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ในระบบสื่อสารไอพีเคลื่อนที่

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PERFORMANCE IMPROVEMENT IN LOW LATENCY HANDOFF
SCHEME IN MOBILE IP COMMUNICATION SYSTEM

Mr. Kimtho Po

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คิม โท โป : การปรับปรุงสมรรถนะในแบบแผนการแฮนด์ออฟที่ใช้เวลาแฝงในการแฮนด์ออฟน้อย ในระบบสื่อสารไอพีเคลื่อนที่. (PERFORMANCE IMPROVEMENT IN LOW LATENCY HANDOFF SCHEME IN MOBILE IP COMMUNICATION SYSTEM) อ. ที่ปรึกษา : รศ. ดร.วาทิต เบญจพลกุล, จำนวนหน้า 56 หน้า. ISBN 974-17-4636-9.

แบบแผนการแฮนด์ออฟที่ใช้เวลาแฝงในการแฮนด์ออฟน้อย (Low Latency Handoff Schemes) และใช้งานในระบบไอพีเคลื่อนที่ได้มีด้วยกัน 2 วิธี คือ การลงทะเบียนล่วงหน้า (Pre-Registration) และการลงทะเบียนล้าหลัง (Post-Registration) สำหรับสมรรถนะของแบบแผนการแฮนด์ออฟทั้ง 2 วิธี สามารถประเมินค่าได้จากแพ็กเกตสูญหายด้วยการใช้เครื่องจำลองแบบโครงข่าย (Network Simulator) วิทยานิพนธ์นี้กล่าวถึงวิธีการประยุกต์ใช้งานวิธีการแฮนด์ออฟแบบต่างๆ บนมาตรฐาน IEEE 802.11 ด้วยเครื่องจำลองแบบโครงข่าย

เราได้เปรียบเทียบสมรรถนะของแบบแผนการแฮนด์ออฟที่ใช้เวลาแฝงในการแฮนด์ออฟน้อย ทั้ง 2 วิธี กับแบบแผนการแฮนด์ออฟแบบดั้งเดิมของระบบไอพีเคลื่อนที่ ด้วยการพิจารณาจากแพ็กเกตสูญหาย ดังนั้นเพื่อที่จะลดการสูญหายของแพ็กเกต เราจำเป็นต้องสร้างบัฟเฟอร์ไว้ที่สถานีฐานและมีพื้นที่ที่สถานีฐานซ้อนทับกันอย่างเหมาะสม

นอกจากนี้ เราได้ศึกษาผลกระทบของปริมาณการให้สัญญาณ (signaling) ที่อยู่บนสมอของตัวแทนต่างพื้นที่ (anchor Foreign Agent) ของการแฮนด์ออฟด้วยการลงทะเบียนล้าหลัง และผลกระทบของปริมาณการให้สัญญาณ (signaling) ที่อยู่บนประตูทางออกของตัวแทนต่างพื้นที่ (Gateway Foreign Agent) ของการแฮนด์ออฟด้วยการลงทะเบียนล่วงหน้า ดังนั้นเพื่อให้มีการใช้ทรัพยากรที่มีอยู่ในโครงข่ายน้อยที่สุด เราจึงควรเลือกกลุ่มของตัวแทนต่างพื้นที่ (Foreign Agent) ที่อยู่ใต้สมอของตัวแทนต่างพื้นที่ หรือ อยู่ใต้ประตูทางออกของตัวแทนต่างพื้นที่อย่างเหมาะสม

สำหรับแบบแผนการแฮนด์ออฟแบบการลงทะเบียนล้าหลัง อาจจะทำให้มีปริมาณการให้สัญญาณที่เพิ่มสูงขึ้นเนื่องจากจำนวนตัวแทนต่างพื้นที่ถูกสร้างขึ้นและส่งสัญญาณ Bi-directional Edge Tunnel (BET) ระหว่างกันและกัน ดังนั้นวิทยานิพนธ์นี้จึงได้เสนอวิธีการเลือกจำนวนตัวแทนต่างพื้นที่ที่เหมาะสมสำหรับการแฮนด์ออฟแบบการลงทะเบียนล้าหลัง โดยจะพิจารณาจากแบบจำลองการวิเคราะห์ที่ลดต้นทุนการปรับตำแหน่งให้ทันกาล, การส่งแพ็กเกต และกระบวนการ BET ให้มีค่าน้อยที่สุด นอกจากนี้ยังศึกษาปริมาณการให้สัญญาณทั้งหมดที่มีอยู่บนสมอตัวแทนต่างพื้นที่ในแบบแผนการแฮนด์ออฟแบบการลงทะเบียนล้าหลังด้วยแบบจำลองการวิเคราะห์ที่เสนอและการจำลองโครงข่าย

ภาควิชา วิศวกรรมไฟฟ้า ลายมือชื่อนิสิต ....

สาขาวิชา วิศวกรรมไฟฟ้า ลายมือชื่ออาจารย์ที่ปรึกษา ....

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4570703621: MAJOR ELECTRICAL ENGINEERING
KEY WORD: MOBILE IP/PRE-REGISTRATION HANDOFF/POST REGISTRATION HANDOFF/FAST HANDOFF/ TRAFFIC OVERHEAD

KIMTHO PO, MR.: PERFORMANCE IMPROVEMENT IN LOW LATENCY HANDOFF SCHEME IN MOBILE IP COMMUNICATION SYSTEM THESIS. ADVISOR: ASSOCIATE PROFESSOR WATIT BENJAPOLAKUL, D.ENG.

Performance of two low latency handoff schemes in mobile Internet protocol (Mobile IP), pre-registration handoff and post-registration handoff are evaluated in terms of packet loss by means of Network Simulation (NS). We describe several handoff implementations over wireless access based on the IEEE 802.11 standard on an NS simulation.

We compare the system performance of pre-registration handoff and post-registration handoff with the original regional registration mobile IP with respect to packet loss. To reduce the packet loss in both schemes, the buffer is needed to implement at each base station and the overlapping area of each base station is considered.

We, moreover, study the influence of the signaling cost over the anchor Foreign Agent (aFA) for post-registration handoff and over the Gateway Foreign Agent (GFA) for pre-registration handoff when both schemes have been implemented with the regional registration mobile IP. The group of FAs under the aFA or under the GFA has been selected in order to consume the minimal network resource.

Post-registration handoff scheme, however, may lead to excessive signaling cost to an aFA where numerous FAs establish the bi-directional edge tunnel (BET) with it. Therefore, a method to determine the optimal number of FAs performing BET with the aFA in post-registration handoff is proposed. It is based on an analytical model by minimizing the total location update, packet delivery and processing BET costs. We investigate the total signaling cost at the aFA in the post-registration handoff by the proposed analytical model and NS simulation.

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LIST OF ABBREVIATION

HA	Home Agent
FA	Foreign Agent
GFA	Gateway Foreign Agent
aFA	Anchor Foreign Agent
nFA	New Foreign Agent
oFA	Old Foreign Agent
MN	Mobile Node
CN	Correspondent Node
CoA	Care of Address
IP	Internet Protocol
TCP	Transmission Control Protocol
IETF	Internet Engineering Task Force
MAP	Mobility Anchor Point
NS	Network Simulator
LAN	Local Area Network
BET	Bi-directional Edge Tunnel
RtSol	Router Solicitation
RtAdv	Router Advertisement
ProxyRtSol	Proxy Router Solicitation
ProxyRtAdv	Proxy Router Advertisement
RegRegReq	Regional Registration Request
RegRegRep	Regional Registration Reply
HReq	Handoff Request
HRep	Handoff Reply
AReq	Association Request
ARes	Association Response
L2-LD	Layer 2 Link Down
L2-LU	Layer 2 Link Up
ECS	Eager Cell Switching
LCS	Lazy Cell Switching
NS HMIP	Network Simulator of Hierarchical Mobile IP
AP	Access Point
CBR	Constant Bite Rate
UDP	User Datagram Protocol

CHAPTER 1

INTRODUCTION

1.1 LITERATURE REVIEW

Internet is a common application and service environment for interconnected networks. In today's networks, there is one layer in the protocol stack, which is becoming the most ubiquitous and obvious protocol to allow voice, data, graphic and videoconferencing access to the users. That protocol is the Internet Protocol of the TCP/IP protocol suite.

By design, an IP address is tied to the home network address, nodes are assumed to be immobile and intermediate routers only taken at the network address. If the node is moved from its home network and attached to a new network without changing its IP address, then it will not be able to communicate with other nodes on the network. Thus, the Internet of today lacks mechanisms for the support of users traveling throughout the world.

With the growing of Internet devices and success of wireless networks today, people will expect to use their networks terminals (laptops, PDA, and mobile phones) anywhere and anytime.

There are still many isolated interconnected networks, which are not connected to the global Internet but instead using the Internet Standard. Thus, the major strength is actually the seamless connectivity with devices in the neighborhood.

Consider to what we just discussed, the Internet Engineering Task Force (IETF) has proposed the mobile IP that is a mobility enabling protocol for the global Internet [1]. Mobile IP is the best-known solution to solve the problem breaks under mobility of IP based network.

Mobile IP allows a mobile node to move around without changing its permanent IP address. Each mobile node has a home agent on its home network. The mobile node establishes a care of address when it is away from its home network. The care of address is obtained from the foreign agent on the foreign network. The correspondent node always sends the packets to the permanent IP address of the mobile node. The packets are routed to the mobile node home network, where the home agent intercepts the packets and forwards them to the current care of address.

To enable IP mobility, the standard mobile IP has introduced new messages such as router advertisement, registration request and registration reply messages [2].

In the standard of mobile IP, the home agent and foreign agent broadcast the router advertisement every one second to show their presence and service. The agent advertisement messages are sent in discrete time intervals that determine the granularity in which a handoff can be detected. Decreasing the time interval results in shorter latency for handoff detection and triggering but increases the signaling overhead [3]. The mobile node constantly listens to the agent advertisement. The mobile node can know whether it is on its home network or foreign network according to the lifetime of the agent advertisement or the network identification carried by the advertisement. If the mobile node is on its home network it will act just like any other fixed node of that network and uses its fixed home address. When the mobile node moves to a foreign network, it obtains the care of address and then registers to its home agent by sending a registration request through the foreign agent. The home agent replies a registration reply to the mobile node. When this process completes the mobile node fully establishes the connection with the foreign agent. The phenomenon when the mobile node migrates from one network to another is called handoff.

Although the basic mobile IP protocol proposes a simple and elegant mechanism to provide IP mobility support, there is a major drawback, where each packet destined to the mobile node must be routed through the home agent along an indirect path. This is known as the triangular routing problem. The mobile IP requires that the mobile node send the location update to its home agent whenever it moves from one network to another, even though it does not communicate with other users.

This approach, when applied to an environment with frequent handoffs, may lead to high associated signaling load and unacceptable disturbance to ongoing communication sessions, or even break off the communication session [4] [5]. Hence, the signaling cost and handoff process is an important consideration in the design of IP mobility protocols.

Following the description above, the based mobile IP does not extend well to the requirements for future networks that, especially, support real time service. To help alleviate these problems just discussed, some protocols have been proposed such as mobile IP Regional Registration in IPv4 [6] and Mobility Anchor Point (MAP) in IPv6 [7].

In both protocols, the mobility agents are configured hierarchically under Gateway Foreign Agent (GFA) or MAP to support local mobility and the home agent does not aware the movement of the mobile node while it changes foreign agent within a regional network unless the mobile node moves out of GFA or MAP domain. They aim at reducing the amount of signaling required for updating to the home agent and also shorten the latency for handoff execution.

However, some studies report that the handoff latency is not much better than the original mobile IP because both protocols use the same algorithm for handoff detection and triggering as the original mobile IP, which is based on network layer information detected from the advertisement message.

As an alternative to network layer handoff triggers, the IETF has proposed a new scheme called Low Latency Handoff [8] that uses link layer information to initiate handoff. Link layer information allows a Mobile Node (MN) to detect the loss of connectivity more quickly than a network layer in the advertisement based algorithm. With the facilities of link layer information, the handoff latency may be reduced.

Low Latency Handoff is classified into two methods: Pre-Registration handoff and Post-Registration handoff. Pre-Registration handoff allows the mobile node to communicate with the foreign agent while still connects to the old foreign agent. For the Post-Registration handoff, the packets can be delivered to the mobile node at the new foreign agent even before the formal registration process has completed.

Pre-Registration handoff scheme allows the mobile node to solicit the new foreign agent to send the advertisement message even before the regularly advertisement interval time. By this, the latency for handoff triggering can be reduced. Upon receiving the advertisement from the new foreign agent, the mobile node performs the standard registration of the mobile IP. We also expect that the packets during the ongoing communication shall be reduced when compared with the original mobile IP.

Post-Registration scheme allow the new foreign agent to construct a bi-directional edge tunnel with the old foreign agent whenever the mobile node has connected to the new foreign agent but still not register its new care of address to its home agent. Thus, the old foreign agent tunnels the packets destined to the mobile node along the bi-directional edge tunnel. The packet loss during the communication can be reduced.

As discussed above, the Regional Registration scheme aims at reducing the signaling costs to the home agent, and the Pre-Registration handoff and Post-Registration handoff aims to shorten the latency for handoff process by means that the interruption of the communication may be avoided.

Within the appropriate condition to shorten handoff latency and reducing the traffic overhead in the backbone network, we apply the Low Latency Handoff scheme with the mobile IP Regional Registration.

However, when the Pre-Registration handoff is implemented with the mobile IP Regional Registration, it is not clear how many foreign agents should be beneath the GFA within a regional network. A small number of foreign agents will cause the frequent handoff to home network. A large number of foreign agents under GFA will generate high packets delivery costs on the GFA and will degrade the system performance.

As for the Post-Registration handoff, the old foreign agent plays an important role of intercepting the packets from the GFA and tunneling them to the new foreign agent.

When the mobile node moves from a new foreign agent to another new one, but it does still not register its care of address with the previous new foreign agent, the current new foreign agent requests the permission to set up the bi-directional edge tunnel with the old foreign agent. At this point the old bi-directional edge tunnel between the old foreign agent and previous new foreign agent has been broken down. Therefore the packets destined to the mobile node can be tunneled from old foreign agent to the current new foreign agent along the new bi-directional edge tunnel. This process may continue until the mobile node makes the formal registration with the current new foreign agent and then this new foreign agent may have the role to perform the bi-directional edge tunnel with another current new foreign agent of the mobile node. Hence, it is not also clear how many foreign agents are needed to perform the bi-directional with the old foreign agent. When the number of foreign agents becomes too large, the system performance will degrade in terms of packet loss and produce high signaling cost at the old foreign agent. This introduces the failure point at the old foreign agent.

What we just mentioned is that the Low Latency Handoff scheme aims to reduce the handoff triggering and execution. This reduces the packet loss during the ongoing communication, especially, while the mobile node handoffs to the new network. However, the drawback of this scheme is that the signaling costs will increase at the GFA for the Pre-Registration handoff scheme and at the old foreign agent for the Post-Registration handoff scheme. This effect will increase the packet loss and the signaling overhead, which is not acceptable when considering the scarce bandwidth of the wireless or wired networks.

Our work motivates to evaluate the system performance of the Low Latency handoff scheme by means of the Network Simulator (ns). We propose a solution to avoid the problem of the signaling overhead and system-centralized architecture of the Pre-Registration handoff and Post-Registration handoff schemes. We will compare the performance of the Low Latency handoff with the original mobile IP in terms of handoff latency and packet loss. We will also implement the buffer at every mobility agents in order to alleviate the packet loss.

This thesis is organized as follows. In Chapter 2 we describe the basic background of standard mobile IPv4, mobile IP Regional Registration and Low Latency handoff scheme. Chapter 3 describes our proposed solution that bases on simulation and analytical model. Chapter 4 describes the implementation of the Pre- and Post- Registration handoff in Network Simulator by using the wireless LAN as the link layer. The performance evaluation and comparison between the original mobile IP and Low Latency handoff scheme are interpreted in Chapter 5. Finally Chapter 6 concludes our work and the recommendation.

1.2 SCOPES AND GOALS

1. Implement the Pre- and Post- Registration handoff scheme in the Network Simulator
2. Evaluate the system performance of the Low Latency handoff in terms of handoff latency and packet loss and compare these parameters with those of the original mobile IP.
3. Investigate the signaling overhead in the Pre- and Post-Registration handoff when implemented with the mobile IP Regional Registration.

1.3 EXPECTED BENEFIT

1. To study the original mobile IP and the mobile IP Regional Registration and their performance evaluation with the Network Simulator.
2. To study the Low Latency handoff scheme and its performance evaluation in the Network Simulator.
3. To use the minimum consumption of the network resource due to the proposed method to reduce the signaling overhead.

CHAPTER 2

MOBILE IP OVERVIEW

This chapter provides the overview of mobile IPv4 in section 2.1. The mobile IP Regional Registration is described in section 2.2. Section 2.3 will describe the Low Latency handoff scheme.

2.1 MOBILE IP CONCEPT

Mobile IP is an Internet standards-track protocol that enhances the existing IP to accommodate mobility. Mobile IP comes without changing the network infrastructure of the existing IP based network but it introduces the following new functional entities [2].

The mobile IPv4 architecture, as proposed by IETF, is shown in Figure 1.

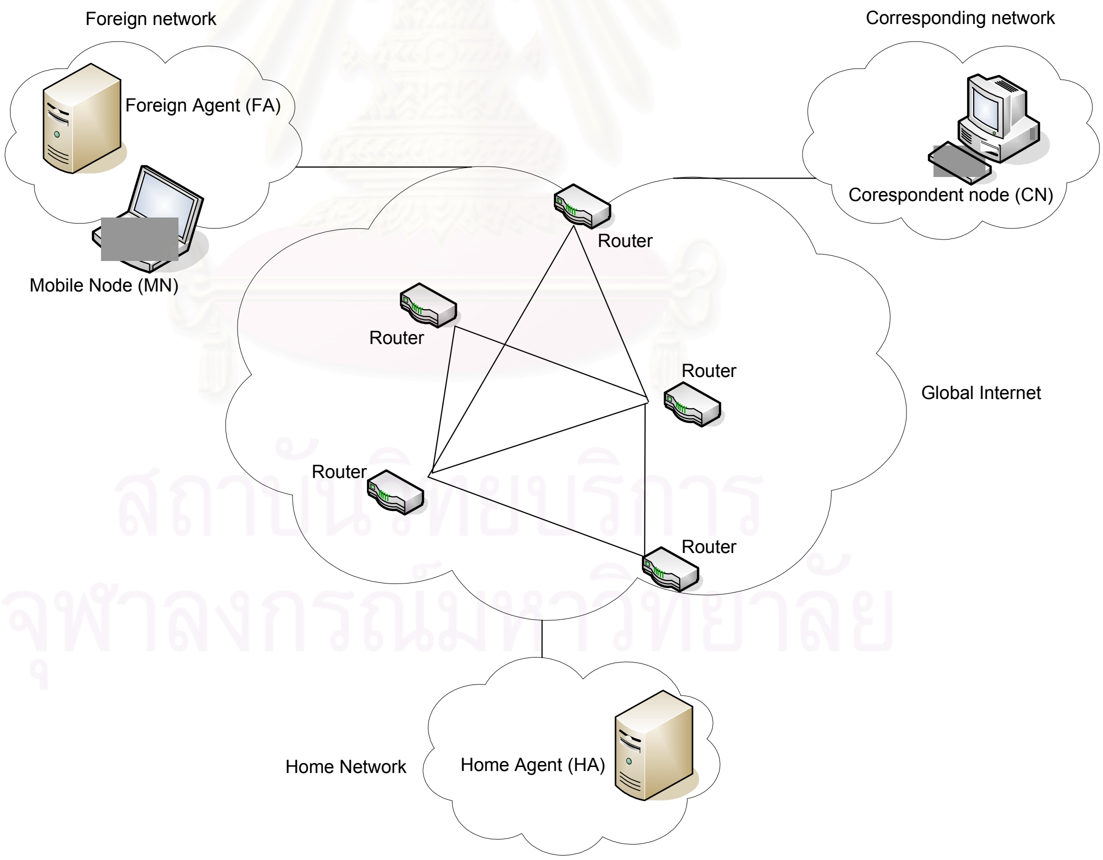

Figure 1. Mobile IP architecture

Mobile Node (MN): A host or router that changes its point of attachment from one network to another without changing its permanent address.

Home Agent (HA): A router on a mobile node's home network that delivers datagram to the mobile node.

Foreign Agent (FA): A router on a mobile node's visited network (foreign network) that cooperates with the HA to complete the delivery of datagram to the MN while it is away from its home network.

The solution proposed by IETF suggests that the MN should use two different IP addresses: a permanent home address and a care of address (CoA) that changes at each point of attachment. This solution requires that, when the MN moves from one network or sub-network to another, it must register its CoA to the HA on its home network. Hence, the IETF proposes the following new messages for maintaining the service.

Advertisement Message: A special message broadcast from the FA to present its available service with which the CoA contains.

Registration Request: A message sent by the MN to the HA to inform about its CoA.

Registration Reply: A message response to the MN indicating that the registration has been accepted.

The mobile IP protocol works as follows:

- Mobility Agents (HA or FA) advertise their presence and service by sending agent advertisement messages. An MN may optionally solicit an agent advertisement.
- After receiving an agent advertisement, an MN determines whether it is on its home network or a foreign network. An MN, which is on its home network acts like any other fixed node.
- When an MN moves away from its home network, it obtains a CoA on the foreign network. Then, the MN registers its new CoA with the HA using a Registration Request and receiving the Registration Reply.
- Datagrams sent to the MN's permanent address are intercepted by its HA. They are encapsulated in a new datagram that contains the CoA and are sent to the FA, and finally the FA delivered them to the MN.
- In the reverse direction, datagrams sent by the MN need not be returned to the HA, but can be sent directly to the destination.

Figure 2 shows the procedure with which the mobile node performs the registration process with the new foreign agent (nFA) while it is away from its home agent.

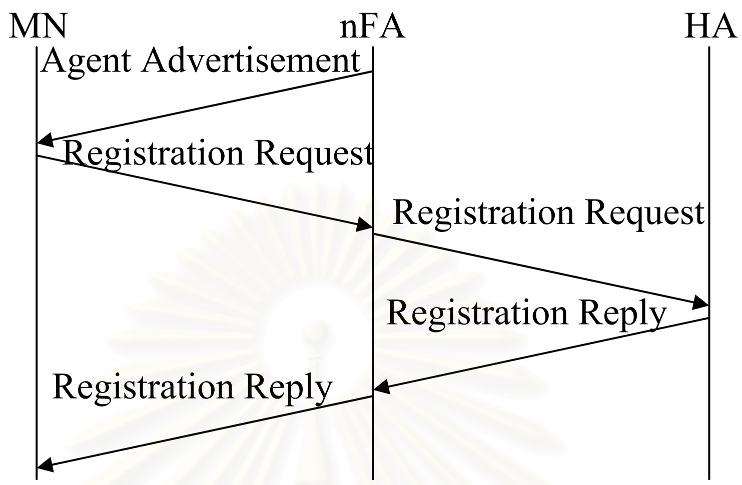

Figure 2. Mobile IP registration process

Figure 3 illustrates the routing of datagrams to and from a mobile node when it is away from home network, once the mobile node has registered with its home agent.

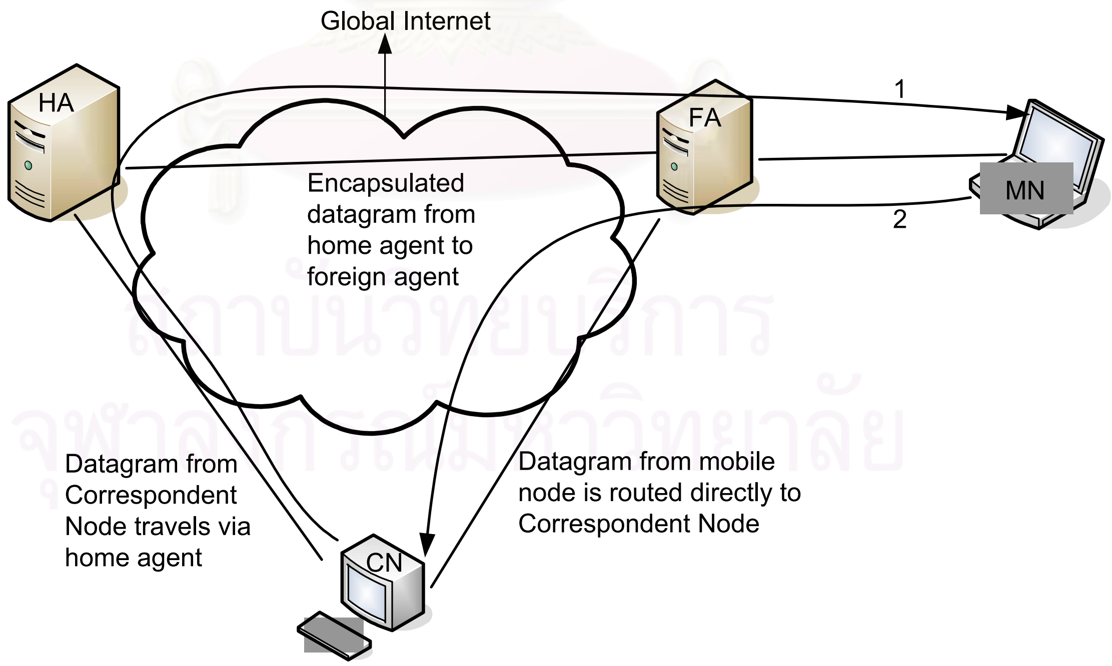

Figure 3. The routing of datagrams to and from a mobile node

In Figure 3, a CN sends the datagrams to an MN along the direction 1 and a mobile node sends the datagrams to the correspondent node along the direction 2.

Mobile IP has disadvantages as follows:

- Handoff may be slow, because the mobile node must register its change of CoA to the home agent. This may take a long time to process handoff if the HA is far away.
- The signaling overhead may be significant, because the mobile node always sends the messages to its HA to report about its new care-of-address, particularly if the mobile node has frequent handoff.

Because of these problems, the IETF group has proposed a several new protocols to solve this so called micromobility problem. Thus, in section 2.2, we explain the micromobility called mobile IP Regional Registration.

2.2 MOBILE IP REGIONAL REGISTRATION

Mobile IP Regional Registration [6] introduces a local mobility agent so called Gateway Foreign Agent (GFA), which is a specialized router that essentially acts as a local proxy for the home agent. When the mobile node moves from one foreign agent to another, that is under the same local mobility agent, the mobile node does not need to register with its HA. Instead, the MN performs a regional registration to the GFA to update its new CoA of the current foreign agent. If the mobile node changes GFA, within or between visited networks, it must register with the home agent. This is called the home registration. The mobile node uses the GFA's IP address as its CoA when it registers to the HA.

Mobile IP regional registration aims at reducing the signaling messages forwarded to the home network as well as lowering the signaling latency that occurs when the mobile node immigrates from one FA to another.

The network model of mobile IP regional registration is shown in Figure 4.

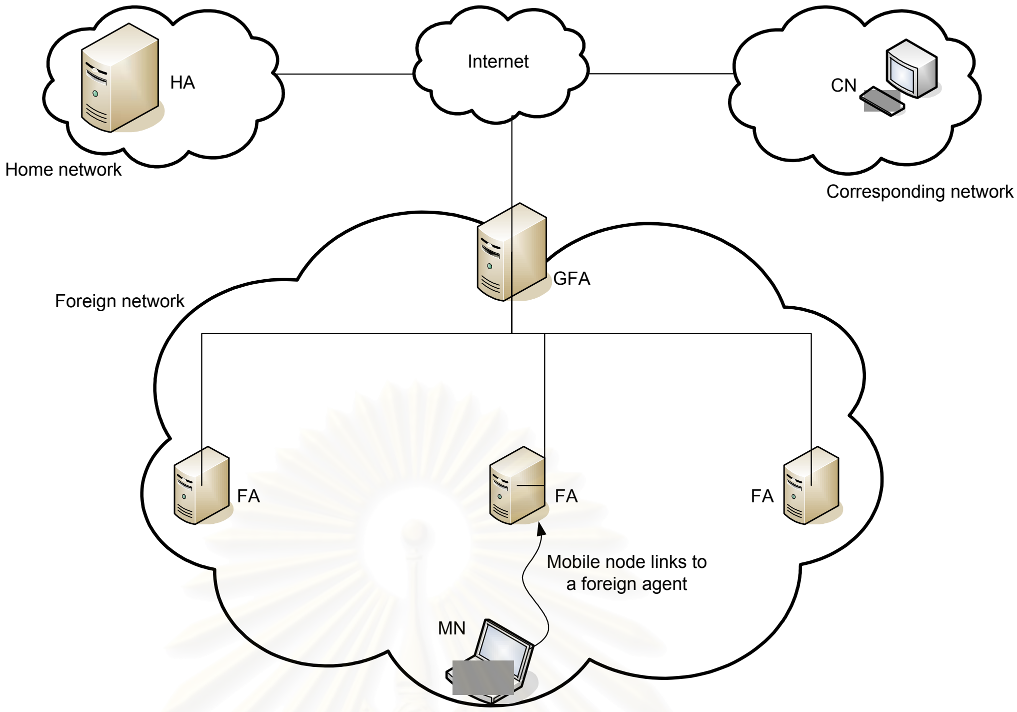

Figure 4. Mobile IP regional registration model

To operate the mobile IP regional registration, two new message types are introduced: the regional registration request and regional registration reply. These are just like the normal mobile IPv4 registration request and reply, but are used for registration with the GFA.

Figure 5 indicates the registration process of home registration in mobile IP regional registration when the MN firstly moves away from its home network.

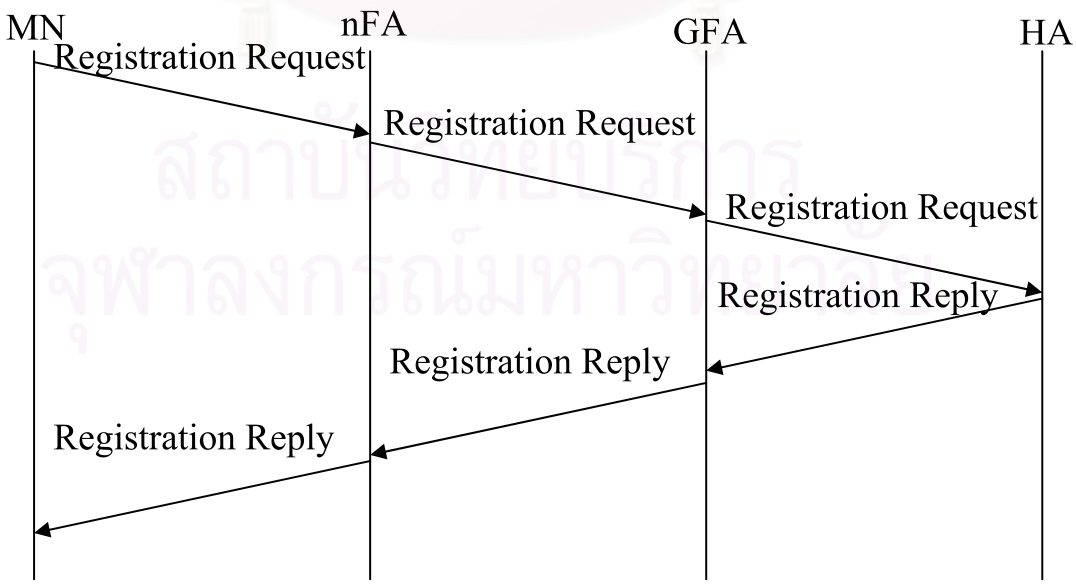

Figure 5. Home registration of mobile IP regional registration

Figure 6 indicates the registration process of regional registration in mobile IP regional registration when an MN changes the FA under the same GFA.

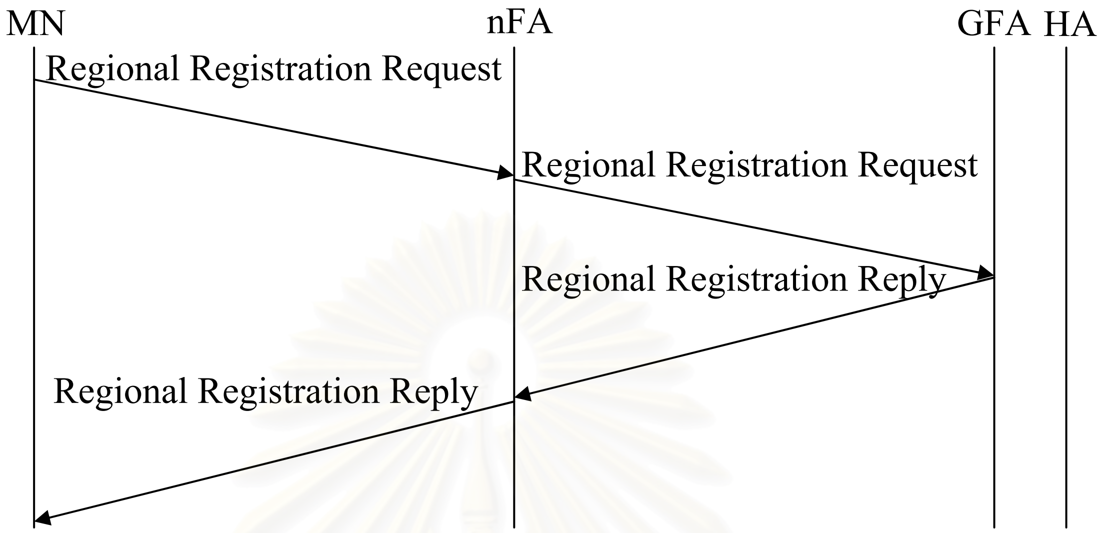

Figure 6. Registration of mobile IP regional registration

However, some studies report that the handoff latency is not much better than the original mobile IP, because both mobile IP and mobile IP regional registration use the network layer to operate the handoff. This can suffer from a break in communications during a handoff. Section 2.3 will outline a new scheme called Low Latency handoff that is proposed by IETF, with which the handoff latency may be small.

2.3 LOW LATENCY HANDOFF

Low Latency handoff [8] has been proposed by IETF to shorten handoff latency and to prevent packet loss. It uses the link layer (L2) to initiate handoff. With the facilities of link layer information such as signal strength and its fast-transmitted rate, allows a mobile node to detect the connectivity more quickly than a network layer (L3) in advertisement based algorithm. Link layer contains the information such as the new FA's IP address identifier or the old FA's IP address identifier.

Low Latency handoff is classified into two methods: Pre-Registration handoff and Post-Registration handoff. Both methods use link layer to operate handoff. Sub-section 2.3.1 describes the Pre-Registration handoff. The Post-Registration handoff is described in sub-section 2.3.2.

2.3.1 Pre-Registration Handoff

The Pre-Registration handoff scheme allows the MN to be involved in an anticipated L3 handoff by using L2 trigger. It allows the MN to prebuild its registration state on a new foreign agent (nFA) before the L2 disconnects from the old foreign agent (oFA) and the MN can communicate with the nFA while still connected to the oFA.

Both mobile node (mobile-initiated) and foreign agent (network-initiated) are able to initiate handoff. Here, we describe only the mobile initiated handoff, which occurs when an L2 trigger is received at the MN informing that it will shortly move to an nFA. For the mobile initiated handoff, the L2 trigger contains information about the nFA's IP address identifier. The overall Pre-Registration handoff mechanism is summarized in Figure 7 and the following messages are involved:

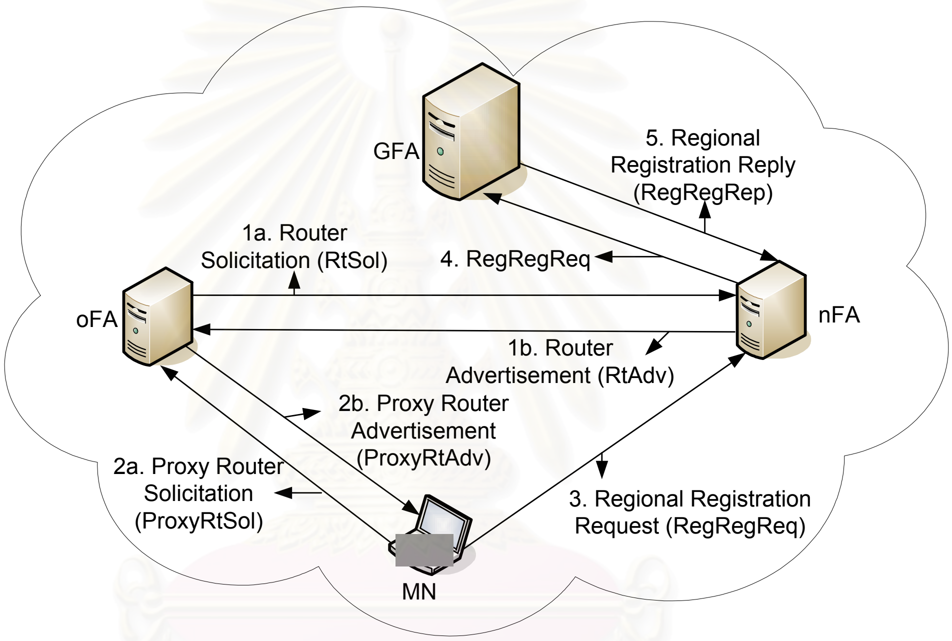

Figure 7. Pre-registration handoff

1. Messages 1a and 1b are the Router Solicitation (RtSol) from the oFA to the nFA and the Router Advertisement (RtAdv) from nFA to the oFA, respectively. The oFA should solicit and cache advertisements from the nFA in advance of the pre-registration handoff in order not to delay the handoff.
2. Message 2a, a Proxy Router Solicitation (ProxyRtSol) is issued by the MN as a consequence of the L2 triggers.
3. Message 2b, a Proxy Router Advertisement (ProxyRtAdv) is sent by the oFA as a result of the MN solicitation message. The ProxyRtAdv is used to inform the MN about the prospective nFA.
4. Message 3, a Regional Registration Request (RegRegReq) to the nFA should be sent via the oFA if the L2 handoff is not completed or directly to the nFA if the L2 handoff is already finished.

5. Message 4, a Regional Registration Request (RegRegReq) to the GFA, issued by the nFA.

6. Message 5, a Regional Registration Reply (RegRegRep), sent by the GFA to the nFA.

Until the MN actually completes the L2 handoff to the nFA and fully establishes the new link with nFA, the MN can receive the packets from a CN through the nFA. Thus, the main idea of the Pre-Registration handoff is made by registering the mobile node with the nFA in advance of L2 triggering. This realizes that the handoff latency might be small.

2.3.2 Post-Registration Handoff

The Post-Registration handoff scheme uses L2 trigger to set up a Bi-directional Edge Tunnel (BET) between the oFA and nFA, that allows the MN to continue using its old CoA while the MN is on nFA's subnet. The oFA bicasts packets to the nFA down the tunnel, so that when the mobile node makes a link layer connection with the nFA, it immediately obtains its downlink packets.

Post-Registration handoff is based on a network-initiated model of handoff and the MN is not involved in performing the handoff process until the actual L2 connection to the nFA is completed.

In Post Registration handoff, instead of making a new mobile IP registration with the nFA, the MN defers the registration while maintaining connectivity with this nFA using the bi-directional edge tunnel. The MN makes a standard mobile IP with the nFA if it receives the advertisement message from the nFA, subsequently, it will of course need to tell the oFA to stop bicasting and to tear down the tunnel.

Two network-initiated handoffs are defined, namely, source trigger and target trigger handoff. Here, we describe only the target trigger handoff, which occurs when an L2 trigger is received at nFA. The overall Post-Registration handoff mechanism is summarized in Figure 8 and the following messages are involved:

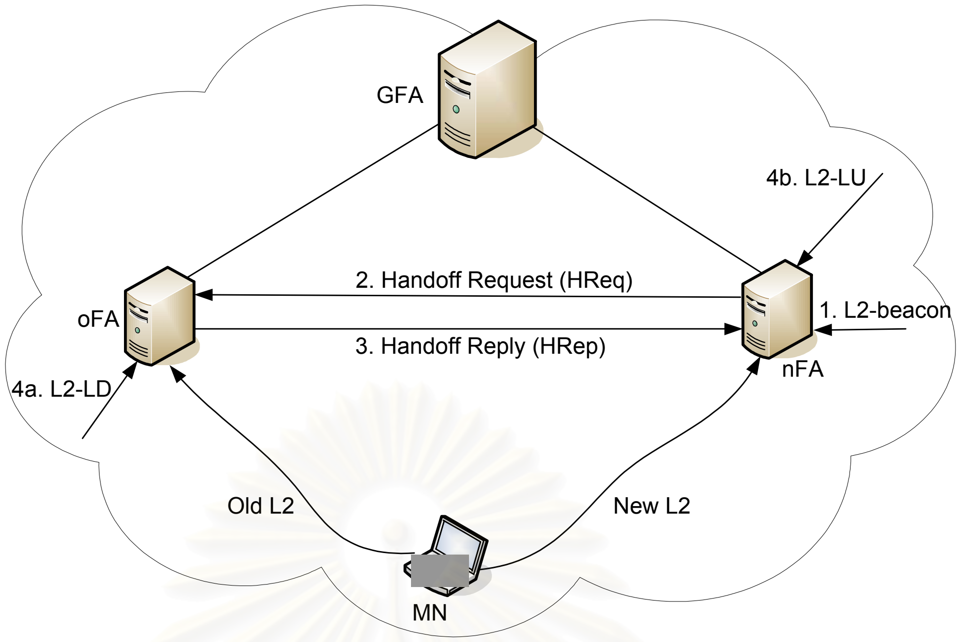

Figure 8. Post-registration handoff

1. The nFA receives an L2-beacon, informing that the MN is about to move to the nFA.
2. After receiving an L2-beacon, the nFA sends a Handoff Request (HReq) to the oFA.
3. After receiving HReq, the oFA sends a Handoff Reply (HRep) to the nFA. At this point, the bi-directional edge tunnel between the oFA and nFA has been established.
4. During the L2 handoff, the MN may lose the connection with the oFA, if an L2 Link Down (L2-LD) is triggered at the oFA. An L2 Link Up (L2-LU) is triggered at the nFA if the L2 handoff to the nFA is completely established.

After the bi-directional edge tunnel between the oFA and the nFA is established, the oFA starts to tunnel the packets to nFA, so that the MN continues to receive the packets through the bi directional edge tunnel without registering with the nFA. But later, if the MN receives the router advertisement from nFA, the MN must register with the nFA.

2.4 DRAWBACK OF LOW LATENCY HANDOFF

Here, we will describe the drawback of Pre-Registration handoff and Post-Registration handoff schemes when they are implemented with the mobile IP regional registration. Subsection 2.4.1 will show the drawback of the Pre-Registration handoff. The drawback of Post-Registration handoff will be outlined in subsection 2.4.2.

2.4.1 Drawback of Pre-Registration Handoff

We learn that, when the Pre-Registration handoff is implemented with the mobile IP Regional Registration, it is not clear how many FAs should be beneath a GFA within a regional network.

A small number of FAs will cause frequent handoff to home network. This results in high handoff latency, especially, when the HA is located far from FAs [9].

A large number of FAs under the GFA will generate high packets delivery costs on GFA and will degrade the system performance in terms of packet loss.

Pre-Registration may cause packet losses in flight between the GFA and oFA when operating handoff. If the MN receives the L2 beacon from the nFA after it has already disconnected with the oFA, the packets will also be lost because the GFA still does not know the new location of the MN.

2.4.2 Drawback of Post-Registration Handoff

Basically, in the Post-Registration handoff scheme, when an MN moves to an nFA, the bi-directional edge tunnel (BET) will be set up between the oFA and nFA. At this point, we call the oFA an anchor foreign agent (aFA), which means that a mobile node has already completed the mobile IP registration with the oFA.

If there is no router advertisement message broadcast from nFA, the oFA and nFA keep the BET, otherwise the MN has to register with the nFA using the standard mobile IP registration and the BET will be released.

If the MN moves to a third nFA before forming the registration with the previous nFA, the oFA or aFA has to set up a new BET to the third nFA.

In our case, we suppose that an MN does not register to an nFA where it moves to. Thus, the oFA/aFA always sets up the BET to the current nFA of the MN and the aFA always intercepts all the packets destined to the MN.

This approach may have problems if the aFA establishes the BET with many nFAs. It may cause unnecessary traffic in the wired backbone network and increase the failure points of attachments. As a consequence, the signaling cost needed to perform BET will be high at the aFA and the packet delivery cost at the aFA is also high.

Post-Registration handoff scheme may cause packet losses if the handoff is initiated after the MN has disconnected from the oFA.

Post-Registration handoff scheme may cause packet losses if there is no buffer at the aFA.

CHAPTER 3

PROPOSED SOLUTION

This chapter will outline our proposed solution that motivates to enhance the system performance of Low Latency Handoff scheme as described in the Chapter 2. In section 3.1, we explain our proposed method to enhance the system performance of the Pre-Registration handoff scheme. In section 3.2, we explain our proposed method to enhance the system performance of the Post-Registration handoff scheme.

3.1 PROPOSED SOLUTION IN THE PRE-REGISTRATION HANDOFF

As explained in Chapter 2, the Pre-Registration handoff may cause packet in flight between a GFA and oFA to be lost during handoff. To avoid this problem, we propose that the GFA should bicast the traffic destined to both oFA and nFA, since the GFA sends the regional registration reply to the MN.

If the MN receives the L2 beacon from the nFA after it has already disconnected from the oFA, the packets will also be lost because the GFA still does not know the new location of the MN. In this case, we propose that the overlapping area between the oFA and nFA should be big enough to complete the handoff operation before the MN disconnects from the oFA.

As also explained in Chapter2, when the Pre-Registration handoff is implemented with the mobile IP Regional Registration, it is not clear how many FAs should be beneath a GFA within a regional network. This is called the centralized architecture’s problem that the traffic is relied on only one GFA. Hence, to avoid this problem, we define the signaling for location update cost and packet delivery cost addressed to the GFA. The optimal number of FAs beneath the GFA can be defined due to the optimum total signaling cost (location update cost and packet delivery cost) that the GFA can support in order not to degrade the system performance.

The optimal number of FAs beneath a GFA can be selected due to the constraint of each operator, as an example, how much bandwidth of a network operator can be provided? How much traffic can the backbone network support in the operating system? All these parameters play the important role in selecting the number of FAs in a regional network.

In subsection 3.1.1, we define the signaling cost for location update to GFA. In subsection 3.1.2, we define the packet delivery cost at the GFA.

3.1.1 Location Update Cost

Similar to [9], we define the parameters for location update as follows:

- C_{fm}: The transmission cost of location update over the wireless link between the FA and the MN.
- C_{gf}: The transmission cost of location update between the GFA and FA.
- a_f: The processing cost of location update at FA.
- a_g: The processing cost of location update at GFA.
- l_{gf}: The average distance between the GFA and the FA in terms of the number of hops that packets travel.

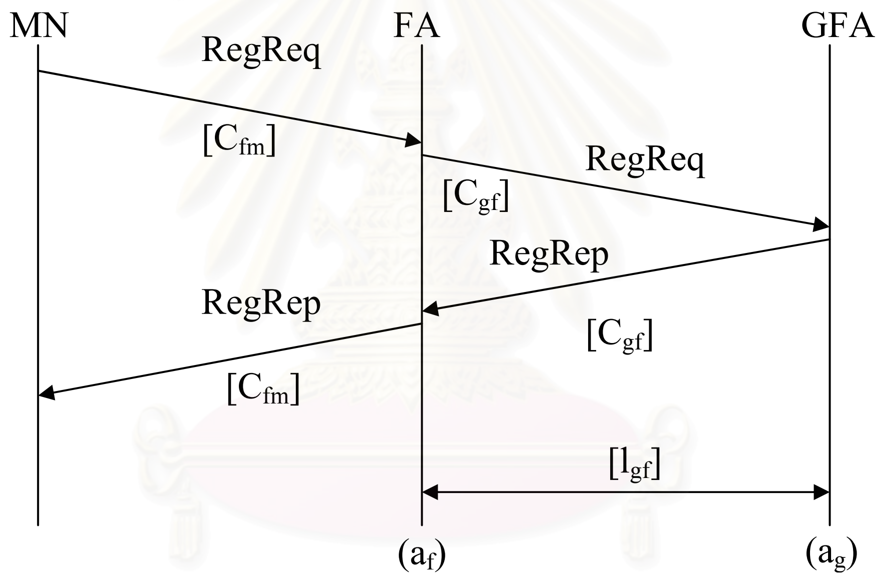

Figure 9. Process of location registration update to GFA

Figure 9 shows the signaling flows for location registration update to GFA within one regional network. From these message flows, the cost of location registration update to GFA of one regional network can be calculated as:

$$C_{LU} = 2a_f + a_g + 2C_{gf} + 2C_{fm} \tag{1}$$

We assume that the transmission cost of location update is proportional to the distance between the source and destination mobility agents and the proportionality constant is δ_U. Thus, C_{gf} can be expressed as:

$$C_{gf} = l_{gf}\delta_U \tag{2}$$

The transmission cost over the wireless link is generally ρ times higher than that of the wired link [8]. Then, the transmission cost between the FA and the MN can be defined as:

$$C_{fm} = \rho\delta_U \tag{3}$$

We also assume that the average time each MN stays in the regional network under the GFA is T_f. Then, the location update cost per unit time is:

$$c_{LU} = \frac{C_{Lu}}{T_f} = \frac{2a_f + a_g + 2C_{gf} + 2C_{fm}}{T_f} \tag{4}$$

3.1.2 Packet Delivery Cost

We define the following parameters:

- v_g: The processing cost of packet delivery at the GFA.
- T_{gf}: The transmission cost of packet delivery between the GFA and FA.

Assume that the transmission cost of packet delivery is proportional to the distance between the sending and the receiving mobility agents with the proportionality constant δ_D. Thus, T_{gf} can be expressed as:

$$T_{gf} = l_{gf}\delta_D \tag{5}$$

The load on a GFA for the processing and routing packets to each FA depends on k, which is the number of FAs beneath GFA. If k is large, the complexity of the visitor list lookup and IP routing table lookup in the GFA is high [10]. These factors will result in a high processing cost at the GFA.

We assume that on average, there are ω_1 MNs (under one FA) in the subnet of the GFA. Then, the total number of MNs that a GFA serves in a regional network is $\omega_1 k$. Therefore, the complexity of the GFA visitor list lookup is proportional to $\omega_1 k$.

The IP routing table look up in the GFA is proportional to the algorithm of the length of the routing table k [11]. Therefore, the IP routing table lookup is proportional to $\log(k)$.

Finally, similar to [9], we define the packets processing cost function at the GFA:

$$v_g = \varsigma_1 \lambda_a k(\alpha_1\omega_1 k + \beta_1 \log(k)) \tag{6}$$

Where λ_a is the average packet arrival rate for each MN, α_1 and β_1 are weighting factors of visitor list and IP routing table lookups and ς_1 is a constant which captures the bandwidth allocation cost at the GFA. Then the total packets delivery cost per unit time is:

$$c_{PD} = v_g + T_{gf} = \varsigma_1 \lambda_a k(\alpha_1 \omega_1 k + \beta_1 \log(k)) + l_{gf} \delta_D \tag{7}$$

3.1.3 Total Signaling Cost

The total signaling cost per unit time is the summation of the location update cost and the packet delivery cost of (4) and (7).

$$C_{TOT}(k, \lambda_a, T_f) = c_{LU} + c_{PD} \tag{8}$$

It is clear that the total signaling cost per unit time at the GFA depends on how many FAs beneath the GFA are, how long the MN stays in the regional network, and how much the sending rate of the CN is.

From equation (8), first, we consider that the average packet arrival rate (λ_a) is constant and then, we will illustrate the variation of the total signaling cost under different average residence time (T_f). Second, we consider that the average residence time is fixed and then, we will observe the variation of signaling cost under different average packet arrival rate. Both of these will be explained in Chapter 5.

3.2 PROPOSED SOLUTION IN THE POST-REGISTRATION HANDOFF

As explained in Chapter 2, Post-Registration handoff may cause packets losses if there is no buffer at the aFA. This is because the aFA plays the important role to intercept the packets from the CN and forward them to the current foreign agent of the MN along the bi-directional edge tunnel. Thus, we need to implement the buffer at every mobility agents in order to store the packets when the MN handoffs to another FA while still not establish the BET with the nFA.

Post-Registration handoff scheme may cause packet losses if the handoff is initiated after the MN has disconnected from the oFA. In this case, we need to design the distance of the overlapping area between the two FAs. This work is based on simulation model.

In the Post-Registration handoff scheme, the oFA/aFA always sets up the BET to the current nFA as explained in section 3.2. This approach may have problems when the oFA/aFA performs the BET with many FAs.

Therefore, to limit the number of FAs, which perform the BET with the same aFA, we define the signaling cost for location update and packet delivery addressed to the aFA. We then find the optimal number of FAs that the aFA can support in order not to degrade our system performance in terms of packet loss during ongoing communication. We will use the iterative algorithm as illustrated in [8] to apply to our case in order to minimize the total signaling cost at the aFA. Note that an iterative algorithm was proposed to solve the location minimum problem which define the cost difference function between the currently system and the previous system.

In [8], the optimal number of FAs beneath the GFA in Mobile IP scheme was proposed. In our thesis, we compute the optimal number of FAs theat establish the BET with aFA.

In the following, we will define the signaling cost for location updates at the aFA and the packet delivery cost at the aFA.

The optimal number of FAs served by an aFA can be selected due to the constraint of each operator. For example, how much the bandwidth of a network operator can be provided? How much does the backbone network can support the traffic in the operating system? All these parameters play the important role in choosing the number of FAs beneath the region of aFA.

In subsection 3.2.1, we define the signaling cost for location update at the aFA. In subsection 3.2.2, we define the packet delivery cost at the aFA.

3.2.1 Location Update Cost at aFA

Similar to subsection 3.1.1, we define the following parameters for location update:

- C_{fm} : The transmission cost of location update over the wireless link between the aFA and the MN.
- C_{afanfa} : The transmission cost of processing BET between the aFA and nFA.
- a_f : The processing cost of location update at aFA.
- l_{gf} : The average distance between the GFA and the aFA in terms of the number of hops packets travel.
- l_{afanfa} : The average distance between the aFA and the nFA in terms of hops packets travel.

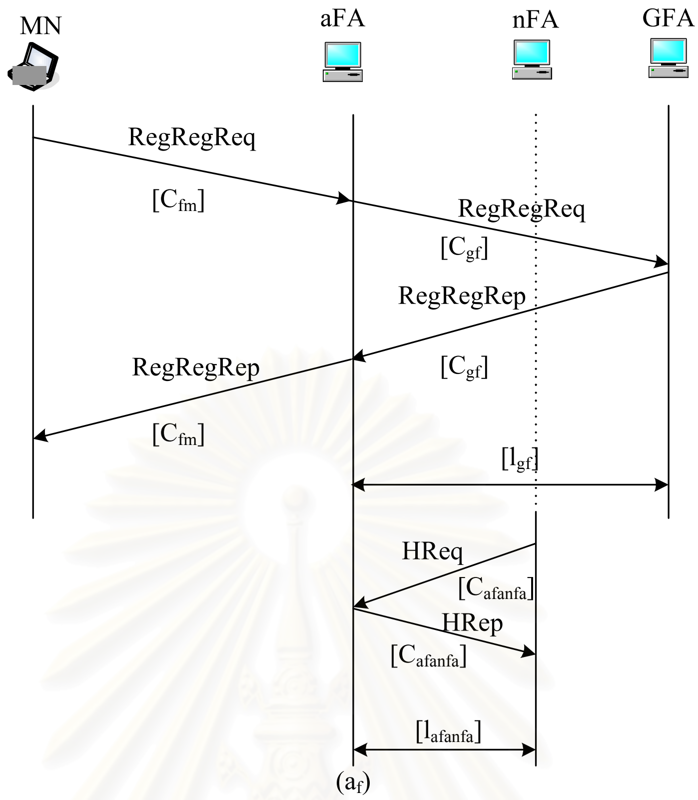

Figure 10. Process of location registration update and processing BET at aFA

Figure 10 shows the signaling flows for location registration update to GFA through aFA and the signaling flow to set up the BET between the aFA and the nFA.

From these message flows, the cost of location registration update to GFA at aFA can be calculated as:

$$C_{LUafa} = 2a_f + 2C_{fm} \tag{9}$$

The signaling cost at aFA to set up BET to nFAs can be expressed as:

$$C_{BET} = a_f + 2C_{afanfa} \tag{10}$$

We assume that the transmission cost of location update is proportional to the distance between the source and destination mobility agents and the proportionality constant is σ_U. Thus, C_{afanfa} can be expressed as:

$$C_{afanfa} = l_{afanfa}\sigma_U \tag{11}$$

The transmission cost over the wireless link is generally ρ times higher than that of the wired link [8]. Then, the transmission cost between the aFA and the MN can be defined as:

$$C_{fm} = \rho\sigma_U \tag{12}$$

We also assume that the average time each MN stays within the aFA is T_{afa}. Then, the location update cost at the aFA per unit time is:

$$c_{LUafa} = \frac{C_{LUafa}}{T_{afa}} \tag{13}$$

Assume that, there are N FAs within a regional network and there are k FAs performing the BET with the aFA. The MN may visit an FA more than once and it may also move back and forth between two FAs. We model the movement of an MN as a discrete time. At movement 1, the MN may reside in either FA 1, 2, … or N. At movement 2, the MN may move to any of the other N-1 FA. We assume that the MN will move out to the other N-1 FAs with equal probability $\frac{1}{N-1}$. Similar to [8] the probability that mobile node changes an aFA at movement m is:

$$P_{afa}^{(m)} = \left(\frac{N-k}{N-1}\right)\cdot\left(\frac{k-1}{N-1}\right)^{(m-2)} \tag{14}$$

Where $2 \le m < \infty$

Assume that at movement M, the mobile node changes the aFA that means the mobile node makes a standard mobile IP registration with the nFA and then, this nFA becomes the aFA. As a consequence, the BET between the nFA and the previous aFA has been torn down.

Thus, the expectation of M can be written as:

$$E[M] = \sum_{m=2}^{\infty} mP_{afa}^{(m)} = 1 + \frac{N-1}{N-k} \tag{15}$$

Assume the average time each MN stays before changing the aFA is T_f. Therefore, the signaling cost for location update to GFA at aFA and the signaling cost for processing BET per unit time can be written as:

$$c_{LU} = \frac{E[M]C_{BET} + c_{LUafa}}{E[M]T_f} \tag{16}$$

3.2.2 Packet Delivery Cost at aFA

We define the following parameters as:

- v_g: The processing cost of packet delivery at the GFA.
- v_{afa}: The processing cost of packet delivery at the aFA.
- T_{gafa}: The transmission cost of packet delivery between the GFA and the aFA.

- T_{afanfa}: The transmission cost of packet delivery between the aFA and the nFA.

Thus, the total packet delivery cost at the aFA can be expressed as:

$$C_{PD} = v_g + v_{afa} + T_{gafa} + T_{afanfa} \tag{17}$$

As described is subsection 4.1.2, the transmission cost of packet delivery is proportional to the distance between the sending and the receiving mobility agents with the proportionality constant σ_D. Thus, the transmission cost of packet delivery between the GFA and aFA can be expressed as:

$$T_{gafa} = l_{gf}\sigma_D \tag{18}$$

The transmission cost of packet delivery between the aFA and the nFA is proportional to the number of BETs (k). Thus T_{afanfa} can be written:

$$T_{afanfa} = kl_{afanfa}\sigma_D \tag{19}$$

Assume the GFA acts like the other FAs. This is because when the MN moves from oFA to nFA, the MN does not register to the GFA. The MN receives the L2-beacons from nFA, and then the MN sends the association request to the nFA, which triggers the nFA to perform the BET with oFA. In this case, the complexity of the GFA is not dependent on the number of the FAs beneath it and on the IP routing table as explained in section 3.1.2. Thus, we can define the processing cost function at GFA as:

$$v_g = \eta\lambda_a \tag{20}$$

Where η is a packet delivery processing cost constant at GFA.

In our model, the aFA always establishes the BET to the other FAs. It serves the other FAs for sending the packets from GFA to those nFAs. The aFA creates the table IP routing for the other nFAs. Therefore the complexity of aFA depends on the number of nFA (k) served by aFA, the IP routing table lookup in the aFA and the average packet arrival rate for each MN (λ_a). The total number of MNs, which the aFA are serving, is $\omega_2 k$ on average. Thus, we define the packet processing cost function at the aFA as:

$$v_{afa} = \varsigma_2\lambda_a k(\alpha_2\omega_2 k + \beta_2 \log(k)) \tag{21}$$

Where α_2 and β_2 are weighting factors of visitor list and routing table lookups and ς_2 is a constant which captures the bandwidth allocation cost at the aFA. Then the total packet delivery cost per unit time is obtained by using (17), (18), (19), (20) and (21).

$$c_{PD} = \eta\lambda_a + \varsigma_2\lambda_a k(\alpha_2\omega_2 k + \beta_2 \log(k)) + (l_{gf} + kl_{afanfa})\sigma_D \quad (22)$$

3.2.3 Total Signaling Cost per Unit Time at aFA

The total signaling cost per unit time is the summation of the location update cost and the packet delivery cost of (16) and (22).

$$c_{TOT}(k, \lambda_a, T_f) = c_{LU} + c_{PD} \quad (23)$$

3.2.4 Optimal Number of FAs Served by aFA

The optimal number of FAs served by aFA, k_{opt}, is defined as the value of k that minimizes the total signaling cost function. Because k can only be an integer and the cost function is not a continuous function of k, hence it is not appropriate to take derivatives with respect to k of the cost function to get the minimum.

We use an iterative algorithm to compute the k_{opt} by differentiating the cost function between the system with number k and the system with number $k-1$ ($k \geq 2$), i.e.

$$\Delta(k, \lambda_a, T_f) = c_{TOT}(k, \lambda_a, T_f) - c_{TOT}(k-1, \lambda_a, T_f) \quad (24)$$

Given Δ, the algorithm to find the optimal value of k is defined as follows:

$$k_{opt}(\lambda_a, T_f) = \begin{cases} 1, & if \Delta(2, \lambda_a, T_f) > 0 \\ \max\{k : \Delta(k, \lambda_a, T_f) \leq 0\}, & otherwise \end{cases} \quad (25)$$

It is indicated that the optimal number of FAs served by aFA may be a designed value. It is computed before the communication takes place and it is based on the average packet traveling rate and the average residence time of the users in the coverage region of aFA. It is also based on how big the bandwidth of the wired network can support the signaling cost.

CHAPTER 4

SIMULATION OF LOW LATENCY HANDOFF OVER IEEE 802.11

In this chapter, we describe the simulations of the Pre- and Post-Registration handoff schemes over the wireless LAN IEEE 802.11 in the Network Simulator (NS). In section 4.1, we describe the overview of the handoff algorithm. In section 4.2, we describe the simulation of the Pre-Registration handoff. In section 4.3, we describe the simulation of the Post-Registration handoff. In section 4.4, we describe the L2 triggers.

4.1 HANDOFF ALGORITHM

In the Simulation of Hierarchical Mobile IP implementation given in [12] [13] the handoff is completely managed in layer 3 (L3). This implementation requires that: every FA broadcasts Router Advertisement (RtAdv) every 1 second. The MN captures Router Advertisements and makes a decision when to handoff to an nFA. Well-known algorithms for handoff detection and triggering that are managed in layer 3 are Lazy Cell Switching (LCS) and Eager Cell Switching (ECS) [2]. The first algorithm, LCS, is based on the lifetime of the advertisement sent by the network. The mobile node monitors any advertisements, records the lifetime and updates the expiration time when a new advertisement is received from the network. When the advertisement lifetime of the current foreign agent expires, the mobile node assumes that it has lost connectivity and attempts to execute a new registration with the new foreign agent. Although the mobile node might already be informed about the availability of a new foreign agent, the mobile node defers switching until the advertisement lifetime of the old foreign agent is expired. The second algorithm, ECS, makes use of the network identification carried by the advertisement. If the mobile node detects an advertisement with a different network identifier other than the current network, the mobile node assumes that a handoff has happened and registers with the new foreign agent.

The latency for handoff detection incurred by the LCS algorithm corresponds directly with the lifetime of the advertisement that is a multiple of the advertisement interval. The advertisement lifetime is typically set to three times of the interval [2]. The ECS algorithm reduces the service interruption, but the fact that when the mobile node receives an advertisement does not necessarily mean that the link to the current foreign agent is broken. Though the current foreign agent is reachable, the mobile node registers with an nFA. In these cases, an unnecessary handoff is triggered.

The advertisement interval takes into account that, the rate of advertisement is rather slow when using the LCS algorithm. For the ECS algorithm, there might be no improvement and inherits disadvantage.

An alternative to layer 3 handoff triggers is layer 2 triggers. These layer 2 triggers reduce the time to detect and trigger handoff by means of cross-layer information from layer 2 to layer 3 [14].

To achieve our requirement, we simulate a mobile-initiated handoff of Pre-Registration handoff scheme and a target trigger handoff of Post-Registration handoff scheme. Here, the link layer trigger has been modified in the wireless LAN IEEE 802.11 and other implementations have been added in Network Simulator of Hierarchical Mobile IP (NS HMIP).

4.2 SIMULATION OF PRE-REGISTRATION HANDOFF

In 802.11 a layer 2 handoff mechanism has been specified [14] [15] and base station refers to as Access Point (AP).

In our simulations, we have assumed the following:

- The Foreign Agent (FA) is an embedded entity in the Access Point (AP). Therefore, the term FA and AP throughout this thesis are used synonymously.

- We assume that the MN uses the same channel with both AP (thus, the MN can communicate with both AP during the overlapping region) and movement at L2 layer is detected upon receiving the first beacon from the new access point. IEEE 802.11 beacons are sent every 100ms.

- Router Advertisements are sent every 1 s.

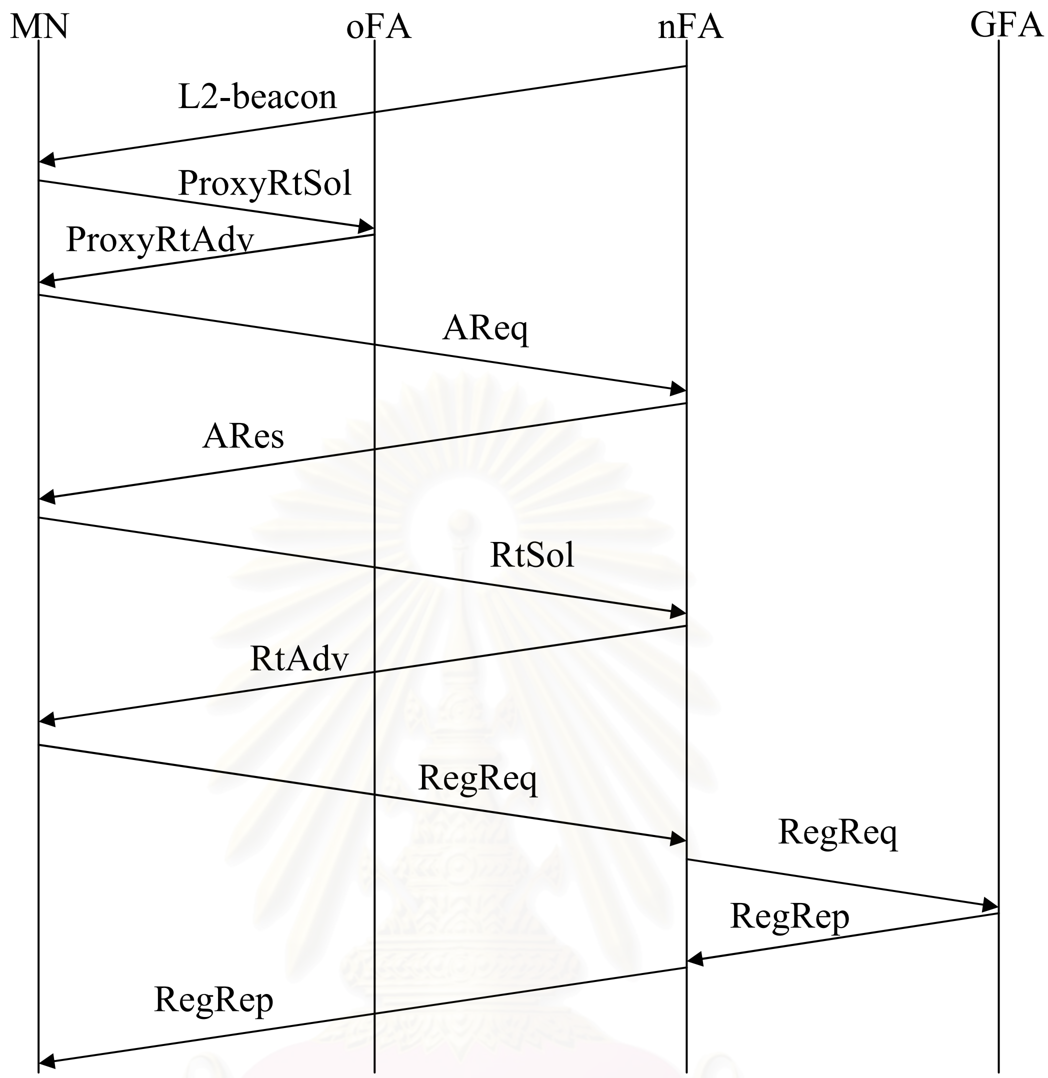

Figure 11. Mobile-initiated handoff in pre-registration handoff over IEEE 802.11

Before the MN attaches to the nFA, the MN always establishes an association with this nFA by sending an Association Request (AReq) frame and in turn nFA replies back an Association Response (ARes) frame. The MN uses L2 beacons to determine which FA would make the best connection.

Since L2 beacons are sent at a rate much higher than the Router Advertisements, the packets loss during the handoff is likely to be reduced.

The MN sends a Proxy Router Solicitation to the oFA once it has chosen a new AP. The oFA maps the nFA link layer address into the IP address of the nFA (assuming the oFA maintains a mapping table) and returns a Proxy Router Advertisement to the MN. The MN sends a Registration Request message to the nFA through the oFA since the MN is not yet connected to the nFA. The nFA will forward the Registration Request message to the GFA. At this point the MN should complete the L2 handoff, which means exchanging re-association messages. The Registration Reply message will be unicast by the nFA to the MN as soon as the MN connects to the nFA. If the Registration is successful then packets for the MN will be tunneled from the GFA to the nFA where the MN has moved out.

The implementation of mobile-initiated handoff in Pre-Registration handoff scheme using 802.11 as link layer in a simulation is shown in the timing diagram in Figure 11. The events during the handoff are as follows.

1. When the MN receives the L2-beacons from nFA, the MN sends Proxy Router Solicitation (ProxyRtSol) to the oFA informing this oFA that it has chosen an nFA.
2. The oFA, then, maps the nFA link layer into the IP address of the nFA and replies a Proxy Router Advertisement (ProxyRtAdv) to the MN.
3. The MN is now preparing to associate with the nFA by sending an Association Request (AReq) to the nFA.
4. Then, the nFA returns an Association Response (ARes) to the MN.
5. Upon receiving the ARes, the MN solicits the nFA with Router Solicitation (RtSol) message.
6. Then, the nFA replies a Router Advertisement (RtAdv) to the MN.
7. Finally, the MN makes a registration to GFA by using the standard mobile IPv4.

4.3 SIMULATION OF POST-REGISTRATION HANDOFF

We simulate a target trigger handoff of Post-Registration handoff scheme using IEEE 802.11 as link layer in the Network Simulator (NS). In this scheme the MN re-associates with the nFA once it has chosen a new AP. This re-association message will act as an L2 target trigger at the nFA. The nFA and the oFA will establish a bi-directional edge tunnel after the exchange of a handoff request and handoff reply message. At this point the bi-directional edge tunnel is established and the traffic is tunneled between the two FAs so that the MN continues to receive service through the bi-directional edge tunnel without registering with the nFA. Later, the MN will register itself with the nFA.

Figure 12 shows the simulation of the Post-Registration handoff scheme. The events during the handoff are as follows.

1. Upon reception of the 802.11 beacons (L2-beacon) from nFA, the MN re-associates with the nFA by sending Association Request (AReq) to nFA. This association message will act as an L2 target trigger at the nFA. In return, the nFA sends the Association Response (ARes) to the MN.
2. The AReq triggers the nFA to send a Handoff Request (HReq) to the oFA.
3. When the oFA receives the HReq, it sends back the Handoff Reply (HRep) to the nFA. This establishes the BET between the oFA and nFA. At this point, the oFA can send the packets addressed to the MN through the BET.
4. When the MN receives the Router Advertisement from the nFA, the MN initiates the standard mobile IP registration with the nFA.

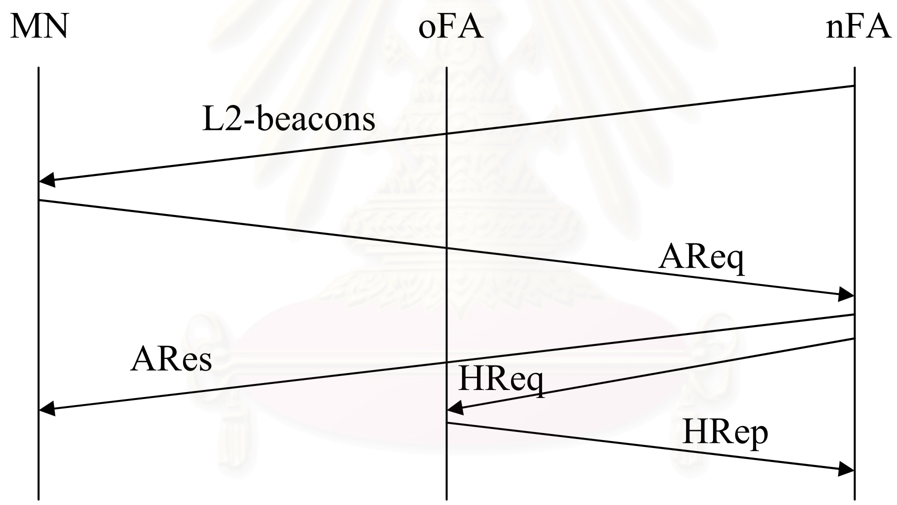

Figure 12. Target trigger handoff in post-registration handoff over IEEE 802.11

4.4 L2 TRIGGERS

Mobile IP was originally designed without assumptions concerning the underlying link layer (L2). This approach implies a clear separation between L2 and L3 functionality but leads to unacceptable handoff latencies. Indeed, an MN involved in a handoff may only begin the registration process after the L2 handoff to the nFA has been completed. Moreover, as the messages generated by the registration process need some time to propagate through the network, the MN is unable to send or receive packets during that time. For these reasons, the Pre- and Post-

Registration Handoff has been proposed based on L2 triggers as described above.

By considering the usage of an L2 triggers for handoff, some potential parameters must be taken into account: signal strength, signal to noise ratio (SNR) and bit error rate. All these parameters can be used to detect a decaying wireless link and therefore provide an indication that a handoff is about to occur.

The impairment, however, is caused by attenuation, reflection, refraction, scattering and diffraction. They may result the received signal strength fluctuates significantly, which may impact the performance of handoff.

In this thesis, thus, we suppose that the MN receives at least a signal from the access point. If the signal strength is higher than threshold (-65dBm) [15], the link is considered as good. If the signal strength is lower than this threshold, the link is considered as bad and a handoff will be triggered.

In the worst case, if an L2 trigger is lost, the MN will listen to the router advertisement from the nFA where it just entered. When the MN receives the router advertisement, it registers to the GFA using standard of mobile IP registration process.

Note that the usage of link layer to initiate handoff may allow a mobile node to detect the loss of connectivity more quickly than layer 3 advertisement-based algorithm (ECS and LCS). Moreover, the link layer trigger can be employed for other functionality such as paging as well. An inactive mobile node can be triggered by link layer information to re-register when it enters a new paging area. However, using link layer trigger for handoff gives dependency between layer 2 and layer 3, which violates a general design paradigm of the Internet Protocols. Compared with the link layer solution, the network layer schemes should be easier to scale to large networks because the mobile IP can operate over any link layer. In order to reduce this dependency, an L2 trigger should be regarded as an abstract of a notification from layer 2 that a certain event has occurred or is about to occur.

CHAPTER 5

PERFORMANCE EVALUATION

In this chapter, we show the simulation results of the original Mobile IPv4, the Pre- and Post-Registration handoff scheme. We then, compare the system performance of the original Hierarchical Mobile IPv4 with those of the Pre- and Post-Registration handoff schemes. Finally, we show the simulation results of our proposed method. This chapter is organized as follows. In section 5.1, we describe the environment of the simulation. In section 5.2, we show the simulation results of the Mobile IP Regional Registration, Pre-Registration handoff and Post-Registration handoff schemes. In section 5.3, we compare the system performance of the Mobile IP Regional Registration, Pre-Registration handoff and Post-Registration handoff schemes. Finally, the results of our proposed method over the Low Latency handoff scheme by means of analytical model and simulation model are illustrated in section 5.4.

5.1 SIMULATION ENVIRONMENT

In order to evaluate the performance of a Mobile IP Regional Registration, Pre-Registration handoff and Post-Registration handoff schemes, the network diagram for our simulation shown in Figure 13 is used for the Network Simulator (NS).

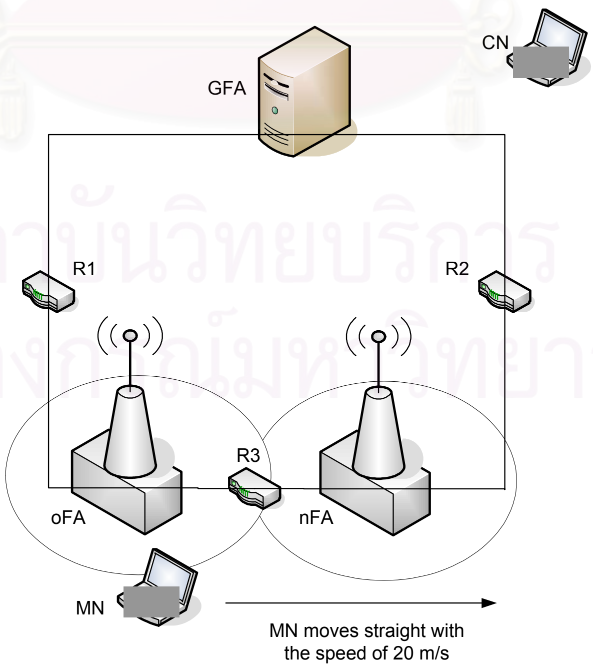

Figure 13. Network topology in the simulation

The simulation for NS is created using the TCL (Tool Command Language) program. The TCL program codes are written using the commands available for mobile IP in the NS simulator. Two foreign agents are created using the NS's node creation programming model, and then these nodes are programmed to act as FA. One GFA has introduced in the network. It is programmed to serve the mobility agents (oFA and nFA). One mobile node (MN) is created to roam around and travel from a foreign network (oFA) cell to another foreign network (nFA) cell. One correspondent node (CN) is created in order to generate the traffic to the MN.

During the movement phase, the mobile node maintains its connection to the corresponding mobility agents via the wireless links that are made possible by using IEEE 802.11 data link layer protocol.

In order to simulate real traffic congestion on the links, the Constant Bite Rate (CBR) data traffic is used. This CBR traffic is generated using NS traffic generation programming model. The CBR traffic is attached to the User Datagram Protocol (UDP) agent.

NS, upon running a TCL scenario program file, generated a trace file. This trace file contains the detailed information about the scenario that has been executed. It is a large (1-2 MB), non-uniform text file. The information about the packet arrival time, transmission time, the number of dropped packets, types of packets, source, destination and timestamps are contained within the trace file along with unwanted information as well.

Scenario TCL programs are written to test and check the handoff latency of the Mobile IP Regional Registration, Pre-Registration handoff and Post-Registration handoff. Each scenario generates a large trace file that is analyzed based on the Microsoft Excel.

5.2 SIMULATION RESULTS

The simulation parameters are defined as follows.

- The correspondent node (CN) sends the CBR packets of size 500 bytes in a period of 10 ms.
- All links have a transmission rate of 5 Mbps and each link has a delay 3 ms.
- Mobility agents (oFA and nFA) send the Router Advertisements every 1 s.
- The IEEE 802.11 beacons are sent every 100 ms.
- The MN travels straight from the oFA to nFA with the speed of 20 m/s.

- There is 1 MN in our simulation.
- The MN is, initially, located in the oFA.
- The cell diameter is 122 m

5.2.1 Mobile IP Regional Registration

In the Network Simulator Mobile IP Regional Registration implementation given in [12] [13], the handoffs are completely managed at layer 3 (L3). The simulation consists of the foreign agent sending the Router Advertisements that are captured by MN to decide when to handoff to a new foreign agent. However, the drawback of this implementation is that the Router Advertisement is rather slow; therefore it may happen that the MN receives the Router Advertisement from the nFA that triggers the handoff when it has already moved out of coverage from the oFA. In this case, the packets tunneled to the oFA when the MN has moved out of coverage would be lost. This situation is depicted in Figure 14. The trace shown in this figure has been obtained using the NS with the network topology shown in Figure 13.

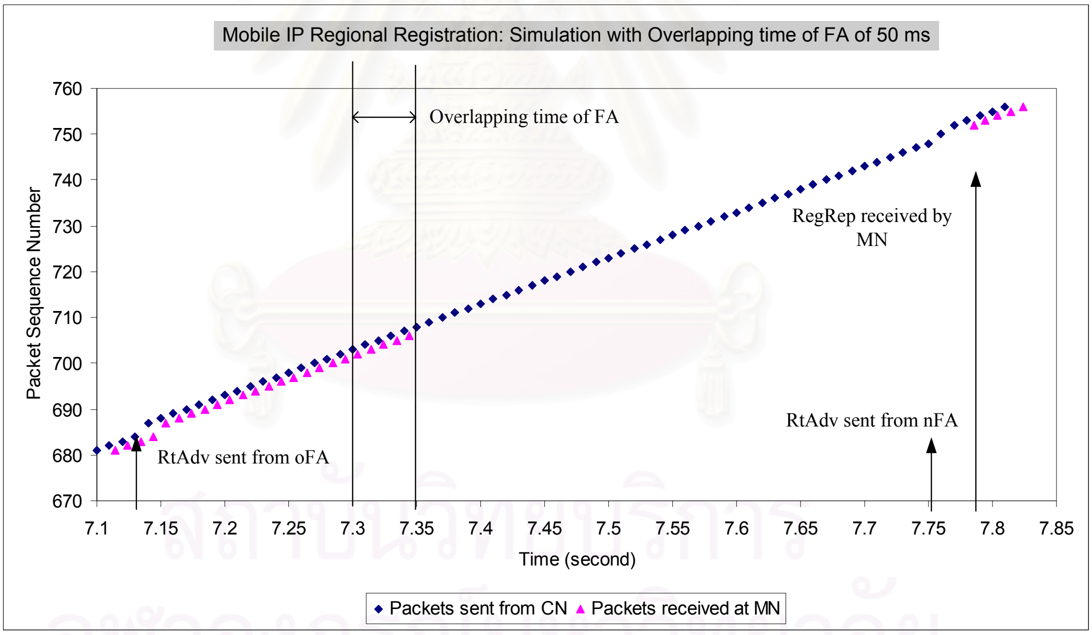

Figure 14. Mobile IP regional registration handoff

The figure shows the instants when the CN sends the packets and the instants when the MN receives them, as remarked in the Figure 14. The figure also shows the instant when the nFA sends the Router Advertisement that causes the MN to perform the handoff to the nFA by sending the registration message to the nFA and then in turn, the MN receives the Registration Reply from the nFA. These traces are indicated in the Figure 14. Finally, the figure shows the packets that are lost because they are sent by the oFA when the MN has moved out of coverage.

Figure 14 shows that the MN disconnected from the oFA since at time 7.35 s, but it can't hear the Router Advertisement from the nFA. The MN just received the Router Advertisement from the nFA at time 7.755605322 s, and then it registers its CoA to the nFA and the MN receives the Registration Reply from the nFA at time 7.782253669 s. After that the GFA recognizes that the MN is now connected with the nFA, then the GFA intercepts the packets from the CN and forwards directly to the nFA. In this case, we got 43 packets lost, this is because of the Router Advertisement from the nFA is rather slow.

The drawback of the Mobile IP Regional Registration previously described may be avoided using the Pre-Registration handoff and Post-Registration handoff schemes.

5.2.2 Pre-Registration Handoff Scheme

Since the L2-beacons are sent at a rate much higher than the Router Advertisements, the losses illustrated in Figure 14 are likely reduced. This is shown in Figure 15 and Figure 16. The trace shown in these figures have been obtained using the NS with the network topology in Figure 13.

- **Case 1:** We suppose that the MN receives the L2-beacon from the nFA after it disconnects from the oFA

In this case, the simulation result shows the packet losses can be reduced compared with the Mobile IP Regional Registration but there are still some packet losses because they are sent by the oFA when the MN has moved out of coverage.

In our simulation; when the MN approaches the nFA, the L2-beacons sent by the nFA at time 7.399842546 s as shown in the Figure 15, triggers the L2-handoff at the MN. Upon receiving the L2-beacons from nFA, the MN sends Proxy Router Solicitation (ProxyRtAdv) to oFA but fails because the MN has already disconnected from oFA. The MN, then, sends Association Request (AReq) at time 7.451300783 s to the nFA as indicated in Figure 15. Upon receiving the Association Response (ARes) from nFA, the MN sends Router Solicitation (RtSol) at time 7.454233592 s to the nFA to trigger the nFA to send Router Advertisement (RtAdv) to the MN. Finally, the MN performs the standard mobile IP registration with the nFA by processing the Registration Request (RegReq) and Registration Reply (RegRep). The MN receives the RegRep at time 7.472735728 s from the nFA as indicated in Figure 15. After receiving the RegRep, GFA intercepts the packets from the CN and forwards directly to the nFA and then to the MN. In Figure 15, we got 13 packet losses.

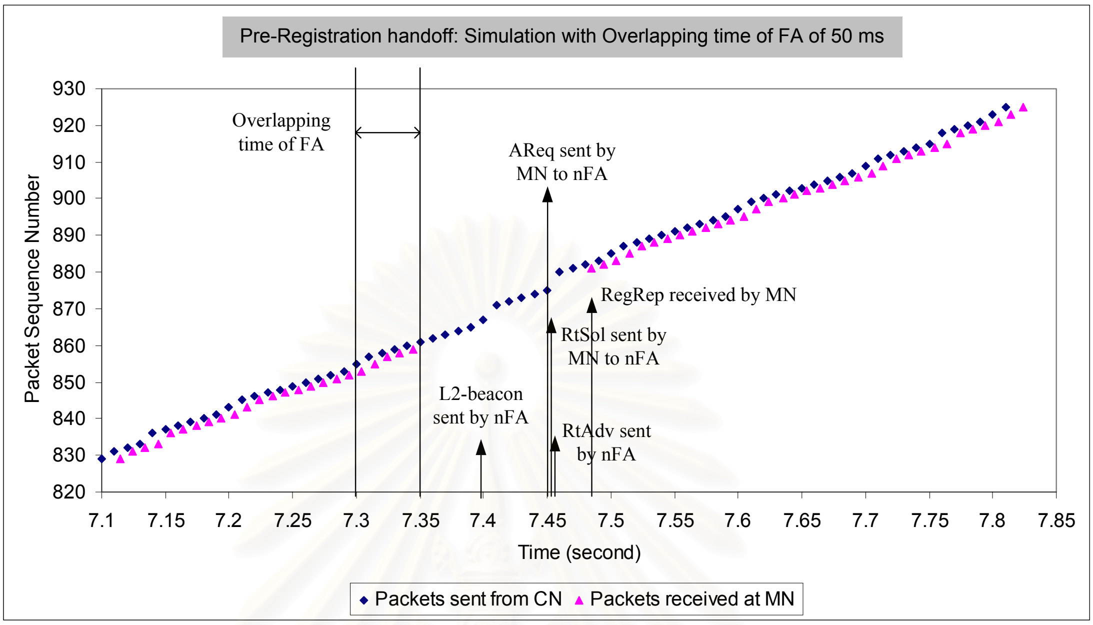

Figure 15. Pre-registration handoff with overlapping time of 50 ms

- **Case 2:** We suppose that the MN receives the L2-beacon from the nFA while it locates in the coverage of both the oFA and nFA

In this case, the simulation result shows that the losses illustrated in Figure 14 and Figure 15 are likely to be avoided. This is shown in Figure 16, where we assume that the MN remains for a while under the coverage of both the oFA and nFA.

In Figure 16; when the MN approaches the nFA, the L2-beacons sent by the nFA at time 7.399842546 s as shown in the Figure 16, triggers the L2-handoff at the MN, which sends a Proxy Router Solicitation (ProxyRtAdv) to oFA. Upon receiving this message, the oFA sends a Proxy Router Advertisement (ProxyRtAdv) at time 7.300111847 s to the MN as indicated in Figure 16. Upon receiving the ProxyRtAdv, the MN performs the standard mobile IP to the GFA; we do not show the signaling flows in this Figure.

On the same time, the MN sends Association Request (AReq) at time 7.316173626 s to the nFA as indicated in Figure 16. Upon receiving the Association Response (ARes) from nFA, the MN sends Router Solicitation (RtSol) at time 7.322774059 s to the nFA to trigger the nFA to send Router Advertisement (RtAdv) to the MN. Finally, the MN performs the standard mobile IP registration with the nFA by processing the Registration Request (RegReq) and Registration Reply (RegRep). The

MN receives the RegRep at time 7.345778803 s from the nFA as indicated in Figure 16. After receiving the RegRep, GFA intercepts the packets from the CN and forwards directly to the nFA and then to the MN.

In this case, the MN can communicate with both oFA and nFA. Therefore there is no packet loss during the handoff.

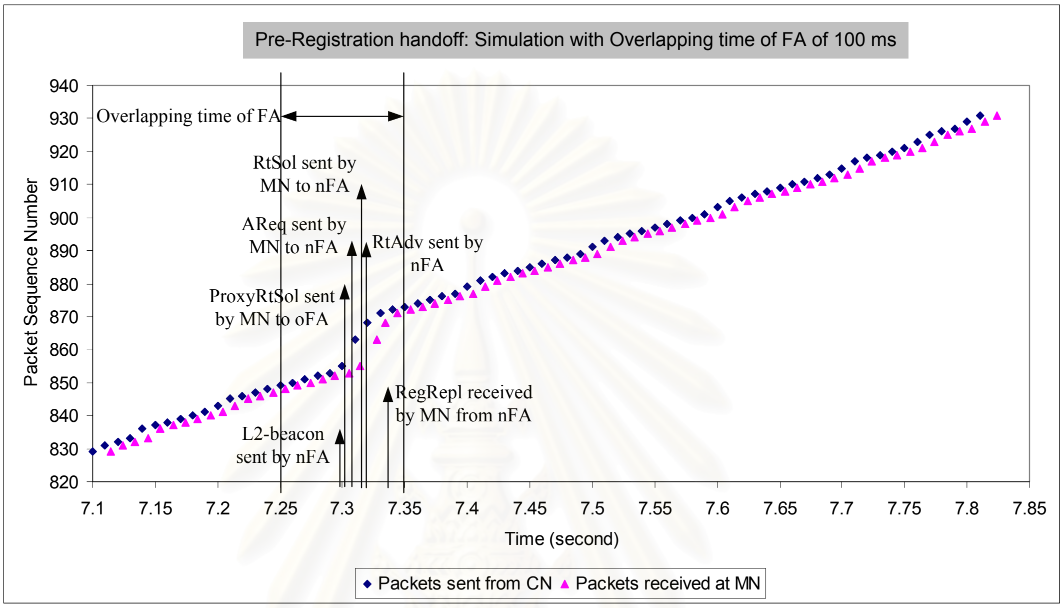

Figure 16. Pre-registration handoff with overlapping time of 100 ms

5.2.3 Post-Registration Handoff Scheme

- **Case 1:** We suppose that the MN receives the L2-beacon from the nFA while it moves out of the coverage of the nFA

Figure 17 shows that the MN receives the L2-beacon at time 7.400171132 s, from the nFA to trigger the L2-handoff at the MN, which sends an Association Request at time 7.402163342 s to the nFA. Upon receiving this frame, there is a target trigger at the nFA, which sends the Handoff Request (HReq) at time 7.402371745 s to the oFA. Upon receiving the HReq, the oFA sends the Handoff Reply (HRep) to the nFA and establishes a tunnel with the nFA. In this way, the packets can reach the MN via the nFA through the tunnel. Finally, when the nFA sends the Router Advertisement, the MN makes a Registration with the nFA. However, there are still some packet losses because the MN has already disconnected from the oFA and it has just started to establish the tunnel with the nFA, and the oFA cannot store the packets destined to the MN due to lacks of buffer at the oFA.

These drawbacks can be avoided if we enlarge the overlapping time of the oFA and nFA or if we implement the buffer at the oFA. The simulation results will be explained in the case 2 and case 3 in the following steps.

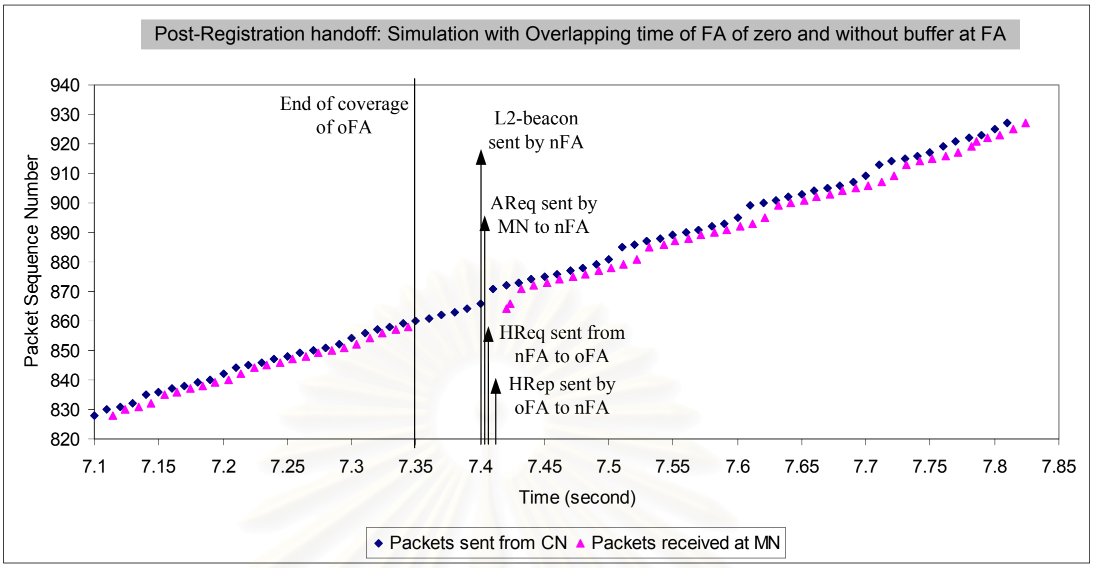

Figure 17. Post-registration handoff with overlapping time of zero

- **Case 2:** We suppose that the MN receives the L2-beacon from the nFA while it remains in the coverage area of the oFA and the nFA

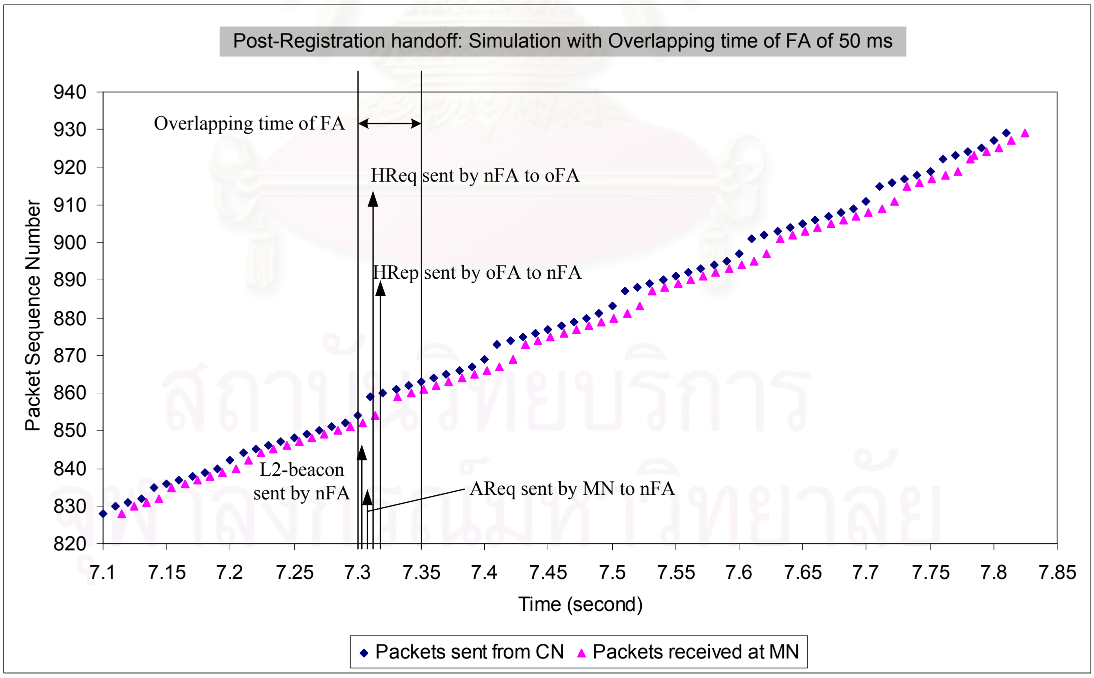

Figure 18. Post-registration handoff with overlapping time of 50 ms

Figure 18 shows that the MN receives the L2-beacon at time 7.300588504 s, from the nFA, to trigger the L2-handoff at the MN, which sends an Association Request at time 7.305757023 s to the nFA. Upon receiving this frame, there is a target trigger at the nFA, which sends the Handoff Request (HReq) at time 7.305965429 s to the oFA. Upon receiving the HReq, the oFA sends the Handoff Reply (HRep) to the nFA and establishes a tunnel with the nFA. In this way, the packets can reach the MN via the nFA after the coverage with the oFA has been lost.

Finally, when the nFA sends the Router Advertisement, the MN makes a Registration with the nFA. However, there are still some packet losses because the MN has already disconnected from the oFA and it has started to establish the tunnel with the nFA, and the oFA cannot store the packets destined to the MN due to lacking of buffer at the oFA.

- **Case 3:** We suppose that the MN receives the L2-beacon from the nFA while it moves out of the coverage of the oFA

Since we implements the buffer at the oFA, where the packets can be stored when the MN loses its connection with the oFA, the losses illustrated in Figure 17 are likely to be avoided. This is shown in Figure 19.

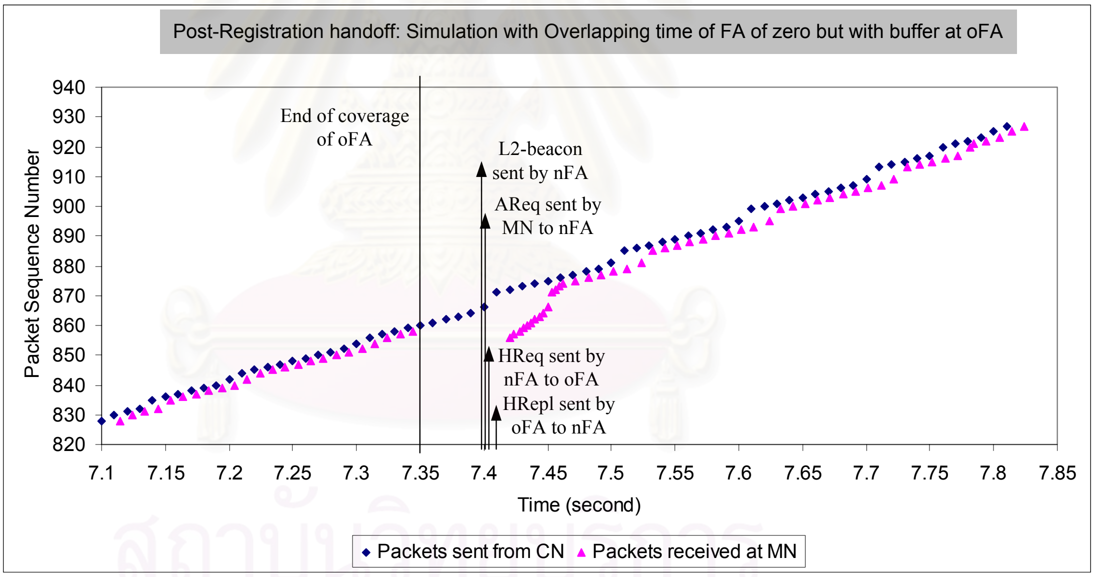

Figure 19. Post-registration handoff with overlapping time of zero but with buffer at the oFA

Figure 19 illustrates that the MN receives the L2-beacon at time 7.400171132 s from the nFA to trigger the L2-handoff at the MN, which sends an Association Request at time 7.402163342 s to the nFA. Upon receiving this frame, there is a target trigger at the nFA, which sends the Handoff Request (HReq) at time 7.402371745 s to the oFA. Upon receiving the HReq, the oFA sends the Handoff Reply (HRep) to the nFA and establishes a tunnel with the nFA. In this way, the packets that stored at the oFA can reach the MN via the nFA through the tunnel. Therefore, there is no packet loss during the MN handoffs from oFA to nFA.

Finally, when the nFA sends the Router Advertisement, the MN makes a Registration with the nFA.

5.2.4 COMPARISON AMONG MOBILE IP, PRE-REGISTRATION HANDOFF AND POST-REGISTRATION HANDOFF SCHEMES

We present simulation results of the Mobile IP Regional Registration, Pre-Registration handoff and Post-Registration handoff during the handoff. We use the network topology of Figure 13 for our simulation. During simulation, a mobile node moves from oFA to nFA at speed of 20 m/s. We use UDP traffic between the correspondent node and mobile node, and count the average number of packets lost during handoff for each protocol. Using this approach we measure handoff delay.

We performed simulations in four different scenarios with various overlapping time of oFA and nFA. The overlapping time is 0, 50 ms, 100 ms, 150 ms. Figure 20 shows the average number of packet loses for each of the four cases.

Our observation is that the losses in Mobile IP Regional Registration are much higher than those in Pre- and Post-Registration handoff schemes. This is because of the difference between the time period between L2-beacons (100 ms) and routers advertisements (1 s). When the overlapping time of foreign agent is higher than the L2-beacons period, the Pre-Registration handoff and Post-Registration handoff schemes produce zero packet loss.

Figure 20 shows that the packet loss in Mobile IP Regional Registration remains constant though we change the overlapping time between oFA and nFA from 0, 50, 100 and 150 ms with the overlapping interval 0 at time 7.4 s, 7.35 s to 7.4 s, 7.30 s to 7.40 s and 7.25 s to 7.40 s respectively. This is because the MN moves out of coverage of oFA since at time 7.40 s, which is the end of the transmission range of oFA and it just received the router advertisement at time 7.75 s from the nFA. Thus the MN cannot receive any packet from time 7.40 s to 7.75 s.

The packet loss in Pre-Registration Handoff, as shown in Figure 20, is constant when the overlapping time is increased from 0, 50 and 100 ms with the overlapping time interval 0 at time 7.4 s, 7.35 s to 7.4 s, 7.3 s to 7.4 s respectively. This is because the MN disconnected from oFA at time 7.4 s and it received the L2 beacon from nFA at time 7.4 s. Thus, there is no benefit to increase the overlapping time interval from 50 ms to 100 ms but when we increase the overlapping time to 150 ms the MN can receive the L2 beacon at time 7.3 s, which allows the MN to prepare its registration state with nFA.

The Pre-Registration Handoff has a constant packet loss, shown in Figure 20, when the overlapping time is increased from 50 ms to 100 ms. The reason is the same as that in case of the Pre-Registration Handoff and the packet loss in Post-Registration Handoff is less than in the Pre-Registration Handoff because the time to establish the BET is very short.

Figure 20 also shows that the best performance is obtained using the Post-Registration handoff scheme. This is because the BET established between the oFA and nFA is able to save some packets arriving at oFA when the MN has already moved out of the coverage.

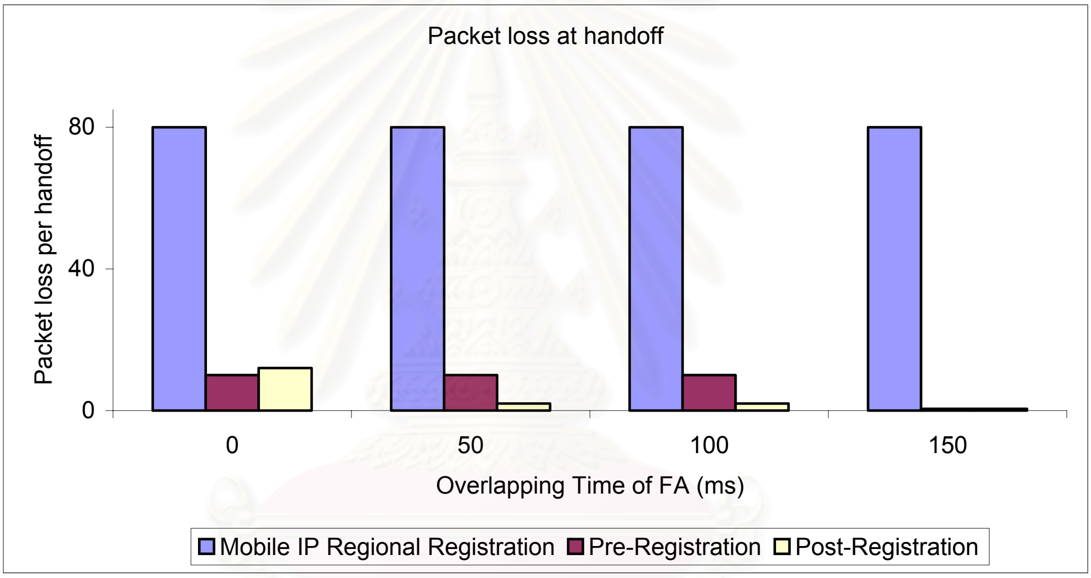

Figure 20. Packet loss per handoff with no buffer

5.3 ANALYTICAL RESULTS

5.3.1 Analytical Result of Pre-Registration Handoff Scheme

From equation (8) in Chapter 3 we investigate the signaling cost as follows:

- First, we illustrate the variation of the total signaling cost under different average residence times while the average packet arrival rate is constant.
- Second, we observe the variation of total signaling cost under different average packet arrival rates while the average residence time is fixed.

In our simulation, we assume that the l_{gf} is a fixed number $l_{gf} = 10$, the processing cost of location update at GFA is $a_g = 20$ and the processing cost of location update at FA is $a_f = 15$, the proportionality constant of distance cost $\delta_U = 0.2$ and $\delta_D = 0.05$, the wireless coefficient $\rho = 10$, the number of MNs per subnet $\omega_1 = 15$, weighting factors of visitor list is $\alpha_1 = 0.3$ and weighting factors of routing table lookups is $\beta_1 = 0.7$, packet delivery constant at the GFA is $\varsigma_1 = 0.01$.

A) The Impact of Residence Time on the Total Signaling Cost

Figure 21 shows the amount of the total signaling cost versus the number of FAs (k) beneath the GFA when the average packet arrival rate is constant ($\lambda_a = 0.3$).

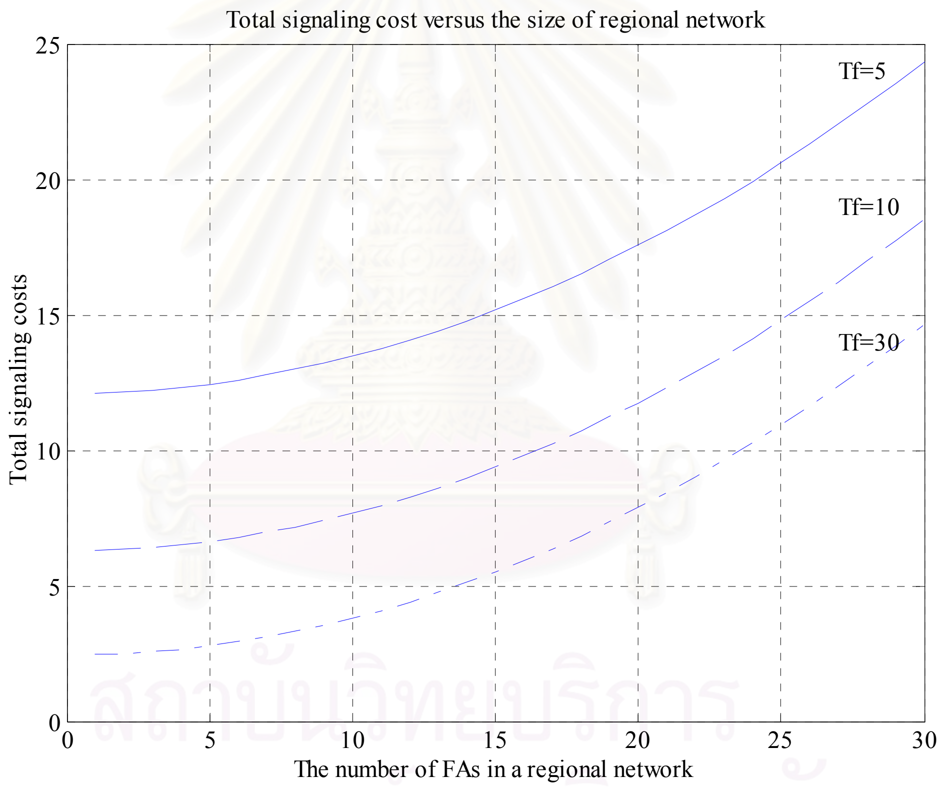

Figure 21. Total signaling cost versus the number of FAs in a regional network

We learn that the total signaling cost increases as the average residence time decreases. This is because when the T_f is small, the mobility rate of the MN is high and this leads the MN to perform more frequent handoff.

For the same regional network size, high mobility rate leads to more frequent location updates and thus high signaling cost. It is also observed that in case the average value of residence time T_f is small, the total signaling cost can reach the minimum when the number of FAs beneath of GFA is small. As T_f increases, the system requires a smaller regional network size to achieve the better performance.

Our simulation results shows that the number of FAs beneath the GFA must be chosen according to the network resources in order to minimize the total signaling cost.

B) The Impact of Packet Arrival Rate on the Total Signaling Cost

Figure 22 shows the total signaling cost versus the number of FAs beneath the GFA when the average value of residence time is constant ($T_f = 4$).

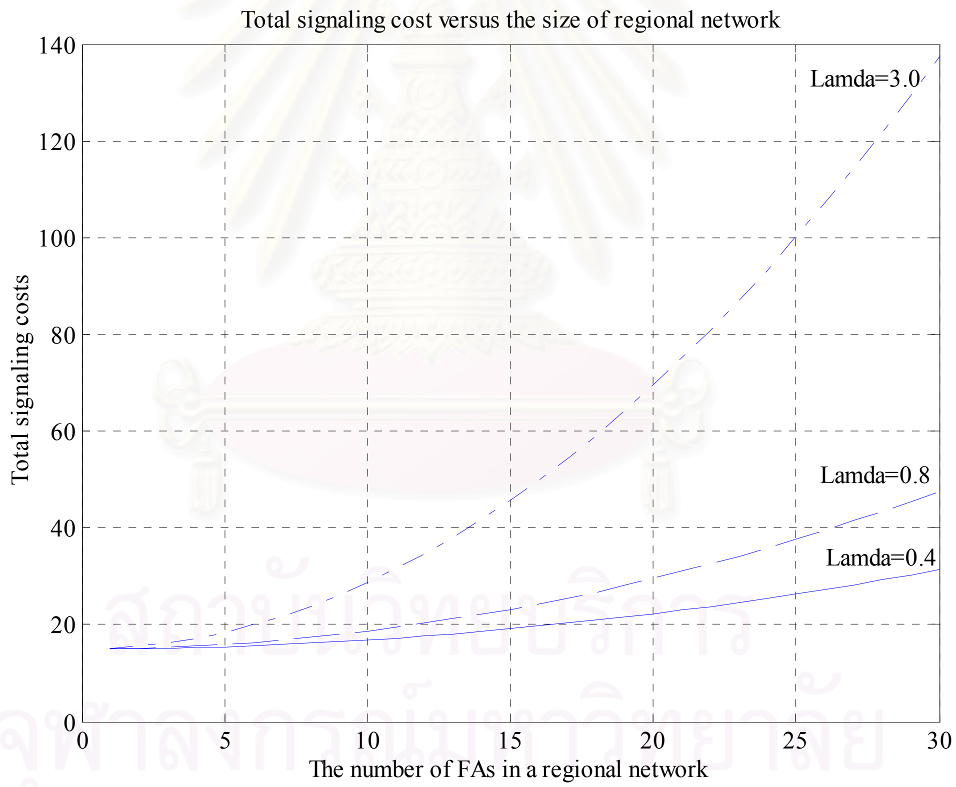

Figure 22. Total signaling cost versus the number of FAs in a regional network

It is indicated that the total signaling cost increases when the transmission rate (λ_a) of the CN increases. The total signaling cost is the highest when $\lambda_a = 3.0$. This is because when the transmission rate is high; the packet delivery cost at the GFA is high too, which results in high signaling cost. When λ_a is high, the better performance can be reached when the system have a small number of FAs in the regional network. As λ_a decreases, the minimum total signaling cost can be achieved with larger regional networks.

We also observed that, with the same number of FAs in a regional network, the transmission rate increases the total signaling cost as well. This makes clear that the number of FAs under the GFA impacts the network performance. Thus, the number of FAs beneath a GFA must be selected according to network resources in order to minimize the total signaling cost.

5.3.2 Analytical Result of Post-Registration Handoff Scheme

From equation (23) in Chapter 3, we investigated the signaling cost as follows:

- First, we illustrate the variation of the total signaling cost under different average residence times when the average packet arrival rate is constant.
- Second, we observe the variation of total signaling cost under different average packet arrival rate when the average residence time is fixed.

We assume that the l_{gf} and l_{afanfa} are fixed numbers $l_{gf} = 10$ and $l_{afanfa} = 5$, the packet processing cost $a_g = 20$ and $a_f = 15$, the proportional constant of distance cost $\sigma_U = 0.2$ and $\sigma_D = 0.05$, the wireless coefficient $\rho = 10$, the number of MNs per subnet is $\omega = 15$, weighting factors of visitor list is $\alpha_2 = 0.3$ and weighing factors of routing lookups is $\beta_2 = 0.7$, packet delivery costs $\varsigma_2 = 0.01$ and the average time MN stays in the aFA is $T_{afa} = 2$ s.

A) The Impact of Residence Time on the Total Signaling Cost

Figure 23 shows the total signaling cost versus the number of FAs that establish the BET with the aFA when the average packet arrival rate is constant ($\lambda_a = 0.3$).

We learn that the total signaling cost is proportional to the average residence time (T_f) of the MN in a regional network of aFA. The total signaling cost increases as the average residence time T_f increases. This is because when the T_f is longer, the number of FAs served by aFA increases, which results that the processes to perform BET with the aFA is high and thus high signaling cost at aFA. If the T_f is long, the minimum signaling cost can be reached when the number of FAs under aFA is small. In contrast, when the T_f is small, the number of FAs under aFA can be increased but the minimum of signaling cost can be achieved as well.

Therefore, the number of FAs served by the aFA must be chosen according to the constraint of the network.

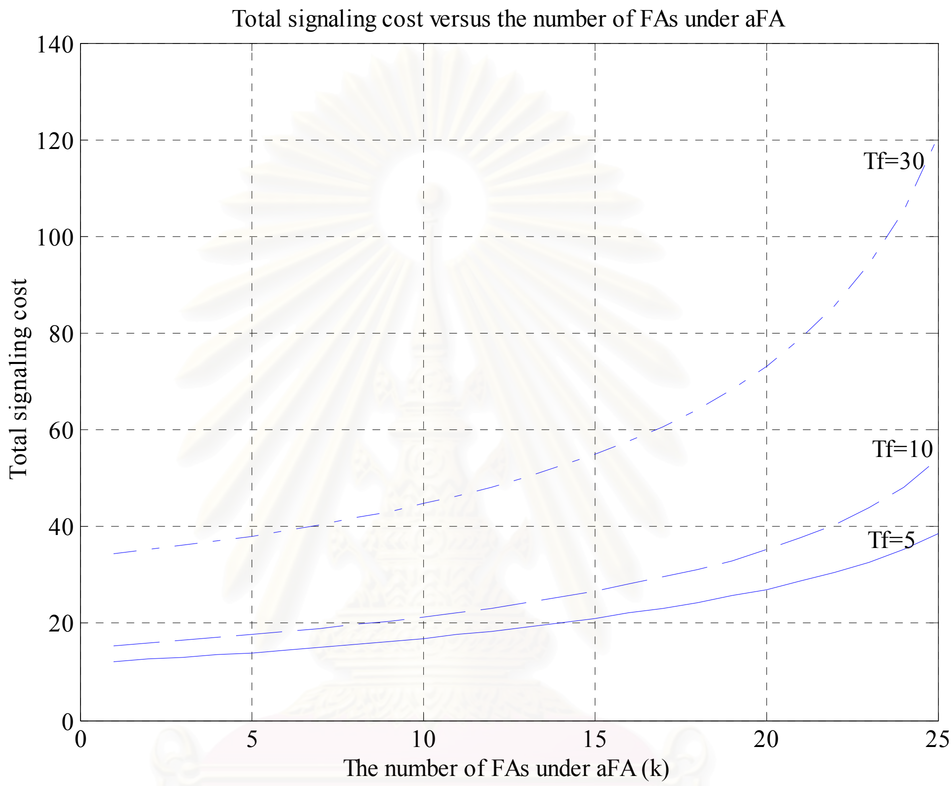

Figure 23. Total signaling cost versus the number of FAs served by aFA

B) The Impact of Packet Arrival Rate on the Total Signaling Cost

Figure 24 shows the total signaling cost versus the number of FAs served by aFA when the average residence time is constant ($T_f = 4$).

Figure 24 indicated that the total signaling cost increases when the transmission rate (λ_a) of the CN increases. The total signaling cost is the highest when $\lambda_a = 3$. This is true because when the transmission rate (λ_a) is high, the traffic load to the GFA is high and thus the packet delivery cost at the aFA is high too. Note that when the λ_a is large, the optimal performance can be reached when the system has a small number of FAs under aFA. As λ_a decreases, the minimum signaling cost can be achieved with lager number of FAs served by aFA.

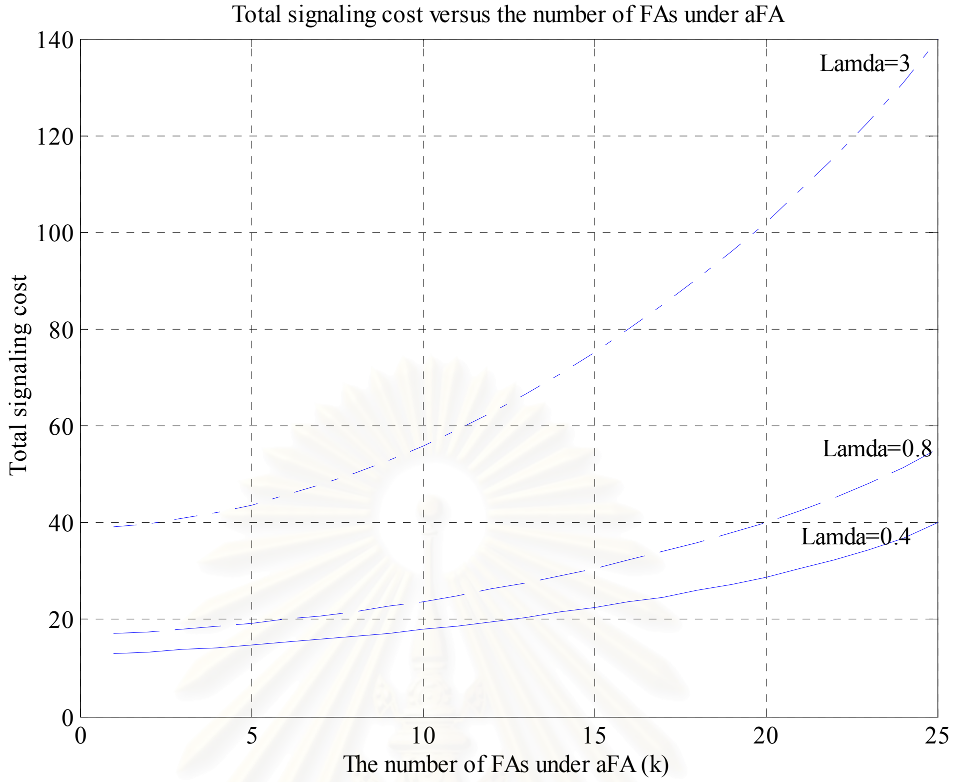

Figure 24. Total signaling cost versus the number of FAs served by aFA

Figure 24 makes clear that the number of FAs served by the aFA impacts the network performance. Therefore, the number of FAs under aFA must be selected due to the network resources.

C) The Impact of Packet Arrival Rate on the Optimal Number of FAs

Here, we investigate how the optimal number of FAs served by aFA size varies with the packet arrival rate.

Figure 25 shows the optimal number of FAs as a function of the average packet arrival rate when the average residence time $T_f = 1$, $T_f = 10$ and $T_f = 15$.

We see that when the T_f is small under the same average packet arrival rate λ_a, the optimal number of FAs served by aFA is large. Also note that the optimal number of FAs decreases as λ_a increases. This is because when the packet delivery cost dominates, the saving in packet delivery becomes significant. Thus, the number of FAs served by aFA becomes small.

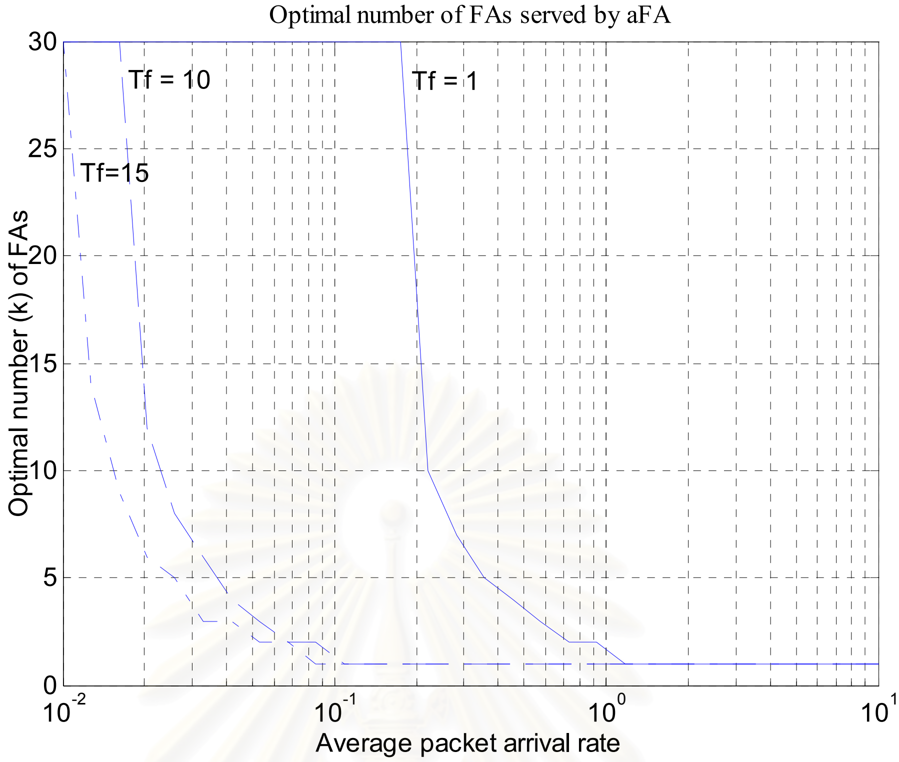

Figure 25. Optimal number of FAs served by aFA

D) The Impact of Residence Time on the Optimal Number of FAs

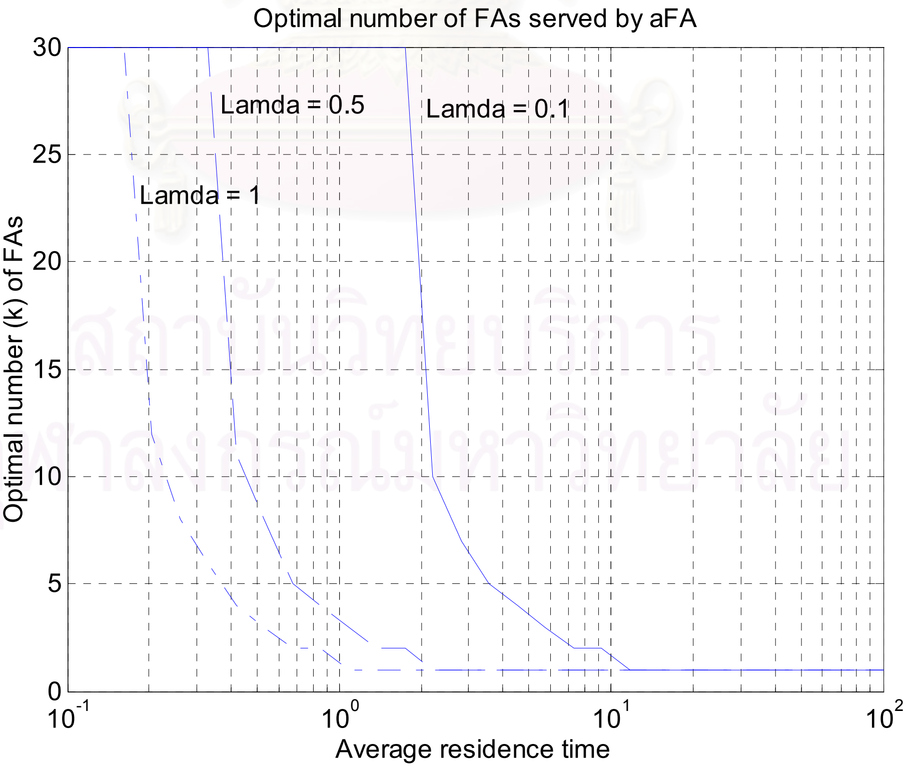

Figure 26. Optimal number of FAs served by aFA

Here, we investigate how the optimal number of FAs served by aFA varies with the average residence time.

Figure 26 plots the optimal number of FAs as a function of the average residence time T_f, when the average packet arrival rate $\lambda_a = 0.1$, $\lambda_a = 0.5$ and $\lambda_a = 1.0$.

We see that when λ_a is large under the same average residence time T_f, the optimal number of FAs served by aFA is small. We may also see that the optimal number of FAs served by aFA decreases as T_f increases. This is because of bi-directional edge tunnel between the aFA and nFA, which causes the cost for location update dominates.

5.4 SIMULATION RESULTS OF SIGNALING COST

We investigate the total signaling cost by means of simulation. We vary the number of FAs beneath the GFA in case of Pre-Registration Handoff Scheme and we vary the number of FAs beneath the aFA in case of Post-Registration Handoff Scheme.

Here, we observe the total signaling cost versus the number of FAs of 3, 5 7, 10, 12 and 15.

A) Pre-Registration Handoff Scheme: The Impact of Packet Arrival Rate on the Total Signaling Cost

We simulate our network by maintaining the average residence time $T_f = 50s$ constant and varying the transmission rate of the CN (λ_a) with the value of 4, 10 and 50 ms. The simulation result is given in Figure 27.

The plot in Figure 27 shows that the total signaling cost is the highest when λ_a = 50 ms. The total signaling cost increases when the number of FAs increase. This is because when the number of FA increases, the handoff will occur more frequently.

We learn that our simulation result and the analytical result are quite similar.

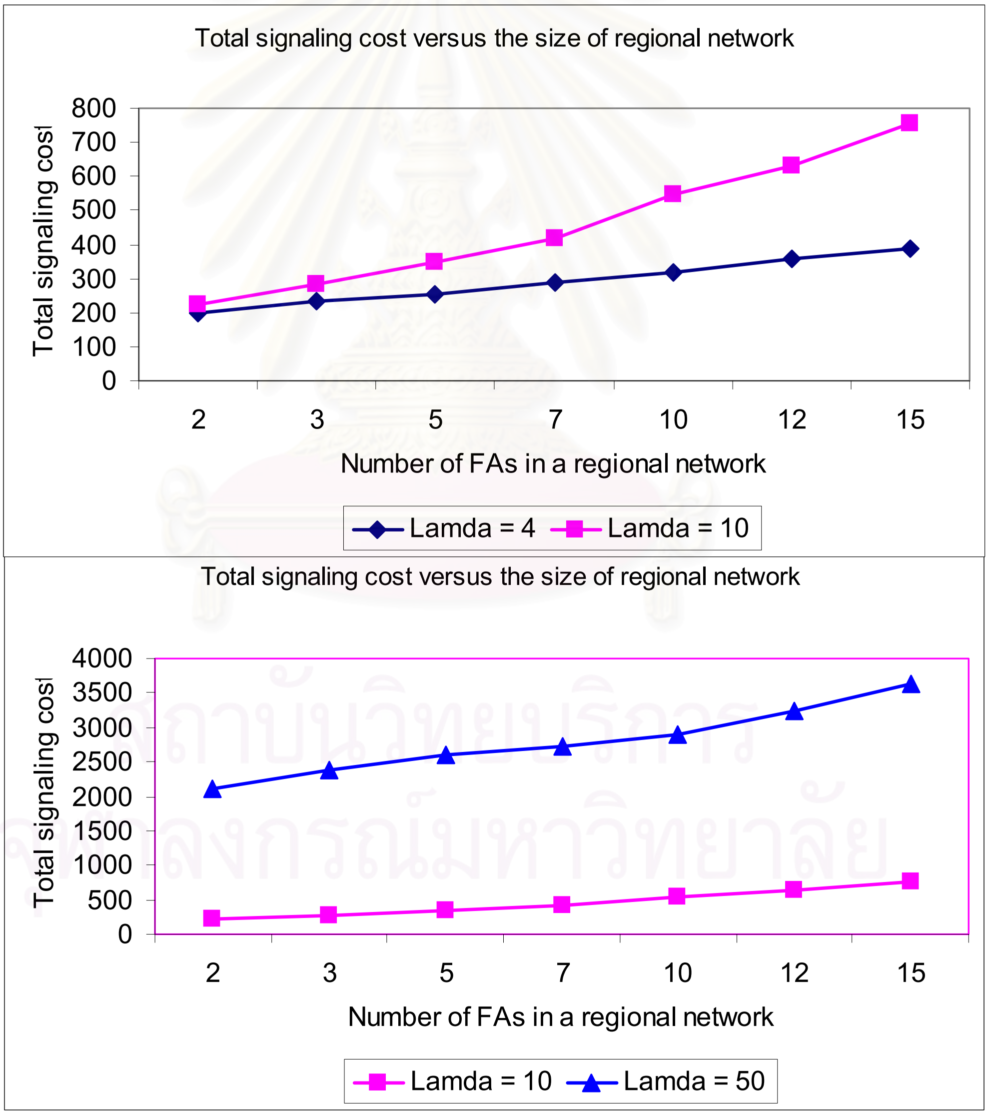

Figure 27. Total signaling cost versus the number of FAs beneath GFA

B) Post-Registration Handoff Scheme: The Impact of Packet Arrival Rate on the Total Signaling Cost

We simulate our network by maintaining the average residence time $T_f = 50s$ constant and varying the transmission rate of the CN (λ_a) with the values of 4, 10 and 50 ms. The simulation result is given in Figure 28.

The plot in Figure 28 shows that the total signaling cost is the highest when λ_a = 50. The total signaling cost increases when the number of FAs increases. This is because when the number of FA increases, the handoff will occur more frequently.

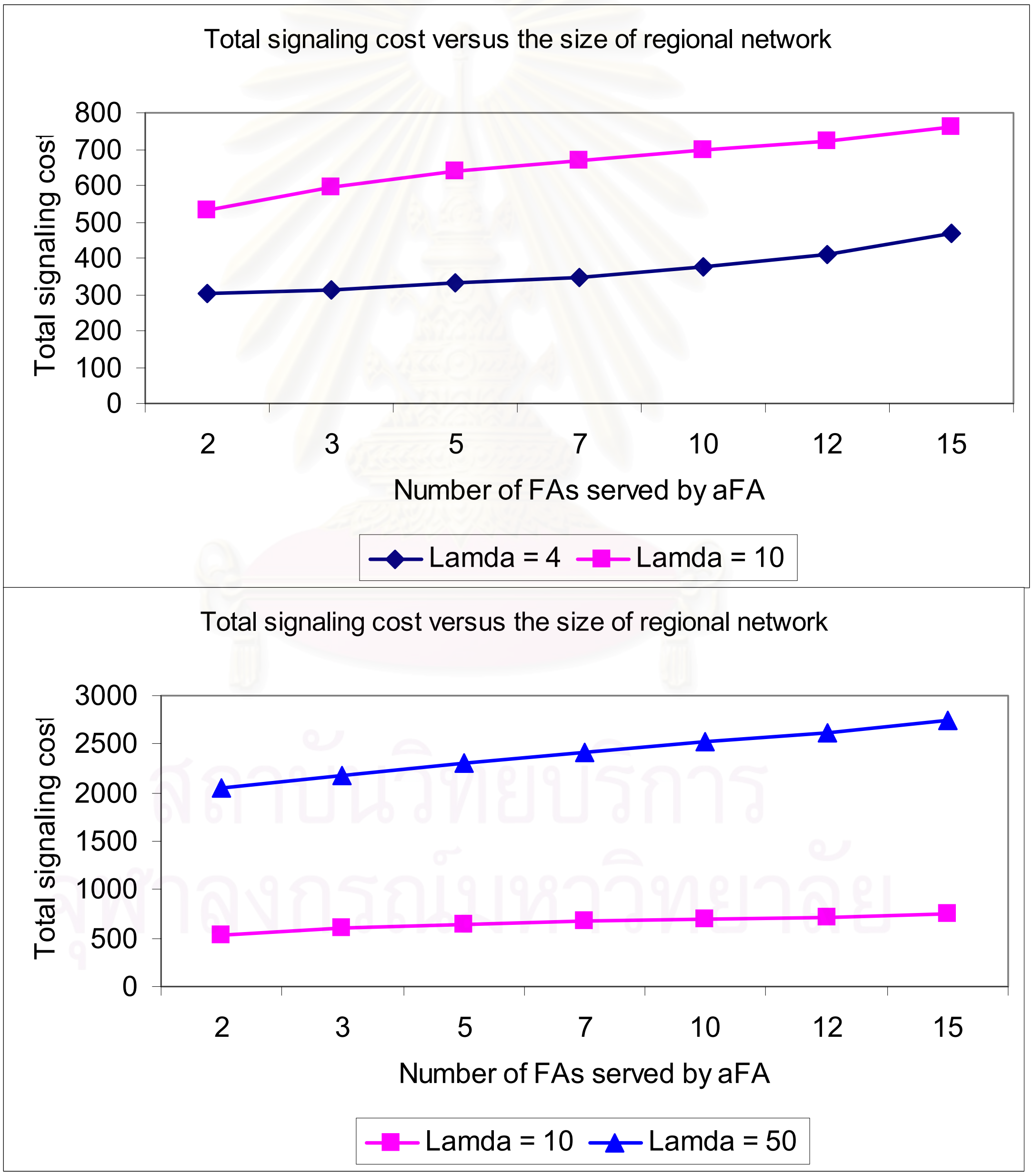

Figure 28. Total signaling cost versus the number of FAs served by aFA

CHAPTER 6

CONCLUSION AND RECOMMENDATION

This research tries to evaluate the system performance of the Pre-Registration Handoff Scheme and the Post-Registration Handoff Scheme that are based on L2-triggers proposed by IETF by means of simulation.

We have described the possible implementation of these protocols in an IEEE 802.11 wireless LAN. We have implemented Pre- and Post-Registration Handoff Schemes in the Network Simulator in order to analyze them.

We compare the system performance of Pre-Registration Handoff Scheme and Post-Registration Handoff Scheme with the original Regional Registration mobile IP.

The simulation has shown that the timing of the triggers has a major impact on the packet loss rate. The faster of the timing of the triggers, the lower the packet loss is.

Furthermore, the simulation has shown how the Pre-Registration Handoff Scheme and the Post-Registration Handoff Scheme avoid the losses that can happen when using only Regional Registration mobile IP. There is a clear benefit to use the Pre-Registration Handoff Scheme and Post-Registration Handoff Scheme over the original Regional Registration mobile IP in terms of packet loss and handoff latency.

We also observed that the Post-Registration Handoff Scheme has the best performance comparing with the Pre-Registration Handoff Scheme and Regional Registration mobile IP.

In Pre-Registration Handoff Scheme, the packet loss can be avoided if the MN solicits the Router Advertisement from the nFA after it has received the L2-beacon in the overlapping time of base station. During that time the MN can communicate with both oFA and nFA.

In the Post-Registration Handoff Scheme, the packet loss can be avoided if the MN receives the L2-beacon from the nFA while it is in the overlapping time of base station. It means that the MN can communicate with both oFA and nFA while it is in the overlapping time of these base stations. As a result the nFA has established the bi-directional edge tunnel with the oFA while the MN still connects with the oFA. In the reverse sense, if the MN receives the L2-beacon from nFA when it has already disconnected from the oFA, the packet may be lost. In this case, we have implemented the buffer at the oFA in order to store the packets sending from the CN to the MN. When the bi-directional edge tunnel between the oFA and the nFA has been established, the oFA tunneled the storing packets to the nFA along this bi-directional edge tunnel. Therefore, the packet loss can be reduced.

In both protocols: Pre- and Post-Registration Handoffs, the packet losses can be avoided if the user stays in the overlapping time of base station longer than the L2 rate (100 ms).

We have, moreover, studied the influence of the signaling cost over the network when the Pre-Registration Handoff and Post-Registration Handoff Scheme have been implemented with the Regional Registration mobile IP.

In Pre-Registration Handoff Scheme, we observe the total signaling cost (location update and packet delivery cost) versus the number of FAs beneath the GFA. Our research motivates to show how the signaling cost is, when the number of FAs varies under one GFA. The number of FAs beneath the GFA should be selected in order to consume the minimal network resource.

In the Post-Registration Handoff Scheme, we observed the total signaling cost on the anchor FA versus the number of FA that have to establish the bi-directional edge tunnel with the aFA. Our work shows how the signaling cost is when the number of FA varying under one aFA. We evaluate the signaling cost by means of analytical model and simulation.

We have proposed an iterative algorithm to find the optimal number of FAs that establishes bi-directional edge tunnel with an aFA, which consumes the minimal network resource.

Our algorithm can compute the optimal number of FAs before communication and it is based on the average packet travel rate and the average residence time of the MN in the coverage region of aFA.

In parallel, we evaluate the signaling cost of both schemes by means of simulation.

Future Work

In this research, however, the Pre-Registration Handoff Scheme and Post-Registration Handoff Scheme were studied separately. The combined method should be investigated in the future research.

For the signaling cost, however, only single user is considered. The multiple users in the case of network with limited capacity should be investigated in the future study.

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List of Publications

Performance of Low Latency Handoff Schemes in Mobile IP Communication System. ECTI Annual Conferences (ECTI-CON), 13-14 May 2004, Pattaya, Thailand.

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Kimtho Po was born in 1974 in Battambang, Cambodia. In 2000, he received his Ing. in electrical engineering from Institute of Technology of Cambodia (ITC), Cambodia. From 2000 to 2002, he worked at ITC as an instructor. His research interest is in the mobile communications system.