UNIVERSITI PUTRA MALAYSIA

OPTIMIZED SCHEME FOR FAST MOBILE IPV6 HANDOVER AND MOBILITY IN IEEE 802.16 NETWORK

SEYYED MASOUD SEYYEDOSHOHADAEI

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By

SEYYED MASOUD SEYYEDOSHOHADAEI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

April 2013

DEDICATION

To

my dearest family,

my kindest Wife, Shahrzad,

my lovely daughter, Tandis,

my sweet son, Arta,

my mother and father, for their encouragement

…in all love, humility, and gratitude

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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April 2013

Chairman: **Professor Borhanuddin Mohd Ali, PhD**

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The IEEE 802.16 standard defined mobility capability to cover the physical (PHY) and Medium Access Control (MAC) layer and intra-domain mobility. When the FMIPv6 is utilized for inter-domain mobility in WiMAX, reducing the handover latency and packet loss are still two major challenges in order to realize seamless handover. Long Latency is the main problem of previous schemes especially for real-time applications such voice over IP (VOIP) and video streaming. In addition, previous schemes cannot guarantee predictive mode for high speed users and handle handover in reactive mode with longer latency than predictive mode. To reduce overhead of handovers in group mobility in WiMAX network, a protocol such as Network Mobility Basic Support (NEMOBS) is required. However, utilizing NEMOBS in WiMAX network causes handover latency due to consequent layer-2 and layer-3 handover execution. This latency is not negligible for real-time applications.

To address these issues, this thesis proposes an Optimized Fast Handover Scheme (OFHS) and an Optimized Fast NEMO (OFNEMO) that will support inter-domain handover and network mobility in IEEE 802.16e network respectively. In OFHS, a pre-established multi-tunnel concept is adapted to prepare for handover in advance. Both link layer handover procedure in IEEE 802.16e and IP layer handover procedure in FMIPv6 are blended and the messages of both layers are interleaved effectively to reduce handover latency. This scheme uses cross layer design and cross function optimization. In OFNEMO the messages of handover procedure in both layer-2 in IEEE 802.16 and layer-3 in the NEMOBS are merged. In addition, preparation and pre-established multi-tunnel concept are used to reduce service disruption time. In both OFHS and OFNEMO, the time consuming reactive mode is eliminated and a semi-predictive mode which results in better performance is designed.

Performances of proposed schemes have been evaluated through numerical timing model, cost analysis model (considering probability of predictive mode failure) and simulation scenarios through QualNet v5.0 simulator. All three evaluation methods were applied to the proposed schemes and related standard works published as RFC5270 and RFC3963 respectively. The simulation results show that the OFHS predictive mode reduces at least 6.3% of total handover time and 40% handover latency compared to RFC5270 predictive mode. Also, OFHS semi-predictive mode reduces 9% of total handover time and 72% handover latency compared to RFC5270 reactive mode. OFNEMO reduces 11% of total handover time and 91% handover latency in predictive mode, and 6% total handover time and 73% handover latency in

semi-predictive mode respectively, compared to RFC3963. In addition, the proposed protocols increase probability of predictive mode which has better performance than reactive mode, even for high speed movement.

The results demonstrate that OFHS and OFNEMO can optimize inter-domain handover procedures to achieve lower handover latency, reduced packet losses and increased probability of predictive mode. Hence, with this improvement, the OFHS and OFNEMO should be able to provide seamless communications for high speed mobile users, and support network mobility in WiMAX.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SKIM OPTIMUM UNTUK IPV6 MUDAH ALIH PANTAS DAN RANGKAIAN MUDAH ALIH DALAM RANGKAIAN IEEE802.16

Oleh

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Piawaian IEEE 802.16 mendefinisikan keupayaan pergerakan untuk meliputi lapisan fizikal (PHY) dan Kawalan Capaian Medium (MAC), dan mobiliti dalam-domain. Apabila FMIPv6 digunakan untuk mobiliti antara-domain dalam WiMAX, pengurangan pendaman serahan dan kehilangan paket masih menjadi dua cabaran utama untuk merealisasikan serahan lancar. Pendaman yang panjang adalah masalah utama pada skima terdahulu terutama untuk aplikasi masa-nyata seperti Suara atas IP (VoIP) dan pengaliran video. Selain dari itu, skima-skima terdahulu tidak dapat memastikan mod ramalan untuk pengguna kelajuan tinggi dan sebaliknya mengendalikan serahan dalam mod reaktif dengan pendaman yang lebih lama dari mod ramalan. Untuk mengurangkan overhed serahan dalam mobility kumpulan dalam rangkaian WiMAX satu protocol seperti Sokongan Asas Mobiliti Rangkaian atau Network Mobility Basic Support (NEMOBS) adalah diperlukan. Walau

bagaimanapun, NEMOBS memberi kesan yang negatif ke atas prestasi pendaman pergerakan, ia itu yang tidak boleh diabaikan untuk aplikasi masa-nyata.

Untuk menangani isu-isu ini, tesis ini mencadangkan satu skim optimum untuk penyerahan pantas Optimized Fast Handover Scheme (OFHS) dan Optimized Fast NEMO (OFNEMO) yang boleh menyokong serahan antara-domain dan pergerakan rangkaian dalam rangkaian IEEE 802.16e masing-masing. Dalam OFHS, suatu konsep bebilang terowong yang ditubuh terlebih awal adalah diterima pakai untuk bersiap-sedia membuat penyerahan terlebih dahulu. Kedua-dua prosedur serahan lapisan pautan dalam IEEE 802.16e dan prosedur serahan lapisan IP dalam FMIPv6 digabungkan dan risalah relatif kedua-dua lapisan adalah disalingpintal dengan berkesan untuk mengurangkan pendaman.. Skim ini menggunakan rekabentuk lapisan bersilang , dan pengoptimuman bersilang fungsi. Dalam OFNEMO risalah prosedur penyerahan untuk kedua-dua lapisan-2 dalam IEEE 802.16 dan lapisan-3 dalam NEMOBS adalah digabungkan. Selain itu, mekanisme persediaan dan konsep berbilang-terowong dibentuk-dahulu, digunakan untuk mengurangkan tempoh gangguan perkhidmatan. Dalam kedua-dua OFHS dan OFNEMO, mod reaktif yang memakan masa adalah dihapuskan dan mod separa-ramalan yang menatijah prestasi yang lebih baik adalah direkabentukkan.

Prestasi skim cadangan ini telah dinilai melalui model masa numeric, model analisis kos (mengambil kira kebarangkalian kegagalan mod ramalan) dan senario simulasi melalui simulator QualNet v5.0. Kesemua tiga kaedah penilaian telah diaplikasikan kepada skim yang dicadangkan dan kerja-kerja piawaian yang diterbitkan sebagai RFC5270 dan RFC3963 masing-masing. Hasil keputusan simulasi menunjukkan bahawa OFHS mod ramalan mengurangkan sekurang-kurangnya 6.3% jumlah masa serahan dan 40% pendaman serahan dibandingkan dengan mod ramalan RFC5270.

Juga, OFHS mode separa-ramalan mengurangkan 9% jumlah masa serahan dan 72% pendaman serahan berbanding dengan RFC5270 mod reaktif. OFNEMO mengurangkan 11% daripada jumlah masa serahan dan 73% pendaman serahan dalam mod separa-ramalan masing-masing berbanding dengan RFC3963. Sebagai tambahan, protokol cadangan ini meningkatkan kebarangkalian mod ramalan yang mempunyai prestasi lebih baik dari mod reaktif, walaupun dalam kelajuan tinggi.

Hasil keputusan menunjukkan bahawa OFHS dan OFNEMO boleh mengoptimumkan prosedur penyerahan antara-domain untuk mencapai pendaman serahan lebih rendah, kehilangan paket yang lebih kecil dan kebarangkalian mod ramalan yang lebih tinggi. Oleh itu, dengan pembaikan ini, OFHS dan OFNEMO seharusnya mampu memberi komunikasi lancar untuk pengguna WiMAX berkelajuan tinggi, dan menyokong pergerakan rangkaian.

Kata kunci- penyerah mudah alih yang laju, penyerahan kependaman, IEEE 802.16, mobiliti jaringan, terowong wujud-semula, WiMAX.

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I certify that a Thesis Examination Committee has met on (5/5/2013) to conduct the final examination of Seyyed Masoud Seyyedoshohadaei on his thesis entitled "Optimaized Scheme for Fast Mobile IPv6 Handover and Network Mobility In IEEE 802.16 Network" in accordance the with Universities and University Colleges Act 1971 and the Constitution of Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at University Putra Malaysia or other institutions.

SEYYED MASOUD SEYYEDOSHOHADAEI

Date:

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LIST OF ABBREVIATIONS

AES	Advanced Encryption Standard
AP	Access Point
AR	Access Router
ASN	Access Services Network
BPSK	Binary Phase Shift Keying
BS	Base Station
BSID	Base Station Identifier
BSS	Basic Service Set
BU/BA	Binding Update & Acknowledgement
CBR	Constant Bit Rate
CN	Correspondent Node
CoA	Care-of-Address
CSN	Connectivity Services Network
DAD	Duplicate Address Detection
DES	Data Encryption Standard
ETSI	European Telecommunications Standards Institute
FBU/FBAck	Fast Binding Update & Acknowledgement
FDMA	Frequency Division Multiple Access
FHMIPv6	Fast Handover for Hierarchical Mobile IPv6
FMIPv6	Fast Handover for Mobile IPv6
FNA	Fast Neighbor Advertisement
HA	Home Agent
Hack	Handover Acknowledge

HI	Handover Initiation
HI/HAck	Handover Initiation & Acknowledgement
HIPERMAN	High Performance Radio Metropolitan Area Network
HMIPv6	Hierarchical Mobile IPv6
HoA	Home-of-Address
HARQ	Hybrid Automatic Repeat Request
IEEE	Institute of Electrical and Electronic Engineering
IETF	Internet Engineering Task Force
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ITU	International Telecommunication Union
LHI	Link Handover Impend
LSW	Link Switch
LUP	Link Up
LOS	Line of Sight
MAC	Media Access Control
MAG	Mobile Access Gateway
MAP	Mobility Anchor Point
MIH	Media Independent Handover
MIMO	Multiple-in Multiple-out
Mipshop	Mobility for IP, services, handover, performance
MIPv6	Mobile Internet Protocol version 6
MN	Mobile Node
MR	Mobile Router
MS	Mobile Station

NAR	**N**ew Access Router
NCoA	**N**ew Care-of-Address
NEMO	Network Mobility
NEMOBS	Network Mobility Basic Support
NLD	Link Detected
NLOS	Non Line Of Sight
NRM	Network Reference Model
NWG	Network Working Group (WiMAX Forum)
OFDMA	Orthogonal Frequency Division Multiple Access
OFNEMO	Optimized Fast Network Mobility
PAR	Previous Access Router
PDA	Personal Digital Assistant
PDN	Packet Data Network
PHY	Physical Layer
PMIPv6	Proxy Mobile IPv6
PrRtAdv	Proxy Router Advertisement
QAM	Quadrate Amplitude Modulation
QPSK	Quadrate Phase Shift Keying
QoS	Quality of Service
RA	Router Advertisements
RIPng	Routing Information Protocol next generation Open
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunication System
UNA	Unsolicited Neighbor Advertisement
VoIP	Voice over IP

WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network

CHAPTER 1

INTRODUCTION

1.1 Overview

The telecommunication infrastructures that were dependent on wires, fiber optic cable, coaxial cable or twisted pair copper wire make movement limited for data users. Hence, users do not able to roam around while using the twice. In past decades, wireless communications technologies have developed very fast due to the increasing demands for various multimedia applications, with varying quality services and mobility. Using more mobile devices, such as sensors, smart phones, tablets and laptops, has driven demand for novel wireless network with higher data rate services, higher efficiency, lower cost and faster mobility support for anytime and anywhere this gives rise to Broadband Wireless Access (BWA) systems.

Among many standards that are available, Worldwide Interoperability for Microwave Access (WiMAX) is one of the utilized technologies for BWA. WiMAX Forum defines the name "WiMAX" and network architecture of WiMAX which was created in 2001. Consortiums of industrials make up the WiMAX Forum that was formed with an objective to certify the WiMAX products.

WiMAX is based on an emerging broadband wireless standard which is called Wireless Metropolitan Area Networks (WMAN) or 802.16 family of standards. It was started by

Institute of Electrical and Electronic Engineers (IEEE) in 2001. The ease of application and low cost of installation are the main attractive features of IEEE 802.16 (IEEE 802.16, 2001) which is particularly useful in the rural areas where there is not much availability of wired infrastructure or in crowded metropolitan areas where development of wired infrastructure would be complicated. The most attractive aspect of WiMAX is the mobility capability that IEEE 802.16e (IEEE 802.16e, 2005) standard adds to the previous standard. Upon mobility support was added to the standard, handover has become one of the most important factors that influence the performance of IEEE 802.16e system. Handover is the process where the active sessions of the Mobile Station (MS) are maintained as it changes its attachment point to the access network. When the MS migrates from one Base Station (BS) to another, handover occurs in order for the ongoing session to continue. However during hard handover, for a short time interval, the MS cannot send or receive any packets. This time interval is called handover latency. Handovers are broadly classified into two categories; hard handover and soft handover. There are further two categories of the hard handover; the intra-domain and inter-domain handover.

WiMAX supports several movement scenarios which need particular handover procedures. When a MS changes its location, it changes the point of attachment to the network in two difference scenarios. They are namely,

- Micro-mobility, Access Services Network (ASN)-anchored, intra-domain or layer-2 handover. This occurs when MS or Mobile Node (MN) changes its air interface attachment between the BSs under the same ASN. The base station in the handover is located in the same IP subnet in the case of link layer handover. The IP configurations are not changed when the terminal only requires re-establishing a link layer connection with the new base station.

- Macro-mobility, Connectivity Services Network (CSN)-anchored, inter-domain, or layer-3 handover. This occurs when the MS changes its air interface attachment between the BSs under different ASNs (different IP subnets). A MS must establish both a new link layer connection in an IP configuration, with a new IP configuration to maintain the connectivity.

The intra-domain handover procedure requires support from the physical and MAC layers. Layer-3 handover algorithm is also required to support the IP addressing during the inter-domain handover although; the IEEE 802.16 has its own MAC layer or layer-2 handover algorithm. Mobile IP is a typical protocol in network layer for mobile terminals, which can be Mobile IPv4 (MIPv4) (Perkins, 2002) or Mobile IPv6 (MIPv6) (Johnson, et al., 2004). These have been standardized by the Internet Engineering Task Force (IETF) in 2002 and 2004, respectively.

Since MIPv6 is designed for supporting the mobility of single mobile hosts, the Network Mobility (NEMO) Working Group of IETF extended it for supporting the mobility of networks. The NEMO Working Group in IETF standardized NEMO Basic Support (NEMOBS) protocol (Devarapalli, 2005), as an extension of the MIPv6 protocol. This is concerned with the mobility of an entire network which dynamically changes its point of attachment to the Internet. The mobility functionality is moved from MS to a mobile network's router or Mobile Router (MR) by the NEMOBS protocol.

There are many problems with MIPv4, such as triangular routing, security and limitation of address space which are now solved by using MIPv6. But there still remain some problems, such as handover latency, packet loss and signaling overhead.

The handover latency problem is not solved by the MIPv6 and leads to a long latency problem which cannot be neglected for real time application like Voice over IP (VoIP) and video streaming. The solution to the problem of MIPv6 handover latency was proposed through the use of Hierarchical Mobile IPv6 (HMIPv6) (Soliman, 2007), Proxy Mobile IPv6 (PMIPv6) (Gundavelli, 2008) and Fast Mobile IPv6 (FMIPv6) (Koodli, 2005 and Koodli, 2009).

The FMIPv6 was standardized in 2005 by MIPv6 Signaling and Handoff Optimization (MIPSHOP) working group of IETF. FMIPv6 can reduce the handover latency and packet loss by mobility detection, creating new address for the target network and receiving data through tunneling in advance. It is a difficult task to design an effective handover to handle all sorts of mobility with minimum latency owing to the IP addressing and the complicated mobility pattern in WiMAX. WiMAX Forum also seems interested in the aspect of deploying IPv6 over WiMAX. To effectively coordinate the FMIPv6 handover algorithm in layer-3 with handover algorithm of the IEEE 802.16 system in layer-2, many proposals have been introduced. The usage of FMIPv6 to decrease latency of inter-domain handover for both the MS and MR in

WiMAX network will be studied in detail in this thesis finding out methods for its optimized usage. This chapter discusses the research problems and motivation, establishes its objectives and defines its scope.

1.2 Research Motivation and Problem Statement

In the inter-domain handover, layer-3 prepares IP handover and the MAC and PHY layers support the procedure by providing information and triggers. Support for the inter-domain handover in the WiMAX can be provided through the usage of MIPv6 handover algorithm in the layer-3 with handover algorithm of the IEEE 802.16 in layer-2. If these are performed serially (Figure 1.1), it causes a long latency problem which is not negligible for real-time applications.

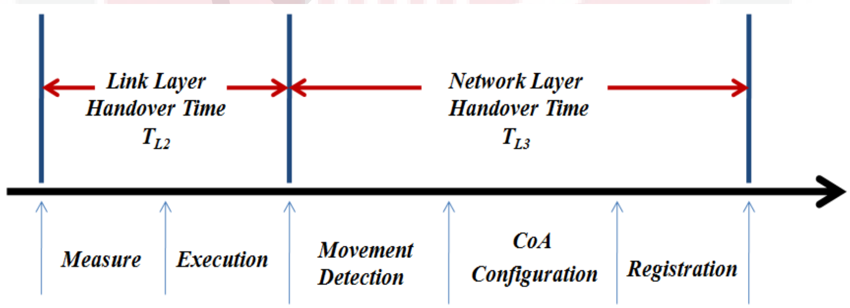

Figure 1.1. Handover Latency of Layer-2 and Layer-3

The layer-2 and layer-3 handover latency are involved in the overall handover delay in MIPv6 and NEMO. The time spans when the MN/MR is disconnected from the link of the current Access Router (AR) till the time it successfully accesses the link of the new AR is called the layer-2 handover latency. The latencies that occur during the processes of Care of Address (CoA) configuration, IP layer movement detection, network re-authentication, and Binding Update (*BU*) are all included in the category of layer-3 handover latency.

In FMIPv6, several techniques are employed to perform actions to exchange handover information between two ARs in advance. The FMIPv6 reduces the handover latency by executing those time consuming processes when MS is still present on the current link. The proactive mechanism which was used in FMIPv6 can also be used to reduce latency of the NEMO protocol. Using the FMIPv6 in IEEE 802.16e networks reduces overall handover latency of IP handover. The application of FMIPv6 handover algorithm in the IEEE 802.16e environments can be done through the various schemes which are explained in the next section. One of the biggest challenges faced in the mobile WiMAX includes the issue of reducing the handover latency in the IP layer for the high speed MS, especially for real time application's support. The handover latency and packet loss can be reduced further by introducing more improvements in handover procedure.

With the growing demand of using WiMAX as a broadband communication technology, providing seamless communication for high speed movement users, preparing real-time application services and supporting network mobility are the main motivations of this research. This thesis presents an approach to further optimize the handover schemes. The problem statements of this thesis can be stated as follows:

- To achieve a high standard of real time quality, it is essential that continuous network connectivity is provided. The voice quality in the VOIP applications and the video quality in the video streaming are affected by the continuous disruptions or intermittent discontinuation of transmission due to the excessive handover processing of current standard protocols. Handover latency in consequence of duplicate address detection and handover messages exchange increases service disruption time and packet loss. Hence, there are still issues in the handover latency of current schemes in the IP layer handover in IEEE802.16 networks to support real-time applications, which in turn degrades the quality of real time applications.

- There are two ways in which the mobility is dealt by the current schemes that use the FMIPv6 for layer-3 protocol in WiMAX handover. These are predictive and reactive modes, respectively. Handover will proceed in the predictive mode when a sequence of preparation messages has been received on time. The handover procedure will be continued in the reactive mode when the messages are delayed or lost which will lead to long delays. The probability of using predictive mode is reduced when the MS moves at high speed which means the handover is handled in a reactive mode and as a result latency cannot be acceptable for real time applications.

- When using NEMOBS for group mobility in WiMAX, long latencies are induced due to serial handover execution of layer-2 and layer-3, therefore an effective handover scheme is needed to support NEMO in WiMAX systems.

In addition, the path to commercialization of WiMAX mobility framework is full of research challenges. Potential handover-related research issues in the existing and future WiMAX mobility framework has been described in (Ray, et al., 2010). The MWiMAX Handover Research Issues classified by (Ray, et al., 2010) is shown in Figure 1.2.

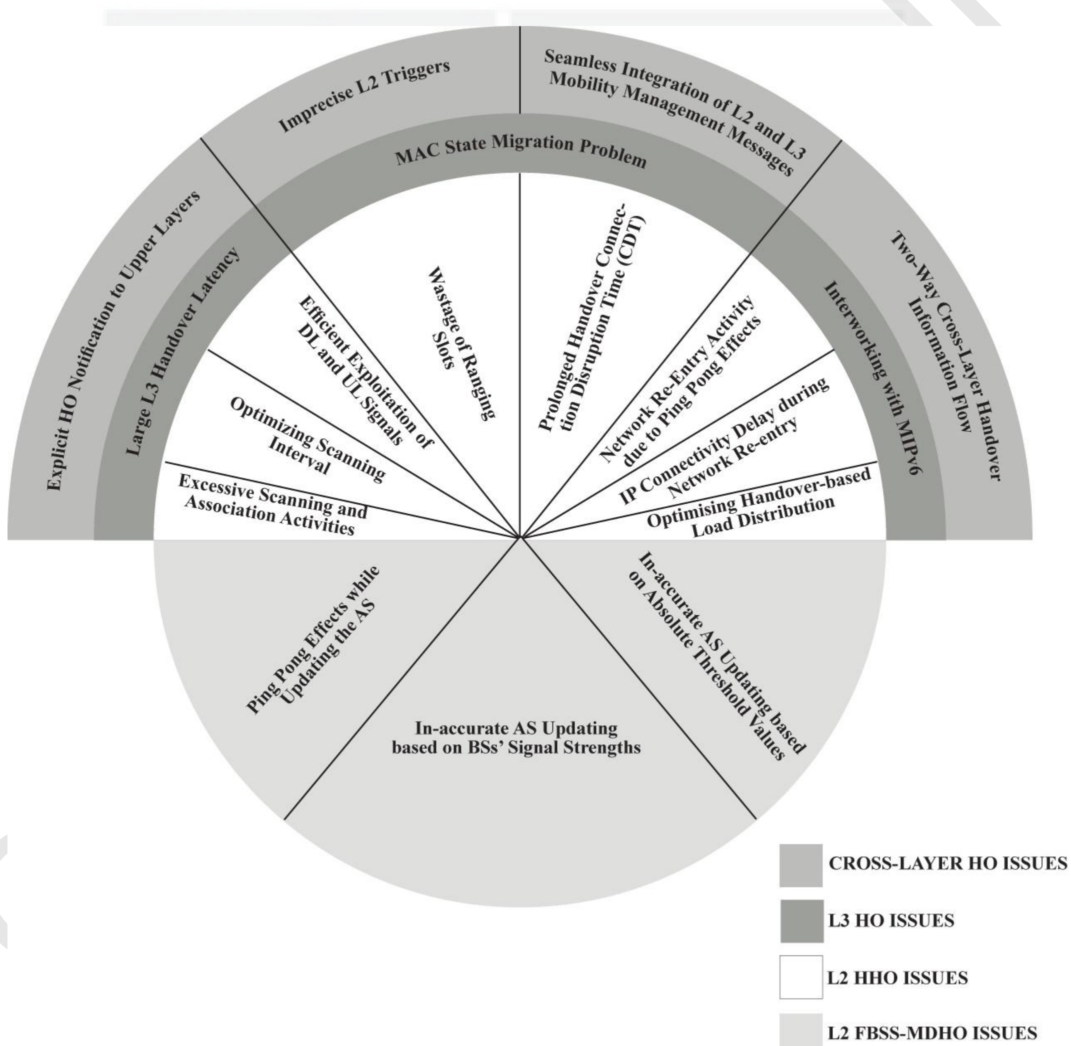

Figure 1.2. Mobile WiMAX Handover Research Issues (Ray, et al., 2010)

1.3 Research Objectives

This thesis proposes an effective handover scheme for the IP layers in WiMAX (IEEE 802.16) network. It focuses on issues such as handover latency, packet loss and probability of predictive mode in WiMAX inter-domain handover for both mobile nodes and mobile routers, thus objectives of this thesis can be stated as follows:

1. To design an optimized protocol for inter-domain handover in Mobile WiMAX networks to reduce handover latency and achieve lower packet loss and higher probability of predictive mode compared to the standard schemes by utilizing pre-establish multi-tunnel, cross layer and cross function optimization.

2. To design a new protocol to support mobile router handover in Mobile WiMAX networks. The protocol defines network mobility in IEEE 802.16 network to reduce handover latency and packet loss compared to the standard schemes by using pre-established multi-tunnel, cross layer concept and cross function of layer-2 and layer-3 messages.

3. To develop a cost analysis for network overhead investigation that is caused by newly proposed protocols compared with the standard schemes.

1.4 Research Scope

The inter-domain hard handover which includes layer-2 and layer-3 handover will be addressed in this thesis. Layer-2 handover procedure has been explained in IEEE 802.16. The FMIPv6 was however applied on layer-3 handover protocol. This thesis primarily focuses on how FMIPv6 can be used as IP layer protocol to support macro-mobility in the IEEE 802.16 networks. Introduction of the protocol to support group mobility by defined handover procedure for mobile router will also be focused upon in this thesis. Route optimization will not be included in this thesis and all traffic between CN and the MS passes through the HA. Figure 1.3 depicts the scope of this thesis that highlights the related field and outcome schemes.

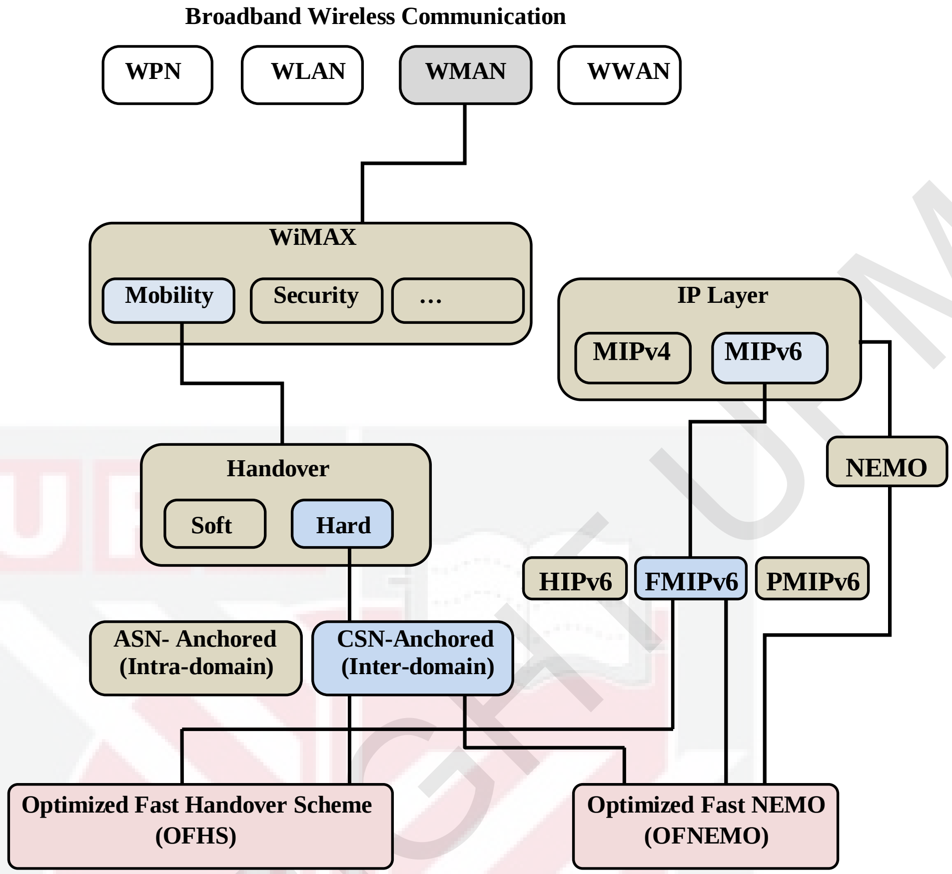

Figure 1.3. Research Scope

1.5 Contributions

The main contributions of this thesis are as follows:

a. The integration of messages in layer-2 and layer-3 which helps to reduce traffic overhead while performing the handover process.

b. The omission of some control messages which are exchanged between wireless parts and the introduction of new messages in the wired parts of network, which helps to reduce delays further.

c. A method to pre-establish multi-tunnel mechanism to prepare tunnels in advance to reduce the overall handover delay caused by the FMIPv6 Duplicated Address Detection (DAD) test.

d. The use of predictive mechanism similar to FMIPv6 in NEMO in order to get the channel ready while layer-2 and layer-3 handover are taking place.

e. The cross-layer scheme which incorporates handover procedures of layer-2 and layer-3 and coincident the processes of both layers.

1.6 Organization of Thesis

The introduction to the study, research scopes, the problem statement, research objectives, contributions and outline of thesis are presented in the first chapter. The thesis is organized according to the chapters which are explained below:

The background about basic concepts of the MIPv6, FMIPv6, NEMO and IEEE802.16 is expressed in the Chapter 2. The literature review on the current and the past research on the IP handover in WiMAX network are also included in this chapter.

The methods proposed are stated in the Chapter 3. The optimized scheme of FMIPv6 over IEEE 802.16e standard is presented in this chapter. It will also explain the timing model, cost analysis and simulation of proposed method (OFHS) and current standard method in FMIPv6 over IEEE 802.16 (RFC5270). The second part will describe the optimized scheme for NEMO in IEEE 802.16 that was designed using the same concepts. Chapter 3 will also give details about aspects such as timing model, cost analysis and simulation of proposed NEMO solution (OFNEMO) and current NEMO protocol (RFC3963) in IEEE 802.16 network (NEMOBS).

Chapter 4 discusses the results of the analytical model and simulations. The performance is evaluated by comparing the results of the current RFCs and the proposed optimized schemes.

Chapter 5 gives the main conclusions of this thesis and states the recommendations for future research.

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