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Using Link Layer Information to Enhance Mobile IP Handover Mechanism

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An investigation in to the design, analysis and performance evaluation of the enhanced Mobile IP handover mechanism using link layer information schemes in the IP environment

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Abstract

Mobile computing is becoming increasingly important, due to the rise in the number of portable computers and the desire to have continuous network connectivity to the Internet, irrespective of the physical location of the node. We have also seen a steady growth of the market for wireless communication devices. Such devices can only have the effect of increasing the options for making connections to the global Internet. The Internet infrastructure is built on top of a collection of protocols called the TCP/IP protocol suite. Transmission Control Protocol (TCP) and Internet Protocol (IP) are the core protocols in this suite. There are currently two standards: one to support the current IPv4 and one for the upcoming IPv6 [1]. IP requires the location of any node connected to the Internet to be uniquely identified by an assigned IP address. This raises one of the most important issues in mobility because, when a node moves to another physical location, it has to change its IP address. However, the higher-level protocols require the IP address of a node to be fixed for identifying connections.

The Mobile Internet Protocol (Mobile IP) is an extension to the Internet Protocol proposed by the Internet Engineering Task Force (IETF) that addresses this issue. It enables mobile devices to stay connected to the Internet regardless of their locations, without changing their IP addresses and, therefore, an ongoing IP session will not be interrupted [2, 3, 4]. More precisely, Mobile IP is a standard protocol that builds on the

Internet Protocol by making mobility transparent to applications and higher-level protocols like TCP. However, before Mobile IP can be broadly deployed, there are still several technical barriers, such as long handover periods and packet loss that have to be overcome, in addition to other technical obstacles, including handover performance, security issues and routing efficiency [7].

This study presents an investigation into developing new handover mechanisms based on link layer information in Mobile IP and fast handover in Mobile IPv6 environments. The main goal of the developed mechanisms is to improve the overall IP mobility performance by reducing packet loss, minimizing signalling overheads and reducing the handover processing time. These models include the development of a cross-layer handover scheme using link layer information and Mobile Node (MN) location information to improve the performance of the communication system by reducing transmission delay, packet loss and registration signalling overheads.

Finally, the new schemes are developed, tested and validated through a set of experiments to demonstrate the relative merits and capabilities of these schemes.

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- Mohamed Alnas, Irfan Awan and D. R. W. Holton, "Performance Evaluation of Fast Handoff in Mobile IPv6 Based on Link Layer Information", *Journal of Systems and Software,* Elsevier JSS, S0164-1212-8. 2010

- Mohamed Alnas, Irfan Awan and D. R. W.Holton, "A Cross-Layer Decision for Mobile IP Handover", *Proceedings of the IEEE 24^rd^ International Conference on Advanced Information Networking and Applications, IEEE Computer Society*, 2010 ISBN: 978-0-7695-4018-4.

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List of Abbreviations

AP	Access Point
AR	Access Router
ADSL	Asymmetric Digital Subscriber Line
BS	Base Station
BU	Binding Update
CBR	Constant Bit Rate
CIMS	Columbia IP Micro-Mobility Suite
CN	Correspondent Node
CoA	Care-of Address
CCoA	Co-located Care-of Address
DNS	Domain Name Server
DHCP	Dynamic Host Configuration Protocol
DRR	Domain Root Router
DAD	Duplicate Address Detection
FA	Foreign Agent
FTP	File Transfer Protocol
FQDN	Fully Qualified Domain Names
GFA	Gateway Foreign Agent
GPRS	General Packet Radio Service

GPS	Global Positioning System
HA	Home Agent
HMIP	Hierarchical Mobile IP
HMIPv4	Hierarchical Mobile IPv4
HMIPv6	Hierarchical Mobile IPv6
HTTP	Hypertext Transfer Protocol
HRply	Handover Reply
HRqst	Handover Request
ICMP	Internet Control Message Protocol
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IDMP	Intra-Domain Mobility Protocol
L2	Link Layer Information
L3	Network Layer
LCoA	Link Care-of Address
MN	Mobile Node
MSF	Multiple Streams Forwarding
MNF	Multicast Non-Forwarding
MAP	Mobility Anchor Point
MA	Mobility Agent
nFA	New Foreign Agent
nAR	New Access Router

nCoA	New Care-of Address
NTP	Network Time Protocol
oAR	Old Access Router
oCoA	Old Care-of Address
oFA	Old Foreign Agent
PrRtAdv	Proxy Router Advertisement
PPP	Point to Point Protocol
RtSol	Router Solicitation
RtSolPr	Router Solicitation for Proxy Advertisement
RFA	Regional Foreign Agent
RCoA	Regional Care-of Address
RTT	Round Tripe Time
SPI	Security Parameters Index
SSF	Single Stream Forwarding
SA	Subnet Agent
TCP	Transport Control Protocol
UDP	User Datagram Protocol
UNF	Unicast Non-Forwarding

Chapter 1

Introduction

1.1 Background

The increasing range of wireless devices offering IP connectivity is starting to change our perceptions of the Internet. People want to work remotely from home and the office, almost everywhere [1]. Workers must be able to log in to their companies' networks at any moment during the day, regardless of where they are working [2].

The number of wireless devices for voice or data is projected to exceed the number of fixed devices. Mobile data communication will most likely emerge as the technology supporting the majority of communication means, including voice and video. Mobile data communication will be pervasive in cellular systems and Wireless Local Area Networks (WLANs) such as 802.11, offering a higher data bandwidth at a shorter distance and expanding into satellite communication. Whereas, the Worldwide Interoperability for Microwave Access (WiMAX) is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways, from full mesh to point-to-point, from dedicated bandwidth to shared bandwidth and from best effort service to guaranteed

Quality-of-Service (QoS), across different link layer technologies. It is based on the IEEE 802.16 standard, which is intended for wireless metropolitan area networks.

The IP is expected to become the main carrier of traffic to mobile and wireless nodes; this includes ordinary data traffic like HTTP, FTP and e-mail, as well as voice, video and other time-sensitive data. The goal is to allow applications on a Mobile IP node to keep on communicating with other nodes while roaming between different IP networks. Roaming typically occurs when an MN physically moves from its location to a new location and decides to make use of a different access link technology; this can result in the node disappearing from one point on the Internet, and, topologically at least, re-appearing at another point.

Mobile computing will offer many advantages to users, such as access to the Internet anytime or anywhere and the mobile network will not be disrupted when the user changes the computer’s point of attachment to the Internet. With standard IPv4 or IPv6 such a move would result in disruption to the MN’s ongoing communication. Using Mobile IP the MN perceives only a short disruption and then continues exchanging packets as though nothing has happened [4, 7].

Mobile IP is an Internet standards protocol, proposed by the Internet Engineering Task Force (IETF), which enhances the existing IP to accommodate mobility [4, 6]. Mobile IP in wireless networks is intended to be a direct extension for existing fixed/wireline networks with uniform end-to-end Quality-of-Service (QoS) guarantees. In addition, using Mobile IP, seamless roaming and access to applications will make users more productive, and they will be able to access applications on the fly, perhaps giving them an edge on the competition.

1.1.1 Why Mobile IP

Mobile IP solves the problem introduced by the fact that traditional IP addresses simultaneously represent the node's identity and encode the node's topological location on the IP network [9, 10]. Moving a node's physical attachment point to an IP network often results in the node moving to a new sub-network with respect to the network's IP topology. When this occurs, a new IP address must be assigned to the node, in order that packets may be correctly routed to the node's new location [5, 11].. However, since the node's IP address is also used as a transport-level end-point identity, such a move breaks any transport layer connections (for example, TCP sessions) that were active at the time of the move. Packets being sent to the node's old IP address are simply lost, and the node's old peers will not know the new address to which they should now send their IP packets.

It is not hard to imagine scenarios where Mobile IP could be attractive. For example, you are in the office and begin transferring files to your laptop over the wired LAN. The files are still downloading when you need to leave and attend a meeting elsewhere in the building, the laptop is unplugged. With traditional IP your connection would be broken and the file download would be disrupted (and most likely terminated, unless the application is specifically redesigned to handle such mobility events at the application level) [5, 8]. On the other hand, Mobile IP could, for example, allow the building's 802.11 wireless LAN to seamlessly take over as your laptop's IP network link while you are away from the office, ensuring your applications stay online without being restarted or interrupted, and leaving you largely unaware of any change in the node's IP connectivity.

Many common applications react inadequately to IP addresses being changed mid-session. As mentioned, it is because the IP address was designed to be static and transport layer protocols do not handle changes of IP address while the connection is active. These applications would thus benefit from the transparent manner in which Mobile IP enables one or both ends of the session to move around the IP network. Rather than require each and every application designer to build mobility-awareness into his or her network protocol, Mobile IP solves the problem in a transparent and application independent manner. A key target of Mobile IP is the class of users who need to work in a geographically flexible and transient manner, whether in the office, on the road, at customer premises or at home. Both Mobile IPv4 and Mobile IPv6 can be deployed incrementally, with upgrades limited only to the MNs and networks the MNs will visit. A Corresponding Node (CN) does not need Mobile IP extensions in order to communicate with a MN [2, 7].

1.1.2 Needs for Mobile IP

It has been foreseen that mobile computing devices will become more pervasive, more useful and more powerful in the future. The power and usefulness will come from being able to extend and integrate the functionality of all types of communication such as Web browsing, e-mail, phone calls, information retrieval and perhaps even video transmission. For Mobile IP computing to become as pervasive as stationary IP networks of the world, an ubiquitous protocol for the integration of voice, video and data must be developed. The most widely researched and developed protocol is Mobile IP.

The advantages of using Mobile IP can be summarized as follows [12]:

1. Mobile IP allows fast, continuous low-cost access to corporate networks in remote areas where there is no public telephone system or cellular coverage.
2. Mobile IP supports a wide range of applications from Internet access and e-mail to e-commerce.
3. Users can be permanently connected to their Internet provider and charged only for the data packets that are sent and received.
4. There are lower equipment and utilization costs for those requiring reliable high-speed data connections in remote locations worldwide.
5. A user can take a laptop computer anywhere without losing the connection to the home network.

6. Mobile IP finds local IP routers and connects automatically. It is phone-jack and wire free.
7. Other than mobile nodes/routers, the remaining routers and hosts will still use the current IP.
8. Mobile IP leaves transport and higher protocols unaffected.
9. Authentication is performed to ensure that rights are being protected.
10. Mobile IP can move from one type of medium to another without losing connectivity. It is unique in its ability to accommodate heterogeneous mobility, in addition to homogenous mobility.

The Mobile IP network is also characterized by some disadvantages as well [13]:

1. There is a routing inefficiency problem caused by the triangle routing formed by the Home Agent (HA), CN and the Foreign Agent (FA). It is hoped that Mobile IPv6 can solve this problem.
2. Security risks are the most important problems facing Mobile IP. Besides the traditional security risks with IP, one has to worry about faked Care-of-Addresses (CoA). By obtaining an MN's CoA and rerouting the data to itself, an attacker can obtain unauthorized information.

The characteristics that should be considered as baseline requirements to be satisfied by any candidate for a Mobile IP are the following [8]:

1. Compatibility: a new standard cannot require changes for applications or network protocols already in use. Mobile IP has to remain compatible with all lower layers used for the standard non Mobile IP. It must not require special media or a special protocol.
2. Transparency: mobility should remain invisible for many higher layer protocols and applications. Other than maybe noticing a lower bandwidth and some interruption in service, higher layers should continue to work even if the mobile changes its point of attachment to the network.
3. Scalability and efficiency: introducing a new mechanism into the Internet must not degrade the efficiency of the network. Due to the growth rates of mobile communication, it is clear that Mobile IP must be scalable for a large number of participants over the whole Internet.
4. Security: all messages used to transmit information to another node regarding the location of an MN must be authenticated to protect against remote redirection attacks.

1.2 Motivation

Since the Internet Protocol (IP) suite was designed under the assumption that end systems are fixed, the network session is broken when one network end moves. When somebody moves with his laptop to a new location the point of connection to the Internet will be changed. If another node decided to start a communication session with the moving laptop, it would try to reach it under its home address in the home network. The request would be routed to the router that is responsible for the home network, but since the MN is not available there, delivery of the request would fail. Mobile IP was originally designed to allow an MN to access the Internet and changes its point of attachment from one Access Point (AP) to another without losing the connection [19, 20, 35].

Mobile IP provides mobility to mobile users and terminals while they are changing their point of attachment from a previous wireless access network to a new access network. This mobility is managed within the L3 through the Mobile IP extensions where mobile connectivity can be supported while the MN is roaming between different wireless access networks. The original fixed IP address of the MN will not change; therefore, an ongoing IP session will not be interrupted [19, 36].

It is worth noting that transmission delay, packet loss and registration overheads occur in many wireless communication systems. These issues can cause communication systems to degrade their performance. Thus a key question for improving system performance is how to get rid of the effect of time delay, packet loss and registration overheads when they become large and significant [10]. However, before Mobile IP can be broadly deployed, there are still several technical barriers, such as long handover periods and packet loss that have to be overcome, in addition to other technical obstacles, including handover performance, security issues and routing efficiency [37]. As a result, many Mobile IP supplemental protocols have also been proposed by the IETF, in order to enhance the overall performance and functionality of Mobile IP.

The motivation for this investigation is to develop a new mechanism based on link layer information in the Mobile IP environment to provide an efficient scheme when it is running. Thus, the registration overhead, packet loss and handover latency would be reduced.

1.3 Aims and Objectives

The overall aim of this investigation is to design and implement a cross-layer handover scheme for the Mobile IP environment, using MN location information to improve the performance of the communication system by reducing handover latency, packet loss and registration signalling overheads. To achieve this aim, the objectives are as follows:

- To improve the Mobile IP handover in heterogeneous wireless access networks using link layer information.
- To characterize and quantify the handover latencies of Mobile IP and Mobile IPv6.
- To analyze the characteristics of standard Mobile IPv6 and fast Mobile IPv6 handovers independent of the link layer technology.

- To describe the need for link layer handover information to assist the network layer handover.
- To evaluate the proposed handover schemes in comparison with existing schemes to explore their qualities and capabilities.
- To develop a new mechanism to support QoS in micro- and macro-mobility environments.
- To investigate the merits of the network and the link layer approach design and implementation in Mobile IP networks. This approach provides a new mechanism based on location information of the MN, which produces a fast mechanism by also reducing the signalling overheads and transmission delay.
- To experimentally evaluate the likely performance impact of fast Mobile IPv6 handover on common applications.
- To evaluate and compare the proposed schemes with other existing schemes to explore their merits and capabilities.

1.4 Thesis Contribution

In this investigation many original contributions will be made for designing micro-mobility schemes. These contributions are summarized as follows.

- The design and development of a new protocol called Enhanced Mobile IP: a handover scheme to reduce the overheads produced by registration signalling, transmission delay and packet loss for the process in wireless IP networks [19].

- The development of an effective Mobile IP handover based on link layer information that can be deployed and implemented with reduced overheads and packet loss [23, 25].
- Evidence of the capabilities of the proposed schemes shown through performance comparisons and evaluations of the developed algorithms with the existing approaches through a set of simulation experiments.
- Indication that the proposed algorithm will support different applications to better exploit QoS. To support delay-sensitive applications, the algorithm provides delay-bound provisioning. The long-term throughput should be guaranteed for all connections when sufficient bandwidth is provided [38, 39].

1.5 Thesis Outline

The rest of the thesis is organized as follows.

Chapter 2 presents an overview of mobility and considers the basic operation of Mobile IP. This chapter includes details of some Mobile IP shortcomings, improvements and mobility managements.

Chapter 3 presents the new idea and the algorithm of the Enhanced Mobile IP handover based on link layer information, thereafter explaining the design and the performance of this scheme. It then goes on to describe the experimental scenarios and the setting of simulation parameters. In addition, this chapter presents and analyzes the performance results of the Enhanced Mobile IP handover based link layer information.

Chapter 4 presents the new idea and the algorithm of the Low Latency handover in Mobile IP and explains the design and the performance of this scheme. It then continues to describe the experimental scenarios and the setting of simulation parameters. In addition, this chapter presents and analyzes the performance results of the pre- and post-registration algorithms in handover rate and packet loss.

Chapter 5 presents the proposal algorithm of the Fast Mobile IPv6 handover based link layer information. Moreover, in this chapter, a detailed comparison with the other existing scheme is undertaken.

Chapter 6 concludes the dissertation and points to potential areas for future research.

Chapter 2

Literature Review

2.1 Introduction

Mobility is not supported by default in the IP, and the common implementations of the TCP are unable to differentiate between congestion avoidance and handover. In fact, the Internet Protocol suite was designed for fixed networks; IP addresses are associated with a fixed network location. Thus, as one network end moves, the network session is broken. For the operating system, the session simply times out, and new kernel bindings are required to support mobility [8, 12].

Since the Internet Protocol was not designed with mobility in mind there are several problems that need to be addressed before all IP wireless networks are deployed. Network layer mobility has been improved by the use of registered stations that take care of the routing and forwarding of packets whose destination is currently moving [40].

Mobile IP is an Internet standards protocol proposed by the IETF that enhances the existing IP to accommodate mobility. Mobile IP in wireless networks is intended to be a direct extension for existing fixed/wireline networks with uniform end-to-end QoS guarantees [41]. Mobile IP can be thought of as the cooperation between three major subsystems:

1. There is a discovery mechanism defined so that mobile computers can determine their new attachment points (new IP addresses) as they move from place to place within the Internet.
2. Once the mobile computer knows the IP address at its new attachment point, it registers with an agent representing it at its home network.
3. Mobile IP defines simple mechanisms to deliver datagrams to the MN when it is away from its home network.

Mobile IPv4 is the current standard solution for mobility management in the IP network; it is based on registration and packet forwarding. In IPv6 mobility is built in, but some modifications still need to be made.

2.2 Overview of Mobile IP

Mobile IP allows transparent routing of IP packets to MNs on the Internet. Each MN is identified by its home address, regardless of its current point of attachment to the Internet. A host that communicates with the MN is called a CN. The CN does not have to be aware of the mobility of the MN. It can function as if the MN were a normal stationary host on the Internet [2, 8, 12]. Mobile IP protocols also identify two types of mobility agents, the HA and the FA, as shown in Figure 2.1.

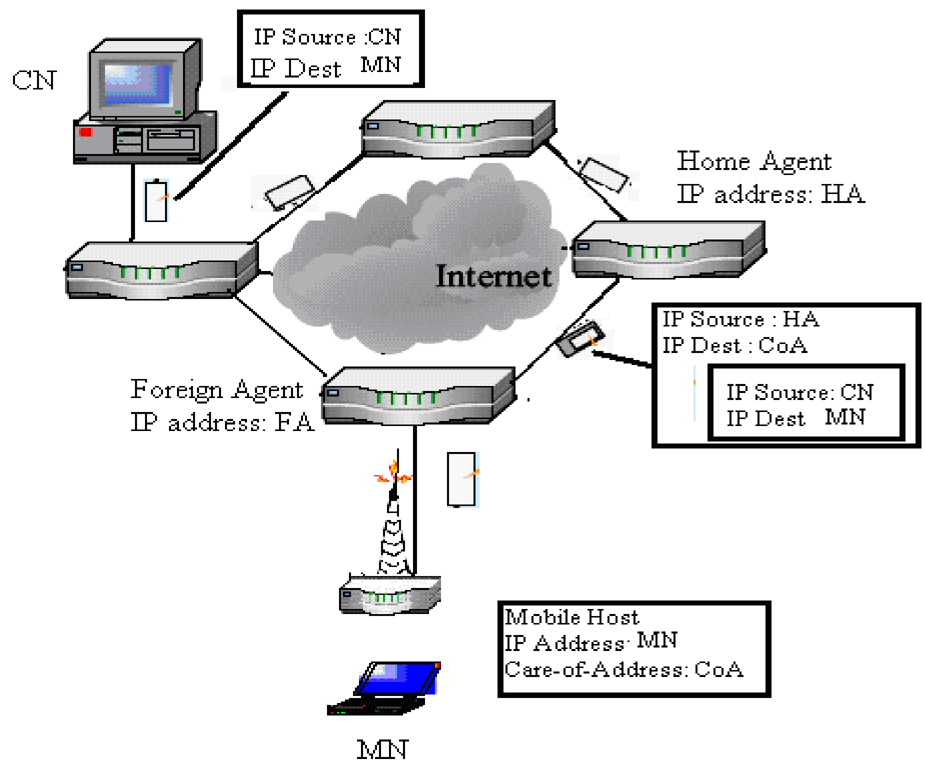

Figure 2.1: Mobile IP Component and Operations Flow

The HA resides at the home network of the MN, the same network in which the home address of the MN is allocated. Packets sent from the CN to the MN are routed using the home address. The HA intercepts the packets and tunnels them to the current location of the MN.

To be able to tunnel packets to the MN, the HA must be aware of the current location of the MN. For this purpose, the MN acquires a CoA from the network it is visiting, which is represented in Table 2.1 [14]. The home address of the MN is 192.168.16.5 and the CoA of the MN is 195.152.12.8 while it is away from HA and visits this FA.

Table 2.1 Mobility Binding

Home Address	Care-of-Address	Lifetime in (s)
192.168.16.5	195.152.12.8	500
192.168.16.45	120.12.15.65	100

Every time the MN moves, the current CoA is registered to the HA. An FA resides in the visited network. It offers routing services for the registered MN. The FA provides the MN with a CoA and de-tunnels and delivers datagrams to the MN that were tunnelled by the HA. The FA can also serve as a default router for the registered MNs [14]. Each entry in the visitor list is identified by the permanent home address, the HA address, the media address of the MN and associated lifetime, which is represented in Table 2.2

Table 2.2 Visiting List

Home Address	Home Agent Address	Media Address	Lifetime in (s)
192.168.16.5	192.168.16.8	00-50-FC-8E-1D-26	120
120.126.10.45	120.126.10.3	00-50-08-68-A2-56	300

Datagrams sent by the CN to the home address of the MN are tunnelled by the HA to the CoA of the MN. IP in IP encapsulation [15] is the default tunnelling method in Mobile

IP. The routing is done according to the outer IP header, whose destination address is the CoA and the source address is the IP address of the HA. Inside the tunnel, the original packet remains unchanged.

From the application point of view, the home address can be used as a static IP address for the host. As the MN sends packets to the CN, it uses the home address as a source address. Packets can be routed directly to the CN or tunnelled via the HA. Figure 2.2 demonstrates the Mobile IP triangular routing and the tunnelling of the packets. The CoA determines the tunnel endpoint of datagrams from the HA to the MN [16].

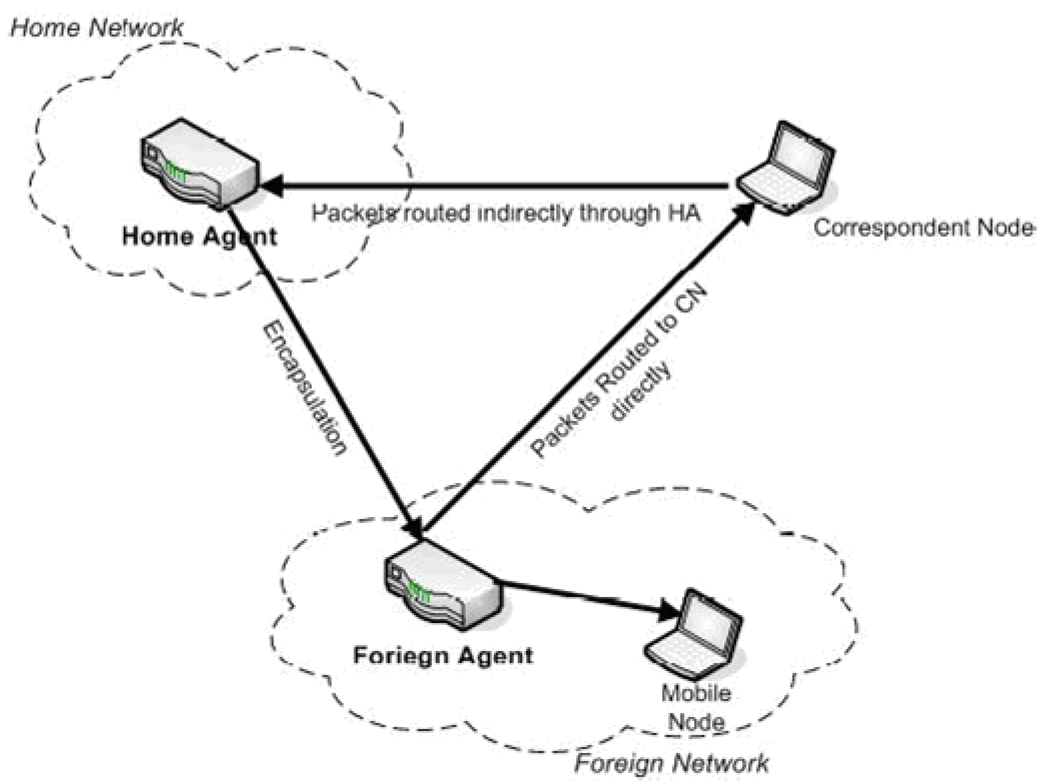

Figure 2.2: Triangle Routing

There are two types of CoAs. The FA's CoA is the IP address of the FA that serves as the tunnel end-point on behalf of the MN. The FA decapsulates arriving packets and delivers the packets to the MN. The MN obtains the FA's CoA by listening to the agent advertisements sent by the FAs in the network. An FA can allow multiple MNs to use its IP address as a CoA. The FA maintains a visitor list of the link layer addresses and the home addresses of the registered MNs to deliver packets to their right recipients. This saves the Internet address space as every MN does not need its own CoA [15, 17].

A Co-located Care-of-Address (CCoA) is a CoA acquired by the MN itself. The CCoA is associated with one of the network interfaces of the MN. In this scenario the MN acts as a tunnel endpoint and performs the encapsulation and decapsulation of the packet itself. A Co-located CoA can be acquired dynamically using, for example, the Dynamic Host Configuration Protocol (DHCP) [18]. Alternatively, the address may be owned by the MN as a long-term address for its use only, while visiting a specific foreign network. The mode of using a CCoA has the advantage of allowing the MN to function without the FA.

2.3 Mobile IP Handover

The handover time can be defined as the time between reception of the last packet through the old FA (oFA) and reception of the first packet through the new FA (nFA). Throughout the time between the MN leaving the old foreign network and HA receiving the MN registration message, HA does not know MN's latest CoA and, therefore, it still forwards the packets destined for MN to the old foreign network. These packets will be discarded and lost. The packet losses could cause impossible disruptions for real-time services, degrade the QoS and lead to severe performance deteriorations of upper layer protocols, especially when the handover is frequent and the distance between MN and the HA is great [19, 20, 21, 22].

Mobile IP handover can also be classified according to the number of connections that an MN maintains during the handover procedure: hard and soft handover.

2.3.1 Hard and Soft Handover

The MN is connected to two links concurrently. As it moves from one area to another, it switches from one link to another. When connected to two links, the MN can receive packets from both links and the network combines information received from different routes to obtain a better QoS than the old one [1, 10, 20].

In hard handover, the handover process involves both link layer and IP layer reestablishment. The connection to the source is broken before the connection to the target is made; for this reason such handovers are also known as *break-before-make*. On the other hand, in soft handover the MN switches the communication from the old link to the new link. There will be a short interruption in transmission after the old link is discarded, and before the new link is established. There will be only one active connection from the MN at any time [23]. In this case the connection to the target is established before the connection to the source is broken; for this reason this handover is called *make-before-break.*

2.3.2 Fast Handover

Fast handover is concerned with the interruption time between disconnection at the old attachment point and connection to the new attachment point. There are triggers [25] to let an MN know that a handover is about to happen, so the MN can start doing the necessary work. After an MN has received its CoA, and has become IP capable, it will begin to scan its neighbourhood for new Access Routers (nAR). When the scan results in the detection of an nAR the MN is able to determine information about this new neighbour.

AR uses the Router Solicitation for Proxy Advertisement (*RtSolPr*) and Proxy Router Advertisement (*PrRtAdv*) messages to gather information about the neighbours, and the MN can formulate a new Care-of-Address (nCoA) while it is still connected to the previous subnet. The MN can then use the gathered information to compose a Fast Binding Update (FBU) message when the actual handover takes place. This FBU is the message that MN sends to the old Access Router (oAR) before a handover [26, 27]. This reduces the IP capability latency and Binding Update (BU) latency, which, in turn, results in a smoother handover with less chance of packet loss occurring [28].

2.3.3 Smooth Handover

Smooth handover is concerned with the rate of packet loss during the time that an MN is establishing its link to the new attachment point. An example is as follows. MN sends a BU containing the bindings of the nCoA and the oCoA to HA. Packets destined to the oCoA from CNs will be intercepted by the HA and the HA will tunnel these packets to the nCoA. The MN will then send the BU with its nCoA to the CN so that CN can send packets to the MN's new address through direct binding.

For smooth handover, the MN also may use multiple CoAs when it is in an overlap network region, such as overlapping wireless cells [29]. This employs both pre- and post-registration handover methods to eliminate packet loss; however, it also requires altering the behaviour of the HA, the FAs and the MN, and extending the Mobile IP specifications, which makes it difficult to apply this proposal to networks where the standard Mobile IP is already deployed [30].

2.4 π- Calculus

The π-calculus is a mathematical model of processes whose interconnections change as they interact. The calculus is a way of describing and analysing systems consisting of agents which interact with each other and whose configurations or neighbourhoods are continually changing. The basic computational step is the transfer of a communication link between two processes; the recipient can then use the link for further interaction with other parties [31].

This makes the calculus suitable for modelling systems where the accessible resources vary over time. It also provides a significant expressive power since the notions of access and resource underlie much of the theory of concurrent computation, in the same way as the more abstract and mathematically tractable concept of a function underlies functional computation.

The most primitive entity in π-calculus is a name. Names, infinitely many, are $x, y \ldots \epsilon X$, etc. and have no structure. In the basic version of π-calculus there is only one other kind of entity: a process. Processes are $P, Q \ldots P$ and are built from names from the following syntax:

$$P ::= \sum i \in I \ \pi i . Pi \ \big| \ P \ \big| \ Q \ \big| \ !P \ \big| \ (vx)P$$

Here I is a finite indexing set, where in the case of $I = \phi$ we write the sum as **0**. In a summand $\pi.P$, the prefix π represents an atomic action, the first action performed by $\pi.P$. There are two basic forms of prefix:

$x(y)$, which binds y in the prefixed process, means "input some name, call it y, along the link named x".

$\bar{x}\langle y \rangle$, which does not bind y, means "output the name y along the link named x".

In each case we call x the subject and y the object of the action, the subject is *positive* for input and *negative* for output.

A name refers to a link or a channel. It can sometimes be thought of as naming a process at "the other end" of a channel. Polarity is used with regard to the names: $\bar{x}$ the *co-name* of x is used for output, while x itself is used for input [32, 33].

2.4.1 Why π-Calculus

The π-calculus theory of the mobile systems provides a conceptual framework for understanding mobility and mathematical tools for expressing systems and reasoning about their behaviours. It explains how the terms of the calculus describe the structure and the behaviour of mobile systems. It also develops the basic theory of behavioural equivalence, and introduces basic techniques for reasoning about systems [34].

1. The π-calculus considers the links in the mobility – it directly expresses movement of links in a space of linked processes.
2. Processes can interact by using names that they share.
3. The π-calculus has a rich blend of techniques for reasoning about the behaviour of systems.
4. The π-calculus is a general model of computation, which views interaction in a primitive way.

2.5 Handover Control

Handover evaluated in a different handover control mechanism, which can be either a network or a mobile controlled. In the case of using a network controlled handover, the elements of the visited network will guide the MN's handover to the desired a new location [8, 12].

1. Mobile Evaluated (Network Controlled) Handover: the MN interprets downlink behaviour, but the network decides when to handover.
2. Network Initiated (Network Controlled) Handover: the network interprets uplink behaviour and decides when to handover.
3. Mobile Assisted (Network Controlled) Handover: the network assisted by the MN to take the required measurements from the downlink, then the network decides when to handover depends on these measurements.

In the case of using a mobile controlled handover, the MN is responsible of making the right decision to determine the new point of attachment and to complete the handover procedure.

1. Mobile Initiated (Mobile Controlled) Handover: the MN interprets downlink behaviour and decides when to handover [42, 43].

2.6 Mobility Management

Mobility management consists of two components, namely location management and handover management [20, 44].

2.6.1 Location Management

Location management is a two-stage process that enables the network to discover the current attachment point of the mobile user for call delivery, as shown in Figure 2.3: Initially, there is the location registration or location update. In this stage, the MN periodically notifies the network of its new AP, allowing the network to authenticate the user and adjust the user's location profile [45, 46]. Secondly, there is call delivery [22, 30]. Here the network is asked about the user location profile, so the incoming communication for the MN can be routed to the corresponding location.

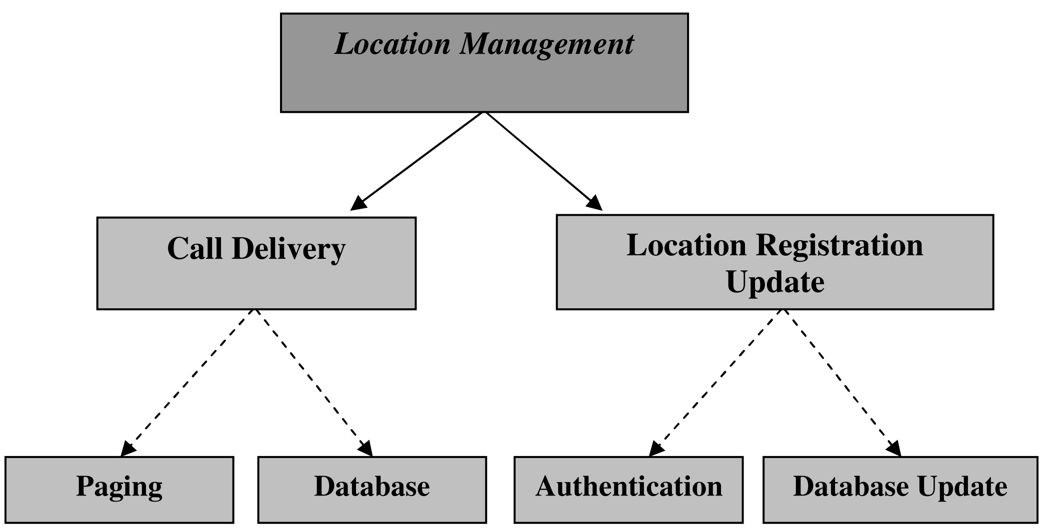

Figure 2.3: Location Management Operations

Location registration involves the updating of location databases when current location information is available. On the other hand, call delivery involves the querying of location databases to determine the current location of a called MN [47, 48].

2.6.2 Handover Management

Handover management is the most significant issue in mobility management. It refers to the ability of the network to allow a call in progress to continue as the MN continues to travel and change its point of attachment. The handover processes involve three activities. The first stage is initiation and generation, as shown in Figure 2.4, where user, network agent or changing network conditions identify the need for handover [49].

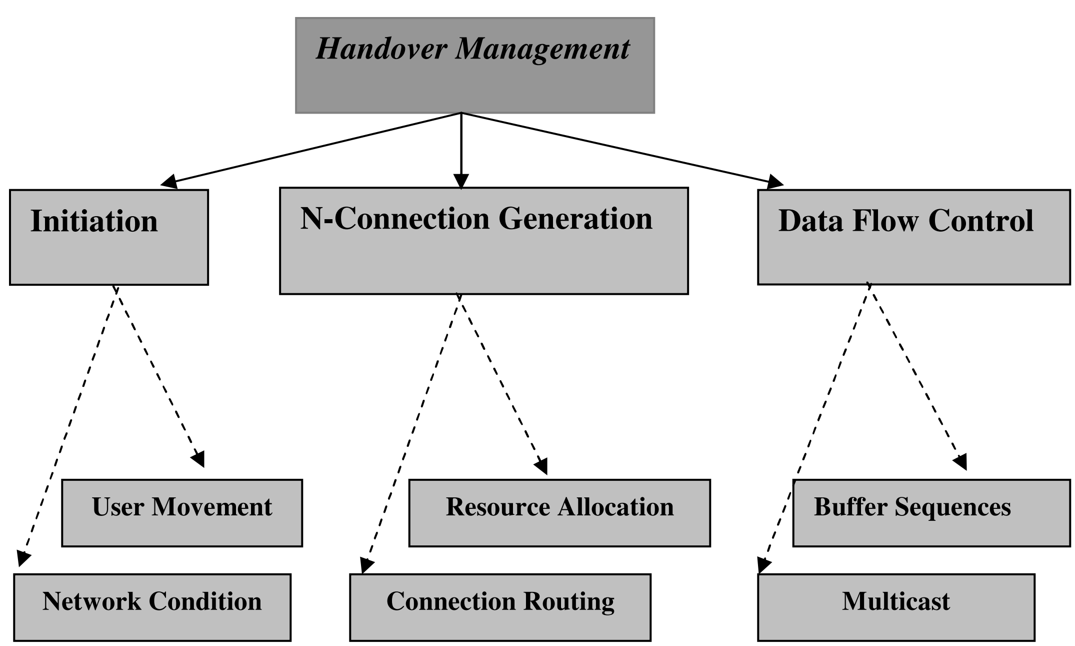

Figure 2.4: Handover Management

The second stage is a new connection generation, where the network must find new resources for handover and perform any additional routing operations. Finally, is data-flow control, where the delivery of the data from the old connection path to the new connection path is maintained according to agreed-upon service guarantees [46, 50].

K. Pahlavan et al. [51] classified handover management by architectural and decision time algorithm issues. The handover architecture defines the framework of the system in which handovers occur. The handover architecture can be divided into three concepts: handover procedures, handover methodology and handover control, .

The handover procedures involve a set of protocols to notify all the related entities of a particular connection that the handover has been or will be executed. In Mobile IP, these entities are MN, HA, and involved FAs. At the IEEE-802.11 link layer, handover procedures would include Inter Access Point Protocol (IAPP) [52], which APs use to share information in re-association situations. IAPP enables old AP, for example, to free resources and to transfer the security context to the new AP.

The handover methodology classifies handovers by their qualities. A soft handover occurs if the MN can communicate simultaneously with two or more APs during the handover. A hard handover occurs if only one connection is available at a time. A fast handover introduces only a short interruption to the communication. A smooth handover causes an interruption, but no packets are lost. A seamless handover occurs if no interruption or packet loss can be perceived.

Handover control denotes the party that makes the handover decision. In a network controlled handover the network side entities decide when the handover should occur. The network controls the execution of the handover. A mobile controlled handover stands for exactly the opposite approach. The mobile terminal makes the handover decision and handles the registration at the new BS or AP. A mobile assisted handover is between the network controlled handover and mobile controlled handover. Usually, the mobile terminal sends measurements about the received signal to a network entity, and the network makes the handover decision based on the data.

Decision time algorithms are classified by the metrics that are used and by the type of the algorithm. The algorithm can be anything between a linear function measuring signal strengths and a neural network operating with various types of inputs.

Handover management classification of architectural issues and decision time algorithms by K. Pahlavan et al. [51] omits the heterogeneous L3 handover management altogether. They identify Mobile IP as one solution for IP mobility, but do not discuss controlling the registration processes between multiple interfaces of different transfer media. Another good classification for the handover management framework was given by G. Dommety et al. [53]. They state that the handover procedure is determined by the following factors:

1. The element that makes the handover decision: either the network or the MN can initiate and/or execute the handover.

2. The amount of information available before the handover: the handover procedure is accelerated if the configuration parameters needed at the new point of attachment can be obtained before the handover occurs. Knowing the gateway IP and MAC addresses, or the nCoA to be used in the visited network allows a faster L3 handover.
3. The extent of L2 support, L2 triggers and statistics can be used to improve handovers. The amount of coupling between the link layer and the network layer is an essential factor in speeding up handovers.
4. The amount of prediction that is possible, if the movement of the MN can be predicted, it is possible to achieve lower latency handovers and choose more wisely the next point of attachment.

2.7 Link Layer Information

L2 information allows an MN to predict the loss of connectivity more quickly than L3 advertisement-based algorithms. It is used to predict a breakdown wireless link before the link is broken. This facilitates the execution of the handover, and the elimination of the time to detect handover [36, 99].

MN monitors any advertisements, records the lifetime and updates the expiration time when a new advertisement is received from a new network. When the advertisement lifetime of the current Mobile IP's FA expires, the MN assumes that it has lost connectivity and attempts to execute a new registration with another FA. Although the MN might already be informed about the availability of the nFA, the mobile agent defers switching until the advertisement lifetime of the oFA is expired [38].

Mobile IP handovers that are based on movement detection being handled by the L3 are not appropriate to provide seamless and lossless connectivity of MNs, such movement detection causes packet loss and detects movements after the previous link has been broken [19, 100, 101].

2.8 Enhancements of Mobile IP Handovers

Many proposed techniques were implemented to improvement the L3 handover of the Mobile IP. The improvements of these techniques are based on the FA co-operation and assistance in handover situations, which can be highlighted as follows

- Localized registrations: the registrations process of FAs can be arranged in hierarchy structure in order to localize the registrations within the same domain. The registration process is terminated depending on the hierarchy level, in which the FA can be closer to the MN than the HA [54].
- Multicasting: it is an efficient improvement method of the handover hierarchy inside an FA. In comparison with the Mobile IP simultaneous binding, seamless handovers can be acquired with less bandwidth consumption. The simultaneous

binding duplicates the traffic between the HA and the MN, while multicasting can be limited to the hierarchy [55].

- Buffering packet: to obtain a soft handovers and ensure there is no packet loss, the packets sent from the CN destined to the MN are buffered at the FA. Packet buffering is a method used to eliminate packet loss
- Forwarding: the FAs may execute protocols (such as DHCP) to figure out tunnels between each other to redirect the MN intended traffic. When an MN is handed over to an nFA, the oFA starts to tunnel packets to the new location [56].

Most of the handover architecture proposals use some combination of the above-mentioned methods. Localized registrations have been used in many micro-mobility architectures. Cellular IP [57], developed by A. Campbell et al., introduces mobility management ideas from telecommunications networks like GPRS to IP mobility. Mobile IP handles the macro-mobility i.e. moving between Cellular IP domains, while Cellular IP manages the micro-mobility. Location management is integrated to routing, and schemes like paging are used to track the mobile node. HAWAII [58] is another micro-mobility extension to Mobile IP. It introduces QoS support to handovers within the HAWAII hierarchy.

S. Seshan [59] developed a handover scheme for cellular data networks that relies on mobility hints i.e. in-cell location information and user movement patterns to predict handovers. Packets are multicasted to several neighbouring base stations to achieve fast handovers. Buffering at the BSs ensures that no packets are lost. R. Caceres and V. N. Padmanabhan [60] presented another buffering based solution. Their solution employs packet buffering and interaction between APs to forward traffic. The new access point (nAP) requests buffered packet from the old access point (oAP), and then delivers them to the MN via the new link. Multicast-based architectures have also been studied by C. Tan and S. Pink [61]. A Two layer FA hierarchy is utilized. Domain FAs at the top of the hierarchy multicast packets to the lower FAs, and the FA that has a L2 association with the MN transmits them over the wireless link.

2.9 Mobile IP Low Latency Handovers

K. E. Malki et al. [62] present two techniques to support delay-sensitive and real-time applications in Mobile IPv4. The first technique is the pre-registration which is based on L2 triggers, proxy agent advertisements and agent solicitations (AS). In advance of a handover, the neighbouring FAs exchange agent advertisements messages with each other. This happens before the actual L2 handover. The MN receives a proxy agent advertisement from the nFA relayed by the old foreign agent (oFA). Now, the MN can issue a Registration Request *(ReReq)* to the nFA via the oFA. In this case the oFA is used up to the time of the registration is completed. Then; the overall handover latency will be reduced to the L2 handover latency.

Tunnels between FAs used in the post-registration system to forward received packets to the MN's existing location. The packets sent from the HA are received by an anchor FA, which is the FA that relayed the last Registration Request/Reply pair to the HA, it forwards packets to the subnet of the FA that currently serves the MN. Tunnels between FAs are established by a Handover Request *(HReq)* and a Handover Reply *(HRep),* the messages that are exchanged upon the L2 trigger that indicate the handover [105].

S. Goswami [63] proposed an approach that uses link events information to optimize L3 movement detection in Mobile IPv6. The work considers smooth handovers for MNs that are equipped with multiple interfaces moving across different types of links. Theses are link-up, link-down and link-type hints that are commonly used for the Mobile IP nodes, which are moving between a different type of network (e.g movement between GPRS and 802.11). Related research is also in progress both at IETF and IEEE. Some optimizations were proposed to the current specifications that would allow an MN to reconfigure its IPv6 layer faster, such as L2 indications and fast Router Advertisements (RAs), but it is centralized, requires extra signalling and imposes a boundary on the speed of MNs [64].

J. Puttonen et al [65] developed the L2 hints that are used as an input to a handover decision process. An algorithm for handover initiation and decision has been developed based on the policy-based handover framework introduced by the IETF. A cost function was designed to allow networks to judge handover targets based on a variety of user and network valued metrics. These metrics include L2 hint parameters, as well as other QoS metrics. Evaluation of this method considered only the network controlled side, while mobile control was not mentioned, which in fact makes a difference between both of them.

2.9.1 Pre-Registration Mode

A pre-registration low latency handover can be initiated by the access network or the MN. In the case of a network-initiated pre-registration low latency handover, the handover can either be triggered by the oFA or the nFA. J. Kempf and J. Wood [66] analyzed Mobile IPv4 low latency handover algorithms. The pre-registration, post-registration and standard Mobile IPv4 (SMIPv4) handover algorithms were compared. Their conclusions were that the pre-registration method is difficult to implement. Furthermore, it behaves badly if the time interval between the L2 trigger and the beginning of the L2 handover is either too short or too long. When the interval is too short, the pre-registration does not have enough time to complete, and the handover procedure falls back to the standard Mobile IP handover. If the interval is too long, packets are lost because they are routed to the nFA before the L2 association has been formed.

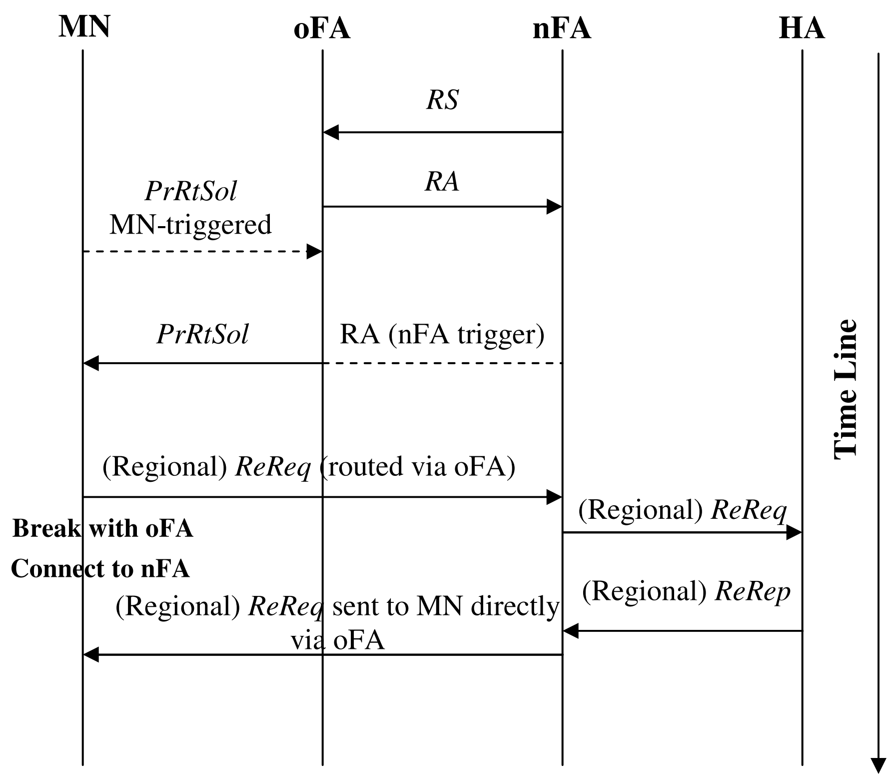

Figure 2.5: Pre-Registration Low Latency Handover Message Flow

Figure 2.5 summarizes the pre-registration low latency handover mechanisms (where the messages represented by dashed lines may or may not be present, depending on the scenario) [25, 67].

The following provides more details on the protocol:

1. The oFA should send Router Solicitations (RS) and cache RA from all potential nFAs in advance of a handover in order not to delay the handover.
2. If the handover is initiated by the MN on receipt of an L2 trigger, the MN sends a Proxy Router Solicitation *PrRtSol* to the oFA. However, the *PrRtSol* is used to solicit an advertisement from the nFA rather than the oFA.

Since the oFA has cached the RA from the nFA, it returns a *PrRtAdv* to the MN on behalf of the nFA. Alternatively, the handover can also be initiated by the access network (that is, the oFA or the nFA). If the nFA receives an L2 trigger indicating an incoming handover, it tunnels an RA to the oFA immediately. On receipt of the RA, the oFA sends a *PrRtAdv* to the MN. If the oFA receives an L2 trigger indicating an incoming handover, it simply immediately sends a *PrRtAdv* to the MN.

3. On receipt of a *PrRtAdv*, the MN performs movement detection and sends a *ReReq* message to the nFA via the oFA.
4. The nFA relays the (regional) *ReReq* to the MN's HA. The nFA also relays the (regional) *ReRep* to the MN, both through the oFA and directly when the MN connects to the nFA.

   This is to guarantee that the MN receives the (regional) *ReRep* as soon as possible and more reliably.
5. If the registration is successful, the HA starts tunnelling packets for the MN to the nFA.

Note that, since the handover is initiated by an L2 trigger, the timing of the L2 trigger is important for the optimal low latency handover performance. For example, in the low latency handover pre-registration mode, if the IP layer handover is triggered too early, the MN may still stay be connected to the oFA for a long time after registering the location of the nFA with the HA. However, at this time all packets destined for the MN are tunnelled to the nFA [67, 68].

On the other hand, if the L2 trigger's timing is too late, the MN may not be able to receive the *PrRtAdv* before its connection with the oFA breaks, and thus the low latency handover pre-registration mode fails.

2.9.2 Post-Registration Mode

A post-registration low latency handover can only be triggered by the access network without involving any MN operations. The basic idea of it is to set up a tunnel (either bi-directional or unidirectional) between the oFA and the nFA on a handover, so that the MN can continue to use its oFA for packet forwarding when it has connected to the nFA but has not performed or finished the registration process [25, 67].

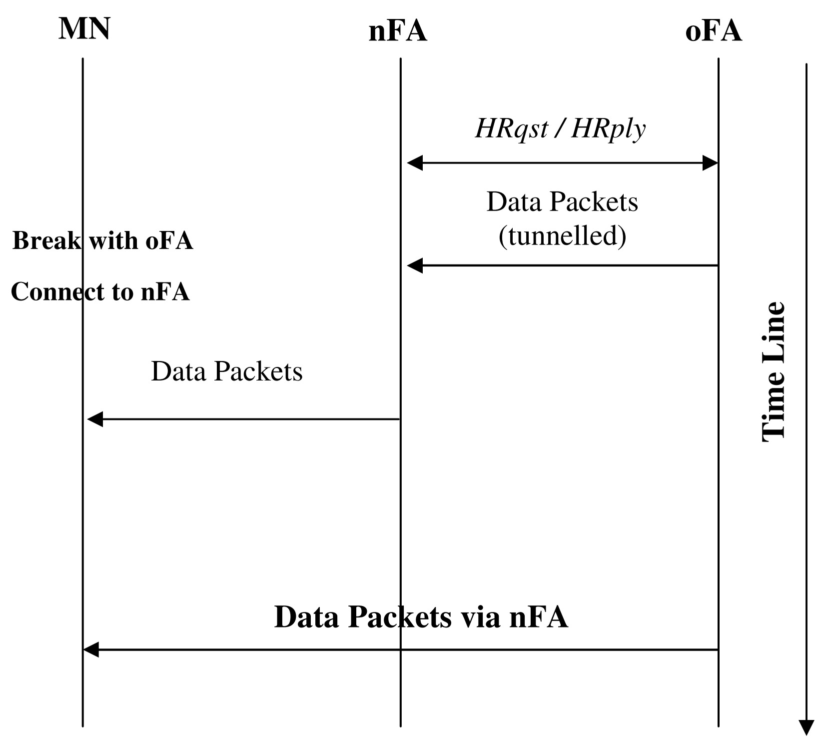

Figure 2.6: Post-Registration Low Latency Handover Message Flow

Two messages are defined to manage the tunnel between the oFA and the nFA for both *HRqst* and *HRply*. Figure 2.6 shows the post-registration low latency handover message flow, and the following describes the protocol running steps.

1. Triggered by an L2 event, the oFA and the nFA exchange the *HRqst/HRply* message pair in order to set up a tunnel between them. Whether the *HRqst* is sent by the oFA or the nFA depends on the location of the L2 trigger.
2. Once the MN disconnects with the oFA (informed by an L2 trigger), the oFA starts to tunnel the packets destined for the MN to the nFA.
3. Once the MN connects to the nFA, the nFA forwards the packets tunnelled from the oFA to the MN.
4. The MN still uses its oFA to send and receive packets via the nFA, until it successfully performs the registration to update its location [69].

In low latency handover post-registration mode, the timings of L2 triggers are also important. For example, if the packet tunnelling from the oFA to the nFA initiated by an L2 trigger is too late, the MN may not be able to receive packets immediately after it connects to the nFA. However, if the packet tunnelling from the oFA to the nFA is too early, the MN may not be able to receive packets even if its connection with the oFA is still available. In both cases, the communication disruption time increases [68, 70].

The post-registration algorithm is straightforward to implement, but requires good operating system support for the tunnel management. Both algorithms achieve around the same level of optimization, provided that the pre-registration method can be tuned. In reality this is not possible, which leads to favour for the post-registration method.

2.9.3 Mobile IP Regional Registration

To improve handovers, E. Gustafsson et al [71] proposed a method that uses FA hierarchies. This approach defined Mobile IPv4 Regional Registrations, which makes a local registration for the MNs to be in the visited subnets. Using this mechanism will decrease the number of signalling messages to the HA and reduces the handover latency.

The specification introduces a new network entity: a gateway foreign agent (GFA) and new messages: a Regional Registration Request and a Regional Registration Reply. When an MN enters a domain supporting regional registrations, it notifies the HA about the nCoA, the address of the GFA. This CoA will not change if the MN changes FA under the same GFA. Location updates are handled within the hierarchy using regional registrations. The hierarchy can have multiple levels and cover wide geographical areas.

2.9.4 A Link Layer Assisted Fast Handover

In H. Chung-Ming et al. [74] a L2 assisted fast handover scheme using the alternative path approach is used to improve performance of roaming in wireless mobile networks, minimize handover latency and reduce packet loss. In this proposal, the LLA-AL scheme, each MN connects to wireless network interfaces. One wireless network interface is used to connect the original wireless path. The other one is used to collect the signal strength of all nearby APs.

When the original wireless path is not suitable for connection (i.e. signal strength is below the pre-defined threshold strength) the other wireless network interface starts to discover an nAP that has higher signal strength and builds a new wireless path in advance. The MN first attaches to the nAP and receives router advertisements (RA) of the nAR to form an nCoA. After obtaining an nCoA, the MN sends a BU message to the HA. A new alternative wireless path is created after the registration is complete [37, 38].

The handover gap is reduced by overlapping the transmission of the original connection with the construction of the new wireless path. Handover latency can be reduced in two ways: The first way is with the help of L2 information. The second is through preparing for a new link handover when the MN is still with the old link. Using L2 information such as signal strength, an MN can be informed and start to search for a better link when the signal strength of the old link becomes unacceptable for connection.

2.10 Explicit Proactive Handover with Motion Prediction for Mobile IP

F. Fang [75], proposed an explicit proactive handover scheme with motion prediction for Mobile IPv4. The proposed scheme is used to reduce the latency and packet loss of L3 handover. The scheme utilizes the L2 trigger mechanism. The mobile trigger notifies the MN about an impending L2 handover, and the Link-Up Trigger informs the FA that an MH has connected to the radio link of its subnet. Each MN records its movement patterns and predicts its future subnet. Before L2 handover, the MN explicitly notifies its current FA of its predicted subnet. The current FA then duplicates packets sent to this MN, and forwards them to these predicted subnets.

A L3 handover latency is close to that of L2 handover, and packet loss is reduced by buffering forwarded packets at FAs. However, if it is the first time that the MN associates with the current subnet, it will not do a proactive handover, and the standard Mobile IPv4 mechanism will be used. This scheme will consume extra bandwidth since packets will be forwarded to all predicted subnets.

2.11 Seamless Fast Handover in Mobile IPv4 using L2 Triggers

Y. Kim et al. [76] proposed a scheme involving a L3 handover which is able to reduce packet loss and provide more seamless handover without buffering. The proposed scheme uses L2 triggers and applies the tunnel mechanism and pre-registration method of the low latency handover scheme in Mobile IPv4.

However, the direction of the established tunnel of this scheme is opposite to that of the low latency handover of post-registration, in that data traffic arriving at the nFA is tunnelled to the oFA. When an L2 trigger is issued, the MN sends a seamless fast registration request (*SF_RegReq*) to the nFA, this message should carry the oCoA to create a tunnel between the nFA and the oFA.

Upon receiving *SF_RegReq*, the nFA forwards it to the HA, creates a *HRqst* message and sends it to the oFA to make the oFA is ready to create a tunnel with the nFA. Then, the data traffic for the MN is able to be transferred to the nFA. After receiving a seamless fast registration reply (*SF_RegReply*), which is replied to by the HA, the nFA encapsulates the data traffic received from HA and transmits it to the oFA. Therefore, the MN, which is still connected to the oFA, can receive the data traffic. When an L2 handover to the nFA completes, a link-up trigger is generated at both mobile and network sides. Then the nFA removes the tunnel and starts swapped these round data traffic to the MN [102].

2.12 Mobile IP Shortcomings and Improvement

Even though Mobile IP does solve the mobility problem, there are several issues and problems that remain unsolved. Reverse tunnelling [77, 78] offers a solution to the asymmetry problem. Route optimization [79] has been proposed as a solution to inefficiencies caused by tunnelling. Moreover, when an MN moves from one FA to another, there is no way to inform the oFA about the movement of MN. Hence packets already tunnelled to the oCoA and in flight cannot be delivered to the MN and are lost.

2.12.1 Route Optimization

In the basic Mobile IP protocol, all datagrams destined to an MN are routed through the MH's HA. Thus, datagrams sent to the MN are often routed along paths that are significantly longer than the best possible route; this is known as triangle routing, as shown in Figure 2.5 and it adds an extra delay to all traffic sent to an MN from any CN as the HA can be at a large routing distance from both the CN and MN. Consider the case when the CN and the MN are in the same network, but not in the home network of the MN. In this case the messages will experience unnecessary delays since they have to be first routed to the HA that resides in the home network.

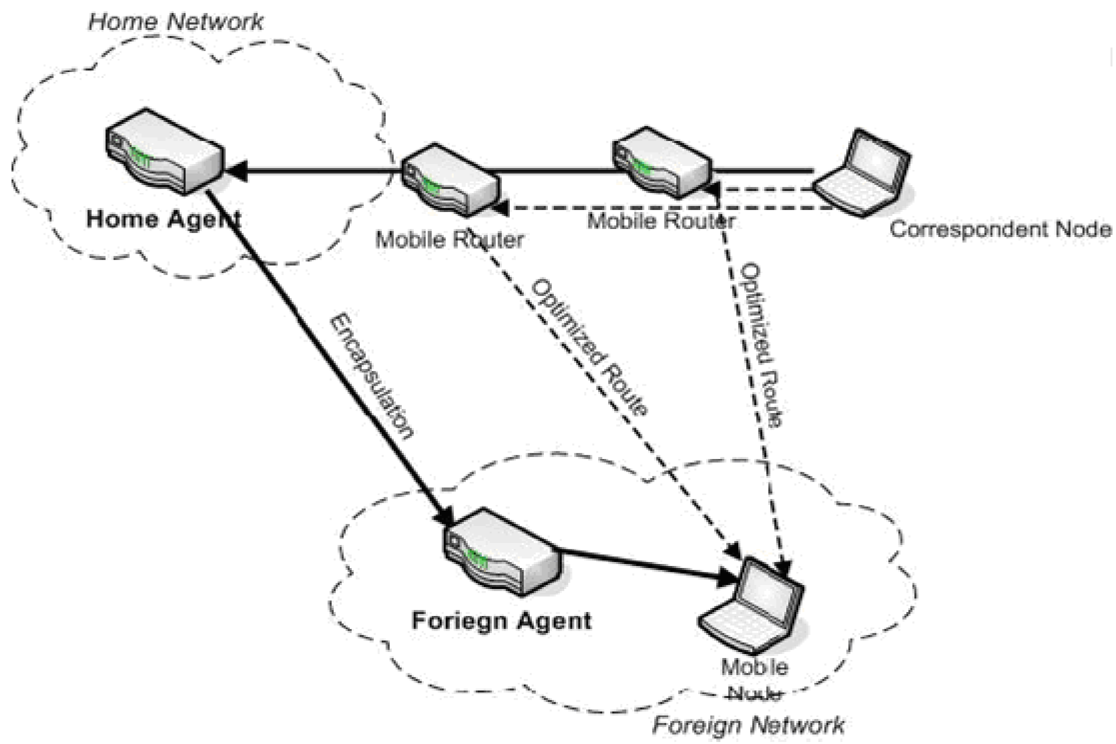

Figure 2.7: Mobile IP Route Optimization

Route optimization extension [79] proposes that the basic Mobile IP protocol allows the CN to maintain a binding cache to one or more MNs and then tunnel their packets directly to the current CoA of the MN, as shown in Figure 2.7.Whenever the CN sends a packet to the MN this packet is intercepted and tunnelled by the HA; the HA then sends a BU to the CN that holds the CoA of the MN, and from this point onwards the CN can tunnel traffic directly to this CoA [80, 81, 82, 83].

2.13 Mobile IPv6

As a new version of the IPv6 [5, 84] standard has been developed, mobility issues have also been addressed from the start. Mobile IPv6 follows the same basic principles as Mobile IPv4. In Mobile IPv4 traffic forwarding to the MN is almost always managed through an FA, while in Mobile IPv6 the FA no longer exists and it is assumed that the MN is always able to acquire a Co-located-Care-of-Address (CCoA) for the visited network by other means. Indeed, the MN can configure its CoA using either stateless address autoconfiguration [85], or some means of stateful address autoconfiguration, such as DHCPv6 [86]. The decision about which manner of automatic address configuration to use is made according to the methods of IPv6 neighbour discovery [87].

Likewise, movement detection, which in Mobile IPv4 was supplied by agent advertisement messages, is also provided by neighbour discovery. Basically, the FA of Mobile IPv4 was meant to reduce the demand for IP addresses by sharing the same CoA among multiple MNs. This is no longer a problem in Mobile IPv6 as it has increased the number of available IP addresses. Mobile IPv6 development is still underway by the IETF Mobile IP Working Group. Some advantages of Mobile IPv6 over Mobile IPv4 are the following [88]:

1. A MN can configure its CoA using stateless address autoconfiguration and neighbour discovery [87], enabling MNs to work any where without the services

of any specific router located in that location. So, FAs are not needed in Mobile IPv6.

2. There is an optional set of extensions for the route optimization in Mobile IPv4 that may not be suitable to use by all nodes, while it is built in as a primary element of Mobile IPv6. Moreover, route optimization and the registration procedure with the HA are both done by new defined BU messages.
3. Security is the biggest difference; in comparison Mobile IPv6 can use IPSec for all security requirements (authenticating, data integrity protection and reply protection), while it is not possible for the Mobile IPv4.
4. In Mobile IPv4, the MN uses its home address as the source of the packet during the communication with a CN. Therefore, access filtering routers are used to filter the packet. While, in Mobile IPv6 the MN uses the CoA as the source address and having a home address destination option, allowing the use of the CoA to be transparent over the IP layer.
5. Mobile IPv6 uses the source routing feature. This feature makes it possible for a CN to send packets to an MN while it is not in its home network using an IPv6 routing header instead of IP encapsulation, whereas Mobile IPv4 must use encapsulation for all IP packets [89].

2.14 Summary

This chapter describes the difficulty of mobility and examined ways in which it is possible to resolve the key problems in Mobile IP. In addition, we clarified the main problems and existing enhancements, and explained the main Mobile IP management handover.

A fast-moving MN may associate with an AP at L2, but does not have enough time to complete the registration of the CoA (L3 handover) until the link is lost again. The acknowledgement of the detriment time of the L2 handovers would be beneficial. When the L3 handover is scheduled accordingly, the interface of the next network can be prepared in advance (e.g acquiring a CoA and sending the *ReReq* in advance to schedule L3 handover at the same time the L2 connection to the previous point of attachment is lost).

For the low latency handover protocols to work, the presence of anticipation triggers is required, which informs the receiving node (which can be the oFA, nFA or MN) that the MN is going to conduct a handover in the very near future, and to which nFA. This destination information can be the nFA’s IP address, or any other form of identification.

Instead of focusing on what is happening at L3 to see what can be done there, we now break the paradigm of strict protocol layer separation and look for further information down in the L2. Mobile IP uses L2 information to force a handover to a new access network before any mobility at the L3 can be detected. L2 information is used to predict a breakdown wireless link before the link is broken. This facilitates the execution of Mobile IP handover, and the elimination of the time to detect handover.

Chapter 3

Enhanced Mobile IP Handover Based on Link Layer Information

3.1 Introduction

The main source of the problem in Mobile IP handover is the latency and packet loss that are introduced by the lengthy registration processes: the registration messages must traverse all the way to the HA and back [94]. Besides, the Mobile IP L3 movement detection mechanism is slow. This delays the initiation of the registration process even more. Nowadays, real-time requirements are rapidly infiltrating the IP world and the Mobile IP L3 handover procedure is seen as insufficient. In addition, the packets sent by the CNs are lost until they receive the BU indicating the nCoA of the MN. To reduce the number of lost packets during this time, the MN can request the oAR to forward all its incoming packets to the nAR [93, 95].

To do so, the MN has to send a BU to a HA on its old link indicating its nCoA, but with its oCoA instead of the home address. Then, the HA on the old link intercepts the packets intended for the oCoA of the MN and forwards them to the current localization of the MN.

The use of L2 information to reduce the handover requirement detection delay is used to improve the handover performance of Mobile IP [91]. However, the current IEEE 802.11 [23, 24, 92] design does not provide the fast handover required for real-time multimedia applications. K. Malki [67] reported and summarized the measured handover delay and indicated that the handover delay is unacceptable in terms of supporting multimedia applications in IEEE 802.11 networks, since IEEE 802.11b is a *break-before-make* protocol, meaning it will finish its connection with the current AP before being able to discover and associate itself with the new one [96].

Mobile IP handovers can be improved through L2 information to reduce packet loss during handovers. L2 information can be used as hints when a handover has to be performed. It avoids link disruption during Mobile IP handovers and reduces packet loss. Mobile IP uses L2 information to force a handover to a new access network before any mobility at the L3 can be detected. This accelerates Mobile IP handovers with respect to changes in L2 characteristics.

Efficient execution of the handover requires the time that the MN is unable to exchange packets with the CNs should be minimal, and the number of packets dropped because of the handover should be minimal as well.

3.2 Proposed Mobile IP Handover Based on Link Layer Information Mechanism

Link layer information, such as signal strength, is continuously available, providing important accurate information about the link's quality. Therefore, L2 information allows an MN to predict the loss of connectivity more quickly than the L3 advertisement based algorithm [36, 102]. It is the best choice used to predict a breakdown wireless link before the link is broken. This facilitates the execution of the handover and eliminates the time to detect handover [39].

We propose Enhanced Mobile IP (E-Mobile IP) handover using L2 information, such as signal strength, network prefix, bandwidths and link indicator, which is continuously available, providing important information about the availability of new links [102]. Therefore, E-Mobile IP uses L2 information to allow an MN to predict the loss of connectivity more quickly than L3 advertisement based algorithms. Figure 3.1 describes the overall E-Mobile IP protocol message flow.

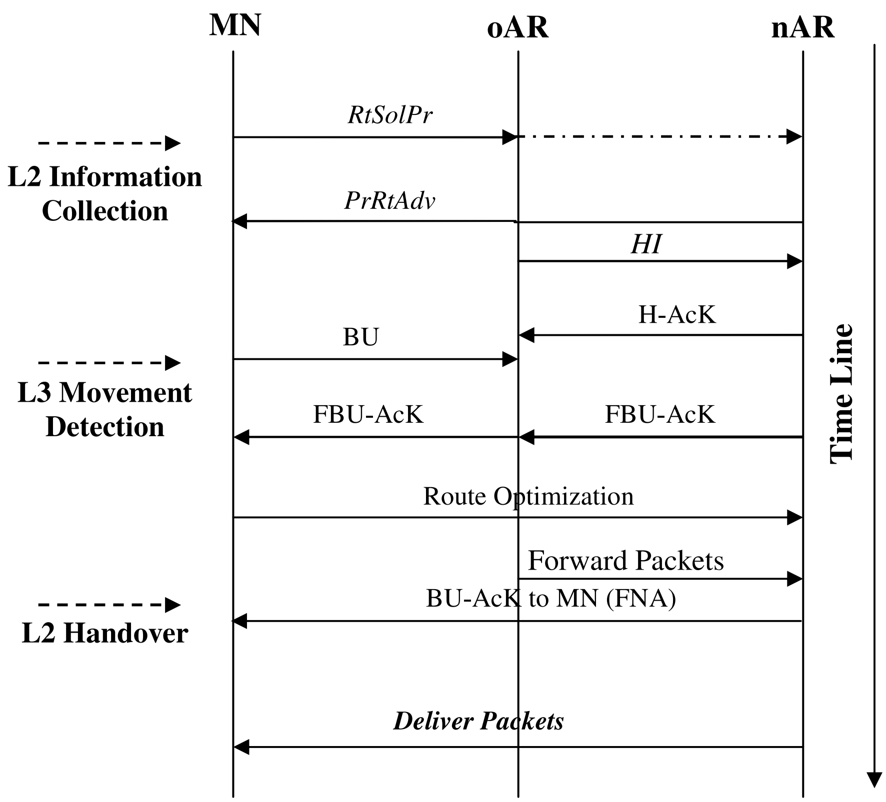

Figure 3.1: E-Mobile IP Protocol Message Flow

The π-Calculus E-Mobile IP handover system is described in terms of the following actions.

Handover system

The handover system is made up of the MN and access routers as follows:

$$System \overset{def}{\equiv} \mathrm{MN}\langle CoA \rangle \mid \mathrm{oAR} \mid \mathrm{nAR}$$

The E-Mobile IP handover system is made up if parallel compositions of a MN primitive to (CoA) communicate with both oAR and the nAR

1. Mobile Node (MN)

The MN will receive a link from the nAR, which is used to communicate with it. Then, the MN sends *RtSolPr* to inform the oAR that it is going to handover to the nAR.

$$MN\left(CoA\right) \overset{def}{\equiv} \overline{RtSolPr}\,\langle CoA\rangle\,.\,PRtAdv\;(nCoA, Link\;Information, LinkIdentifier)$$
$$\overline{BU}\langle new\rangle\;.\;FBU\text{-}AcK.\;FNA.\;MN\langle\;nCoA\;\rangle$$

MN will send a disassociation request including all other requirements to the oAR to let it know that it is going to make a handover to the nAR. MN will initiate L3 handover by sending an *RtSoIPr* message to the oAR, if the L2 trigger is received at the mobile-initiated handover. On the contrary, the oAR will send *PRtAdv* to the MN, if the L2 trigger is received at the network controlled handover [99, 104].

Then; MN checks the neighbour cache to determine the L2 address of the next nodes, a neighbour is considered reachable if it has recently received confirmation that packets sent to the neighbour have been received [43, 105].

An MN obtains an nCoA while it is still connected to the oAR; it performs this by receiving the RA included in the visited network information from the nAR.

2. Old Access Router (oAR)

The oAR is made up of the following components:

RtSolPr: an action utilized by the MN, sent to its current AR to request information about likely candidate APs and handle the MN initial request for the handover.

Forward: an action which passes both new and old CoAs.

HI: a request message sent to the nAR to make the handover process.

The oAR first receives the handover request from the MN, and then sends it directly to the nAR:

$$\begin{aligned} oAR \overset{def}{\equiv} & \ \mathrm{RtSolPr}\ (\mathrm{oCoA})\,.\,\overline{\mathrm{Forward}}\,\langle \mathrm{oCoA} \rangle\,.\,PRtAdv\,(nCoA, Link\ Informatio\,n, LinkIdenti\,fier). \\ & \overline{PRtAdv}\,(nCoA, Link\ Informatio\,n, LinkIdenti\,fier)\,\overline{\mathrm{HI}}\,.\ \mathrm{HAcK} \\ & BU.\ FBU\text{-}Ack.\ \overline{FBU\text{-}AcK}\,.\ \langle\ Forward\ P\,ackets\ \rangle.\ oAR \end{aligned}$$

The oAR will validate the nCoA and send a Handover Initiation (HI) message to the nAR to establish the bi-directional tunnel process between oAR and nAR [102].

After the oAR receives the BU, it must verify that the requested handover is accepted as it was indicated in the H-AcK message.

The oAR starts forwarding packets addressed for the oCoA to the nAR and sending a Binding Update Acknowledgement (BU-AcK) with a Fast Neighbour Advertisement (FNA) to the MN.

3. New Access Router (nAR)

The nAR is made up of the following components:

Forward: an action which passes both new and old CoAs.

PRtAdv: the response by the present AR, containing the neighbouring router's advertisement for the link information and network prefix.

H-Ack: a confirmation sent back to the oAR to make the handover to the nAR.

$$nAR \overset{def}{\equiv} Forward(oCoA).\overline{PRtAdv}\langle nCoA, Link\ Information, LinkIdentifier\rangle.$$
$$HI.H\text{-}AcK.\overline{FBU\text{-}Ack}.\langle Forward\ Packets\rangle.\overline{FNA}.nAR$$

The nAR will respond with the Handover Acknowledgment (H-AcK) message. Then the MN sends a BU to the oAR to update its binding cache with the MN's nCoA.

When MN receives a *PrRtAdv*, it has to send a BU message prior to disconnecting its link.

Upon verification of the variables, nAR will send the Acknowledgment (*ACK*) to confirm its acceptance; then the oAR will start sending the buffered packets to the nAR distend to the MN.

3.3 Evaluation Environment

3.3.1 The Network Simulator (NS-2)

The network simulator (NS-2) is based on two languages: an object oriented simulator, written in C++, and an OTcl (an object oriented extended Tcl) interpreter, used to execute user command scripts [106, 107, 108]. The NS-2 is a discrete event simulator, where the advance of time depends on the timing of events which are maintained by a scheduler.

3.3.2 Why NS-2

NS-2 covers a very large number of applications, protocols, network types, network elements and traffic models. It is at its core, a Discrete Event Simulation (DES) environment. Packets and protocol dynamics are all explicitly modelled and scheduled as sequential events at exact simulation times, in instances which are managed by the simulation kernel. A protocol modelled in a DES simulation behaves in much the same way in a real-life production environment, as any protocol can be modelled in the same intricate detailed way. While these alternatives are generally quicker in execution, and can be used to study reachability and routing across a network, they will not reflect the impact of timer expiration and packet jitter on application performance.

We chose NS-2 as it is open and not commercial [109, 110]. There are several open source and commercial alternatives around, such as OPNET, OMNeT++, GloMoSim and QualNet. Our decision to go with the NS-2 product was based on several factors:

1. It is a very solid, robust and scalable simulation kernel.
2. Most of the standard library models are open source and well documented to allow modifications.
3. It has an integrated graphical environment, including network editors and result analysis tools.
4. It has a huge standard model library, ranging from detailed wireless communication modelling, to a feature-rich IP stack, to detailed application modelling.

3.4 Simulation Scenario and Configuration

The simulations are carried out using network simulator ns-2 version ns-allinone-2.31, implementations of the E-Mobile IP handovers [110, 111]. The simulator is modified to emulate IEEE 802.11 infra-structured behaviours with multiple disjoint channels. This modification forces L2 handover operations, where stations only receive data packets via one AP at a time. The domain contains eight ARs, each one managing a separate IEEE 802.11 cell.

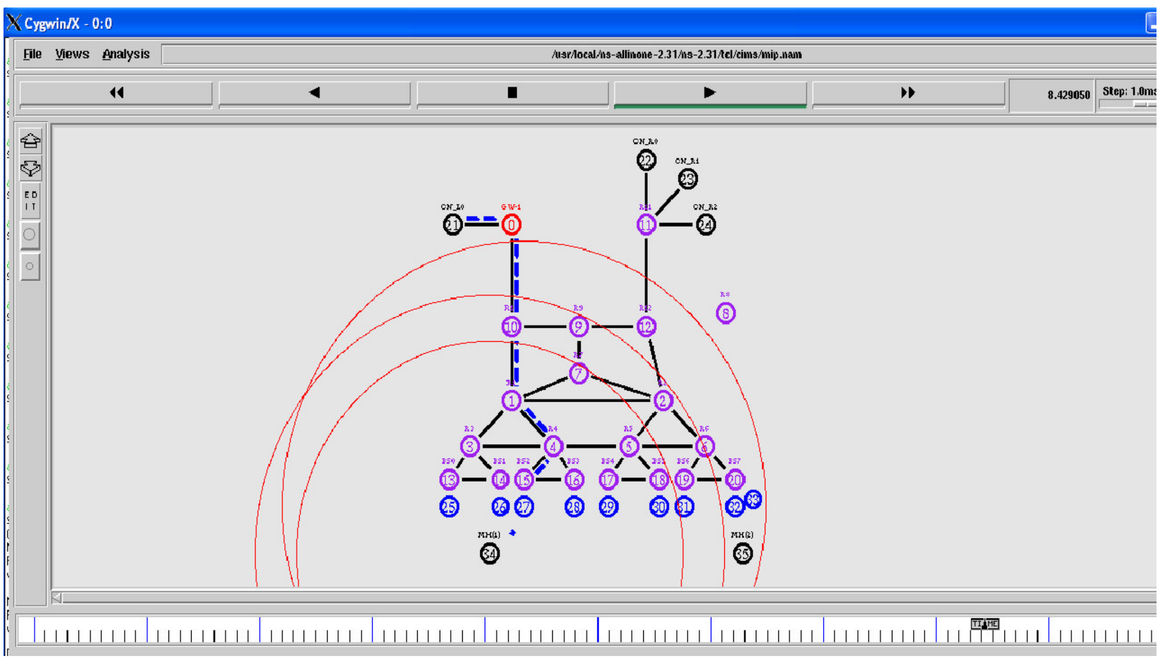

Figure 3.2: Simulation Snapshot

The network features three MNs connected to it; the first will move sequentially from AR to AR, starting at AR1. In each test, the MN1 will be the receiver of a CBR or FTP traffic source, generating either UDP or TCP packets. This traffic originates from the CN1 outside the network, or inside the domain from CN2. All presented results are taken as the average of multiple independent runs, coupled with a 95% confidence interval.

Table 3.1: Simulation Parameters

Simulation parameter	Value
Simulator	Ns-allinone-2.31
Network range	600m×600m and 1000m×1000m
Transmission range	25m
Mobile nodes	3 and 7
Traffic generator	Constant bit rate
Bandwidth	2Mbps
Packet size	512 bytes
Packet rate	10 packet per second
Simulation time	900s and 1200s

In our simulation, we use a 600m × 600m and a 1000m × 1000m area with a 3 to 7 MNs [19, 36]. The network bandwidth is 2 Mbps and the medium access control (MAC) layer protocol is IEEE 802.11 [63]. The packet size is 10p/s which will generate enough traffic when we increase the number of connections for example at 40 connections of source-destination pairs, it will generate 400 packets per second for whole scenario. Other simulation parameters are shown in Table 3.1. These parameters have been widely used in the literature [74, 76, 91].

The main purpose behind the proposed approach is to reduce the handover latency and the number of packets loss. As a result, end-to-end delay can also be reduced and the throughput can be improved.

3.5 Performance Analysis and Evaluation

The measured services are defined as follows.

- Throughput is the amount of data transferred from one place to another or processed in a specified amount of time. Normally throughput and latency are conflicting goals.
- Latency is measured from the time a request (for example, a single packet) leaves the client, to the time the response (for example, an acknowledgment) arrives back at the client from the serving entity and the unit of latency is time.
- Packet loss is considered to be the number of packets that have been sent from the source and not received by the destination.

3.5.1 Fast Registration

In order to allow fast registration this system defines a network initiated handover which is faster than the MN initiated handover. This allows us to forward data to the nFA while the MN is still on its way to the nFA [neighbours]. Therefore, with prediction it is possible to prepare an L3 before the L2 handover to reduce latency and packet loss.

The TCP throughput between MN and CN was measured for the E-Mobile IP, Standard Mobile (S-Mobile IP) and previous study of Mobile IP [74, 76]. Some of these results are shown in Figure 3.3, values are averages over several measurements made on the receiving process for CN to MN down stream traffic.

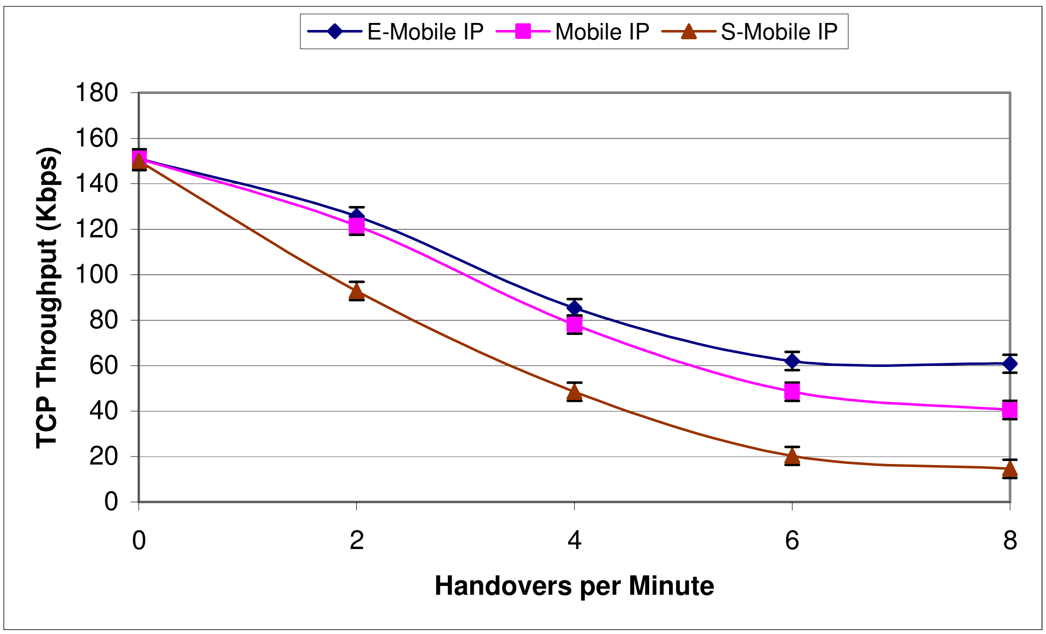

Figure 3.3: TCP Throughput for Data Transfer from CN to MN

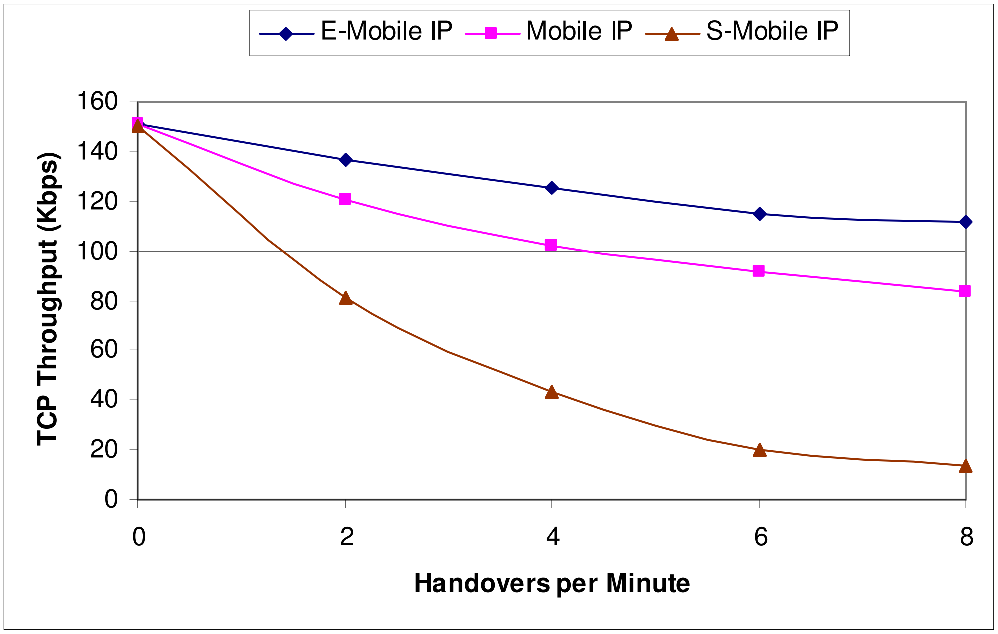

Figure 3.4: TCP Throughput for Data Transfer from MN to CN

Measurements of TCP throughput in Figure 3.4 are also made for upstream traffic from the MN to the CN. The throughput degradations using Mobile IP with an increasing number of handovers per minute are similar in this case to the previous case. These are not unreasonable values for Mobile IP, where HA and FA could be very far away from each other, the resulting degradation in performance is evident.

However, E-Mobile IP performs better in upstream direction, because, even before the crossover node is aware of the handovers, data packets following the handover message are already taking the right path for transferring packets, due to the route update (TCP acknowledgments may be lost during this time though, accounting for the slight degradation in throughput as the handover rate increases).

3.5.2 Packet Buffering

Mobile IP does not buffer packets sent to an MN during handovers. Therefore, these packets may be lost and need to be retransmitted. The use of buffering aims to eliminate packet loss during handover. This is because an MN needs a time to switch its L2 connectivity from the oFA to the nFA. During this time the incoming packets can be stored in the nFA buffer. The MN starts receiving the buffered packet after it connects to the nFA. Therefore, an improvement, often part of the solutions suggested, is the use of buffers located at the FAs during handovers. These are used to catch packets destined for the MN. When the MN is connected to an nFA, the oFA will forward the buffered packets to the MN.

In Figure 3.5 and Figure 3.6 the expected number of lost packets is shown as a function of the buffer size at the oFA. Figure 3.5 shows that the results for link delays are equal to 5ms on every scheme of the simulated Mobile IP, whereas in Figure 3.6 the three schemes on the nFA path are increased to 10ms each.

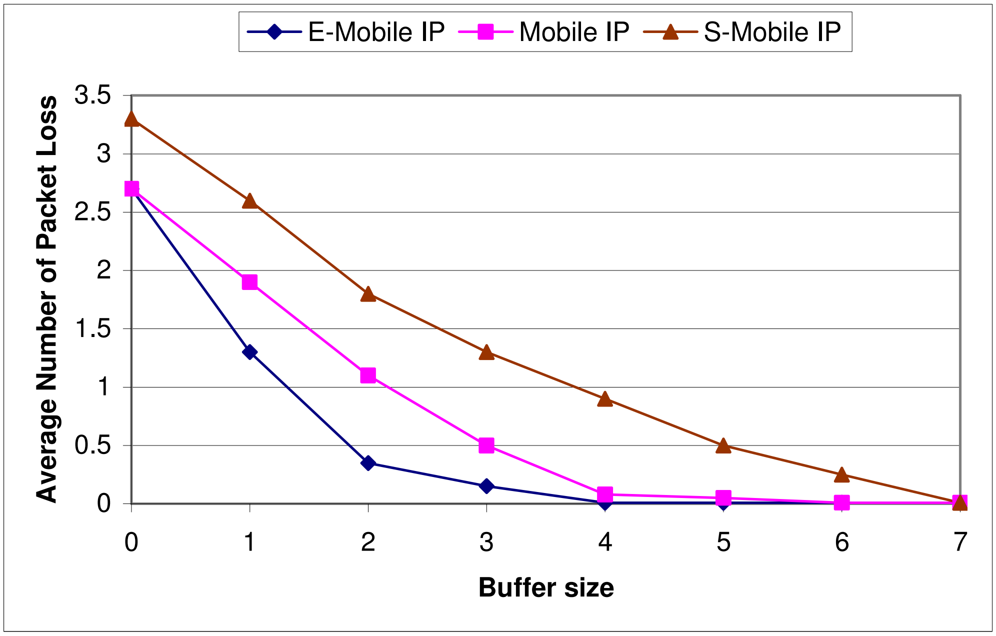

Figure 3.5: Packet Loss as a Function of the Buffer Size (Link Delay 5ms)

Obviously, whenever the buffer size is increased the loss in the buffer at the oFA is decreases. However, it possibly contributes, in the latter case, to the number of lost packets at the nFA. This is especially true for the case of the 10ms-link delay on the nFA-oFA path, because the all buffered packet will early reach the destination of the nFA before the registration reply (*ReRep)* message from the nFA reaches the oFA. More precisely, when the delay is going to be long on the nFA path, if a packet is not dropped at the oFA, it is considered to be lost at the nFA.

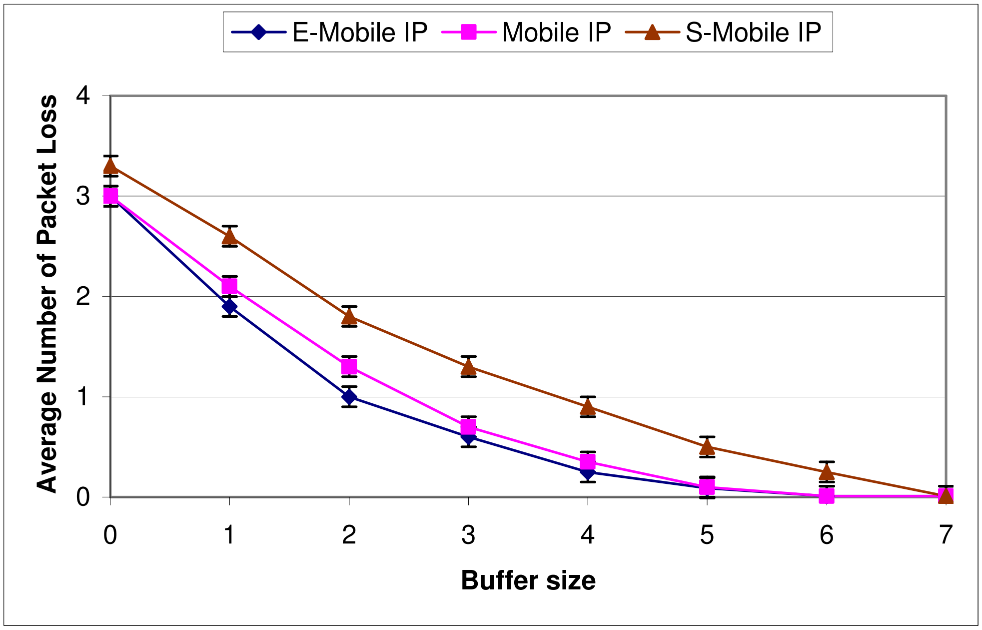

Figure 3.6: Packet Loss as a Function of the Buffer Size (Link Delay 10ms)

In order to avoid packet loss at the oFA, the dimensions of the forwarding buffer need to be such that it can store packets in the order of the product bit rate of the stream times delay (MN; nFA; oFA). The loss at the nFA, on the other hand, depends on the difference of the distance between each of (nFA; HA) (nFA; oFA). If the latter is smaller than the former, then packets may get lost. A possible solution would be to provide the nFA with a buffer to store temporarily unauthorized traffic until the *ReRep* from the oFA arrives at the nFA.

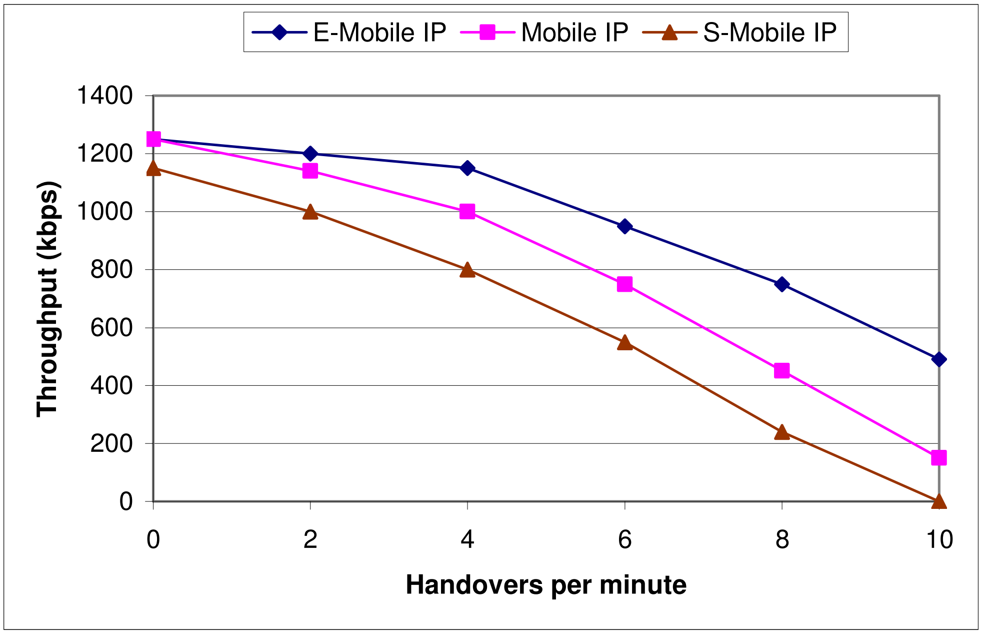

Figure 3.7: TCP Throughputs with Handover

Packet retransmission behaviour is more useful for TCP traffic, because throughput is more closely related to the packet transmission and retransmission behaviour. Slight differences in the number of packets dropped may result in timeouts occurring in one situation and not another, resulting in rather significant differences in packet retransmission behaviour, and hence, in throughput performance.

As indicated in Figure 3.7, it is expected that the packet loss, in TCP transmissions using E-Mobile IP, is always low compared to in other schemes of the implemented Mobile IP. This result shows throughput with handoff rate: the Mobile IP and S-Mobile IP schemes have lower performance compared to the E-Mobile IP handover; this is because of the packet loss for S-Mobile IP in the oFA is still a big issue. The process involves the registration message going from the nFA to the HA, but during the time between the MN leaving the oFA and HA receiving the MN registration message the HA still forwards packets intended for the MN to the oFA and eventually these packets will be discarded. While in the case of the E-Mobile IP scheme the packet will be forwarded to the nFA in advance and will be received by the MN.

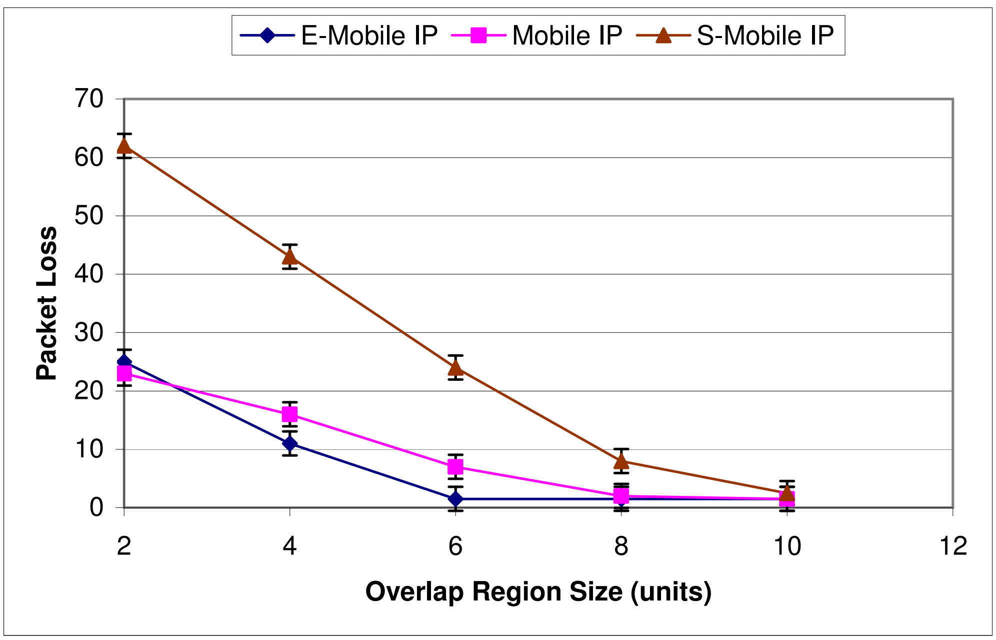

Figure 3.8: Average of Packet Loss per Handover and Overlap Region Size

The total number of packets loss over 5 handovers increases as the time in the overlap region decreases. Figure 3.8 shows that, for E-Mobile IP, when the size of the overlap area increases the number of packets lost will decrease. The effect for the two other Mobile IP schemes is due to the channel loss.

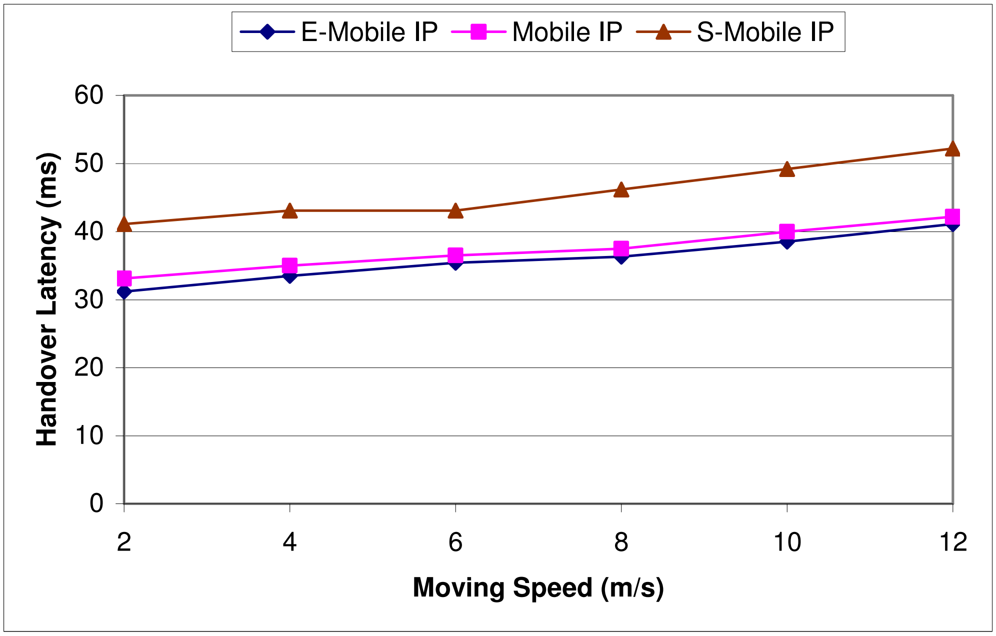

Figure 3.9: Impact of Moving Speed and Layer 2 Beacons

Next we vary the movement speed of MN from 2m/s up to 12m/s, and vary the L2 beacon period from 20ms to 60ms. As shown in Figure 3.9, when MN's moving speed is less than 5m/s, the impact of moving speed is not obvious. When MN moves faster, the whole Mobile IP scheme will experience higher handover latency due to MN having insufficient time to prepare for the handover. Therefore, there is a higher possibility that the packets are forwarded to the outdated path and are lost. The time instance during which MN can receive packets from a new path will be postponed and the handover latency increases accordingly.

Comparing the curves of different L2 beacon periods in Figure 3.9, we can see S-Mobile IP generates the highest handover latency at low moving speeds (under 50m/s). This is because of too small a beacon period (for example, 12ms) produces a high volume of beacons. The packet loss rates for the signalling packets thus increase, and require additional retransmission time to deliver them successfully. The handover latency will, therefore, increase. However, at higher speeds (more than 5m/s), the small L2 beacon period can help the MN to detect the nAP and begin the L2 connection setup earlier, thus reducing the possibility that packets are forwarded to the outdated path, resulting in a decrease in the handover latency.

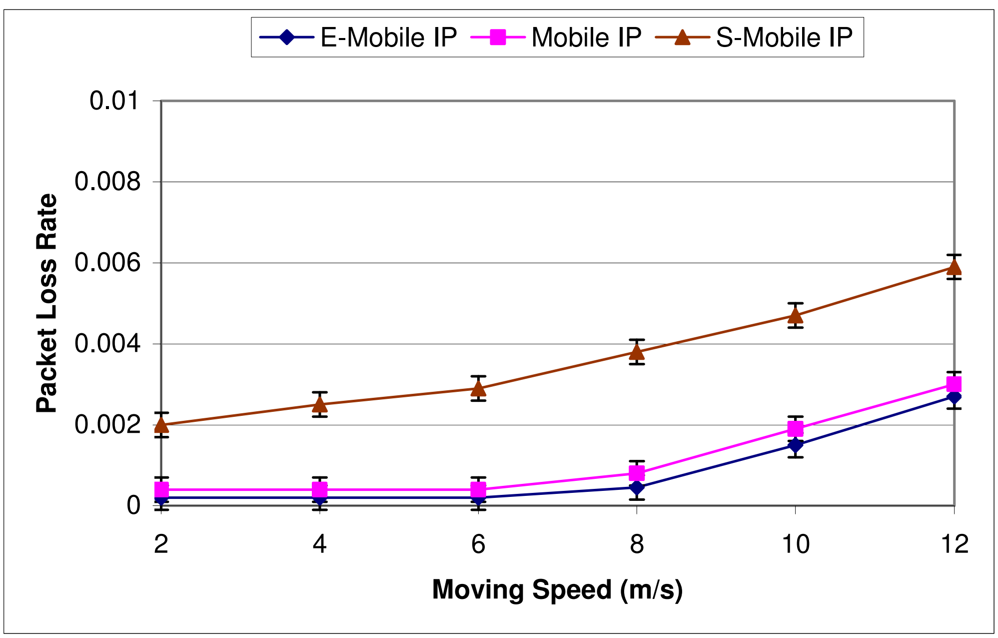

Figure 3.10: Impact of Moving Speed and Beacon Period on Packet Loss Rate

When the MN moves faster than 6m/s, S-Mobile IP experiences a higher packet loss rate in Figure 3.10 and decreased throughput in Figure 3.11 when compared with those of a low moving speed. This is because the possibility of packets being forwarded to an outdated path increases with an increase in the speed

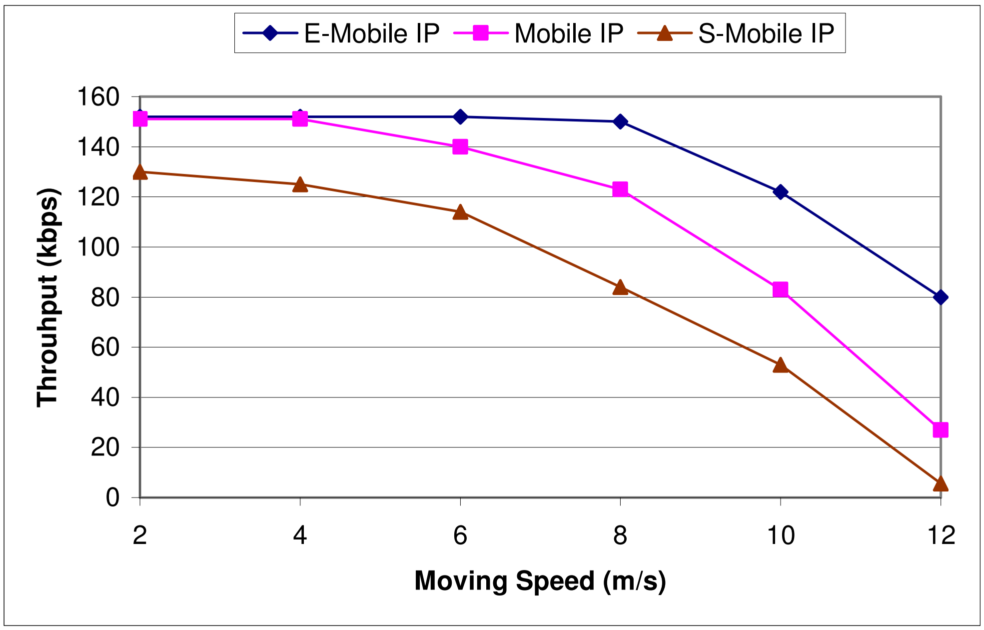

Figure 3.11: Impact of Moving Speed and Beacon Period on Throughput

These packets are dropped by AR1/AR2, either because they are not aware of MN's current location or because the buffer space is full. We can also notice that reducing the L2 beacon period somewhat offsets the impact of high speed by detecting the nAP and beginning the L2 connection setup earlier. Therefore, there will be a smaller probability that the packets are sent to an outdated location and get dropped by the AR.

3.6 Summary

In this chapter we developed and analyzed the proposed scheme of the Enhanced Mobile IP (E-Mobile IP) handover based on the L2 information scheme, we then compared the experimental results with the results of the Mobile IP and S-Mobile IP. The performance study in this chapter indicates that the use of L2 information with location information helps to minimize packet loss and improve the throughput of Mobile IP handover.

We have seen that the starting point for packet loss could happen in two ways: first, packets may get lost in the oFA when the forwarding buffer overflows and secondly, packets may get lost in the nFA when, upon their arrival, the *ReRep* from the HA has not arrived in the nFA. The first reason for loss may be avoided by appropriately dimensioning the forwarding buffer. This buffer should be able to store arriving packets at least during a time equal to the delay on the nFA and oFA path. The second loss is more difficult to deal with. It is determined by the difference between the delays of the paths oFA, nFA and nFA, HA.

In addition, we evaluated the impact of L2 setup on different performance measures of Mobile IP, together with handover latency, packet loss and throughput. The simulation results show that E-Mobile IP handover latency is not too sensitive to L2 setup latency and beacon periods compared to the other schemes of Mobile IP. Moreover, E-Mobile IP can achieve a fast and seamless handover if MN's moving speed is not too high, but is within reasonable limits.

The reasons for the improved performance of the proposed scheme include the exploitation of location information and the use of the powerful entity RA for complex tasks. In the proposed scheme the powerful RA was used for most of the decision processes necessary for handover. Simulation results in this chapter demonstrate that in most cases the L2 information handover scheme improves the TCP and UDP performances.

Chapter 4

Mobile IP Low Latency Handover

4.1 Introduction

Mobility management requires two steps, movement detection by the MN and registration with the HA. Every time the MN changes its point of attachment, the MN must perform these two steps to continue to receive packets [113, 114]. However, it is the MN that initiates the process by sending a registration request (*RegReq*) after it has detected that it has moved from one network to another, and has obtained a new point of attachment. This introduces two causes of latency: move detection latency and registration latency. Move detection latency is the time required by the MN to detect that it has changed its point of attachment. It can be lengthy since the movement detection mechanisms in Mobile IP are based on either expiration of the lifetime indicated in the FA advertisements, or on the comparison of the address prefixes of two different agent advertisements [115].

Registration latency is the required time to complete registration with the HA. As this HA can be located anywhere on the Internet, this process can take a long time and sometimes is impossible to complete [97, 98]. This delay is inherent in the round trip incurred by Mobile IP as the *RegReq* is sent to the HA and the response is sent back to the FA [90].

Tunnelling mechanisms introduce network overheads in terms of increased delay, packet losses and signalling [112]. For example, many real-time wireless applications (for example, Voice-Over-IP) would experience noticeable degradation of service with frequent handovers.

In certain cases, the latency involved in handover can be above the time required for the support of delay-sensitive or real-time services. The presented techniques allow greater support for real-time services on a Mobile IP network by minimizing the period of time when an MN is unable to send or receive IP packets due to the delay in the Mobile IP registration process [82, 116, 117].

4.2 Combined Pre-Post Registration Mode

In a low latency handover combined mode, both pre-registration and post-registration handover methods are used.

Firstly, the combined mode follows the pre-registration handover procedure. If the pre-registration handover does not finish prior to the expiration of a timer (maintained by either oFA or nFA), the post-registration method is launched.

Secondly, with the combined method, the handover disruption time can be kept to a minimum (close to the L2 handover latency), the registration process can be carried out as soon as possible and it is possible to retrieve the packets destined for the MN that have arrived at the oFA during the MN's L2 handover period. In other words, the combined mode has the advantages of both the pre-registration and the post-registration modes [67, 117].

4.3 Proposed Mobile IP Low Latency Handover

The protocol of low latency handover in Mobile IPv4 [23] is designed to provide the following functions:

1. To allow an MN to get in touch with its handover target FA (nFA) before its connection with its current FA (or oFA) breaks.
2. To deliver packets to and from the MN as soon as its connection with the nFA is set up, without waiting for the registration process to be complete.

As shown in Figure 4.1, with the first function listed above, the agent discovery phase can be moved from after the L2 handover to before the L2 handover. In other words, the movement detection process can start before an actual handover occurs.

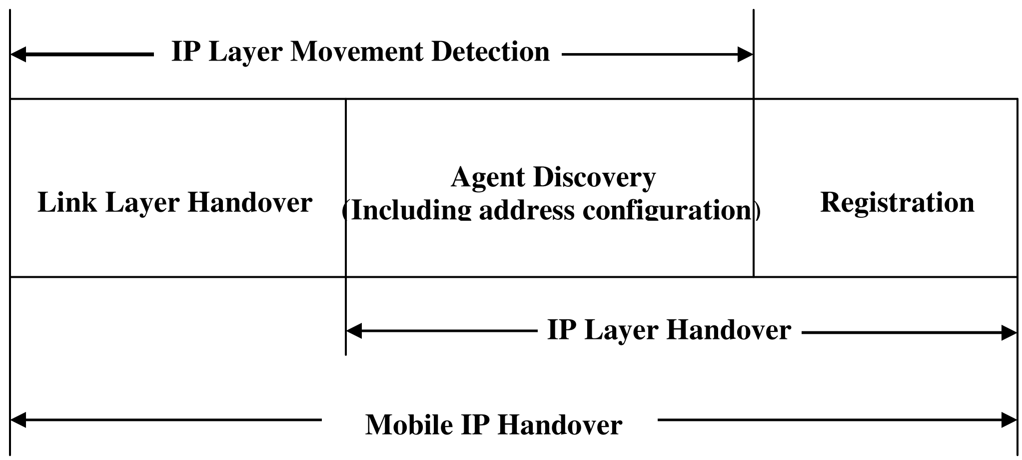

Figure 4.1: Major Mobile IP Handover Phases

Moreover, the registration process can also be launched via the oFA and, therefore, it can be run in parallel with the L2 handover. With the second function, the MN's registration latency can be removed from the total Mobile IP handover interruption period, even if the registration process has not been finished after the L2 handover. As a result, in an optimal situation, the overall Mobile IP handover latency can be limited to be close to the L2 handover latency [118, 119].

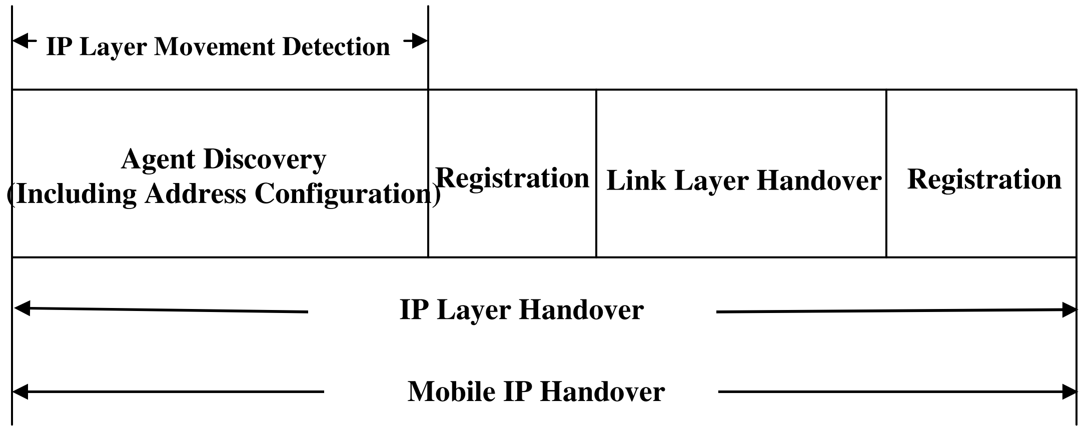

Figure 4.2: A Possible Sequence of Mobile IPv4 Low Latency Handover Phases

Figure 4.2 shows a possible sequence of a Mobile IPv4 handover's phases with the assistance of the low latency handover protocol. Comparing Figure 4.1 with Figure 4.2, the difference lies in the fact that, in Mobile IPv4 low latency handover, the IP layer handover is run in parallel with the L2 handover [118]. Moreover, only in the L2 handover phase is the MN definitely not able to send and receive IP packets in Mobile IPv4 low latency handover; on the other hand, in normal cases, the MN is usually not able to send and receive IP packets during the whole Mobile IP handover process [119].

The low latency handover in Mobile IP protocol enables an MN to quickly detect in the IP layer that it has moved to a new subnet by receiving link related information from the L2; furthermore, it gathers anticipation information about the new AP, and the associated subnet prefix when the MN is still connected to the previous subnet [5, 35, 120]. The overall message exchange is described below in Figure 4.3:

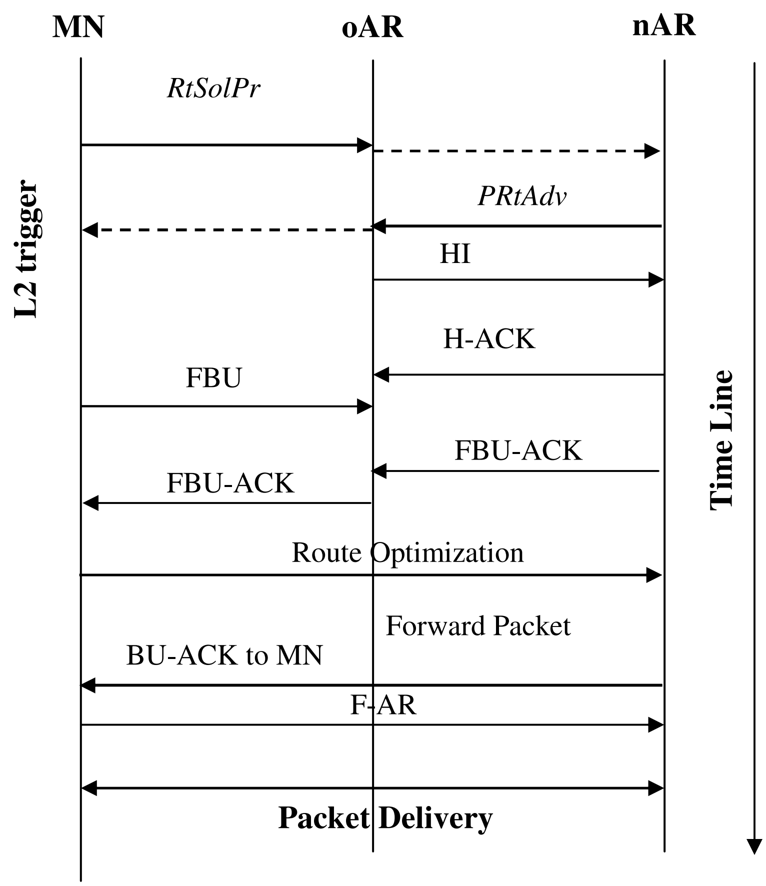

Figure 4.3: Message Exchange during Mobile IP Handover

Handover system

The handover system is made up of MN and access routers as follows:

$$System \overset{def}{\equiv} \mathrm{MN}\langle CoA \rangle \mid \mathrm{oAR} \mid \mathrm{nAR}$$

The E-Mobile IP handover system is made up if parallel compositions of a MN primitive to (CoA) communicate with both oAR and the nAR

1. Mobile Node (MN)

The MN will receive a link from the nAR, which is used to communicate with it. Then, the MN sends *RtSolPr* to inform the oAR that it is going to handover to the nAR.

$$MN\,(CoA) \overset{def}{\equiv} \overline{RtSolPr}\,\langle CoA\rangle\,.\,PRtAdv\,(nCoA, Link\ Information, LinkIdentifier)$$
$$H\text{-}Ack.\ \overline{FBU}\,\langle new\rangle\,.\,FBU\text{-}AcK.\ \overline{FAR}\,.\,MN\langle\, nCoA\,\rangle$$

MN will send a disassociation request including all other requirements to the oAR to let it know that MN will make a handover to the nAR. MN will initiate L3 handover by sending an *RtSoIPr* message to the oAR.

Then, MN checks the neighbour cache to determine the L2 address of the next hop node. The MN obtains an nCoA in time while it is still connected to the oAR, it does so by receiving included information about the visited network from the nAR

2. Old Access Router (oAR)

The oAR is made up of the following components:

RtSolPr: an action utilized by the MN, sent to its current AR to request information about likely candidate APs and handle the MN initial request for the handover.

Forward: an action which passes both new and old CoAs.

HI: a request message sent to the nAR to make the handover process.

$$oAR \overset{def}{\equiv} \text{RtSolPr}\ (oCoA)\,.\,\overline{\text{Forward}}\,\langle oCoA\rangle\,.\,PRtAdv\ (nCoA, Link\ Informatio\,n, LinkIdenti\,fier)$$
$$\overline{PRtAdv}\,\langle nCoA, Link\ \ Informatio\,n, LinkIdenti\,fier\rangle.$$
$$\overline{HI}\ .\ H\text{-}Ack\ .\ FBU - AcK\,.\ \overline{FBU\text{-}Ack}\ .\ oAR$$

The oAR first receives the handover request from the MN, and then sends it directly to the nAR. When MN receives a *PRtAdv*, it has to send FBU message prior to disconnect its link.

The MN sends an FBU to the oAR to update its binding cache with the MN's nCoA. After the oAR receives FBU, it must verify that the requested handover is accepted as it was indicate in H-ACK message.

Then; the oAR starts forwarding packets addressed for the oCoA to the nAR and sending BU-ACK with fast access router F-AR to the MN.

3. New Access Router (nAR)

The nAR is made up of the following components:

Forward: an action which passes both new and old CoAs.

PRtAdv: the response by the present AR, containing the neighbouring router's advertisement for the link information and network prefix.

H-Ack: a confirmation sent back to the oAR to make the handover to the nAR.

$$
\begin{aligned}
nAR \overset{def}{\equiv} & \; Forward\,(oCoA).\overline{PRtAdv}\,\langle nCoA, Link\ Informatio\ n, LinkIdenti\ fier\rangle . \\
& HI.\ \overline{H\text{-}AcK}\ .\ \overline{FBU\text{-}AcK}\ .\ BU\text{-}AcK.\ \langle Forward\,Pa\ ckets\rangle\ .FAR\,.nAR
\end{aligned}
$$

The nAR will respond with a H-ACK message. Upon verification of the variables, nAR will send the Acknowledgment (*ACK*) to confirm its acceptance; then oAR will start sending the buffered packet to nAR to send to the MN

4.4 Evaluation Environment

The base simulation setup for our simulation of E-Mobile IP handover is implemented using IST-CIMS in ns-2 version ns.allinone.2.31 which has been adopted to conduct the simulation experiments. This section will lay out the experimental scenarios and how simulation parameters were configured [109, 110, 111]. A simple wireless model is used that assumes perfect overlapping coverage, no propagation delay and no transmission errors. Furthermore, handovers are smooth, instantaneous at L2 and below. Routing needs to be refreshed and the route update intervals used are 3 and 60 seconds, respectively.

Lightly loaded network conditions are simulated, with only 3 to 5 MNs and 8 CNs. The handover rate is once every five seconds on average, with exponentially distributed handover intervals, and the handovers are back and forth between ARs.

Table 4.1: Simulation Parameters

Simulation parameter	Value
Simulator	Ns-allinone-2.31
Network range	500m×500m
Transmission range	25m
Mobile nodes	3 and 5
Traffic generator	Constant bit rate
Traffic load	Varies, 200–800 Kbps
Band width	2Mbps
Packet size	512 bytes
Simulation time	800s and 1200s

The simulation scenarios studied in this research were designed to investigate the performance of the low latency Mobile IP handover. The scenarios are composed of 3 and 5 MNs, with an area of 500m x 500m. Each MN operates under the IEEE 802.11 [23, 38] standard at a 2 Mbps network bandwidth [67], and traffic load are varies, 200–800 Kbps other parameters are shown in Table 4.1.

4.5 Performance Analysis and Evaluation

1.5.1 Handover Rate

As the MN moves faster, it spends less time in the overlap region so the possibility of losing packets increases. We define the handover rate as the number of handovers in one minute.

The loss rate on wireless links varies from 0.0001 to 0.1, and the initial traffic load is fixed at 400 Kbps; the results are shown in Figure 4.4 and Figure 4.5. One can see that in a very low packet loss rate (0.0001), both E-Mobile IP and the previous study of Mobile IP [38, 67] have a throughput higher than that of S-Mobile IP. When the packet loss rate is in the mid-range (that is, 0.001 and 0.01), E-Mobile IP performs well. When the packet loss rate is very high (that is, 0.1), most schemes drop their throughput to very low values.

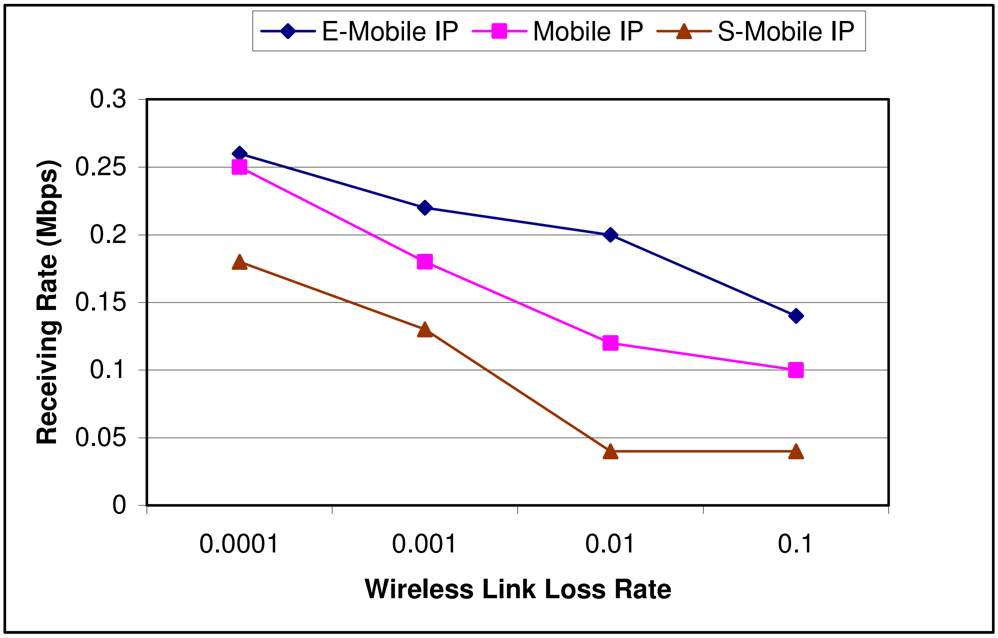

Figure 4.4: Comparison of Receiving Rate

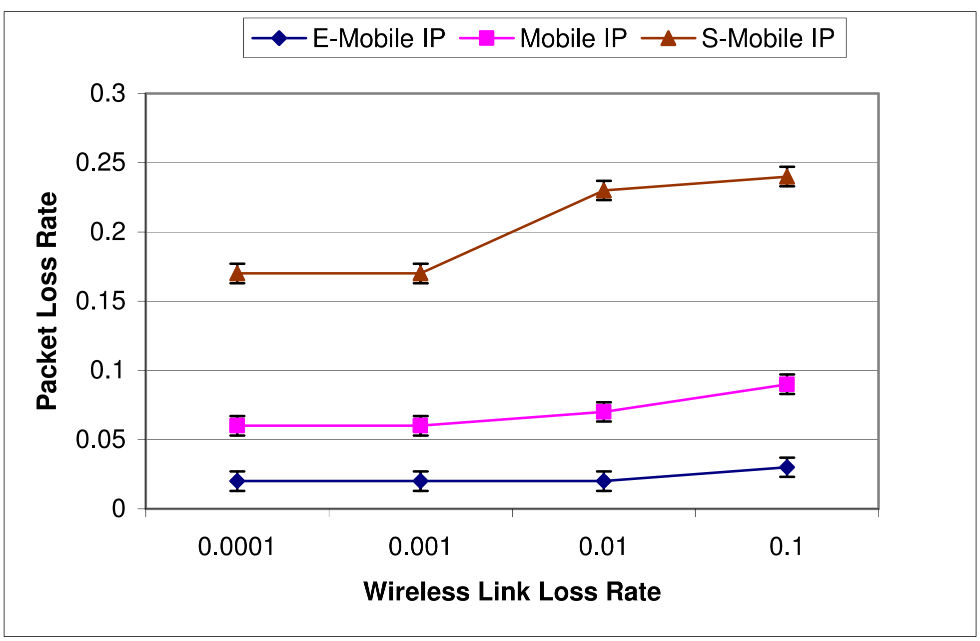

Figure 4.5: Comparison of Loss Rate

Figure 4.5 show that all schemes except S-Mobile IP keep a low loss rate. When the link is very low (0.1 loss rate), E-Mobile IP still maintains a loss rate lower than both schemes, even while keeping a higher throughput. This set of experiments verifies the fact that E-Mobile IP performs well in loss links; it maintains a stable throughput and a low packet loss rate.

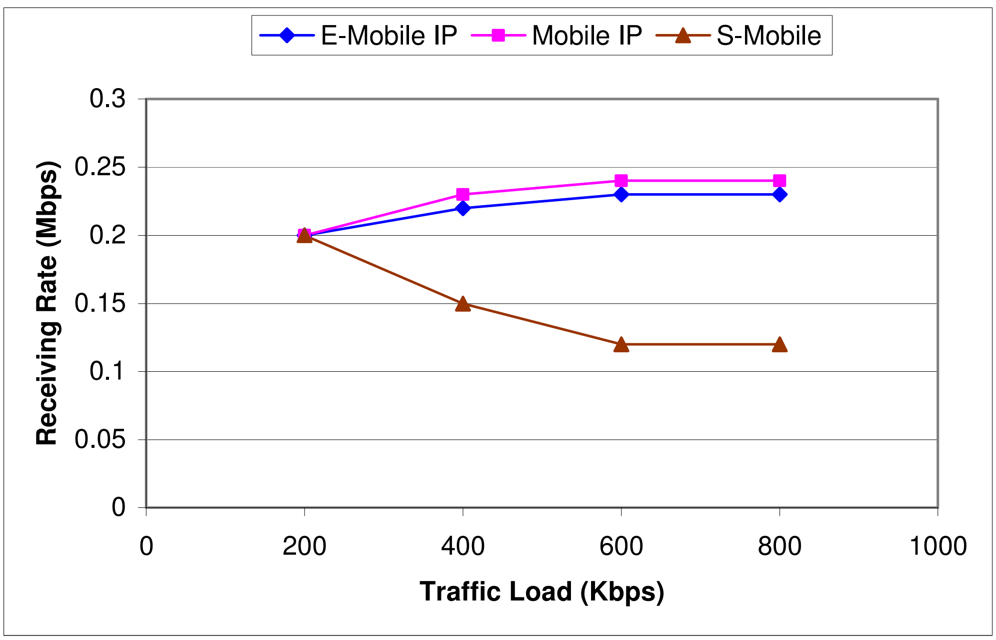

Figure 4.6: Comparison of Receiving Rate

The initial traffic load of the E-Mobile IP is varied, ranging from 200 Kbps to 800 Kbps. Results on averaged receiving rate and the packet loss rate measured at receivers, are shown in Figure 4.6 and Figure 4.7, respectively (results on average for the sending rate are not shown, as they are very similar to those of the receiving rate).

E-Mobile IP yet it maintains a rate slightly lower than the previous result for Mobile IP, and they have the highest receiving rate compared to the S-Mobile IP. All control schemes are able to maintain a very low packet loss rate (below 3%), except S-Mobile IP; this is due to the absence of slow-start rate control for the sender that causes an initial large packet loss.

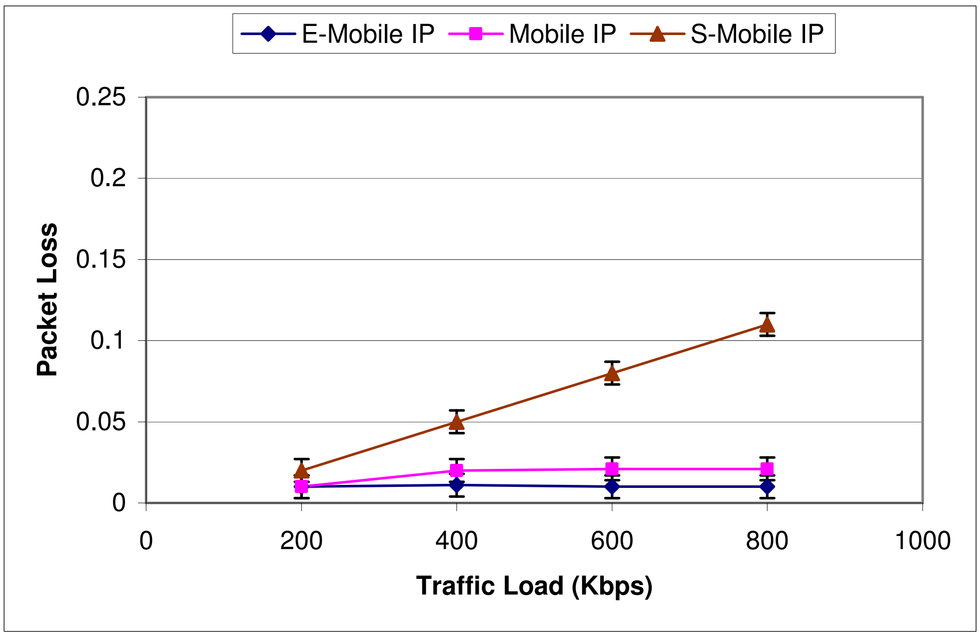

Figure 4.7: Comparison of Loss Rate

1.5.2 Packet Loss

Some results for the simulations in a light and heavy traffic scenario are shown in Figure 4.8 and Figure 4.9. As can be expected, increasing the link bandwidth would decrease the number of packets dropped per handover, because the packets spend less time in transit. Similarly, increasing the sizes of the update packets would increase the number of packets dropped per handover, as the update packets will take longer to arrive at their destinations.

Looking next at a light traffic scenario, it can be seen that for E-Mobile IP, the short packet has more dropped packets per handover. However, as in the heavy traffic scenario, the variation is greater for S-Mobile IP, in addition to the actual numbers being worse.

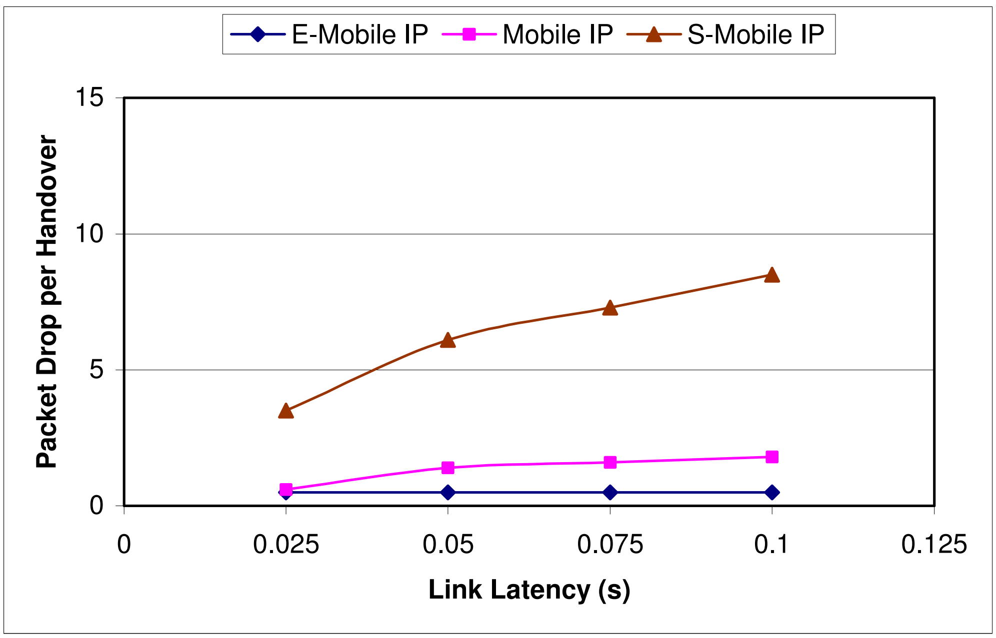

Figure 4.8: Packet Dropped per Handover in a Light Traffic Scenario

With S-Mobile IP, the performance is worse (more packets dropped per handover), even for this best-case scenario where the CN and HA are close together. Furthermore, the spread is worse between the performances of the different cases when the link bandwidths are modified and/or the update packet size is modified.

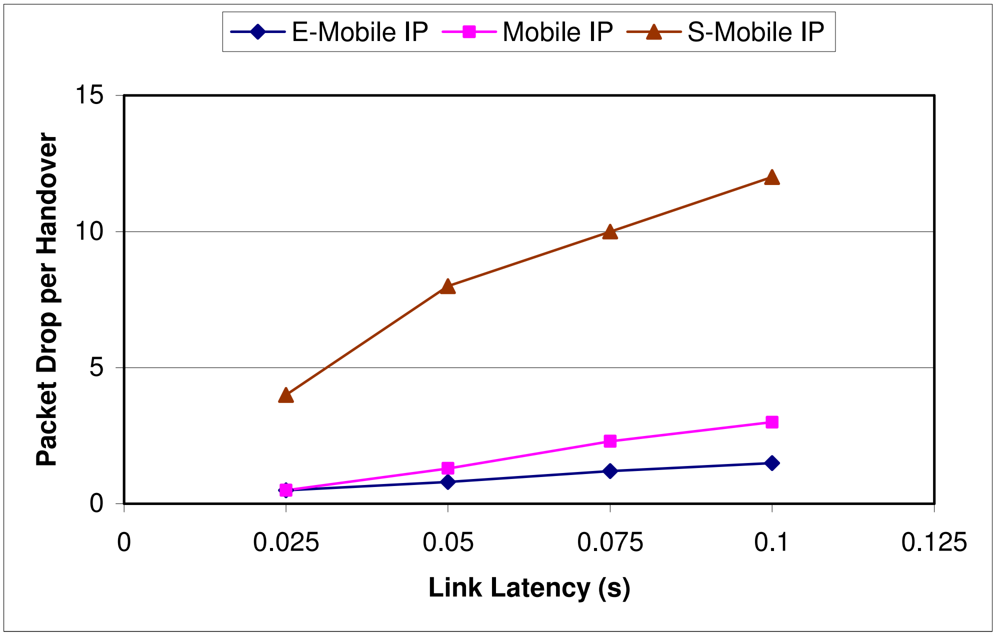

Figure 4.9: Packet Dropped per Handover in a Heavy Traffic Scenario

In E-Mobile IP, the spread is very slight, from the best case (large link bandwidths and regular size update packets) to the worst case (regular size bandwidths and large update packets).

4.6 Summary

The low latency handover protocol proposal consists of two handover mechanisms, pre- and post-registration. As their names suggest, pre-registration attempts to complete L3 handover signalling before the L2 switch, while post-registration postpones the Mobile IP registration until after the L2 handover, while still enabling the MN to receive traffic during this phase.

These low latency protocols will show very good handover performance, but at a fairly large cost, they pose some very heavy requirements on the L2. Low-latency handover tries to use L2 information to inform the MN of its nFA, possibly employing the help of the old and/or nFA.

As discussed in this chapter, IP layer handover can only be performed after the L2 handover is complete in most normal cases. Therefore, the overall latency of a Mobile IP handover is usually the sum of the link and IP layer handover latencies.

The low latency schemes presented here, however, require a much deeper integration of L2 and L3, moving away from the paradigm of strict layer separation. For the low latency handover protocols to work, anticipation triggers are required, which inform the receiving node (which can be the oFA, nFA or MN) that the MN is going to conduct a handover in the very near future and to which nFA. This destination information can be the nFA’s IP address, or any other form of identification.

Chapter 5

Mobile IPv6 Fast Handover Based on Link Layer Information

5.1 Introduction

Mobile IPv6 specification defines how an MN can maintain connectivity to the Internet when its AP changes from one AR to another one. It allows an MN to communicate with other nodes (stationary or mobile) after changing its L2 point of attachment from one IP subnet to another, yet without changing the MN's IPv6 address. An MN is always addressable by its home address, and packets may be routed to it using this address regardless of the MN's current point of attachment to the Internet [121, 122, 123, 124].

During the handover procedure, there is a period of time in which an MN cannot send or receive packets, because of the link-switching delay. This period of time is known as handover latency; it is the primary cause of packet loss. Moreover; there is a high Mobile IPv6 handover delay because of the agent discovery and registration periods; eventually

Mobile IPv6 handover can cause significant performance degradation, especially in large scale mobility environments [123, 125].

Fast handover addresses the following problems: how to allow an MN to send packets as soon as it detects a new link, and how to deliver packets to an MN as soon as its attachment is detected by the nAR [126, 127].

The protocol enables an MN to quickly detect that it has moved to a new subnet by providing the nAP and the associated subnet prefix information with the L2 information when the MN is still connected to its current oAR. For instance, an MN may discover available APs using L2 specific mechanisms, and then request subnet information corresponding to one or more of these discovered APs [68, 99]. The MN may do this after performing router discovery or at any time while connected to its current router.

The aim of the fast handover for the Mobile IPv6 (FMIPv6) protocol [128] is to allow an MN to configure an nCoA, before it moves and connects to a new network. It also allows the MN to use the nCoA immediately upon connecting to the new network. Furthermore, the FMIPv6 protocol seeks to eliminate the latency involved during the MN's BU procedure by providing a bi-directional tunnel between the old and new networks while the BU procedures are being performed.

Several extensions [129] have been proposed to improve the performance of FMIPv6, but these studies did not consider reducing the anticipated handover delay that limits the time for the MN to perform a fast handover procedure in the predictive mode. In addition [130], all of these enhancements issue more signalling messages during this critical period; therefore, these proposals are inappropriate for high-speed MN movement.

A new message proposed in R. Koodli and C. Perkins [129], the *RtSolPr* message, is utilized by the MN and sent to its current AR to request this information about likely candidate APs. The response by the present AR is called a *PrRtAdv* message and contains the neighbouring router's advertisement (including its prefix). As the MN receives this information, it can immediately formulate a prospective nCoA for the nAR, while still being present on the oAR's link.

5.2 Problem of Fast Handover in Mobile IPv6

As described above in section 5.1, an oAR will stop forwarding packets to the MN when it has received the FBU message in FMIPv6. However, if the MN is still in the oAR's link, it slows down its moving speed before the L2 handover is completed or initializes the FMIPv6 predictive handover too early, it cannot receive any packet destined for it; this may cause unnecessary packet loss. To avoid this, FMIPv6 must be modified [127]. This section proposes a method which tries to utilize two FBU messages to solve the problem.

When the handover is needed, the MN follows the FMIPv6 standard [84], which sends the FBU message to notify the oAR of the oncoming handover. After receiving the FBU from its link, the oAR builds a tunnel for the oncoming handover like the original FMIPv6 does, but keeps forwarding packets to the MN. When an MN decides to switch to the nAP, it will send the second FBU message to notify the oAR of its leaving. Then, the oAR will forward the packet to the nAR.

The first FBU is used to complete all the works that the predicative handover should finish at the oAR's link, except binding the current CoA to the nCoA.

The second FBU, however, is used to notify the oAR of the binding of current CoA to the nCoA and then the oAR can forward the packet to the nAR [132].

After sending the second FBU message, the MN switches to the best channel that the active scheme detected. Then, it attaches to the new link in L2, and then sends an FNA message to the nAR to notify it of its appearance in the network, as shown in Figure 5.1. Using two FBU messages, FMIPv6 is told when to prepare the tunnel for the oncoming handover in advance, and when to change the attachment to the nAR's link. This scheme avoids FMIPv6 experiencing the worst signal status and increasingly allows FMIPv6 to benefit from the predictive handover procedure.

5.3 Proposed Mobile IPv6 Fast Handover Based on Link Layer Information

While the MN is connected to its oAR, and is about to move to the nAR, fast handover in Mobile IPv6 requires:

1. The MN to obtain an nCoA at the nAR while being connected to the oAR;
2. The MN to send a BU message to its oAR to update its binding cache with the MN's nCoA;
3. The oAR to start forwarding packets destined for the MN to the nAR

As shown in Figure 5.1, the sequence messages of the fast handover protocol in Mobile IPv6, either the MN or the oAR may initiate the handover procedure by using the L2 trigger. The L2 information indicates that the MN will soon handover from one AP to another one, with these two APs being attached to the oAR and nAR, respectively.

If the L2 trigger is received at the MN (mobile-initiated handover) the MN will initiate L3 handover by sending an *RtSolPr* message to the oAR. On the other hand, if the L2 trigger is received at the oAR (network-controlled handover), then the oAR will transmit *PrRtAdv* messages to the appropriate MN, without any solicitation messages [127].

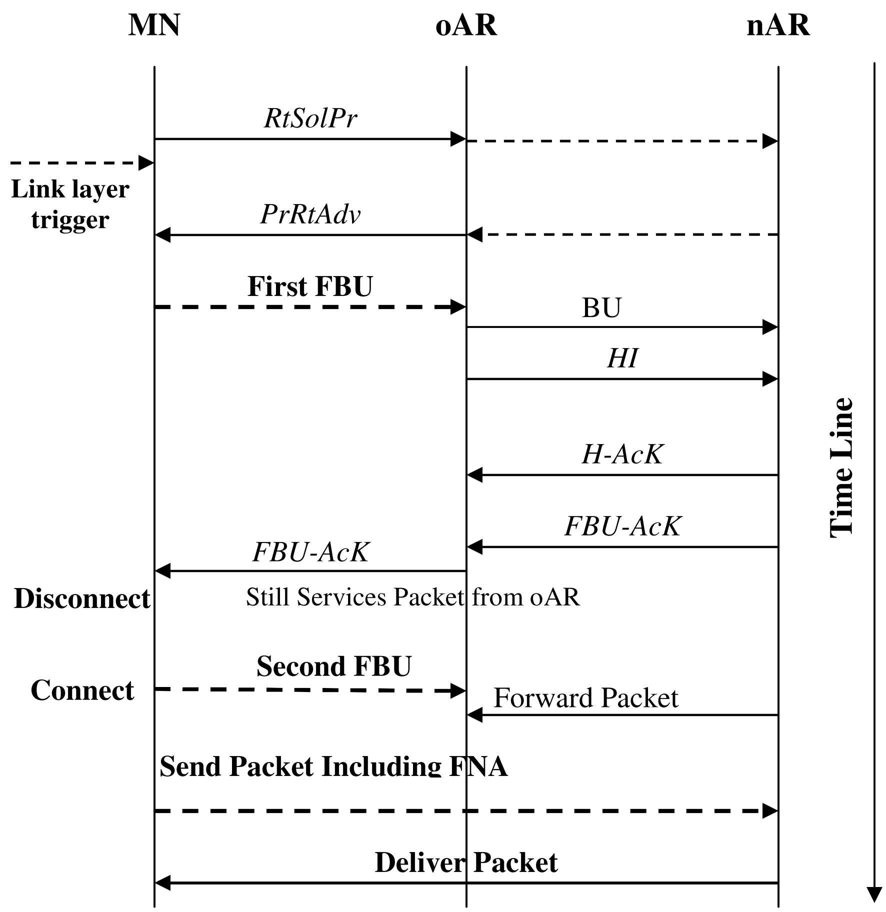

Figure 5.1: Fast Mobile IPv6 Handover Protocol Message Flow

Handover system

The handover system is made up of the MN and access routers as follows:

$$System \stackrel{def}{\equiv} \mathrm{MN}\langle CoA \rangle \mid \mathrm{oAR} \mid \mathrm{nAR}$$

The FMIPv6 handover system is made up if parallel compositions of a MN primitive to (CoA) communicate with both oAR and the nAR

1. **Mobile Node (MN)**

The MN will receive a link from the nAR, which is used to communicate with it. Then, the MN sends *RtSolPr* to inform the oAR that it is going to handover to the nAR.

$$MN\,(CoA) \overset{def}{\equiv} \overline{RtSolPr}\,\langle CoA\rangle\,.\,PRtAdv\;(nCoA\,,Link\;\;Informatio\;n,LinkIdenti\;fier)$$
$$\overline{BU}\;\langle\,first\,\rangle\,.\,FBU\text{-}AcK\;\;.\,\overline{BU}\;\langle \sec ond\,\rangle.\;\overline{FNA}.\;MN\,\langle nCoA\,\rangle$$

The MN obtains an nCoA while still being connected to the oAR, by means of RA from the nAR containing network information.

When the MN receives a *PrRtAdv* message, it should send an FBU message, prior to disconnecting its link.

2. **Old Access Router (oAR)**

The oAR is made up of the following components:

RtSolPr: an action utilized by the MN, sent to its current AR to request information about likely candidate APs and handle the MN initial request for the handover.

Forward: an action which passes both new and old CoAs.

HI: a request message sent to the nAR to make the handover process.

The oAR first receives the handover request from the MN, and then sends it directly to the nAR:

$$oAR \overset{def}{\equiv} \text{RtSolPr (oCoA)}.\overline{\text{Forward}}\langle\text{oCoA}\rangle.\text{Pr}\,RtAdv\,(nCoA, Link\ Information, LinkIdentifier)$$
$$\overline{PRtAdv}\langle nCoA, Link\ Information, LinkIdentifier\rangle.\ BU\ (first)\overline{BU}$$
$$\overline{HI}.\ H-AcK.\ FBU-AcK.\overline{FBU\text{-}AcK}.\ BU\ (\text{sec}ond).\,oAR$$

The oAR will validate the nCoA and initiate the process of establishing the bi-directional tunnel between the oAR and nAR, by sending a HI message to the nAR.

When the oAR receives an FBU message, it must verify that the requested handover is accepted by the nAR as indicated in the H-AcK message status; then it will start forwarding packets intended for oCoA to the nAR and send an FBU-AcK to the MN.

3. New Access Router (nAR)

The nAR is made up of the following components:

Forward: an action which passes both new and old CoAs.

PRtAdv: the response by the present AR, containing the neighbouring router's advertisement for the link information and network prefix.

H-Ack: a confirmation sent back to the oAR to make the handover to the nAR.

$$nAR \overset{def}{\equiv} Forward\ (oCoA).\ \overline{PRtAdv}\ \langle nCoA, Link\ Information, LinkIdentifier\rangle.$$
$$\text{BU}.\ HI.\ \overline{H\text{-}AcK}.\ \overline{FBU\text{-}Ack}.\langle Forward\ Packets\rangle.\ FNA.\ nAR$$

The nAR verifies that the nCoA can be used on the nAR's link. Moreover, in response to the HI message, the nAR sets up a node route for the MN's oCoA, and responds with a H-AcK message [99, 135].

Upon verification of the variables, nAR will send the Acknowledgment (*ACK*) to confirm its acceptance; then the oAR will start sending the buffered packets to the nAR distend to the MN.

5.4 Evaluation Environment

The fast handover scheme is implemented in ns-2 version ns-allinone 2.31 with the Mobile IPv6 model from Columbia IP Micro-mobility Software (CIMS) [111]. We evaluate the performance of the fast handover in the Mobile IPv6 (FMIPv6) based link layer information algorithm. We compare the proposed algorithm against a Mobile IPv6 and Mobile IP. The performance metrics for comparison include the handover latency, packet loss, throughputs and handover delay [108].

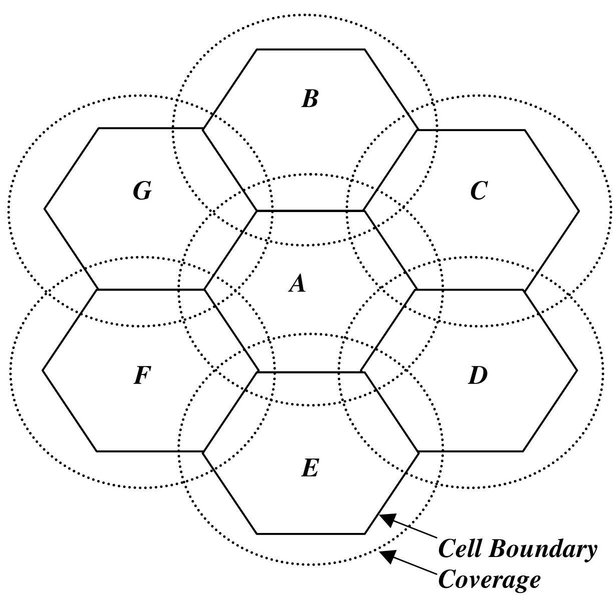

Figure 5.2: Overlapping Coverage Area

For simplicity we assume that there is no change in direction while the MN moves inside the overlapping area. The best possible handover point occurs at position A, as shown in Figure 5.2.

The coverage area can be defined in terms of signal strength; the effective coverage is the area in which MNs can establish a link with acceptable signal quality with the AP. The coverage radius is defined as the distance from an AP to its coverage boundary. The cell radius is the distance from an AP to its cell boundary.

Table 5.1 Simulation Parameters

Simulation parameter	Value
Simulator	Ns-allinone-2.31
Network range	400m×400m and 1000m×1000m
Transmission range	25m
Mobile nodes	5 and 12
Traffic generator	Constant bit rate
Band width	2Mbps
Packet size	512 bytes
Packet rate	10 packet per second
Simulation time	800s and 1200s

In our simulation, we use a 400m × 500m and a 4000m × 1000m area with a 5 to 12 MNs. The network bandwidth is 2 Mbps and the medium access control (MAC) layer protocol is IEEE 802.11 [125]. The packet size is 10p/s which will generate enough traffic when we increase the number of connections for example at 40 connections of source-destination pairs, it will generate 400 packets per second for whole scenario.

Other simulation parameters are shown in Table 5.1. These parameters have been widely used in the literature [129, 139].

The main purpose behind the proposed approach of the FMIPv6 is to reduce the signalling overhead, handover latency and the number of packets loss.

5.4.1 Movement Detection for Mobile IPv6 over 802.11 Networks

The movement detection method of RA caching in L2 APs [130, 132, 135] makes the AP responsible for sending triggered RAs. RAs are sent to the MN when the MN attaches to an AP associated with this network. The AP caches RAs that have been recently sent from the router, and delivers a frame to the MN when it attaches to the AP.

When the AP advises the router of the L2 connection, the router can send unsolicited RAs before receiving an router solicitation (RS) from the MN. In this case, less frequent transmission of unsolicited multicast RA messages is possible. Deployment requires each AP in the network to be capable of both caching and triggering sending operations.

5.4.2 Router Access Filtering

This approach to movement detection [131, 135] provides an MN with the capability of filtering RAs to avoid faulty processing of handovers, by providing an RA cache in the handover module. This enables the MN to determine its best choice of a forthcoming link and reduces the MN dependence on the RA period and the RS response time. The MN receives and processes cached RAs immediately after it moves to a new network and thus movement detection time is reduced.

Two important criteria used to determine the priority of the RAs stored in the cache are:

1. The link signal strength (signal quality) and the time since the RA entry was last updated;
2. The number of nodes to the AR on the foreign network and whether or not the AR is link local (priority is given to link local ARs since this may help the MN to detect that it is still reachable via its current IP address). [134]

5.5 Performance Analysis and Evaluation

Figure 5.3 shows an example of the uplink MN to CN transmission behaviour with six handovers in the unit time of all simulated schemes, Mobile IP, Mobile IPv6 and FMIPv6. The resulting graphs show the transmission bit rate of each handover protocol. Handover delay periods are known in both Mobile IP and Mobile IPv6, although Mobile IPv6 receives more data than Mobile IP, but both of them shows inherent handover delay; this is because of their registration periods. On the other hand, FMIPv6 handover shows the highest transmission rate without any delay period. This is because FMIPv6 uses the multi-homing and buffer procedure, which provides fast and accurate data transmission.

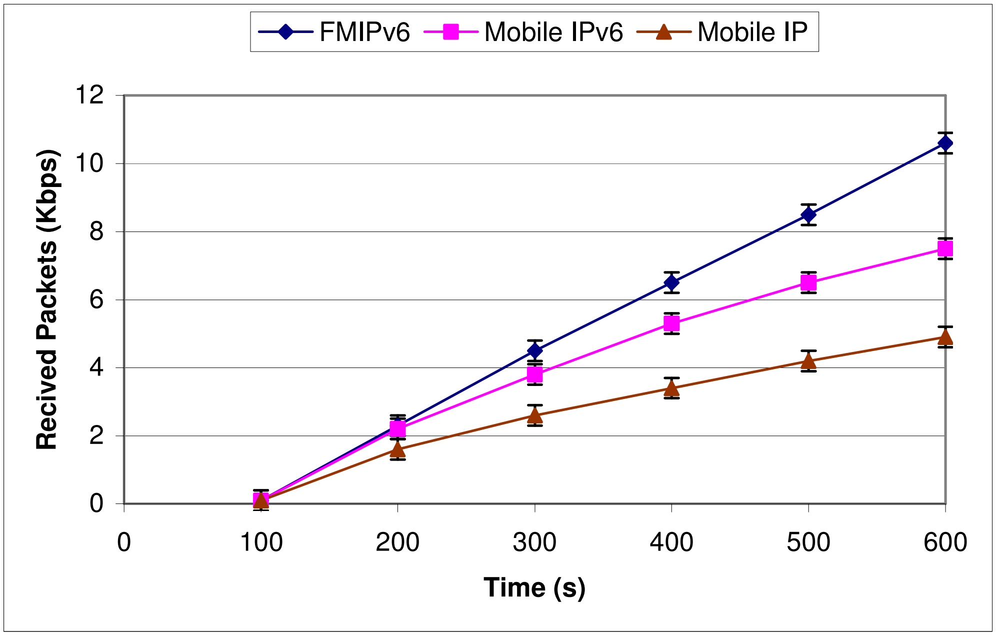

Figure 5.3: Handover Behaviour

As acknowledged throughput is an important performance metric that measures the transmission ability of a network. The average throughput is calculated as the mean volume of data that is actually delivered to the destination within each time unit. The overall throughput graph for different rates is given in Figure 5.4. It shows that the throughput increases as the sending rate increases; FMIPv6 performs better than Mobile IP, because it does not depend on the sending rate and the inter-arrival of packets reaches the average value, since there is no compensation for packets lost with Mobile IP.

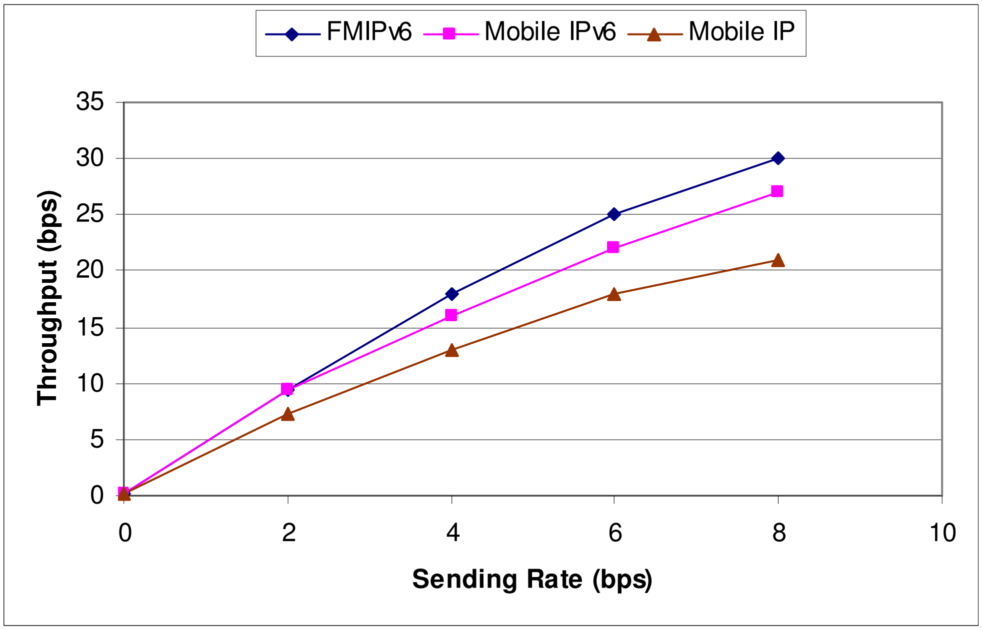

Figure 5.4: Throughput versus Rate

Since the number of packets lost is smaller in FMIPv6, as we have seen in the instantaneous throughput graph, FMIPv6 performs slightly better compared to both Mobile IPv6 and Mobile IP.

5.5.1 Packet Loss

Figure 5.5 and Figure 5.6 shows the increase in handover latency and the packet loss due to an increase in the number of MNs sharing the wireless channel. The results gained for up to 10 MNs indicate that the dominating factor of the handover latency is the wired link delay for a small number of MNs.

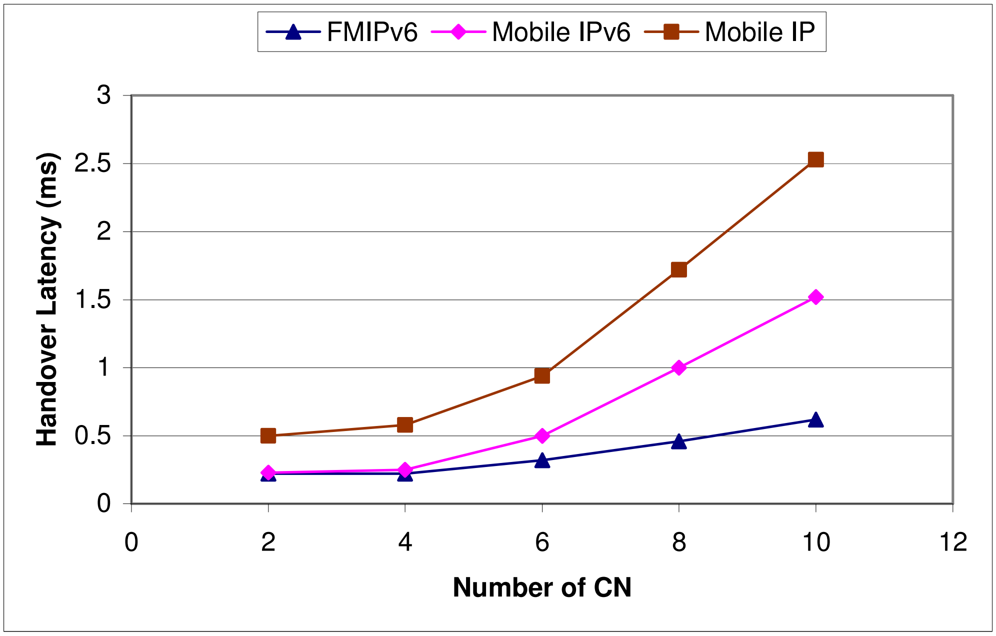

Figure 5.5: Impact of Handover Latency

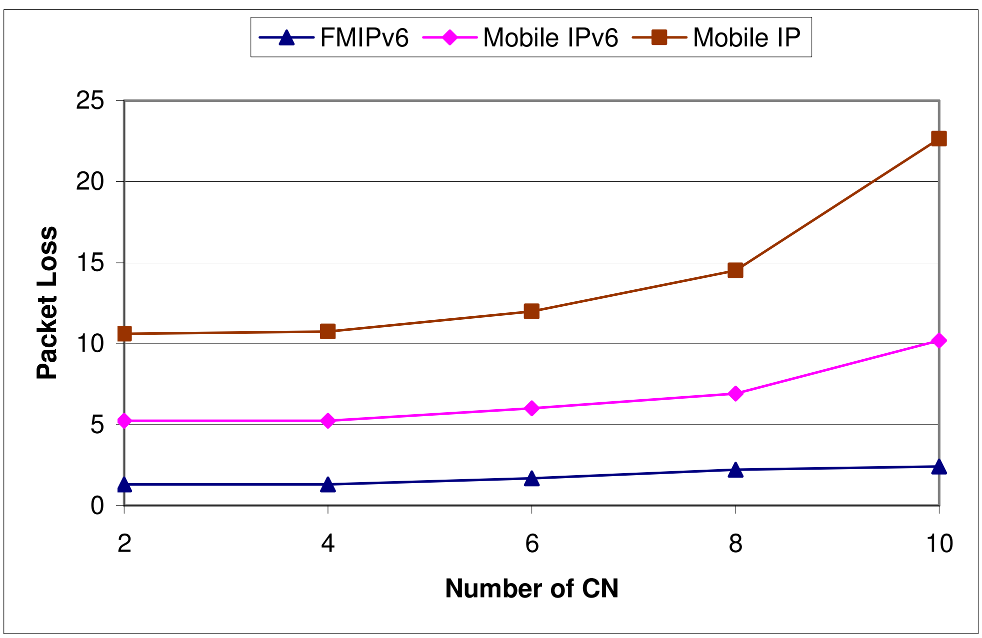

Figure 5.6: Impact of Packet Loss

As can be seen, the FMIPv6 approach performs better in terms of the handover latency and packet loss, although the fast handover protocol is designed to minimize packet loss and latency during a handover; a worse performance is observed with respect to the Mobile IP and Mobile IPv6 protocols when channel availability arises. Under high load conditions, the additional signalling messages of fast handover schemes in the local domain result in reaching the saturation level on the wireless channel earlier.

5.5.2 Delay

Figures 5.7 and Figure 5.8, shows the packet number with the delay. Handover latency is related to the round-trip time between the MN and crossover node. When the MN is performing a handover with a small distance, the time during which packets could be lost is shorter, which results in fewer packets being lost in total compared to larger handover distances.

Figure 5.7 shows the uplink MN to CN handover delay of Mobile IP, Mobile IPv6 and FMIPv6 over the handover rate. The total handover delays versus handover rates reveal how the handover delay of each handover protocol reacts when the scale of mobility varies. The total handover delays of Mobile IP and Mobile IPv6 increase as expected; in contrast, FMIPv6 handover does not incur any delay, irrespective of the handover rate. This is due to the fundamental difference between the FMIPv6 handover registration procedure and other schemes procedures. Handover delay of Mobile IP and Mobile IPv6 becomes more significant as handover rate increases.

As we can see, handover delay and the handover rate product directly affect the end-to-end throughput and packet loss. Thus, Mobile IP and Mobile IPv6 cannot be used as proper handover approaches in large-scale mobility environments. On the other hand, FMIPv6 does not incur any significant throughput decrease nor packet loss by keeping handover delay zero, regardless of the handover rate.

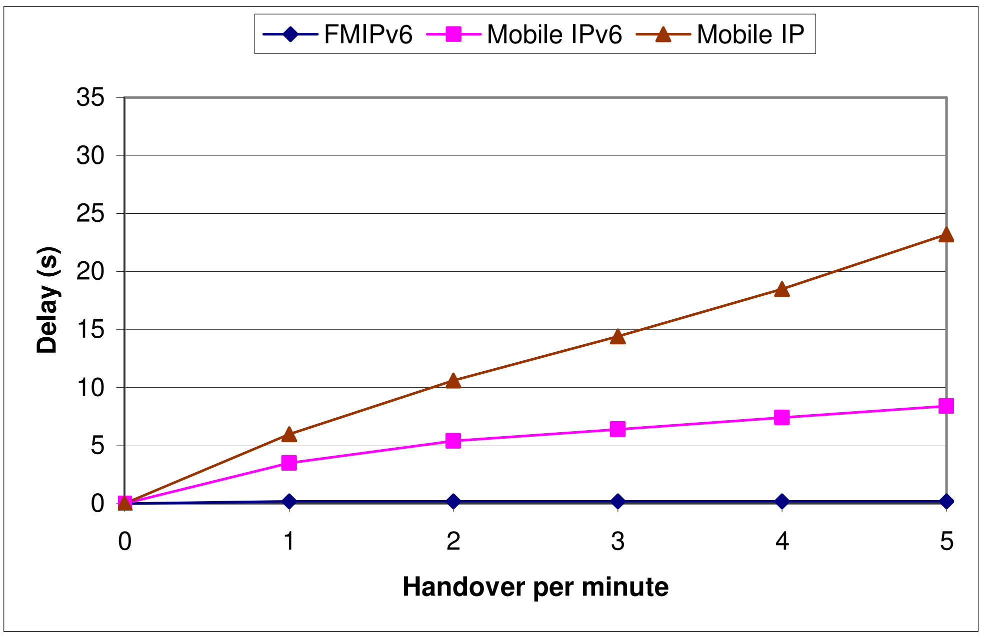

Figure 5.7: Handover Delay

The partially better behaviour for Mobile IPv6 is a consequence of the higher wireless load of the fast handover approach. A higher number of signalling messages sent via the wireless medium yields to a higher channel access delay and higher collision rate, resulting in a lower bandwidth being achieved.

In order to offer smooth handover in the simulation the buffer size is set to be able to recover all misrouted packets during the handover. The number of packets lost depends on both the size of buffer used to store packets for potential handovers and the sending rate, as seen in Figure 5.8. The number of packets lost increases for Mobile IP, since no buffer is used, and increases as the sending rate increases since more packets are sent while the MN is unable to receive them during handover.

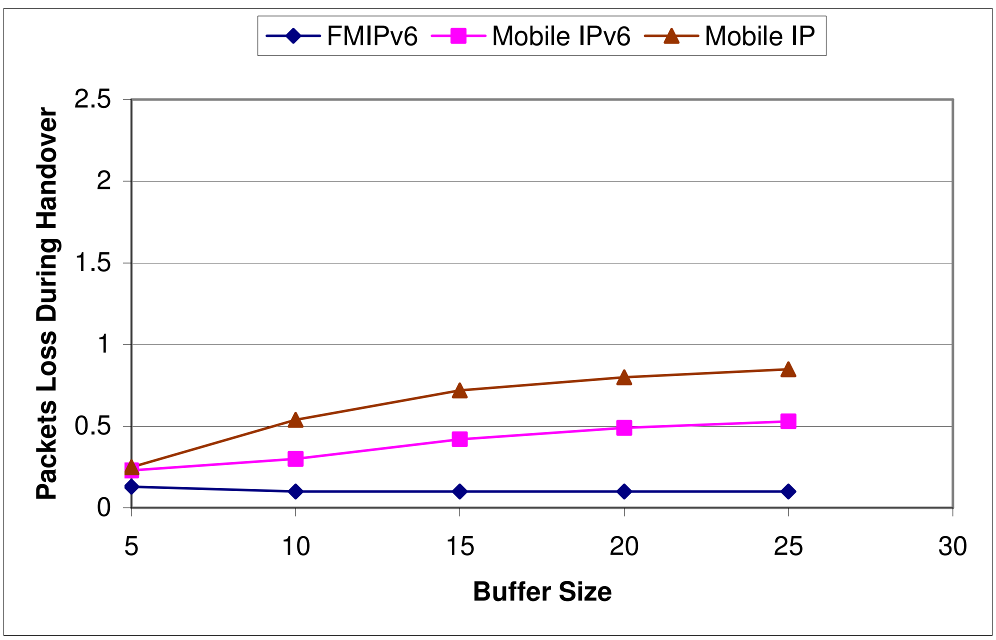

Figure 5.8: Packet Loss versus Buffer Size

On the other hand, the number of packets lost decreases as buffer size increases for FMIPv6. This means that the packet loss can be totally eliminated if the buffer size chosen is large enough. Furthermore, this buffer size can be adjustable according to the sending rate, since the number of packets lost increases as the sending rate increases for constant buffer size.

Figure 5.9 shows the average end-to-end delay with advertisement intervals between 2 and 45 seconds. As the result graph shows, the average end-to-end delay is less for the FMIPv6 and Mobile IPv6 than for the Mobile IP approach. The reason is that the periodic AR information sent by the nAR allows the MNs to update their route entries for the nAR more often, resulting in fresher and shorter routes.

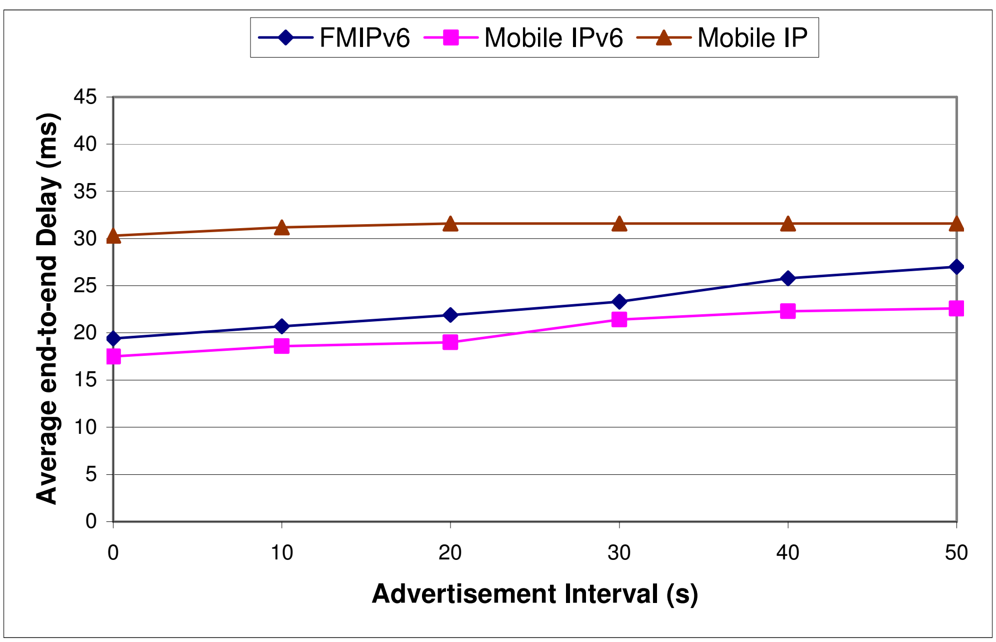

Figure 5.9: Average End-to-End Delay

With the Mobile IP approach an MN continues to use a route to a nAR until it is broken. In some cases this route can be pretty long, and even if the MN is much closer to another

AR it does not use this nAR, but continues to send the data packets along the long route to the nAR further away until the route is broken. Therefore, the end-to-end delay increases for these data packets, resulting in an increased average end-to-end delay for all data packets.

The result also shows that the average end-to-end delay decreases slightly for short advertisement intervals when the advertisement interval is increased. At first thought this might seem unexpected. However, it can be explained by the fact that very short advertisement intervals result in a lot of control traffic, which leads to higher processing times for data packets at each node. Moreover, since the Mobile IP messages for all schemes are prioritized over data packets, these have to wait in the routing queue until the mobile messages are sent, resulting in higher end-to-end delay

5.6 Summary

This chapter presented an investigation into the FMIPv6 handover scheme in order to provide rapid handover and reduce packet loss, signalling traffic and lengthy latency for handover management. This scheme is used to achieve rapid handover and reduce packet loss during the handover. Therefore, if the overlap time is short then handover quality will be poor regardless of the micro-mobility protocol.

The fast handover proposal anticipates the movement of an MN allowing the MN to register with the nFA prior to L2 connectivity being established. Basically, FMIPv6 tries to perform nAR discovery and nCoA configuration before the L2 handover starts, and sets up a tunnel between the oAR and nAR for smoothing the handover and minimizing the handover disruption time. However, the nCoA registration is expected to be performed after the L2 handover, and the oAR continues to be used by the MN for packet forwarding after it connects to the nAR while the nCoA registration is not finished. Some form of synchronization is required so that L3 registration is completed before the MN is instructed to perform L2 handover.

One important aspect is that the operation of FMIPv6 relies less on L2 triggers, making the protocol more practical to implement. Specifically, Mobile IPv4 low latency handover requires that L2 triggers must carry a lot of information in order for the protocol to run properly. For example, in Mobile IPv4 low latency handover pre-registration mode MN-initiated cases, the L2 trigger that initiates a *PrRtSol* from the MN to the oFA is expected to contain the nFA's identifier, such as the IP address, so that the *PrRtSol* can tell the oFA which nFA's advertisement the MN is soliciting. Similarly, in network-initiated cases, the L2 trigger also needs to contain the IP address information of the nFA or the oFA, in order to guide the oFA to send a proper unsolicited *PrRtAdv* (oFA triggered) or guide the nFA to send a *PrRtAdv t*o the proper oFA (nFA-triggered).

The performance study in this chapter indicates that the use of FMIPv6 based link layer information with location information helps to minimize packet loss and improve throughput. It is noted that the simulation proposed scheme has many desirable properties, such as rapid handover and low packet loss compared to the other handover scheme.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

The IPv6 and Mobile IP have a little effect on the operating systems of mobile computers outside the L3 of the protocol stack application. Mobile IP techniques have become an important research topic and received more attention from researches.

The most important focus of the thesis was to develop handover algorithms that provide solutions to current handover problems, such as packet loss and long handover latency. The research study showed that the problem of packet loss and handover delay has not been completely resolved. Thus, in an attempt to overcome this problem we developed and proposed some new mechanisms for Mobile IP and Mobile IPv6. In order to reduce the movement detection delay taken by the MN to predict that it has to move to a new location, the location information has been used to facilitate the handover mechanism.

This research presented an investigation into the design and development of a Mobile IP handover scheme using L2 information and location information to provide a fast handover to reduce packet loss, signalling and handover latency. The CN in our scheme is used to predict and control most of the decision processes necessary for handover. When the current CN detects that the MN is about to move to a new CN it will send a handover request to the nFA to redirect and forward the new data to the nCN while the MN is moving to the nC.

This research presented an investigation into developing new handover mechanisms based on L2 information in Mobile IP environments. The major impact of the work has been to free mobile devices from the restriction of poor access to mobile applications, due to the latency and packet loss of previous handover schemes. Whilst many of the previous proposals have led to improvements, true seamless IP connectivity is now a possibility with minimum disruption to the existing network, insignificant signalling overhead and little additional processing load on the base stations.

Finally, the proposed algorithms for E-Mobile IP and FMIPv6 handovers were implemented and verified using the network simulator (NS-2). Simulation results show that E-Mobile IP and FMIPv6 can improve handover performance by reducing packet loss, signalling load and handover latency.

The following points highlight the contributions of this thesis.

- The problems with mobility were described the study examined the possibilities for resolving the key problems.

- The mechanisms of Mobile IP were illustrated, the main problems were clarified along with existing enhancements and the main Mobile IP management handover was explained.
- The micro-mobility protocols that use routing based schemes avoid the tunnelling overhead, but suffer from the high cost of propagating host-specific routes in all the routers within the domain.
- The proposed scheme was developed and analyzed based on the L2 information handover scheme compared with Mobile IP. The performance study indicates that the use of L2 information helps to minimize packet loss and improve throughput.
- Test results have provided added confidence that the Mobile IP specification is sound, implementable and of diverse interest throughout the Internet community.
- A series of simulation experiments were undertaken to exhibit the capabilities of the proposed schemes. An in-depth comparison was also presented to compare the proposed schemes with the existing schemes.
- The results regarding E-Mobile IP show that it can improve the handover performance by avoiding the use of encapsulation and minimizing handover signalling. Mobile IP routing and handover are simple and have the ability to offer seamless mobility for TCP and UDP. The results also show how it improves the level of delay and packet loss compared to the hard handover.
- The simulation shows how the L2 information handover scheme avoids the losses that can happen when using Mobile IP. This is due to the use and implementation of proactive location information in the indirect proactive handover.

- The simulation results also show the effect of the overlap. The handover performance will decrease as the overlap time becomes shorter. Therefore, the performance of the handover can be improved if we increase the overlap or increase signalling beacons.
- Using buffering on the nFA instead of the oFA will allow us to avoid redirected, buffered and packet duplication since the duplicated packets will waste bandwidth resources, especially on wireless links, and cause packet duplication acknowledgments, which will cause congestion on the network and affect network performance.
- The UDP offers much faster transmission of packets because it does not have error detection and correction and this can be an excellent solution for use with wireless communications as they delay intolerances.
- As a result, Mobile IPv4 low latency handover complicates the implementation of L2 triggers and, therefore, it is believed to be less practical compared with FMIPv6.
- To some level, FMIPv6 is similar to the Mobile IPv4 low latency handover post-registration mode, but the protocol design methods of FMIPv6 and Mobile IPv4 low latency handover are different.
- Due to the inherent particular characteristics of Mobile IPv6 and Mobile IPv4 (for example, Mobile IPv6 does not have FAs, while Mobile IPv4 does, and Mobile IPv6 supports stateless CoA configuration while Mobile IPv4 does not), the design of FMIPv6 is improved relative to Mobile IPv4 low latency handover.

6.2 Future Works

Based on the contributions, the research conducted in this thesis opens up options for future work and could include the following:

- A number of open issues remain. What is the minimal coupling between the IP and radio layers to facilitate fast handover? Here the challenge is to keep the (interface) as simple and radio independent as possible.
- The presented fast handover rely on predicting the position of the nARs in advance. Is this assumption reasonable?
- An investigation could be made into the implementation of the indirect proactive scheme with a low latency handover scheme based on L2 information proposed by IETF for micro-mobility.
- An investigation could be undertaken into the styles of handover control which should be supported? The proactive proposal advocates network-controlled handover while fast handover is mobile initiated.
- In future work an investigation could be undertaken on security and scalability for the Mobile IP and Mobile IPv6; this could be compared with Celluer IP (CIP) and Hierarchical Mobile IP (HMIP).
- In future research it would be desirable to investigate the combination of signalling and location to improve handover performance and reduce packet loss. The improvements could be compared to the information available on the quality of the wireless channel and location of the new base station.

In summary, the proactive and fast handover proposals being discussed by the IETF working group make a number of assumptions regarding handover control, radio behaviour, movement prediction, and protocol synchronization. Any limitations associated with these design choices need to be understood to determine whether there is any hidden cost or lack of generality of the two schemes.

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