. This scenario assumes same service provider offering WiFi and WiMAX communication services.

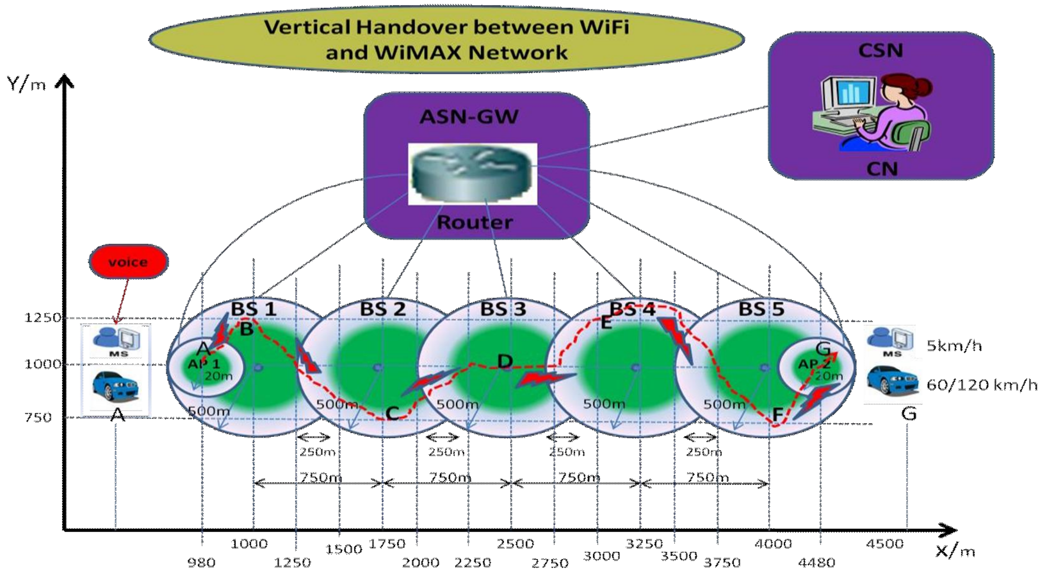


Figure 4.6: Vertical HO at half cell overlap

4.5 *Speed and Application Traffic Modeling*

The speed input in NS-2 is in metres per second (m/s), hence the conventional speeds units in km/h are converted to m/s. The traffics used for these scenarios are constant bit rate (CBR) voice with UDP as transport layer protocol, constant bit rate (CBR) video with UDP as transport layer protocol and File Transfer Protocol (FTP) data with TCP as transport layer protocol. These speeds and traffics are modelled for the simulation in NS-2.

- **Speed modeling:**

Pedestrian: 5km/h -> 5000m/3600s= 1.3889m/s

Low vehicular speed: 60km/h -> 60000/3600 = 16.6667m/s

High vehicular speed: 120km/h -> 120000/3600 = 33.3333m/s

- **Traffic modeling:**

Voice traffic model:

Voice packet size: 160 bytes

Voice packet interval: 0.02sec -> 50 packets per second

➔ 8000 bytes/sec; (160 bytes by 50 voice packets)

➔ 64000bps = 64kbps; (1byte contains 8bits)

(Assuming a MS terminal using uncompressed µlaw or A-law companding pulse code modulation)

Video traffic model:

Video packet size: 2960 bytes

Video packet interval: 0.02sec -> 50 packets per second

➔ 148000 bytes/sec

➔ 1184000bps = ≈1.2Mbps (Assuming a VCD quality picture)

FTP data traffic model:

FTP data packet size: 1500 bytes

FTP data packet interval: 0.0125sec -> 80 packets per second

➔ 120000 bytes/sec

➔ 960000bps = 960kbps

The FTP newreno type will be used for the simulation due to it better retransmission capability.

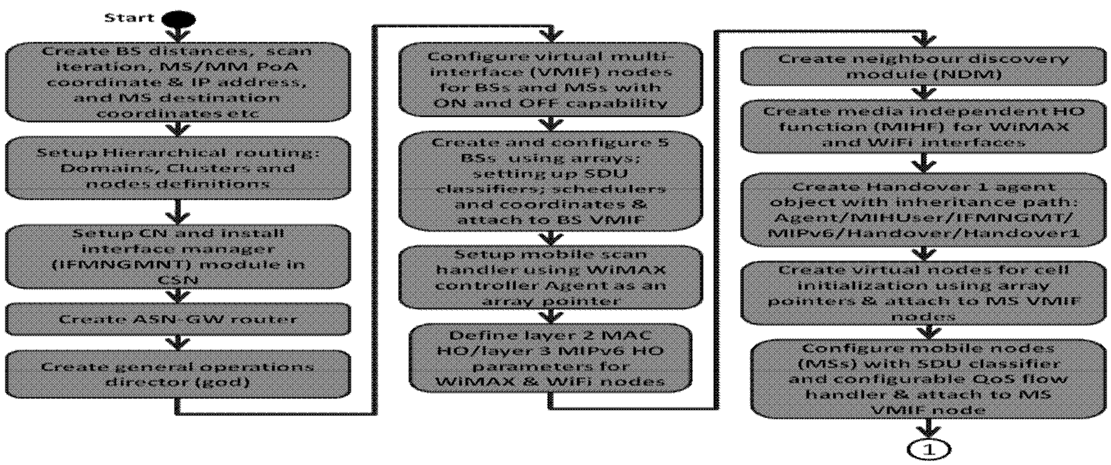
4.6 Simulation

For the simulation, ns-allinone-2.29.3 version on Linux Fedora 9 platform was used. The handover simulation to be carried out is a system-level simulation on the MAC layer. This involves packet-level analysis of the MAC PDU of voice, video and FTP data packets sent by the MS at the various speeds mentioned. The handover performance analysis will be done in layer 2, but for the purpose of taking precaution for best result as stated in the Trace Graph manual, Mobile IP addresses will be assigned to the BSs and to the MS in the home network. This means that hierarchical addressing with Layer 3 IP assignment will be carried out on all the nodes in the designs. This is done using the „domain.cluster.node" NS-2 IP nomenclature. See figure 4.10

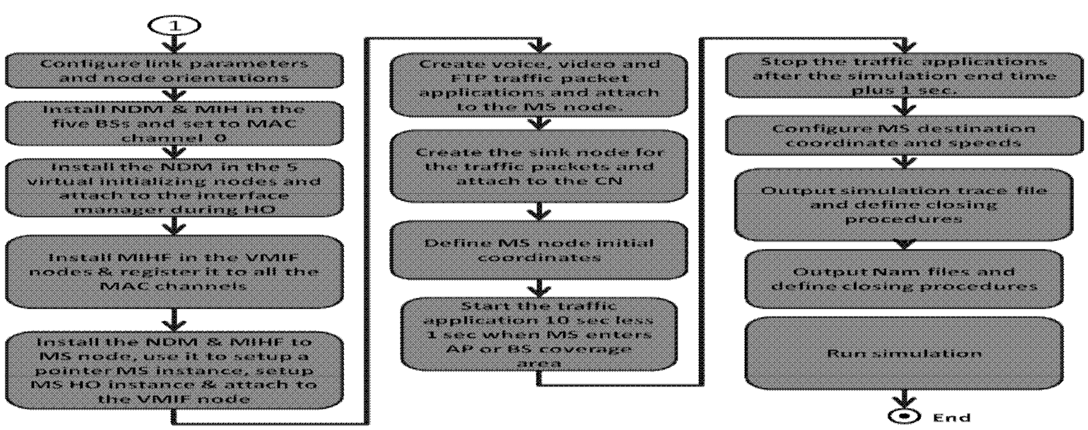
and figure 4.11 of section 4.6.3. Hence the MAC trace, IP trace, and Agent (layer 4) trace will all be turned ON in the all the simulations. Section 4.6.1 shows the flow charts and finite state machines illustrating the modifications made on the original API script.

4.6.1 The Handover API Flow chart

The flow chart of the modified API OTCL script is given in Figure 4.7 (a) and Figure 4.7 (b). Figure 4.8 is a flow chart for the simulated MIH handover. These flow charts illustrate the configurations and behaviour of the handover scripts in NS-2. The full NS-2 code is located in the attached CD. The file names are in the Appendix.



(a) Simulation flow chart



(b) Simulation flow chart (continued)

Figure 4.7: Simulation flow chart for the API script

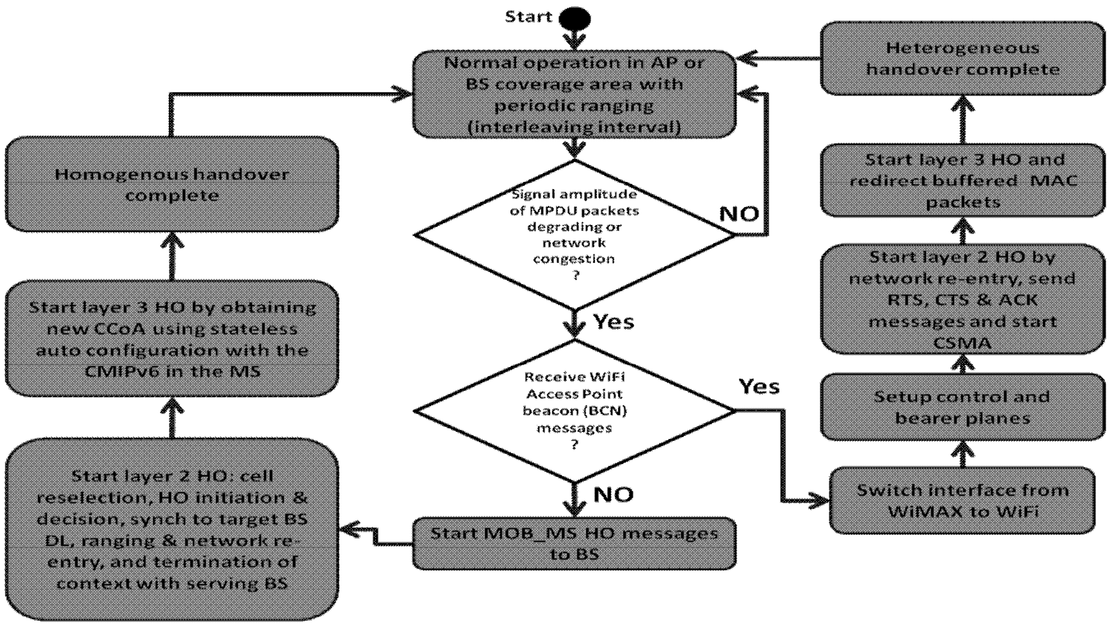


Figure 4.8: Handover flow chart for the API script

The WiMAX controller agent messages were mapped between the BSs via the MAC „0" channel for: (1) effective update of the routing table (2) to send neighbour advertisements messages and (3) to send UCD, DCD messages, and synchronization messages between the BSs through the 100MB backbone link. The Virtual finite state machine (VFSM) mapping is shown in Figure 4.9.

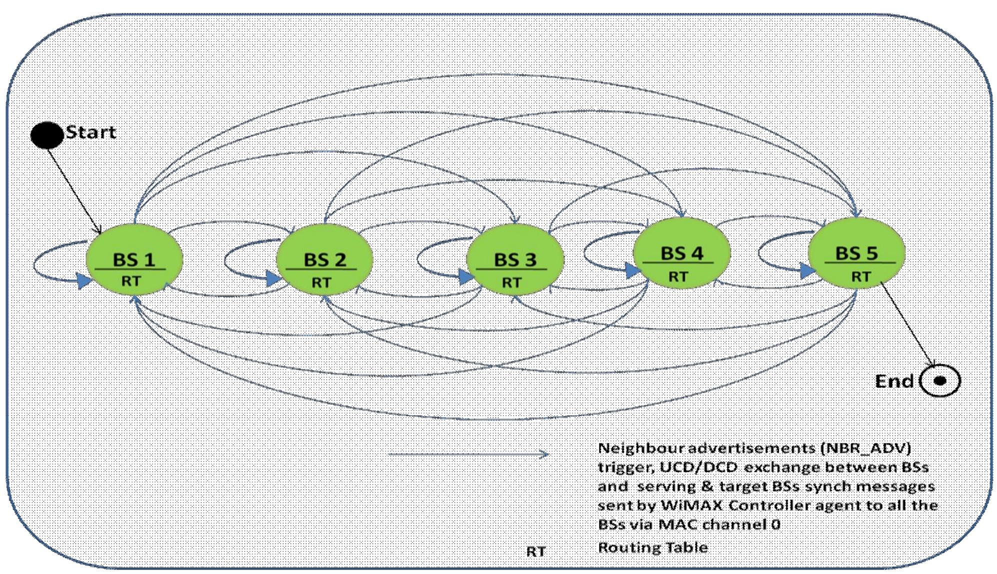


Figure 4.9: VFSM mapping for neighbour advertisement

4.6.2 Configuration and Simulation Parameters

Table 4.1 shows some of the configurable simulation parameters. A more exhaustive parameter is on the API scrip. The MIHF routing protocol used is „*Noah*" designed by NIST to handle node address change and to interwork the WiFi and WiMAX interfaces.

Table 4.1: Simulation parameters

Simulation parameter	Values
MAC/802_16 scan iterations	5
MAC/802_16 scan duration	50 sec
MAC/802_16 interleaving interval	40 sec
MAC/802_16 link going down factor	1.1
MAC/802_16 UCD interval	5 sec
MAC/802_16 DCD interval	5 sec
MAC/802_16 channel number	0
WiMAX Frequency bandwidth	5 MHz
WiMAX bit rate bandwidth	10Mbps
WiFi frequency bandwidth	5MHz
WiFi bit rate bandwidth	11Mbps
Number of channels per base station	5 (0-4)
Modulation and code rate	OFDM 16 QAM 3/4
Vehicular speeds	60 km/h and 120 km/h
Pedestrian speed	5 km/h
Number of packets sent per second	50
Frequency band	3.5GHz
Cyclic Prefix	0
Base station transmit power	15w
Base station coverage area (High dense	500m
Channel type	Wireless channel
Radio propagation model	Two ray ground
Wireless interface queue length	50
Antenna model	Omni directional antenna
Routing protocol	*Noah (modified DSDV for inter technology*
Number of base stations	5
Number of access points	2
Number of domain for horizontal handover	13
Number of domain for vertical handover	15
Scheduling algorithm	Round robin

4.6.3 MIP address modeling

The MIP (mobile IP) address modelling is due to the NIST MIP version 6 implementation. The MS"s 802.16 interface IP address is assigned as 2.0.2 and node ID as 18 being PoA parameter at the home network (base station 1). That of the virtual multi-interface node is assigned as 12.0.0 with node number 7. This models Client MIPv6 IP address assignment on the MS terminal. The remaining IP addressing and node number assignment on the interfaces are shown in figure 4.10 with legend illustrating the BSs. Virtual initializing cells (these are needed to initialize the cells), and multi-interfaces (making it MIH capable) are also shown. Note that the BSs, the multi-interface nodes, the ASN-GW and the CSN-CN are assigned to different domains or subnets giving a total of 13 domains (0 to 12). Each domain has different clusters and each cluster has different nodes. For instance, the MS 802.16 interface on PoA to BS1 is on the third domain, first cluster and is the third node. BS1 is also on the third domain. Now from the trace file output of the simulation, it was observed that as the MS traverses the BSs the PoA IP address changes to new CCoA in each domain causing layer 3 handover (i.e. node 18"s IP address kept changing until it became 6.0.2 in the last subnet or foreign network of BS5). This is as a result of stateless auto configuration by the CMIPv6 client in the MS terminal when a new network prefix is detected with the aid of route advertisement broadcasts by the BSs to the MS. The multi-interface node on the MS (node 7) maintains IP address 12.0.0 throughout the journey with the cluster and node number remaining the same. This IP address change is very important during the IP address-to-node-number mapping in the conversion and parsing of the trace file data in other to produce the graphs in chapter 5. Figure 4.10 and Figure 4.11 also shows the link parameters.

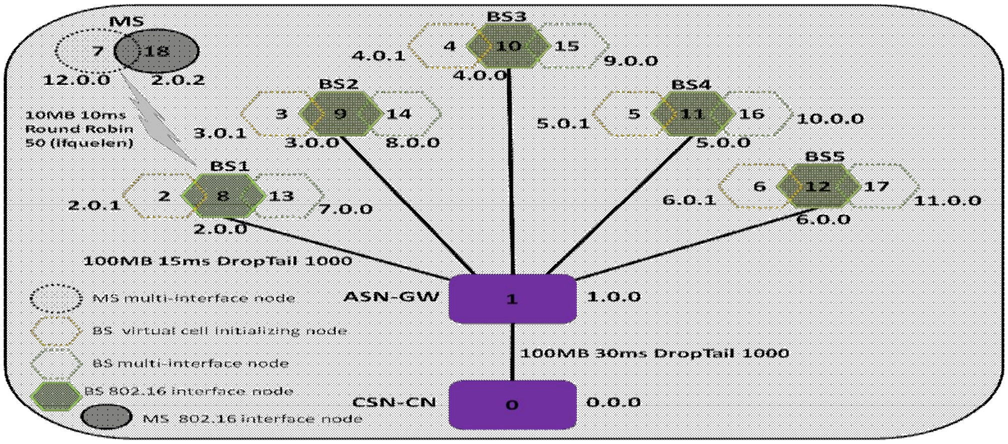


Figure 4.10: Horizontal HO showing node number and IP addressing

Similarly, for the heterogeneous handover, Figure 4.11 shows the node and IP address assignment network for the simulation with the multimode terminal, The MM terminal PoA IP address and node ID is 14.0.0 (for the virtual multi-interface node) and 7 respectively; 2.0.2 for the WiMAX (802.16) interface node with node ID 18, and 2.0.3 for the WiFi (802.11) interface with node ID 21. From the trace file the IP addresses also changed in the entire domain. During handover from AP1 to BS2, after the management messages are communicated, it was observed that the voice packets transmission switched from the WiFi interface to the WiMAX interface.

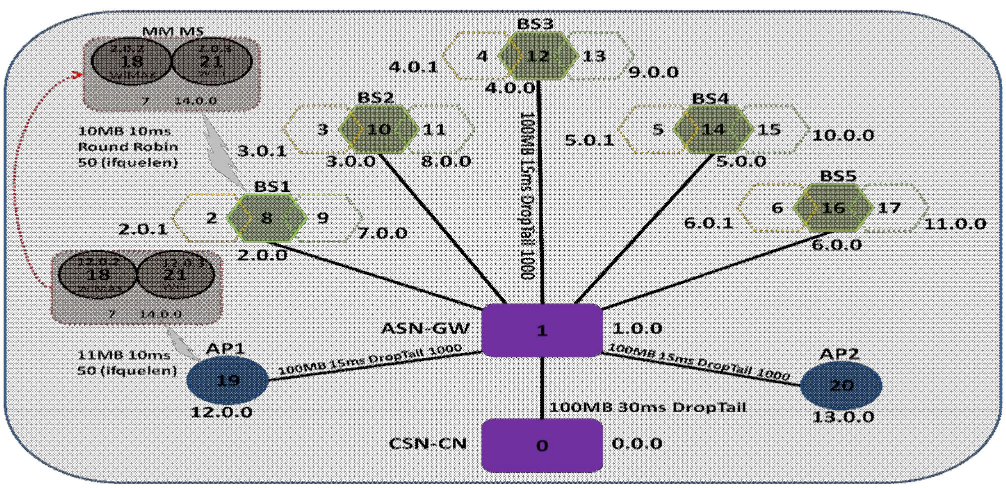


Figure 4.11: Vertical handover node ID and IP addressing

4.6.4 Network Animations (NAM) of the Simulation Scenarios

This section shows the NS-2 NAM output for the horizontal and vertical handover (VHO). It shows the different control and voice packets communications during network entry, interleaving interval and handover periods.

4.6.4.1 Scenarios 1-4: WiMAX horizontal Handover NAM Display

Figure 4.12 shows the exchange of the MAC and layer 3 control messages during the network entry period. This include the neighbour solicitation (nd_sol) messages by the MS; the neighbour discovery route advertisement (nd_rads) broadcast by the BSs on the wireless links; and the exchange of WiMAX controller agent messages (wimaxctrl) between BSs based on the mapping on Figure 4.9 of Section 4.6.1. Figure 4.12 (a) to Figure 4.12 (f) shows the NAM outputs for the homogeneous handover in different speeds and cell orientations scenarios.

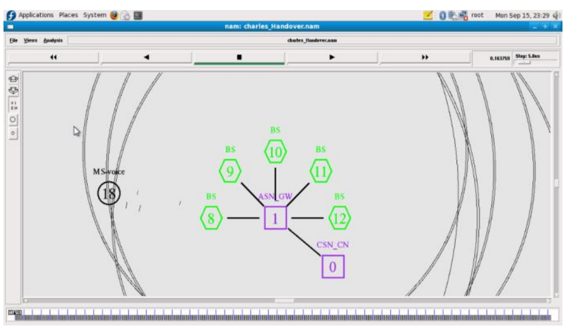


Figure 4.12: (a) control messages

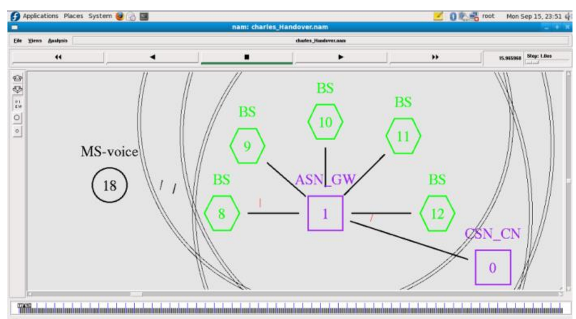


Figure 4.12: (b) voice traffic through BS1

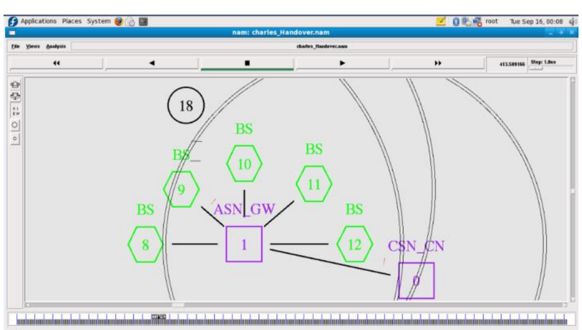


Figure 4.12: (c) voice traffic through BS2

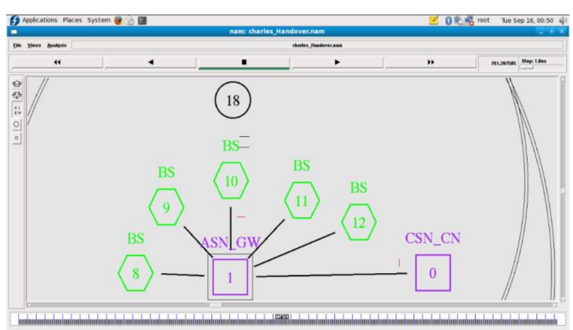


Figure 4.12: (d) voice traffic through BS3

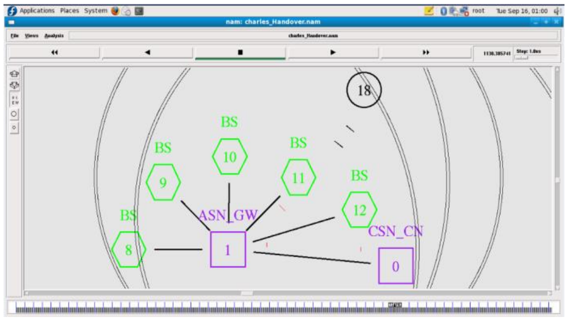


Figure 4.12: (e) voice traffic through BS 4

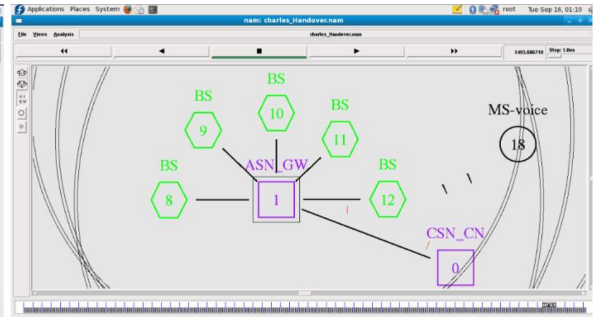


Figure 4.12: (f) voice traffic through BS 5

Figure 4.12: Homogeneous handover NAM display

4.6.4.2 Scenario 5: WiMAX-WiFi Vertical Handover NAM Display

Figure 4.13 (a) to Figure 4.13 (j) shows the vertical handover displays in NAM.

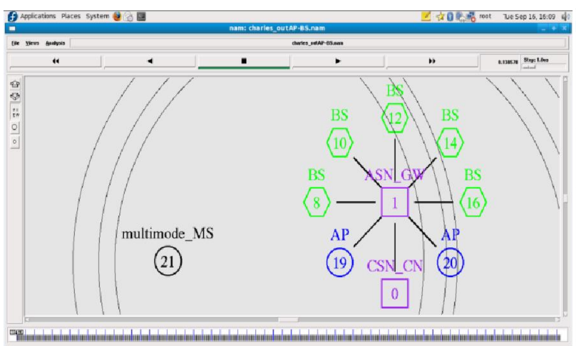


Figure 4.13: (a) APs sending beacon signals

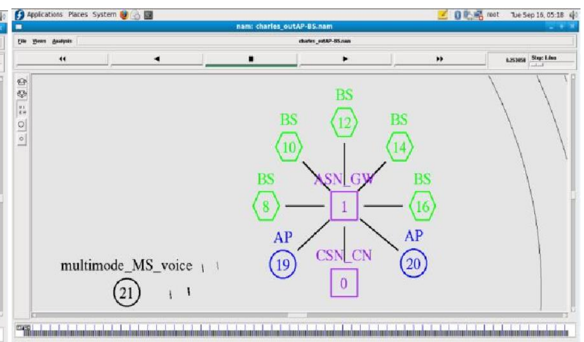


Figure 4.13: (b) RTS/CTS and ACKS

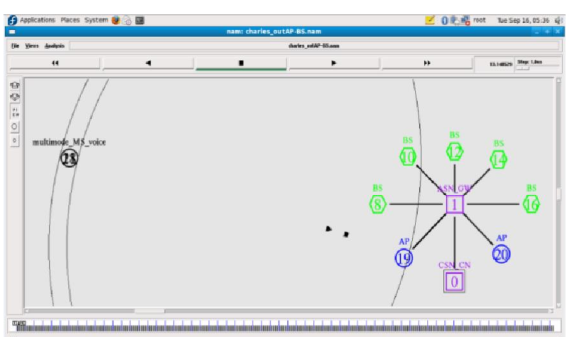


Figure 4.13: (c) Association REQ/RES

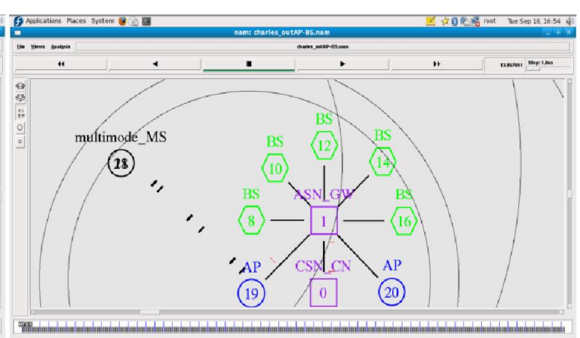


Figure 4.13: (d) Voice comm. with AP1

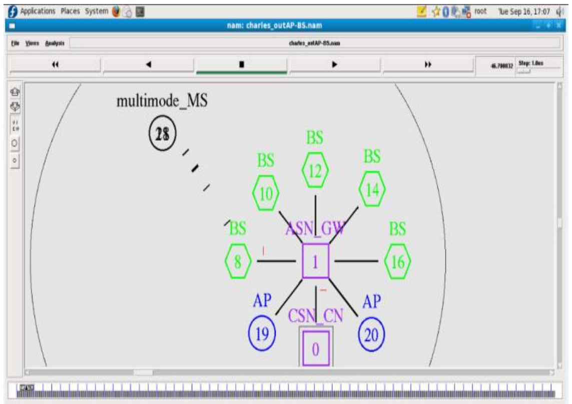


Figure 4.13: (e) VHO to BS1

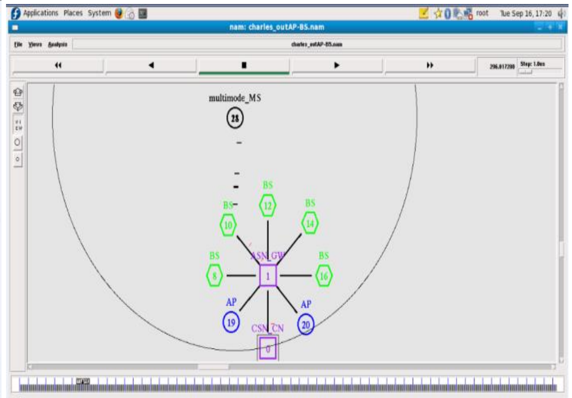


Figure 4.13: (f) HO to BS2

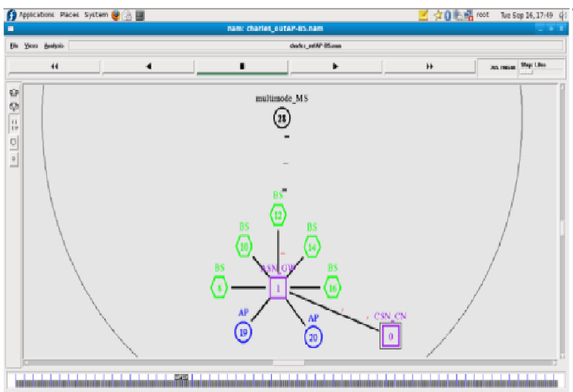


Figure 4.13: (g) HO to BS3

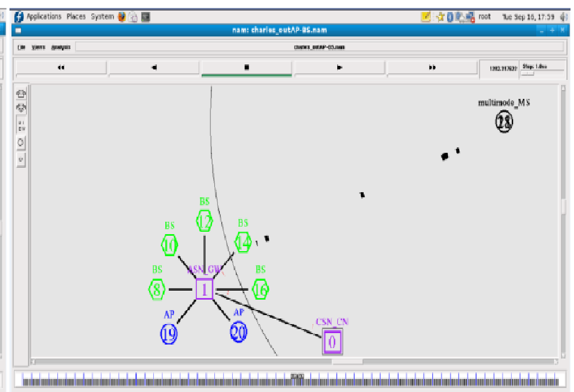


Figure 4.13: (h) HO to BS4

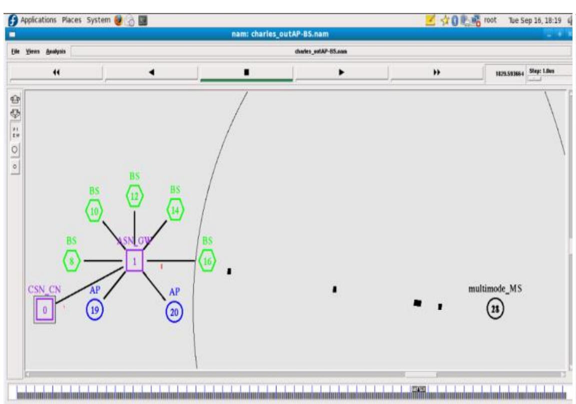


Figure 4.13: (i) HO to BS5

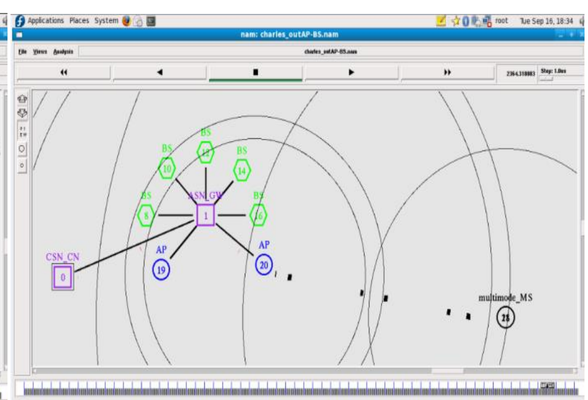


Figure 4.13: (j) VHO to AP2

Figure 4.13: Vertical handover NAM display

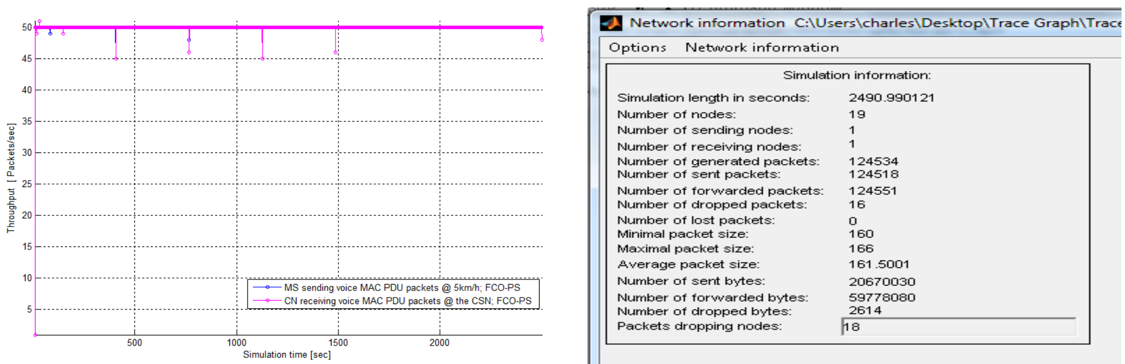
5 ANALYSIS OF SIMULATION RESULTS

5.1 Introduction and Observations

This simulation results is based on the *trace file* output from the simulation in the previous chapter. The average size of each trace file is about 800Mb with approximately 7.5 million DES lines. The total trace file size of all the scenarios is about 8GB. This file has to be opened in order to be *parsed*; hence the simulation PC must have at least 1.5 GB of system memory to be able to open the 800Mb files and accommodate other memory residence programmes running on the PC background. The trace file simulation data where parsed using *Trace converter* to adapt it to a format that will be accepted by the input of the MATLAB-based *Trace Graph* database. For the pedestrian speed the UNIX *grep* command was used to reduce the trace file size (from 1.3 GB to about 400 MB) by filtering out only the voice traffics since it could not be ported into Trace Graph after the conversion. The large file size is caused by the longer transmission time due to the low speed of the MS. Also, only throughput and packet loss output could be achieved due to memory constraint on the Trace Graph tool; hence delay and jitter could not be determined. See Section 5.2.1 for the specific reason. Also the simulation time for the pedestrian speed was set to 2500 seconds to give more time for the MS to traverse all the base stations. The *grep* tool was also used to filter out the packet drop events from the trace files for packet loss analysis. Since Trace Graph gives the total number of packets dropped during handover periods alone without graphical output, the actual packet lost during handover is observed based on the time at which handover occurred from the throughput graphs and analysed with Microsoft excel. The analysis of the horizontal handover is done in packet level while that of vertical handover is done in bit level. This is because the bit level gives a better graphical outlook for the further zoom analysis based on the overlay distance of transmits and receive traffic. The E2E delay and E2E jitter in the graphs is in the context of the delay and jitter between a MS and user at the CN.

5.2 Scenario 1: Full Cell Overlap

5.2.1 Pedestrian Speed

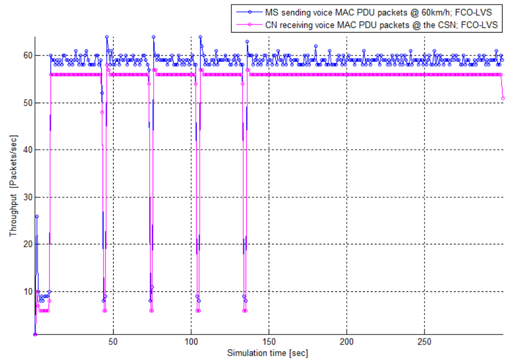


(a) System Throughput (b) total packet drop

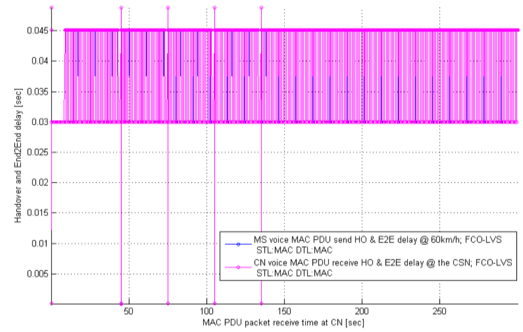
Figure 5.1: Pedestrian speed at FCO

This scenario would be the base line of the whole designed scenario. Although the delay and jitter could not be determined due to large voice traffics in the trace file owing to longer simulation time and low speed causing this trace data to exceed the memory matrix dimension of Trace graph. As a result of this, the delay and jitter will be compared with standard values in table 3.1. Figure 5.1 (a) shows that there is a stable and uniform throughput during the normal (interleaving) interval with the transmit traffic and receive traffic having same throughput the journey from the home network to the foreign networks of the simulation time. The throughputs dropped to 45 packets/sec during the first and third handover and at about 46 packets/sec during the second and fourth handover. This is due to fewer packets lost during sudden lost of synchronization and resumed channel scanning observed from the simulation debug output. There was a slight drop in transmit and receive throughput in the first interleave interval in the coverage area of BS1. This is probably due to radio propagation problems. Total packet lost during the whole journey is 16 while the average packet lost during handover is 4.

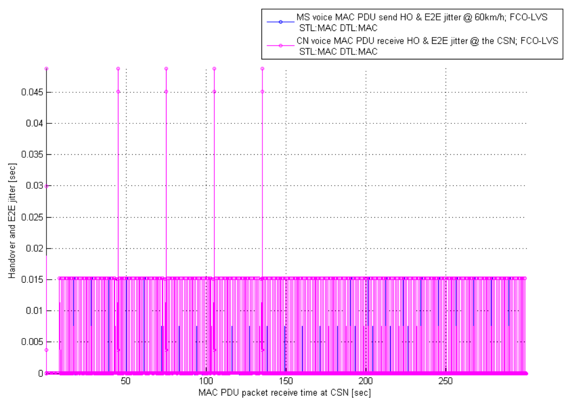
5.2.2 Low Vehicular Speed



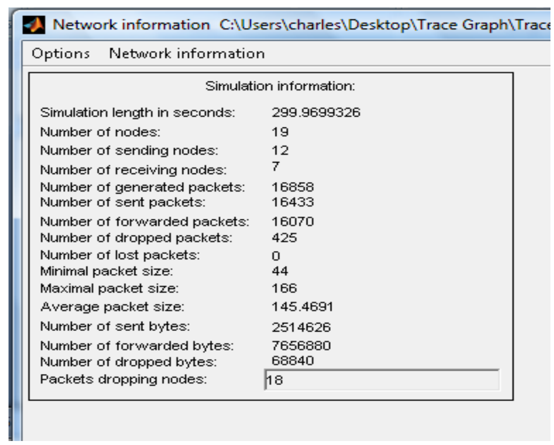
(a) System Throughput



(b) Delay



(c) Jitter



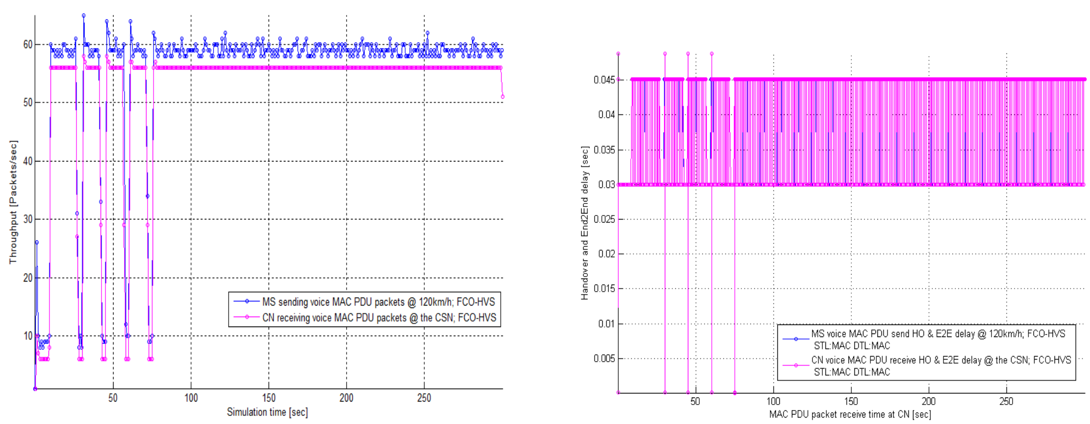
(d) Total packet drop

Figure 5.2: Low vehicular speed at FCO

From Figure 5.2 (a) the transmit throughput (of the wireless link) in this speed and scenario is unstable and non uniform at around 60 packets/sec. This is due to complex radio propagation effects, like delay spread and Doppler spread (caused by the relative motion of the MS and the BSs) which affects the OFDM symbol of the voice MAC PDU packet. Adapting the sampling rate without affecting the orthogonality of the OFDM symbol as the speed increases could mitigate this effect. The non uniform throughput is inherent in all the scenarios. During handover the throughput dropped significantly to about 5 packets/sect. This is due to the above mentioned effects and packet lost during time and frequency synchronization in the target BS at network re-entry. Notice the initial drop in throughput to 5 packets/sec at the beginning of transmission. This is due to a delayed network entry during the start of the simulation at the home network. Notice also the sharp rise in throughput after handover. This could be due to the sudden rise of voice MAC PDU as a result of packet redirection on the wireless interface buffer of the BSs. Notice also the fairly stable throughput in the received MAC PDU at the CN due to the wired link between the BSs and the CN which is not affected by radio propagation effects.

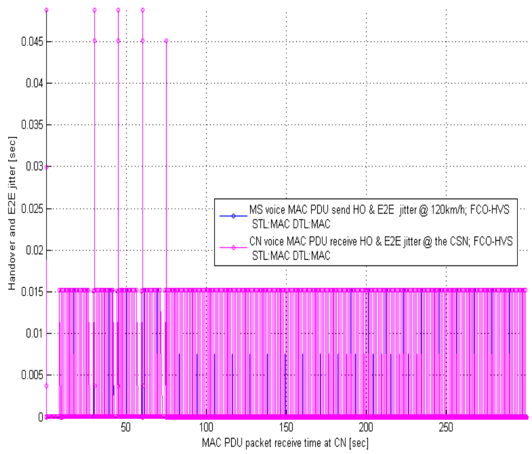
The E2E delay during interleaving interval in Figure 5.2 (b) varies between 0.03 sec (30 msec) and 0.045 sec (45 msec) while the handover delay is 0.0475 sec (47.5 msec). The E2E Jitter in Figure 5.2 (c) is between 0 msec to 15 msec while peaking at 47.5 msec during handover. From Figure 5.2 (d) the total packets dropped or lost is 425 while the average packet lost during handover is 106.

5.2.3 High Vehicular Speed

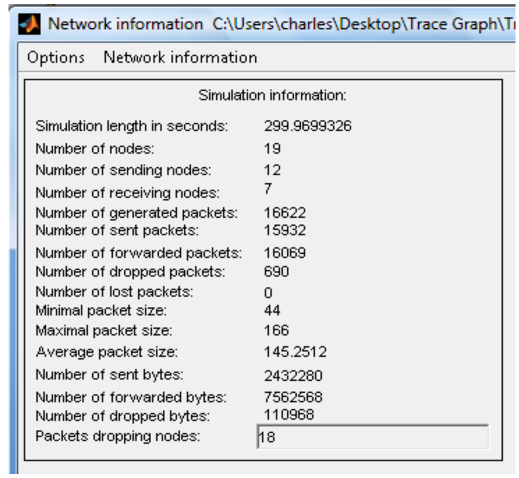


(a) Throughput (b) Delay

Figure 5.3: High vehicular speed at FCO



(c) Jitter



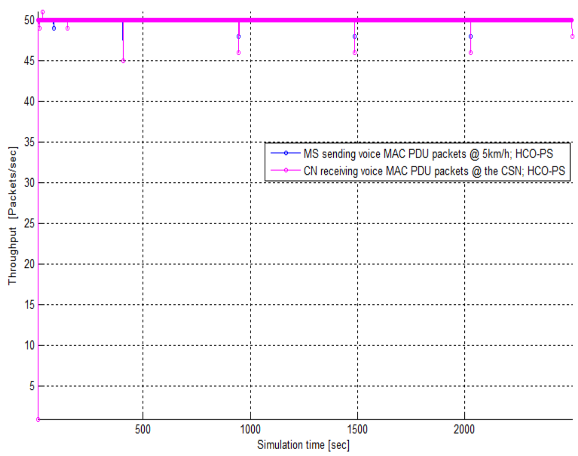
(d) Total packet drop

Figure 5.3: High vehicular speed at FCO

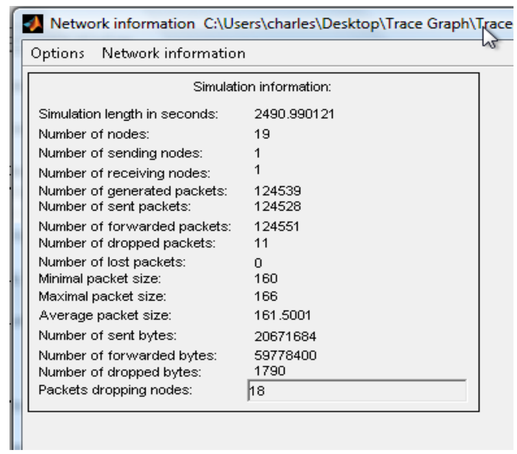
It can be seen clearly from Figure 5.3 (a) that the throughput follows the same pattern with LVS at FCO except that the period of normal operation (interleaving interval) is shorter in the coverage area of BS1 to BS4 due to the MS travelling at a higher vehicular speed. The MS spent more time in BS5 having traversed BS1 to BS4 at faster simulation time. The delay and jitter in Figure 5.3 (b) and Figure 5.3 (c) respectively are the same as in the LVS of Figure 5.2 (b) and Figure 5.2 (c) except for the fast handover delay which has a lower value of 45 msec. This is probably due to early obtaining of CID and SFID as a result of faster synchronization in finding a target channel in BS5 in the first scan. The total packet lost in this speed is 690, while the packet lost during handover is 173.

5.3 Scenario 2: Half Cell Overlap

5.3.1 Pedestrian Speed



(a) Throughput

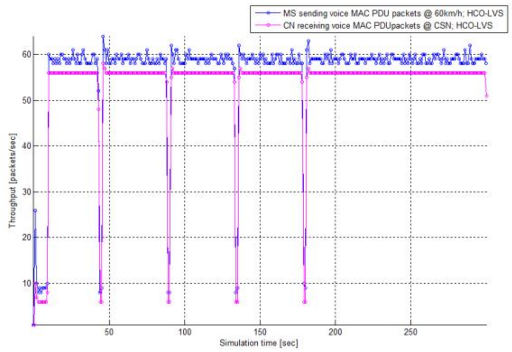


(b) Total packet drop

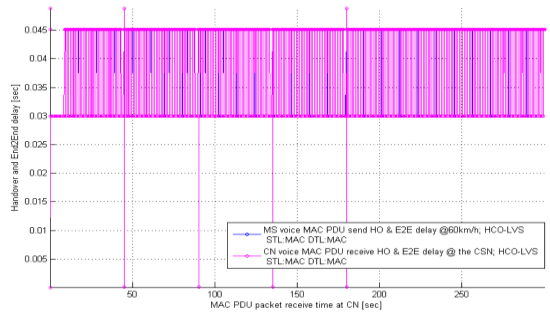
Figure 5.4: Pedestrian speed at HCO

The interleaving interval throughput and drop in throughput during handover in this scenario and speed is the same as that of the FCO at PS. The only significant difference is the time in handover throughput drop due to the larger distance between adjacent BSs in Figure 5.4 (a). This causes the last handover throughput drop to occur at about 2000 sec simulation time as against its occurrence at approximately 1500 sec simulation time in Figure 5.1 (a) above. In Figure 5.4 (b) the total packet drop is 11 and the average drop during each handover is 3.

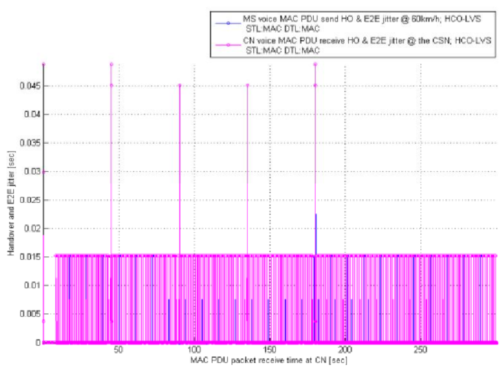
5.3.2 Low Vehicular Speed



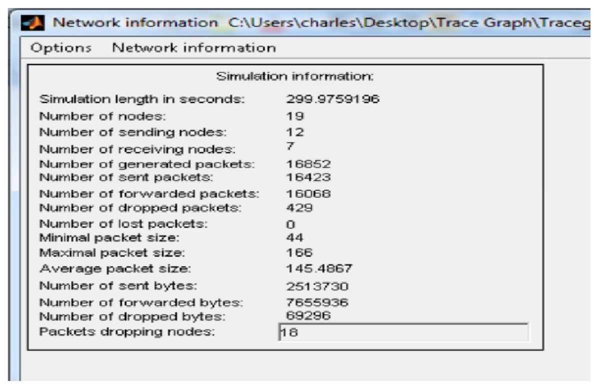
(a) Throughput



(b) Delay



(c) Jitter

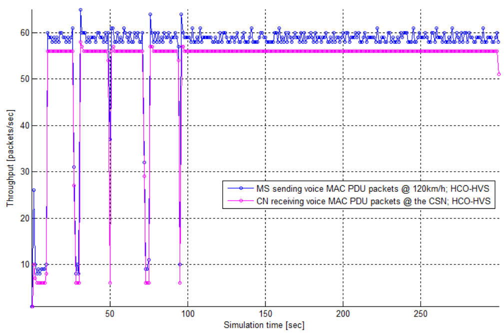


(d) Total packet drop

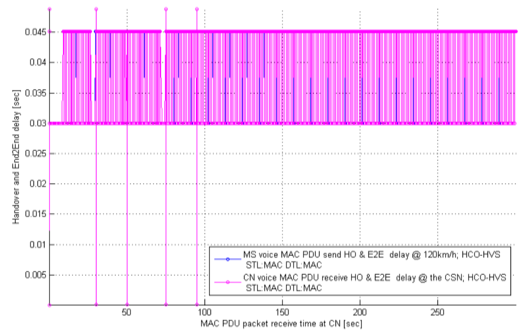
Figure 5.5: Low vehicular speed at HCO

For the throughput graph in Figure 5.5 (a), the drop in throughput during handover is the same as in the FCO-LVS. The only difference being the interleaving interval throughput being longer than that of the FCO-LVS due to increased adjacent BS distance. The delay in Figure 5.5 (b) and Jitter in Figure 5.5 (c) in this case is the same with that of the FCO-LVS. Except for the second and third handover delay and Jitter which are both 45 msec due to the reasons stated for Figure 5.3 (b) and Figure 5.3 (c) of Section 5.2.3 above. The total packets lost throughout the journey is 429. This increase is due to cell edge effect caused by decreasing SINR as the adjacent BS increased as well as the Doppler spread due to increase in speed and relative motion. The loss during handover is 107.

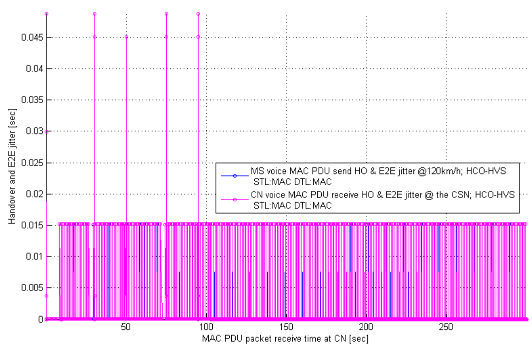
5.3.3 High Vehicular Speed



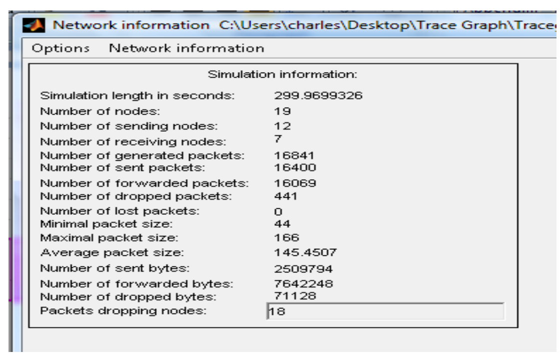
(a) Throughput



(b) Delay



(c) Jitter


Network information C:\Users\charles\Desktop\Trace Graph\Trace

Options Network information

Simulation information:

Simulation length in seconds:	299.9699326
Number of nodes:	19
Number of sending nodes:	12
Number of receiving nodes:	7
Number of generated packets:	16841
Number of sent packets:	16400
Number of forwarded packets:	16069
Number of dropped packets:	441
Number of lost packets:	0
Minimal packet size:	44
Maximal packet size:	166
Average packet size:	145.4507
Number of sent bytes:	2509794
Number of forwarded bytes:	7642248
Number of dropped bytes:	71128
Packets dropping nodes:	18

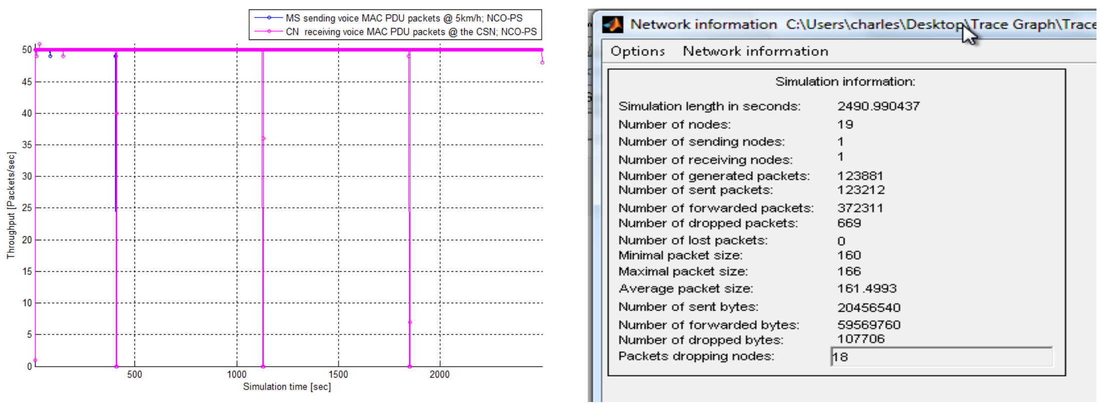
(d) Total packet drop

Figure 5.6: High vehicular speed at HCO

From Figure 5.6 (a), the throughput drop is the same except for longer interleaving interval throughput compared to FCO-HVS. This is due to the increased distance between adjacent BSs. The delay and jitter in Figure 5.6 (b) and Figure 5.6 (c) respectively is the same with that of FCO-HVS except for the second handover which has a delay and jitter value of 45 msec due to faster synchronization with the target BS. Total packet drop is 441 while drop during handover is 110.

5.4 Scenario 3: Non Cell Overlap with Zero Distance

5.4.1 Pedestrian Speed

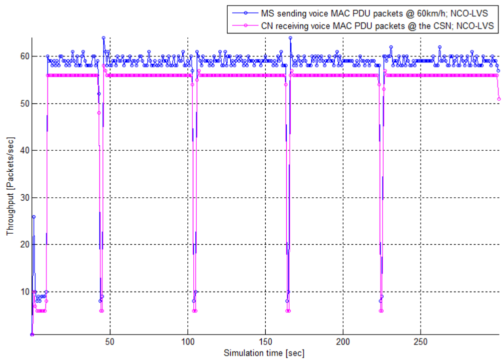


(a) Throughput (b) Total packet drop

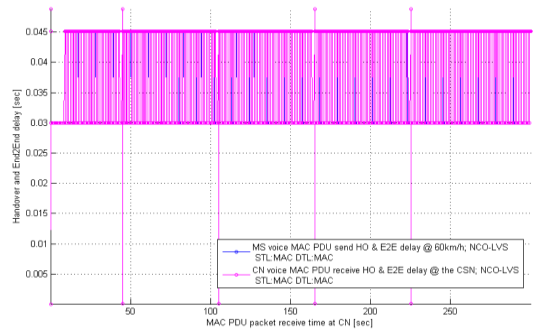
Figure 5.7: Pedestrian speed at NCO

For the pedestrian speed of this scenario, there is a complete drop of the voice session during all the handover periods. See Figure 5.7 (a) Also notice the three throughput drops instead of five. This could be due to loss of data in *parsing* the large raw trace file generated in this scenario, since four handovers were actually observed in the NS-2 NAM output. The total packet lost from Figure 5.7 (b) is 669 while the packets lost during handover are 167.

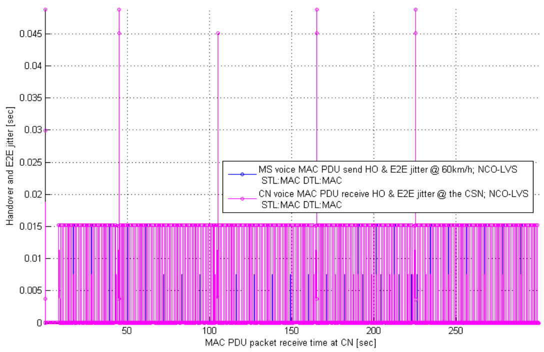
5.4.2 Low Vehicular Speed



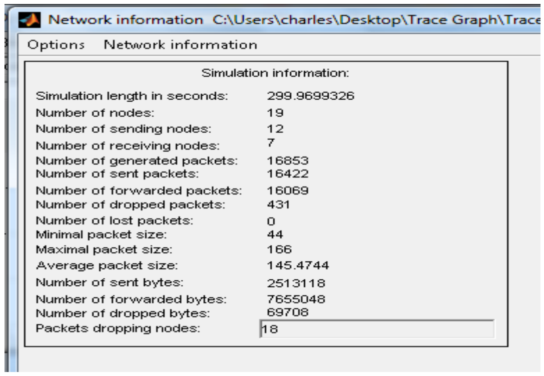
(a) Throughput



(b) Delay



(c) Jitter

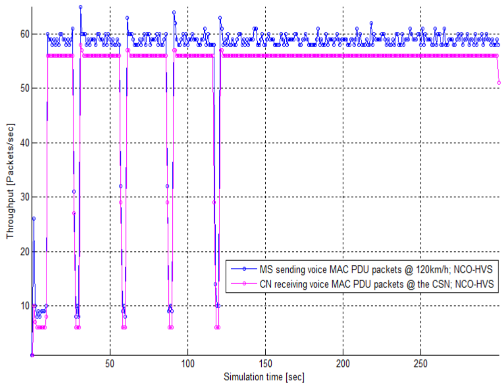


(d) Total packet drop

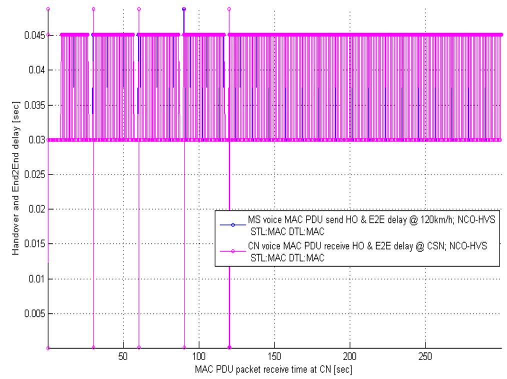
Figure 5.8: Low vehicular speed at NCO

The interleaving interval throughput is longer in Figure 5.8 (a) compared with that of the Figure 5.2 (a) obviously due to the larger distance between adjacent BSs. In Figure 5.8 (b) and Figure 5.8 (c) a shorter handover time and jitter is observed respectively during the second handover due to the reasons stated for Figure 5.3 (b) and Figure 5.3 (c) of Section 5.2.3 above. The total packet drop is 431, while the packet drop during handover is 108.

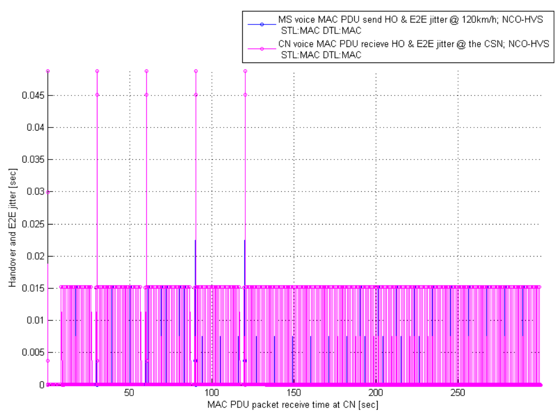
5.4.3 High Vehicular Speed



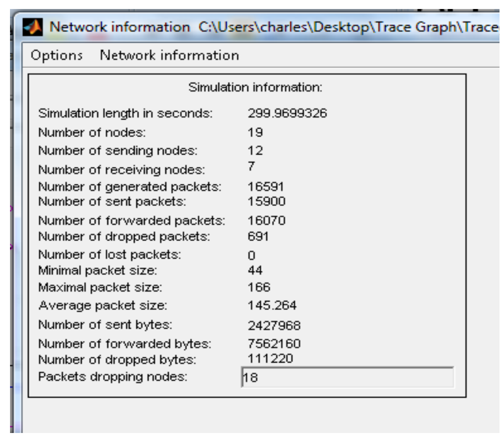
(a) Throughput



(b) Delay



(c) Jitter


Network information C:\Users\charles\Desktop\Trace Graph\Trace

Options Network information

Simulation information:

Simulation length in seconds:	299.9699326
Number of nodes:	19
Number of sending nodes:	12
Number of receiving nodes:	7
Number of generated packets:	16591
Number of sent packets:	15900
Number of forwarded packets:	16070
Number of dropped packets:	691
Number of lost packets:	0
Minimal packet size:	44
Maximal packet size:	166
Average packet size:	145.264
Number of sent bytes:	2427968
Number of forwarded bytes:	7562160
Number of dropped bytes:	111220
Packets dropping nodes:	18

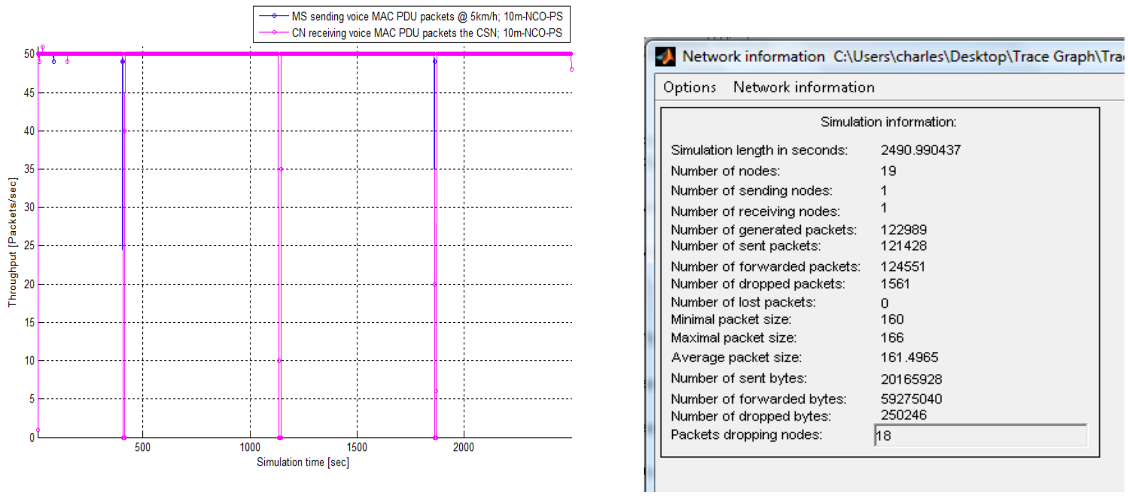
(d) Total packet drop

Figure 5.9 High vehicular speeds at NCO

The throughput in the interleaving interval is longer in Figure 5.9 (a) due to the longer distance between the BSs. The delay and Jitter is 47 msec compared to the HVS FCO except for the transmit delay being equal to the receive delay during the third handover; see the blue line in Figure 5.9 (b). The total number of packet dropped is 691 while the handover packet drop is 173.

5.5 Scenario 4: No Cell Overlap with 10 metre Distance

5.5.1 Pedestrian Speed

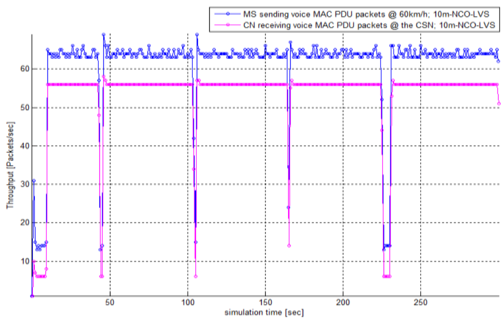


(a) Throughput (b) Total packet drop

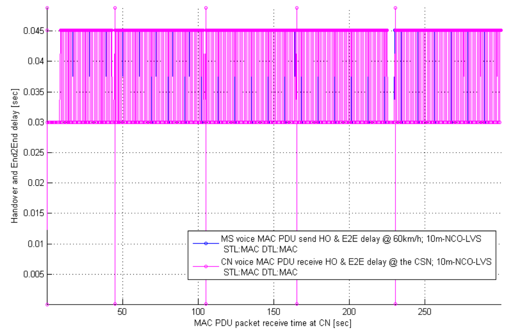
Figure 5.10: Pedestrian speed at 10 m of NCO

The throughput in Figure 5.10 (a) is similar with that of Figure 5.7 (a) of section 5.4.1 due to the same reason However, the total packet drop is very high in this scenario, 1561 due to the 10 m cell gap and the longer time spent in it at pedestrian speed. The packet drop during handover is 390.

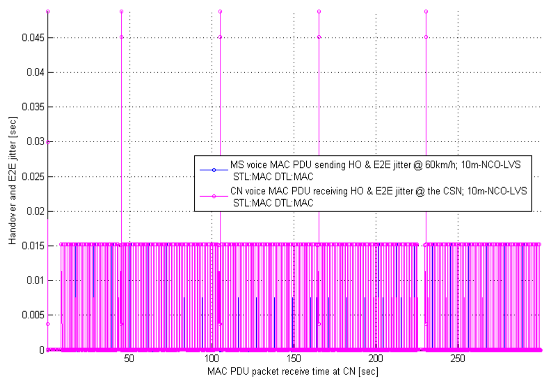
5.5.2 Low Vehicular Speed



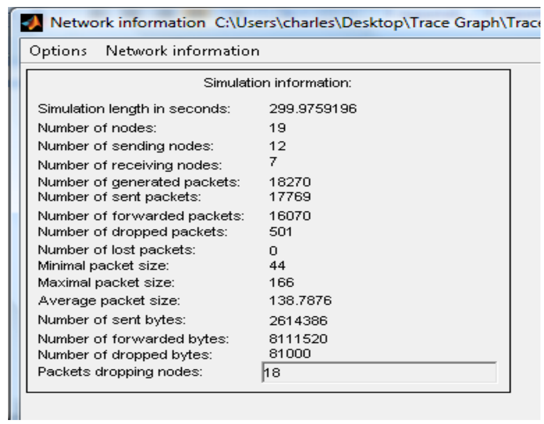
(a) Throughput



(b) Delay



(c) Jitter


Network information C:\Users\charles\Desktop\Trace Graph\Trace

Options Network information

Simulation information:

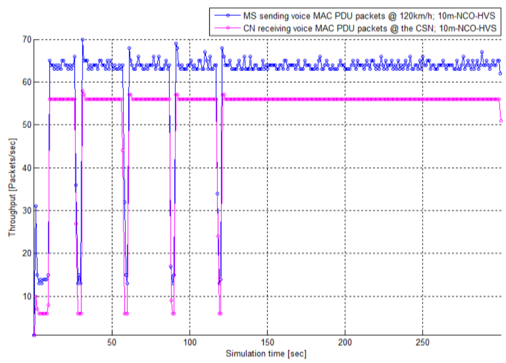
Simulation length in seconds:	299.9759196
Number of nodes:	19
Number of sending nodes:	12
Number of receiving nodes:	7
Number of generated packets:	18270
Number of sent packets:	17769
Number of forwarded packets:	16070
Number of dropped packets:	501
Number of lost packets:	0
Minimal packet size:	44
Maximal packet size:	166
Average packet size:	138.7876
Number of sent bytes:	2614386
Number of forwarded bytes:	8111520
Number of dropped bytes:	81000
Packets dropping nodes:	18

(d) Total packet drop

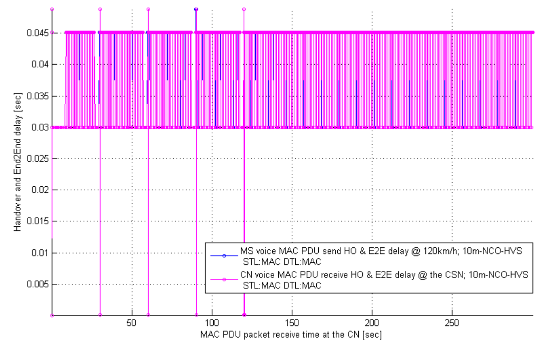
Figure 5.11: Low vehicular speed at 10 m for NCO

The throughput drop during the third handover in figure 5.11 (a) went up to about 15 packets/sec as against 5 packets/sec in the first, second and fourth handover periods. This could be due to fewer packets in the wireless interface queue and faster packet redirection from the BS3 to the BS4. The delay and Jitter is the same as that of the FCO HVS for the first second and third handover. In section 5.2.3 except for the longer interleaving interval delay and jitter. The packet dropped from figure 5.11 (d) is 501. This is lower than the PS 10 m NCO due to the less time spent in the 10 m cell gap. The handover packet lost is 125.

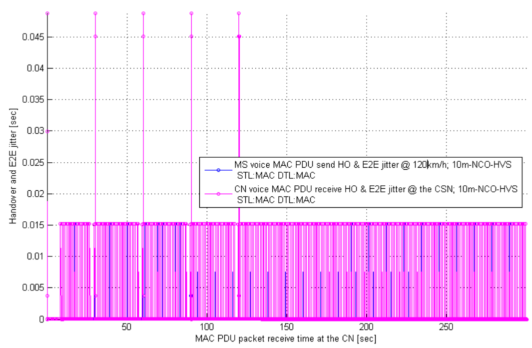
5.5.3 High Vehicular Speed



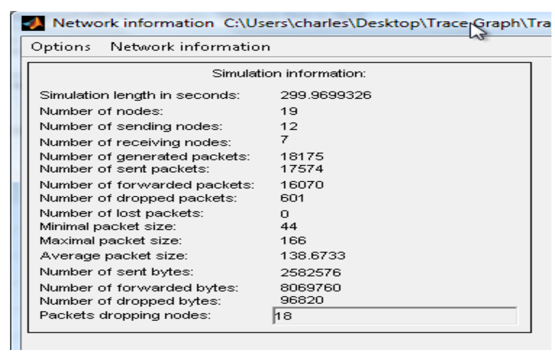
(a) Throughput



(b) delay



(c) Jitter



(d) Total packet drop

Figure 5.12: High vehicular speed at 10 m for NCO

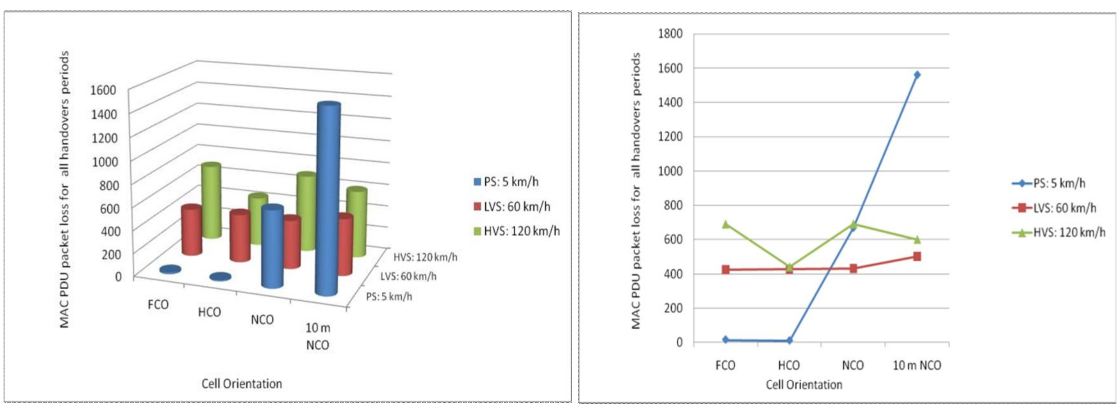
From figure 5.12 (a), (b), and (c) the throughput, delay and Jitter thesame except for the longer interleaving time compared to the HVS FCO graphs, except for the higher packet drop due to longer the cell gap. The drop is also higher than that of the HVS FCO due to the speed and cell gap. The total packet drop is 601 while the drop during handover is 150.

The total dropped packets for all handover (also shown in Figure 5.2 (d) to figure 5.12 (d)) are extracted from the trace file using UNIX *grep* tool and are presented in Table 5.1 while the average drop value for each handover period is presented in Table 5.2 and graphs ploted using Microsoft excel.

Table 5.1: Total MAC PDU lost per simulation

Speed / Cell orientation	FCO	HCO	NCO	10 m NCO
PS (5 km/h)	16	11	669	1561
LVS (60 km/h)	425	429	431	501
HVS (120 km/h)	690	441	691	601

The voice MAC PDU Packet drops during handover is observed from the extracted drop events from the trace file. The first set of drops occured due to lack of connection between the MS and the BS as the queue that stores pending frames became full. Another reason as observed is due to sometimes lost of connection between the MS and the BS from inability to achieve successful time and frequency synchronization during network re-entry. Lastly, during the handover periods voice MAC PDU where lost because the voice SDU recieved at the MAC sublayer could not be matched to CID connections. Figure 5.13 shows graph of total packet lost during these handover periods due to the different cell orientation scenarios and speeds of the MS.



(a) 3-D result

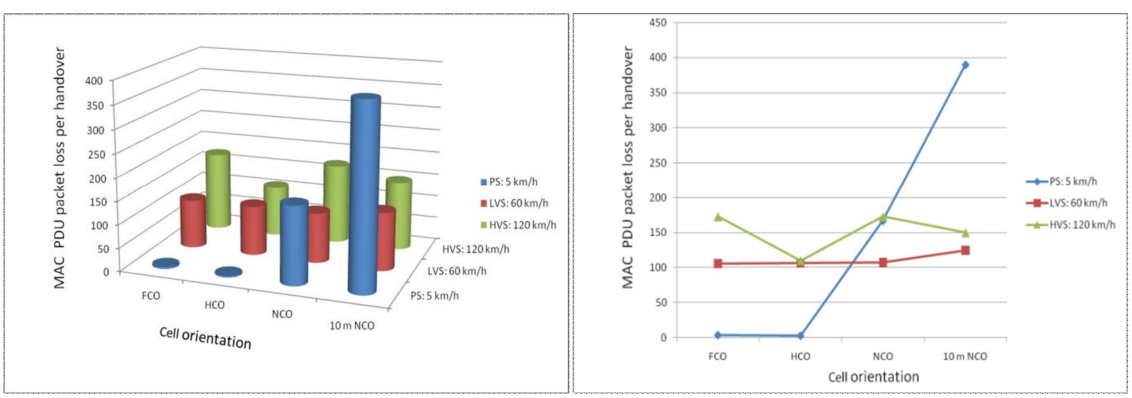
(b) 2-D result

Figure 5.13:Total packet MAC PDU lost per simulation

From Figure 5.13 (a) and (b), it is observed that the FCO and HCO for the pedestrian speed experienced low packet drop, but then increased during NCO and the 10 m NCO cell orientation scenario. The graph also shows that the high vehicular speed experienced more packet loss than the low vehicular speed for the different cell orientation except at HCO where they experinced similar drop. The high drop in LVS and HVS is due to doppler effect while that due to NCO and 10 m NCO cell orientation is due to decreasing SINR at the cell edges. This reason also explains the graph of Figure 5.14 for the average packet drop at each particular handover period. However the graph of figure 5.13 (b) and figure 5.14 (b) shows that most of the packet lost during the whole journey is the packet lost during handover.

Table 5.2: Average MAC PDU lost during each handover

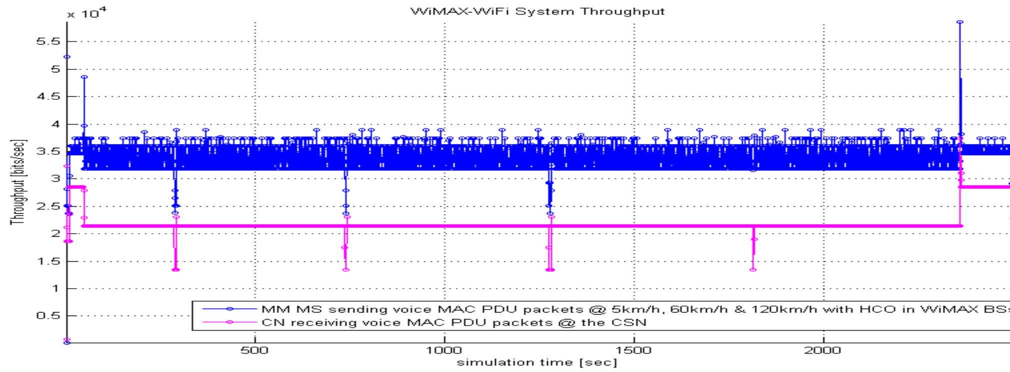
Speed / Cell orientation	FCO	HCO	NCO	10 m NCO
PS (5 km/h)	4	3	167	390
LVS (60 km/h)	106	107	108	125
HVS (120 km/h)	173	110	173	150



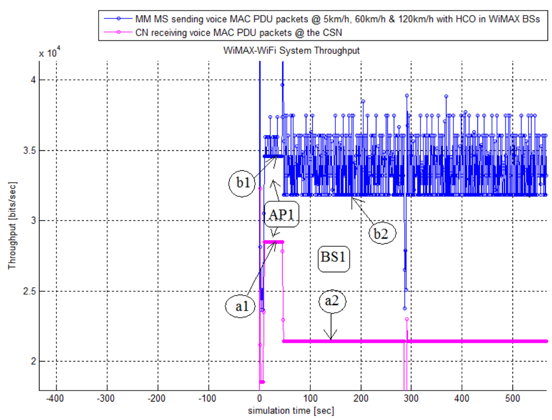
(a) 3-D result (b) 2-D result

Figure 5.14: Average MAC PDU lost per handover

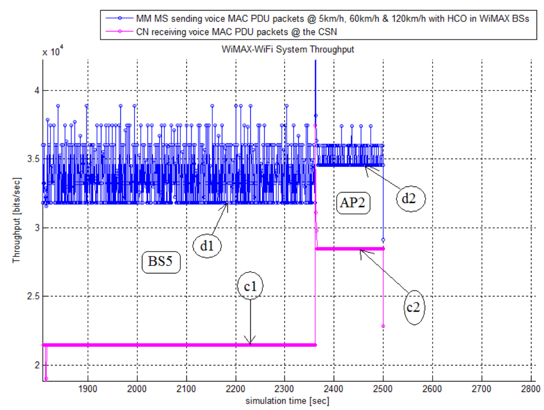
5.6 Scenario 5: Vertical WiFi-WiMAX-WiFi handover



(a) WiFi WiMAX handover Throughput



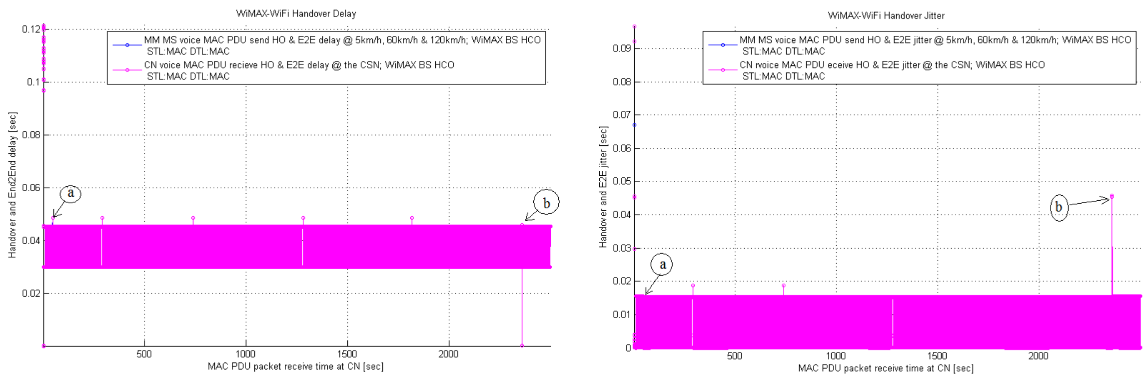
(b) Throughput drop between AP1 and BS1



(c) Throughput rise between BS5 and AP2

Figure 5.15: WiFi-WiMAX handover Throughput

In fig 5.15 (a) there is a sharp instantaneous throughput peak during the mode switch which could be due to additional packet flow during mode switch and the redirection of MAC PDU between these interface and also at the interface buffer of the base station. From fig 5.15 (b) there was a drop in throughput from 34 kbps at b1 to 32 kbps at b2 during handover and at the MM terminal switching from WiFi interface to WiMAX interface on leaving AP1 for BS1. This is because the WiFi bit rate bandwidth (11Mbps) is higher than that of the WiMAX (10Mbps) in this scenario. See simulation parameters in table 4.1. The CN which has a lower recieve throughput has a drop of throughput from 28 kbps at a1 to 22 kbps at a2 due to thesame reason of bandwidth difference. Similarly, from figure 5.13 (c), the MM terminal, on leaving BS5 and entering AP2 experinced a throughput rise from 32 kbps at d1 to 34 kbps at d2 due to the entering of WiFi network with a higher bandowidth. At the CN the throughput also rised back to 28 kbps form 22 kbps from c1 to c2.



(a) Delay (b) Jitter

Figure 5.16: WiFi-WiMAX handover delay and jitter

From Figure 5.16 (a) the handover delay from AP1 to BS 1 is 0.048 sec (48 msec) at point „a" and 0.045 sec (45msec) at point „b" on entering AP2 from BS5. In Figure 5.16 (b) the jitter is 0.015 sec (15 msec) at point „a" and 0.045 sec (45 msec) at point „b" This difference could be due to delay variation in receiving beacon signal from AP2 as a result of delayed waking up of the 802.11 interface.

From the trace file observation, no packet was lost during handover and mode switch from WiFi to WiMAX interface and from WiMAX to WiFi interface. This could be due to the proximity of the interfaces in the MM terminal and faster mode switch between these interfaces. See file outAP-BS_tg on the appendix CD.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The various mechanism for improving handover latency like adaptive channel scanning (ACS), use of link going down factor for immediate channel scanning and the use of MIPv6 in the NIST mobility model could account for the low delay and jitter from all the simulation output graphs for the homogeneous and heterogeneous handover as compared to Table 3.1. However, the throughputs which is a function of successfully transmitted or received packets, experienced significant drop of the voice MAC PDU at vehicular speeds and non cell overlap orientation scenarios as seen from the graphs in chapter five. The high packet loss and throughput drop are PHY layer problem which is due to Doppler spread caused by the relative motion of the MS and the BS and low SINR due to cell edge effect caused by greater distances between the BSs as well as non overlapping cells. This often leads to signal degradation, loss of time and frequency synchronization at network re-entry, and difficulty in channel recovery during signal measure for RSSI thereby corrupting the orthogonality of the OFDM symbols. Mobile Channel modelling, Long channel impulse response with spatial and polarization correlation, channel estimation, frequency diversity, hybrid automatic repeat request (HARQ), forward error correction with space time coding and adaptive antenna techniques with MIMO (multi input multi output) technology can mitigate these problems. Also high packet loss and throughput drop for the non overlapping cell can be avoided by making sure that all cells overlap during base station site installation. However, where logistics becomes a constraint due to additional CAPEX, packet lost during handover will definitely be inevitable.

6.2 Findings and Contributions of Research

The communications industry is heading towards wireless data transfers with great speed and several competing technologies are emerging to replace the old ones. The traditional Wireless

Local Area Network (WLAN) has gained a strong place in the market and is definitely the leader for short distance wireless networks. However, the coverage and mobility are adequate for indoor usage only. The Mobile WiMAX is planned to be independent or to extend the mobile access when a user exits the WLAN hotspot coverage area. This research adds to knowledge by determining how seamless mobility in WiMAX networks can be achieved.

6.3 Recommendations for Future Work

- The simulation should be carried out between two or more mobile subscribers communicating at different speeds and traffic types as a way to determine end-to-end performance of the MIH model using a high end PC. This was attempted but the trace file could not be opened in order to parse the file for the node to IP address mapping owing to its very large size (3GB), since the simulation PC memory is only 2GB.
- Total handover latency and jitter at layer 1, layer 2 and layer 3 as well as the latency during interface switching on the multimode terminal and media redirection time on the NIST model should be critically analysed for proper and fool-proof handover predictions.
- The network can be subjected to higher vehicular speed to determine the effect on the performance metrics used in this report.
- The network scenario in the MIH can be extended to the UMTS and satellite network for a global network performance measure.
- The delay and jitter for the pedestrian speed could not be analysed due to the trace file output exceeding the Trace graph memory matrix dimension. Use of a better analysis tool is therefore suggested.
- The video and FTP data traffics where simulated on the same scenario with voice traffics as shown in the appendix. These traffics should be simulated separately on different scenarios to determine the throughput and packet loss.

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