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Dedication

To the loving memory of my late mother who left us during the final stages of this thesis. To my father who always has been my inspiration, my grandmother the oldest of our family, my niece Amina the youngest of our family and the rest of my family.

Muhammad Qasim Khan

Abstract

The most prevailing feature that led to the massive success of current *Wireless Mobile Tele-Communication* systems, is mobility. Being able to communicate on the go, anywhere and anytime has revolutionized modern day communication. In recent times the focus has not been only on simply being reachable while on the move but at the same time to use a variety of rich media content services over a variety of available network technologies, termed as *4G networks*. The telecommunication development from the very beginning took two different tracks. One was the Internet which provided a fixed means of communication delivering rich media content taking full advantage of its packet switched nature. The second track was that of the cellular systems taking advantage of their circuit switched nature providing mainly voice and short messaging services to wireless and mobile users. In time both these technologies made major advances following their own respective tracks and it became evident that the convergence of both these technologies would be of even greater value. The driving force for this convergence was that a great need was felt for the support of mobility in the Internet. But since the Internet was not designed keeping mobility in mind, it did not support mobility by design. On the other hand in cellular systems in addition to circuit switching, packet switching was needed for flexibility, to make better use of network resources, and to deliver rich media content to the user at cheaper prices.

For non-mobile user's, packet switched networks performed really well in providing the required *Quality of Service (QoS)*. However such networks faced considerable problems to achieve similar QoS for mobile users. With no support for mobility in the Internet from scratch, new components and functionalities were needed to be incorporated into the Internet for mobility support. Examples of such functionality include *location tracking, network discovery, packet re-routing* to the current point of attachment of the Mobile Node (MN), *accounting, authorization* and *authentication*. Special mobility management protocols to provide the required new functionalities were needed. For this purpose the Internet Engineering Task Force (IETF) proposed *Mobile IP version 4 (MIPv4)* and *Mobile IP version 6 (MIPv6)* to support mobility for a single IP host and *Network Mobility (NEMO)* protocol to support mobility for a whole network in motion. These protocols have the ability to maintain data connections for mobile IP enabled devices when they roam across different subnets or networks. When a mobile user moves across network boundaries, it has to perform handover to maintain its connections. When performing a handover a MN may not be able to send or receive data packets therefore the handover duration becomes a critical factor in guaranteeing real time applications (e.g. *Voice over IP (VoIP)*) their QoS.

The purpose of this research work is to deal with handover issues in packets switched networks. A stepwise approach was followed during this study. Starting at layer-2 of the TCP/IP protocol stack and after identifying major problems at this layer for 802.11 networks, solutions were devised for seamless handovers by utilizing the *Media Independent Information Service (MIIS)* of the *Media Independent Handover (MIH)*.

After dealing with major handover issues at the *MAC* layer of 802.11 networks, the work moved one layer up in the TCP/IP protocol stack to *layer three* or the *IP layer*. The MIH framework which was originally proposed for vertical handovers is proposed to be utilized for improving the efficiency of horizontal handovers. Keeping the research work focused on horizontal handovers in 802.11 networks only, an Access Point (AP) selection scheme is proposed and an investigation was carried out regarding the implications of proposed solutions at the MAC layer, on MIPv6 handover delays.

In the next step, the study is extended to vertical or heterogeneous handovers. This part proposes to *break up* a heterogeneous handover algorithm in a Wi-Fi/WiMAX integrated environment, into *two* parts. The handover algorithm parts are proposed to be executed separately from each other *distributed* among multiple network components, resulting in intelligent resource utilization and good scalability, without sacrificing handover efficiency.

For proof of concept and the effectiveness of the proposed schemes simulations were performed in *Network Simulator-2 (ns-2)* for a scenario in which a MN moves linearly in the topology, performs handovers and makes use of MIH facilities for improved handovers.

An important portion of this research also deals with the *analysis* of a variety of NEMO route optimization schemes proposed in the literature and their implications on handovers in NEMO networks. The goal of this part is to overview the handover signaling complexity of the various proposed NEMO route optimization schemes.

Preface

This thesis is submitted to the *Norwegian University of Science and Technology (NTNU)* for partial fulfillment of the requirements for the degree of philosophiae doctor.

This doctoral work has been performed at the *Department of Telematics, Faculty of Information Technology, Mathematics and Electrical Engineering NTNU, Trondheim*, with Professor **Steinar Hidle Andresen** and co-supervisor Professor **Poul Einar Heegaard**. This work has been carried out in the period *August 2008 to April 2012*.

Acknowledgements

I wish to thank my supervisor Professor *Steinar Hidle Andresen* for his invaluable supervision. It is due to his able guidance that I was able to transform a collection of ideas into a PhD thesis. I would also like to thank my co-supervisor and head of the department Professor *Poul Einar Heegaard* for his inputs to this thesis. It has been a pleasure to work with Professor Lill Kristiansen. Special thanks are given to Randi Schrøder Flønes and Mona Nordaune for their support and cooperation. I appreciate and acknowledge the technical support from our department engineer Pål Sturla Sæther. Pål has also been my colleague for a short time when I was working in the *NETLab* project at the department of Telematics. Thanks to the National Institute of Standards and Technologies (NIST) and open source community for making their software modules used in this thesis, publicly available for the scientific community.

I offer a special gratitude to my colleagues and friends, with whom I have shared the ups and downs of this research and life in general. It has been a pleasure to work at the department of Telematics and pleasant memories of the department, the people I met and worked here with, will accompany me for a lifetime.

Contents

Acronyms

AHP Analytical Hierarchical Process.

AP Access Point.

BS Base Station.

C-CoA co-located CoA.

CDMA Code Division Multiple Access.

CoA Care of Address.

DHCP Dynamic Host Control Protocol.

FA Foreign Agent.

FA-CoA Foreign Agent CoA.

GRA Grey Relational Analysis.

HA Home Agent.

IETF Internet Engineering Task Force.

ITU International Telecom Union.

MADM Multiple Attribute Decision Making.

MAHO Mobile Assisted Handover.

MCHO Mobile Controlled Handover.

MICS Media Independent Command Service.

MIES Media Independent Event Service.

MIH Media Independent Handover.

MIHF Media Independent Handover Function.

MIHO Mobile Initiated Handover.

MIIS Media Independent Information Service.

MIP Mobile IP.

MIPv4 Mobile IP version 4.

MIPv6 Mobile IP version 6.

MN Mobile Node.

MR Mobile Router.

NAHO Network Assisted Handover.

NCHO Network Controlled Handover.

NEMO Network Mobility.

NIHO Network Initiated Handover.

NIST National Institute of Standards and Technology.

NS-2 Network Simulator 2.

PMIP Proxy Mobile IPv6.

QoS Quality of Service.

RO Route Optimization.

RSS Received Signal Strength.

SAW Simple Additive Weighting.

SLA Service Level Agreement.

TCP Transmission Control Protocol.

TOPSIS Technique for Order Preference.

UMTS Universal Mobile Telecommunication System.

VoIP Voice over IP.

Wi-Fi Wireless Fidelity.

WiMAX Worldwide Interoperability for Microwave Access.

Part I

Introduction

Chapter 1

Thesis Introduction

Wireless and mobile networks have affected our lives in an unprecedented manner. Today there are several wireless and mobile networking technologies such as such as *Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunication System (UMTS), Code Division Multiple Access (CDMA)*. All these technologies are distinct from each other in many aspects such as network architecture, Quality of Service (QoS), coverage area, mobility support and bandwidth. Recently the vision has been the *convergence* of these technologies. The convergence is expected to result in flexible and customizable communication means, allowing the users to connect to a network that best fit their needs. For example a user might want to connect to a low price, high bandwidth 802.11 network at home or in the office, and to a wide area network like WiMAX or UMTS when driving his/her vehicle on the highway at a high speed. This convergence apart from architectural issues faces many other technical challenges, from *network selection* and *handover* point of view. The latter is the subject of this thesis and has been one of the most important and critical factor in providing QoS in wireless and mobile packet switched networks.

1.1 Motivation

Handover Efficiency

In wireless and mobile networks handovers are inevitable. As the Mobile Node (MN) may not be able to exchange data packets, when performing a handover, the handover delay becomes critical in guaranteeing real-time applications their QoS requirements. The *International Telecom Union (ITU)* has specified that this delay should not be more than 50 ms to avoid jitter in Voice over IP (VoIP) applications [1]. Thus there is a need to reduce the handover failure probability, by reducing the handover latency and packet loss to values that are tolerable by the MN's applications during handovers. If handover latency is too long, it might cause the existing *Transmission Control Protocol (TCP)* connections of the MN to break and result in poor voice quality for VoIP applications. Therefore the handover delay is an important metric in evaluating network performance for mobile users.

Ideally there should be absolutely no disruption when a MN moves and changes its point of attachment to the network and handovers must exhibit low handover delay, low packet loss and good scalability [2]. In communication networks a handover might occur in different scopes (e.g. *horizontal handovers or vertical handovers, MAC layer or IP layer*). Regardless of the scope the user must be provided with the desired QoS of the currently active applications taking into consideration user preferences. According to ITU recommendations Y.1541 [3], highly interactive VoIP applications require a class-0 QoS, characterized by a jitter that does not exceed 50 ms and a network latency (packets delay) of about 100 ms. Thus it is highly desirable that the end to end packets latency is deterministic to some extent and that the variance in packet delays is kept less than 50 ms. For class-1 type traffic network delay of up to 400 ms is acceptable according to ITU.

The handover mechanism needs to be understood in its scope to identify potential problems and to devise solutions to those problems. For example in a MAC layer handover in 802.11 networks, a major contributor to the overall MAC layer handover delay is channel scanning discussed in more detail in Section 2.2.1. In IP layer handovers the configuration of new IP address, authentication and the re-direction of IP flows to the new address are crucial. Total handover delay is the sum of handover delays at all layers. Different types of applications have different QoS requirements and their network selection preferences vary. For example for a real time service like VoIP packet delays and jitter might be more important than excessive bandwidth, but for a non-real time service such a file download, packets delay and jitter might not be as critical as excessive bandwidth. Apart from active applications, human users might have their own preferences regarding the desired QoS, usage cost of a particular service and its availability. It is obvious that heterogeneity does not only exist in the QoS provided by different types of media (i.e. 802.11, 802.16) but also in applications QoS needs and user preferences.

1.2 Research Objectives

In terms of objectives this work can be divided into two major branches.

1. *Devising optimized handover solutions for mobile nodes.*
2. *The analysis of handover signaling of different Route Optimization (RO) schemes proposed in the literature for mobile networks.*

For the former this research focuses on handover issues within packet switched wireless and mobile networks (Wi-Fi, WiMAX). The purpose here is to evaluate the protocol mechanism of 802.11 and Media Independent Handover (MIH) and to propose how handover mechanisms can be made more seamless by using MIH services, more specifically by the use of Media Independent Information Service (MIIS) services. In this regard a variety of handover cases have been taken into account, starting with horizontal handovers at the MAC layer, moving one level up in the TCP/IP protocol stack, to consider layer three horizontal handovers and finally considering vertical handovers. Crucial parameters for handover performance include *round trip times, packet loss, volume of updates and control messages, throughput and handover latency*. These parameters are studied carefully and optimized handover solutions are proposed for seamless handovers across both homogeneous and heterogeneous media, with the help of MIH and the services provided by it. The goal is to design seamless handover solutions, such that all types of communication flows whether real time or non-real time are unaffected by the handover process and that the MN is always connected to the best available network. More specifically this thesis addresses the following research questions.

Question 1. How the facilities of the MIH framework can be utilized for the mitigation of scanning delays in 802.11 networks during handovers?

Question 2. How the facilities of the MIH framework can be utilized at the IP layer and above, for seamless handovers and Access Point (AP) selection in homogeneous networks?

Question 3. How the facilities of the MIH framework can be utilized at the IP layer and above, for seamless handovers and efficient network selection in heterogeneous networks?

From mobile network's point of view the main objective of the research is to study a variety of route optimization schemes proposed in the literature, in terms of their signal complexity during handovers. The objective here is not to introduce a new optimized handover solution or a new route optimization scheme, but to perform a comparative analysis study, giving an estimate of the signaling overhead of different route optimization solutions during handovers. Important parameters for this study include volume of updates messages, control messages and status messages, required by a particular route optimization scheme for its functionality. The extent to which the considered route optimization solutions require changes to network architectures is also included in the analysis. In this part this thesis attempts to answer the following question.

Question 4. What is the cost of the important Network Mobility (NEMO) route optimization solutions, in terms of changes required to the functionality of network components and to the architecture of mobile networks? What is the efficiency of these solutions in terms of reduction of the number of tunnels and their signaling complexity during handovers?

1.3 Research Method

In order to meet the objectives stated above for a single MN, analytical and simulation models have been used to study *packet loss, round trip times, throughput and handover latency*. For homogeneous and heterogeneous handovers utilizing *MIH*, simulations were performed using a simulation frame work built by *National Institute of Standards and Technology (NIST)* [4] as joint work with *IEEE 802.21*. This framework provides the implementation of MIH draft version 3 [5] in the form of an add-on module [6] for Network Simulator 2 (NS-2) [7] version ns-2.29. However the implementation comes with limited support for the different services provided by MIH. Both Media Independent Event Service (MIES), Media Independent Command Service (MICS) are supported but not MIIS [5]. To realize the simulations of heterogeneous networks, NIST integrated ns-2 implementations of Wi-Fi [8] and WiMAX [9] into their framework. Further extensions and improvement to the NIST module were carried out at Instituto de Telecomunicações Universidade de Aveiro in collaboration with PT Inovação [10]. Most ingredients needed (i.e. implementations of MIH, Wi-Fi, WiMAX, Mobile IP version 6 (MIPv6) etc.) for the simulations in this thesis were already present in the NIST module. Therefore apart from some needed extensions, the NIST module suited to the requirements of this work perfectly. The needed extensions and amendments were made to the NIST framework during the course of this research and constitute an important portion of this study.

The extensions were mainly made to first enable and then extend the MIIS for intelligent handovers support. The MIIS was envisioned as a dedicated node in the wired network part that had the ability to receive, store and share network topology and configuration information. This information consisted of mainly static information like Global Positioning System (GPS) coordinates and operational radio channels of BS's, but also contained dynamic information such as traffic conditions and resource availability in a particular BS. Specific functional extension made to MIIS, are the use of MN's context information like its GPS coordinates and speed, the ability to locate the MN on a virtual map of the network and to find QoS ranking of BS's. Some related messages in the existing MIH implementation of NIST were extended so that an MN can query a dedicated node in the network for MIIS services. For the research work on MAC layer handovers in 802.11 networks, the behavior of the MAC implementation of 802.11 in ns-2 was changed to make way for the implementation of the intelligent scanning strategies proposed in this thesis. The MIIS was further extended to perform mobile controlled and network assisted handovers. These extensions paved the way for the testing of the proposed PoA selection algorithm in 802.11 networks and network selection algorithm in heterogeneous networks, during handovers. Corresponding appropriate changes were made to the MN and BS implementations to make use of the MIIS during handovers. Changes and extensions that were made to the NIST module for this thesis have been summarized in Figure 1.1.

For mobile networks, signal complexity of different proposed NEMO route optimization solutions and their impact on handovers, was studied using analytical modeling. The signal complexity of each route optimization solution considered was modeled with the help of a mathematical equation, giving an estimate of its signaling overhead during handovers. A comparison among different route optimization schemes considering a variety of properties and limitations is also provided.

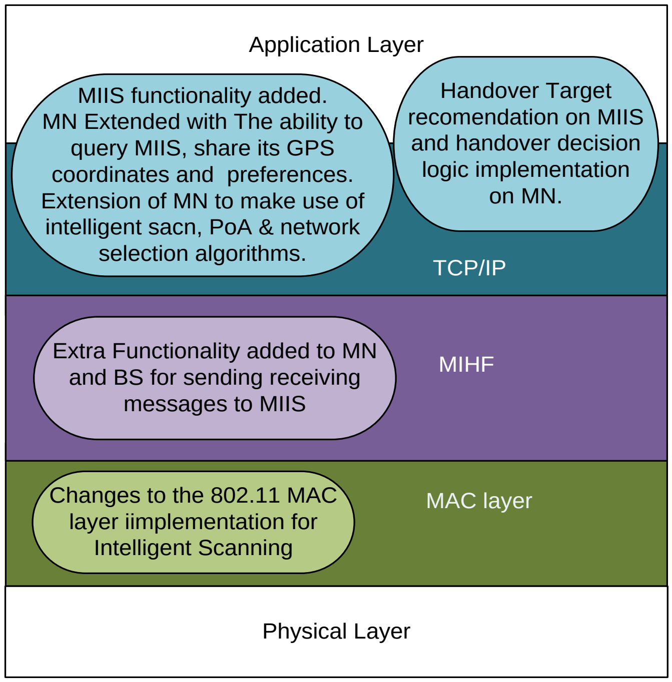

Figure 1.1: Summary of changes made to the NIST module and TCP/IP protocol suit.

1.4 Included Publications

Research papers produced as part of this research work and included in this thesis are listed in this section. The list contains both published and unpublished work and has been ordered based on the relation of the research papers to the TCP/IP protocol stack given in Figure 1.2 and to each other, and not on the basis of the date of their production or publication. The type of handovers the papers focus on is elaborated in Figure 1.3. A more detailed handover classification is provided in the next chapter.

- *Paper A :* Muhammad Qasim Khan, Steinar Hidle Andresen, "An Intelligent Scan Mechanism for 802.11 Networks by Using Media Independent Information Server (MIIS)". in proceedings of the 25th IEEE International Conference on Advanced Information Networking and Applications Workshops (WAINA 2011). IEEE Computer Society 2011 ISBN 978-0-7695-4338-3. pp. 221-225.

- *Paper B :* Muhammad Qasim Khan, Steinar Hidle Andresen, "Zero Scanning Time for 802.11 Networks by Using Media Independent Information Server (MIIS)". in proceedings of 26th IEEE International Conference on Advanced Information Networking and Applications (AINA-2012). IEEE Computer Society 2012 ISBN 978-0-7695-4651-3. pp. 467-473.

- *Paper C :* Muhammad Qasim Khan, Steinar Hidle Andresen "Application of Media Independent Handover (MIH) for Intra Technology Handover". in proceedings of the Mosharaka International Conference on Communications, Networking and Information Technology Dec 2009 Amman Jordan.

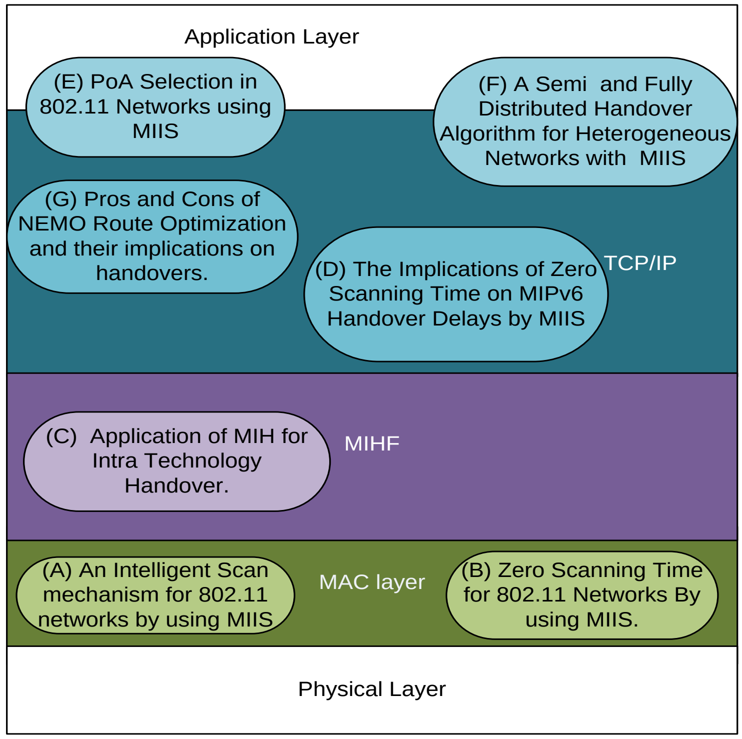

Figure 1.2: Included publications and TCP/IP protocol suit.

- *Paper D :* Muhammad Qasim Khan, Steinar Hidle Andresen, "The Implications of Zero Scanning Time on MIPv6 Handover Delays by Using Media Independent Information Server (MIIS)". in proceedings of the 17th Asia-Pacific Conference on Communications (APCC 2011). IEEE 2011. pp. 324-329.

- *Paper E :* Muhammad Qasim Khan, Steinar Hidle Andresen, "PoA Selection in 802.11 Networks using Media Independent Information Server (MIIS)". in proceedings of the 25th IEEE International Conference on Advanced Information Networking and Applications Workshops (WAINA 2012). IEEE Computer Society 2011 ISBN 978-0-7695-4652-0. pp. 454-459, doi: 10.1109/WAINA.2012.142.

- *Paper F :* Muhammad Qasim Khan, Steinar Hidle Andresen, "A Semi and Fully Distributed Handover Algorithm for Heterogeneous Networks using MIIS". in the proceedings of 17th IEEE Symposium on Computers and Communication (ISCC'12) Cappadocia Turkey 1 - 4 July 2012. IEEE Computer Society 2012 ISBN 978-1-4673-2711-4. pp 145-150 , doi: 10.1109/ISCC.2012.6249283

- *Paper G :* Muhammad Qasim Khan, Steinar Hidle Andresen, "Pros and Cons of Route Optimization Schemes for Network Mobility (NEMO) and Their Implications on Handovers". to appear in Transactions on Electrical and Electronic Engineering (IEEJ) Vol. 7 / No. 6 (November 2012 issue).

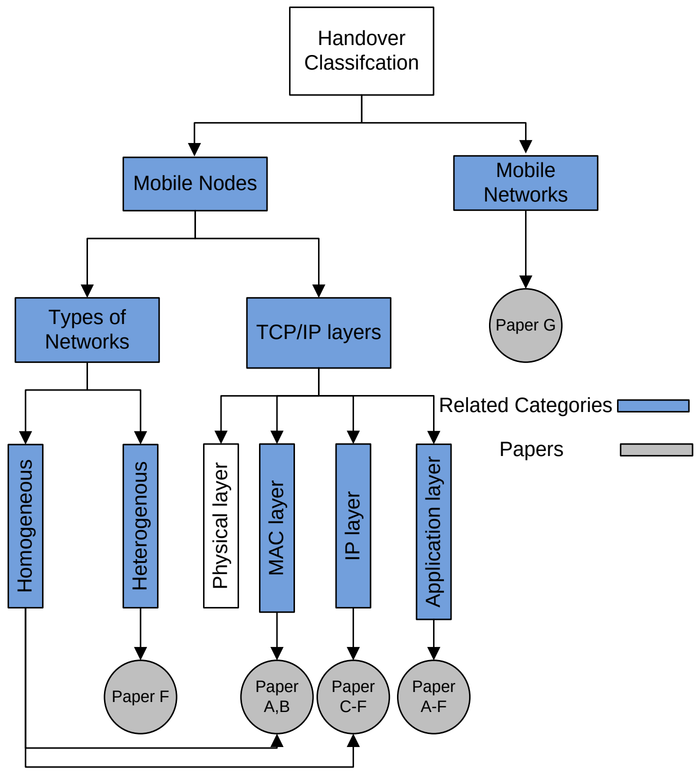

Figure 1.3: Included publications and different types of handovers.

1.5 Thesis Structure

The arrangement of this thesis has been done in three parts and each part is further sub divided into chapters. Part I consists of the first three chapters. The current chapter i.e. Chapter 1 provides the motivation for this work, main theme of the thesis and its organization. Chapter two "Background" provides introduction to the main concepts and provides definitions of important related terms. Chapter three provides the contribution of the thesis and the summary of the included individual research papers. Part II constitutes of the papers included in this thesis, in their entirety. Finally Part III contains the appendix. Figure 1.4 provides a pictorial view of the organization of this thesis.

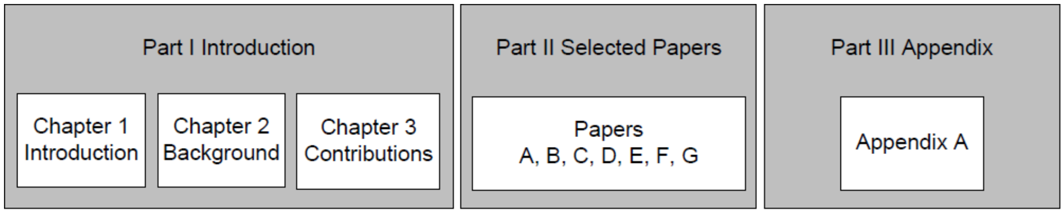

Figure 1.4: Thesis organization and structure.

Chapter 2

Background

This chapter provides background on important basic concepts and definitions. Some of these topics (especially MIH and related literature) might also have been concisely introduced already, in the research papers produced as part of this work and included in Part II of this thesis. Therefore there might be some repetition of text and concepts. This chapter also elaborates the relationship of the introduced concepts and facilities, with the research work reported in this thesis. A summary and comparison of some of the concepts introduced in this chapter is provided in Table 2.1 at the end of the chapter.

2.1 Handover and its Types

Handovers also referred to as "Handoffs", is a process through which a MN attempts to keep its communication flows intact, while it changes its point of attachment to the network. There are many types of handovers discussed below and classified in Figure 2.1.

Handovers may be categorized depending upon which layer(s) of the TCP/IP protocol stack, the handover process forces certain reconfigurations. Therefore in a *"Physical layer handover"* the MN changes the physical layer frequency to connect to the same Base Station (BS). A *"MAC layer handover"* occurs if a MN breaks down its MAC layer connection with the current BS and establishes a new one with another nearby BS. Such a handover usually occurs within the same IP subnet also called "Intra IP subnet handover", where a MN keeps on using the pre-handover IP address. In an *"IP layer handover"* a MN must acquire a new IP address to keep its communications sessions active, in the new IP subnet. An IP layer handover is also called "Inter IP subnet handover". Similarly a handover might occur and managed at the application layer and therefore called *"Application layer handover"*.

Different types of handovers (i.e. MAC layer, IP layer, Application layer) have different and specialized handover management protocols on their respective TCP/IP protocol stack layer. For example in 802.11 MAC layer handover management is technology dependent.

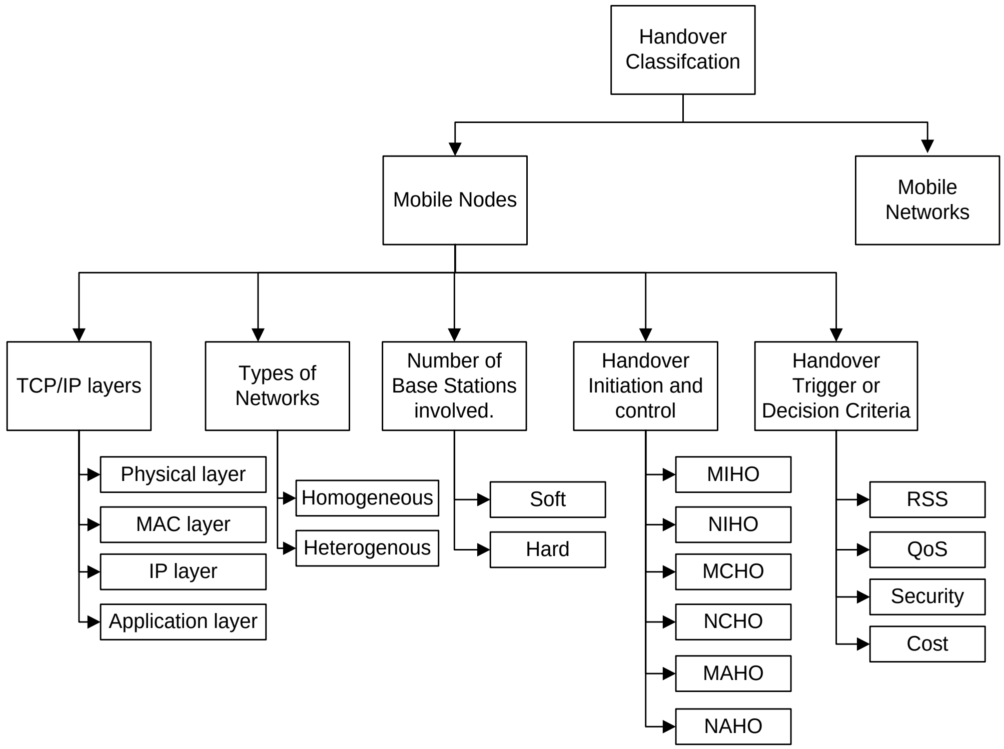

Figure 2.1: Handover Classification.

802.11 MAC layer has dedicated mechanisms for the detection of changes in MAC layer connections and to configure new ones. For IP layer mobility management, Mobile IP (MIP) based protocols discussed in the next section, are employed. For application layer mobility management a well-known protocol is the Session Initiation Protocol (SIP). Although a handover on one TCP/IP layer does not necessitate a handover on another layer [11], generally a typical inter subnet handover requires both connections at the MAC and the IP layer to be re-established. With respect to this classification of handovers the work presented here in this thesis is focused only on MAC layer, IP layer and Application layer handovers and not on Physical layer handovers.

A handover can be termed as either *"homogeneous"* or *"heterogeneous"* depending upon if both the source and target networks are of the same or different networking technologies respectively. For example a handover between two 802.11 Access Points (Ap's) is homogeneous and a handover between an 802.11 AP and an 802.16 BS is heterogeneous. Another familiar term used for homogeneous and heterogeneous handovers is *"horizontal handover"* and *"vertical handover"* respectively. A homogeneous handover is also referred to as *"intra technology handover"* while a heterogeneous handover is called *"inter technology handover"*. This thesis takes into account both homogeneous and heterogeneous handovers.

Handovers can also be categorized based on the number of BS's; the MN is able to communicate with simultaneously during a handover. Therefore a handover during which the

MN is in contact with more than one BS's is called *"soft handover"*. *Soft handovers* are also called *make-before-break handovers*. Soft handovers takes place when the MN is moving between cells operating on the same frequency [2]. On the other hand a handover is called *"hard handover"*, if the MN is in contact with only one BS during handover execution. Hard handovers are also called *break-before-make handovers*. Hard handovers support is mandatory while soft handover is optional for most wireless and mobile networks. Soft handovers are usually characterized by low packet loss and therefore are desirable for seamless handovers.

A handover might also be identified on the basis of the reason, which triggered the handover. A MN might initiate a handover due to changes in physical layer conditions. For example when the Received Signal Strength (RSS) from the current BS is going down continuously, such a handover is called *"imperative"* or *"forced handover"*. If a handover is triggered by user policies and preferences then such a handover is called *"alternative handover"* [12].

Handover might be categorized on the basis of whether the MN or the network initiated and controls the handover process [13] [14]. The types of such handovers are elaborated in the next section.

The Handover Process

The type of operations and procedures that are carried out during a handover depends upon, the layer of the TCP/IP protocol stack which the handover belongs to, the mobility management protocol being used and the type of source and target networks. However these specific operations can be grouped into handover stages or phases that are common to all types of handovers. According to reference [15] the handover process is a three-stage process *(i.e. handover initiation, connection generation and data-flow control)*. [16] [14] also divide the handover process into three phases namely *network/system discovery, handoff decision, handoff implementation/execution*. This thesis divides the overall handover process into *five phases* depicted in Figure 2.2. These phases are concisely described next.

Handover initiation and detection is the first phase in the handover process. In this phase the MN uses specialized mechanisms mostly at the MAC layer to detect or predict that a handover is imminent. The actual procedures used for this purpose are technology dependent. However traditionally most wireless and mobile technologies perform such predictions from the changes in the link layer conditions. For example *Received Signal Strength (RSS)* from the current BS, is monitored continuously and a handover is initiated if the recorded RSS falls below a certain threshold. Similarly monitoring of QoS experienced by MN's can also be used as criteria for triggering a handover if it falls below a certain QoS threshold. Such QoS threshold based handover is mostly controlled by higher protocol layers. Handover initiation and detection is very crucial for handover performance. It is not only required to be triggered precisely to avoid unnecessary and false handovers but

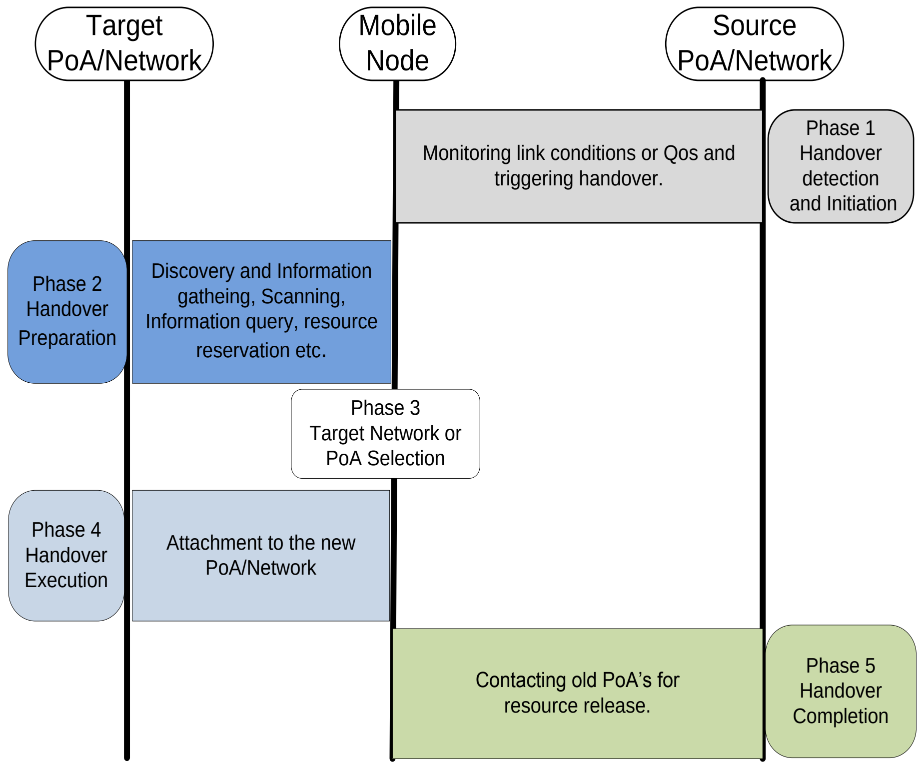

Figure 2.2: Phases of a handover process.

also needs to be initiated in a timely manner. A handover might be initiated by the MN (Mobile Initiated Handover (MIHO)) or by a network entity (Network Initiated Handover (NIHO)) [13] [14].

Handover preparation phase is usually triggered by handover detection. During this phase the MN gathers information regarding potential future point of attachments. Specialized discovery procedures are used for the collection of such information. The type of the required information depends upon the scope of a particular handover, although in general more information is good for accurate and efficient handovers. For example a heterogeneous handover might need more comprehensive information regarding the handover parameters than a homogeneous one, simply because it needs to consider more factors. The most basic type of information is regarding the availability of candidate BS's or networks. This is usually determined by the MN's by scanning through a fixed set of wireless channels or frequencies for beacons sent out by BS's. For efficient handovers and network selection, the information about the mere existence of candidate AP's or networks is not enough. Other high level information like the QoS conditions [17], user preferences, available resources in the target network or BS and its technology type are also very important considerations [18]. Some of the parameters required for efficient handovers can only be measured or gathered at the network side while others only on the MN side. The handover logic needs information from both the MN and network sides, and can be located on either the MN or in the network [13]. This mandates that both the network and the MN cooperate or assist each other by sharing their recorded handover parameters for efficient mobility management and handover decisions.

Once the handover decision logic either on the MN or in the network, has enough information, it takes network selection or handover decisions. The network selection logic or the handover algorithm is usually simple for horizontal handovers and is mostly based on *RSS* [14]. But in heterogeneous handovers the handover algorithms are more complex as discussed in the previous paragraph and need to consider a variety of factors for handover decision making [17]. If the handover decision phase is carried out by the MN then such a handover is called *Mobile Controlled Handover (MCHO)*, else if the handover decision is taken by the network then such a handover is called *Network Controlled Handover (NCHO)* [13] [12]. The handover execution phase is said to be successful if the MN successfully attaches to a candidate BS or network and resumes all its data connections. As discussed in the previous section that both the MN and the network cooperate by sharing information. In case the handover decision is taken by the MN based on local and remote information received from the network then such a handover is called *Network Assisted Handover (NAHO)*. But if the handover decision is taken by the network entity based on the information measure on both the network side and the MN, like in GSM [12], then such a handover is called *Mobile Assisted Handover (MAHO)* [13] [14].

Once a handover decision is made and a target network or a BS is identified, the MN has to perform a handover to it. This phase is termed as handover execution. In *MCHO* the mobile node attempts to connect to the target network or BS, while in *NCHO* the network entity remotely instructs the MN to handover to a target network or BS. The actual procedures carried out during handover execution depends upon the TCP/IP protocol layer to which the handover belongs, the respective mobility management protocol being used at that layer and the type of source and target networks.

During handover completion the MN or the network entity in control of handover needs to inform the pre-handover BS about the handover completion, so that it can release any resources allocated to the MN before the handover.

Although all the above phases are important from a handover performance point of view, the handover preparation and execution are the ones which usually determine the bulk of the overall handover delay. This is because these phases require carrying out certain critical but time consuming discovery procedures. The relative flexibility in the timing of these phases can be exploited for efficient and low latency handovers as proposed in the literature and some of the schemes presented in this thesis. For example if the handover detection can be somehow performed well in advance, then the handover preparation phase can be carried out in a proactive manner. The MN and the network side can cooperatively share information, critical for handover decisions. Thus delay intensive discovery procedures are performed before the pre-handover link is lost, resulting in considerably shorter handover latencies. The handover schemes presented in this thesis are based on this idea and belong to *MCHO and NAHO* categories.

2.2 Mobility Management Protocols in Packet Switched Networks

Efficient mobility management is a key challenge in modern day communication networks, where mobile users are looking to exploit all available media to fulfill their applications QoS needs and their preferences. Traditional homogeneous handover procedures are not sufficient for this challenge [19]. Network architecture wise mobility management is of three types *centralized, de-centralized and device-driven* [20]. The three types of architectures have their respective advantages and disadvantages, and for future networks a *hybrid* approach is needed [20]. As stated earlier a handover can be controlled by either the MN or the network. The location of the handover control logic partly depends upon the effort required for the collection of handover parameters in the MN or in the network and some other aspects discussed in more detail in [13] and [20]. The direction of the flow of the recorded data for cooperative use between the MN and the network is towards the location of the handover decision logic. Thus the MN sends its measurement to the network if the network is taking handover decisions and vice versa if the MN is taking handover decisions. For majority of the situations *Mobile Initiated Handover (MIHO)* seems to be better according to [13].

The handover schemes presented in this thesis are based on close cooperation between the network and the MN. The proposed solutions are mainly based on centralized architectures, although decentralized architectures are also considered. The next section gives an introduction to mobility management protocols in packet switched networks, heterogeneous handovers and MIH.

2.2.1 MAC Layer Handovers in 802.11 Networks

802.11 MAC layer handovers are carried out by the MN and belongs to the *MCHO* category. In 802.11 networks the MAC layer is responsible for detecting and initiating homogeneous handovers. It is also responsible for discovery and selection of candidate AP's. Therefore the 802.11 MAC layer handover spans the first four handover phases discussed before. Mac layer handovers are technology dependent. Although most wireless technologies use the same concept of scanning or searching wireless channels, their timers, number of scanned channels, scanned frequencies and layer two attachment procedures are different. In this thesis MAC layer handovers of only 802.11 networks are considered. Once handover at the MAC layer is completed successfully, the MN checks if its higher layers configurations are still valid. If not then layer three handover mechanisms discussed in the next section, are initiated.

In 802.11 networks [21] a MAC layer handover occurs when a MN changes its point of attachment to the network on the MAC layer. The 802.11 [21] MAC layer handover is completed in three stages namely *Scanning, Authentication and Association or Re-association*. In the standard way of detecting a MAC layer handover, a MN is required to keep a continuous track of the *RSS* from the current BS and a handover is triggered, when the recorded RSS falls below a certain threshold. During the scanning stage of the MAC layer handover the MN attempts to discover possible candidate BS's or AP's by scanning through all available radio channels. The scanning process can potentially be a few hundreds of milliseconds long depending upon the total number of channels to be scanned and the number of BS's detected. The total number of available channels in an 802.11 network is different in different parts of the world, subjected to local regulations [22]. For example the total number of channels available in the US is *11* [23] [22], *13* in most of Europe and *14* in Japan [22].

In 802.11 networks scanning is of two types *Passive and Active*. In *Passive Scanning* the MN listens on each channel passively for beacons transmitted by AP's, to detect whether an AP is present at the current channel or not. By default the beacon is sent out by AP's every 100 ms. The MN will have to wait a bit more than 100 ms on each of the channels to successfully receive a beacon. Therefore scanning 11 channels might take *11 x 0.1 = 1.1 seconds*. Generally for a total number of available channels m (both empty and active) passive scanning delay D_P is given by the following equation.

$$D_P = m * 0.1 sec \tag{2.1}$$

In *Active Scanning* the MN does not wait passively for AP beacons but instead actively probes the available AP's in its surroundings, by sending a probe request message on the current channel and waiting *MinChannelTime* for a probe response from the AP's. If a probe response is received on the current channel, the MN prolongs its waiting to *MaxChannelTime* to make sure that it receives responses from all reachable AP's. If no response is received on the channel in *MinChannelTime* or response is received but *MaxChannelTime* times out, the MN proceeds to scan the next channel and repeats the same process. Once the MN is finished scanning all available channels, it selects the best AP with respect to some criteria e.g. *Received Signal Strength Indication (RSSI)*, for association. Active scanning performs better than passive scanning but result in bandwidth wastage [24]. The study presented in this thesis considers active scanning only. The active scanning delay can be computed from the following equation included here from the author's work in [25].

$$D_A = n(MaxChTime) + (m - n)(MinChTime) \tag{2.2}$$

Where D_A represents active scanning delays, m is the total number of channels, n is the total number of active channels in an 802.11 cell and *MaxChTime*, *MinChTime* are *MaxChannelTime* and *MinChannelTime*. For a configuration of *m=11*, *n=1*, *MaxChTime=60 ms* and *MinChTime=20 ms* D_A =0.26 sec.

The MN after successful BS discovery performs *authentication* with the BS having the highest RSS. A successful authentication is followed by an *association* with the same

BS. This completes the 802.11 standard MAC layer handover. Authentication can be performed by many different methods all having their own respective authentication delays. Association is usually carried out in a request-reply manner between the MN and the BS, and consists of only two messages exchange.

Once an MN attaches successfully to a new BS at the MAC layer, it may proceed to *layer three* handover. The three stages of an 802.11 MAC layer handover have their own associated delays but the *probe delay (scanning stage)* constitutes more than *90%* of the overall MAC layer handover delay [26]. In an 802.11 network several channels are expected to be empty in the MN surroundings, to reduce interference between adjacent cells. The need for reducing interference arises, because in an 802.11b network only three channels *1, 6, 11* are non-overlapping [27] while in 802.11g only four channels *1, 5, 9, 13* are non-overlapping. The 802.11 standard requires the MN to scan *all* available channels during a MAC layer handover, irrespective of these channels being empty or active. The requirement is due to the fact that the MN normally has no knowledge about active and passive channels until it performs a full scan. But due to this full scan, the MN ends up wasting time, scanning empty channels which results in high handover delays. Section 3.1 presents the efforts of this thesis to reduce handover delays, by reducing the 802.11 scanning delays using the MIIS. The proposed schemes work by exploiting the fact that out of all the available channels, scanning for *empty channels can be easily skipped* resulting in shorter handover delays. A brief overview of the efforts to reduce 802.11 scanning delays in the literature is given below.

Reference [22] proposed to limit the scanning process by making use of selective scan approach to scan just one probable channel. If the MN fails to find a channel, the algorithm selects a second candidate and the process continues until all channels are scanned. A special dedicated host called selective scan agent is used to distribute a *weighted channel list* providing the probability of having an AP at each channel. Selective scan agent gathers handoff experiences from all Selective Scan-aware stations and uses it to maintain the weighted channel list. The main problem with this scheme is that the weighted channel list is based on MN's movement history between AP's and therefore constructing an efficient weighted channel list will take a long time. Secondly adding and removing AP's could be a serious problem. In [28] the authors have introduced a fast pre-scan mechanism called *SyncScan*. In this scheme the MN while connected to a BS and having active data connections keeps scanning continuously for other AP's in synchronization with the beacons of surrounding AP's. To achieve such synchronization all the AP's operating in the same frequency are required to broadcasts beacons at the same time. Also a channel number assigned to a particular BS should have a certain relationship with the channel number being used by the surrounding BS's. This way the MN is able to discover candidate BS even before the handover is triggered and no scanning is required during handover execution. Some of the disadvantages of this scheme are high packet loss and its sensitivity to synchronization and inter BS interference. Continuous scanning even when a handover is not apparent very soon, will result in wastage of MN battery resources.

A somewhat similar to SyncScan, a partial pre-scan mechanism called the *Deuce-Scan* was introduced in [29] and [30]. The authors compared their scheme to 802.11, SyncScan and some other algorithms and claimed that their scheme performed better. They make the same assumptions as the *SyncScan* and therefore mainly share the same drawbacks. Authors in [31] and [32] have proposed a scheme that reduces the handover delay by identifying a set of potential AP's by taking into account the handoff history. The problem with this technique is that, it requires a large amount of memory [30]. Pack [33] introduced an improved variant of the *Neighbor Caching* scheme but missing caches becomes serious problem for handovers in this scheme. Shin et al. [34] proposed a selective scanning algorithm to scan a subset of all the channels by using a dynamic channel mask. In [35] the authors have proposed a QoS supported dynamic channel scanning algorithm. In this scheme the scanning process is scheduled into small scan times termed as service interruption times. In their scheme if the current QoS measure is less than a *QoS_Scan_Start* link layer trigger, the MN sends query messages to the 802.21 [36] *MIIS* to get neighbor network information. The neighbor network information is then used to perform QoS supported scanning. In [37] the authors compared both theoretical and actual experimental scanning delays. Another approach in [38] proposes to use the *MIIS* to get information about network configuration to perform limited channel scanning and an algorithm for selecting candidate PoA.

From an overview of the related literature one can easily grasp that a large number of proposals are present in the literature for reducing scanning delays in 802.11 networks. However for convenience the proposed schemes can be categorized in two broad categories. Category one might contain the schemes which are based on *history or past events*. The main draw backs of these schemes are that it might take a very long time to build a database of important past events and will also put extra processing and memory burdens on the resource limited MN. Another problem with these schemes is the lack of their ability to quickly adapt to abruptly changing conditions. The second category might contain schemes which are based on *pre-handover scanning mechanisms*. A disadvantage with these schemes is high packet loss because they require the MN to schedule channel scanning slots when the MN might be busy with active data connections. Schemes belonging to the latter category will also drain MN's battery faster, due to continuous scanning even at times when the MN might already have a stable connection.

2.2.2 Mobile IP based protocols

For mobility management at the IP layer the Internet Engineering Task Force (IETF) has developed standard communications protocols like Mobile IP version 4 (MIPv4) [39] and MIPv6 [40] to support the mobility of a single terminal. To support a moving group of users the NEMO protocol [41] was designed. MIP based mobility management protocols are technology independent and only needs an underlying IP based network infrastructure. This is one of the main reasons that MIPv6 based mobility management protocols are considered very important for mobility management in all IP networks.

An IP layer handover has its own handover phases. It is usually detected or initiated when a MN roams into a new IP subnet and receives a router advertisement from an access router in the new subnet after a successful MAC layer handover. After detection the IP layer mobility management protocol is responsible for making necessary configurations (*e.g. a new IP address*) and resuming its communication flows by redirecting them to the new point of attachment. Therefore layer three mobility management protocols are usually involved in the handover detection and initiation phase and handover execution phase. MIP based protocols have no direct or indirect involvement in target AP or network selection. That determination usually has been done already during a MAC layer handover in homogeneous handovers, while in heterogeneous handovers it is decided by upper layers. Most MIP based protocols are carried out by the MN and therefore they come under the category of *Mobile Initiated Handover(MIHO)* and *Mobile Controlled handover (MCHO)* categories, although some *Network Initiated Handovers (NIHO)* and *Network controlled Handover (NCHO)* protocols also exist.

MIPv4 [39] enables a MN to maintain a permanent IP address and to receive packets addressed to this permanent address regardless of its current point of attachment to the network. The network, to which this permanent IP address of the MN belongs to, is termed as the home network. When MN is away from the home network, a special router at the home network called Home Agent (HA) is responsible for keeping track of the MN's movement. When the MN enters into a foreign network or a new IP domain, it must configure a temporary IP address called Care of Address (CoA), to be able to keep its connections active in the new IP domain. A CoA may be configured with help of a special router present in the foreign network called foreign agent. Such a CoA is called Foreign Agent CoA (FA-CoA). The MN might also use a dedicated Dynamic Host Control Protocol (DHCP) server to configure a CoA. CoA configured using DHCP is called co-located CoA (C-CoA). After successfully configuring a CoA (i.e. FA-CoA or C-CoA) the MN must registers this CoA with its HA through the Foreign Agent (FA). Data packets from corresponding nodes addressed to the MN's permanent address (i.e. home address) arrive at the home network through regular routing where they are intercepted by the HA and tunneled to the current CoA of the MN. MIPv4 suffered from high end to end packet delays due to the packets being forwarded to the MN through the HA. This indirect routing is called the problem of triangular routing. The original description of MIPv4 has been updated in IETF RFC 4721 [42] and obsoleted by RFC 5944 [43].

MIPv6 [40] was designed based on the knowledge gained from *MIPv4* and uses the same concepts of home agents and CoA's. It makes the MN reachable regardless of its current point of attachment and makes its movement transparent to the correspondent nodes. In MIPv6 there is no concept of FA's therefore only co-located CoA's configured either with help of a DHCP server or IPv6 address auto configuration are employed. While route optimization was introduced in MIPv4 as an extension, MIPv6 supported route optimization by default. Both MIPv6 and MIPv4 are host based solutions and both belong to the *MIHO* and *MCHO* categories. Although MIPv6 mitigated many short comings of MIPv4, it still suffered from high handover latencies. MIPv6 has been obsoleted by RFC-6275 [44]. For the simulations of the concepts presented in this thesis, a simple MIPv6 based mobility management protocol with basic functionalities was required. For this purpose an already available MIPv6 implementation in the NIST module [6] was used. This implementation is not a full MIPv6 protocol implementation and lacks many MIPv6 key features. But since the goal of this research was not to optimize MIPv6 signaling or mobility management, the implementation served the purpose. Basic MIPv6 functionalities like *movement detection, IP address auto configuration and route optimization* were supported in the NIST module.

Proxy Mobile IPv6 (PMIP) [45] is another IETF *layer three* mobility management protocol. PMIP takes a network based approach to mobility management for a MN and moves all mobility support related functions from the MN to the network. Therefore PMIP belongs to the *NIHO* and *NCHO* handover categories. A *PMIPv6* domain is required to consist of one or more *Local Mobility Anchor(s) (LMA's)* and a *Mobile Access Gateway (MAG)*. The local mobility anchor is required to have the functional capabilities of a HA as defined in MIPv6 [40]. Additional capabilities for supporting Proxy Mobile IPv6 protocol operations are also required as defined in [45]. MAG manages the mobility-related signaling on behalf of the MN that is attached to its access link. It is responsible for tracking the MN's movement and maintains a bi-directional tunnel with the MN's LMA. From the perspective of the MN the entire PMIPv6 domain appears as a single link. The network ensures that the MN does not detect any changes with respect to its layer three configurations even after changing its point of attachment to the network. PMIP does not support the route optimization supported by MIPv6. PMIP only supports local route optimization which only benefits corresponding nodes residing on the same link as the MN. PMIP have no direct relationship with the research work presented in this thesis and therefore won't be covered here in more detail.

The related work regarding MIP based handover schemes can be broadly divided into two types. In the first type the efforts which concentrate on reducing MIP based protocols handover delays, might be grouped together. The second type might consist of efforts concerning efficient access point selection in 802.11 networks.

Many proposals can be found in the literature which fit into the first group. Within the IETF, a work group called *Mobility for IP: Performance, Signaling and Handoff Optimization (mipshop)* [46] was chartered to work on optimization of MIP mobility management based solutions. The work group has proposed new protocols, which have better handover delays. Such as *Fast MIPv6 (FMIPv6)* [47] was introduced as variant of the original MIPv6 protocol for improved handover latency. To support intra subnet fast handovers micro mobility management protocols like *Hierarchical Mobile IPv6 (HMIPv6)* [48] were introduced. HMIPv6 has the ability to reduce the amount of global mobility management signaling in the network and has improved handover delays. Some technology specific versions of *FMIP* have also been introduced. For example for Wi-Fi, WIMAX, and 3G, FMIP schemes were proposed in [49], [50] and [51] respectively. A modified binding update procedure that takes half or less time to complete than that of a standard MIPv6 binding update procedure was proposed in [52]. In reference [53] the authors have analyzed both FMIP, HMIP and have proposed to combine both protocols for better handover performance. Jiang Xie et.al [54] provides the analytical modeling of handover latency for the two MIPv6 based fast handoff protocols, FMIPv6 and HMIPv6; using IEEE 802.11 based wireless local area networks as the wireless access networks. In [55] the authors have taken a cross layer perspective to analyze the predictive FMIPv6 handover latency, considering both the link layer and network layer factors. In reference [56] the authors have proposed an enhanced handover mechanism with new additional primitives and parameters to the MIH services defined in the IEEE 802.21 [36]. Authors of [57] optimize the handover procedures in FMIPv6 protocol by using the IEEE 802.21 MIH services. An enhanced FMIPv6 protocol using Media Independent Handover services has also been proposed in [58]. Another paper [59] has proposed a mechanism to optimize the original FMIPv6 with the help of MIH services and have also provided a mechanism of discovering the information server address.

A number of proposals for AP selection considering more factors than just *RSS* can also be found in the literature. [60] introduced a two-pass method called *Mark-and-Sweep* to characterize neighborhood networks. Reference [61] presented a scheme called *Virgil*. Virgil finds a usable connection 22% to 100% more often than AP selection based on RSS alone. Virgil has dedicated mechanisms for estimating network parameters such as bandwidth and round trip times by using as set of reference servers in the network. Virgil also requires the MN to store information of AP's discovered during scanning in a local database. In [62] the authors have proposed a collaborative scheme where the MN's are required to generate *reports* about their experience of using different AP's. These reports represents historical usage information of BS's in the network topology and are shared with other MN's to help them in AP selection in a commercial set-up. The use of such reports increases the AP selection performance over other approaches *30% to 60%* of locations. A more recent proposal on making use of bandwidth knowledge is presented in [63]. Another proposal in [64] makes use of the advertised information in the *beacon or probe response frame* in IEEE 802.11e AP, to determine the load status of the AP and also takes into account hidden terminals. The authors claim *20%* throughput enhancement when compared to two other schemes. [65] provides a *fully distributed* AP selection scheme that improves throughput fairness among mobile users. Physical relocation of users from one network area to another to attach to a lightly loaded AP has been modeled as a game in [66] utilizing *game theory*.

2.2.3 Heterogeneous Handovers

Heterogeneous handovers are of two types namely *upward* and *downward*. An upward heterogeneous handover takes place when an MN handovers from a low coverage and high bandwidth network like 802.11 to an overlay large cell size network like WiMAX or 3G [2]. In downward heterogeneous handovers the MN handovers from a wide coverage network like 3G to a small coverage network like 802.11. Although a heterogeneous handover might generally have all the five handover phases explained before, the number of handover phases might depend upon the architecture of heterogeneous networks. The location of the handover control logic and mobility management also depends upon the network architecture.

From handovers decisions point of view, heterogeneous networks pose a different kind of a challenge than homogeneous networks. As discussed before *traditional homogeneous handover procedures* are not sufficient for this challenge [19]. In heterogeneous environments, heterogeneity does not only exist in network technologies but also in user needs and contexts. For handovers, heterogeneity in technologies generally means that two different networking technologies have different characteristics *(radio coverage, QoS, bandwidth, cost, signal strength threshold)* and therefore cannot be directly compared with each other for handovers decisions.

Although RSS based handover algorithms have been successfully used for horizontal handovers, they cannot be used for heterogeneous handovers because of the overlay structure of the heterogeneous networks and the difference in physical layer techniques [2]. Although in the literature several proposals exists which make use of separate RSS threshold for different network types and one type of network is given preference over another. In overlay heterogeneous networks a stable RSS from the current BS might not trigger a handover, even though a handover to another network might be urgently needed, if the current network is unable to fulfill the MN required QoS. In heterogeneous environments as the name implies, the users have more than one networking technologies, having different QoS and service costs, to choose from for connectivity. This naturally allows the users to define their preferences regarding the importance of the QoS of the network services and their usage cost. For example a particular user might term service continuity more important the cost of the connection. But there might be other users who are interested in availing cheap connectivity opportunities even if it comes at the cost of a degraded QoS. User preferences might also define which kind of service is more important for the user and therefore select a network which best suits this particular type of service. For example from a user perspective, is a real time service like *VoIP* more important or a non-real time service like a file download? *User context* is also an important consideration in heterogeneous handover decisions making e.g. a highly mobile user if handed over to a network with small network coverage might result in a very short new network connection time and therefore might lead to unneeded communication disruptions [67]. From the nature of the problem of heterogeneous handovers, it is very obvious that heterogeneous handover algorithms need to consider a variety of factors or parameters for the sake of accurate and efficient handover decision making.

The problem of heterogeneous handover has been around for a while and a large number of handover algorithms have been proposed in the literature. However a majority of those solutions have a great deal of similarities. Most of these algorithms are based on either *Multiple Attribute Decision Making (MADM)*, artificial neural networks, fuzzy logic, cost functions or they are modeled as a Markov process. Some proposals are based on the combination of the above mentioned methods. The *Analytical Hierarchical Process (AHP)* seems to be a common method for determining the relative importance of parameters by assigning weights to them, in the MADM and cost function based algorithms. The cost function and MADM based solutions takes into account multiple parameters and are able to provide improved handover performance [68]. A brief overview of the related work in heterogeneous network is given below.

In reference [69] the author has proposed to use fuzzy logic in combination with classical MADM methods *Simple Additive Weighting (SAW)* and *Technique for Order Preference (TOPSIS)*. In [70] *Grey Relational Analysis (GRA)* is used to rank the candidate networks while AHP [71] is used for weighing the criteria. [72] provides a performance comparison of four algorithms i.e. Multiplicative Exponential Weighting (MEW), SAW, TOPSIS and GRA. In [68] and [73] the authors have provided a survey of different heterogeneous handover algorithms. Reference [74] has proposed a fuzzy extension to AHP and an MADM method called *ELECTRE* is proposed for ranking. *Distributed* proposals are provided in [75] and [76] in which the rank calculation is delegated to the visiting networks. In [77] the authors have provided the performance comparisons of different MIP based configurations (i.e. CoA, C-CoA, route optimization) for a UMTS/WLAN environment. The authors conclude from their results that the three considered configurations produce roughly the same delay for low network load, but MIPv6 produces significantly higher delays for moderate and high network load due to its long headers. A breakdown of handover delays of different handover procedures is also provided and the authors claim that the security procedures of 3G constitutes 60% to 67% of the overall handover delay for all the schemes and that DHCP delays constitutes up to 20%.

2.2.4 Network Mobility (NEMO)

The IETF introduced the *NEMO* [41] protocol to support mobility for a group of internet users. All users moving together at the same time in a bus or train are said to be part of a moving network called mobile network. Although MIPv6 and its different variants can be used to support mobility for each individual user in such a mobile network, their application might have certain drawbacks. First every MN is required to be MIPv6 enabled to be able to perform MIPv6 operations and secondly performing MIPv6 operations (binding update messages, movement detection, and network discovery) on a per MN basis might potentially generate a lot of excess overhead.

The basic principle in NEMO is that, all mobility management tasks are carried out by a special mobile network router called Mobile Router (MR), for all the nodes in the mobile network. The nature of basic operations in NEMO is the same as in MIPv6 except that the MR takes on the role of a MIPv6 MN. The MR runs the *NEMO basic support protocol* and maintains communications sessions for all nodes in the mobile network. This is achieved by the MR by making sure that the mobile network is reachable at all times from the home network by maintaining bindings for all nodes in the mobile network, at the *HA*. One major difference of NEMO with MIPv6 is that NEMO does not support route optimization and therefore suffers from *triangular routing* problem. There are many proposals in the literature for route optimization in NEMO networks. However they all have their associated costs with respect to handover signaling complexity and their required amendments to network architecture. An important part of this research work as highlighted in Chapter 1, is based on the analysis of the effects of some of those solutions, on handovers. On the basis of the analysis, comparisons are drawn among different NEMO RO solutions, considering many attributes. An overview of the literature of the analysis of NEMO route optimization solutions is given next.

Basic issues and classification of NEMO RO mechanisms was provided in [78]. Various types of RO in NEMO, their benefits, and trade-offs are discussed in [79]. Authors in reference [80] provide a survey, classification and comparison of different NEMO RO mechanisms. They conclude that delegation-based and BGP-assisted schemes suites the server client Internet architecture. Hierarchical schemes are found to be more useful for intra subnet RO and that source routing is not suitable for networks with higher nesting levels due to their overhead. A classification of the RO schemes is proposed based on the RO type and the schemes are compared to each other with respect to the protocol signaling and memory overhead. [81] evaluated the NEMO RO approaches in satellite networks. Requirements for incorporating multi-homing into the basic RO approaches are also provided. On the base of their analysis the authors conclude that delegation and hierarchical based RO approaches are more suitable for RO in satellite networks. Performance of three prefix based RO mechanisms are compared in [82]. A survey of different RO solutions and their suitability for different types of applications is provided in [83]. In [84] the authors have classified the proposed NEMO RO solutions in three groups based on if the address configured by the MR is topologically correct or not, and if the approach is based on hierarchical mobility management concepts. The different RO solutions are also compared to each other. A theoretical and empirical analysis of the different NEMO RO schemes was presented in [85].

2.3 Media Independent Handover (MIH)

As discussed previously Section in 2.2.3 different wireless and mobile communications networks belongs to different standards and therefore are non-interoperable. Integrating such non-interoperable networks require additional facilities. The *Media Independent Handover (MIH)* frame work was introduced for this purpose.

MIH [36] is an IEEE standard that was specifically designed to enable a MN to perform handovers across *heterogeneous networks*. The goal of MIH is not to replace any of the existing mobility management protocol discussed in the previous section, but to assist them in taking efficient handover decisions with its intelligence rich set of services. This is achieved by MIH by making two important contributions.

1. MIH bridges the gaps for the integration of media dependent layers of different types of networks.
2. MIH supports the media independent higher layers with its intelligent services in all important phases of a handover process.

It works as glue between IEEE (both wired and wireless), 3GPP and 3GPP2 media types.

A major aspect of the standard is the *cooperative use* of information available at both the MN and within the network infrastructure. The information can be utilized in network discovery and network selection. The standard also specifies the means by which such information can be obtained and be made available to the MIH users. Because of this information retrieval and dissemination capability, the standard makes it possible for both the MN and the network to make handover decisions. Specifying actual handover decision algorithms is identified to be outside the scope of the MIH standard. As discussed earlier heterogeneous handover algorithms needs to consider a variety of information from both the users and the networks side, for handover decision making. Such information can be gathered with the help of MIH framework [86]. The MIH standard supports both layer two and layer three transport options for information access. Both *soft and hard handovers* are supported in the standard. The frame work is general and all the different types of handovers with respect to handover initiation and control i.e. *MIHO, NIHO, MAHO, and NAHO* can be realized. The location of the handover control logic is also flexible and can be either on the MN side or the network side. Therefore the standard supports both *MCHO and NCHO*. Although the information available networks is proposed to be stored in a central server the MIH framework is flexible enough to support centralized, decentralized, or hybrid architectures.

A new logical entity *Media Independent Handover Function (MIHF)* facilitates handover decision making. Figure 2.3, taken from reference [36] presents an overview of the MIHF and the way it is interfaced with other layers of the protocol stack in a multi face MN or a network node. A single media independent interface MIH *Service Access Point (MIH_SAP)* is used to provide services to the MIH users. This SAP has been defined as a media independent interface common to all technologies, so that the MIHF layer can be designed independently of the technology specifics. All interactions of the MIHF with the lower layers take place with the help of media-specific protocol instantiations of *MIH_LINK_SAP*. These primitives are then mapped to technology specific primitives offered by the various technologies considered in MIH. MIH users may be any of the IP mobility management protocols discussed in the previous section, seeking to use the services provided by the MIHF for efficient handovers.

Figure 2.4 from [36] provides a logical diagram of the mutual interactions of MIH enabled nodes. The network side of the MIH entity with which the MN exchanges MIH information is called *Point of Service (PoS)*. A MN in this figure has an 802 interface and a 3GPP one, and is currently connected to the network via the 802 interface. Local and remote interactions can also be seen from this figure. The MIH standard allows both layer two and layer three transport options for mutual interaction between the nodes in an 802.21 network. *MIH_Link_SAP* and *MIH_SAP* are utilized for local interactions within a single node and for remote interactions between remote MIHF's *MIH_NET_SAP* is used.

The MIHF provides three kinds of services to support all phases of a handover process discussed before in Section 2.1, except handover execution. The handover execution phase is left to the mobility management protocols in use. These supported stages are *handover detection and initiation, handover preparation, handover decision and handover comple-*

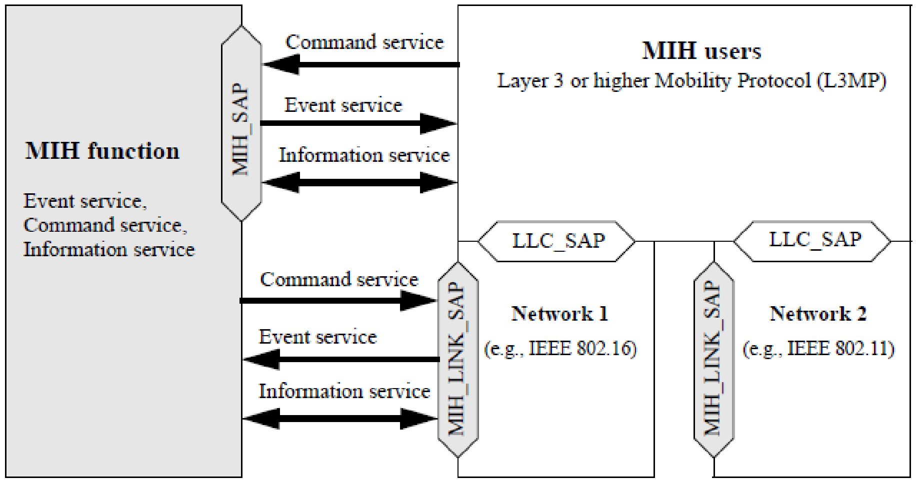

Figure 2.3: MIH Services and their initiation.

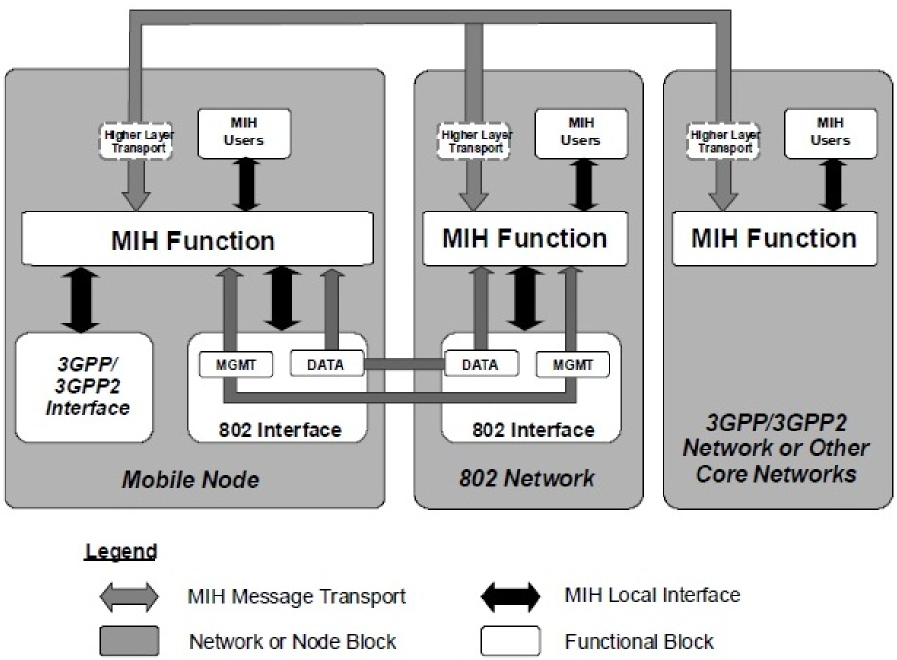

Figure 2.4: MIHF relationships.

tion. A short description of these services is given next.

2.3.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the change of the status of physical, data link and logical link layers or to predict the state change of these layers. *MIES* gives MIH enabled node link layer intelligence for optimized handovers. Some of these events play a central role in the *initiation, detection and completion* of the handover process. In a MIH network a handover may be triggered either by the MN or by a network node and the source of handover events is either a local or a remote MIH entity. Remote events traverse the network and a transport protocol is needed for carrying them to the remote recipients. Multiple higher layer entities might be interested in receiving certain events therefore the MIHF must be able to dispatch events to multiple destinations. Events by nature are discrete and asynchronous, therefore all MIH users and MIHFs interested in specific events need to subscribe to them first. Event subscription is achieved with the help of a subscription request from the MIH users and a corresponding subscription reply from the MIHF. For the recipient it's not mandatory to react to these events and the decision of performing an action in response to a particular event, rests with the recipient itself.

Events are of two types i.e. *link events and MIH events*. Link events are generated by media specific link layers. The destination for link events is the MIHF. Events that are generated within the MIHF are media independent and destined to MIH users or upper layers are known as MIH events. Link layer events are first translated by the MIHF to MIH events and then forwarded to upper layers or MIH users. A MIH event can be either local event or a remote event. The scope of a local MIH event remains limited to the protocol stack of a particular MIH entity but remote MIH events are transported via the communication network to remote MIH enabled hosts and then delivered to MIH users which have remote subscription for this event. Separate subscriptions are required for local and remote events. Figure 2.5 shows the flow of local and remote events.

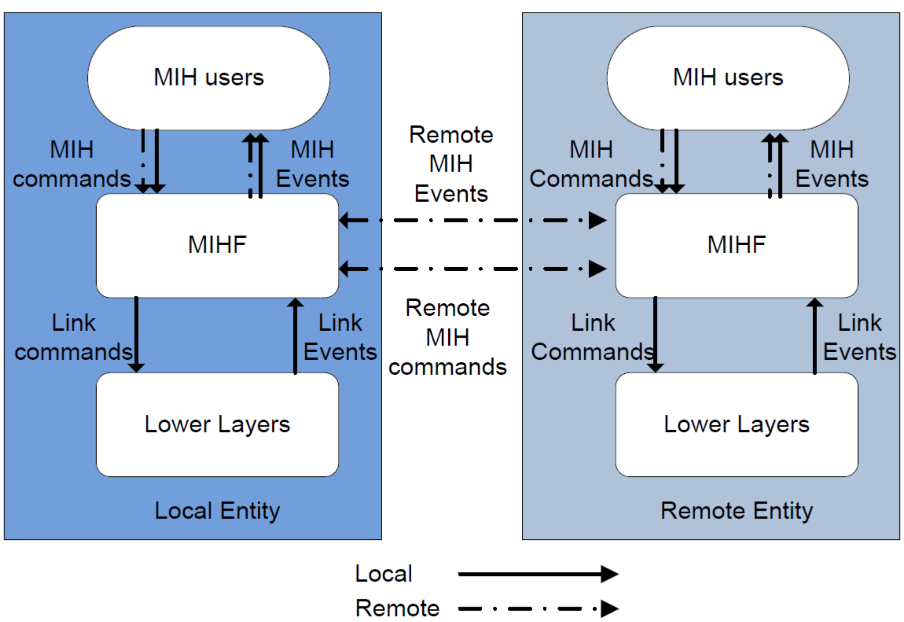

Figure 2.5: Flow of events and commands.

When a link event occurs due to a change in link conditions, it is not known at that instant if this would lead to intra-technology handover or inter-technology handover. That determination is done higher up in the protocol stack by the network selection entity based on variety of other factors. Certain link layer events such as *Link_Going_Down* may lead to either *intra-technology or inter-technology* handover. The network selection entity attempts to maintain the current connection, by first trying an intra-technology handover and only later on resorts to inter-technology handover.

From the perspective of the research work reported in this thesis, the most important MIH events are *MIH_Link_Detected, MIH_Link_Down, MIH_Link_Going_Down, MIH_Link_Up and MIH_Link_Handover_Complete*. Crucial Link events include *Link_Detected, Link_Down, Link_Going_Down, Link_Up* and *Link_Handover_Complete*. As indicated by their names these events are helpful in handover detection, initiation and completion.

2.3.2 Media Independent Command Service (MICS)

Commands are used by higher layers (i.e. interface managers or mobility managers) to perform certain reconfigurations of interface parameters or to switch to another interface. When a MIHF receives a command it is always expected to execute it. The decisions about the reconfiguration of certain interfaces or parameters are taken by handover policy engine aided by the information services discussed in the next section. The need for such reconfiguration might arise when a change is detected in the link layer conditions or network conditions, with the help of MIES introduced in the previous section or through other means.

Like MIES, commands can also be characterized as either MIH commands or Link commands. MIH commands are generated by MIH users to instruct the MIHF. Link commands on the other hand are generated by MIHF itself to instruct the lower layers and therefore Link commands have local scope. Figure 2.5 shows the flow of MICS.

Scope wise MIH commands are of two types i.e. *local MIH commands* and *remote MIH commands*. The destination of local MIH commands as implied by its name is local MIHF and the destination of the remote MIH commands is a remote MIHF entity. Remote MIH commands are required to be transported to remote recipients. Local MIH commands are used by handover policy engines on the MN's, for *MIHO* while remote MIH commands are used by handover policy engine in the network for *NIHO*. This allows both *MCHO* to be realized by the use of local *MICS* and *NCHO* with remote *MICS*.

For the work reported in this thesis, MIH commands like *MIH_MN_HO_Candidate_Query, MIH_N2N_HO_Commit, MIH_MN_HO_Commit, MIH_MN_HO_Complete* and in addition *MIH_Link_Actions* played an important role. In Link commands the important one for the proposals made in this thesis is *Link_Actions*.

2.3.3 Media Independent Information Service (MIIS)

The MIIS provides a framework and the corresponding mechanisms by which an MIHF MN entity can discover and obtain network configuration information existing within a geographical area to facilitate network selection and handovers. The MIH standard specifies that the information provided by MIIS mainly consists of static information although network changes are accounted for. Dynamic information about the available active networks should be obtained directly from their respective networks using MIH facilities. The *MIIS server* has a holistic view of the network topology and has stored information regarding the types of available networks, the number and location information of all the BS's, their configured radio channels and capabilities. As discussed in the previous section that, as a reaction to changing link conditions detected though *MIES*, the MN might decide to change link layer parameters or switch to another network interface and perform a handover. The handover decision process requires information both collected by the MN and available on the network side.

The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The information from the MIIS is delivered to the MN in the form of Information Elements (IE's) as a result of query request from the MN and query response from the MIIS. The information provided by IE ranges from PoA specific information and access network specific information to high level general information about the different operators and available networks. Vendor specific IE's can also be defined. Figure 2.6 provides a message flow example for both local and remote MIIS services.

This information might be critical for efficient and accurate handover decisions. Therefore the MN and the network need to cooperate with each other by sharing information. The direction of the flow of such information is in the direction of the location of the *handover decision logic*. Thus if the handover decision logic is located on the MN, it might explicitly ask for assistance from the network side using MIIS. Similarly if the network is in control of the handover, it might use MICS to ask the MN to perform measurements and report them to the MIIS. MN can also voluntarily share the information it has measured with the MIIS, for efficient handovers as proposed in some of the handover schemes presented in this thesis. In this way through the use of MIIS, the MIH framework makes it possible to support both *NAHO's* and *MAHO's*. The MIIS functionality is at the very heart of the schemes proposed presented in this thesis. Both local and remote MIIS services were put to the use.

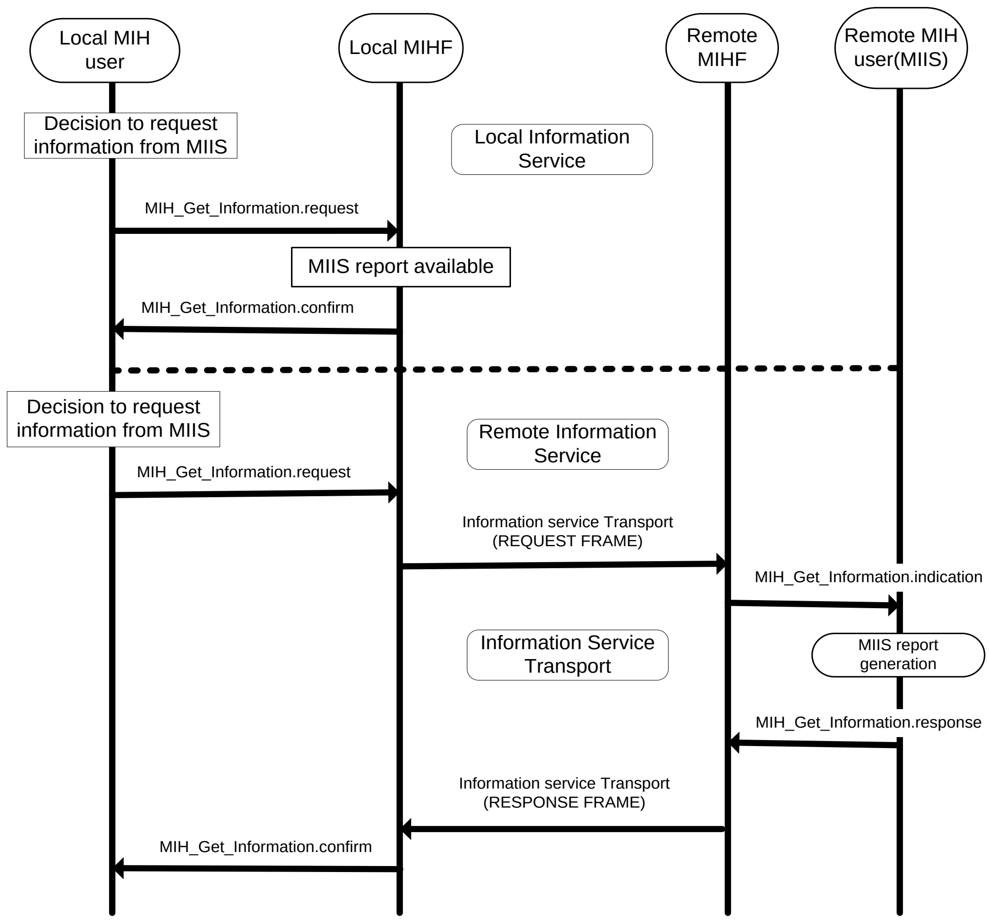

Figure 2.6: MIIS information flow.

Table 2.1: Mobility Management (MM) Protocols and Handovers.

	802.11 MAC Layer	NEMO/MIP Based	MIH	Proposed Schemes
Purpose	MAC layer handover & MM, BS's discovery & selection	IP layer handovers, MM & discovery of new IP domains	Support heterogeneous handovers	Support homogeneous & heterogeneous handovers
TCP/IP layer	Layer 2	Layer 3	Cross layer	Cross layer
Technology independent	No	Yes	Yes	Yes/No
Handover phases	All except completion	All except decision, Completion	Support all	All
Heterogeneous handover support	No	Yes	Yes	Yes
Homogeneous handover support	Yes	Yes	Possible but not specified by the MIH standard	Proposed in this thesis
Handover decision	AP selection	No role	Support role	Support role & handover decisions
Bottleneck operations	Scanning delays	CoA configuration, MIP update messages and security	Additional components and signaling	Additional components and signaling
Handover initiation and control	MIHO, MCHO	MIHO, MCHO PMIP allows NCHO, NIHO	Support all types	MIHO, NAHO MCHO

Chapter 3

Contributions

This chapter provides the contributions of this thesis for efficient handovers in wireless and mobile networks. The *contributions or proposed solutions* are grouped together with respect to TCP/IP layer they apply to, homogeneous or heterogeneous handovers and their application to a single mobile node or a mobile network. The relation of papers containing the proposed schemes, with the handover classification is depicted in Figure 3.1. Table 3.1 at the end of this chapter gives the comparative summary of all the included papers. A concise list of the contributions is as follows.

1. For *MAC layer handovers* in 802.11 networks, an *intelligent scan mechanism* is proposed to reduce scanning delays. The proposed intelligent scan mechanism works by limiting the 802.11 scanning process to *active channels* only by utilizing *MIIS*, resulting in shorter handover delays than 802.11 standard scanning. The proposed scheme is further extended and GPS coordinates of the MN are considered to scan just *one channel or to skip the scanning stage completely, yielding zero scanning time during handovers*. The proposed intelligent schemes are presented in paper A and B.

2. For *IP layer horizontal handovers* the MIH framework is proposed to be utilized for horizontal handovers, although the original goal of MIH was to support heterogeneous handovers. The *implications* of the proposed intelligent scan mechanism for 802.11 networks on MIPv6 handover delays are investigated. A *PoA selection algorithm* in 802.11 networks is proposed making use of MIIS facilities. The proposed algorithm has the capability to consider more parameters like *bandwidth, security and cost of the connection*, than just RSS for efficient handover decisions. These proposals are presented in paper C, D and E.

3. *A heterogeneous handover algorithm* based on *Simple Additive Weighting (SAW)* is proposed to be distributed among multiple MIH enabled nodes for better scalability without sacrificing handover performance. The proposed algorithm is carried out in two steps and satisfies both user QoS and preferences needs. The proposed scheme is presented in paper F.

4. *Different Route Optimization (RO)* schemes proposed in the literature for NEMO networks, are compared to each other and analyzed with respect to the degree of achieved route optimization and the amount of signaling they generate during handovers. The analysis is presented in paper G.

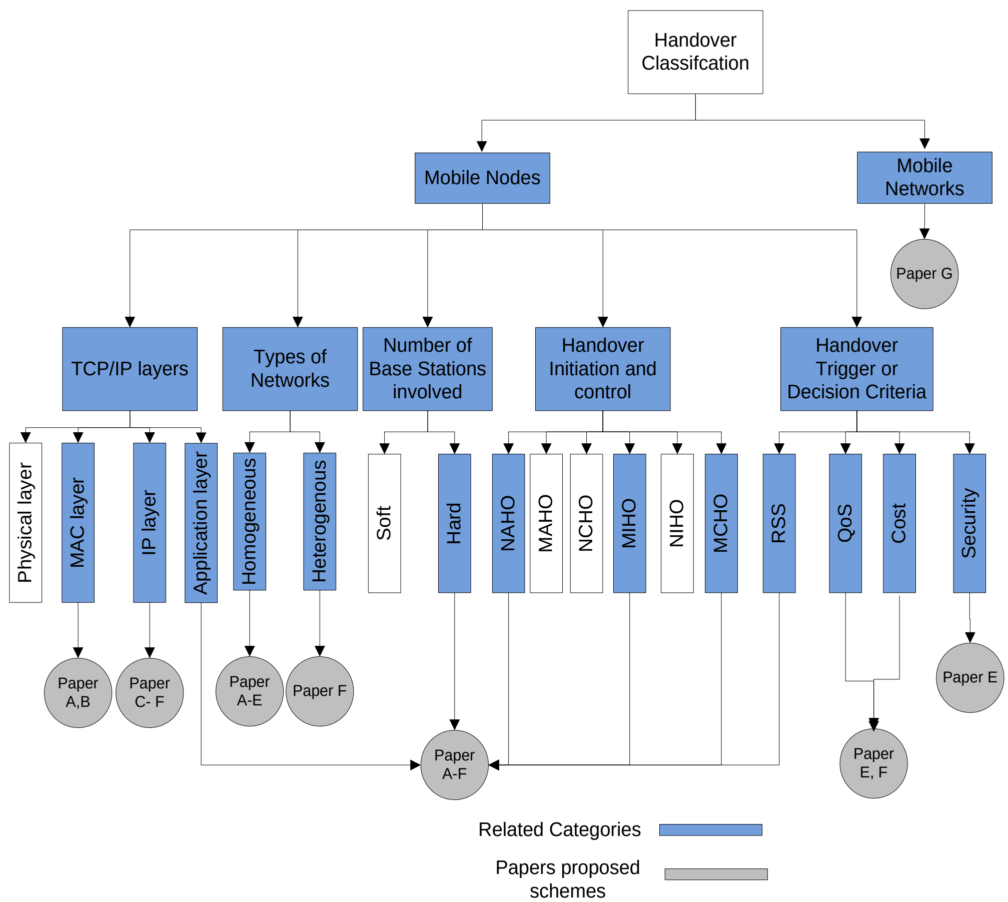

Figure 3.1: Relation ship of papers and handover classification.

3.1 MAC Layer Handovers

This section summarizes the *contribution* of this thesis in *reducing channel scanning delays* during handovers in 802.11 networks. The focus here is to find answers to *Question 1* posed in *Chapter 1*. Proposing to use MIH facilities for horizontal handovers marked the start of this research work.

Although the original goal of MIH is to support vertical handovers; it can also be used to improve the efficiency of horizontal handovers. Especially if the MIH infrastructure exist already to support vertical handovers [87]. Proposing MIH for horizontal handovers paved the way for proposing the MIIS based intelligent scanning schemes for 802.11 networks, presented in paper A and B. The main contribution of this thesis for MAC layer handovers is the use of MIIS services for reducing scanning delays by limiting the scanning process to active channels only in the first stage, resulting in *shorter handover delays as compared to 802.11 standard scanning*. In the second stage the GPS coordinates of the MN are considered to *scan just one channel or to skip the scanning stage completely, yielding zero scanning time during handovers in 802.11 networks*.

As compared to the 802.11 standard scanning mechanisms the proposed intelligent scanning schemes come with big advantages in terms of handover latencies. In comparison to the related work the schemes presented in this thesis are *simple, efficient in terms of handover latency and puts very little processing and memory overhead burden* on the MN. The proposed schemes are based on a simple query request and query reply between the MN and the MIIS. The time instant at which the query is fired, is determined by the MIH users in the light of the received MIH intelligent link triggers. Using the proposed intelligent scanning schemes, the MN which is the most resource restricted component in a mobile and wireless network topology, is not required to store and consider history of past events (MN's movement trajectory and discovered BS's configuration). Intelligent scanning strategies frees the MN from performing complicated tasks proposed in the literature, like full or partial pre scanning and still achieves a good handover performance. At their best the schemes proposed here despite being simpler, provide better or comparable performance to most of the proposed schemes in the literature.

Contribution and Summary of the Related Papers

Paper A

An Intelligent Scan Mechanism for 802.11 Networks by using Media Independent Information Server (MIIS)

This paper provides details on how the MIH framework can be used to share the channel configuration information of the network or the surrounding AP's, with a MN in an 802.11 network? The MN utilize the *MIH_Link_Going_Down* event to detect that the current link with its BS is going to end soon and therefore it needs to trigger the handover preparation phase to equip itself with channel configurations of the potential future PoA's, before the handover execution starts. For this purpose the MN queries the Media Independent Information Server (MIIS) asking for channel configuration information. The MN includes a newly defined parameter *NET_CHANNEL_CONFIG* in its query to identify the type of its desired information. The MIIS in response to the query request sends back to the MN a list of active channels, in a newly defined Information Element (IE) container by the name of *IE_CONTAINER_802.11_CHINFO*.

The MN after receiving the reply from the MIIS uses this information during handover execution to scan only the active set of channels and to skip the empty ones, in the network or in the surroundings of the MN. In this paper four scanning strategies are defined, tested and compared to each other in terms of handover delay efficiency. The first strategy is called *ScanALL* and like an 802.11 standard scanning mechanism, scans all channels available in the network. The second strategy is called *ScanAll-StopFirst*. The behavior of this strategy is a modified version of *ScanALL*. With *ScanAll-StopFirst* the MN scans all channels but stops on the first BS detected (i.e. first active channel) for the sake of low handover latency. Third scheme is called *Intelligent-ScanAll* and scans all channels in a reduced list of active channels received from the MIIS. A fourth scheme is a variant of the third scheme and is called *Intelligent-StopFirst*. In this scheme the MN stops at the first AP detected in a reduced set of active channels in the network, received from the MIIS.

Simulations are performed for a topology consisting of four 802.11 AP's. The MN moves linearly at a seed of 5 m/s and performs handovers between the four 802.11 AP's. Handover delays are recorded for the four proposed intelligent scanning schemes. Simulation results reveal that *ScanAll-StopFirst* shows a *38%* handover delay improvement over *ScanALL*. *Intelligent-ScanAll* shows *53%* and *Intelligent-StopFirst* shows *65%* handover delay reduction compared to the standard 802.11 scanning (i.e. *ScanALL*).

Paper B

Zero Scanning Time for 802.11 Networks by Using Media Independent Information Server (MIIS)

This Paper is an extension of the work presented in Paper A. The main contribution of this paper is to further reduce the number of channels to be scanned by an MN during MAC layer handover to *just 1 or to ignore the scanning phase completely resulting in zero scanning time*. Instead of returning a list of active channels in the network as proposed in paper A, the *GPS coordinates* of an MN are considered in this paper, to return just one channel of the future PoA to the MN. The query of the MN for this purpose was further extended to enable the MN to report its *GPS coordinates* to the MIIS. The MIIS first locates the MN on a *virtual map* in the topology, with the help of the MN's and the surrounding BS's GPS coordinates. The MIIS then decides on which BS the MN is about to handover based on its geographical information and replies to the MN with the channel configuration information of this target AP.

When the reply from MIIS reaches the MN, it makes use of this information during handover execution to perform intelligent scanning. Two intelligent strategies are defined to enable the MN to discover reachable candidate AP's. The first proposed strategy is called *Intelligent-ScanOne*. Using this strategy the MN scans only one channel during MAC layer handovers. The scanning is performed to discover the BS whose information is received from the MIIS as a response to its query request. This information contains the *Basic Services Set Identifier (BSSID)* and the operational *radio channel number* of the target BS. The second scheme is called *Intelligent-ScanNone*. In this scheme no scanning is performed and the MN goes directly into the association phase of the 802.11 MAC layer handover utilizing the *BSSID and channel number* received from the MIIS for association.

Simulations are employed to compare the handover delay performance of the two schemes proposed in this paper to an 802.11 standard scanning mechanisms. Simulation results show that *Intelligent-ScanOne* results in *93%* handover delay improvement over standard 802.11 scanning. *Intelligent-ScanNone* results in *99%* handover delay improvement over standard 802.11 scanning delays. Packet loss during handovers is also low for both the intelligent handover schemes than 802.11 standard scanning. Despite such big advantages the communication overhead of both the proposed schemes is a single query and reply between the MIIS and the MN, as part of the handover preparation phase.

3.2 IP Layer Handovers

This section reports the contribution of this research work to *IP layer horizontal handovers* in 802.11 networks. Answers to *Question 2* posed in *Chapter 1* are presented here. First an investigation is made regarding the potential use of MIH services for replacing MIPv6 time costly operations with MIH intelligence for proactive handovers. The potential use of all the three kinds of MIH services *(i.e. MIES, MICS, and MIIS)* is outlined for reducing layer three handover delays in 802.11 networks. Another contribution of this thesis for IP layer horizontal handover is the investigation of the effects of intelligent scanning mechanisms introduced in *Paper B*, on MIPv6 handover delays. The last contribution of this work for IP layer horizontal handovers in 802.11 networks is a proposed algorithm for *PoA selection*. The proposed algorithm considers more factors or parameters like *bandwidth, security and cost*, than just RSS for PoA selection during handovers. A simple method of *ranking 802.11 AP's*, with respect to security is also purposed.

Contribution and Summary of the Related Papers

Paper C

Application of Media Independent Handover (MIH) for Intra Technology Handover

The main contribution of this paper is to propose the MIH framework for optimizing horizontal handovers in 802.11 networks. This paper outlines the possible replacement of certain MIPv6 time costly handover operations with the services provided by MIH. Although MIH was originally introduced to support heterogeneous handovers, its presence makes it quite logical to utilize its services for optimizing horizontal handovers as well. The basic idea is to make the handover process proactive in nature so that the handover delay is reduced by performing some time consuming operations even before the handover starts. Such operations are normally carried out during handover execution and therefore add to handover latency.

Pre configuration and pre authentication achieved with the MIH framework can be used to speed up the handover process. Link layer event triggers, such as *Link_Going_Down* and *Link_Up* along with MIH function ID can be used to indicate departure and arrival of MNs at access routers in the foreign network or subnet and such indications can replace layer three protocols signaling for the same purpose and thus expedite the handover process. In case of network controlled handovers MIPv6 can use triggers like *Link_Going_Down*, to redirect packets in parallel with other handover control messages exchange and can thus reduce handover delays and packet delays. Upper layers can use *Link_Handover_Complete* event to check if the IP configuration of the MN needs to be updated. This is a link-layer event that exists for intra-technology handovers defined in many media types. An MIH user makes use of this notification to configure IP layers for handovers.

MIH commands indicate a future state change in one of the link layers, in the local node. These indications notify subscribed MIH users of link state changes in the near future. Thus the MIH users can prepare in advance by taking appropriate action. In MN initiated handovers *MIH_MN_HO_*** commands usually will trigger indirectly MIH_N2N_HO_*** commands. The MN can smartly use these commands to query the list of available candidate networks/subnets, reserve any required resources (e.g. CoA, setting up security parameters) at the candidate target network, and indicate the status of handover operation to the remote MIHF in the network. The current PoA can provide the status of the MN's reserved resources and its potential future CoA to the HA. HA can in turn set up registration and packet forwarding to the new POA during a network initiated handover. The network uses the set of MIH_Net_HO_*** in conjunction with any MIH_N2N_HO_*** commands for initiating handovers. The network can use these commands to query the list of resources currently being used by the MN, the serving network can reserve any required resources at the candidate target network, and the network can order the MN to performing a handover to a specific network/subnet.

For optimized horizontal handovers, PoA specific information received from the MIIS is crucial. Information Elements (IEs) containing PoA addressing information, PoA location, data rates supported, the type of physical and MAC layers, and channel configuration information can be used for horizontal proactive handovers. Higher layer services and individual capabilities of different PoAs can also be provided in a similar way. Some specific IE's important for horizontal handover are *IE_POA_LINK_ADDR*, *IE_POA_LOCATION*, *IE_POA_SUBNET_INFO*, *IE_POA_IP_ADDR*. MIPv6 protocol obtains some of this information by executing specialized and time costly discovery procedures.

MIPv6 and MIPv4 enabled nodes can get IP configuration information of the surrounding subnets by making use of the *MIH_Get_Information* primitive and replace the time consuming discovery operations. These operations include Neighbor Discovery, DHCP and Stateless Auto configuration. Another MIIS primitive *MIH_Push_Information* service can be used to push information from the MIIS to the MN. Such MIIS primitives might be even more beneficial for Proxy MIP because in Proxy MIP the MN has no special capabilities for detecting or gathering configuration information, about its surrounding networks.

Paper D

The Implication of Zero Time Scanning Time on MIPv6 Handover Delays by Using Media Independent Information Server (MIIS)

In this paper the effects of intelligent scan mechanisms proposed in Paper B on MIPv6 handover delays are investigated. The handover performance of *MIPv6* utilizing the intelligent scan mechanisms *Intelligent-ScanOne* and *Intelligent-ScanNone*, is compared to *MIPv6* using 802.11 standard scanning using simulations. Handover delays, packet loss are recorded at the IP layer. Both UDP and TCP traffic is tested. Handover delays recorded revealed that *Intelligent-ScanOne* brings *82%* handover delay improvement as compared to traditional MIP handover and *Intelligent-ScanNone* brings *89%* improvement. One important observation here was the increased variance in IP layer handover delays as compared to MAC layer handover delays in Paper B. This could be explained by the fact that in IP layer handovers, MIP control messages have to be transported over the wired network part to remote corresponding nodes resulting in different network packet delays.

In terms of *packet loss* the two MIPv6 approaches utilizing intelligent strategies outperform the traditional MIPv6. For TCP traffic type, MIPv6 using intelligent scanning strategies recover quickly during handovers and *maintain better throughput* than standard MIPv6 because of low handover delays. An interesting finding with TCP traffic was that handover delays and packet loss was more unpredictable. Handover delays were much higher with TCP than with UDP. This might be due to long TCP segments in the network which causes long end to end packet delays for MIPv6 flow redirection messages. A side effect of these high handover delays appeared in the form of loss of MIPv6 control packets and more frequent TCP retransmission.

Paper E

PoA Selection in 802.11 Networks using Media Independent Information Server (MIIS)

The contribution of this paper is *three* fold. *First contribution* is the proposal to consider more than one parameter for PoA selection in 802.11 networks for efficient handover decision making. *Second contribution* is the implementation of such an algorithm with the help of MIIS. Finally *third contribution* is a proposal for the ranking of 802.11 AP's with respect to security.

The proposed PoA selection algorithm is very useful in a Wi-Fi jungle environment. Where the MN has the luxury of multiple AP's to choose from, for attachment. The proposed *PoA selection algorithm considers four factors or parameters* for AP selection in 802.11 networks. The four parameters are distance of the MN from the BS, available bandwidth in the BS, security level of the BS and cost of the connection. When a MN realizes through the use of MIH link layer events that the signal strength from the current AP is going down continuously and a handover is imminent, it performs a query to the

MIIS for handover assistance. The MIIS on receiving the query request form the MN first locates the MN on a virtual map with the help of its coordinates and then decides which AP's are within the reach of the MN by calculating the distance between the MN and its surrounding AP's with the help of Equation 3.1. The MIIS calculates the ranking of all the within reach AP's of the MN, using the proposed algorithm with the help of Equation 3.2. The information of the AP with the highest rank is returned to the MN. The MN soon after receiving the reply from the MIIS performs handover execution to the AP return by the MIIS.

$$D_j = \sqrt{(X_j - X_i)^2 + (Y_j - Y_i)^2} \tag{3.1}$$

Where D_j represents distance between an MN i and a particular AP j, in its surroundings. X_i, Y_i are GPS coordinates of an MN i and X_j, Y_j are coordinates of an AP_j respectively.

$$F_j = \frac{1}{\sum_{k=1}^{4} W_k} \left(W_1 \frac{B.A_j}{B.T_j} - W_2 \frac{D_j}{R_j} + W_3 \frac{S_j}{S_m} - W_4 \frac{C_j}{C_m} \right) \tag{3.2}$$

Where F_j represents the final fitness value or rank of a particular AP_j, $B.A_j$ is available bandwidth and $B.T_j$ represents total bandwidth of an AP_j, D_j represents distance between MN and an AP_j taken as input from Equation 3.1, and R_j represents the radio coverage of an AP_j. S_j and S_m represent the security level of an AP_j and maximum possible security ranking respectively. Similarly C_j and C_m represent cost of connection of a particular AP_j and maximum connection cost. The weights of the parameters are represented by W_1, W_2, W_3 and W_4.

The handover performance of the proposed algorithm is compared with a scheme purely based on the distance between the MN and the surrounding AP's. The distance based scheme is assumed to be analogous to traditional AP selection method, based on maximum *Received Signal Indication (RSSI)* in this paper. Although the proposed algorithm has the ability to consider four or more parameters for handover decisions, the scheme was simulated considering only two criteria or parameters (i.e. available bandwidth and distance) for simplicity reasons. TCP traffic is used to draw comparisons between the two schemes. Simulation results reveal that the *proposed algorithm performs better* than the scheme based on distance only and *maintain better TCP throughput during handovers*. The reason for the *better performance* of the proposed scheme is its ability to consider more factors than just distance or RSS for handover decisions. The proposed algorithm enables the MN to exploit a situation where an MN might be closer to a highly overloaded BS, than a lightly loaded BS further away but still within range. Classical methods of AP selection considering just one factor like RSS or just distance will cause the MN to attach to the BS which have the highest RSS or which is the closest to the MN. It is important to note that the difference in performance gain of the two schemes depends upon the difference in traffic conditions of the candidate PoA's for a particular handover.

3.3 Heterogeneous Handovers

In this section *Question 3* posed in *Chapter 1* is taken up. The main contribution of this part for heterogeneous handovers is the proposal made as part of this thesis, to *divide and then distribute heterogeneous handover algorithms among multiple network components for better scalability* in a Wi-Fi/WiMAX integrated environment. A *Simple Additive Weighting (SAW)* based algorithm is first broken down into two portions and each portion is carried out in two separate stages. In the first portion of the algorithm, the BS's perform their own ranking for the four different service classes provided by WiMAX *(i.e. UGS, rtps, nrtps and BE)*. This ranking of the BS's is carried out in a proactive manner before the handover execution. The second portion of the algorithm is carried out during handover execution and takes the pre-calculated BS ranks in the first part of the algorithm as input and calculates a final candidate BS ranks taking into account the user preferences and QoS needs.

The distribution of the algorithm does not result in additional handover delays and frees the resource limited MN from processing, scanning and memory requirements overheads. A natural advantage of such distribution of processing among multiple network components is that, it will allow the heterogeneous handover algorithms designers to consider many parameters to design more powerful and general heterogeneous handover algorithms, without getting worried about their processing complexity and memory requirements.

Contribution and Summary of the Related Paper

Paper F

A Semi and Fully Distributed Handover Algorithm for Heterogeneous Networks using MIIS

In this paper two proposals are made (i.e. *Semi* and *Fully Distributed*) for distributing a tailored Simple Additive Weighting (SAW) based algorithm. The algorithm is carried out in two steps. In the first step of the algorithm each BS in the topology tracks its own parameters and on the basis of those parameters calculates its own rank by using Equation 3.3 for the four different service types considered in the WiMAX standard. Second part of the algorithm is executed when a handover from a MN is detected. In the second stage the pre-computed ranks in the first step, of base stations in the vicinity of the MN, are revised by using Equation 3.5 in the light of the user cost preferences and QoS requirements. The second stage is carried on the MIIS in case of *Semi Distributed* approach and on candidate BS's in case of *Fully Distributed Approach.*

$$QoS_{ik} = W_{bk}\frac{B.A_i}{B.T_i} + \frac{W_{jk}}{J_i} + \frac{W_{dk}}{D_i} + \frac{W_{lk}}{L_i} \tag{3.3}$$

$$W_{bk} + W_{jk} + W_{dk} + W_{lk} = 1 \tag{3.4}$$

Where QoS_{ik} denotes the QoS rank of particular BS i for a particular service type k defined in the WiMAX standard. $B.A_i$ represents available bandwidth and $B.T_i$ represents total bandwidth of a BS_i, L_i represents packet loss, J_i represents packet jitter and D_i represents packet delay. W_{bk}, W_{jk}, W_{dk} and W_{lk} are the corresponding relative weights of bandwidth, packet loss, jitter and delay for service type k.

$$F_{ik} = W_{QoS} * QoS_{ik} + \frac{W_c}{C_i} \tag{3.5}$$

$$W_{QoS} + W_c = 1 \tag{3.6}$$

Where F_{ik} represents the final rank or fitness score of a particular BS i for a particular service type k. QoS_{ik} is taken as input from the first part, W_{QoS} and W_c are the corresponding relative weights of QoS and cost of the connection.

Simulations are performed in an overlay topology where a WiMAX BS has three 802.11 AP's within its coverage. Three different types of user Service Level Agreement (SLA) and four different service types of the WiMAX standard are considered. The purpose of the simulation was to test the performance of the proposed semi and fully distributed schemes to test, if they satisfy the different user SLA's and QoS requirements of the different user service types. Simulations are designed such that the sensitivity of the proposed SAW algorithm to different service types is tested by keeping a user SLA type fixed and varying the type of user services. Similarly the proposed network selection algorithm sensitivity to different types of user SLA's was tested by varying the SLA type while keeping the service type fixed.

From the simulation it is concluded that the proposed SAW algorithm performs efficient network selection, satisfying all considered user SLA's types and also fulfills the QoS requirements of the four different user service types. To prove the handover efficiency of the proposed distributed schemes they are compared to each other and to an 802.11 preferred scheme. As indicated by its name, in an 802.11 preferred scheme the MN always prefers Wi-Fi network over a WiMAX network for attachment. Simulation results for handover efficiency showed that the proposed distributed schemes outperform the 802.11 preferred scheme and maintained better throughput during handovers. Another interesting phenomenon revealed during the simulations was the ping-pong effect that occurred during handovers for 802.11 preferred scheme only. The two proposed distributed schemes did not suffer from this issue.

3.4 Handovers in Mobile Networks

This section provides insights on *Question 4* posed in *Chapter 1*. The contribution of this section is to provide a survey of some of the most important RO solutions for mobile networks proposed in the literature. The advantages/disadvantages of the considered RO solutions are discussed and are compared to each other with respect to the degree of achieved RO and amount of signaling overhead each proposal requires generating during handovers. Discussions about the effect of the signaling overhead of each solution on handover delays is also provided. A summary is provided in the form of a comparison table on the basis of many parameters.

Contribution and Summary of the Related Paper

Paper G

Pros and Cons of Route Optimization Schemes for Network Mobility (NEMO) and their effects on Handovers

A preliminary version of this paper included in Appendix A of this thesis, was published in the proceedings of Frontiers of Information Technology (FIT) Islamabad Pakistan 2010 (FIT 2010).

All the considered RO mechanisms are first characterized using an IETF categorization and then an introduction to each scheme is provided. Every scheme is analyzed from two important aspects. First is the pros and cons of the scheme and the second is their effects on handovers for mobile routers. Arguments in favor or against the effectiveness of the schemes are backed with a mathematical formulation of the scheme giving an estimate of its signaling overhead. The signaling overhead of all the considered solutions during handovers is compared to the signaling overhead of NEMO basic support protocol and to each other. The signaling overhead of the NEMO protocol given by the following equation, is taken as the base for estimating signaling overhead of the other schemes.

$$\begin{aligned} NEMO_{sig} &= LN_{MR}[BU_{HA} + BA_{HA}] \\ NEMO_{tun} &= m \end{aligned} \tag{3.7}$$

Where the symbols BU, BA, m, N_{MR}, L are used to represent binding update, binding acknowledgment, depth of nested hierarchy, number of mobile routers and number of handovers respectively. The entity and protocol that these message apply to are identified by the subscript of these variables.

Optimized Route Cache (ORC), Path Control Headers (PCH) and Prefix Delegation (PD) come under the IETF category of Network Based RO. The main advantages of ORC are that it is secure, scalable and achieves location privacy. The main disadvantages of ORC are that it requires a new network component and the degree of achievable route optimization depends upon the placement of ORC routers in the network. ORC reduces the number of tunnels to 1 only and its signaling overhead during handovers is moderate. Its security procedures might come at the cost of high handover delays. PCH make use of smart mechanisms to use both signaling and IP packet header information for RO. Such smart mechanisms are required to be carried out by a special router. Some advantages of PCH are its intelligence and simplicity. The main disadvantages of PCH are that it lacks security and has no mechanisms for detecting absence of corresponding routers. The signaling overhead during handover of PCH is low and maintains only one tunnel for its RO. PCH has low handover latency. PD is simple and efficient network based RO mechanism. Its main disadvantages include lack of location privacy and the need for new components in the network. PD does not need any tunnels for its operation but its signaling overhead during handover is high.

Reverse Routing Header (RRH), Access Router Option (ARO) and Hierarchical Mobile IP (HMIP) comes under the IETF category Nested Tunnel Optimization. RRH solves only the pin-ball routing problem. A special header by the name of RRH is defined and contains the route of the nested mobile network. The RRH header is used by the HA's of nested MR's for route optimization. RRH does not require special routers and distributes the processing burden among multiple components. A major problem with RRH protocol is the security of RRH header and lack of location privacy. In terms of handover performance, RRH has the same performance as the NEMO basic support protocol in non-nested scenario but performs better in nested scenarios. ARO belongs to the same category as RRH. ARO works by informing the root MR and the HA of a nested MR about each other to achieve RO. To achieve this several extensions are made to existing standard mobility messages. Strong aspects of ARO are that, it does not require any additional components in the network and has the same degree of security as MIPv6. HMIP based RO solutions also exits. Mobility Access Point (MAP) works as HA for the MR and sends updates messages to the CN's. HMIP based RO have the advantages of less global signaling overhead and shorter handover delay. Disadvantages of HMIP are that it requires a new network component in the form of a MAP and that the packets do not always follow the most optimized route possible at all times. The handover efficiency of HMIP depends upon the scope of handovers i.e. Inter-MAP or Intra MAP and will have the advantage of less global signaling overhead during handovers.

Mobile IPv6 Route Optimization for NEMO (MIRON) is based on MIPv6 route optimization scheme and forms a separate NEMO RO IETF category. The MR achieves end to end RO by updating all correspondent nodes with its current CoA. Advantages of MIRON are that it removes all tunnels and is very simple. Its main problems are limited scalability and the possibility of binding update storms. During handovers MIRON might have to update a large number of CN's and therefore results in a large signaling overhead.

Adhoc routing protocols based RO mechanisms also exists and comes under the IETF category Intradomain Route Optimization. Such solutions are expected to benefit both Adhoc and NEMO domains. The main problem with this category of solutions is that they are only applicable for intra domain RO as indicated by its category name. This is why their inter domain handover efficiency is the same as NEMO while its intra domain handover efficiency depends upon the Adhoc protocol used.

3.5 Conclusions and Future Work

To support seamless heterogeneous handovers in future networks, a strong aspect of the MIH standard is its flexibility. Which makes it possible to realize centralized, decentralized, device driven or the most promising hybrid [20] mobility management architectures. Although the MIH standard specifies centralized and device driven approaches only. To answer the questions 1 to 3 of chapter 1, this thesis has proposed many handover schemes having MIH facilities at their very core. With the help of simulations results and arguments made in this work, it can be concluded that MIH framework can indeed be very useful for improving handover efficiency and network selection at all layers of the TCP/IP protocol stack in both homogeneous and heterogeneous networks. However certain aspects still need to be addressed. While estimating the effectiveness of new handover support procedures for a single node or a mobile network, it's important to consider their related signaling costs as well. For example in this thesis and the related work, although the benefits of using MIH to support mobility management protocols in heterogeneous networks have been stressed upon, there is not much work on the analysis of the signaling cost of the MIH framework in comparison with the advantages that it provides and with other similar frameworks or architectures. One of the big advantages of the MIH framework is the cooperative use of information and interaction between the MIH enabled nodes. However this advantage may become a disadvantage if not employed wisely. Handover and other network management policies that require too much interaction might cause a lot of signaling overhead resulting in wastage of precious network resources. Therefore an important consideration apart from accurate and efficient handover decision making in wireless and mobile networks is the scalability and signaling overhead of such handover algorithms.

Handover efficiency has always been a challenge for packet switched wireless networks mainly due to some deficiencies in technology specific handover procedures and MIP to meet modern day communications needs. The convergence of different technologies makes the handover problem even more complex. Although many solutions have been proposed in the literature and in this thesis for seamless handovers, the majority of the proposed solutions are only applicable to specific network types, specific protocols and homogeneous or heterogeneous handovers. In reality it is not known in advance whether a MN would perform a homogeneous handover or a heterogeneous handover. In fact a MN might perform a combination of both homogeneous and heterogeneous handovers, depending upon the availability of certain preferred network types, QoS conditions of the source and target networks, and the user's cost and QoS preferences. While technically a heterogeneous handover is more sophisticated than a horizontal handover, ideally from a mobile user required QoS perspective there should not be any perceivable difference between the two. Handovers might have different scope involving different layers of the

TCP/IP protocol stack at different times. Therefore there is a great need to devise new efficient and general handover solutions that are applicable to most handover situations. However this generality of the handover algorithms should not come at the price of a degraded handover performance in the form of high handover delays or false handover decisions. Therefore while the new algorithms should be general in their application, in order to be efficient they also need to adapt dynamically to individual user context and preferences, specific application QoS requirements and scope of a particular handover (i.e. homogeneous or heterogeneous, IP layer or MAC layer).

Since the handover performance in a heterogeneous environment depends on a variety of factors using the traditional performance matrices (i.e. handover latency, packet loss and handover success probability) alone for measuring the performance of handover algorithms are no longer enough. In heterogeneous environments, the handover algorithm should ideally support the QoS requirements of both real time and non-real time services in both homogeneous and heterogeneous networks and at the same time satisfy user preferences taking into account a particular user context.

Although simulations are helpful in testing the applicability and effectiveness of such algorithms, the implementations of such algorithm in real world environments can be a challenge from two perspectives. One simulation environments are controlled environments and it might not be possible to model and test the uncertainty and unreliability that exists in practical systems, with simulations. Secondly most of the handover solutions proposed in the literature lack adaptability and dynamism to be able to tackle real world dynamic handover parameters, varying QoS conditions, changing user preferences and contexts. For example most methods proposed in the MADM class algorithms use AHP and some other methods for assigning weights to handover parameters to determine their relative importance. But since the assigned weights are static in nature, such schemes are not capable of dynamic adaptation.

The route optimization problem in NEMO networks has been around for a long time. Most of the solutions proposed in the literature to this problem are specific in their applications and target specific scenarios. Therefore is no RO solution that is scalable, achieves maximum RO possible, provides perfect security and applies to all kind of scenarios.

Table 3.1: Summary.

Paper	Target layer	Decision layer	Problem addressed	Handover (HO) scope	HO initiation & control	Single MN or mobile N/W
A	MAC	App	802.11 scanning	Homog	MIHO, MCHO , NAHO	MN
B	MAC	App	802.11 scanning	Homog	MIHO, MCHO , NAHO	MN
C	IP	App	MIP operations	Homog	All	MN
D	IP	App	layer 3 HO delays	Homog	MIHO, MCHO, NAHO	MN
E	MAC	App	PoA selection	Homog	MIHO, MCHO , NAHO	MN
F	All	App	N/W selection	Heterog	MIHO, MCHO , NAHO	MN
G	IP	IP	HO delays, routing & signaling	Homog or Heterog	MIHO, MCHO & NAHO	Mobile N/W

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Part II

Selected Publications

Paper A

An Intelligent Scan Mechanism For 802.11 Networks by Using Media Independent Information Server (MIIS)

Muhammad Qasim Khan, Steinar Hidle Andresen

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Abstract

Handover efficiency in wireless and mobile communication networks is an important factor in providing QoS guarantees for real time applications. The 802.11 standard requires a Mobile Node (MN) to scan all the possible channels (11 in the US) to discover available Access Points (AP's) during a handover. In a given 802.11 cell several channels are expected to be empty. Due to a full scan the MN ends up wasting time scanning empty channels, which results in a high handover delay. This handover delay can be reduced by simple refining the scanning procedure to a limited set of channels, currently being used throughout the network or by the surrounding access points.

In this paper we propose to use the Media Independent Information Server (MIIS) to inform the MN of the channel configuration information of the network or the surrounding AP's. In our scheme the MN acquires channel configuration information from MIIS server and then uses that information to scan a limited set of channels being used by the surrounding access points or through out the network rather than scanning all possible channels resulting in reduced handover delay. We define a parameter *NET_CHANNEL_CONFIG* which is passed in the query by the MN to the MIIS, so that the MIIS knows which information is being requested by the MN. We also define an Information Element Container *IE_CONTAINER_802.11_CHINFO* which is used by MIIS to return the requested channel configuration information of the network to the MN. We call our scheme Intelligent Scan.

1 Introduction

Mobile Communication networks are one of the most rapidly developing fields and compared to its predecessors offers high bandwidth and improved Quality of Service (QoS) for a variety of multimedia applications. However with the advancement in communications networks, more innovative and advanced applications have also emerged which are very demanding in terms of their QoS requirements. One critical issue for such applications is handover efficiency. Ideally there should be no disruption when a Mobile Node (MN) moves and changes its point of attachment to the network. As the MN is not able to exchange data packets, when performing a handover from once access point to another, the handover delay becomes very critical in guaranteeing real-time applications their QoS requirements. The ITU (International Telecom Union) specify that this delay should not be more than 50ms [1] to avoid jitter in VOIP applicatons. A handover might take places at the MAC (Medium Access Control) layer or at the IP layer depending on the scope of mobility of the MN. Total handover delay is the sum of handover delays at all layers. The 802.11 standard [2] requires scanning all available channels (11 in US [3] [4], 13 in most of Europe and 14 in Japan [4]) during a MAC layer handover. Generally an 802.11 cell is expected to have many empty channels to reduce interference between adjacent cells and skipping scanning empty channels can save us considerable time.

In this article we propose to use the information service of the Media Independent Handover (MIH) [5] to inform the MN of the active channels. The MN can then use this information during a handover and reduce handover delay by scanning only active channels in the network or in the vicinity. This article is in line with our earlier work [6], in which we proposed to use MIH and it services for horizontal handovers, although the original goal of MIH is to support vertical Handovers. Here we take a specific case of scanning and develop a framework on how an MN will equip itself with enough information to perform a more efficient scan to reduce MAC layer handover latency. MIH services can help to expedite both inter and intra technology handover. Moreover MIH infrastructure is expected to be already present to support vertical handovers anyway.This article is arranged as follows.

Section 2 of this article provides some related work. In Section 3 we present a short introduction to Media Independent Handover (MIH) and 802.11 scanning process. Section 4 provides an overview of our proposed intelligent scan. Section 5 contains results discussions and simulation parameters. Finally in Section 6 we present conclusions and discuss future research directions

2 Related Work

Discussed in Section 3.2 the 802.11 [2] scanning consists of three stages. All these three stages have their own delays but the probe delay (scanning stage) constitutes more than 90% of the overall mac layer handover delay [7], therefore most of the research efforts have focused on reducing scanning delays. A selective scan approach can limit the scanning process to just one probable channel [4]. A pre scan mechanism to reduce handover latency called the Deuce Scan has been proposed in [8]. Another scheme to reduce MAC layer handover latency based on identifying a set of potential AP's by taking into account the handoff history has been proposed in [9] [10]. But this technique requires a large amount of memory [8]. Pack [11] introduced an improved variant of the Neighbor Caching scheme but missing caches becomes serious problem for handovers in this scheme. Shin et al. [12] proposed to scan a subset of all the channels by using a dynamic channel mask in the selective scanning algorithm. In [13] the authors introduced a fast pre-scan mechanism called SyncScan. A QoS supported dynamic channel scanning algorithm was proposed in [14]. In this scheme the scanning process is scheduled into small scan times termed service interruption times. If the current QoS measure is less than a *QoS_Scan_Start* link layer trigger, the MN sends query messages to the 802.21 [5] MIIS server to get neighbor network information. The neighbor network information is then used to perform QoS supported scanning. In [15] the authors compared both theoretical and actual experimental scanning delays. Another approach in [16] proposes to use the MIIS server to get information about network configuration to perform limited channel scanning and an algorithm for selecting candidate PoA.

The overall idea to improve scanning presented in [16] is very similar to our idea presented in this paper but they don't provide details of their scheme e.g when and how the MN decides to request information from the MIIS, nor do they provide any in depth analysis or comparison of their proposed MAC layer handover approach. Their main focus is on improving layer three handover delay and target candidate PoA selection. In contrast to [16] our focus here is totally on link layer handovers. We present a framework for exchange of channel configuration information between the MIIS and the MN. We define four different scanning strategies and evaluate their performance by using the NIST-MIH [17] implementation of 802.21 (draft 3) in Network Simulator (ns-2) [18]. We also define a new parameter to be included in the MN's query to the MIIS and an Information Container which is used by the MIIS to return the requested information.

3 Background

3.1 Media Independent Handover (MIH)

Media Independent Handover [5] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. The purpose of the standard is not to design a new protocol but to complement the existing mobility management protocols and procedures in taking handover decisions. The MIH Function (MIHF) provides three kinds of services to achieve this, as shown in Figure 1 taken from reference [5]. A short description of each type of these services is given next.

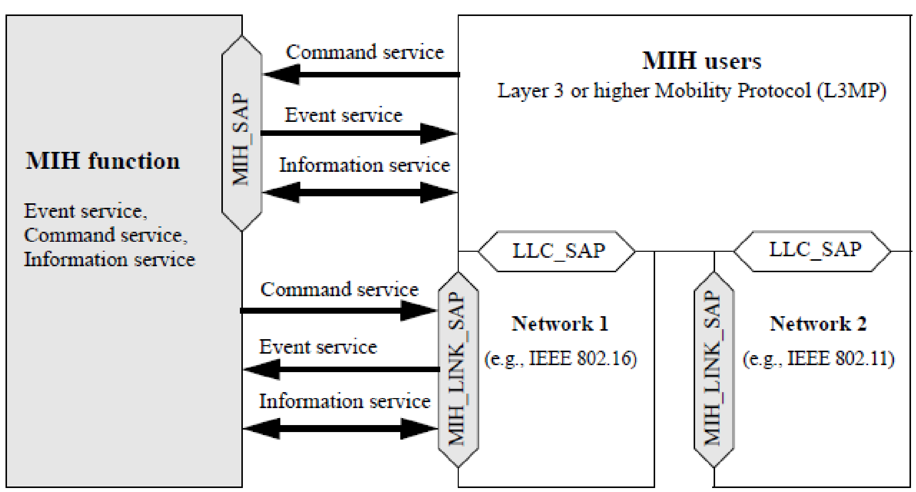

Figure 1: MIH Services and their Initiation.

3.1.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIH Function (MIH Events) or any lower layer (Link Events) with in the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

3.1.2 Media Independent Informations Service (MIIS)

The MIIS provides a framework and corresponding mechanisms by which an MIHF (MN) entity can discover and obtain network information existing within a geographical area to facilitate network selection and handovers. MIH Information Service can be used to provide network information to the MIH function. The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The network side of the MIH entity with which the MN exchanges MIH information is called Point of Service (PoS). The MIH standard supports both layer 2 and layer 3 transport option for information access.

3.1.3 Media Independent Command Service (MICS)

The high layer can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands) or by MIHF itself (Link Commands). The destination of these commands my be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

3.2 Scanning in 802.11

The 802.11 [2] MAC layer handover consist of 3 stages i.e. Scanning, Authentication and Association or Re-association. The 802.11 standard requires scanning all available channels. The purpose of the scanning phase is to discover available AP's. Once AP's are discovered the MN can associate itself with the best available AP after authentication, which completes the MAC layer handover. The standard defines two types of scanning i.e. Passive and Active.

In *Passive Scanning* the MN listens on each channel passively for beacons transmitted from AP to detect active channels. By default the beacon is sent out by base stations every 100 ms. The MN will have to wait a bit more than 100 ms on each of the channels to successfully receive a beacon. Therefore scanning 11 channels might take 11 x 0.1 = 1.1s.

In *Active Scanning* the MN actively probes the available AP's by sending a Probe Request message on the current channel and then waits *MinChannelTime* for a probe response from the AP's. If the MN detects activity on the channel it prolongs its wait for *MaxChannelTime* to make sure it receives responses from all reachable AP's. If there is no activity on the channel in *MinChannelTime* or activity is detected but *MaxChannelTime* times out, the MN goes on to scan the next channel and repeat the same process. Once the MN is finished scanning all the channels, it selects the best AP according to some criteria (e.g. *Received Signal Strength Indication (RSSI)*) for association. Active scanning performs better than passive scanning [19] but result in bandwidth wastage. In this article we consider active scanning only.

4 Intelligent Scan

4.1 Scanning Strategies

Apart from knowing which channels to scan and which to skip another important factor that influences scanning delay is to decide that sufficient information is collected and stop scanning e.g. an MN might decide to associate with the first AP detected and cancel scanning for the rest of the channels. Keeping this in mind we define the following four different scanning strategies.

1. *Scan-All:* In *Scan-All* the MN scans all the possible channels (11 in total) in ascending order starting with channel 1, before selecting the best AP for association. This is the default mode of scanning operation for 802.11 [2].

2. *ScanAll-StopFirst:* In this strategy the MN starts scanning all channels consecutively starting from the first one but stops on the first AP detected e.g. when the MN performs a handover from BS1 to BS2 (operating on channel 5) in Figure 2 the MN scans only the first 5 channels. This scheme is expected to have low handover delay than the first one but might not guarantee the selection of the best available AP.

3. *Intelligent-ScanAll:* This schemes requires that the MN request channel configuration information of the network from the MIIS. The MIIS returns a list of channels currently being used by the neighboring access points or throughout the netw ork e.g. in our simulation scenario the MIIS returns *AP1-CH3, AP2-CH5, AP3-CH7, and AP4-CH9*. The MN during a handover scans all channels in list that it receives from the MIIS even if a channel that appears earlier in the list is found active.

4. *Intelligent-StopFirst:* In this scheme first the MN retrieves channel configuration information from the MIIS as in scheme three but stops scanning on the first AP

detected e.g. when the MN perform a handover from BS1 to BS2 (operating on channel 5) in Figure 2 the MN scans only the two channels i.e. 3 and 5. Similar to *ScanAll-StopFirst* this scheme also might not guarantee the selection of best available AP.

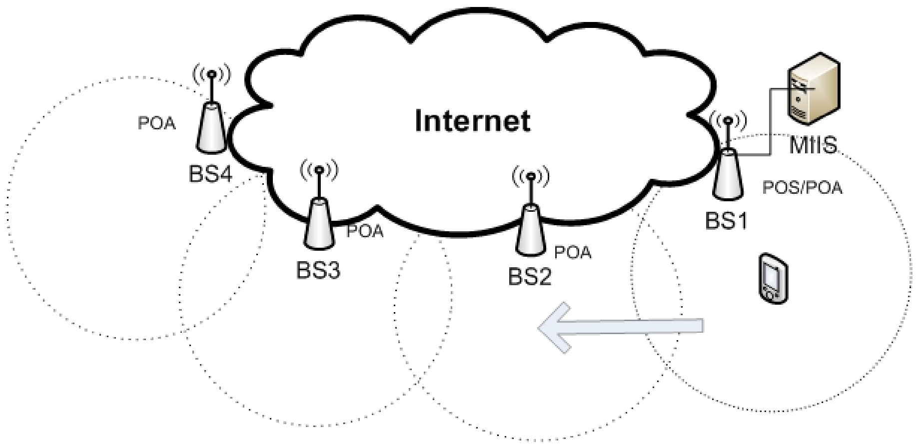

Figure 2: Simulation Scenario.

It is expected that the *ScanAll-StopFirst* strategy will outperform the *Scan-All* strategy in terms of handover latency. *Intelligent-ScanAll* strategy is expected to outperform both *Scan-All* and *ScanAll-StopFirst*. *Intelligent-StopFirst* is expected to outperform all the others with respect to handover delays.

4.2 Querying the Information Server

For both *Intelligent-ScanAll and Intelligent-StopFirst* strategies to work, it is necessary that the MN knows the list of active channels. To get this information the MN broadcasts an information request or more specifically a binary query in Type Length Value (TLV) format [5] and the MIIS replies with the required information. As an MIIS server has a lot of information stored with it from PoA specific information to the different types of access networks available in the area, the MIH standard allows the MN to request the specific information it needs and therefore can limit the size of the reply from MIIS. Figure 3 shows the interaction between the MN and MIIS.

In our case as we need the 802.11 network channel configuration information, therefore we need to specify our network type (i.e. 802.11) in our query. This can be achieved by using the *NET_TYPE_INC* parameter defined in the 802.21 standard. The MN also need to specify that it needs network channel configuration information. But since the MIH standard does not specify any parameter for this purpose, we define a new one by the name of *NET_CHANNEL_CONFIG*. We also define a new information container i.e. *IE_CONTAINER_802.11_CHINFO*, which will be used by MIIS to return the requested network channel configuration information. The list of channels will be stored in the form

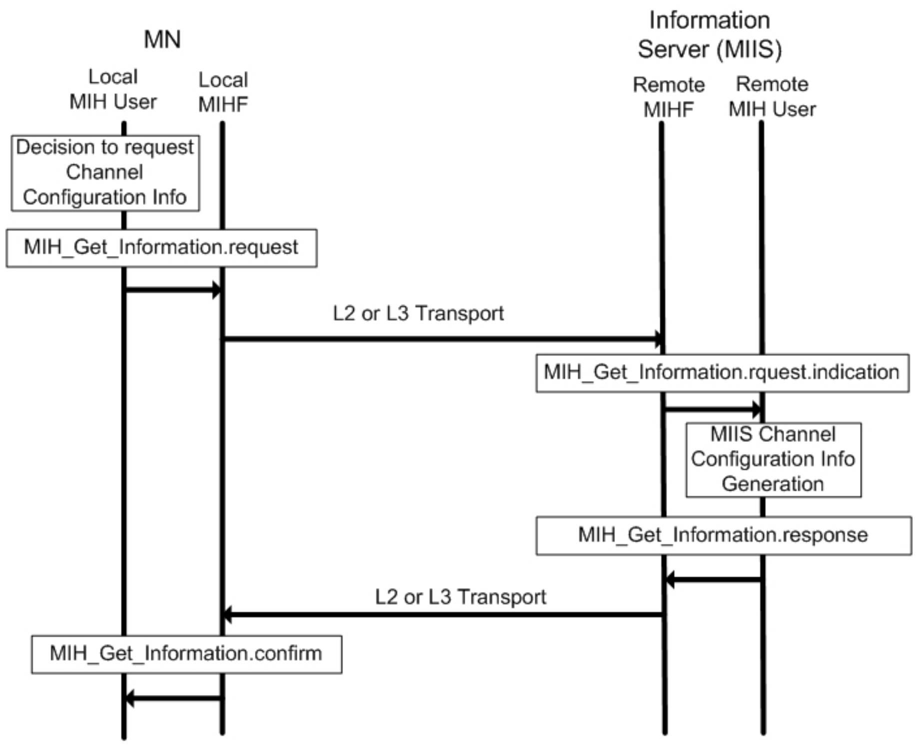

Figure 3: Interaction between MN and MIIS

of Information Elements (IE's) in the IE container. The number of channels included by the MIIS server in the *IE_CONTAINER_802.11_CHINFO* will depend upon the network configuration and MIIS policy. For example if all 11 channels are being used throughout the network then the MIIS will return a subset of channels currently in operation in the vicinity of the MN. For this the MIIS needs to know the current position of the MN which can be signaled by the MN by using the parameter *QUERIER_LOC* parameter defined in the 802.21 standard. However if only a subset of channels are used throughout the network then the MIIS can either return the whole list of channels or alternatively consider current coordinates of the MN to return a more refined list of channels. In our case we assume that only four channels are in operation throughout the network and therefore the MIIS returns a list of four channels.

5 Simulation Scenario and Parameters

The National Institute of Standards and Technology (NIST) have implemented the Media Independent Handover Function (MIHF) based on draft 3 of 802.21 standard in the form of an add-on module [17] for Network Simulator (ns-2) [18] version ns-2.29. The implementation supports both MIES and MICS but does not support MIIS [20]. We have used this implementation for our simulation and have added a limited MIIS server functionality. The NIST module also provide implementation of 802.11 [21].

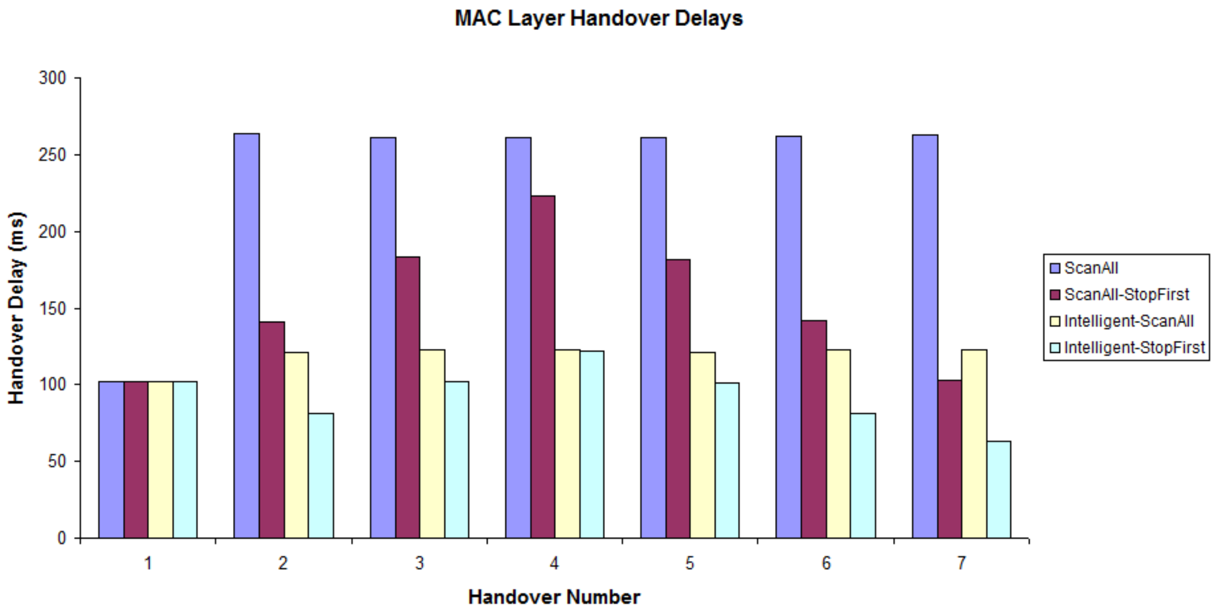

Figure 4: MAC Layer Handover Delays for four different strategies.

Figure 2 represents the topology of our simulation scenario. The simulation area was set to 100x100 meter and consisted of four base stations. At the start of the simulation the MN associates on a pre-determined channel with BS1 and no scanning is performed. The MN then moves at a constant speed of 5 m/s toward's BS2. When the MN moves out of the coverage of BS1, an *MIH_Link_Down* event is generated and the MIHF receives an *MIH_Link_Down_indication* event notification. The MIHF then sends a *Link_Action.request* to command the local interface to perform a scan, which causes the MN to start the scanning process to search for available APs. Then MN finds BS2 on channel 5 and associates itself with it. The MN continues its motion and reaches BS4. The MN at simulation time 50 sec takes back the same route in the reverse direction at the same speed and reaches BS1. Thus the MN performs 6 handovers in one simulation run. The handover delays recorded for each scanning strategy has been summarized in Table 1 and plotted in *Figure 4*.

5.1 Discussion

It is evident from both the graph in Figure 4 and the average delay for each scanning strategy in Table 1 that, *Intelligent-StopFirst* performs better than all the other schemes while *Intelligent-ScanAll* out performs the other two strategies which do not make use the MIIS server. Therefore the results strongly recommends using MIIS server for reducing handover latency. The handover delay have been considered as the time duration from the time instant when an MN start scanning for APs for the first time, till it successfully associates itself with an AP. The NIST 802.11 module [21] does not support authentication therefore handover delays calculated in our case does not include authentication delays.

Table 1: Mac Layer Handover Delays for different Scanning Strategies

HandOvers	Scanning Strategies delays in ms			
	ScanAll	ScanAll StopFirst	Intelligent ScanAll	Intelligent StopFirst
1	101,663119	101,663119	101,663119	101,663119
2	264,039591	140,967384	121,227385	81,267386
3	261,467493	183,251707	122,791711	101,807791
4	260,887544	223,171757	122,631247	121,807791
5	261,087691	181,187694	121,287696	101,527549
6	261,607544	141,647548	123,031764	81,58755
7	262,811996	102,651713	122,711711	63,091769
Average	261,9836432	162,1463005	122,2802523	91,848306

The time recorded for handover number 1 represents association delay of the MN with BS1 only and no scanning is performed. Therefore the average is calculated for handover number 2 to 7 for each category. This is also the reason that the handover 1 delays are the same for all strategies in Figure 4 and Table 1.

6 Conclusion and Future Research Directions

The 802.11 standard requires that an MN performs a full scan each time it performs a handover. This wastes precious time as the MN has to scan empty channels as well. In this article we presented that how an MN can use the Media Independent Information Server to refine the scanning mechanism of 802.11 to active channels only. For this purpose we defined a parameter that must be included in the MN request when it queries the MIIS and also an information container that is used by the MIIS to return the requested information.

In future this work can be further extended by further reducing the number channels to scan by considering the GPS coordinates of both the MN and the BS. Proactive behavior can also be introduced to exchange keys, perform resource availability check etc. Another direction could be to optimize layer three handovers or consider heterogeneous environment. It would also be interesting to investigate channel scanning assuming multi 802.11 networks like 802.11a, 802.11b/g and 802.11p using 802.21 MIIS server.

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Paper B

Zero Scanning Time for 802.11 Networks by Using Media Independent Information Server (MIIS)

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Abstract

Handover efficiency in wireless and mobile communication networks is an important factor in providing QoS guarantees for real time applications. The 802.11 standard requires a Mobile Node (MN) to scan all the possible channels (11 in the US) to discover available Access Points (AP's) during a handover. In a given 802.11 cell several channels are expected to be empty. Due to a full scan the MN ends up wasting precious time scanning empty channels. This results in a high handover delay. This handover delay can be simply reduced by making the MN aware of the channel configuration of its future Point of Attachment (PoA).

In this paper we propose that when an MN concludes that a handover is imminent, it should inquire the Media Independent Information Server (MIIS) of the Media Independent Information Handover (MIH), for channel configuration information of the future access point rather than scan for this information by itself. The query for this information should contain the current GPS coordinates of the MN. The MIIS first locates the MN on a virtual map with the help of the GPS coordinates and then returns the precise channel configuration information of the future AP to the MN. The MN stores this information locally and uses it to scan just one channel or to skip the scanning completely and associate directly with an access point during a handover. We define a new parameter *NET_CHANNEL_CONFIG* which is passed in the query by the MN to the MIIS, so that the MIIS knows which information is being requested by the MN. We also define an MIH Information Element Container *IE_CONTAINER_802.11_CHINFO* which is used by the MIIS to return the requested channel configuration information of the PoA to the MN.

The communication overhead for our scheme is just one message exchange with the MIIS as part of the handover preparation phase. Simulation results shows that our scheme Intelligent-ScanOne, that scans just one channel, results in a 93% improvement over standard 802.11 scanning. Our second scheme Intelligent-ScanNone avoids channel scanning completely and results in a 99% improvement over standard 802.11 scanning delays.

1 Introduction

Mobile Communication networks are one of the most rapidly developing fields and compared to its predecessors offers high bandwidth and improved Quality of Service (QoS) for a variety of multimedia applications. However with the advancement in communications networks, more innovative and advanced applications have also emerged. These new applications have strict demands in terms of their QoS requirements. One critical issue for such applications is handover efficiency. Ideally there should be no disruption when a Mobile Node (MN) moves and changes its point of attachment to the network. As the MN is not able to exchange data packets during a handover, the handover delay becomes very critical in guaranteeing real-time applications their QoS requirements. The ITU (International Telecom Union) specify that this delay should not be more than 50ms [1] in order to avoid jitter in VOIP applications. A handover might take places at the Medium Access Control (MAC) layer or at the IP layer depending on the scope of mobility of the MN. Total handover delay is the sum of handover delays at all layers. The 802.11 standard [2] requires scanning all available channels (11 in US [3] [4], 13 in most of Europe and 14 in Japan [4]) during a MAC layer handover. Generally an 802.11 cell is expected to have many empty channels to reduce interference between adjacent cells and skipping the scanning of channels altogether can save us considerable time.

In this article we propose to use the Media Independent Information Service (MIIS) of the Media Independent Handover (MIH) [5] to inform the MN of the channel currently being used by a potential future Point of Attachment (PoA). The MN can then use this information during a handover and reduce handover delay by scanning just one channel or proceeding directly to the association phase of 802.11 MAC layer handover by skipping channel scanning all together. This article is in line with our earlier work [6] and [7]. In [6] we proposed to use MIH and it services for horizontal handovers, although the original goal of MIH is to support vertical handovers. In [7] we proposed an intelligent scan mechanism, which scans only a subset of channels operational in an 802.11 network. Here we further improve the scheme in [7] by considering the GPS coordinates of the MN to scan just one channel or go directly to the association phase of 802.11, on a predecided channel during a handover. MIH services can help to expedite both inter and intra technology handover. Moreover MIH infrastructure is expected to be already present to support vertical handovers anyway.

This article is organized as follows: Section 2 of this article provides some related work. In Section 3 we present a short introduction to MIH and 802.11 scanning process. Section 4 provides an overview of our proposed intelligent scan mechanisms. Section 5 contains simulation parameters, results and discussion. Finally Section 6 provides conclusions.

2 Related Work

Discussed in more detail in Section 3.2 the 802.11 [2] scanning consists of three stages. All these three stages have their own delays but, the probe delay (scanning stage) constitutes more than 90% of the overall mac layer handover delay [8]. Therefore most of the research efforts have focused on reducing scanning delays. A selective scan approach can limit the scanning process to just one probable channel [4]. A pre scan mechanism to reduce handover latency called the Deuce Scan has been proposed in [9]. Another scheme to reduce MAC layer handover latency based on identifying a set of potential AP's by taking into account the handoff history has been proposed in [10] and [11]. But this technique requires a large amount of memory [9]. Pack [12] introduced an improved variant of the Neighbor Caching scheme but, missing caches becomes serious problem for handovers in this scheme. Shin et al. [13] proposed to scan a subset of all the channels by using a dynamic channel mask in the selective scanning algorithm. In [14] the authors introduced a fast pre-scan mechanism called SyncScan. A QoS supported dynamic channel scanning algorithm was proposed in [15]. In this scheme the scanning process is scheduled into small scan times termed service interruption times. If the current QoS measure is less than a *QoS_Scan_Start* link layer trigger, the MN sends query messages to the MIH [5] MIIS server to get neighbour network information. The neighbor network information is then used to perform QoS supported scanning. In [16] the authors compared both theoretical and actual experimental scanning delays. Another approach in [17] proposes to use the MIIS server to get information about network configuration to perform limited channel scanning and an algorithm for selecting candidate PoA.

The overall idea to improve scanning presented in [17] is very similar to our idea presented in this paper but, they don't provide details of their scheme e.g. when and how the MN decides to request information from the MIIS, nor do they provide any in depth analysis or comparison of their proposed MAC layer handover approach. Their main focus is on improving layer three handover delay and target candidate PoA selection. In contrast to [17] our focus here is totally on link layer handovers. We present a framework for the exchange of channel configuration information between the MIIS and the MN. We define a new scanning strategy based on GPS coordinates of the MN and evaluate its performance by using simulations. We also define a new parameter to be included in the MN's query to the MIIS and an Information Container which is used by the MIIS to return the requested information.

3 Background

3.1 Media Independent Handover (MIH)

Media Independent Handover [5] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. *Figure 1*, taken from reference [5] shows how the MIH Function (MIHF) is interfaced with other layers of the protocol stack in a multi face MN or network node. With the help of single media independent interface *MIH Service Access Point (MIH_SAP)*, the MIHF provide services to the MIH users. The MIHF takes services from the lower layers through more than one media dependent service access points *MIH_LINK_SAP* and all interactions between the MIHF and the lower layers of media-specific protocol stacks takes place through media-specific instantiations of *MIH_LINK_SAP*. The purpose of the MIH standard is not to design a new protocol, but to complement the existing mobility management protocols and procedures in taking handover decisions. The MIHF provides three kinds of services to achieve this. A short description of each type of these services is given next.

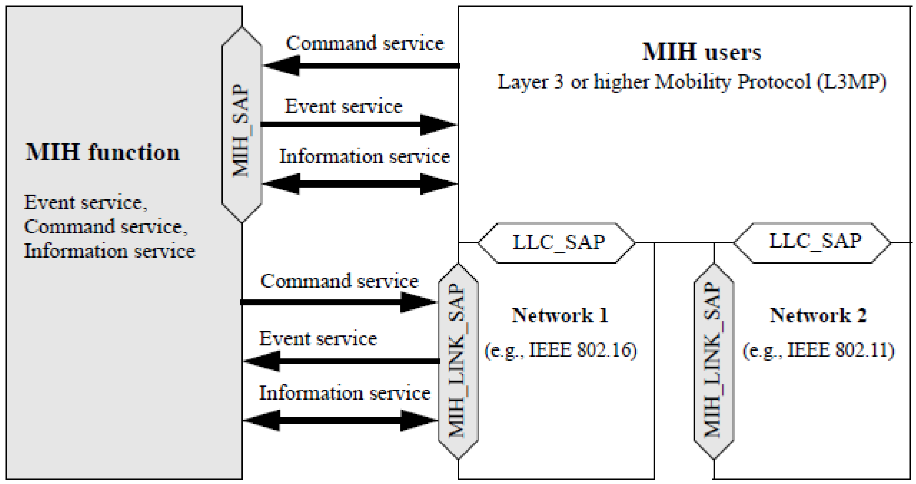

Figure 1: MIH Services and their Initiation.

3.1.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIHF (MIH Events) or from a lower layer (Link Events) with in the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

3.1.2 Media Independent Information Service (MIIS)

The MIIS provides a framework and corresponding mechanisms by which an MIHF (MN) entity can discover and obtain network information existing within a geographical area to facilitate network selection and handovers. MIH Information Service can be used to provide network information to the MIHF. The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The network side of the MIH entity with which the MN exchanges MIH information is called Point of Service (PoS). The MIH standard supports both layer 2 and layer 3 transport option for information access.

3.1.3 Media Independent Command Service (MICS)

The higher layers can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands) or by MIHF itself (Link Commands). The destination of these commands may be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

3.2 Scanning in 802.11

The 802.11 [2] MAC layer handover consist of three stages i.e. Scanning, Authentication and Association or Re-association. The 802.11 standard requires scanning all available channels. The purpose of the scanning phase is to discover available AP's. Once AP's are discovered the MN can associate itself with the best available AP after authentication, which completes the MAC layer handover. The standard defines two types of scanning i.e. Passive and Active.

In *Passive Scanning* the MN listens on each channel passively for beacons transmitted from AP to detect active channels. By default the beacon is sent out by base stations every 100 ms. The MN will have to wait a bit more than 100 ms on each of the channels to successfully receive a beacon.

$$D_P = m * 0.1sec \tag{1}$$

Where D_P represents passive scanning delays and m is the total number of channels (both empty and active). Therefore scanning 11 channels might take D_P=1.1s.

In *Active Scanning* the MN actively probes the available AP's by sending a *Probe Request* message on the current channel and then waits *MinChannelTime* for a probe response from the AP's. If the MN detects activity on the channel it prolongs its wait for *MaxChannel-Time* to make sure it receives responses from all reachable AP's. If there is no activity on the channel in *MinChannelTime* or activity is detected but, *MaxChannelTime* times out, the MN goes on to scan the next channel and repeat the same process. Once the MN is finished scanning all the channels, it may discover that more than one AP's are available in a particular location. The MN selects the best AP according to some criteria (e.g. *Received Signal Strength Indication (RSSI)*) for association. Active scanning performs better than passive scanning with respect to handover delay but, results in bandwidth wastage [20]. In this article we consider active scanning only. Active scanning delay can be computed with the help of the following equation.

$$D_A = n(MaxChTime) + (m - n)(MinChTime) \tag{2}$$

Where D_A represents active scanning delays, m is the total number of channels, n is the total number of active channels in an 802.11 cell and *MaxChTime*, *MinChTime* are *MaxChannelTime* and *MinChannelTime*. For a configuration of *m=11*, *n=1* and default values for *MaxChTime*, *MinChTime* D_A =0.26 sec.

4 Intelligent Scan

In our proposed Intelligent Scan mechanism, when an MN concludes that soon it will have to handover to another 802.11 cell, it retrieves the channel configuration information of the future PoA from MIIS server. For this purpose the MN performs a query as part of the handover preparation phase, rather than having to discover this information through scanning during handover execution phase. The communication overhead for our scheme is just one message exchange with the MIIS server. The two most important phases of our scheme are described as follows.

4.1 Querying the MIIS

For our *Intelligent-Scan* strategy to work, it is necessary that the MN knows the *Basic Services Set Identification (BSSID)* and the current channel number of the future PoA. To get this information the MN queries the MIIS server in a timely manner. The MN broadcasts a binary query in Type Length Value (TLV) format [5] and the MIIS replies with the required information. The MIH standard suggests that the information query must be made as soon as the MN attaches itself successfully to the network. However in our case the MN queries the MIIS server at once after receiving a *MIH_Link_Going_Down (LGD)* trigger (it then, apparently, has an urgent need to do a handover). An MIIS server has a lot of information stored with it, from PoA specific information to the different types of access networks available in the area. Therefore the MIH standard allows the MN to request the specific information it needs and therefore can limit the size of the reply from the MIIS. *Figure 2* shows the interaction between the MN and MIIS.

In our case as we need the 802.11 network channel configuration information, therefore we need to specify our network type (i.e. 802.11) in our query. This can be achieved by using the *NET_TYPE_INC* parameter defined in the MIH standard. The MN also needs to specify network channel configuration information is required. But since the MIH standard does not specify any parameter for this purpose, we define a new one by the name of *NET_CHANNEL_CONFIG*.

It is crucial for our scheme that the MN also provides its GPS coordinates in the query to the MIIS. For this purpose the MN uses the parameter *QUERIER_LOC* parameter defined in the MIH standard. The coordinates of the MN are used on the server to locate the MN on a virtual map. This helps the MIIS server to determine, which candidate PoA the MN is likely to attach to in the near future, because the MIIS server has a holistic view of the network topology and knows about the coordinates, BSSID and coverage of all the access points in the network. All this information is stored as static information as defined in the MIH standard.

We also define a new MIH information container i.e. *IE_CONTAINER_802.11_CHI NFO*, which is used by MIIS to return the requested future PoA channel configuration information. The channel number and BSSID of the future PoA are stored in the form of

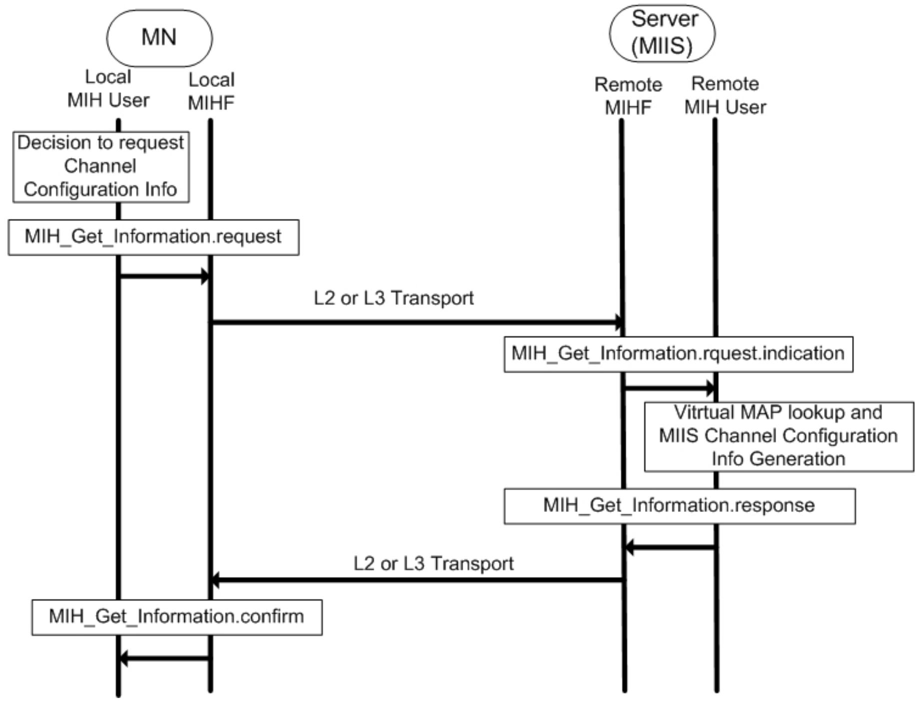

Figure 2: Interaction between MN and MIIS

Information Elements (IE's) in the IE container. The amount of information included by the MIIS server in the *IE_CONTAINER_802.11_CHINFO* will depend upon the network configuration and MIIS policy. At minimum our scheme requires BSSID and the currently operational channel number of the future PoA. Additional information such as IP address of the future PoA, bandwidth etc. might also be included. The information received after such a query is stored locally by the MN for future use. Each time an *LGD* trigger is generated the MN checks if the threshold for queering the MIIS has been exceeded, if yes it performs an MIIS query. In this way the MN makes sure that the locally stored information remains fresh and valid.

4.2 Intelligent Scanning Strategy

When the signal quality degrades continuously and the threshold for performing a handover is exceeded, the MN decides that it has to perform a handover. The MN tears down its current connection and starts looking for another PoA. Our proposed Intelligent Scanning Strategy is shown in *Figure 3*.

The MN first checks if it has any valid channel configuration information of the future PoA obtained from MIIS. If yes, then rather to scan all channels, it either scan just one channel, called *Intelligent-ScanOne*, or proceeds directly to associating on the channel number and BSSID, it obtained from the MIIS server. The latter scheme is called *Intelligent-ScanNone*. Sequence of events for *Intelligent-ScanNone* inside the MN,

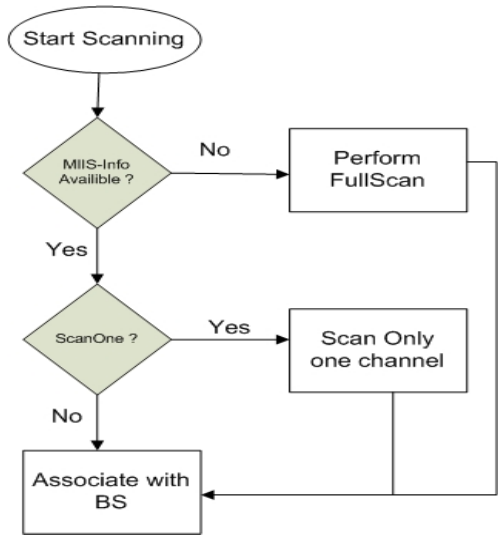

Figure 3: Scanning Flow Diagram.

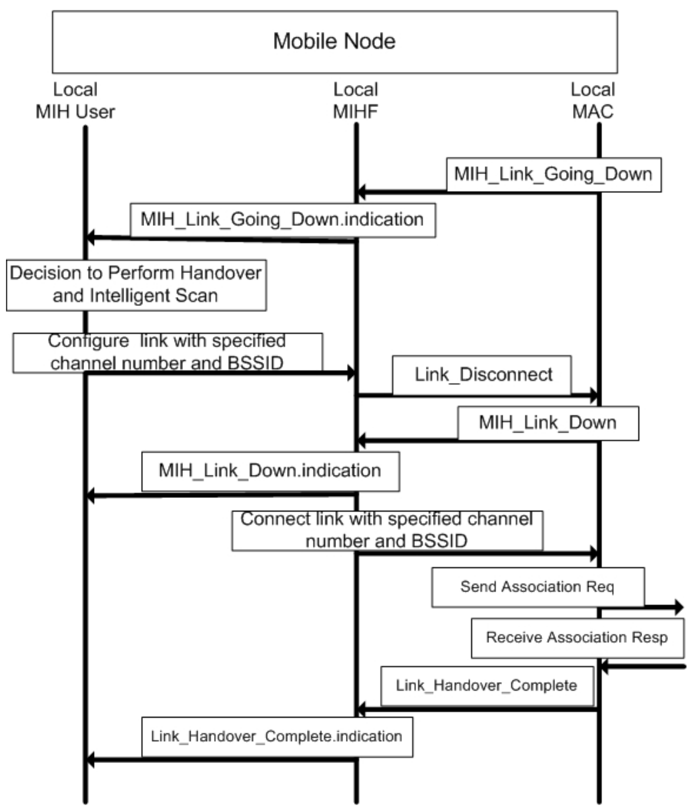

Figure 4: Intelligent-ScanNone.

are shown in *Figure 4*. The decision of performing *Intelligent-ScanOne* or *Intelligent-ScanNone* depends on the scanning policy of the MN. However *Intelligent-ScanNone* will save battery power while *Intelligent-ScanOne* will have the advantage of discovering the AP passed from MIIS. Both the schemes are expected to bring a dramatic decrease in scanning delays and packet loss as compared to 802.11 standard scanning.

5 Simulation Scenario and Parameters

The National Institute of Standards and Technology (NIST) have implemented the Media Independent Handover Function (MIHF) based on draft 3 of MIH standard in the form of an add-on module [18] for Network Simulator (ns-2) [19] version ns-2.29.

The implementation supports both MIES and MICS but, does not support MIIS [21]. We have used this implementation for our simulation and have added a limited MIIS server functionality. NIST also provides implementation of 802.11 [22].

Figure 5 represents the topology of our simulation scenario. The simulation area was set to 300x300 meter and consisted of four base stations. At the start of the simulation the MN associates on a pre-determined channel with base station i.e. BS_1 and no scanning is performed. After connecting to BS_1 at the MAC layer, the MN configures a valid IP address and performs Mobile IPv6 procedures. The MN then performs MIH capability discovery procedures and then finally registers with peer MIHF.

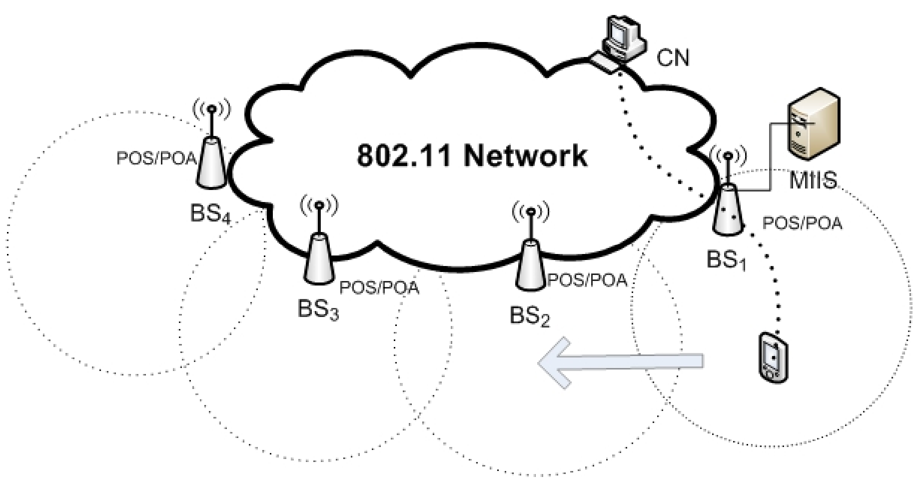

Figure 5: Simulation Scenario.

At simulation time 5sec a correspondent node (CN) as shown in *Figure 5*, starts to send Constant Bit Rate (CBR) traffic with a packet size 1500 bytes and inter arrival time of 0.01sec, to the MN. The MN at simulation time 8sec starts a linear motion with a constant speed of 5m/s in the direction of BS_2. As the MN moves away from BS_1, the signal strength goes down continuously and a *Link_Going_Down* event is generated. The MIHF receives an *MIH_Link_Going_Down* event notification. This MIH event is propagated to the MIH user as depicted in *Figure 4*. The MIH user while connected to BS_1, performs an MIIS query as explained in section 4.1, if conditions for performing an MIIS query are fulfilled.

The MIIS server with the help of GPS coordinates of the MN and a virtual map generates information of the future AP, which in this case is BS_2. This information is returned to the MN as explained earlier in section 4.1.

The MN continues its linear motion and handover is triggered, when the MN goes out of the radio coverage of BS_1. As the MN has local information available on next PoA i.e. BS_2, it scans just one channel i.e. of BS_2 or proceeds directly to associate with BS_2 skipping the scanning phase of 802.11 MAC layer handover completely.

The MN continues its motion and reaches BS_4 in a similar manner. The MN at simulation time 50 sec takes back the same route in the reverse direction at the same speed and reaches BS_1. Thus the MN performs 6 handovers in one simulation run. The handover delays recorded for both 802.11 standard scanning and our intelligent scanning strategies have been summarized in *Table 1* and plotted in *Figure 6*.

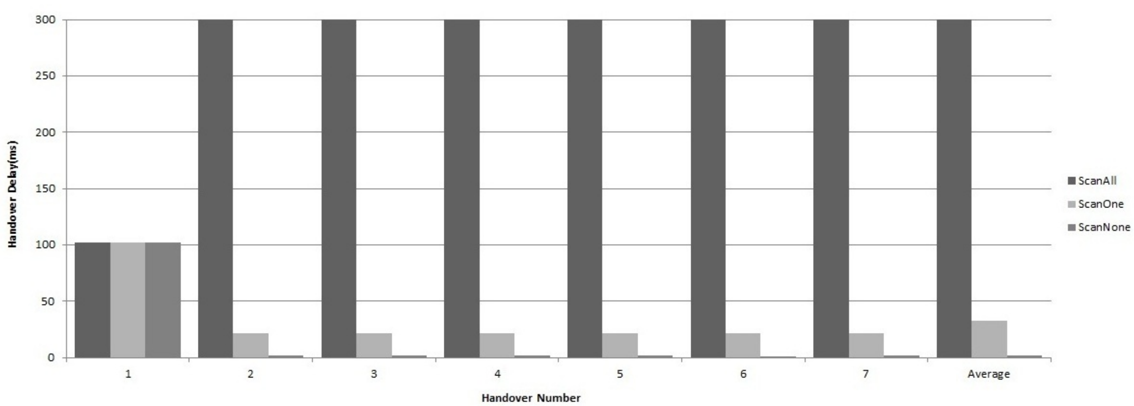

Figure 6: MAC Layer Handover Delays for three different strategies.

Table 1: Mac Layer Handover Delays (ms) for different Scanning Strategies

HandOvers	Scan-All	Intelligent ScanOne	Improvement Improvement	Intelligent ScanNone	Improvement Improvement
1	101.66	101.66	NA	101.66	NA
2	301.77	21.35	93%	1.6068	99%
3	301.45	21.35	93%	1.3468	99%
4	301.33	21.83	93%	1.6068	99%
5	301.65	21.63	93%	1.5868	99%
6	301.59	21.63	93%	0.8668	99%
7	301.03	21.19	93%	1.7668	99%
Average	301.47	21.50	93%	1.46	99%

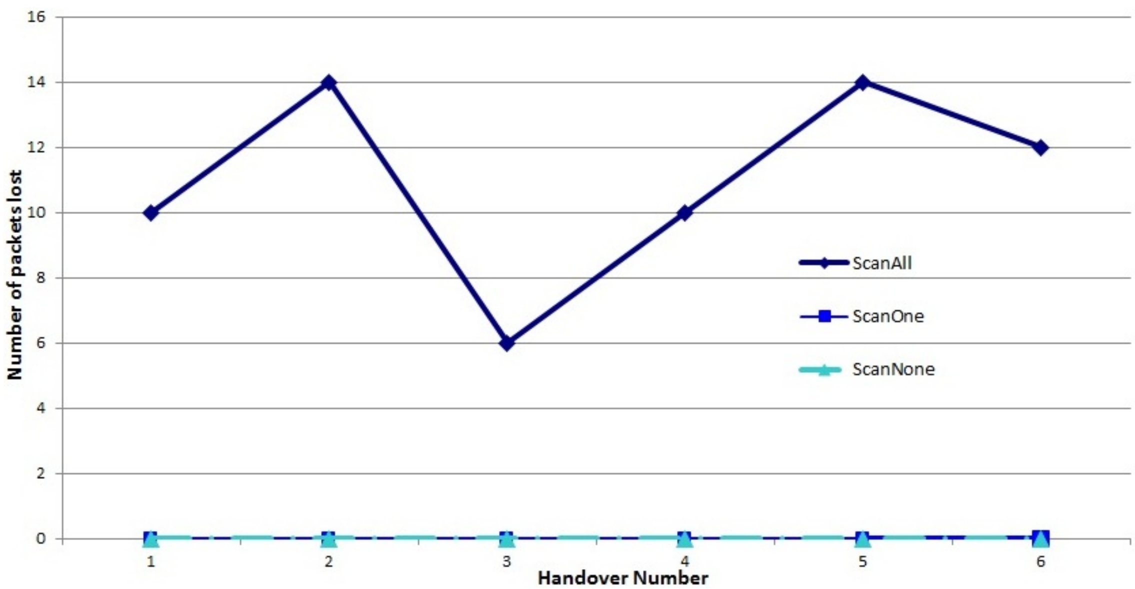

Figure 7: Packets loss in each handover.

5.1 Discussion

It is evident from both the graph in *Figure 6* and the average handover delay for each scanning strategy in *Table 1* that, *Intelligent-ScanNone* performs better than all the other schemes while *Intelligent-ScanOne* outperforms the 802.11 standard scanning mechanisms by a big margin. Therefore the results strongly recommend using MIIS server for reducing handover latency. The handover delay have been considered as the time duration from the time instant when an MN start scanning for APs for the first time, till it successfully associates itself with an AP. The NIST 802.11 module does not support authentication [22], therefore handover delays calculated in our case does not include authentication delays. The time recorded for handover number 1 represents association delay of the MN with BS_1 only and no scanning is performed. Therefore the average is calculated for handover number 2 to 7 for each category. This is also the reason that handover 1 delays are the same for all strategies in *Figure 6* and *Table 1*.

In terms of packet loss we can see from *Figure 7* that both our schemes *Intelligent-ScanOne* and *Intelligent-ScanNone* perform very similar to each other and better than 802.11 standard scanning mechanisms. Both the proposed schemes reduce the packet loss to Zero. The reason for similar performance might be that the difference between our two schemes in terms of handover delay is negligible i.e. only 20ms as seen from *Table 1*. Packet loss calculated for each scheme only consists of packet loss that occurred during link layer handover.

6 Conclusions

The 802.11 standard requires that an MN performs a full scan each time it performs a handover. This wastes precious time as the MN has to scan empty channels as well. In this article we proposed to use the Media Independent Information Server (MIIS) to scan just one channel or skip the channel scanning phase of 802.11 MAC layer handover completely. For this purpose we defined a parameter that must be included in the MN request to the MIIS along with its GPS coordinates and also an information container that is used by the MIIS to return the requested information to the MN. The communication overhead for our scheme is just one message exchange with the MIIS as part of the handover preparation phase. We have shown that based on this mechanism, our two scanning strategies *Intelligent-ScanOne* and *Intelligent-ScanNone* shows 93% and 99% scanning improvement respectively over standard 802.11 scanning.

Studies have shown that in the real world scanning delays also contains channel switching delay which is hardware dependent. Our analysis presented here does not consider channel switching delays. A disadvantage of our scheme is that if the MIIS server returns outdated information to the MN or the target AP somehow disappears, the assumptions for our schemes are broken and the MN needs to recover. The recovering procedure can be facilitated by implementing "freshness" timers. When such a timer is expired, the MN must fall back to 802.11 standard mechanisms. But using such timers might result in slightly longer handover delays than 802.11 standard as the timers will add to the 802.11 standard total handover delay.

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Paper C

Application of Media Independent Handover (MIH) for Intra Technology Handover

Muhammad Qasim Khan, Steinar Hidle Andresen

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Abstract

In this paper we explore the possibilities that how the Media Independent Handover (MIH) infrastructure and procedures originally meant for vertical handovers, can be used for horizontal handovers. We argue that using MIH we can speed up some of the time consuming operations like movement detection, registration and security procedures in mobility management protocols or to perform them before the handover starts. The idea is to use the different services provided by MIH to pre configure the mobile node with crucial parameters before its movement from one point of attachment to another to reduce the handover latency for horizontal handover.

1 Introduction

One of the most important reasons for the enormous success of mobile networks in the last two decades is the mobility. A great need was felt for introducing mobility in networks which did not supported mobility by design e.g. IP based networks. For this purpose protocols like MIP [1] [2] have been proposed. The main hurdle to introduce mobility in IP networks was the way these networks perform packet routing and how they handle node Identity. A good introduction to many handover issues is found in [3]. On the other hand a great need was felt to support data services in cellular networks, for which protocols like Cellular IP [4] were introduced. Soon afterwards the need for supporting mobility across heterogeneous networks was felt. To fulfill this need protocols like Media Independent Handover (MIH) [5] and Communications Access for Land Mobiles (CALM) [6] were developed. Although the original goal of MIH is to support Vertical Handovers, we propose in this article that it can also be used to improve the efficiency of horizontal handover. MIH services can not only help to expedite intra technology handover with in the same administration domain, but it is also expected to improve the handover performance between two different administration domains, using the same access technology. MIH infrastructure is expected to be already present to support vertical handovers anyway. This article is arranged as follows

Section II of this article provides a short introduction to Media Independent Handover (MIH) and its services. Section III provides an overview on how different services provided my MIH can be used for horizontal handover and section IV provides conclusions.

2 Introduction to MIH

Media Independent Handover [5] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. The purpose of the standard is not to design a new protocol but to complement the existing mobility management protocols and procedures in taking handover decisions. The MIH Function (MIHF) provides three kinds of services to achieve this, as shown in Figure 1 from reference [5]. A short description of each type of these services is given below

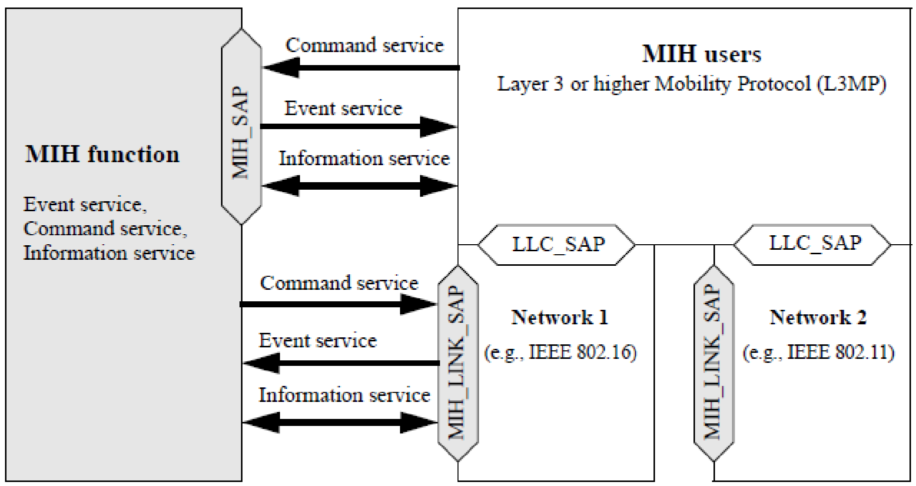

Figure 1: MIH Services and their Initiation.

2.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIH Function (MIH Events) or any lower layer (Link Events) with in the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

2.2 Media Independent Informations Service (MIIS)

The MIIS provides a framework and corresponding mechanisms by which an MIHF (MN) entity can discover and obtain network information existing within a geographical area to facilitate network selection and handovers. MIH Information Service can be used to provide network information to the MIH function. The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The network side of the MIH entity with which the MN exchanges MIH information is called Point of Service (PoS). The MIH standard supports both layer 2 and layer 3 transport option for information access.

2.3 Media Independent Command Service (MICS)

The high layer can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands) or by MIHF itself (Link Commands). The destination of these commands my be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

3 MIH FOR INTRA TECHNOLOGY HANDOVER

Almost all mobility management protocols for packet data services based on Mobile IP, suffer from long handover delays due to time consuming operations like movement detection, registration, configuring a new IP and security procedures each time the nodes moves to a different subnet. This handover latency can be reduced if these costly operations can be speeded up or performed at a time before the handover starts using MIH services which are supposed to be already present to support heterogeneous handovers. In [7] the authors discuss how a location-assisted handover technique can be more efficient than traditional signal-to-noise ratio based scheme. They also discuss the benefits of pre-authentication and pre-configuration in reducing handover delay. The different services provided by MIH can be effectively used to provide such a location-assisted handover and to support pre-authentication and pre-configuration. IETF has investigated problems in transporting MIH services for IP mobility [8] and work is in progress to provide solutions to those problems [9].All mobility management protocols, will benefit from mobile-initiated and network-initiated handover facilities provided by MIH. But PMIP [10] will probably benefit the most because in PMIP MN does not perform any mobile IP signaling and using MIH messages MN's participation capabilities can be improved e.g. MIH can be used to perform movement detection by the MN. A general situation for intra technology handover for MIPV6 [2], MIPV4 [1] and PMIP [10] has been depicted in Figure 2.

3.1 POTENTIAL USE OF MIES FOR HORIZONTAL HANDOVER

Events relevant to handover originate from MAC, PHY, or MIHF at the MN, at the network PoA, or at the PoS. These events can trigger vertical or horizontal handovers. In general when a link event occurs due to a change in link condition it is not known at that instant if this would lead to intra-technology handover or inter-technology handover. That determination is done higher up in the protocol stack by the network selection entity based on variety of other factors. Certain link layer events such as Link_Going_Down lead to either intra-technology or inter-technology handovers. The network selection entity tries to maintain the current connection, by first trying intra-technology handovers and only later on resort to inter-technology handovers. Different types of link events are Link_Detected,

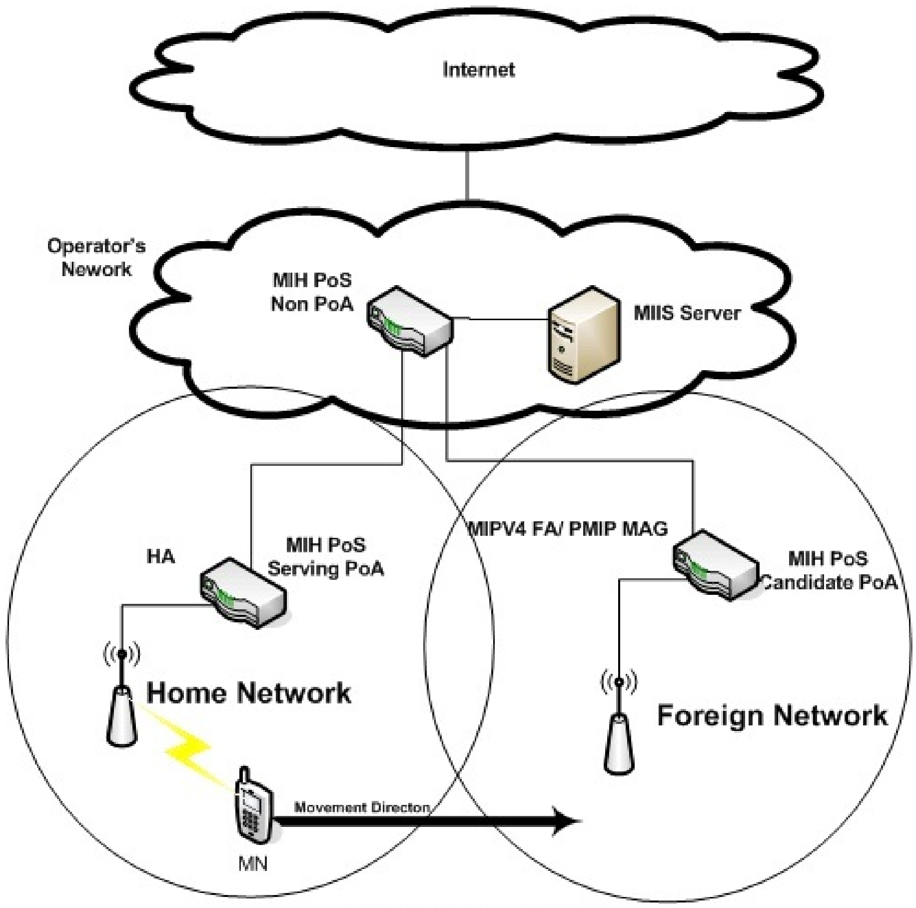

Figure 2: MIH and MIP network.

Link_Up, Link_Going_Down, Link_Handover_Imminent and Link_Down etc. During an inter subnet handover the target PoA (e.g. FA, Foreign network) and the source PoA (e.g. HA) are not on the same subnet as shown in Figure 2. In such cases IP packet delivery can be optimized if context (e.g., change in routing information) from the old AR (Access router) to the target AR is transferred. Link-layer triggers such as Link_Going_Down and Link_Up along with MIH function ID can be used to indicate departure and arrival of MNs at AR(s) in the foreign network or subnet and such indications can replace L3 protocol signaling for the same purpose and thus expedite the handover process. Layer 3 Mobility management protocols, such as MIP can also benefit from Link_Going_Down. Timely receipt of such triggers by the AR in case of network-controlled handovers can enable MIP signaling to establish the new route to take place in parallel with other handover message exchange and can thus reduce the disruption time in IP packet delivery. Link_Handover_Complete event is generated whenever a native link-layer handover/switch has just been completed. The upper layers also use this event to check whether their IP configuration needs to be updated. This is a link-layer event that exists for intra-technology handovers defined in many media types. This event is applicable for the MN only and is valid only for intra-technology handovers. This primitive is issued by the MIHF to report the completion of an intra-technology link handover. An MIH user makes use of this notification to configure other layers (IP, Mobile IP) for various upper layer handovers that are needed. Using MIH services we can reduce the amount of scanning a MN has to do each time its changes its point of attachment and thus reduce the layer 2 handover latency which results in the reduction of overall handover latency. For MIPV4 this has been shown in [11] and for PMIP it as been shown in [12].

3.2 POTENTIAL USE OF MIIS FOR HORIZONTAL HANDOVER

MIIS includes support for various Information Elements (IEs). IEs provide information that is essential for a network selector to make intelligent handover decisions. MIIS provides the capability for obtaining information about lower layers such as neighbor maps and other link-layer parameters, as well as information about available higher layer services such as internet connectivity. Apart from static link layer parameters, information about higher layers services in a network can also help in more effective handover decision making before the MN actually attaches to any particular network. For the purpose of horizontal handovers the most important information can be PoA Specific Information: These information elements provide information about different PoAs for each of the available access networks. Such IEs contains PoA addressing information, PoA location, data rates supported, the type of PHY and MAC layers and any channel parameters to optimize link-layer connectivity. This also includes higher layer services and individual capabilities of different PoAs. To provide access network specific, service specific and vendor specific information network operators can define additional vendor specific IEs. Some crucial information elements that can be important for horizontal handover are IE_POA_LINK_ADDR, IE_POA_LOCATION, IE_POA_SUBNET_INFO, IE_POA_IP_ADDR etc. In mobile IP based protocols all such information is obtained using discovery procedures which are time consuming. Using MIH services will enable the MN to resume operation quickly rather than to wait for the discovery procedures to complete to get the required information. MIH_Get_Information is a MIIS primitive using which a MIH user can request information from MIH information server. Using this primitive, nodes in MIPV6 and MIPV4 can get information about surrounding subnets and optimize its movement detection procedures like Neighbor Discovery [13] for MIPV6 and IP configuration operations like DHCP [14] and Stateless Auto configuration [15] for MIPV6 or perform these operations before an actual handover starts. Another MIIS primitive called MIH_Push_Infomation service can be used by MIIS server to push information to the MN. This primitive can be generated at any time during the life time of the registration. This primitive can be beneficial for MIPV6, MIPV4 and especially for Proxy MIPV6 because of the fact that an MN does not take part in any MIP related signaling in Proxy MIPV6 [10]. Equipping a PMIP node with such information can greatly help in movement detection and will enable MN to solicit MAG advertisements as soon as it enters a new MAG area.

3.3 POTENTIAL USE OF MICS FOR HORIZONTAL HANDOVER

MIH users utilize command services to determine the status of links and/or control the multi-mode device for optimal performance Command services also enable MIH users to facilitate optimal handover policies. MICS and MIIS information could be used in combination by the MN/network to facilitate the handover. The receipt of MIH command requests indicates a future state change in one of the link layers in the local node. These indications notify subscribed MIH users of impending link state changes. This allows MIH users to be better prepared to take appropriate action. In a MN initiated handover The MN directly uses the set of MIH_MN_HO_*** commands and may indirectly cause some MIH_N2N_HO_*** commands to be used when initiating handovers. The MN can use these commands to query the list of available candidate networks/subnets, reserve any required resources (e.g. CoA, setting up security parameters) at the candidate target network, and indicate the status of handover operation to the MIHF in the network. The current PoA can signal status of reserved resources and the MNs future CoA to the home agent. The home agent can setup registration and setup forwarding of packets to the new PoA. In this case, the network initiates the handovers. The network uses the set of MIH_Net_HO_*** in conjunction with any MIH_N2N_HO_*** commands for initiating handovers. The network can use these commands to query the list of resources currently being used by the MN, the serving network can reserve any required resources at the candidate target network, and the network can order the MN to performing a handover to a specific network/subnet.

4 CONCLUSION

In this article we have proposed that MIH apart from vertical handovers can also be used to perform intra technology handovers and improve the efficiency of mobility management protocols for packet switched services. We have outlined the possibilities of using different MIH services to either replace or enhance existing mobility management operations like security associations, movement detection, network layer configuration etc. Using the existing infrastructure of MIH we can make intra technology handover more seamless. The next step is to simulate or implement MIH to prove that it can indeed make a difference to intra technology handover performance. The scenario shown in Figure 2 can serve as the starting point.

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Paper D

The Implications of Zero Scanning Time on MIPv6 Handover Delays by Using Media Independent Information Server (MIIS)

Muhammad Qasim Khan, Steinar Hidle Andresen

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Abstract

Handover efficiency in wireless packet switched networks is very crucial in providing QoS guarantees to real time applications. Mobile IPv6 (MIPv6) is a prevalent choice for mobility management in future generations networks. Although MIPv6 benefited from the design knowledge of its predecessor i.e. MIPv4 and is more efficient, it still suffers from high handover delays. The main reason for MIPv6 being slow is its dependence on information discovery procedures, which are required to be carried out during the critical phase of handover execution. Thus MIPv6 handover delays can be simply reduced to tolerable limits if the discovery procedures are replaced by proactive procedures performed before the handover execution phase. A simple method of equipping the MN with proactive information is the use of an Media Independent Information Server (MIIS).

In this article we investigate the effects of an improved version of our proposed scanning scheme "An intelligent Scan mechanism for 802.11 Networks" on MIPS handover delays. We used the Media Independent Information Server (MIIS) of the Media Independent Handover (MIH) standard to relay channel configuration information of the future access point to the MN to reduce layer-2 handover scanning latency to zero and investigate its effect on MIPv6 handover delays. We compare handover delays achieved using intelligent scanning strategies with handover delays achieved with 802.11 standard scanning, using simulations. Our results show that using intelligent scanning strategies called *Intel-ScanNone* and *Intel-ScanOne* results in 89% and 82% improvement of handover delays respectively.

1 Introduction

The growth of Communication Networks is a continuously evolving process. Modern day communication networks provide incomparable performance to its predecessors in terms of Quality of Service (QoS) support for real time and non real time applications. However the evolution of communication networks have also fueled the development of innovative applications. These applications are much more sophisticated, bandwidth hungry and very sensitive to their QoS requirements. Moreover heterogeneity of communication networks adds its own complexity to the QoS challenges of applications. One major challenge these application face, is in the form of handover efficiency. During a handover as a Mobile Node (MN) does not remain accessible to its communication partners. Therefore the longer the handover delay, the more adversely it effects the running applications. The ITU (International Telecom Union) specify that this delay should not be more than 50 ms [1] to avoid jitter in VoIP applications. A mobility management protocol like Mobile IP (MIP) can never achieve this delay bound with traditional handover mechanism. Therefore additional mechanisms like the 802.21 Media Independent Handover (MIH) [2] are needed not only to make a heterogeneous handover possible but to improve handover efficiency regardless of Inter or Intra Technology handover. Although the original goal of MIH standard was to support heterogeneous handovers, there is no reason why such infrastructure cannot be used to support horizontal handovers [3].

A handover might take places at the MAC (Medium Access Control) layer or at the IP layer depending on the scope of mobility of the MN. Total handover delay (here on wards referred to as MIPv6 handover delays) is the sum of handover delays at all layers. During a MAC layer handover the 802.11 standard [4] requires that the MN discovers reachable access points by scanning which consists of three stages. All these three stages have their own delays but, the probe delay (scanning stage) constitutes more than 90% of the overall mac layer handover delay [5]. The 802.11 standard [4] requires scanning all available channels (11 in US [6] [7], 13 in most of Europe and 14 in Japan [7]) during a MAC layer handover. In our proposal in [8], to reduce this scanning delay we have proposed to reduce the number of channels to be scanned to a subset of channels currently in operation in the network by making use of the Media Independent Information Server (MIIS) of MIH. We have further developed this mechanism to reduce the scanning delay to zero by considering the current GPS coordinates of the MN to scan just one channel or go directly to the association phase of 802.11 on a pre-decided channel during a mac layer handover. Here we investigate by simulation the effect of such a proactive scanning mechanism on UDP and TCP traffic sources in terms of packet loss, handover delay and throughput, using MIPv6 as the mobility management protocol.

This article is organized as follows: In Section 2 we present a short introduction to Media Independent Handover (MIH), 802.11 scanning process and Mobile IPv6. Section 3 provides an overview of the two intelligent scan mechanisms. Section 4 contains simulation parameters, results and discussion. Finally in Section 5 we present conclusions and discuss future research directions

2 Background

2.1 Media Independent Handover (MIH)

Media Independent Handover [2] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. The purpose of the standard is not to design a new protocol but, to complement the existing mobility management protocols and procedures in taking handover decisions. The MIH Function (MIHF) provides three kinds of services to achieve this, as shown in Figure 1, taken from reference [2]. A short description of each type of these services is given next.

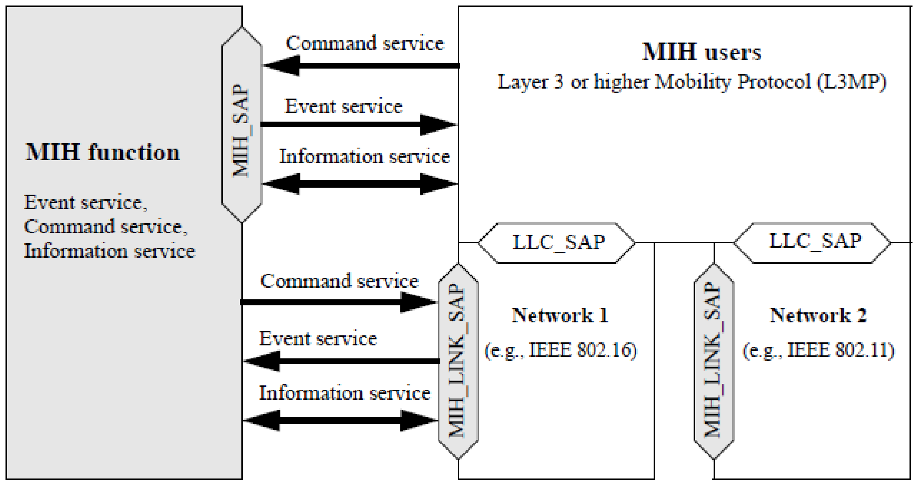

Figure 1: MIH Services and their Initiation.

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Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIH Function (MIH Events) or any lower layer (Link Events) with in the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

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2.1.3 Media Independent Command Service (MICS)

The high layer can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands) or by MIHF itself (Link Commands). The destination of these commands my be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

2.2 Mobile IPv6

MIPv6 [9] was designed by IETF based on knowledge from MIPv4 [10]. MIPv6 makes it possible for an MN to roam around and still maintain connectivity to the Internet. An MN make use of two IP addresses. A static IP is used by the MN for both its identification and to receive packets at home network, called Home-of-Address (HoA). A temporary IP address which is only valid in the visited subnet is used to receive packets at foreign subnet, called Care-of-Address (CoA). MIPv6 make use of a mapping between its HoA and CoA called binding on a special router at home network called Home Agent (H.A). This binding enables the H.A to forwards the packets to the current CoA of the MN at a foreign network. MIPv6 make use of standard IPv6 Neighbor Discovery [11] for movement detection. Route optimization (RO) is designed to be an integral part of MIPv6 in which the MN registers its current CoA not only with HA but also with the corresponding node (CN). CN then instead of sending packets to MN home address, directs packets to the current CoA of the MN. A Mobile Node in MIPv6 acquire CoA in the foreign network using IPv6 Stateless Address Auto Configuration or using stateful protocols like DHCPv6. MIPv6 has the capability of making the change of CoA transparent to higher layers by making use of IPv6 routing header and IPv6 Destinations Options Header. Although MIPv6 removes most of the problems faced by MIPv4 like route optimization, its still suffers from long handover delays which are not desirable for real time communications. To reduce global signaling and hand off delay, a scheme that is based on setting up local home agents called MAP (Mobility Anchor Point) and setting up forwarding from the last CoA has been introduced called Hierarchical MIPv6 [12]. IN HMIP the MN has two CoA's i.e. Regional CoA (RCoA) and On-Link CoA (LCoA). In order to reduce handoff delay in MIPv6 a fast variant has been proposed called Mobile IPv6 Fast Handovers [13].

2.3 Scanning in 802.11

The 802.11 [4] MAC layer handover consist of 3 stages i.e. Scanning, Authentication and Association or Re-association. The 802.11 standard requires to scan all available channels. The purpose of the scanning phase is to discover available AP's. Once AP's are discovered the MN can associate itself with the best available AP after authentication, which completes the MAC layer handover. The standard defines two types of scanning i.e. Passive and Active.

In *Passive Scanning* the MN listens on each channel passively for beacons transmitted from AP to detect active channels. By default the beacon is sent out by base stations every 100 ms. The MN will have to wait a bit more than 100 ms on each of the channels to successfully receive a beacon.

$$D_P = m * 0.1sec \tag{1}$$

Where D_P represents passive scanning delays and m is the total number of channels (both empty and active). Therefore scanning 11 channels might take D_P=1.1s.

In *Active Scanning* the MN actively probes the available AP's by sending a Probe Request message on the current channel and then waits *MinChannelTime* for a probe response from the AP's. If the MN detects activity on the channel it prolongs its wait for *MaxChannelTime* to make sure it receives responses from all reachable AP's. If there is no activity on the channel in *MinChannelTime* or activity is detected but, *MaxChannelTime* times out, the MN goes on to scan the next channel and repeat the same process. Once the MN is finished scanning all the channels, it may discover that more than one Ap's are available in a particular location. The MN selects the best AP according to some criteria (e.g. *Received Signal Strength Indication (RSSI)*) for association. Active scanning performs better than passive scanning [14] but, results in bandwidth wastage. In this article we consider active scanning only.

$$D_A = n(MaxChTime) + (m - n)(MinChTime) \tag{2}$$

Where D_A represents active scanning delays, m is the total number of channels, n is the total number of active channels in an 802.11 cell and *MaxChTime*,*MinChTime* are *MaxChannelTime* and *MinChannelTime* respectively. For a configuration of m=11, n=1 and default values for *MaxChTime*, *MinChTime* D_A =0.26 sec.

3 Intelligent Scan

In Intelligent Scan mechanism, when an MN concludes that soon it will have to handover to another 802.11 cell, it retrieves the channel configuration information of the future PoA from an MIIS server rather than having to discover this information through scanning during a handover. The MN queries the MIIS server at once after receiving a *MIH_Link_Going_Down (LGD)* trigger (it then, apparently, has an urgent need to do a handover). An MIIS server has a lot of information stored with it, from PoA specific information to the different types of access networks available in the area. Therefore the MIH standard allows the MN to request the specific information it needs and therefore can limit the size of the reply from the MIIS. Figure 2 shows the interaction between the MN and MIIS.

The MN specifies the network type (i.e. 802.11) in the query by using the *NET_TYPE_INC* parameter defined in the 802.21 standard. MN also specifies in its query that it needs network channel configuration information by using the parameter *NET_CHANNEL_CONFIG* and its GPS coordinates in the parameter *QUERIER_LOC* parameter defined in the 802.21 standard. The coordinates of the MN are used on the server to locate

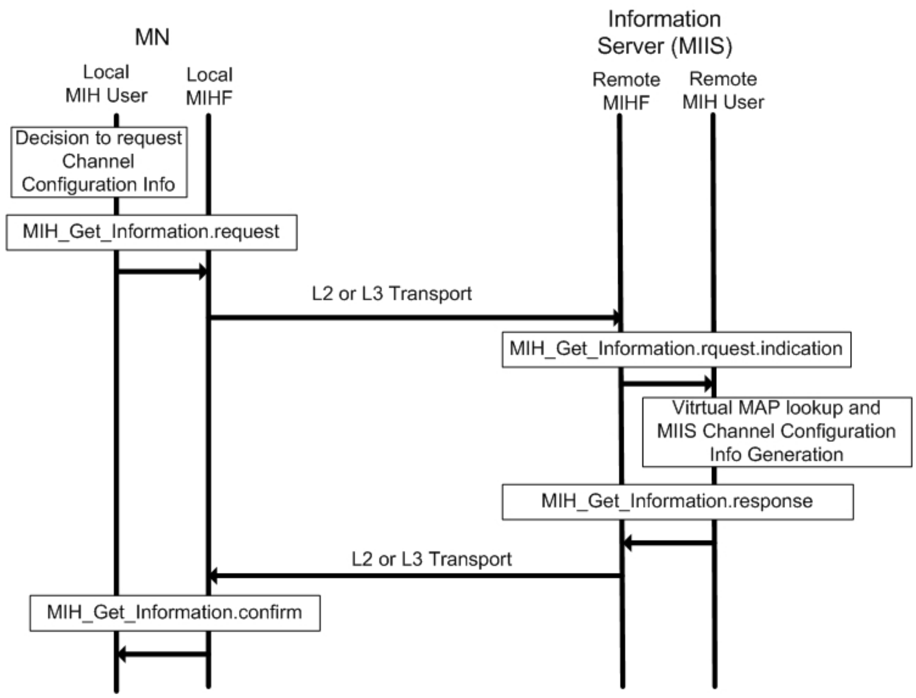

Figure 2: Interaction between MN and MIIS

the MN on a virtual map. This helps the MIIS server to determine, which candidate PoA the MN is likely to attach to in the near future. Because the MIIS server has a holistic view of the network topology and knows about the coordinates, BSSID and coverage of all the access points in the network. This information is stored as static information as defined in the 802.21 standard.

We define a new MIH information container i.e. *IE_CONTAINER_802.11_CHINFO*, which is used by MIIS to return the requested future PoA channel configuration information in the form of Information Elements (IE's). The amount of information included by the MIIS server in the *IE_CONTAINER_802.11_CHINFO* will depend upon the network configuration and MIIS policy. At minimum our scheme requires BSSID and the currently operational channel number of the future PoA. Additional information such as IP address of the future PoA, bandwidth etc might also be included. The information received after such a query is stored locally by the MN for future use. Each time an *LGD* trigger is generated the MN checks if it has valid information on the future PoA, If not, it performs an MIIS query. In this way the MN makes sure that the locally stored information remains fresh and valid.

During the handover execution phase, the MN first checks if it has valid channel configuration information available locally of the future PoA. If yes, then rather to scan all channels, it either scan just one channel, called *Intel-ScanOne*, or proceeds directly to the association phase, associating on the channel number and BSSID, it obtained from the MIIS server. The latter scheme is called *Intel-ScanNone*. The sequence of events inside an MN, for *Intel-ScanNone* is shown in Figure 3. The decision of performing *Intel-*

ScanOne or *Intel-ScanNone* depends on the scanning policy of the MN. Both the schemes are expected to improve throughput and bring a dramatic decrease in MIPv6 handover delays and packet loss.

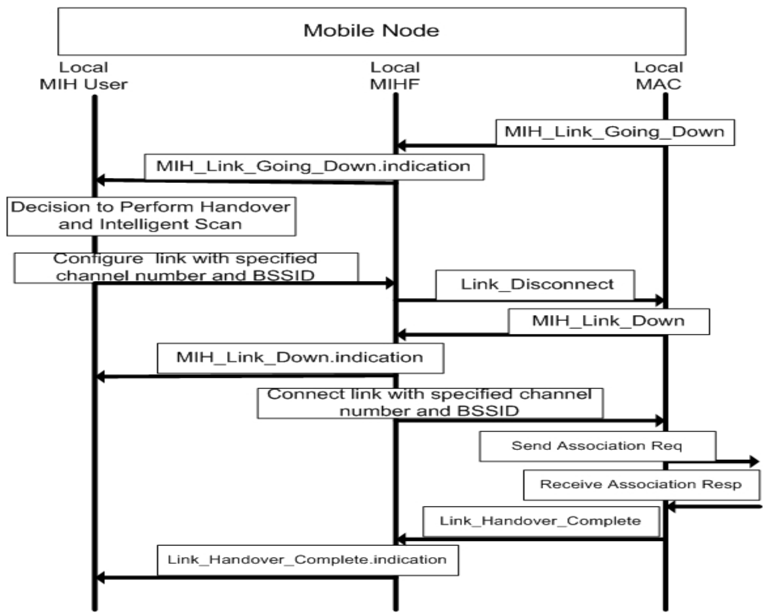

Figure 3: Intelligent ScanNone.

4 Simulation Scenario and Parameters

The National Institute of Standards and Technology (NIST) have implemented the Media Independent Handover Function (MIHF) based on draft 3 of 802.21 standard in the form of an add-on module [15] for Network Simulator (ns-2) [16] version ns-2.29. The implementation supports both MIES and MICS but, does not support MIIS [17]. We have used this implementation for our simulation and have added a limited MIIS server functionality. The NIST module also provide implementation of 802.11 [18].

Figure 4 represents the topology of our simulation scenario. The simulation area was set to 300x300 meter and consisted of four base stations. At the start of the simulation the MN associates on a pre-determined channel with BS1 and no scanning is performed. After connecting to BS1 at the MAC layer, the MN configures a valid IP address and performs Mobile IPv6 procedures. The MN then performs MIH capability discovery procedures and then finally registers its with peer MIHF i.e BS1. The MN at simulation time 8 sec starts a linear motion with a constant speed of 5m/s in the direction of BS2. As the MN moves away from BS1, the signal strength goes down continuously and an *Link_Going_Down* event is generated. The MIHF receives an *MIH_Link_Going_Down* event notification. This MIH event is propagated to the MIH user (handover module of

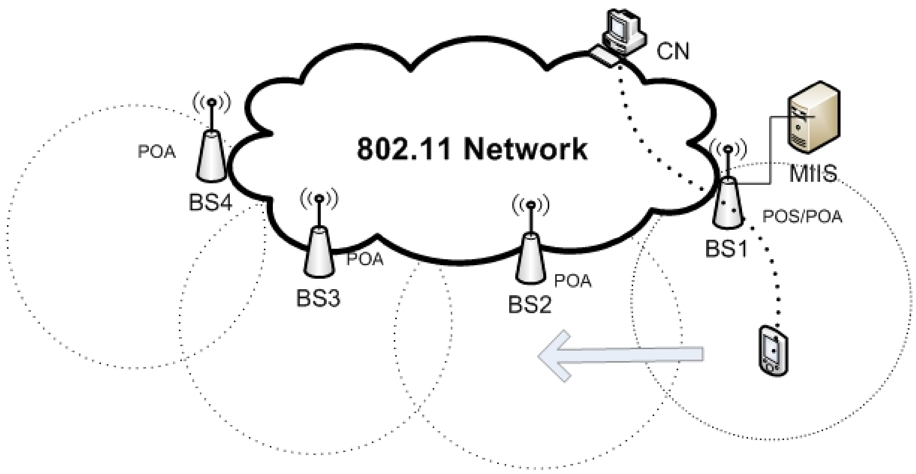

Figure 4: Simulation Scenario.

the M.N). The MIH user while connected to BS1, performs an MIIS query as explained in Section 3.

The MIIS server with the help of GPS coordinates of the MN and a virtual map generates future access point information, which for the first handover is BS2. This information is returned to the MN. The MN continues its linear motion and handover is triggered, when the MN goes out of the radio coverage of BS1. As the MN has local information available on next Access Point i.e. BS2, it scans just one channel i.e. of BS2 or proceeds directly to associate with BS2, skipping the scanning phase of 802.11 MAC layer handover completely. The MN continues its motion and reaches BS4 in a similar manner. The MN at simulation time 55 sec takes back the same route in the reverse direction at the same speed and reaches BS1. Thus the MN performs 6 handovers in one simulation run. This scenario has been tested with both UDP and TCP traffic sources discussed next.

4.1 UDP Traffic Sources

At simulation time 5 sec a correspondent node (CN) starts to send CBR traffic with a packet size 1500 bytes and inter arrival time of 0.01sec, to the MN. The handover delays for both layer-2, layer-3 and their sum, recorded for both 802.11 standard scanning and our intelligent scanning strategy has been summarized in *Table 1* and plotted in *Figure 5*. Each value in *Table 1* is an average of four observations.

- Discussion It is evident from the average handover delay achieved with each scanning strategy in Figure 5 and *Table 1* that, *Intel-ScanNone* performs better than the other two schemes while *Intel-ScanOne* outperforms the 802.11 standard scanning mechanisms by a big margin. Therefore the results strongly recommends using MIIS server for reducing MIPv6 handover latency. The handover delay have been considered as the time duration from the time instant when an MN start scanning for APs for the first time, till the time instant when the MN receives an acknowl-

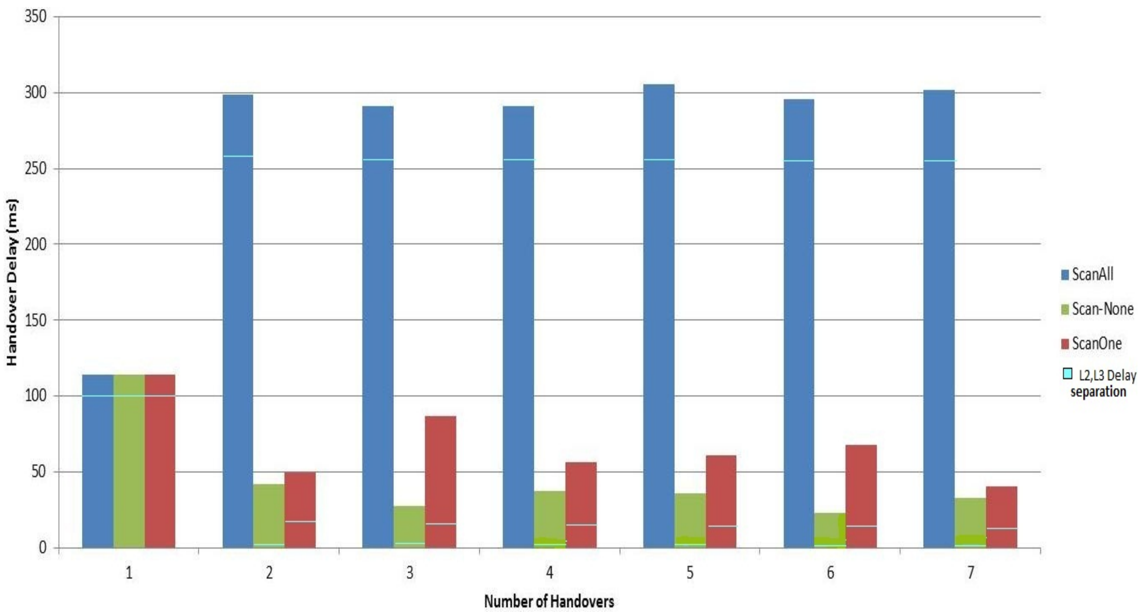

Figure 5: Layer-2 and Layer-3 Handover Delays

edgment from the CN, for its MIP flow redirection request. The NIST 802.11 module does not support authentication [18], therefore handover delays calculated in our case does not include authentication delays. MIPv6 implementation has also limited functionality. MN forms new IP address by auto configuration and no Duplicate Address Detection (DAD) is performed. There is no forwarding mechanism from the previous CoA. The values for the first handover represents an attachment procedure delay with BS1 and no scanning is performed. Therefore the average is calculated for handover number 2 to 7 for each category. This is also the reason that handover 1 delays are the same for all strategies in Figure 5 and *Table 1*.

In terms of UDP packet loss we can see from Figure 6 that both *Intel-ScanOne* and *Intel-ScanNone* reduces the packet loss and performs better than 802.11 standard as the number flows are varied from 1 to 4. *Intel-ScanOne* is out performed by *Intel-ScanNone* both in terms of packet loss and handover delay.

4.2 TCP Traffic Source

To test TCP traffic we configured one TCP flow from MN to CN. TCP agent used was TCP/Reno from ns-2 [16]. Packet size was set to 1000 bytes with default window size.

- Discussion Throughput for the three scanning schemes has been plotted in Figure 7, from which we can see that the performance of *Intel-ScanNone* and *Intel-ScanOne* is almost the same and better than 802.11 ScanAll. Especially during handover2 and handover4, both *Intel-ScanNone* and *Intel-ScanOne* are able to keep better throughput then 802.11 ScanAll.

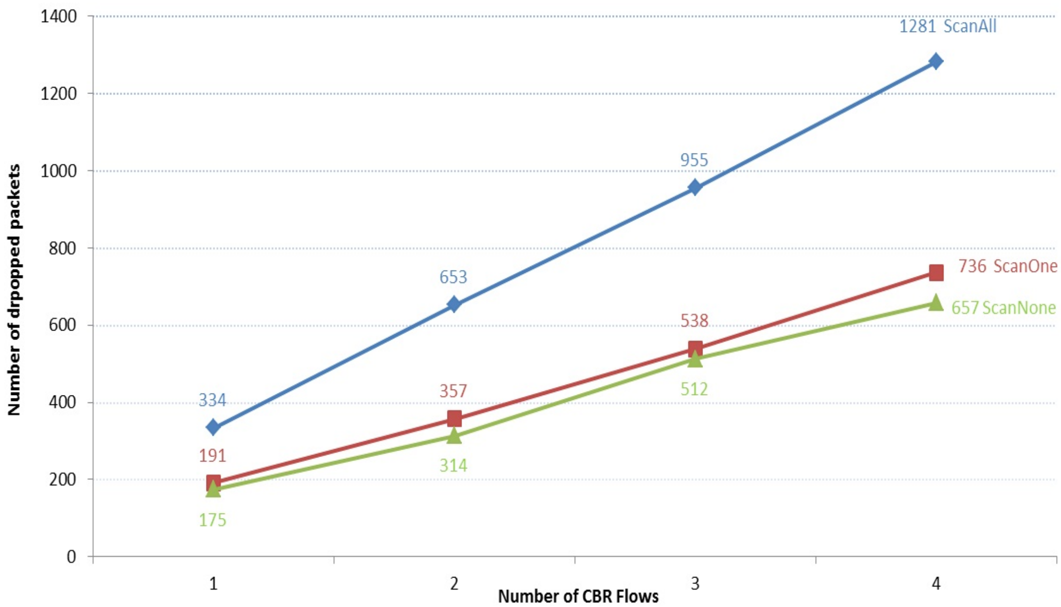

Figure 6: Packets loss in each handover.

In Figure 8 we have plotted the TCP window size for the three scanning strategies. From this figure the difference is not very clear because of the scale of the graph and also due to the high variability of layer-3 handover delays as shown in the Figure 5 . At simulation time 26 sec and 68 sec, the throughput seems to take more longer to recover with 802.11 ScanAll than with *Intel-ScanNone*, after a handover. We can also note that during the simulation time 35 sec and 60 sec the performance is exactly the same. This is due to the fact that the MN spends some time at rest in cell 4, before its starts its return journey. Based on this figure we can say that *Intel-ScanNone* is able to give better performance than 802.11 ScanAll. We have experienced some unexpected behavior with pure TCP traffic and during the simulation experiments control messages of MIPv6 were being dropped at times. Also MIPv6 handover latencies experienced with TCP traffic, were different than UDP traffic. Although layer-2 latencies for both TCP and UDP remained the same.

5 Conclusion and Future Research Directions

The 802.11 standard requires that an MN performs a full scan each time it performs a handover. This wastes precious time as the MN has to scan empty channels as well. In this article we presented the effects of our proposed intelligent handover mechanism on MIPv6 handover delays, using the Media Independent Information Server. We have shown that based on this mechanism, our earlier proposed two scanning strategies *Intel-ScanOne* and *Intel-ScanNone* shows 82% and 89% MIPv6 handover delay improvement over standard 802.11 scanning. Some protocols implementation we have used in this

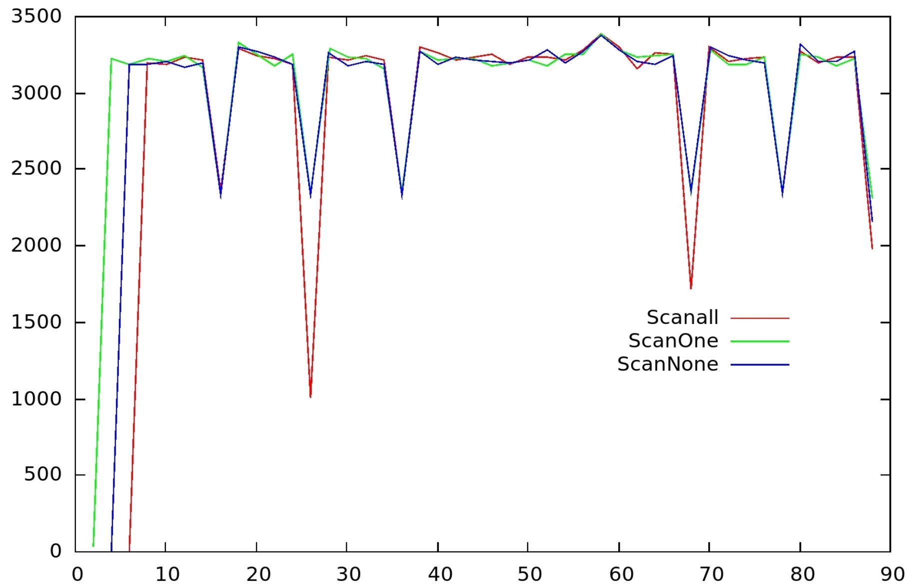

Figure 7: TCP Throughput (kbps)

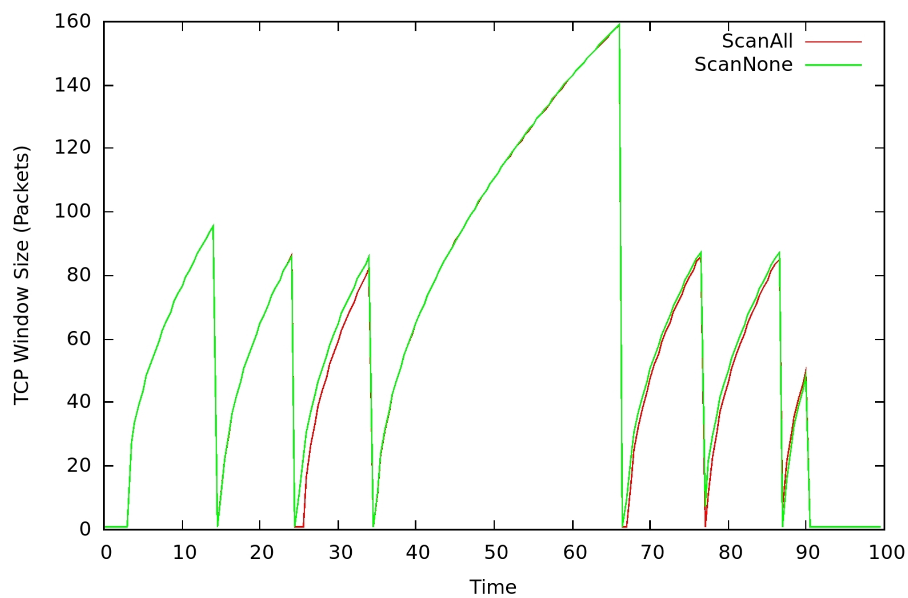

Figure 8: TCP Window Size

article like MIP, are not full implementation, but since the mechanisms remains the same for all scanning types the comparisons still remain fair and valid. Many studies have shown that in the real world scanning delays also contains channel switching delay which is hardware dependent. Our analysis presented in this paper does not consider channel switching delays.

One interesting finding in our simulation experiment is different handover latencies with

Table 1: Layer Three Handover Delays (ms) for different Scanning Strategies

HandOvers	Scan-All			Intel-ScanOne				Intel-ScanNone			
	L2	L3	Total	L2	L3	Total	Gain	L2	L3	Total	Gain
1	102.02	12.21	114,23	102.02	12.21	114,23	NA	102.02	12.21	114,23	NA
2	261.36	37.62	298,98	21.27	15.62	36,89	88%	1.77	40.54	42,31	86%
3	261.31	29.91	291,30	21.41	52.10	73,51	75%	1.63	26.30	27,93	90%
4	261.20	29.60	290,80	21.40	15.20	36,6	87%	1.66	35.77	37,43	87%
5	261.40	43.96	305,36	21.50	39.50	61	80%	1.70	34.40	36,10	88%
6	261.40	34.02	295,42	21.47	48.88	70,30	76%	1.50	21.98	23,48	92%
7	261.52	39.85	301,37	21.35	12.84	34,19	89%	1.59	31.75	33,34	89%
Average			297,2			52,08	82%			33,43	89%

different traffic types like TCP and UDP. Looking into this might be interesting for us as our future work. The information sharing mechanism discussed in this article can be further extended to include other information like IP addresses and resource availability of the future PoA to optimize MIPv6 handover latencies. With such information a QoS based PoA selection method can also be devised. The scenario can be further extended to consider heterogeneous handovers between WiMAX and WiFi. Testing such solutions at vehicular speeds might also be interesting.

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Paper E

PoA Selection in 802.11 Networks using Media Independent Information Server (MIIS)

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Abstract

Mobility is an integral part of modern day wireless and mobile communication networks. Therefore handovers of Mobile Nodes (MN's) from one Point of Attachment (PoA) to another are inevitable. This makes the handover efficiency an important metric for analyzing network performance and user satisfaction level. From an efficient handover perspective, not only the handover delay needs to be acceptably short, but also an intelligent decision is required to select the best available Access Point (AP), so that the currently running applications of the MN are not adversely affected in terms of their Quality of Service (QoS). The traditional way of choosing the best available AP with respect to Received Signal Strength (RSS) may not always perform efficiently. Because it is not necessary that the best AP with respect to RSS is also the best with respect to QoS parameters as well, such as available bandwidth.

In this article we present a novel PoA selection algorithm for 802.11 networks that takes into account the available bandwidth, cost of the connection and security level of the candidate AP, in addition to the distance between the MN and the surrounding AP's. We also propose ranking of AP's with respect to security in the form of a table. We devise a framework for implementing such an algorithm with the help of the Media Independent Information Server (MIIS), of the Media Independent Handover (MIH). Our simulation results shows that our scheme have superior performance when compared to a scheme which is purely based on the distance between the MN and the AP, for nonuniform traffic.

1 Introduction

Quality of Service (QoS) and user experience have always been important aspects of communication systems. Modern day communication systems have evolved to great extents and in comparison to their predecessors provide improved QoS, better user experience and support a variety of services at a dramatically reduced cost and high mobility. However the advancement in mobile and wireless communication systems also fuels more innovative and bandwidth hungry applications like high definition video streaming and video conferencing, online gaming etc. These applications are very sensitive to their QoS requirements and expect the underlying network to provide certain degree of QoS guarantees. QoS requirements of these applications have always been a challenge for researchers in this area.

In mobile and wireless communications handovers are inevitable. During a handover a Mobile Node (MN) has to tear down its connection with the current Access Point (AP) and establish a new connection with another nearby AP. The time duration that elapses between tearing down one connection and successfully establishing a new one is called handover delay. A handover decision can be only termed as optimal, if it does not only keep the handover delay under defined limits but also ensures that the new AP selected for handover is the best one available in terms of the QoS requirements of the running applications. Traditionally Received Signal Strength (RSS) has been used to select the best available AP. However RSS alone for AP selection might not always result in an optimal decision, because it is not necessary that, an AP best with respect to RSS is also the best with respect to QoS parameters such as available bandwidth. Also an AP with the highest RSS in a particular location will attract many MN's and will eventually be overloaded. There might be many lightly loaded AP's which are not considered by the MN due to their weaker RSS. Such an RSS may still be strong enough for a good connection. Therefore there is a great need to consider more parameters for PoA selection along with RSS. Apart from local information like RSS, global information such as available bandwidth, security, cost etc. about future PoA should also be integrated into PoA selection algorithms. The IEEE 802.21 [1] standard of Media Independent Handover (MIH) provides the framework and mechanisms to discover, store and share such global information with all MIH enabled nodes in an 802.21 network. However the 802.21 standard does not specify handover decision algorithms. Although the original goal of MIH is to support Vertical Handovers, it can also be used to improve the efficiency of horizontal handovers [2].

In this article we present a future PoA selection algorithm for 802.11 [3] networks and specify a framework on how the information required for such a PoA selection algorithm can be obtained and used by the Media Independent Information Server (MIIS) of MIH [1] standard. We argue that PoA selection algorithms which based their decision on additional criteria such as available bandwidth, than just only RSS, are much more efficient. We also present simple ranking of AP's with respect to security and use simulation results to prove our point.

The arrangement of our article is: Section 2 contains some related work and a brief introduction to the MIH standard. In section 3 we present the proposed framework and its drawbacks. This section details when and how the MN queries the information server and how the fitness value of an AP is calculated and used during handovers. In section 4 we outline our simulation parameters and discuss the results. Finally section 5 outlines conclusions.

2 Background

2.1 Related Work

In [4] the author has introduced a handover mechanism in cellular networks that takes into account bandwidth utilization alongside with received signal strength indication. In [5] the authors have proposed a QoS-aware Customer Network Management (Q-CNM) system for QoS-aware handover with Proxy Mobile IPv6 (PMIPv6) [6] and IEEE 802.21 Media Independent Handover (MIH). They provide their own functional architecture and propose a QoS-Guaranteed Handover Decision Maker (QHDM) algorithm for PoA selection. QHDM first builds a list for candidate PoA having RSS greater than or equal to a minimum RSS threshold and then refines the list with respect to maximum available bandwidth. The drawbacks with their proposed scheme are that, the MN is required to scan for available AP's and then report the result of scanning i.e. RSS values for all detected AP's to the network or more specifically to the Extended PoS and therefore might result in high handover latency. Another disadvantage with their scheme is that, it requires additional components and procedures in the network in addition to MIH facilities and is only valid for PMIPv6. In [7] the authors have proposed a PoA selection algorithm that takes into account QoS parameters in addition with the distance of the MN from the PoA. In their scheme the MN takes decision on its own with the help of information it receives from the MIIS. However they don't provide the mathematical formulation of their scheme and details of weight assignment to the parameters distance and QoS. Moreover the results provided in [7] show the efficiency of their proposed fast layer-2 handover mechanism rather than their POA selection algorithm.

In our scheme the MIIS returns just one AP information for the MN to attach to. We propose a novel handover algorithm for 802.11 networks and clearly state our mathematical formulation and weighing procedure of the fitness function parameters. Our scheme make use of GPS coordinates to locate the MN with respect to the surrounding AP's, on a virtual map. We also provide ranking of AP's with respect to security in the form of a table. We show with the help of TCP traffic throughput that our PoA selection algorithm is more efficient. Moreover our algorithm considers four parameters and is clearly more extend able with even more parameters if required.

2.2 Media Independent Handover (MIH)

Media Independent Handover [1] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. *Figure 1*, taken from reference [1] shows how the MIH Function (MIHF) is interfaced with other layers of the protocol stack in a multi face MN or network node. A single media independent interface *MIH Service Access Point (MIH_SAP)* is used to provide services to the MIH users. All interactions of the MIHF with the lower layers take place with the help of media-specific protocol instantiations of MIH_LINK_SAP. The purpose of the MIH standard is not to design a new protocol, but to complement the existing mobility management protocols in taking handover decisions. The MIHF provides three kinds of services to achieve this. A short description of these services is given next.

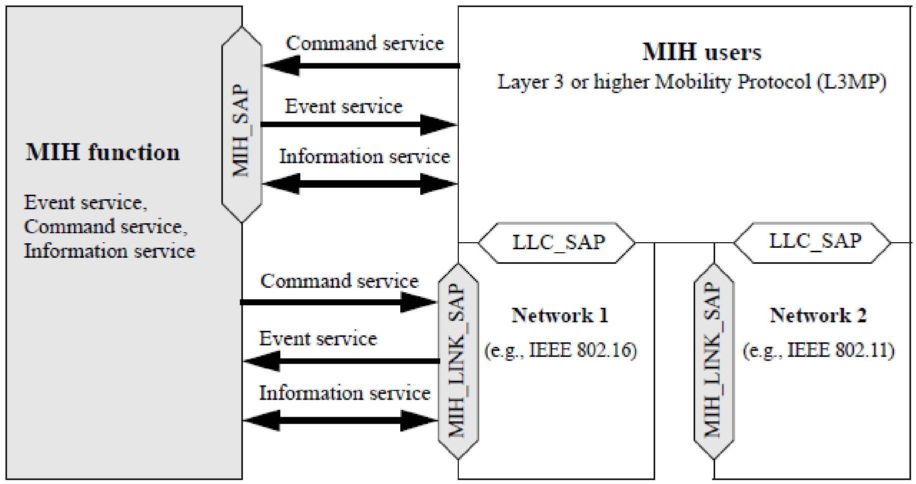

Figure 1: MIH Services and their initiation.

2.2.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIHF (MIH Events) or from a lower layer (Link Events) within the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

2.2.2 Media Independent Information Service (MIIS)

The MIIS provides a framework and corresponding mechanisms by which an MIHF (MN) entity can discover and obtain network information existing within a geographical area to facilitate network selection and handovers. MIH Information Service can be used to provide network information to the MIHF. The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The network side of the MIH entity with which the MN exchanges MIH information is called Point of Service (PoS). The MIH standard supports both layer 2 and layer 3 transport option for information access.

2.2.3 Media Independent Command Service (MICS)

The higher layers can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands)

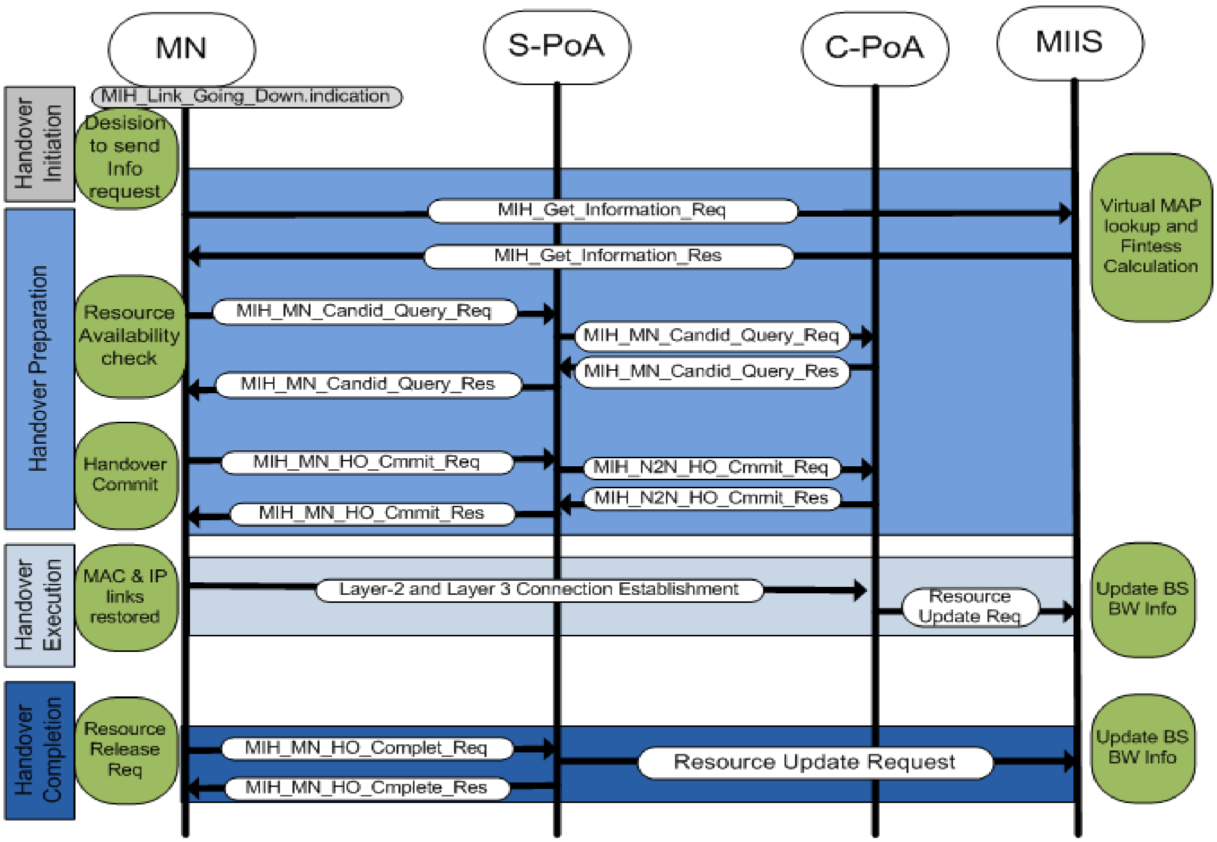

Figure 2: Proposed Handover Framework.

or by MIHF itself (Link Commands). The destination of these commands may be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

3 Proposed Handover Framework

Our proposed handover framework can be divided into four steps or phases as shown in Figure 2. In the first phase "Handover Initiation" the MN concludes through an *MIH_Link_Going_Down* link layer event that soon it will have to perform a handover and therefore it should start looking for candidate PoA. This triggers the "Handover Preparation" phase. In this phase the MN request information form the MIIS server providing its GPS coordinates. The MIIS calculates fitness for all the AP's, within range of the MN. The MIIS then selects the best AP i.e. the one with maximum fitness score and returns its information (containing channel configuration) to the MN. The MN checks for the availability of enough resources on the AP returned by the MIIS by sending *MIH_MN_Candid_Query_Req* message. If the candidate PoA signals enough free resources in the *MIH_MN_Candid_Query_Res*, the MN can proceed to sending handover commit request to the candidate PoA by sending it the *MIH_MN_HO_Commit_Req* message. If the response in the *MIH_MN_HO_Commit_Res* message signals handover success, then the MN proceeds with the "Handover Execution" phase and start executing the handover commands to establish layer-2 and then layer-3 connections. Once this is done the MN enters "Handover completion" phase, in which previous PoA is notified of handover completion so that it can release any resources previously allocated to the MN.

In the proposed handover framework it is possible to omit the *MIH_MN_Candid_Query_req* message exchange if the information received from MIIS can be assumed to be fresh and valid. The two most important steps of our algorithm are carried out during the "Handover Preparation" phase and are explained as follows.

3.1 Querying the Information Server

When the signal strength from the current AP is continuously degrading, an MIH *Link_Going_Down* event is generated. This event is propagated to the upper layers (handover module of the MN). The upper layers conclude that the MN is about to lose its current connection and therefore a new connection needs to be established. In order to make an informed and optimal decision on future PoA selection, the handover module of the MN in addition to local information like RSS needs global information such as available bandwidth in future PoA. Since such information is not available locally, the MN has to query the remote MIIS server. Therefore the MN sends an *MIH_Get_Information_Request* message to the MIIS server as shown in Figure 2. The request contains the GPS coordinates for the MN and a parameter for specifying that 802.11 candidate PoA information is required. The query is performed just before losing the current connection i.e. in the "Handover Preparation" phase rather than "Handover Execution" phase, and therefore it does not introduce any new handover delays. Instead it reduces the handover delay by acquiring in advance the information required for PoA selection. Such information is normally obtained by the MN using discovery procedures during the handover over execution phase (e.g. scanning channels for the discovery of potential future PoA's) resulting in high handover delay.

The MIIS server has a holistic view of the network topology and knows about the GPS coordinates, BSSID, radio coverage, cost of service and QoS conditions of all the AP's in the network. The MIIS server upon receiving an information request from an MN first locates the MN on a virtual map with the help of the GPS coordinates of the MN and the surrounding AP's. Then the MIIS calculates the distance of MN from its surrounding reachable 802.11 AP's. The distance calculation is modeled as the distance between two points in a two dimensional space and the well-known Pythagoras theorem shown in Equation 1 is used.

$$D_j = \sqrt{(X_j - X_i)^2 + (Y_j - Y_i)^2} \tag{1}$$

Where D_j represents distance between an MN i and a particular AP j, in its surroundings.

X_i, Y_i are GPS coordinates of an MN i and X_j, Y_j are coordinates of an AP_j respectively.

The MIIS server already has information about the resource availability e.g. available bandwidth in each AP in its network. This information is sent by each AP in the network to the MIIS server periodically and when there are significant changes in traffic conditions of the AP e.g. when a handover to/from the AP occurs. On the basis of the distance of the MN from the AP and the amount of available bandwidth in the AP, MIIS calculates a fitness score as explained next in section 3.2 for all reachable AP's from the current position of the MN.

3.2 Algorithm for PoA Selection

In this section we present a novel PoA selection algorithm for 802.11 networks. The algorithm is used to calculate fitness score of AP's and takes four input parameters i.e. available bandwidth, distance of MN from its reachable surrounding AP's, security level of AP's and cost of AP's. The fitness function is given by the following Equation 2.

$$F_j = \frac{1}{\sum_{k=1}^{4} W_k} \left(W_1 \frac{B.A_j}{B.T_j} - W_2 \frac{D_j}{R_j} + W_3 \frac{S_j}{S_m} - W_4 \frac{C_j}{C_m} \right) \tag{2}$$

Where F_j represents the final fitness value of a particular AP_j, $B.A_j$ represents available bandwidth and $B.T_j$ represents total bandwidth of an AP_j, D_j represents distance between MN and an AP_j calculated in Equation 1, and R_j represents the coverage range of an AP_j. S_j and S_m represents the security level of an AP_j and maximum possible security ranking respectively. Similarly C_j and C_m represents cost of connection of a particular AP_j and maximum connection cost. W_1, W_2, W_3 and W_4 are the corresponding weights of bandwidth, distance of MN, security and cost respectively. The final value of the fitness function is sensitive to these weights.

Table 1: Security Protocols Ranking

Protocol	Security Level
WPA2 AES-CCMP only	4 (S_m)
WPA2 AES-CCMP + TKIP	3
WPA TKIP	2
WEP	1
OPEN	0

Security of AP's can be ranked by considering which security protocols are currently being used by them. Wi-Fi Protected Access (WPA) provides much stronger security than Wired Equivalent Privacy (WEP), addressing all the weaknesses of WEP and allowing compatibility and upgrades with older equipment [8]. However WPA is a compromised solution and still relies on RC4 encryption algorithm and Temporary Key Integrity Protocol (TKIP) [8]. TKIP has known security problems [10]. An advanced version of WPA is WPA2 which make use of Robust Security Network (RSN). RSN consists of Advanced Encryption Standard (AES) and Counter Mode CBC MAC Protocol (CCMP) and is stronger and scalable [9]. A simple ranking of AP's with respect to security is given in Table 1.

Once the MIIS is finished calculating fitness values of all the AP's reachable to the MN, it then ranks them with respect to their fitness values. The MIIS returns to the MN the information of the AP having the maximum fitness score. The MN trusting the information of the MIIS tears down its current connection and starts to establish new connections with the AP recommended by the MIIS. Thus the MN proceeds to the "Handover Execution" Phase as shown in Figure 2. The MIIS sever might also return a list of candidate PoA's rather than just one PoA with their respective fitness score or just return a list of candidate POA's with their respective channel configuration and available bandwidth information. This will allow the MN to rank these AP's by itself and to make its own handover decisions. In our simulation scenario we have used the first approach.

3.3 Drawbacks

Although our scheme has certain advantages over traditional RSS based mechanism, it might have some disadvantages as well in real in certain situations. For example if the information on the MIIS is not fresh or not valid, the MN might be led into false handover decisions. Therefore some additional efforts are required to keep the dynamic information on the MIIS updated at all times. One way of ensuring this is by sending update messages from the AP's to the MIIS periodically and after each handover. We implemented this in our simulation scenario (in practice this method might waste bandwidth in the wired network part). The resources availability check can also be used to recover from such a situation and therefore can no longer be ignored when the confidence level of the MN on the accuracy of the information received from the MIIS is not high enough. Similarly the MN might need some recovery procedure if the MN does not receive a reply from the MIIS. This might happen if the reply packet is dropped by the network or the MN loses its current connection abruptly due to sudden loss of signal. In such a situation the MN might fall back to traditional RSS based handover mechanisms after a timeout. Since the scheme is based on central server, it might suffer from single point of failure. However having a central server is part of the MIH architecture.

A scheme based on a central server also has the advantage of saving the MN resources and can realize short handover delays. This is so because the handover decision is taken on the MIIS based on already available information and not on the MN which is normally required to discover such information on its own during handover execution. If all the parameters of our algorithm are exactly similar for the surrounding AP's then our scheme will have no advantage. Although such a situation might not be a very likely one. The algorithm and frame work currently does not take into account the exact bandwidth or QoS requirements of an MN and therefore might force a MN to attach to an AP with more available bandwidth further away. While MN's required QoS could also have been provided by a nearby AP having comparatively less but enough available bandwidth. But on the other hand our approach does have an inherent ability of balancing the load among the AP's which might be lost if the handover decision is based on exact bandwidth requirements of an MN. Although such a choice might also depend upon the type of the MN's traffic e.g. for TCP traffic its best to select an AP with the most available bandwidth even if it's a little further away, while for pure UDP traffic, an AP with just enough available bandwidth can be selected. The selected values of parameter weights also will have an effect on such a situation.

4 Simulation Scenario and Parameters

The National Institute of Standards and Technology (NIST) have implemented the Media Independent Handover Function (MIHF) based on draft 3 of 802.21 standard in the form of an add-on module [11] for Network Simulator (ns-2) [12] version ns-2.29. The implementation supports both MIES and MICS but does not support MIIS [13]. We have used this implementation for our simulation and have added a limited MIIS server functionality. NIST also provides an implementation of 802.11 [14].

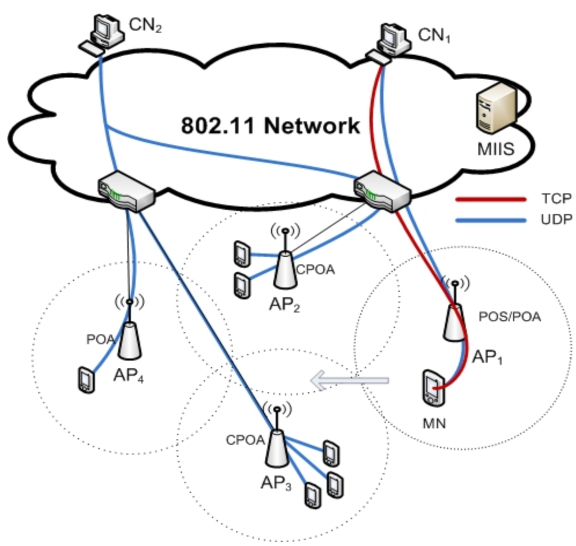

Figure 3: Simulation Scenario.

Figure 3 represents the topology of our simulation scenario. The simulation area was set to 300 x 300 meter and consisted of four AP's. Simulation was run for a total of 100 seconds (sec). AP_1 had one MN attached to it. AP_2 had two, AP_3 had three and AP_4 had one stationary client attached to them. The correspondent node i.e.. CN_2 starts sending continuous unicast Constant Bit Rate (CBR) traffic in the form of UDP packets to all the stationary clients in the topology, while CN_1 sends similar UDP traffic to the MN. All

UDP flows start at simulation time 4 sec and lasts till simulation time 90 sec. The UDP packets size and rate was set to, 1500 bytes and 300 kbps respectively. In addition to a UDP flow the MN was configured with a TCP flow destined to CN_1 with a packet size of 1500 bytes. TCP flow started immediately after a handover.

At simulation time 8 sec the MN attached to AP_1 starts moving out of the its coverage and at simulation time 13.8 sec a *MIH_Link_Going_Down* event is generated and the MN decides to query the information server as explained before in section 3.1. The MIIS must now suggest a PoA for the MN to attach to. We have run two test cases of handovers. In the first test case the MIIS base its decision only on the distance between the MN and the AP. Therefore the MIIS returns the closest AP to the MN. This case is taken as a reference for comparison and is assumed to be equivalent to traditional RSS based handover. For the first handover AP_3 turns out to be the closest to the MN. In the second case the MIIS calculates a fitness score as explained in Section 3.2, considering both distance of MN from the AP and the available bandwidth of AP. In this case AP_2 turns out to be the best for the first handover because it has more free bandwidth available, although it's a little further away from the MN as compared to AP_3. The results for both these cases have been compared in Figure 4 and Figure 5 for two independent TCP flows at different times. The MN performs a total of two handovers. For the parameter weights we have used W_1=5 (strong importance) for available bandwidth of an AP, and W_2=7 (very strong importance) for distance of an MN, following the nine point scale of Analytical Hierarchical Process (AHP) [15], while security and cost were disabled in our experimentation by W_3=W_4=0 and did not contributed to the fitness value calculated in our case. This was done to keep the comparison and simulation scenario simple.

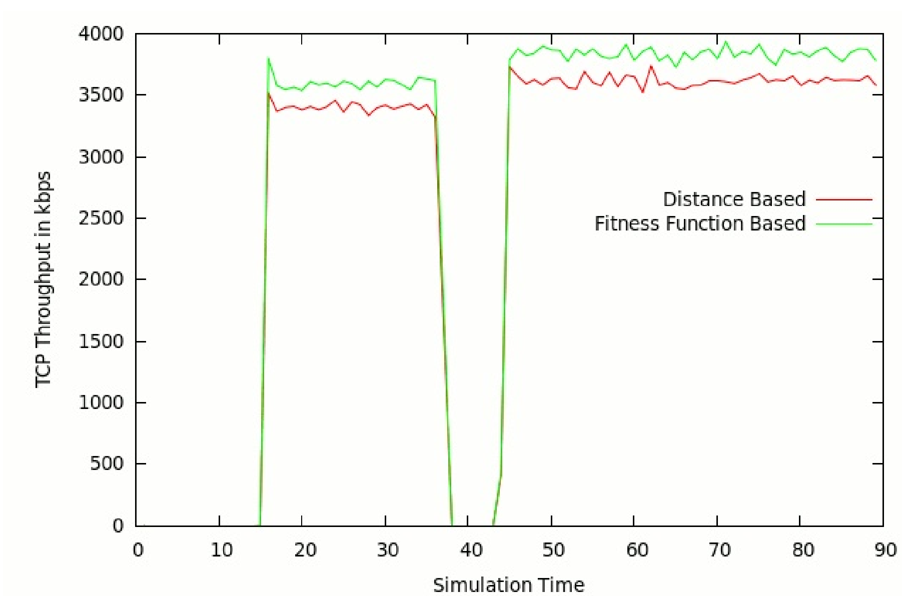

Figure 4: TCP Throughput(kbps).

4.1 Discussion

The MN was configured with a UDP and a TCP traffic flow. TCP traffic was preferred over UDP, for analysis due to its nature of flooding the network to its capacity. This makes it easy to capture the effects of the difference in available bandwidth of different AP's. The resulting throughputs of the two TCP sessions have been plotted in Figure 4. From this figure one can see clearly that the scheme which takes available bandwidth into account (green curve) in addition to distance, performs better than the one which takes into account only distance (red curve). The difference in the throughput performance curves will depend on the difference of the amount of available bandwidth in the AP's. For uniform traffic conditions across the neighboring AP's there will be no gain in performance.

In the Figure 5 the TCP window has been plotted. In this figure it's shown that, the scheme taking both available bandwidth and distance into account for PoA selection (green curve), performs a little better than the one which only uses the distance (red curve) between the MN and the AP.

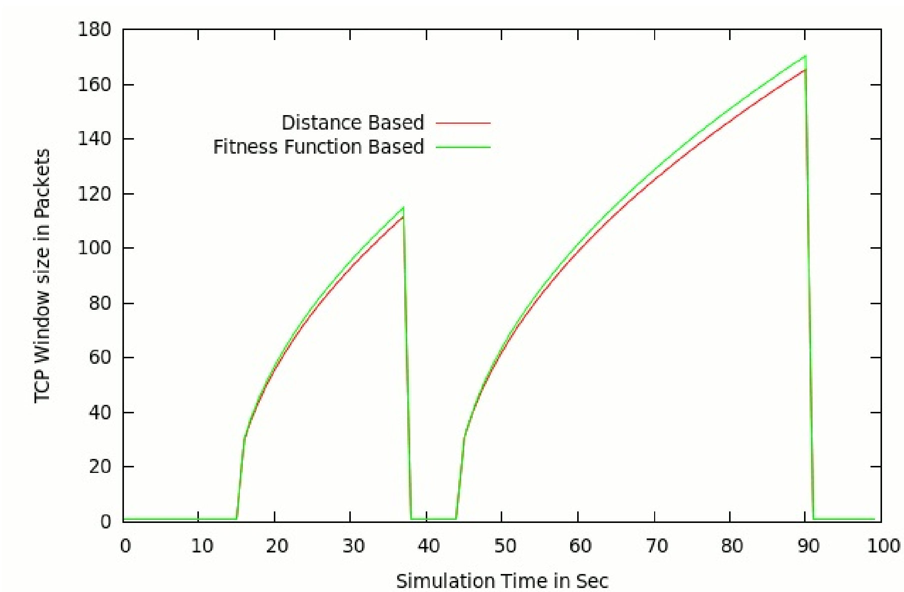

Figure 5: TCP Window Size.

5 Conclusion

Handovers are an essential part of modern day wireless and mobile communication networks. During handovers the selection decision of the most appropriate AP for attachment is very important for full-filling the QoS needs of the MN's applications. The traditional way of identifying the best available AP purely based on RSS might not always be efficient as it does not reflect the current QoS conditions of the target PoA. Therefore there is a great need of integrating QoS information of PoA's such as available bandwidth, into the handover decision making process.

In this paper we have proposed a novel handover algorithm for 802.11 networks that calculates fitness score for each candidate PoA by taking into account the available bandwidth, cost and security level of target AP's alongside the distance of the MN from target AP's. We presented a framework for the implementation and usage of such an algorithm with Media Independent Handover (MIH). A simple ranking of AP's with respect to security is also provided in this paper. We have shown with help of TCP throughput that such a fitness based scheme can be very beneficial for efficient use of network resources like bandwidth.

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Paper F

A Semi and Fully Distributed Handover Algorithm for Heterogeneous Networks using MIIS

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Abstract

Network selection in 4G networks by nature is a multi-dimensional problem and many parameters need to be considered for handover decision making. Successful classical handover methods based on Received Signal Strength (RSS) are no longer applicable for heterogeneous handovers because different network standards use different RSS and cannot be compared directly to each other. Heterogeneity does not only exist in network architectures and in their respective Quality of Service (QoS) but also in user application needs and user contexts. Network selection in heterogeneous networks has been modeled as *Multiple Attribute Decision Making (MADM)*.

In this paper we investigate how the task of network selection can be distributed across multiple network entities putting minimum possible burden on the Mobile Node (MN) which usually is the most restricted network component in terms of memory, processing power and battery life. This distribution increases the scalability of handover algorithm and will also allow the inclusion of more parameters for handover decision making. Considering more parameters for handovers will result in accurate, robust and general algorithms, capable of fulfilling a variety of user contextual, preferential and applications QoS needs. The Media Independent Handover (MIH) and its different services are used to retrieve and share information among MIH enabled nodes and for conformity among different network standards. Simulations are used to show the effectiveness of a simple handover algorithm based on Simple Additive Weighting (SAW) for network selection considering different types of user services and Service Level Agreement (SLA's). SAW belongs to the MADM classification of heterogeneous handovers and is chosen here due its simplicity and efficiency. The handover efficiency of the proposed distributed schemes is compared with an "802.11 Preferred" scheme. Only handovers between Wi-Fi and WiMAX are considered. But the handover framework is general and can be extended to consider other wireless and mobile communication networks like 3G, CDMA etc.

1 Introduction

Handover decisions in a 4G network environment are complex in terms of their actual implementation because they need to consider many factors due to the heterogeneity of the environment, Quality of Service (QoS) of different network media and user needs. This means that handover decisions needs to consider many factors and parameters to be general enough to handle most situations and at the same time to ensure individual user needs are fulfilled. In order to do this the handover algorithms needs extensive processing which limits their scalability as they are expected to be performed for a large number of Mobile Nodes (MN's) and are usually proposed to be carried out by the MN itself which is usually the most resource restricted network component in terms of processing power, battery power and memory. A handover decision performed on the MN assumes that all the parameters considered for handover decision are also acquired by the MN itself by measurements or from the network. The problem with the former is that, the measurable parameters might be limited in number and will also drain MN and network resources. Acquiring them from the network might not be possible as well, as operators might not feel comfortable sharing their network configuration parameters, traffic conditions or handover decision criteria with the user. Apart from considering many parameters the handover decision also need to be efficient in terms of handover latency, so that the QoS requirements of real time communication flows are fulfilled.

One answer to the above stated challenges might be to distribute the processing burden of heterogeneous handovers among multiple network components. For such an approach it is very critical that the handover decision is first broken down into sub parts and then the sub parts are distributed among multiple network components for better scalability. For efficiency it is important to identify which sub parts of the algorithm can be performed even before the handover execution, so that the handover delay is kept to a minimum without sacrificing accuracy and the number of considered parameters for handovers. Such a distribution is expected to result in reduced resource consumption on the MN and will enable handover decision algorithm designers to consider more parameters to design general, robust and powerful handover decision algorithms. Considering more parameters also means that handover decisions can be tailored to each user individual applications QoS, contextual (e.g. location, speed) and preferential (e.g. cost) needs. Handovers in heterogeneous networks have been modeled [6] as *Multiple Attribute Decision Making (MADM)* in the literature. MADM makes it possible to consider more than one parameter. However most MADM methods are proposed to be entirely carried out by a single entity e.g. a MN or a central server. This approach puts heavy processing burden on a single entity and might result in limited scalability.

In this article we present a simple distributed handover algorithm which can fulfill the above mentioned requirements. Two proposals are provided for distributing the processing burden of heterogeneous handovers across multiple network components. A simple but powerful MADM method called *Simple Additive Weighting (SAW)* [1] is first tailored to our needs and then implemented as a test case. Maximum number of network and user criteria is considered for handover decision making. The handover criteria and their exact relative importance used for handover decision remain concealed from the user. The Media Independent Information Handover (MIH) [2] and its facilities are utilized for intelligent handovers.

This article has been arranged as: Section 2 contains the related work and an introduction to MIH. Section 3 provides details on our SAW algorithm and the two distributed proposed approaches. Simulation scenario and parameters details are provided in Section 4. A discussion on generated results is given in Section 5 and in Section 6 conclusions are drawn.

2 Background

2.1 Related Work

In [1] the author has proposed to use fuzzy logic to deal with imprecise handover criteria and user preference. After imprecise data are first converted to crisp numbers, classical MADM methods SAW and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) are applied. In [3] Grey Relational Analysis (GRA) is used to rank the candidate networks while Analytical Hierarchical Process (AHP) [4] is used for weighting the criteria. Multiplicative Exponent Weighting (MEW) [5] is another MADM weighting method. In [6] the authors have provided a comparison of four algorithms i.e. MEW, SAW, TOPSIS and GRA. They show that MEW, SAW and TOPSIS have similar performance for the four considered different traffic classes, while GRA's performance is slightly better. In [7] the authors have provided a survey of different heterogeneous handover schemes. In [8] the authors have proposed to use AHP for weighting and TOPSIS for ranking in a WiMAX, Wi-Fi environment. [9] have proposed a fuzzy extension to AHP and an MADM method called ELECTRE is proposed for ranking. There are a great number of other research papers published on heterogeneous handovers and a great variety of proposed algorithms exists. But most of these algorithms are based on different combinations of SAW, MEW, GRA, ELECTRE and TOPSIS with AHP, fuzzy logic and neural networks etc. Moreover most of the above algorithms are proposed to be carried out in their entirety by a single entity i.e. a central server or by an MN. Similar to our proposal, distributed proposals are provided in [10] and [11] in which the rank calculation is delegated to the visiting networks. However the proposed schemes have certain drawbacks. First both the schemes consider very limited criteria (only three for the scheme in [10]) for handover decision making. User preference consideration is also limited and only cost is considered. Therefore both of them are limited in their accuracy and generality. Secondly both schemes requires the MN to discover point of attachments by scanning which might result in high handover delay depending upon the number of detected BS's as no Media Independent Information Service (MIIS) is used. The scheme in [10] does not make use of MIH at all, while the scheme in [11] makes use of MIH but merely for exchanging messages between the MN and the BS's. Another problem is that the weights used for calculation of ranks are assumed to be provided by the MN as part of its request to the visited networks. Ideally the MN should not be aware of the criteria and their relative weights used by handover decisions.

In contrast to these schemes we consider handover criteria ranging from network traffic conditions to user preferences (both service types and cost). We propose to make use of intelligent services provided by MIIS for low latency handovers where no scanning [12] is performed and the MIIS makes use of MN coordinates to return the information of only relevant BS's. In addition we also propose an MIIS based semi distributed mechanism. Simulations are performed to show the efficiency of our proposed algorithm for network selection in both fully and a semi distributed manner. Handover efficiency of the proposed distributed approaches is compared to an "802.11 Preferred" scheme.

2.2 Media Independent Handover (MIH)

Media Independent Handover [2] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. *Figure 1*, taken from reference [2] shows how the MIH Function (MIHF) is interfaced with other layers of the protocol stack in a multi face MN or network node. A single media independent interface *MIH Service Access Point (MIH_SAP)* is used to provide services to the MIH users. All interactions of the MIHF with the lower layers take place with the help of media-specific protocol instantiations of MIH_LINK_SAP. The purpose of the MIH standard is not to design a new protocol, but to complement the existing mobility management protocols in taking handover decisions. The MIHF provides three kinds of services to achieve this. A short description of these services is given next.

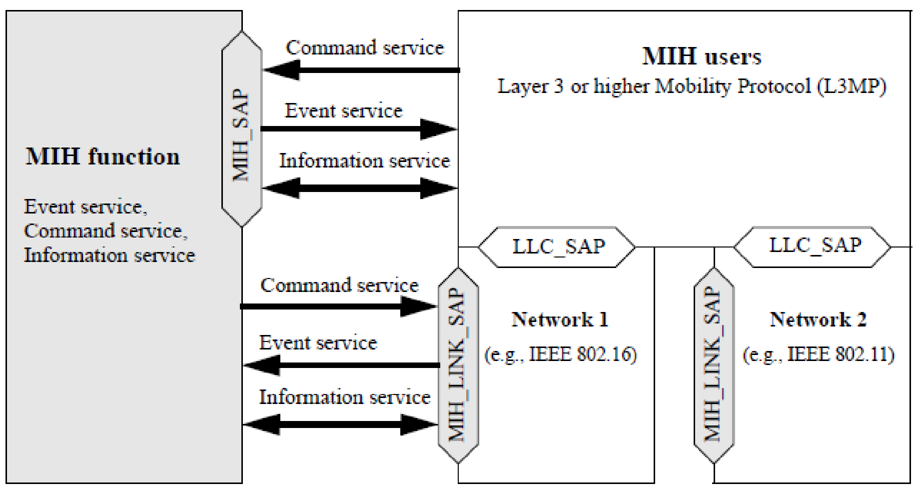

Figure 1: Services and their initiation.

2.2.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIHF (MIH Events) or from a lower layer (Link Events) within the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

2.2.2 Media Independent Information Service (MIIS)

The MIIS provides a framework and the corresponding mechanisms by which an MIHF (MN) entity can discover and obtain network information existing within a geographical area to facilitate network selection and handovers. MIH Information Service can be used to provide network information to the MIHF. The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The network side of the MIH entity with which the MN exchanges MIH information is called Point of Service (PoS). The MIH standard supports both layer 2 and layer 3 transport option for information access.

2.2.3 Media Independent Command Service (MICS)

The higher layers can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands) or by MIHF itself (Link Commands). The destination of these commands may be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

3 Proposed Handover Framework

This section provides details of the handover algorithm we have used and how the ranking is performed in a distributed manner. Details regarding when and how the MN queries the MIIS server are also provided here.

3.1 Handover Algorithm

The handover algorithm considered in this article is based on *Simple Additive Weighting (SAW)*. The main reason of opting for SAW is that despite being simple its efficiency and accuracy is still similar to other heterogeneous algorithms like MEW and GRA [6]. The algorithm is carried out in two steps. In the first step each Base Station (BS) is required to keep track of its own network parameters like (delay, packet loss, jitter, available bandwidth etc.) and calculates its own rank based on the following equations.

$$QoS_{ik} = W_{bk}\frac{B.A_i}{B.T_i} + \frac{W_{jk}}{J_i} + \frac{W_{dk}}{D_i} + \frac{W_{lk}}{L_i} \tag{1}$$

$$W_{bk} + W_{jk} + W_{dk} + W_{lk} = 1 \tag{2}$$

Where QoS_{ik} denotes the QoS rank of particular BS i for a particular service type k defined in the WiMAX standard and listed in Table 1. $B.A_i$ represents available bandwidth and $B.T_i$ represents total bandwidth of a BS_i, L_i represents packet loss, J_i represents packet jitter and D_i represents packet delay. W_{bk}, W_{jk}, W_{dk} and W_{lk} are the corresponding relative weights of bandwidth, packet loss, jitter and delay for service type k.

Table 1: Considered Service Types and their Weights

Service Type (k)	W_b	W_j	W_d	W_l
UGS	0.20	0.35	0.35	0.10
rtPS	0.30	0.30	0.30	0.10
nrtPS	0.70	0.10	0.10	0.10
BE	0.70	0.10	0.10	0.10

The list of service types and their associated weights used in our simulations are given in Table 1. The rank calculated in Equation 1 is assumed to be refreshed by a BS both on a periodic basis and when there are significant changes in network traffic conditions e.g. a handover from/to the BS occurs. The BS rank calculated at this stage does not included user preferences therefore is performed before even the handover starts.

The rank pre-computed in Equation 1 is to be utilized during handover preparation to calculate the final rank of a BS considering specific user needs. The handover decision is made based on this new revised rank and is computed with the help of the following equations.

$$F_{ik} = W_{QoS} * QoS_{ik} + \frac{W_c}{C_i} \tag{3}$$

$$W_{QoS} + W_c = 1 \tag{4}$$

Where F_{ik} represents the final rank or fitness score of a particular BS i for a particular service type k. QoS_{ik} is a pre calculated BS rank, W_{QoS} and W_c are the corresponding relative weights of QoS and cost of the connection. The value of these weights represents which parameter is more important for the user i.e. QoS or cost. The user must have already specified about his/her cost and QoS preference in the form of a Subscriber Level Agreement (SLA) with the operator. For our simulation we have considered three SLA's listed in Table 2.

3.2 Semi Distributed Approach

In this approach all BS's in an 802.21 network calculate its own rank i.e. QoS_{ik} for the different type of services using Equation 1. The BS's then send their ranks to the *Media Independent Information Server (MIIS)* both on a periodic basis and when there is a

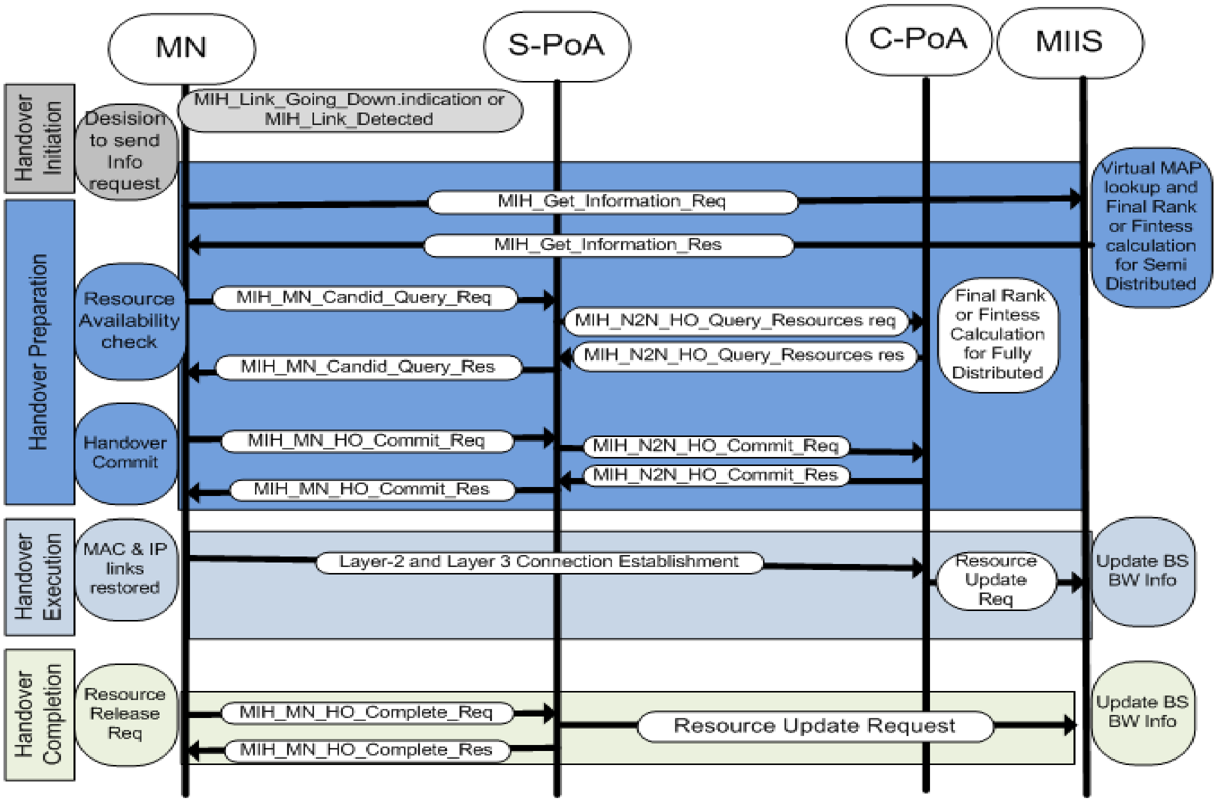

Figure 2: Proposed Handover Framework.

significant change in the BS traffic condition e.g. when a handover to/from the BS occurs. The MIIS stores and maintains the rank of the all the BS's for each considered service type k. We assume that the 802.11 (Wi-Fi) BS's fall within the coverage of WiMAX.

Table 2: Considered SLA Types and their Weights

SLA Type	W_{QoS}	W_c	Description
SLA QoS	0.90	0.10	QoS most important, price least.
SLA Budget	0.70	0.30	A compromise between price and QoS.
SLA LowCost	0.10	0.90	QoS least important, price most.

Whenever an MN detects the presence of an 802.11 network its queries the MIIS server for network selection assistance as shown in Figure 2, providing its contextual information (i.e. GPS coordinates, speed), its SLA type and the active service type. The MIIS locates the MN on a virtual map with the help of the GPS coordinates of the MN and the surrounding BS's, and decides which 802.11 BS's are reachable to the MN. The MIIS then calculates the final rank F_{ik} for reachable BS's, using Equation 3. A BS with the maximum rank is identified and its information is returned to the MN. The MN after receiving this information checks if the received maximum rank is that of the currently connected WiMAX BS if so it does not perform a handover otherwise a handover sequence is initiated to handover to a candidate 802.11 BS. For semi distributed "Resource Availability

Check" shown in Figure 2 is not performed and the MN goes directly into the "Handover Commit" phase.

3.3 Fully Distributed Approach

In a fully distributed approach each BS calculates its rank QoS_{ik} by Equation 1 as explained in the previous section but instead of sending them to the MIIS server, they are stored locally. The MN as before on detection of an 802.11 network queries the MIIS. The MIIS this time only make use of the MN's GPS coordinates only and after identifying one or more reachable candidate BS's, returns the list to the MN. When the MN receives the candidate list it sends *MIH_MN_Candid_Query_Req* message(s) to all candidate BS('s) in the candidate list received from the MIIS. This operation is similar to the one defined in the MIH standard but the only addition is the use of MN's GPS coordinates for refining the list of candidates on MIIS. This list could also be further refined to meet further specific needs of an MN e.g. the consideration of MN's speed in case of high mobile users. The MN must also provide information regarding the service type it is running and its SLA type in *MIH_MN_Candid_Query_Req* message. All BS's receiving a *MIH_MN_Candid_Query_Req* message calculates their final rank F_{ik} by Equation 3 which is then returned to the MN in the *MIH_MN_Candid_Query_Res* message of the MIH standard as shown in Figure 2. The MN after receiving responses from all candidates BS's identifies a BS with the maximum rank and then initiate a handover to it.

4 Simulation Scenario and Parameters

The National Institute of Standards and Technology (NIST) have implemented the Media Independent Handover Function (MIHF) based on draft 3 of 802.21 standard in the form of an add-on module [13] for Network Simulator (ns-2) [14] version ns-2.29. The implementation supports both MIES and MICS but does not support MIIS [15]. We have used this implementation for our simulation and have added MIIS server functionality. NIST also integrated into their module an implementation of 802.11 [16] and 802.16 [17]. Figure 3 represents the topology of our simulation scenario. The simulation area was set to 3000 x 3000 meter and consisted of three 802.11 AP's and one WiMAX BS. At the start of the simulation the MN is stationary and is attached to WiMAX. The correspondent node i.e. CN starts sending continues unicast Constant Bit Rate (CBR) traffic in the form of UDP packets to the MN at simulation time 10 sec. The UDP packets size was set to 1000 bytes and used different traffic rates. The MN after some time starts moving at a speed of 8m/s in the direction of AP_1. When the MN reaches the boundary of the AP_1 cell it receives neighbor advertisement messages from AP_1 and a *MIH_Link_Detected* event is generated. At this point the MN queries the MIIS server for assistance as shown in Figure 2. The MN after receiving the candidate BS ranks from either the MIIS through *semi distributed approach* or from a candidate BS in case of *fully distributed approach*

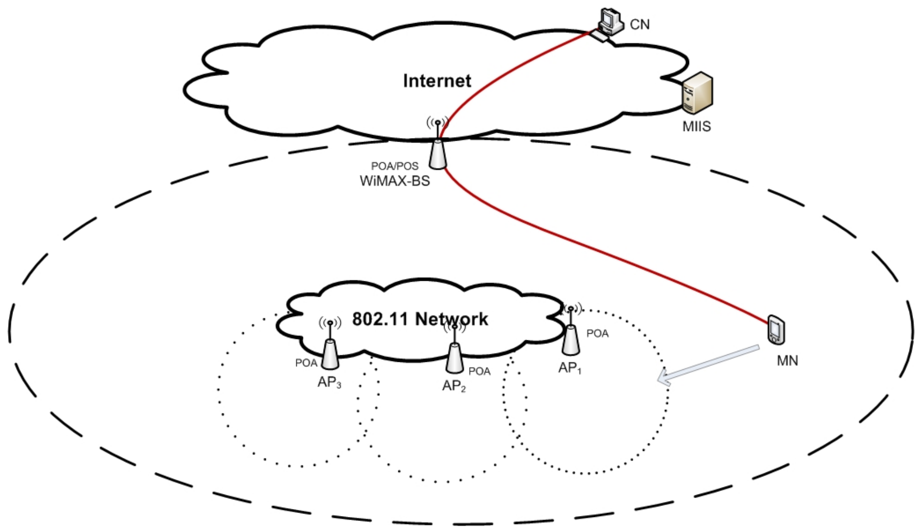

Figure 3: Simulation Scenario.

decide on whether it should perform a handover or keep connected to the WiMAX BS. The MN continuous its motion and if has decided to use the Wi-Fi BS i.e. AP_1 then a *MIH_Link_Going_Down* event is generated, when it is moving out of coverage of AP_1. The MN while connected to AP_1 performs an MIIS query to get assistance on candidate selection either from MIIS or from a candidate BS. After the MN receives the required response, it then either performs a horizontal handover to another 802.11 BS i.e. AP_2 depending upon the rank or a heterogeneous handover back to WiMAX BS. When the MN is leaving the coverage of the last Wi-Fi BS i.e. AP_3, only WiMAX BS is returned as a candidate BS and therefore the MN handovers to WiMAX.

5 Discussion

This section provides some insight on the results that have been gathered from simulations regarding the effect of different user related and network related parameters on network selection. The handover efficiency of the proposed distributed schemes is also evaluated and compared to an "802.11 Preferred" scheme. The configuration of network traffic conditions was kept such that the WiMAX BS would be more favorable for real time applications and is assumed to offer low packed delays, low packet loss, and low packet jitter for a high cost, but also has a high network utilization or load. On the other hand Wi-Fi AP's have low network utilization and offer services with different cost, delays, packet loss and jitter. But the values of these parameters are comparatively higher than WiMAX, making them favorable for mostly non real time flows at low cost. With such a configuration the target is to analyze if the user needs (QoS and service cost) are fulfilled by our SAW algorithm for network selection.

Figure 4 show the effect on network selection, of different types of user services with

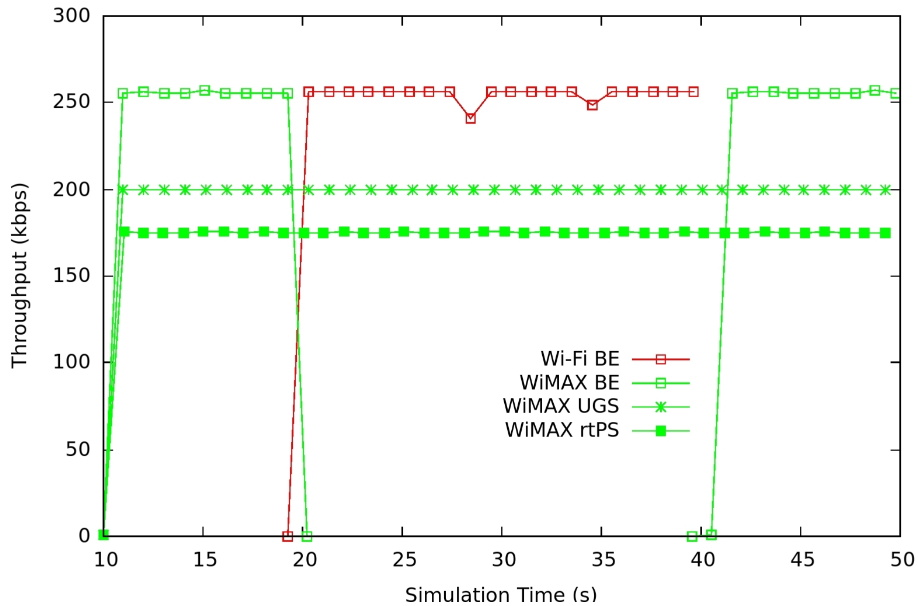

Figure 4: Network Selection with Same SLA and different Traffic Types.

the same SLA i.e. SLA QoS. Since cost of the service is not an issue for this type of SLA, we can see form this figure that real time services UGS and rtPS favorâĂŹs the WiMAX BS even though Wi-Fi is detected. But for a non-real time service like BE the MN makes full use of Wi-Fi coverage due to the fact that Wi-Fi AP's are lightly loaded (more chances of getting high bandwidth) than WiMAX. An important thing to note from this figure is that throughput is not as steady for the MN when using Wi-Fi, as it is when using WiMAX. The reason for this is frequent handovers due to small coverage area of 802.11 BS's. Throughput variation is only critical for real time flows and not so much for non-real time flows like BE. Therefore our SAW algorithm performs well by choosing the most appropriate network type for the current running service type. It is important to note that the difference in maximum achievable throughput in this figure does not represent throughput gain, as we have used different rate sources for different service types to avoid overlapping of curves in the figure for better visibility.

Figure 5 shows the effect on network selection, of different SLA's with the same service type i.e. UGS. The difference in maximum achievable throughput is not relevant. With "SLA QoS" the MN never handovers to the Wi-Fi network and keeps on using WiMAX. At the other extreme is "SLA Lowcost" with which the MN makes full use of the Wi-Fi coverage. For the "SLA Budget" the MN uses the Wi-Fi network but only if it offers a QoS of a certain level. In this case the rank of the last 802.11 BS i.e. AP_3 turns out to be too bad and therefore the MN decides to handover back to the WiMAX network even though cheap Wi-Fi coverage is available. For this test case UGS is best served by WiMAX because of the nature of our assumed network configuration but the inclusion of cost results in different network selection for all users. We can easily conclude here that each MN gets a QoS level that's in accordance with the level of QoS it has a subscription for.

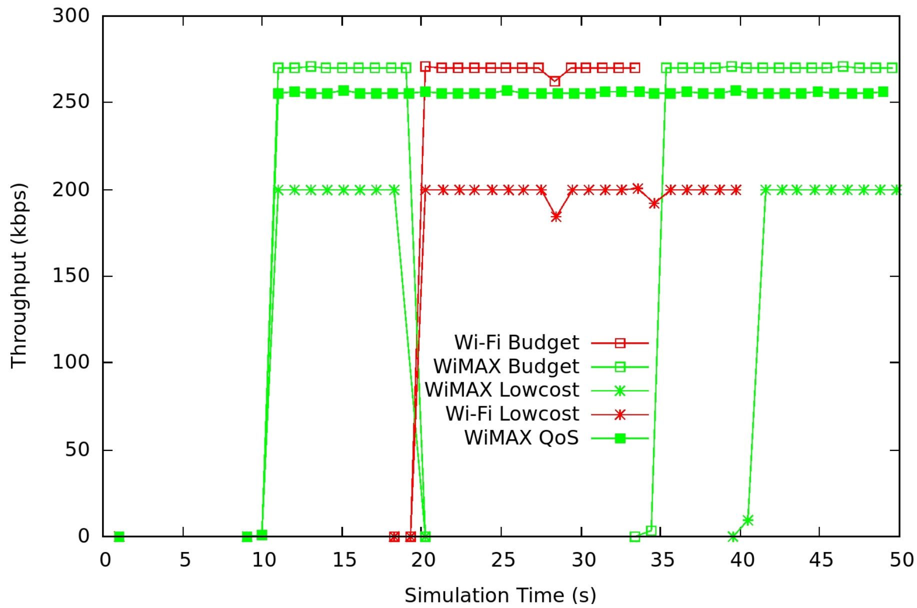

Figure 5: Network Selection with Same Service and different SLA's.

Figure 6 shows the handover performance comparison for our two proposed distributed schemes and an "802.11 Preferred" scheme. In "802.11 Preferred" scheme an MN does not make use of MIH services and always prefers to handover to a Wi-Fi network whenever it is available without considering any other QoS criteria. The maximum achievable throughput here is again not meaningful. We can see that using MIIS services for network selection along with a heterogeneous MADM algorithm can bring big advantages. This can be seen from drop in throughput in the figure for "802.11 Preferred" scheme while the distributed SAW schemes using MIH performs much better. Another important thing to note here is the ping pong effect which occurs in the "802.11 Preferred" scheme, at simulation time 30 sec(s) and 37 sec(s). With this scheme when the MN loses connectivity with the current 802.11 AP it connects to WiMAX, but soon after, handovers back to an 802.11 BS, when it realizes that another 802.11 BS is available. The other two schemes do not suffer from ping pong mainly due to the intelligence provided by MIIS in combination with SAW. From handover performance point of view the two distributed methods perform very similar to each other apart from an extra dip in throughput for Fully Distributed scheme at simulation time 37 sec(s). The reason for this could be that the Semi Distributed approach omits the exchange of messages for "Resource Availability Check" shown in Figure 2 resulting in slightly shorter handover delay.

6 Conclusion

In this paper we have proposed that how a SAW based MADM algorithm can be used in a distributed manner with the help of services provided by MIH. With the help of simula-

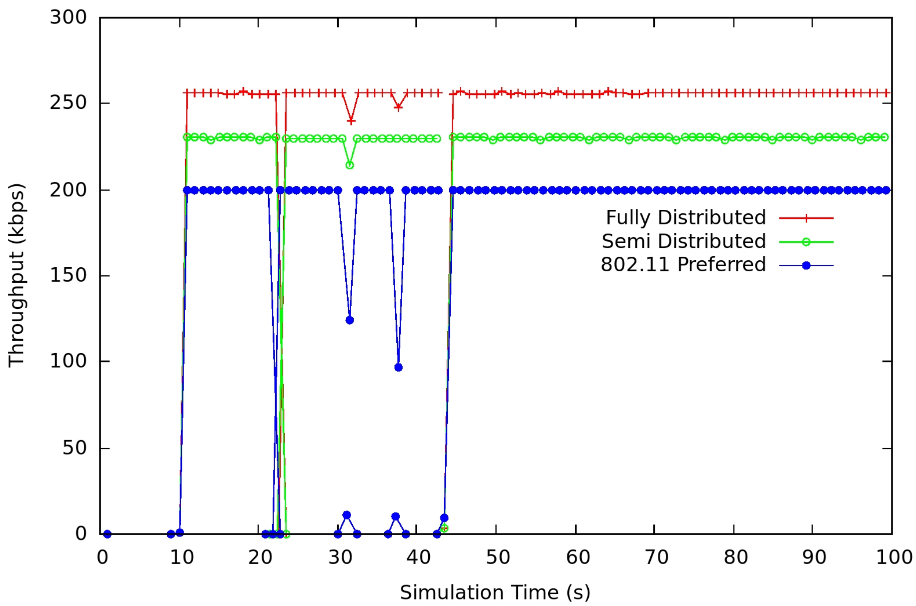

Figure 6: Network Selection with Same Service and different SLA's.

tion results we have shown that a Fully and a Semi Distributed algorithm provide efficient handover mechanisms with good user satisfaction level for all the user service and SLA types. Therefore with such a distributed approach more general, powerful and accurate heterogeneous algorithms can be implemented considering more parameters without sacrificing individual user needs. In terms of handover latency we have shown that the despite being distributed the SAW mechanism with MIH performs efficiently and out performs a simple "802.11 Preferred" strategy.

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Paper G

Pros and Cons of Route Optimization Schemes for Network Mobility (NEMO) and Their Implications on Handovers

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Abstract

No one can deny the importance of mobility in modern communication networks and Internet is no exception. IETF has introduced the *Network Mobility (NEMO)* protocol to support a moving network. NEMO solves many problems of *Mobile IP (MIP)* to support a moving group of users, but introduces some problems of its own like suboptimal routing and multiple levels of encapsulation. These problems occur because the *NEMO Basic Support Protocol (NEMO BSP)* does not support route optimization and because of nested mobile networks respectively. Many solutions have been proposed in the literature to solve these problems. In this article we present a comprehensive survey of those solutions and will discuss their advantages and disadvantages. We also outline the effect of these solutions on handovers and a summary is provided in the form of a table at the end. In this article we backup our earlier work with a comprehensive discussion of the protocols included.

Keywords: MIPv6, NEMO, Route Optimization, Routing

1 Introduction

Using Mobile IP [1] [2] it is possible to move a single IP device from point to point on the Internet without losing the assigned IP address and high layer connections. However using Mobile IP to enable communication in a situation like a bus or train full of passengers with IP based devices would require all devices to be capable of handling mobility and will also generate excess overhead as every device has to perform Mobile IP operations.

A more suitable solution to the problem is Network mobility protocol (NEMO) protocol [3], introduced by IETF to support a moving network. NEMO requires a mobile network router for its operations, called Mobile Router (MR). The protocol is an extension of Mobile IPv6 [2] and provides session continuity for every node in the mobile network as the network moves. Network mobility is transparent to the nodes inside the mobile network. MR takes over the role of Mobile Node (MN) [2] in performing mobility functions. The IP devices hosted in such a mobile network are called Mobile Network Nodes (MNN's). NEMO Basic Support Protocol (BSP) [3] requires that all packets to and from the mobile network must pass through a bidirectional tunnel between MR and a corresponding Home Agent (HA) even if a more direct path exists between the MR and correspondent nodes (CN's). This problem gets amplified when another mobile network joins the mobile network [5]. Because the packets now have to traverse multiple home agents and several levels of encapsulation will be enforced (called "the Pin-ball Routing problem"). This results in high overhead, larger packet size and suboptimal routing as shown in Figure 1. Packets from MR2 to CN follow the same suboptimal route in the reverse direction.

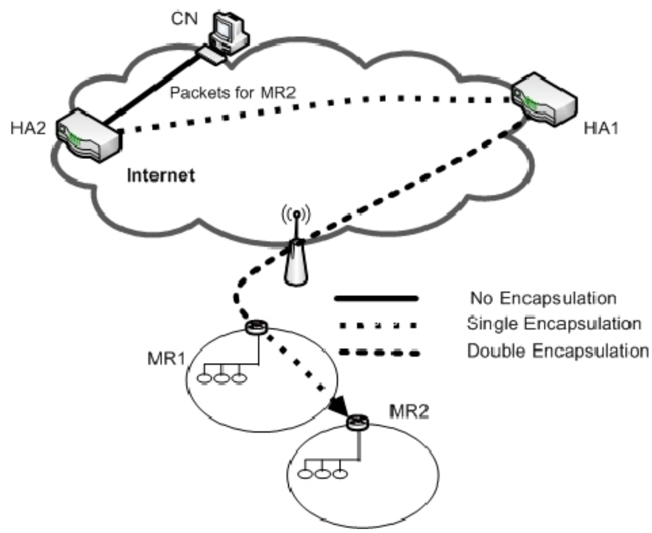

Figure 1: NEMO BSP suboptimal routing

Inefficiencies occurs if two nodes (a MNN and its CN) having different HA's, are both present in the same NEMO domain but exchange packets via their respective HA's. This obviously will give longer than necessary routes and delays as discussed in detail in reference [5]. Using NEMO BSP, the pinball routing problem will become more severe with an increase in levels of nesting for mobile networks as the number of tunnels increases. Introducing route optimization techniques to NEMO may solve these problems [6]. Although introducing a route optimization technique to NEMO BSP can be beneficial, it always comes with a price like additional signaling, increased complexity, additional network components and increased processing overhead [6] that needs to be taken into account. In this paper we present an analysis of some of the most important proposals for NEMO route optimization. The evaluation criteria are explained next.

1.1 Evaluation Criteria

This paper is an extension of our earlier work presented in [7]. Here we provide background, related work and in depth discussions of some of the most important NEMO route optimization solutions. Our evaluation in this paper is twofold.

In the first part, the "Pros and Cons" and the "Effects on Handovers" of each approach is discussed right after each protocol is described. The signaling cost of each proposed RO solution during handovers and the degree to which nested tunnels are reduced, are expressed in the form of mathematical equations. Signaling cost is important to consider for handovers efficiency because high signaling cost might result in bandwidth wastage, long handover delays and scalability problems. Therefore ideally the signaling cost of any proposed RO solution should be as close as possible to NEMO BSP and still provide route optimization without sacrificing important aspects like security, location transparency etc. We analyze the different proposed solutions with respect to the minimum number of binding update messages sent during a handover and the degree of reduction of multi-level encapsulation or tunneling. The analysis is for one mobile network served by a one or more MR's and for one or more handovers. The symbols BU, BA, m, N_{MR}, L are used to represent binding update, binding acknowledgment, depth of nested hierarchy, number of mobile routers and number of handovers respectively. To identify the entity and protocol they apply to, we use the subscript of these variables. The following equations which show the amount of signaling for NEMO BSP during a handover and the number of tunnels needed for its operation are used as the basis for our analysis. Because all proposed RO solutions discussed here build upon NEMO BSP, therefore in the first part of analysis comparison is made with NEMO BSP.

$$\begin{aligned} NEMO_{sig} &= LN_{MR}[BU_{HA} + BA_{HA}] \\ NEMO_{tun} &= m \end{aligned} \tag{1}$$

In the second part of the analysis the proposed RO solutions are compared with each other and analyzed according to the following different criteria, summarized in Table-2. A short description of all the considered criteria is as follows.

a) *Security* For route optimization to take effect interaction among different network components and mobility agents is inevitable. These network components might not have adequate trust relationships in place before hand. Therefore one important aspect of any proposed solution is to analyze its security aspects. The security of each proposed RO solutions is compared with the security of MIPv6 or another well-known protocol.

b) *Problem Addressed* As explained earlier NEMO suffers from two problems namely indirect routing and multi-level encapsulation which occurs due to nesting (Pin-ball routing). Some proposed solutions are designed to solve both problems, while others only targets Pin-ball routing limiting their application. If a protocol targets both problems it is highlighted by the keyword "Both" in Table-2 and by "Pin-ball" if it targets Pin-ball routing problem only.

c) *RO Type* There are two types of route optimizations i.e. Inter-domain and Intra-domain route optimization. Some of the proposed solutions support both types while others support either Inter-domain or Intra-domain route optimization only. Expressions used in Table-2 are "Both" or "Inter" or "Intra" to identify the RO type supported by each RO solution.

d) *Required New Components/Changes* Some solutions require new components in the network for their functionality, while others introduce new procedures, to be carried out by the existing mobility agents and other network components. Some makes use of both new components and new procedures. Introducing new components is considered costly as compared to introducing new procedures, as it requires changes into the network architecture. Identifying the changes required by each RO solution will establish its feasibility as an RO solution.

e) *Min Tunnels* Some solutions eliminate all tunnels while others (especially the ones which target Pin-ball routing only) maintain some tunnels to operate. A scheme eliminating all tunnels is naturally preferred to the one requiring some minimum of number tunnels for its operations, due to less overhead.

f) *Scalability* analyzes the ability of each solution to scale. Some solutions put too much signaling and sessions state maintenance burden on one network component which limits their scalability. Other schemes smartly distribute such burden among multiple network components resulting in better scalability. The expressions used for measuring scalability are "V.Good" and "Limited".

g) *Components to Update* Identifying the network components which are required by each proposed solution to be updated during handovers might be very useful for comparison. Because a scheme requiring a large number of components to be updated is expected to have certain disadvantages like high signaling cost, long handover latencies and low scalability.

h) *Deployment* It measures the difficulty of introducing the proposed solution into existing network architecture. Schemes requiring adding new components to existing network architectures are difficult to deploy as compared to schemes which require changes to the functionality of existing network components or mobility agents. It is expressed in Table-2 by "Difficult" or "Easy"

i) *Location Transparency* is one of the designed goals for NEMO BSP [4]. Location transparency means that the movement of mobile network should remain transparent to the corresponding nodes. Schemes based on end-to-end RO usually sacrifice this requirement. Its availability is identified by "Yes" or "No" in Table-2.

j) *Signaling* Gives a relative comparison of the amount of signaling introduced by each proposed RO solution for its functionality. As discussed earlier, high signaling wastes network bandwidth, and might result in high handover latency and scalability problems. It is represented by "High" or "Moderate" or "Low" in Table-2.

k) *Degree of RO* This is the ultimate goal for all proposed RO solution. It represents the extent to which route optimization is achieved. It is a tradeoff between the amount of signaling and location transparency. It is expressed by maximum "Max" or "Moderate" or near maximum "Near-Max" in Table-2.

The paper is structured as follows. In Section 2 of this paper we introduce some of the most important proposed solutions for NEMO route optimization, discuss their pros and cons and analyze their effect on handovers. In Section 3 we present conclusions and future research directions.

2 Proposed Solutions

As discussed earlier that a large number of proposals exits for NEMO route optimizations. Some proposals are based on merging other proposals for the purpose of NEMO route optimization. This makes the categorization a difficult job. However authors in [8] have arranged the NEMO route optimization solutions in five broad categories. Following this categorization, the categorization of protocols discussed in this article is given in Table 1.

Table 1: Protocols and their IETF Categorization [8]

Protocol	IETF Category
ORC	Infrastructure Based
PCH	Infrastructure Based
PD	Infrastructure Based
RRH	Nested Tunnel Optimization
ARO	Nested Tunnel Optimization
HMIP	Nested Tunnel Optimization
MIRON	MR-to-CN
Adhoc	Intradomain Route Optimization

2.1 Infrastructure Optimizations

2.1.1 Optimized Route Cache Management Protocol for Network Mobility (ORC)

Optimized Route cache management protocol ORC [9] [10] is an infrastructure based route optimization technique [8]. ORC requires a new entity called ORC router. ORC routers work as an anchor router of a mobile network and maintain fresh routes to the current point of attachment of a MR. A route is an association of the mobile prefix served by MR and its current care of address (CoA) called binding route (BR). BR is updated each time by a MR, when it moves to a different subnet by sending BR update messages to ORC routers. BR update messages are similar to MIPv6 [2] binding update messages. The ORC routers intercept packets for all mobile routers for which it has a BR and tunnels them to the current CoA of the mobile network. For this purpose the ORC router advertises proxy routes to the prefixes served by the MR using an Interior Gateway Protocol (IGP). Although ORC routers can be placed anywhere in the Internet, its effect for route optimization is more significant if they are placed where the CN might reside [11] [12].

A Home ORC (H-ORC) router intercepts packets for the MR at the home network and tunnels them to the current CoA of the MR when away from home. Discovered ORC (D-ORC) routers are present at foreign networks and can be dynamically discovered. The discovery process of the D-ORC is triggered by the MR by sending correspondent router discovery request to the D-ORC anycast address. When a CR receives such a CR discovery request, it replies with a CR discovery reply containing all the CR's of the administration domain where the CN is situated. If the discovery process is successful the MR sends a BR to the D-ORC router. The D-ORC router maintains this BR for the MR only while there are CNs communicating with the MR. Figure 2 presents the basic route optimization mechanism proposed by ORC protocol. For the traffic flowing in the direction from MNN to the CN, MR locates the ORC router closest to the CN and establishes a bi-directional tunnel with it after authentication of the BR. Once the BR is set-up, further traffic will not follow the MR-HA tunnel anymore. As long as ORC router is closer to MR than HA, this route is said to be optimized. For the traffic flows from CN to MNN direction, ORC routers intercept the packets and tunnel them to the current CoA of the mobile router by-passing the MR-HA tunnel.

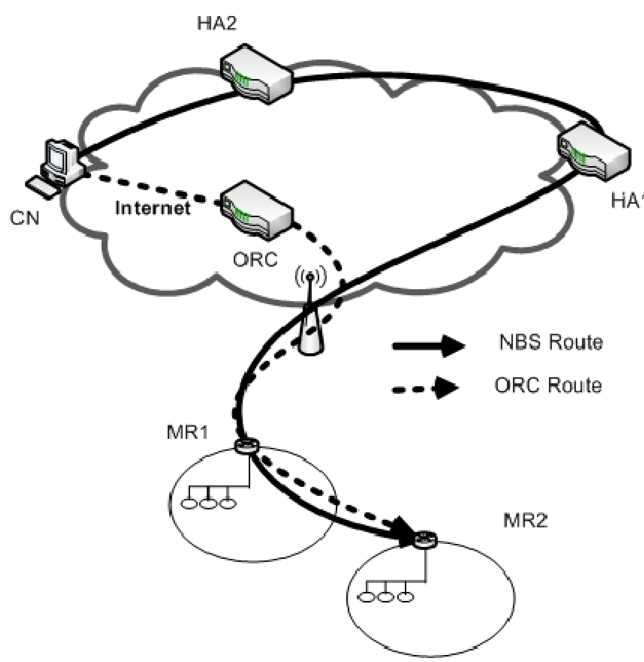

Figure 2: ORC Route Optimization Vs. NEMO BSP suboptimal routing.

For sub optimal routing due to nesting ORC proposes that the child MR configures an IP address by address auto-configuration [11]. The child MR then sends its BR information to the parent MR. Receiving the child MR's BR, parent MR is assumed to send its own BR to the ORC routers of sub MR's. If ORC routers possess BR of both child MR and parent MR, they encapsulate packets with MR-CoA according to a new recursive BR search mechanism [10]. The parent mobile router de-capsulate these packets and send them to the child mobile router.

ORC has been further extended with the help of some additional mechanisms to support a wide variety of NEMO route optimization scenarios in Routing Optimization for Nested Mobile Networks (ONEMO) [13]. ONEMO requires that the CoA of the root mobile router called Nested Entrance point is shared with all the downstream sub mobile routers in the hierarchy by extending Router Advertisements (RA) with a new Nested Entrance Option. In ONEMO a sub MR (e.g. MR2 in Figure 2) notifies CR or corresponding MR of its Nested Entrance Point using a new mechanism called, "Reflective Binding Update". When the CR receives this message it creates a Binding Cache for the prefix carried by MR2. The CR then sends a regular Binding Update message to the address in the Nested Entrance Point retrieved from the Reflective Binding Update, and establishes a bi-directional tunnel with the parent mobile router e.g. MR1 in Figure 2.

a) *Pros and Cons:* ORC provides a route optimization solution that is motivated by scalability, security, quickness, location privacy and network transparency. It tries to follow the mechanisms and procedures of route optimization of MIPv6 [2] for compatibility and simplicity reasons. For security it extends the return routability procedures of MIPv6 to register mobile network prefix information. The authors have shown in [10] that ORC achieves route optimization and compared to other route optimization protocols ORC is more efficient and scalable.

   One of the disadvantages of ORC is that it requires new components in the form of CR's. ORC efficiency is dependent upon the number and placement of ORC router in the Internet. Few or misplaced ORC routers sacrifices maximum route optimization possible with ORC and too many ORC routers results in excess overhead [10]. The ORC signaling overhead is expected to increase with the increase in number of CR's and frequency of movement of the mobile networks. ORC routers do not cover all security aspects. For example it does not specify how security associations between ORC routers belonging to different administration domains could be established. ORC puts a lot of burden on parent mobile routers to perform mobility support operations on behalf of the child MR's and therefore might become bottle neck.

b) *Effects on Handovers:* Using ORC, a MR during handovers will have to update its new CoA with its HA and all the CR's. The volume of these update messages might be enormous depending upon the number of CR's. In a worst case a MR might be serving many MNNs and each MNN might have multiple CNs scattered across different administration domains on the Internet and therefore the MR will have to keep its BR updated on all CR's. As a best case scenario for ORC if a MR is communicating with corresponding nodes all residing on a single administration domain (same IGP domain), the amount of signaling done by the MR will still be more than double then that of NEMO BSP. ORC reduces the number of tunnels to 1 independent of the value of m which represents the depth of nested hierarchy of mobile networks. Return routability procedures will add to handover delays.

$$\begin{aligned} RR_{sig} &= HoT + CoT + HoTI + CoTI \\ ORC_{sig} &= NEMO_{sig} + LN_{MR}[n(BU_{ORC} + BA_{ORC} \\ &\quad + RR_{sig}) + D(ORC_{disc})] \\ ORC_{tun} &= 1 \end{aligned} \tag{2}$$

Where n is the number of corresponding routers, ORC_{disc} stands for ORC discovery signaling, RR stands for return routability procedure and D is the number of different administration domains the MN is communicating with. RR is carried out for security and consist of exchange of HoT, HoTI, CoT, CoTI messages as defined in reference [2]. If all the different domains with which the MR is communicating have only one ORC router each, then from a signaling perspective n=D.

2.1.2 Path Control Headers (PCH)

Path Control Header (PCH) [14] is also an infrastructure based [8] route optimization scheme. In PCH the HA piggybacks path control header information (PCH) to a packet, that is reversely forwarded by the MR for the CN to HA. The PCH is a hop by hop option header and therefore can be processed by intermediate routers capable of handling PCH messages called correspondent router (CR). A PCH header for the nested network configuration depicted in Figure 4 is shown in Figure 3. Upon receiving a packet with a PCH header, a CR on the path to from HA to CN, can make use of information in the packet such as CoA of MR to establish a Route Optimization Tunnel (ROT) with the MR.

2	MR1_COA	MR2_COA

Figure 3: Example of PCH Header.

Setting up of RO tunnel between CR and MR consist of a 3-way handshake. Additional messages defined for setting up RO tunnel are carried by MIPv6 Mobility Header option [2]. A new message called Binding Request (BR) is defined, which is used by CR to notify MR of the need of RO tunnel. The MR replies with a BU message and CR replies back with a Binding Acknowledgment (BA) message. Both BU and BA are the same as defined in MIPv6 [2] and NEMO [3]. Additionally a new mobility option to carry a set of network prefixes is also defined which is used by CR to inform MR of the networks which are reachable from RO tunnel. Using this routing information, MR reversely forward the packets to pre-established RO tunnel. For traffic to the mobile network, CR performs the job of intercepting packets for all mobile routers for which it is maintaining the binding information and tunnels them to the current CoA of the MR.

For nested route optimization (NROT), PCH introduces a source routing concept. CR makes use of IPv6 routing header type 0 (RH0). CR gets to know the existence of nested tunnels through PCH information (MR1's CoA and MR2's CoA) and then initiate the signaling for NROT to MR2 via nested tunnels. At this time, Binding Request (BR) message contains Nested Routing Path Option (NRP Option). NRP Option is used to inform MR2 of the nested path information. If MR2 receives BR message having NRP option, MR2 concludes that it is nested. Therefore, the tunnel between CR and MR2

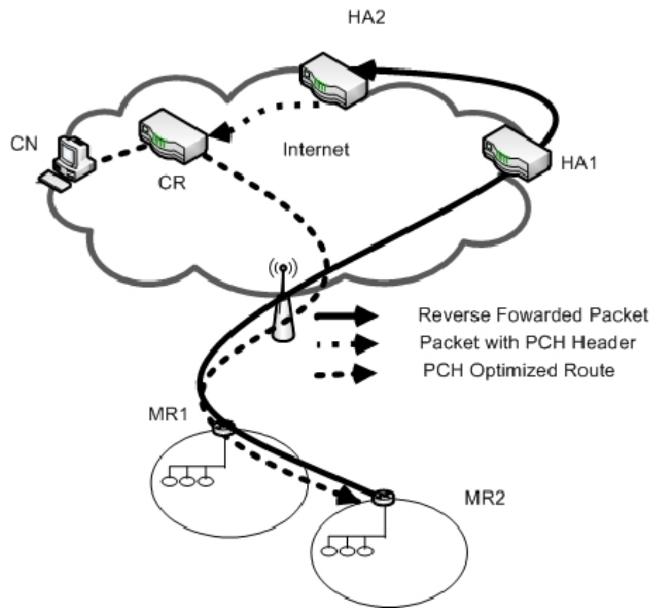

Figure 4: PCH Route Optimization Vs. NEMO BSP suboptimal routing.

becomes a NROT. For the packets tunneled from CR to MR2, source routing is (CR->MR1->MR2). For the packets from MR to CR reverse source routing is used (MR2->MR1->CR).

a) *Pros and Cons:* PCH solution for route optimization is somewhat similar to ORC as both require support from mobile routers and corresponding routers. But both of these solutions take different approaches to solve the nested route optimization problem and the way CR's are discovered. PCH does not require any changes to CN or MNN. All the route optimization is taken care of by HA and CR. PCH solution for nested route optimization seems simpler and more appropriate than ORC. PCH utilizes both signaling and header information for route optimization.

   One disadvantage with PCH seems to be that it is not clear how HA will decide to add PCH headers for the first packet and avoid adding PCH headers for future packets if there is no CR on the route to the CN. Parent mobile routers may become potential bottlenecks as they are responsible for performing operations on behalf of sub mobile routers. Another big issue is that PCH does not provide any kind of security procedures and there is no mechanism to authenticate different messages exchanged between entities belonging to possibly different administration domains e.g. between CR and MRs or CRs and HAs. PCH seems to be susceptible to CR deployment like ORC and also that it requires additional components like CRs to support its operations.

b) *Effects on handovers:* As PCH uses correspondent routers, the MR will have to update is current CoA with all the CR's after each handover. The amount of signaling required by PCH during handovers like ORC depends upon the number of CR's of the MR at any given time. PCH reduces the number of tunnels to 1 independent of the value of depth of nested hierarchy m.

$$\begin{aligned} PCH_{sig} &= NEMO_{sig} + LN_{MR}[n(BR_{CR} \\ &\quad + BU_{CR} + BA_{CR})] \\ PCH_{tun} &= 1 \end{aligned} \tag{3}$$

2.1.3 Prefix Delegation

There are many proposals in the literature for delegating prefixes [15] [16] [17] inside a mobile network for the purpose of route optimizations. Through the process of prefixes delegation the prefixes belonging to the access router of the foreign network are delegated to MR's and visiting mobile nodes. MR's and VMN's create topologically correct CoA's from the prefixes delegated to them and register their CoAs with their respective CNs and HAs through binding updates. The CN's can tunnel packets directly to the CoA of the MR or VMN by-passing the MR-HA and VMN-HA tunnels and achieve route optimization. A comparative study of different prefix delegation based route optimization has been done in [18] and [19]. The authors conclude that while the basic principle behind all techniques remains the same, they use different methods to perform prefix delegation and results in different performance matrices. In [20] the authors have provided cost analysis for different prefix delegation based route optimization schemes.

A variation of the prefix delegation mechanism called Extended Network Mobility has been proposed in [16]. In this scheme a MR obtains a prefix from the access router. The prefix advertised by the MR, can be used by MNNs to auto configure their CoAs. Apart from the functionality required in NEMO BSP [3], the MR is required to act as home agent and as an access router for MIPv6 enabled MNs. MIPv6 enabled mobile nodes do regional registration with MR and also setup route optimization by sending binding updates to CN. MR sends an aggregated BU to its own HA for efficient bandwidth usage. The MR on receiving any packets for the registered nodes will tunnel these packets to the registered CoA of the NEMO enabled nodes. This scheme allows both MR and MIPv6 enabled nodes to perform route optimization. MR can register its CoA with its HA as well as with CNs.

a) *Pros and Cons:* The idea of configuring sub mobile router with prefix delegation is simple and efficient. Prefix delegation can be simply done by extending RA messages. It gets rid of all NEMO suboptimal routing problems and no tunneling is required.

   A major disadvantage with all methods based on topologically correct address is that, if the parent MR moves to a different network sub MR will still have to change their CoA's despite the fact that they have not moved to another network. Prefix delegation compromises location privacy and also some methods for prefix delegation require special routers.

b) *Effects on Handovers:* Prefix delegation method for route optimization configures a topologically correct CoA's for nested routers. The parent MR will have to update its HA and in addition all the CN's. Moreover as discussed in disadvantages section that the movement of the parent MR does not remain transparent to the children MR's and they will also have to update their respective HA's and CN's even if they remain attached to the same MR, if the parent MR changes its point of attachment. The signaling overhead during handovers will increase as a function of number of CN's, frequency of handovers and number of levels of nesting and will always be greater than NEMO BSP.

$$\begin{aligned} PD_{sig} &= NEMO_{sig} + LN_{MR}[n(BU_{CN} + BA_{CN})] \\ PD_{tun} &= 0 \end{aligned} \tag{4}$$

2.2 Nested Tunnel Optimization

2.2.1 IPv6 Reverse Routing Header (RRH)

Reverse Routing Headers (RRH) [21] presents a route optimization mechanism based on a new IPv6 Reverse Routing Header (RRH). RRH targets the pin-ball outing problem only, which occurs due to nesting of mobile networks. RRH is based on a single telescopic tunnel between the nested MR and it's corresponding HA, which is secured by IPSEC Encapsulated Security Payload (ESP) tunnel. The Reverse Routing Header (RRH) is used to perform source routing between CNs and MNNs and contains the route of the nested mobile network which can be converted into a routing header. RRH mechanism modifies the MIPv6 [2] Routing Header (RH) type 2 and introduces two new RHs of type 3 and type 4.

The RH type 4 is defined as RRH and carries the multi-hop IPv6 addresses of all the MR's on its path, that the packet visits starting from source to the destination. Type 3 RH is an optimization replacement of type 4. RRH assumes that the nested mobile network has a tree topology. The root MR is called Top Level Mobile Router (TLMR). As we can see from Figure 5 that RRH mechanism omits all other tunnel that would have been implied by NEMO BSP protocol in such a nested mobile network. The first mobile router on the path from MNN to CN i.e. MR2 in Figure 5 in addition to tunnel the packet to its HA adds a routing header with N=1 (depth of the tree) pre-allocated slots. N is chosen by the Tree Information Option (RATIO) [22], by which an MR knows its current depth in the nested tree hierarchy given that attachment router conforms to tree discovery [21]. In this example, MR2 finds its current tree depth as 1 and so it assigns N=1. MR2 also adds its Home Address, MR2_HoA into slot 0. The reverse routing header inserted by MR2 and MR1 are shown in Figure 6a and 6b respectively.

The type 2 RH of MIPv6 standard is used to carry the home address for packets which are sent from a CN to an MNN and is restricted to carry only one IPv6 address. The type 2 RH of MIPv6 standard is extended in this mechanism to be multi-hop and is built from previous RRH. The packet from a HA of nested MR, containing an extended type 2 RH, is first routed to the TLMR with normal IP routing. The extended type 2 RH has additional semantics inherited from type 0 and contains the path information to traverse the nested Mobile Network from the TLMR to the tunnel endpoint. The extended type 2 RH for the situation depicted in Figure 5 is shown in Figure 6c.

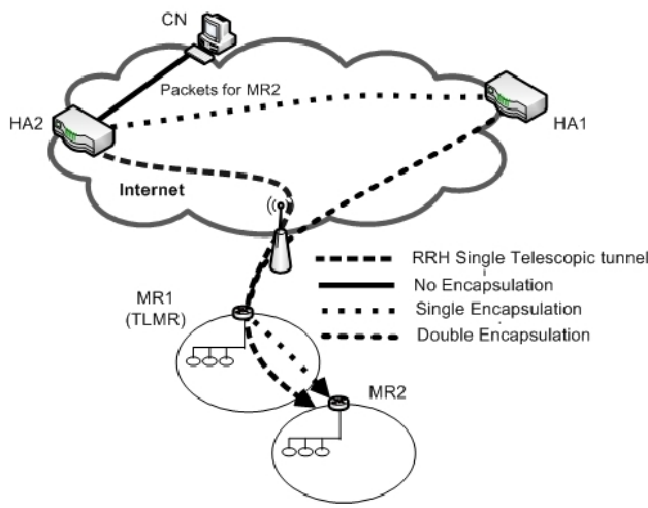

Figure 5: RRH Route Optimization Vs. NEMO BSP suboptimal routing.

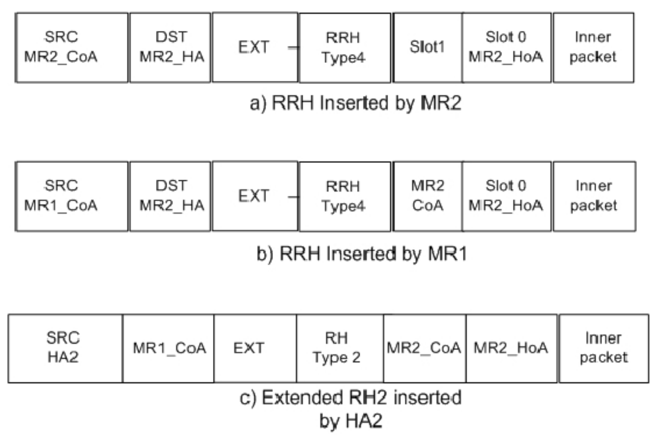

Figure 6: RRH Headers.

A similar approach to RRH has been proposed in [23] which presents a scheme called Regional Information-based Route Optimization (RIRO). All MR's within the RIRO domain sends extended RA's including TLMR's CoA. In RIRO all sub MR's and TLMR maintains a list of the downstream MR's CoA's in the tree and next-hop information in a data structure called Nested Routers List (NRL). When a MR up in the hierarchy receives a packet for a sub MR it can make use to NRL entry for that MR to route the packet to it. To avoid pinball routing RIRO uses a RIRO routing header of type 7 when packets are sent to HA and of type 8 when packets are sent to the CoA of TLMR from HA.

a) *Pros and Cons:* RRH presents an effective solution to pinball routing problem and is based on a single bidirectional tunnel irrespective of the number of MRs in the hierarchy. It does not require any additional routers with special capabilities. For security RRH employs the use of IPSEC Authentication Header (AH) for authentication of outer headers, especially RHs and ESP for confidentiality and authentication of inner packet. Binding information is sent only for the first time a packet is transmitted and as such it smartly overcomes the possibility of binding update storms. RRH leaves the end devices unchanged and leaves operations like binding updates to the MRs and HAs. Unlike the other mechanisms presented so far, RRH smartly distributes the processing burden to all the entities involved in the communication instead of leaving everything for the parent MR.

One security problem with RRH is that packets can be modified in transit by an attacker on their path. However spoofing attacks are also possible in other route optimization schemes. In this context whereby an attacker can spoof the RH type 2 source route options as it is multi-hop. An attacker can modify the RRH to redirect the response packets. The CoA addresses and RRH is not protected at all in transit. As a result, RRH fails to preserve the location privacy of the entities. Moreover, it reveals the actual position of an entity in the hierarchy, to the attacker. So, special care must be taken to secure the RRH in transit.

b) *Effects on Handovers:* As RRH targets only pinball routing problem and the packets still have to traverse at least one HA, its handover signaling overhead is equal to NEMO BSP in a non-nested scenario. In a nested scenario it is expected to have shorter handover delay than NEMO BSP as the update packets sent during handover will follow shorter route and will have to visit only one HA. When a MR moves and configures a new CoA it only has to update this information with its HA only. In this way RRH does not cause the update storm problem during handovers but packets suffer long delays as compared to PCH and ORC, due to indirect routing Via HA, as is the case with NEMO BSP. PCH reduces the number of tunnels to 1 independent of the value of depth of nesting hierarchy m.

$$\begin{aligned} RRH_{sig} &= NEMO_{sig} \\ RRH_{tun} &= 1 \end{aligned} \tag{5}$$

2.2.2 Access Router Option (ARO)

Access Router Option (ARO) [24] [25] is similar to RRH [21], because it only targets the nested tunnel problem and is based on a single tunnel between a nested MR and its HA irrespective of its depth in the nested hierarchy.

ARO requires that the Router Advertisements (RA) of root MR e.g. MR1 in Figure 7 is extended to include Router Global Address Option (RGAO) that advertises the home-address (HoA) of MR1. After MR2 configures a CoA, its BU message to HA2 in addition to the prefix information as detailed in [3], also contains an extension "Access Router Option" (ARO) which contains HoA of MR1 (ie Parent MR). HA2 records and uses the HoA of MR1, when sending back the Binding Acknowledgment (BA). HA2 make use of

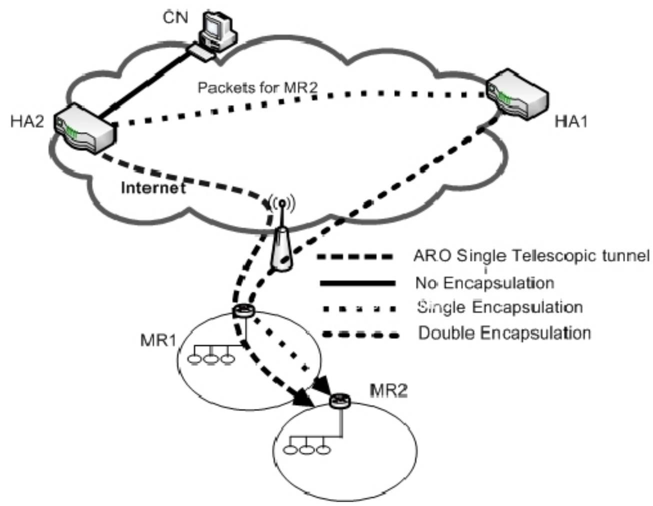

Figure 7: ARO Route Optimization Vs. NEMO BSP suboptimal routing.

the extended type 2 Routing Header (RH2) to forward the BA message to MR2 via the HoA of MR1. MR1 de-capsulates the BA message and it notices that there is an extended RH2. It proceeds to swap the destination address with the appropriate entry in the RH2 and forward it to MR2. From the processing of the extended RH2 MR1 may then send a BU to HA2. The Return Routability (RR) procedure specified in [2] must be carried out before sending the BU message. Once the binding update is successful, MR1 should add the host address of HA2 to a locally maintained Binding Update List (BUL). BUL contains a list of hosts that have an active binding cache entry of MR1's current CoA.

After receiving the BU message from MR1, the bi-directional tunnel between HA2 and MR2 need not go through the tunnel between HA1 and MR1. Instead tunneled packets from HA2 to MR2 can be sent directly to the CoA of MR1 with an attached extended RH2. For packets form MNN to CN they are received by MR2 and tunneled to HA2. The outer packet is appended with a mutable Router Alert Option (RAO) [25], in addition to the Home Address destination Option (HAO). Using RAO upstream ARO-enabled routers forward packet directly to the HA of sub MR directly than to tunnel them to their parent MR HAs first. In our example when MR1 receives a packet with RAO, it checks if it has a binding update with the specified destination. If so, it changes the source address to its CoA and sends the packet to the HA2, else the packet is forwarded using NEMO BSP [3]. For the latter case, MR1 might want to send a BU message to the destination (i.e. HA2) to setup route optimization.

Another approach Nested Path Information (NPI) proposed in [26] combines the routing concepts of RRH [21] and with security aspects from ARO [24] for NEMO route optimization. The proposed solution has been considered to preserve the efficiency of RRH without the lack of security. In this approach, MR uses Nested Path Information (NPI) to inform the optimized routing path of its HA. NPI is sent by Access Router (AR) in their RA messages to downstream mobile routers. Sub MRs deliver this information to their HA through BU. Unlike RRH, NPI cannot be modified or forged by the intermediate

ARs.

a) *Pros and Cons:* ARO like RRH makes NEMO route optimization possible by introducing extensions to existing messages (i.e. RA, BU, RH2) and do not require any additional components in the network. A strong aspect of ARO is that it makes use of the MIPv6 [2] return routability procedure for security.

   A disadvantage with ARO is that, for ARO to work HA, sub MR and parent MR must be ARO enabled. At its best ARO will always operate with minimum one tunnel.

b) *Effects on Handovers:* As ARO like RRH only targets the pin ball routing problem but takes a different approach to solve it, ARO mechanism have the same effect on handover signaling as RRH. ARO reduces the number of tunnels to 1 independent of the value of depth of nesting hierarchy m. ARO has to execute the RR procedure and exchange BU, BA packets with the HA of each nested MR which will add to its signaling cost. The number of CR's with which the MR must exchange in this case will be equal to the depth of nested hierarachy m.

$$\begin{aligned} ARO_{sig} &= NEMO_{sig} + LN_{MR}[m(BU_{CR} \\ &\quad + BA_{CR} + RR_{sig})] \\ ARO_{tun} &= 1 \end{aligned} \tag{6}$$

Where BU_{CR} and BA_{CR} represents the binding update and binding acknowledge messages exchanged with HA of a nested MR is treated as a CR in this case.

2.2.3 Hierarchical Mobile IP (HMIP)

Hierarchical Mobile IP (HMIP) [27] is a route optimization technique for NEMO based on HMIPv6 [28]. HMIP can be used to provide route optimization for two cases. First when MIPv6 enabled MN's visit a mobile network. Second to enable route optimization for local fixed MN's in the mobile network which are not MIP enabled. Here we will discuss only the latter case as it corresponds to NEMO operations more closely. HMIP makes use of Mobility Access Point (MAP) which works like a local home agent. A visiting MR has two CoA's. Regional CoA (RCoA) identifies the MAP that the MR is currently attached to and a Local CoA (LCoA) which identifies current attachment point of the MR. The MAP advertises its address on its subnet in an extended RA. A visiting MR uses these RA's to binds its LCoA, RCoA and the list of MNP's. MR then sends a binding update (BU) message containing this binding information, to the MAP. When the MR detects an initial packet transfer to the Local Fixed Node (LFN), it first executes the return routability (RR) procedure. If the test is successful, it sends the BU to the CN on behalf of the LFN. This BU contains LFN address as the HoA and RCoA of the MR as the current attachment point. The CN tunnels the packets to the MAP using RCOA address by using IP within IP tunnel. The MAP then forwards the packets to the MR LCoA using IP within IP tunnel.

In [29] the authors propose a variant of Hierarchical Mobile IPv6 NEMO route optimization. The basic procedure for route optimization of HMIP remains the same. Their proposal optimizes both BU traffic and tunneling overhead by making use of an adaptive binding update strategy depending on the session to mobility ratio (SMR).

Another approach called hierarchical mobile network binding (HMNB) for route optimization has been presented in [30] which uses asymmetric tunneling and a hierarchical local binding mechanism. Data from an MNN in a visiting mobile network can sent directly to the CN with normal routing without tunneling. But for traffic to the mobile network, a tunnel from the HA to the MR is required. Therefore it is said to use an asymmetric tunneling technique. In the HMNB scheme, a hierarchical local binding scheme is employed between the HA of the nested mobile network and the root-MR in order to reduce the signaling overhead of the nested mobile network. The root-MR can only de-capsulate the packets from the CN.

a) *Pros and Cons:* HMIP provides an efficient way of reducing global signaling and thus is expected to result in shorter hand off delays. Moreover using the already existing HMIP ideas with NEMO is not very demanding if the infrastructure of HMIP already exists. It also supports route optimization for LFN's which does not support HMIPv6. It requires the MR to function as a proxy for LFN's.

   First disadvantage with HMIP is that requires a new component in the network in the form of a MAP. HMIP does not eliminate completely the multi-level encapsulation problem and some tunnels must be maintained for its operations. Also packets don't follow the most optimized route possible at all times.

b) *Effects on Handovers:* As the purpose of introducing HMIP was to reduce global signaling during handovers using MIP. The amount of signaling required during handovers with HMIP depends upon the scope of MN's movement. If the MR performs an intra-MAP handover it is only required to do a local binding update with its current MAP and no updates messages are needed to be sent to HA and CNs'. In this case the HMIP will perform better than NEMO BSP as the scope of signaling is limited to a local MAP. On the other hand if the MR has to perform an inter MAP handover then it will have to register with its new MAP, update HA and all the CN's. In this case the signaling over head of HMIP will be more than NEMO BSP. The degree to which nested tunnels are avoided depends MIPv6 capability of the components involved e.g. if CN is MIPv6 enabled it can send packets directly to the current MAP of the MR without tunneling, if not then packets will reach MR HA which will tunnel them to the current MAP of the MR. Minimum one tunnel is in place at all times.

   Intra-MAP Handover :

$$\begin{aligned} HMIP_{sig} &= LN_{MR}[BU_{MAP} + BA_{MAP}] \\ HMIP_{tun} &= 1 \end{aligned} \tag{7}$$

Inter-MAPHandover :

$$HMIP_{sig} = IntraMAP_{HMIP_{sig}} + NEMO_{sig} + LN_{MR}[n(BU_{CN} + BA_{CN} + RR_{sig})] \quad (8)$$
$$HMIP_{tun} = 2or1$$

2.3 MR-to-CN

2.3.1 Mobile IPV6 Route Optimization for NEMO (MIRON)

MIRON [31] [32] presents a simple NEMO route optimization solution based on the MIPv6 [2] route optimization technique and belongs to the MR-to-CN optimization category [8]. In MIRON the MR perform all the MIPv6 route optimization operations on behalf of MNNs that are carried out by MIPv6 enabled mobile nodes in the MIPv6 route optimization scheme. MR also needs to perform encapsulation and de-capsulation of packets and thus network mobility remains transparent to MNNs. MIRON requires the CN to be MIPv6 enabled. MIRON introduces a new data structure called Binding Update List (BUL) which stores information regarding all the MNN-CN associations for route optimization. MR away from home notices that it is receiving packets from CN via the HA. This triggers the MR to start the route optimization procedure. First MR performs Return Routability (RR) procedures for LFN and CN pair. This is done by sending proper HoT, CoT, HoTI and CoTI messages to the CN as defined in [2].

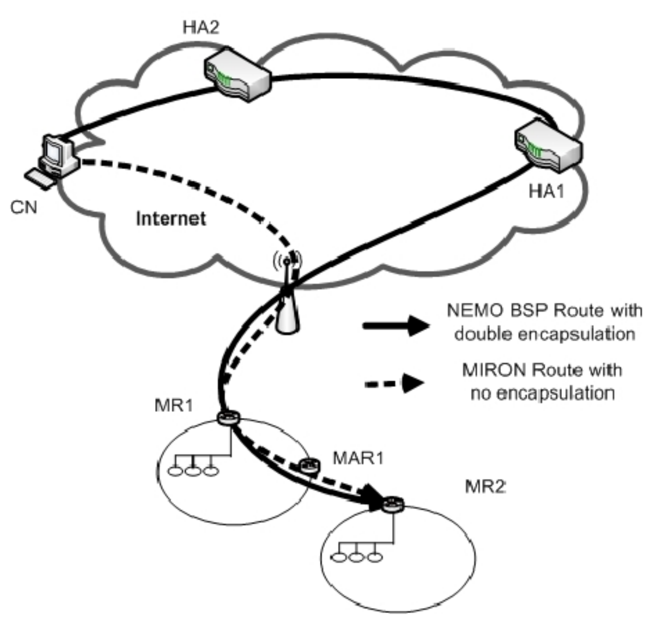

Figure 8: MIRON Route Optimization Vs. NEMO BSP suboptimal routing.

Once the RR procedure is completed, the MR is able to send a BU message to the CN on behalf of the LFN. This completes the route optimization procedure and the Packets from the CN follow an optimized route as shown in Figure 8. Packets from CN are sent to the MRs CoA, carrying a type 2 Routing Header with Next Hop set to the LFNs address. The MR processes the packet by removing the Routing Header, recalculating packet checksums if needed and then forward them to MNN. For the packets from MNN to the CN the MR router uses the BUL entries and tunnel packets directly to the CN without going through home agent. The CN is supposed to de-capsulate the packets by its own.

For nested mobility route optimization MIRON configures an IP address for the sub MR which is topologically correct as its CoA [32]. This requires that, every MR (parent or child) within NEMO is configured by address delegation. Moreover, some routing capability is also needed in order to enable the routing of packets to these delegated addresses inside the nested NEMO.

MIRON also requires a MIRON Access Router (MAR) MAR1 in Figure 8, which implements some operations required by MIRON solution (e.g. modified DHCPv6 [33] relaying function). MR2 attaches to MR1, through MAR1, initially MR2 configures an IPv6 address from MR1, and then requests a topologically correct IPv6 address using DHCPv6 [33]. Next MAR1, acting as a DHCPv6 relay, forwards the request to MR1. MR1 requests an IPv6 address in the foreign network and then delegates this address to MR2 using the DHCPv6 relay router MAR1, MAR1 when receiving the delegated address, first adds a host route to the delegated address in its routing table. Once this process is completed, MR2 has a topologically meaningful IPv6 address that will be used as MR2's CoA by the MIRON mechanism. A packet destined to MR2's CoA first arrives to the foreign link without tunneling, where MR1 is defending this address. After getting this packet, MR1 looks up the routing table and uses the learned host route to forward the packet to the MAR1, which finally delivers it to the destination MR2.

A more recent proposal somewhat similar to MIRON is NERON (Nested Route Optimization in NEMO) [34] [35]. NERON also configures a correct topological address but use different mechanism for configuration of such an IP address. It uses the Neighbor Discovery Protocol [36] and avoid address delegation mechanism of MIRON. NIRON extends the MIPv6 [2] operations for route optimization for its own use. The authors in [34] have shown that NERON has better round trip delay for packets than MIRON and NEMO BSP. NERON allow all sub routers in the hierarchy to compute its own depth and know the address of the egress interface of the root MR. This information is stored in the Nest Gate Table (NGT) by all sub routers. It also proposes to extend the binding cache of CN to store the Nest Gate field to store the CoA of the root mobile router. For routing packets from CN to MR, NERON defines a new routing header called type 3 routing header and thus avoids tunneling.

a) *Pros and Cons:* MIRON and NERON propose one of the simplest methods for RO in NEMO. It applies the basic MIPv6 RO techniques NEMO route optimizations and no additional components like correspondent routers are required. No change is necessary for the MNNs to establish RO and MR carries the burden of performing all the operations to establish RO on behalf of the MNN. No tunneling is done so the packet size remains the same.

The first disadvantage with MIRON and NERON is that a mobile network is expected to serve many MNNs which will be communicating with a large number of CNs. Therefore performing MIPv6 operations like binding updates and return routability procedures will result in binding update storms and excess overhead. In MIRON and NERON MR has to maintain the state of all the optimized routes for all the MNN-CN pairs attached to the mobile network and may suffer from scalability problems. Lastly, as MR is performing the binding updates for MNN, it can be a victim to man in the middle attack if MNN is attached to a fake MR. Although such attacks can be a problem for other RO solutions as well.

b) *Effects on Handovers:* MIRON and all other route optimization techniques belonging to MR-CN route optimization category might suffer from binding updates storm problem during handovers. The MR will have to send binding updates to all the CN's of the MNN's served by the MR, to inform them of its current CoA after handover apart from its HA. Therefore it will have always more signaling to do than NEMO BSP which requires only updating HA but off course does not support route optimization. MIRON signaling overhead during handovers might be more than route optimization techniques based on corresponding routers as a MR is expected to have substantially more CN's to update than CR's after a handover. While NEMO is supposed to run on mobile routers on board vehicles moving at high speed where handovers will occur quite frequently, MIRON signaling overhead to update all the CN's might be too much for the network to support. Also as MIRON supports return routability procedure for security which requires messages like (HoT, HoTi) and (CoT, CoTi) to be exchanged between MR and CN's and will need extra signaling. Also the execution of return routability procedure will add to the handover delay for MIRON. MIRON reduces the number of nested tunnels to 0 independent of the value of the depth of nested hierarchy of mobile networks m

$$\begin{aligned} MIRON_{sig} &= NEMO_{sig} + LN_{MR}[n(BU_{CN} \\ &\quad + BA_{CN} + RR_{sig})] \\ MIRON_{tun} &= 0 \end{aligned} \tag{9}$$

2.4 Intradomain Route Optimization

2.4.1 Adhoc Routing for NEMO Route Optimization

NEMO BSP [3] does not allow multi hop communications. A great deal of work has been done to integrate adhoc networking with NEMO to form Vehicle adhoc networks (VANETS). Such an integration can also serve as a NEMO route optimization technique as well [37]. The basic principle behind such integrations is to use MANET routing protocols for optimized data delivery inside the mobile network, while NEMO is used to maintain global Internet connectivity [38]. Such and integration allows MRs to reach the Internet using either direct or indirect links and also optimize NEMO routing [39]. Authors in [39] have concluded form their experimentation results that using NEMO in combination with OLSR, which is an adhoc routing protocol can help eliminate NEMO sub optimal routing problems. The route optimization requirements for vehicles have been discussed in [39] and for aeronautics in [40].

VARON [41] provides a secured NEMO route optimization using MANET. At the heart of VARON is a MR that is responsible for setting up route optimization. With VARON a MR has to first discover reachable Mobile Network Prefixes (MNP's) though a VANET routing protocol. This is achieved by requiring each MR to advertise the MNP's that are reachable through it. If the MR concludes through router advertisements, that a peer reachable through NEMO BSP is also reachable via an adhoc route, then the MR can setup a secured adhoc route to the host. The MR can thus forward packets for the target mobile network via adhoc routing without tunneling rather than using NEMO BSP. Another approach for combining NEMO and MANET called MANEMO has been presented in [42]. MANEMO solutions are either NEMO centric or MANET centric [43]. Using adhoc routing for NEMO route optimization is a NEMO centric solution.

GEONET [38] is an ITS project which aims at the specification of combining MIPv6 /NEMO with adhoc geo networking protocols specified in a Car-to-Car communication Consortium (C2C) [44]. C2C protocol stack supports geo addressing and geo routing for inter vehicles communication. GEONET extends the geo networking capabilities of C2C with MIPv6/NEMO to connect to the Internet. GEONET has already been successfully completed.

a) *Pros and Cons:* Merging MANETS and NEMO are beneficial for both types of networks. In case of NEMO introduction of MANET routing increases coverage and improves local routing.

   Using MANETS routing protocols with NEMO requires an additional adhoc interface for each mobile router. Adhoc links can only be used to improve intra domain routing and offers no solution for inter domain NEMO suboptimal routing.

b) *Effects on Handovers:* Adhoc routing has no effect on the amount of signaling that needs to be done during an inter domain route optimization and for intra domain route optimization the overhead is the same as the overhead of the adhoc routing protocol.

   Inter-domain

$$\begin{aligned} AdhocOpt_{sig} &= NEMO_{sig} \\ AdhocOpt_{tun} &= m \end{aligned} \tag{10}$$

   Intra-domain

$$\begin{aligned} AdhocOpt_{sig} &= adhocprotocol_{sig} \\ AdhocOpt_{tun} &= 0 \end{aligned} \tag{11}$$

Table 2: Summary

Criteria	Protocols							
	ORC	PCH	PD	RRH	ARO	HMIP	MIRON	Adhoc
Security	Equal to MIPv6	Weak	AAA Server	Weak than MIPv6	Equal to MIPv6	Equal to HMIP	Equal to MIPv6	Adhoc protocol
Problem Addressed (Indirect /Pin-ball)	Both	Both	Both	Pin-ball	Pin-ball	Both	Both	Pin-ball
RO Type (Inter/Intra)	Both	Inter	Inter	Inter	Inter	Both	Both	Intra
Required New Components /Changes	ORC	CR, Changes to MR	Changes to MR	Changes to MR & HA	Changes to MR, HA	MAP, Changes to MR	MAR, Changes to MR	Changes to MR
Min Tunnels(m)	1	1	0	1	1	2 or 1	0	m or 0
Scalability	V.Good	V.Good	Limited	Limited	Limited	Limited	Limited	Limited
Components to Update	CR, HA	CR HA	CN's, HA	HA	HA	CN'S, MAP,HA	CN's, HA	HA
Deployment	Difficult	Difficult	Difficult/ Easy[1]	Easy	Easy	Easy	Easy	Easy
Location Transparency	Yes	Yes	No	Yes	Yes	No	No	No
Signaling	Moderate	Low	High	Moderate	Low	High	High	low/ Adhoc Protocol
Degree of RO	Near-Max	Near-Max	Max	Moderate	Moderate	Moderate	Max	Max

3 Conclusions

The problem of NEMO suboptimal routing has been around for a long time and a large number of solutions have been proposed. All these solutions consider a particular scenario, providing advantages in certain aspects but there is so far no unified solution that applies to all situations. Some approaches based their solution on deploying some special components in the network (e.g. special routers) alongside extensions to basic mechanisms for MIPv6/NEMO for route optimization. Some approaches propose to extend existing knowledge from MIPv6/HMIP for route optimization, while others are based on configuring topologically correct addresses through prefix delegation to solve the prob-

[1]Some PD schemes are easy to deploy while others require special routers and are difficult to deploy.

lem. Some only targets nested NEMO (Pin-Ball routing) route optimization while others target both nested and un-nested scenarios. While a nested scenario may not be very a common situation, it is still a possibility (e.g. in rescue operations) and ideally a route optimization protocol should be able to solve both nested and non-nested route optimization problems. A large number of proposals also exist on how to combine MANET with NEMO for optimized routing.

A critical decision is to decide which entities are to be involved in the RO process. NEMO route optimization is multi-dimensional problem and all proposed solutions have their own tradeoffs. For example maximum end to end route optimization can be achieved if all the RO procedures are to be carried out by the end entities like MN's, MR's and CN's. However solutions involving end devices for RO, compromises location transparency, put more signaling burden on the network and are less scalable. Similarly solutions based on adding new components like correspondent routers to the network, maintain location transparency, put comparatively less signaling burden on the network and are more scalable, but they cannot achieve end to end maximum route optimization and end to end average packet delays might be higher. Also such schemes will not only incur additional costs by requiring additional new components in the network but will also add additional complexity to the network as additional procedures to discover such components and to decide on an optimal choice, are required.

Security is also a major concern for all RO solutions. For NEMO BSP, it's fair to assume that the MR and HA have a trust relationship in place before hand, since they belong to the same administration domain. Such an assumption is not valid for proposed RO solutions. Because almost all route optimization schemes will involve interaction between network components or mobility agents belonging to different administration domains which might not have adequate trust relationships in place. Also new security procedures need to be efficient, more secure and compatible with existing network protocols. Handover efficiency is also a critical aspect of RO solutions. With mobile networks handovers are expected to happen pretty often because mobile networks are expected to be aboard highly mobile cars, trains, planes etc. RO schemes depending on updating a large number of network components are able to obtain better degree of RO. But on the other hand require too much signaling during handovers and therefore might give rise to binding update storms. RO solutions based on Adhoc networks although eliminate all nested tunnels but they are only applicable to do so for intra domain communications. If the CN is residing in another IP domain outside the reach of Adhoc routing protocol, the problem of multiple encapsulation and indirect routing cannot be avoided. Moreover they also violate location transparency. The signaling cost of these solutions will depend upon the signaling cost of Adhoc routing protocol used for route distribution and route updates.

The main reason which makes route optimization in NEMO such a challenging task is that a moving network at vehicular speed presents a very dynamic environment. This requires very tight constraints to be met in terms of latency, overhead, efficiency and security. Procedures which may be potentially improved include Network Discovery, CoA configuration, Security, Tunneling overhead and Routing.

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Part III

Appendices

Appendix A

Pros and Cons of Route Optimization Schemes For Network Mobility (NEMO) and their Effects on Handovers

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Abstract

No one can deny the importance of mobility in modern communication networks and Internet is no exception. IETF has introduced the *Network Mobility (NEMO)* protocol to support a moving network. NEMO solves many problems of *Mobile IP (MIP)* to support a moving group of users, but introduces some problems of its own like suboptimal routing and multiple levels of encapsulation. These problems occur because the *NEMO basic support protocol (NEMO BSP)* does not support route optimization and because of nested mobile networks. Many solutions have been proposed in the literature to solve these problems. In this article we present a comprehensive survey of those solutions and will discuss their advantages and disadvantages. We also outline the effect of these solutions on handovers and a summary is provided in the form of a table at the end.

1 Introduction

IETF has introduced Network Mobility (NEMO) protocol [1] to support the movement of a moving network. NEMO requires a mobile network router called Mobile Router (MR). The protocol is an extension of Mobile IPv6 [2] and provides session continuity for every node in the mobile network as the network moves. Network mobility is transparent to the nodes inside the mobile network. MR takes over the role of Mobile Node (MN) [2] in performing mobility functions. The IP devices hosted in such a mobile network are called Mobile Network Nodes (MNN's). NEMO Basic Support Protocol (BSP) [1] requires that all packets to and from the mobile network must pass through a bidirectional tunnel between MR and a corresponding Home Agent (HA) even if a more direct path exists between the MR and correspondent nodes (CN's). This problem gets amplified when another mobile network joins the mobile network [3]. Because the packets now have to traverse multiple home agents and several levels of encapsulation will be enforced (called "the Pin-ball Routing problem"). This results in high overhead, larger packet size and suboptimal routing as shown in Figure 1. Packets from MR2 to CN follow the same suboptimal route in the reverse direction.

Inefficiencies occurs if two nodes (a MNN and its CN) having different HA's are both present in the same NEMO domain but exchange packets via their respective HA's. This obviously will give longer than necessary routes and delays as discussed in detail in reference [3]. Using NEMO BSP, the pinball routing problem will become more severe with an increase in levels of nesting for mobile networks as the number of tunnels increases. Introducing route optimization techniques to NEMO may solve these problems [4]. Although introducing a route optimization technique to NEMO BSP can be beneficial, it always comes with a price like additional signaling, increased complexity, additional network components and increased processing overhead [4] that needs to be taken into account. In Section 2 of this paper we discuss pros and cons of some of the most important proposed solutions for NEMO route optimization and their effect on handovers. In Section 3 we present conclusions and future research directions.

We analyze the different proposed solutions with respect to the minimum number of binding update messages sent during a handover and the degree of reduction of multi-level encapsulation or tunneling. The analysis is for one mobile network served by a one or more MR's and for one or more handovers. The symbols BU, BA, m, N_{MR}, L are used to represent Binding Update, Binding Acknowledgment, depth of nested hierarchy, Number of mobile routers and Number of handovers respectively. To identify the entity and protocol they apply to, we use the subscript of these variables. The following equations are used as the basis for our analysis while Figure 1 serves as a reference figure.

$$\begin{aligned} NEMO_{sig} &= LN_{MR}[BU_{HA} + BA_{HA}] \\ NEMO_{tun} &= m \end{aligned} \tag{1}$$

2 Proposed Solutions

As discussed earlier that a large number of proposals exits for NEMO route optimizations. Some proposals are based on merging other proposals for the purpose of NEMO route optimization. This makes the categorization a difficult job. However [5] have arranged them in five broad categories. Following this categorization, the categorization of protocols discussed in this article is given in Table 1.

Table 1: Protocols and their IETF Categorization [5]

Protocol	IETF Category
ORC	Infrastructure Based
PCH	Infrastructure Based
PD	Infrastructure Based
RRH	Nested Tunnel Optimization
ARO	Nested Tunnel Optimization
HMIP	Nested Tunnel Optimization
MIRON	MR-to-CN
Adhoc	Intradomain Route Optimization

2.1 Infrastructure Optimizations

2.1.1 Optimized Route Cache Management Protocol for Network Mobility (ORC)

ORC [6] [7] requires a new entity called ORC router. ORC routers work as an anchor router of a mobile network and maintains fresh routes to the current point of attachment of a MR. A route is an association of the mobile prefix served by MR and its current care of address (CoA) called binding route (BR). BR is updated each time by a MR when it moves to a different subnet by sending BR update messages to ORC routers. BR update messages are similar to MIPv6 [2] binding update messages. The ORC routers intercept packets for all mobile routers for which it has a BR and tunnels them to the current CoA of the mobile network. For this purpose the ORC router advertises proxy routes to the prefixes served by the MR using an Interior Gateway Protocol (IGP). Although ORC routers can be placed anywhere in the Internet, its effect for route optimization is more significant if they are placed where the CN might reside [8].

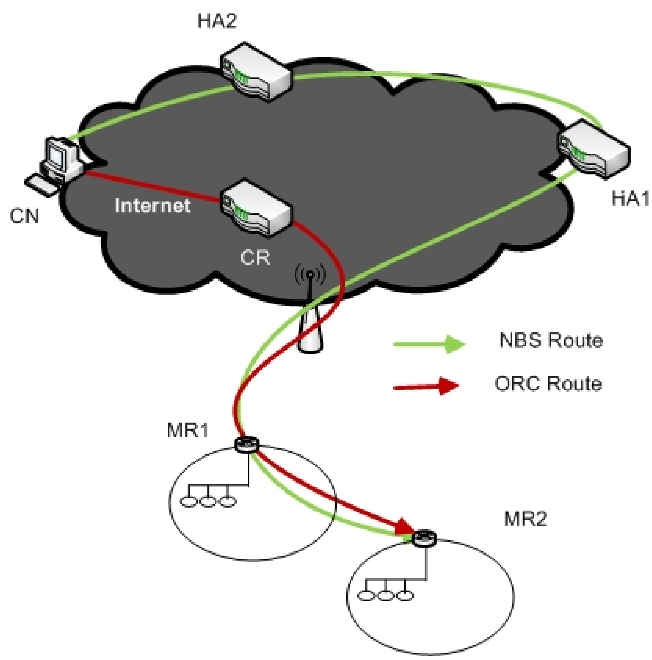

Figure 1: ORC Route Optimization Vs. NEMO BSP suboptimal routing.

For sub optimal routing due to nesting ORC proposes that the child MR configures an IP address by address auto-configuration [8]. The child MR then sends its BR information to the parent MR. Receiving the child MR's BR, parent MR is assumed to send its own BR to the ORC routers of sub MR's. If ORC routers possess BR of both child MR and parent MR, they encapsulate packets with MR-CoA according to a new recursive BR search mechanism [7]. The parent mobile router de-capsulate these packets and send them to the child mobile router.

a) *Pros and Cons:* ORC provides a route optimization solution that is motivated by scalability, security, quickness, location privacy and network transparency. It tries to follow the mechanisms and procedures of route optimization of MIPv6 [2] for compatibility and simplicity reasons. For security it extends the return routeability procedures of MIPv6 to register mobile network prefix information. The authors have shown in [7] that ORC achieves route optimization and compared to other route optimization protocols ORC is more efficient and scalable.

One of the disadvantages of ORC is that it requires new components in the form of CR's. Few or misplaced ORC routers sacrifices maximum route optimization possible with ORC and too many ORC routers results in excess overhead [7]. If multiple ORC routers are available, the ORC protocol has no mechanism to find an optimum choice. The ORC signaling overhead is expected to increase with the increase in number of CR's, number and frequency of handovers of the mobile networks. ORC routers do not cover all security aspects.

b) *Effects on handovers:* Using ORC, a MR during handovers will have to update its new CoA with its HA and all the CR's. The volume of these update messages might be enormous depending upon the number of CR's. In a worst case a MR might be serving many MNNs and each MNN might have multiple CNs scattered across different administration domains on the Internet and therefore the MR will have to keep its BR updated on all CR's. In a best case scenario for ORC if a MR is communicating with corresponding nodes all residing on a single administration domain served by a single CR (same IGP domain), the amount of signaling done by the MR will still be more than double then that of NEMO BSP. ORC reduces the number of tunnels to 1 independent of the value of m which represents the depth of nested hierarchy of mobile networks. Return routeability procedures will add to handover delays.

$$\begin{aligned} RR_{sig} &= HoT + CoT + HoTI + CoTI \\ ORC_{sig} &= NEMO_{sig} + LN_{MR}[n(BU_{CR} + BA_{CR}) \\ &\quad + RR_{sig} + ORC_{disc}] \\ ORC_{tun} &= 1 \end{aligned} \tag{2}$$

Where n is the number of corresponding routers, ORC_{disc} stands for ORC discovery signaling and RR stands for return routeability procedure [2].

2.1.2 Path Control Headers (PCH)

In PCH [9] the HA piggybacks path control header information (PCH) to a packet that is reversely forwarded by the MR for the CN to HA. The PCH is a hop by hop option header and therefore can be processed by intermediate routers capable of handling PCH messages called correspondent router (CR). A PCH header for the nested network configuration depicted in Figure 1 is shown in Figure 2. Upon receiving a packet with a PCH header, a CR on the path to from HA to CN, can make use of information in the packet such as CoA of MR to establish a Route Optimization Tunnel (ROT) with MR.

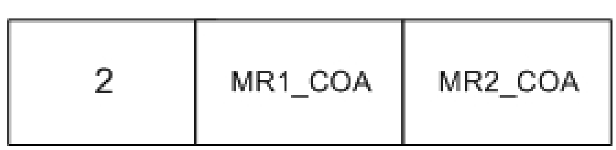

Figure 2: Example of PCH Header.

For nested route optimization (NROT), PCH introduces a source routing concept. CR makes use of IPV6 routing header type 0 (RH0). CR gets to know the existence of nested tunnels through PCH information (MR1s CoA and MR2s CoA) and then initiate the signaling for NROT to MR2 via nested tunnels. At this time, Binding Request (BR) message contains Nested Routing Path Option (NRP Option). NRP Option is used to inform MR2 of the nested path information.

a) *Pros and Cons:* PCH is somewhat similar to ORC, but PCH takes a different approach to solve the nested route optimization problem and the way CR's are discovered. PCH does not require any changes to CN or MNN. All the route optimization is taken care of by HA and CR. PCH solution for nested route optimization seems more simple and appropriate than ORC. PCH utilizes both signaling and header information for route optimization.

   One disadvantage with PCH seems to be that it is not clear how HA will decide to add PCH headers for the first packet and avoid adding for future packets if there is no CR on the route to the CN. Parent mobile routers may become potential bottlenecks as they are responsible for performing operations on behalf of sub mobile routers. Another big issue is that PCH does not provide any mechanisms to authenticate different messages exchanged between entities belonging to possibly different administration domains e.g. between CR's-MRs and CR's-HA's. PCH seems to be susceptible to CR deployment like OCR and also requires additional components like CR's.

b) *Effects on handovers:* As PCH uses correspondent routers, the MR will have to update is current CoA with all the CR's after each handover. The amount of signaling required by PCH during handovers like ORC depends upon the number of CR's of the MR at any given time. PCH reduces the number of tunnels to 1 independent of the value of depth of nested hierarchy m.

$$\begin{aligned} PCH_{sig} &= NEMO_{sig} + LN_{MR}[n(BR_{CR} + BU_{CR} \\ &\quad + BA_{CR})] \\ PCH_{tun} &= 1 \end{aligned} \tag{3}$$

2.1.3 Prefix Delegation

There are many proposals for delegating prefixes [10] [11] [12] inside a mobile network for the purpose of route optimizations. Through the process of prefixes delegation the prefixes belonging to the access router of the foreign network are delegated to MR's and visiting mobile nodes. MR's and CN's create topologically correct CoA's from the prefixes delegated to them. The CN's can tunnel packets directly to the CoA of the MR or VMN by passing the MR-HA and VMN-HA tunnels and achieve route optimization. A comparative study of different prefix delegation based route optimization has been done in [13] [14]. The authors conclude that while the basic principle behind all techniques remains the same, they use different methods to perform prefix delegation and results in different performance matrices. In [15] the authors have provided cost analysis for different prefix delegation based route optimization schemes.

a) *Pros and Cons:* Prefix delegation is an efficient mechanism and can be simply done by extending RA messages. It gets rid of all NEMO suboptimal routing problems and no tunneling is required.

   A major disadvantage with all methods based on topologically correct address is that, if the parent MR moves to a different network sub MR will still have to change their CoA's despite the fact that they have not moved to another network. Prefix delegation compromises location privacy and also some methods for prefix delegation requires special routers.

b) *Effects on Handovers:* With PD the MR will have to update its HA and in addition all the CN's during a handover. As the movement of the parent MR does not remain transparent to the children MR's and they will also have to update their respective HA's and CN's even if they remain attached to the same parent MR if the parent MR changes its point of attachment. The signaling overhead during handovers will increase as a function of number of CN's, frequency of handovers and number of levels of nesting and will always be greater than NEMO BSP.

$$\begin{aligned} &PD_{sig} = NEMO_{sig} + LN_{MR}[n(BU_{CN} + BA_{CN})] \\ &PD_{tun} = 0 \end{aligned} \tag{4}$$

2.2 Nested Tunnel Optimization

2.2.1 IPV6 Reverse Routing Header (RRH)

Reverse Routing Headers (RRH) [16] is based on a single telescopic tunnel between the parent MR and it's corresponding HA, which is secured by IPSEC ESP tunnel. RRH targets the pin-ball routing problem only. The Reverse Routing Header (RRH) is used to perform source routing between CNs and MNNs and contains the route of the nested mobile network which can be converted into a routing header. RRH mechanism modifies the MIPv6 [2] RH type 2 and introduces two new RHs of type 3 and type 4. The type 2 RH of MIPv6 standard is extended in this mechanism to be multi-hop. The RH type 4 is defined as RRH here, which carries the multi-hop IPv6 addresses of all the entities that the packet will visit starting from source header to the destination address. RRH assumes that the nested mobile network has a tree topology. The root MR is called Top Level Mobile Router (TLMR).

a) *Pros and Cons:* RRH is based on a single bidirectional tunnel irrespective of the number of MRs in the hierarchy. It does not require any additional routers with special capabilities. For security RRH employs the use of IPSEC Authentication Header (AH) for authentication of outer headers, especially for RHs and Encapsulated Security Payload (ESP) for confidentiality and authentication of inner packet. Binding information is sent only for the first time a packet is transmitted and as such it smartly overcomes the possibility of binding update storms. RRH leaves the end devices unchanged and leaves operations like binding updates to the MRs and HAs. Unlike the other mechanisms presented so far, RRH smartly distributes the processing burden to all the entities involved in the communication instead of leaving every thing for the parent MR.

One security problem with RRH is that packets can be modified in transit by an attacker on their path. However spoofing attacks are also possible in other route optimization schemes. In this context whereby an attacker can spoof the RH type 2 source route options as it is multi-hop. An attacker can modify the RRH to redirect the response packets. The CoA addresses and RRH is not protected at all in transit. As a result, RRH fails to preserve the location privacy of the entities.

b) *Effects on Handovers:* As RRH targets only pinball routing problem and the packets will still have to traverse at least one HA, its handover signaling overhead is equal to NEMO BSP in a non nested scenario. In a nested scenario it is expected to have shorter handover delay than NEMO BSP as the update packets sent during handover will follow shorter route. RRH does not cause the update storm problem during handovers but packets might suffer long delays as compared to PCH and ORC, due to indirect routing. RRH reduces the number of tunnels to 1 independent of the value of depth of nesting hierarchy m.

$$\begin{aligned} RRH_{sig} &= NEMO_{sig} \\ RRH_{tun} &= 1 \end{aligned} \tag{5}$$

2.2.2 Access Router Option (ARO)

ARO [17] requires that the Router Advertisements (RA) of root MR e.g. MR1 in Figure 1 is extended to include Router Global Address Option (RGAO) that advertises the home-address (HoA) of MR1. After MR2 configures a CoA, its BU message to HA2 in addition to the prefix information as detailed in [1], also contains an extension "Access Router Option" (ARO) which contains HoA of MR1 (ie Parent MR). HA2 records and uses the HoA of MR1, when sending back the Binding Acknowledgment (BA). HA2 make use of the extended Type 2 Routing Header (RH2) to forward the BA message to MR2 via the HoA of MR1. MR1 decapsulates the BA message and it notices that there is an extended RH2. It proceeds to swap the destination address with the appropriate entry in the RH2 and forward it to MR2. From the processing of the extended RH2 MR1 may then send a BU to HA2. The Return Routeability (RR) procedure specified in [2] must be carried out before sending the BU message. Once the binding update is successful, MR1 should add the host address of HA2 to a locally maintained Binding Update List (BUL). BUL contains a list of hosts that have an active binding cache entry of MR1's current CoA.

a) *Pros and Cons:* ARO like RRH makes NEMO route optimization possible by introducing extensions to existing messages (i.e. RA, BU, RH2) and do not require any additional components in the network. Also ARO makes use of the MIPv6 [2] return routeability procedure for security.

A disadvantage with ARO is that For ARO to work HA, sub MR and parent MR must be ARO enabled. At its best ARO will always operate with minimum one tunnel.

b) *Effects on Handovers:* ARO mechanism have the same effect on handover signaling as RRH. ARO reduces the number of tunnels to 1 independent of the value of depth of nesting hierarchy m.

$$\begin{aligned} ARO_{sig} &= NEMO_{sig} + LN_{MR}[RR_{sig}] \\ ARO_{tun} &= 1 \end{aligned} \tag{6}$$

2.2.3 Hierarchical Mobile IP (HMIP)

Hierarchical Mobile IP (HMIP) [18] is a route optimization technique for NEMO based on HMIPv6 [19]. HMIP makes use of Mobility Access Point (MAP) which works like a local home agent. A visiting MR has two CoA's . Regional CoA (RCoA) identifies the MAP the MR is currently attached to and a Local CoA (LCoA) which identifies current attachment point of the MR. The MAP advertises its address on its subnet in an extended RA. A visiting MR uses these RA's to binds its LCoA , RCoA and the list of MNP's. MR then sends a binding update (BU) message containing this binding information, to the MAP. When the MR detects an initial packet transfer to the LFN, it first executes the return routeability (RR) procedure. If the test is successful, it sends the BU to the CN on behalf of the LFN. This BU contains LFN address as the HoA and RCoA of the MR as the current attachment point. The CN tunnel the packets to the MAP using RCOA address by using IP with in IP tunnel. The MAP then forwards the packets to the MR LCoA using IP with in IP tunnel.

a) *Pros and Cons:* HMIP provides an efficient way of reducing global signaling. More over using the already existing HMIP ideas with NEMO is not very demanding if the infrastructure already exist from HMIP. It also supports route optimization for local fixed nodes (LFN's) which does not support HMIPv6. It requires the MR to function as a proxy for LFN's.

First disadvantage with HMIP is that requires a new component in the network in the form of a MAP. HMIP does not eliminate completely the multi-level encapsulation problem and some tunnels must be maintained for its operations. Also packets don't follow the most optimized route all the time.

b) *Effects on Handovers:* As HMIP reduce global signaling during handovers, it will result in shorter handover delays. The amount of signaling required during handovers with HMIP depends upon the scope of the movement of MR. For an intra-MAP handover MR is required to send a local BU only to its current MAP and no BU messages are sent to HA and CNs'. In this case the HMIP will perform better than NEMO BSP. But if the MR has to perform an inter MAP handover then it will have to register with its new MAP, update HA and all the CN's. In this case the signaling over head of HMIP will be a bit more than NEMO BSP. For nested tunnels, if CN is MIPv6 enabled it can send packets directly to the current MAP of the MR with out tunneling, else packets will reach MR HA which will tunnel it to the current MAP of the MR. Minimum one tunnel is in operation at all times.

Intra-MAP Handover :

$$\begin{aligned} HMIP_{sig} &= LNMR[BU_{MAP} + BA_{MAP}] \\ HMIP_{tun} &= 1 \end{aligned} \tag{7}$$

Inter-MAPHandover :

$$\begin{aligned} HMIP_{sig} = {} & IntraMAP_{HMIP_{sig}} + NEMO_{sig} \\ & + LN_{MR}[n(BU_CN + BA_CN + RR_{sig})] \\ HMIP_{tun} = {} & 2 \end{aligned} \tag{8}$$

2.3 MR-to-CN

2.3.1 Mobile IPV6 Route Optimization for NEMO (MIRON)

MIRON [20] [21] presents a simple NEMO route optimization solution based on the MIPv6 route optimization technique [2]. In MIRON the MR perform all the MIPv6 route optimization operations on behalf of MNNs that are carried out by MIPv6 enabled mobile nodes in the MIPv6 route optimization scheme . Network mobility remains transparent to MNN's. MIRON requires the CN to be MIPv6 enabled. MIRON introduces a new data structure called Binding Update List (BUL) which stores information regarding all the MNN-CN associations for route optimization. MR away from home notices that it is receiving packets from CN via the HA. This triggers the MR to start the route optimization procedure. First MR performs Return Routeability (RR) procedures for this Local Fixed Node(LFN) and CN pair.

For nested mobility route optimization MIRON configures an IP address for the sub MR which is topologically correct as its CoA [21]. This requires that, every MR (parent or child) within NEMO is configured by address delegation. Moreover, some routing capability is also needed in order to enable the routing of packets to these delegated addresses inside the nested NEMO.

a) *Pros and Cons:* MIRON propose one of the simplest method for route optimization technique for NEMO. It applies the basic MIPv6 RO techniques NEMO route optimizations and no additional components like CR's are required. No change is necessary for the MNNs to establish RO and MR carries the burden of performing all the operations. No tunneling is done so the packet size remains the same.

   The first disadvantage with MIRON is that a mobile network is expected to serve many MNNs which will be communicating with a large number of CNs. Therefore performing MIPv6 operations like binding updates and return routeability procedures might result in excess overhead. In MIRON MR has to maintain the state of all the optimized routes for all the MNN-CN pairs attached to the mobile network and may become potential bottle neck. Lastly, as MR is performing the binding updates for MNN, it can be a victim to man in the middle attack if MNN is attached to a fake MR.

b) *Effects on Handovers:* MIRON might suffer from binding updates storm problem during handovers. The MR will have to send binding updates to all the CN's of the MNN's served by the MR, to inform them of its current CoA after handover apart from its HA. Therefore it will have always more signaling to do than NEMO BSP. MIRON signaling overhead during handovers might be more than ORC and PCH as a MR is expected to have substantially more CN's to update than CR's during a handover. Also the execution of return routeability procedure will add to the handover delay and signaling overhead for MIRON. MIRON reduces the number of nested tunnels to 0 independent of the value of the depth of nested hierarchy of mobile networks m.

$$\begin{aligned} MIRON_{sig} &= NEMO_{sig} + LN_{MR}[n(BU_{CN} + BA_{CN} \\ &\quad + RR_{sig})] \\ MIRON_{tun} &= 0 \end{aligned} \tag{9}$$

2.4 Intradomain Route Optimization

2.4.1 Adhoc Routing for NEMO Route Optimization

NEMO BSP [1] does not allow multi hop communications. A great deal of work has been done to integrate adhoc networking with NEMO to form Vehicle adhoc networks (VANETS). Such an integration can also serve as a NEMO route optimization technique as well [22]. The basic principle behind such integrations is to use MANET routing protocols for optimized data delivery inside the mobile network, while NEMO is used to maintain global Internet connectivity [23]. Such and integration allows MRs to reach the Internet using either direct or indirect links and also optimize NEMO routing [24]. Authors in [24] have concluded form their experimentation results that using NEMO in combination with OLSR, which is an adhoc routing protocol can help eliminate NEMO sub optimal routing problems. The route optimization requirements for vehicles have been discussed in [24] and for aeronautics in [25].

VARON [26] provides a secured NEMO route optimization using MANET. With VARON a MR has to first discover reachable Mobile Network Prefixes (MNP's) though a VANET routing protocol. This is achieved by requiring each MR to advertise the MNP's that are reachable thought it. If the MR concludes through router advertisements, that a peer reachable through NEMO BSP is also reachable via an adhoc route, then MR can then setup a secured adhoc route to the host. The MR can thus forward packets for the target mobile network via adhoc routing without tunneling rather than using NEMO BSP. Another approach for combining NEMO and MANET called MANEMO has been presented in [27]. MANEMO solutions are either NEMO centric or MANET centric [28]. Using adhoc routing for NEMO route optimization is a NEMO centric solution.

GEONET [23] is an ITS project which aims at the specification of combining MIPv6/ NEMO with adhoc geo networking protocols specified in a Car-to-Car communication Consortium (C2C) [29]. C2C protocol stack supports geo addressing and geo routing for inter vehicles communication. GEONET extends the geo networking capabilities of C2C with MIPv6/NEMO to connect to the Internet. GEONET have been successfully completed early this year.

a) *Pros and Cons:* Merging MANETS and NEMO are beneficial for both types of networks. In case of NEMO introduction of MANET routing increases coverage and improves local routing.

   Using MANETS routing protocols with NEMO requires an additional adhoc interface for each mobile router. Adhoc links can only be used to improve intra domain routing and offers no solution for inter domain NEMO suboptimal routing.

b) *Effects on Handovers:* Adhoc routing no effect on the amount of signaling that needs to be done during inter domain route optimization and for intra domain route optimization the overhead is the same as the overhead of the adhoc routing protocol.

   Inter-domain

$$\begin{aligned} AdhocOpt_{sig} &= NEMO_{sig} \\ AdhocOpt_{tun} &= m \end{aligned} \tag{10}$$

   Intra-domain

$$\begin{aligned} AdhocOpt_{sig} &= adhocprotocol_{sig}. \\ AdhocOpt_{tun} &= 0 \end{aligned} \tag{11}$$

3 Conclusions

The problem of NEMO suboptimal has been around for a long time and a large number of solutions have been proposed. All these solutions consider a particular scenario, providing advantages in certain aspects but there is so far no unified solution that applies to all situations. Some approaches based their solution on deploying some special components in the network (e.g. special routers) alongside extensions to basic mechanisms for MIPv6/NEMO for route optimization. Some approaches propose to extend existing knowledge from MIPv6/HMIP for route optimization, while others are based on configuring topologically correct addresses through prefix delegation to solve the problem. Some only targets nested NEMO (Pin-Ball routing) route optimization while others target both nested and un-nested scenario's. A large number of proposals also exist on how to combine MANET with NEMO for optimized routing.

The main reason which makes route optimization in NEMO such a challenging task is that a moving network at vehicular speed presents a very dynamic environment. This requires very tight constraints to be met in terms of latency, overhead, efficiency and security. Procedures which may be potentially improved include Network Discovery, CoA configuration, Security, Tunneling Overhead and Routing.

Table 2: Summary

Protocol	Security	Problem Addressed Indirect/Pinball	RO-Type Inter/Intra	Required new Components /changes	Min Tunnels (m)	Components to Update
ORC	Equal to MIPv6	both	both	CR	1	CR, HA
PCH	Weak	both	Inter	CR, changes to MR	1	CR, HA
PD	AAA Server	both	Inter	changes to MR	0	CN's, HA
RRH	Weak than MIPv6	Pin-ball	Inter	changes to MR & HA	1	HA
ARO	Equal to MIPv6	both	Inter	changes to MR, HA	1	HA
HMIP	Equal to HMIP	both	both	MAP, changes to MR	2 or 1	CN'S, MAP, HA
MIRON	Equal to MIPv6	both	both	MAR, changes to MR	0	CN'S, HA
Adhoc	Adhoc protocol	Pin-ball	Intra	changes to MR	m or 0	HA

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