國立交通大學

電信工程學系

碩士論文

使用事先連結方法的網路啟動
行動IP快速換手機制

Network-Initiated Mobile IP Fast Handoff
Using Early Binding Method

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摘要

隨著行動即時應用(mobile real-time application)的需求成長，快速換手的效率被視為越來越重要。行動 IP 快速換手(Mobile IP fast handoff)機制已被標準化以縮短換手延遲。然而在行動 IP 快速換手機制中，對於高速移動用戶卻無法保證有足夠的時間完成快速換手的程序。事先連結的方法提供此問題一種解決方法。但在其中卻沒有定義如何精準預測事先連結的機制，以及與哪些存取路由器(access router, AR)做連結。

在此論文中，提出一個使用事先連結方法的網路啟動行動 IP 快速換手(network-initiated early binding fast handoff , NEBFH) 機制以及智慧型存取路由器選擇 (intelligent candidate access router selection, ICARS) 的演算法。由模擬結果，透過事先連結機制與換手結果的關係可以得到較好且精準的事先連結機制。另外，ICARS 演算法也降低了選擇錯誤的機率進而改進了換手的延遲。

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Abstract

Since the demand for mobile real-time application grows fast, the handoff efficiency of Mobile IP becomes extraordinarily important. Fast handoff of Mobile IP is standardized to eliminate the handoff delay. Unfortunately, anticipation of fast handoff does not guarantee that mobile node can always have time to exchange messages for fast handoff of those mobile nodes move with high speed. An Early binding method provides a solution to reduce unreliability of anticipation for high speed mode nodes. However, there is no definition how to make an exact early binding event trigger and candidate access router selection. In this thesis, a network-initiated early binding fast handoff (NEBFH) and an intelligent candidate access router selection (ICARS) algorithm were proposed. Simulation results show that the relation of handoff performance and binding event trigger can provide how to make an exact early binding. Moreover, the ICARS algorithm reduces the rate of selection failure and improves the handoff delay.

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Contents

Mandarin Abstract..........i

English Abstract..........ii

cknowledgements.......... iii

Contents..........iv

List of Figures..........vi

List of Tables.......... viii

Acronyms..........ix

Chapter 1 Introduction..........1

Chapter 2 Mobile IP Fast Handoff Issues..........6

- 2.1 Protocol Operation..........6
  - 2.1.1 Mobile Initiated Handoff..........6
  - 2.1.2 Network Initiated Handoff..........8
  - 2.1.3 Reactive Handoff..........8
- 2.2 Early Binding Method..........9

Chapter 3 System Model..........12

- 3.1 Network Topology Model..........12
- 3.2 Mobility Model..........13
- 3.3 Signaling Time of FMIP..........13
- 3.4 Binding Event Trigger and Handoff Event Trigger..........16
- 3.5 Candidate AR Selection..........17

Chapter 4 Network–Initiated Early Binding Fast Handoff (NEBFH)..........19

4.1 NEBFH Procedure 19

4.2 Intelligent Candidate AR Selection (ICARS) Algorithm 24

Chapter 5 Simulation Results and Discussions 27

5.1 Simulation Environment 27

5.2 Simulation Result and Discussions 30

Chapter 6 Conclusions 40

Chapter 7 Appendix: NEBFH Performance Analysis 42

7.1 Handoff Delay Analysis of NEBFH 42

7.2 Signaling Cost Analysis of NEBFH 44

Bibliography 47

Vita 49

List of Figures

Figure 2-1. Mobile Initiated Predictive Fast Handoff Procedure.............................. 7
Figure 2-2. Mobile Initiated Reactive Fast Handoff Procedure................................ 9
Figure 2-3. Early Binding Fast Handoff 10
Figure 3-1. Network Topology Model 13
Figure 3-2. The Time Diagram of Predictive FMIP.. 14
Figure 3-3: The Time Diagram of Reactive FMIP.. 15
Figure 4-1. The Signal Flow of NEBFH for CAR Selection Success 20
Figure 4-2. The Signal Flow of Predictive NEBFH for CAR Selection Failure 21
Figure 4-3. The Signal Flow of Reactive NEBFH for CAR Selection Failure........ 22
Figure 4-4. The Flow Chart of NEBFH... 23
Figure 4-5. An Illustration of ICARS algorithm... 25
Figure 5-1. Cell Layout in the Simulation 28
Figure 5-2. The Handoff Delay of FMIP and NEBFH with distinct CAR Selection Algorithm 31
Figure 5-3. The Reactive Mode Rate of FMIP and NEBFH with distinct CAR Selection Algorithm 33
Figure 5-4. The Signal Cost of FMIP and NEBFH with distinct CAR Selection Algorithm.. 34
Figure 5-5. The CAR Selection Failure Rate of distinct CAR Selection Algorithm.. 34
Figure 5-6. The Handoff Delay of NEBFH with Distinct Early Binding Dwell

Timer at Binding Threshold -80 *dBm* 37
Figure 5-7. The Handoff Delay of NEBFH with Distinct Early Binding Threshold at Binding Dwell Timer 0.1 sec 38
Figure 5-8. The Early Binding Failure Rate of Distinct Binding Trigger Event ... 39
Figure 5-9 The CAR selection Failure Rate of Distinct Binding Trigger Event ... 39
Figure 7-1. The Signaling Cost of NEBFH... 45

List of Tables

Table 3-1. Communication Delays used in the Analysis 14

Table 3-2. Handoff Delay of FMIP 16

Table 5-1. System Parameters in the simulation 29

Table 5-2. The Parameters defined in System Model 29

Table 5-3. The Parameters of Signaling Cost 30

Table 5-4. Trigger Event 38

Table 7-1. All Case in NEBFH Corresponding to the Mode in the FMIP 43

Table 7-2. The Signaling Cost of All Cases in NEBFH.. 46

Acronyms

AR	Access Router
BU	Binding Update
CoA	Care-of-Address
CAR	Candidate Access Router
DAD	Duplicated Address Detection
FBack	Fast Binding acknowledge
EBFH	Early Binding Fast Handoff
FBack	Fast Binding acknowledge
FBI	Fast Binding Indication
FBU	Fast Binding Update
FMIP	Fast Handoff for Mobile IP
FMIPv4	Fast Handoff for Mobile IPv4
FMIPv6	Fast Handoff for Mobile IPv6
FNA	Fast Neighbor Advertisement
HA	Home Agent
HAck	Handoff Acknowledgement
HI	Handoff Initiate
ICARS	Intelligent CAR Selection
IETF	Internet Engineering Task Force
L2	Layer 2
L3	Layer 3
MIP	Mobile IP
MIPv4	Mobile IPv4
MIPv6	Mobile IPv6
MN	Mobile Node
NAR	New Access Router
NCoA	Next Care-of-Address
NEBFH	Network-initiated Early Binding Fast Handoff
PAR	Previous Access Router
PCoA	Previous Care-of-Address
PrRtAdv	Proxy Router Advertisement
RtSolPr	Router Solicitation for Proxy
RSS	Received Signal Strength
VoIP	Voice over IP

Chapter 1

Introduction

As the advancement of wireless communications, demands for the wireless Internet and mobility support are increasing, and the next generation backbone network is potentially deployed by the IP based technology due to the all-IP trend. In order to support mobile IP-based network, Mobile IP (MIP) protocols, such as Mobile IPv4 (MIPv4) [1] and Mobile IPv6 (MIPv6) [2], are standardized by the Internet Engineering Task Force (IETF). Each mobile node (MN) is always identified by its home address, regardless of its current point of attachment to the Internet. While situated away from its home, the MN is also associated with a care-of-address (CoA), which provides information about its current point of attachment to the Internet. Packets destined to the MN's home address are transparently routed to its CoA. For this purpose, the MIP protocol provides for registering the CoA with a home agent (HA). The HA sends datagrams destined for the MN through a tunnel to the CoA. After arriving at the end of the tunnel, each datagram is then delivered to the MN.

MIP enables an MN to maintain its connectivity to the Internet when moving from one access router (AR) to another, a process referred to as handoff. During handoff, there is a period during which the MN is unable to send or receive packets because of link switching delay and IP protocol operations. This “handoff latency” resulting from standard MIP procedures, namely movement detection, new CoA configuration, and binding update (BU), is often unacceptable to real-time traffic such as Voice over IP (VoIP).

Standard MIPv6 procedures have to deal with the same handoff latency problems as MIPv4. In [3], fast handoff for Mobile IPv6 (FMIPv6) was proposed to improve handoff latency in MIPv6 as a fast handoff for Mobile IPv4 (FMIPv4) [4] did for MIPv4. Fast handoff for Mobile IP (FMIP) is a mechanism to improve the handoff latency by predicting and preparing the impending handoff in advance. The FMIP protocol allows an MN to prepare its registration with a new access router (NAR) and obtain its next care-of-address (NCoA) while still connected to a previous access router (PAR). Furthermore, the FMIP protocol seeks to eliminate the latency involved during the BU procedures by providing a bi-directional tunnel between the old and new networks while the BU procedures are being performed. The MN can instruct the PAR to forward packets addressed to it previous care-of-address (PCoA) to it NCoA.

The FMIP protocol has two operation modes due to the unpredictable MN’s mobility. The modes are different according to the precise timing depending on whether the MN completes fast handoff operations or not before layer 2 (L2) handoff. If it does, the fast handoff is referred to as a predictive mode. If it does not, it is referred to as reactive mode. The handoff performances of both the predictive mode and the reactive mode in FMIPv6 have been evaluated in [5]. Results showed that the predictive FMIPv6 has much better handoff performance than the reactive FMIPv6 does. Take UDP experiment for example. In the reactive FMIPv6 mode, there are 49 lost packets and 2.5 seconds handoff disruption period. While in the predictive FMIPv6 mode, there are no lost packet found and 1.1 seconds handoff latency. The reactive fast handoff causes not only the increase of handoff delay but also the increase of signal overhead.

The reactive mode is performed after the unsuccessful predictive if the MN does not complete fast handoff operations. One of the reasons is the late timing of L2 handoff trigger. The anticipation of fast handoff from L2 does not guarantee that MN can always have enough time to exchange layer 3 (L3) fast handoff messages. The case is occurred especially for high speed MN. Moreover, it is possible for fast handoff to fail due to multi-retransmission when signal status is not good enough.

Early binding fast handoff (EBFH) was proposed in [6]. An MN performs early fast binding update with its current AR before an L2 handoff trigger which indicates that an MN is closing to handoff. In order to provide a robust predictive fast handoff mechanism, part of L3 fast handoff message would be exchanged before the L2 handoff trigger. In other words, the L3 fast handoff procedures consumed most of time is performed before the L2 handoff trigger. This method called early binding would guarantee that the MN can have enough time to exchange messages, whereas it consumes more bandwidth of wireless link than the original fast handoff. This is because the geographically adjacent AR option should be included in router advertisements and more binding update and acknowledge messages should be exchanged between the MN and the current AR. The early binding method has more signaling overhead than original fast handoff.

It should be worth noting that there is no definition how to make exact early binding anticipation in EBFH. Generally speaking, more processing cost and signaling cost are consumed if performing early binging too early. And some effect may exist if performing early binging too early. Furthermore, the latest timing of early binding is the L2 handoff trigger. The situation of EBFH is the same with FMIP if the timing of performing early binding is the same with the timing of L2 handoff trigger. Making an exact anticipation for early binding can be a good issue to improve the performance and efficiency of EBFH.

It is further worth noting that an NAR does not be determined before the L2 handoff trigger if using early binding method. Thus, a candidate AR (CAR) selection algorithm is needed by the early binding method. The difference between the CAR and NAR may arise. In this case, the singing cost for early binding with the CAR is in vain. The extra signaling cost of binding with the NAR is consumed. It may be a solution to perform early binding with more than one CAR. The case would not arise if the CAR is all geographically adjacent AR. However, it seems to be an inefficient solution due to much singing cost. There is no definition how to select AR and how many AR selected is efficient in EBFH.

In this thesis, a network-initiated early binding fast handoff (NEBFH) scheme is proposed. One of the reasons to adopt network-initiated handoff is to reduce the early binding messages exchanged between the MN and PAR. Moreover, the specific signal flow of NEBFH is defined. An early binding event trigger is defined. In order to define binding event trigger specifically, not only a signal threshold but also a dwell timer is considered in the binding event trigger. In addition,. The NEBFH can be classified by either CAR selection success or CAR selection failure. The CAR selection can be further classified by either early binding prediction success or early binding prediction failure. Each case of NEBFH can correspond to predictive or reactive mode of FMIP. And distinct signaling costs are consumed in each case. As for CAR selection algorithm, an intelligent CAR selection (ICARS) algorithm is proposed in this thesis. The ICARS algorithm determines one or more AR adaptively. It selects more than one while these AR with similar situation. The handoff performance and signaling cost of NEBFH are analyzed in terms of distinct binding trigger event and CAR selection algorithm.

The reminder of this thesis is organized as follow. In Chapter 2, the FMIP protocol operations and early binding method are introduced. The system model, including the binding event trigger, is presented in Chapter 3. The details of proposed NEBFH scheme and ICARS algorithm are presented in Chapter 4. The simulation results and discussions are presented in Chapter 5. Finally, conclusions are given in Chapter 6.

Chapter 2

Mobile IP Fast Handoff Issues

2.1 Protocol Operation

Mobile IP fast handoff (FMIP) is a solution to the handoff latency problem of mobile IP. FMIP achieves this goal by two mechanisms:

- Resolve the new CoA address to be used before the MN enters into the coverage of the new AR.
- Setup a temporary tunnel between previous access router (PAR) and new access router (NAR) to forward packets to the new location.

The FMIP can be either mobile-initiated or network-initiated, depending on whether the MN or one of ARs initiates the handoff. The two main possibilities are router discovery performed by MN on Layer 3 and a link-specific event (e.g., L2 trigger, such as higher signal strength from a new BS) occurring in the MN or in the network.

2.1.1 Mobile Initiated Handoff

Figure 2-1 provides a signal flow of mobile initiated FMIP. The protocol operates as follow. When an MN senses a Layer 2 trigger, it sends a router solicitation for proxy (RtSolPr) message to its PAR to resolve information about the anticipated new subnet. In response to the RtSolPr message, the PAR sends a proxy router advertisement (PrRtAdv) which contains the binding information between adjacent BSs and ARs. From the information provided in the PrRtAdv message, the MN formulates a prospective new CoA (NCoA) that will be used in the new subnet, and sends a fast binding update (FBU) message to the PAR. The purpose of the FBU message is to inform the PAR to bind previous CoA (PCoA) to NCoA, and arriving packets can be tunneled to the new location of the MN. Upon receiving the FBU message from the MN, the PAR sends a handoff initiate (HI) message to NAR, in response to which a handoff acknowledgement (HAck) is sent by the NAR to setup a tunnel with NCoA. This HI/HAck message exchange also serves a registration of the NCoA already formed by the MN. The registration is a validation for NCoA by duplicated address detection (DAD) procedure in order to avoid address duplication on the links.

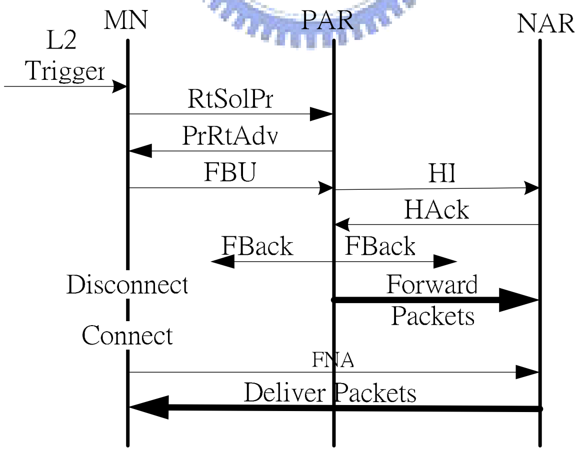

Figure 2-1. Mobile Initiated Predictive Fast Handoff Procedure

The PAR responds to the MN and the NAR with a fast binding acknowledge (FBack) message and starts the tunneling of buffered data toward the MN’s NCoA.

The MN, as soon it attaches on the new link, transits a fast neighbor advertisement (FNA) to inform the NAR of its presence. From this point on, all packets buffered at NAR are delivered to the MN.

2.1.2 Network Initiated Handoff

In some network deployments, it may be possible for the network to initiate the handoff procedure rather than the MN. One example scenario would be for an intelligent subsystem on the PAR to determine that an MN would be better served moving to another nearby network, (e.g. due to it being topologically closer to its corresponding node or for traffic engineering purposes). In such a situation, the PAR will send an unsolicited PrRtAdv message to the MN containing the information which the MN can connect to the new network. The signal flow is the same as that in Figure 2-1 besides the absence of initial RtSolPr message. However, the processing is slightly different in that the MN must connect to the network indicated in the PrRtAdv message by configuring a CoA for itself an issuing a FBU to the PAR.

2.1.3 Reactive Handoff

It should be noted that the above discussion including both the mobile initiated handoff and the network initiated handoff is under some assumption. The assumption is that the MN is aware of the impending handoff, prior to the L2 handoff execution, to have enough time to send the FBU message. Nevertheless, the situation can arise that the MN moves to the new network before it has had a chance to send the FBU to the PAR. In this case, the MN will send the FBU message encapsulated inside the FNA message that it sends to the NAR, as shown in Figure 2-2. The NAR will then forward the FBU message to the PAR thus allowing the

PAR to make the PCoA and NCoA binding and forward any packets destined for PCoA to NCoA.

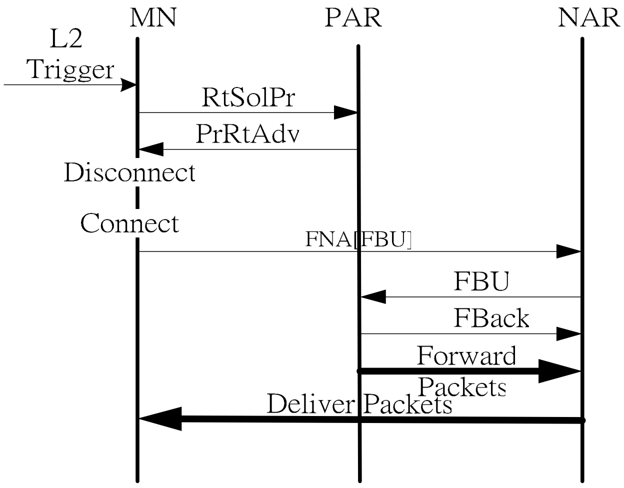

Figure 2-2. Mobile Initiated Reactive Fast Handoff Procedure

Therefore, FMIP can further be classified into a predictive mode and a reactive mode, whose signal flows are shown in Figure 2-1 and Figure 2-2, respectively. The difference between the predictive mode and the reactive mode is depending on the validation (DAD) before or after the link layer handoff.

2.2 Early Binding Method

For a high speed MN, whose signal strength goes down fast, it is possible that there is not enough time to complete the predictive mode signal flow. As a result, FMIPv6 operates in the reactive mode, which has worse performance than predictive mode. In order to provide a reliable fast handoff for MN, early binding fast handoff (EBFH) has been proposed in [6] . The EBFH signal flow is shown in Figure 2-3. The first step of EBFH after an MN finished its link layer handoff is that it receives a route advertisement which includes information about geographically adjacent ARs, and the next step is that it formulates new CoA about next foreign networks. The geographically adjacent ARs option makes the MN can perform early binding update with its current access router. Once MN would like to perform handoff, the fast binding indication (FBI) will be sent to instruct PAR which new AR will be.

Compared with the original fast handoff, the tunnel would start to establish when the link going down trigger occurs. The tunnel establishment of EBFH is earlier than the fast handoff. Thus, it calls "early binding."

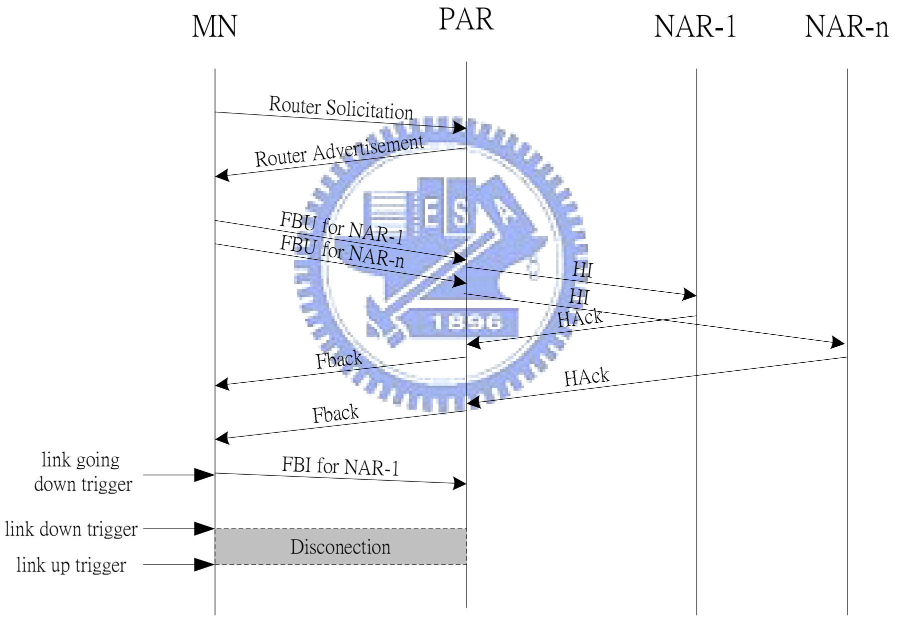

Figure 2-3. Early Binding Fast Handoff

The EBFH would provide a better handoff performance than original fast handoff. That is because early binding method would guarantee that the MN has enough time to exchange L3 fast handoff message before the L2 handoff. However, The EBFH consumes more bandwidth of wireless of wireless link than original fast handoff. That is because the geographically adjacent AR option more binding update and acknowledge messages should be exchanged between the MN and the current AR. On the other hand, there is no definition the exact timing of performing early binding in EBFH. More processing cost and transmission cost are consumed for EBFH if performing early binding too early. From the view of signaling cost, the EBFH which adopts mobile-initiated handoff may not be proper scheme.

In this thesis, not only the handoff performance but also signaling cost is considered. Based on the concept of EBFH, the aim of this thesis is threefold. One is network-initiated handoff. Another is the early binding procedure. The other is CAR selection algorithm. The above are described in detailed in Chapter 4.

Chapter 3

System Model

3.1 Network Topology Model

As shown in Figure 3-1, one access router (AR) is connected to more than one wireless BS areas. There are two handoff cases. One is the intra-domain handoff which performs the handoff within the BSs of the same AR; it is the link layer handoff without IP address change under the same AR. The other is the inter-domain handoff which needs to perform link layer and IP layer handoff between different AR. As discussed before, the IP layer handoff needs more procedures and time than the link layer handoff. In order to choose to perform either IP layer handoff or link layer handoff, a method to distinguish between the inter-domain handoff and the intra-domain handoff is needed.

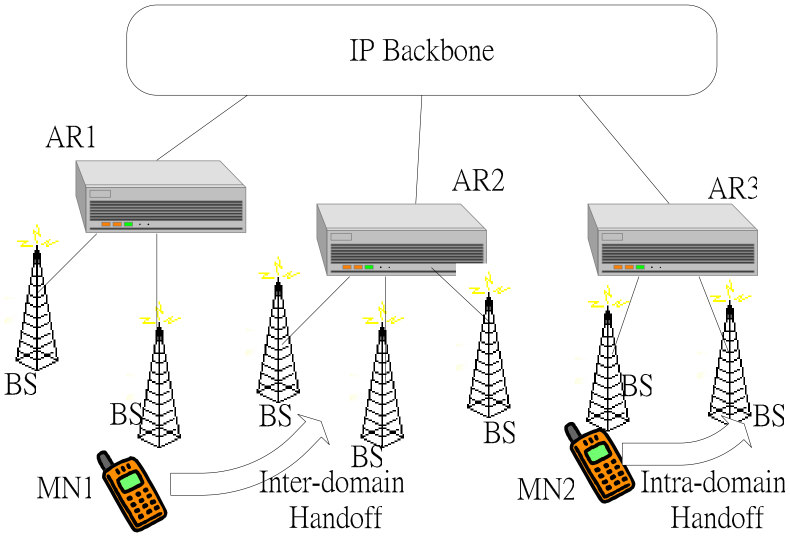

Figure 3-1. Network Topology Model

3.2 Mobility Model

Vehicular environment (typical urban) mobility model [7] is assumed. The vehicular reference mobility model uses a pseudorandom mobility model with semi-direct trajectories. The mobile position gets updated according to the decorrelation length, and direction can change at each position. MN has a constant velocity between V_{low} km/hr to V_{upper} km/hr, drawn from a uniform distribution; position updates are done every L_{dec} meter; and at each position update, the direction of movement can randomly change up to an angle A° according to a predefined probability P_p. Mobiles are uniformly distributed on the map and their direction is randomly chosen at initialization.

3.3 Signaling Time of FMIP

Table 3-1 shows some notations for the communication delays and their chosen ranges according to the suggested values in [8]. The communication delays inside the same AR and the L2 handoff delay are kept constant and are set in accordance with the assumptions made by Hsieh et al. in [9].

Table 3-1. Communication Delays used in the Analysis

Delay	**Meaning**	**Value**
D_{mn_par}	RTT(MN, PAR)	2 ms
D_{mn_nar}	RTT(MN, NAR)	2 ms
D_{par_nar}	RTT(PAR, NAR)	10-100 ms
D_{L2}	Delay for Layer 2 handoff.	20 ms

Note that the RTT(A, B) means the round trip time for a packet to pass from A to B. For example, RTT(MN, PAR) denotes the time require for a packet to pass from an MN to a PAR. It is assumed that RTT(A, B) = RTT(B, A).

In the following, the formulas used to calculate the signaling time for the predictive fast handoff and reactive fast handoff are presented. Firstly, each signaling time of predictive FMIP shown in Figure 3-2 is defined below:

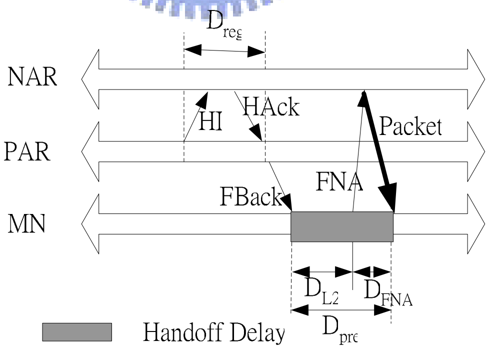

Figure 3-2. The Time Diagram of Predictive FMIP

- D_{reg}: Delay for registration to NAR. It defines the time interval from the moment that HI message is sent to the moment that Hack is received by PAR. The D_{reg} consists of the transmission time and the DAD procedure, where

D_{DAD} denotes the delay for DAD execution. $D_{reg} = 2D_{par\_nar} + D_{DAD}$, The most time-consuming procedure is DAD execution. The RFC 2462 [10] states that a node should delay sending its neighbor solicitation for DAD by a random time interval between 0 and MAX_RTP_SOLICITATION_DELAY seconds if it is the first packet sent from the interface after initiation. In RFC 2461 [11], MAX_RTP_SOLICITATION_DELAY is defined to be 1 second in duration. In the average case, D_{DAD} will be an extra 500 *ms*, and up to 1000 *ms* (1 second) in the worst case. Hence, the delay for registration to NAR is

$$D_{reg} = 2D_{par\_nar} + D_{DAD} = 520 \sim 1200\ ms \tag{3.1}$$

- D_{FNA}: Delay to perform FNA. $D_{FNA} = 2 \cdot D_{mn\_nar} = 4\ ms$
- D_{pre}: Handoff delay for predictive fast handoff. As shown in Figure 3-2, the handoff delay is L2 handoff delay and the delay to perform FNA. Therefore, D_{pre} can be obtained by

$$D_{pre} = D_{L2} + D_{FNA} = 24\ ms. \tag{3.2}$$

Secondly, each signaling time of reactive FMIP shown in Figure 3-3 is defined below:

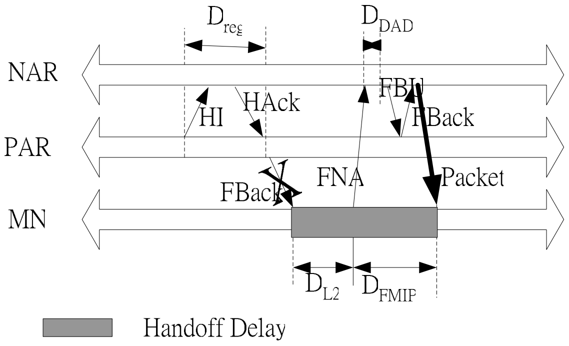

Figure 3-3: The Time Diagram of Reactive FMIP

- D_{FMIP}: Time needed to complete the FMIP operation (from time FBU is sent-encapsulated in FNA if sent from new link to time FBack is received.)

$$D_{FMIP} = D_{FNA} + D_{DAD} + 2 \cdot D_{par\_nar} = 524 \sim 1204 \; ms \tag{3.3}$$

- D_{rec}: Handoff delay for reactive fast handoff. As shown in Figure 3-3, the handoff delay is the L2 handoff delay and the delay for FMIP operation to complete. Thus, D_{rec} can be given by

$$D_{rec} = D_{L2} + D_{FMIP} = 544 \sim 1224 \; ms \tag{3.4}$$

Finally, the handoff delay of FMIP is presented in Table 3-2. It can be seen obviously that the handoff latency of predictive fast handoff is much smaller than that of reactive fast handoff.

Table 3-2. Handoff Delay of FMIP

Fast Handoff Mode	**Figure Reference**	**Notation**	**Handoff Delay**	**Reference Value in [8]**
Predictive mode	Figure 3-2	D_{pre}	$D_{L2} + D_{FNA}$	24 *ms.*
Reactive mode	Figure 3-3	D_{rec}	$D_{L2} + D_{FMIP}$	544 ~ 1224 *ms*

3.4 Binding Event Trigger and Handoff Event Trigger

The approach to the handoff problem have been considered in cellular networks using the received signal strength (RSS) as an indicator for service availability from a certain point of attachment. The RSS of serving BS, RSS_s, is an indicator for handoff event trigger used in this theses.

There are three signal strength thresholds defined. One is the binding threshold T_b, which implies that PAR needs to perform binding for IP fast handoff. The second is the threshold T_{ho}, which implies that MN needs to perform handoff for link switch.

The last is the threshold T_{dis}, which implies that link disconnects if RSS_s is below T_{dis}.

There event triggers are defined in this thesis. One is early binding event trigger for L3 handoff. Another is link layer handoff event trigger. The other is link disconnection event trigger. The early binding event trigger, E_{eb}, is an event if the RSS_s is below T_b for a predefined period, t_b, where t_b is a binding dwell timer. The link layer handoff event trigger, E_{ho}, is an event if the following conditions is satisfied: (i) the RSS_s is below T_{ho}, (ii) the RSS of candidate BS is higher than RSS_s, (iii)the above two conditions are satisfied for a predefined period, t_{ho}, where t_{ho} is a handoff dwell timer. In this case, the timer is started when the first two conditions are satisfied. The MN performs a handoff if the handoff condition is satisfied for the entire dwell timer. The link disconnection event trigger, E_{ld}, is an event if RSS_s is below T_{dis}.

3.5 Candidate AR Selection

The candidate AR (CAR), which is the geographically adjacent AR of PAR, involves the high possibility to be the NAR in the impending handoff. The number of CAR, denoted by N_{CAR}, could be one or more depending on the system design or other reasons. The CAR is determined by a CAR selection algorithm using some information such as the RSS of neighbor BS.

Thus, some notations list below for the CAR selection algorithm:

- N_s: The number of scanning BS. We assume that the intra-domain BS excluded from the scanning BS.
- BS_n: The set of scanning BS. The BS_n ranks from the largest RSS of scanning BS to the least RSS of scanning, $1 \le n \le N_s$.
- RSS_n: The set of received signal strength of each BS_n, $1 \le n \le N_s$.

- BS_t : The target BS is the BS which MN switches to after handoff. The target BS is the BS with the largest RSS at the time of occurring E_{ho}.
- CAR_n : The set of CAR determined by the CAR selection algorithm, $1 \leq n \leq N_s$.

For instance, the CAR selection algorithm could choose the adjacent AR whose BS with the largest RSS. In this case, N_{CAR} is 1, and CAR_1 is the AR of BS_1.

Chapter 4

Network–Initiated Early Binding Fast Handoff (NEBFH)

A network-initiated early binding fast handoff (NEBFH) is proposed. One of the reasons for adopting network-initiated handoff in early binding method is to reduce the early binding messages exchanged between a MN and a PAR. On the other hand, it is possible to disconnect between the current BS because the signal strength is weaker while the MN close to handoff. If there is no time when the MN is informed of the L2 handoff and the link between the MN and the PAR is terminated, the PAR can initiate the IP-level handoff procedure by sending the L3 fast handoff messages. For early binding method, the network- initiated handoff is more proper than mobile-initiated handoff in terms of signaling cost and reliable transmission.

4.1 NEBFH Procedure

The signal flow of network-initiated early binding fast handoff (NEBFH) is presented in Figure 4-1, where the CAR selection is successful. The handoff control resides in the network side (i.e. PAR) in NEBFH. The first step of NEBFH after the early binding event trigger (E_{eb}) is that a PAR sends an RtSolPr message to its MN and receives an FBU message form the MN. The PrRtAdv message contains one or more [BS-ID, AR-Info] tuples which is the information of CAR. The CAR is determined by a CAR selection algorithm. In this these, an intelligent candidate AR selection (ICARS) algorithm is proposed. Next, The PAR sends the HI message to one or more CAR and waits for the HAck message. The HAck message sent by the CAR_n means that the tunnel between the PAR and the CAR_n has been setup. The early binding is completed while all HAck message of N_{CAR} CAR are received.

The PAR sends the FBack message to the MN after the link layer handoff event trigger(E_{ho}). The FBack message contains the information of NAR, that is, the AR of target BS. As shown in Figure 4-1, if the NAR is CAR-N_{CAR}, the MN performs L2 handoff to the target BS , whose AR is CAR-N_{CAR} after receiving the FBack. The remaining procedure after the disconnection is the same as that of the predictive fast handoff.

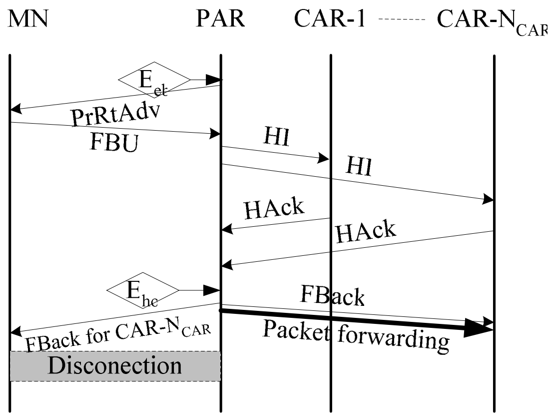

Figure 4-1. The Signal Flow of NEBFH for CAR Selection Success

The above description has assumed that the NAR is included in the set of CAR. However, the situation may be arisen that the NAR is not included in the set of CAR, that is, the CAR selection failure. In this situation, the PAR sends a fast binding indication (FBI) to the MN as shown in Figure 4-2. The FBI message contains the information of NAR to let the MN know the AR of the impending handoff. At the same time, the PAR sends the HI message to the NAR to establish the tunnel. In fact, the case for CAR selection failure is consistent with to the case in original FMIP. If the HAck message sent by the NAR can be received before the link disconnection, the procedure that the PAR sends the FBack message to the MN is the same as the predictive fast handoff. Otherwise, if the HAck message sent by the NAR cannot be received before the link disconnection trigger event(E_{ld}) as shown in Figure 4-3, the procedure that MN sends the FBI encapsulated inside the FNA to the NAR is similar to that of the reactive fast handoff.

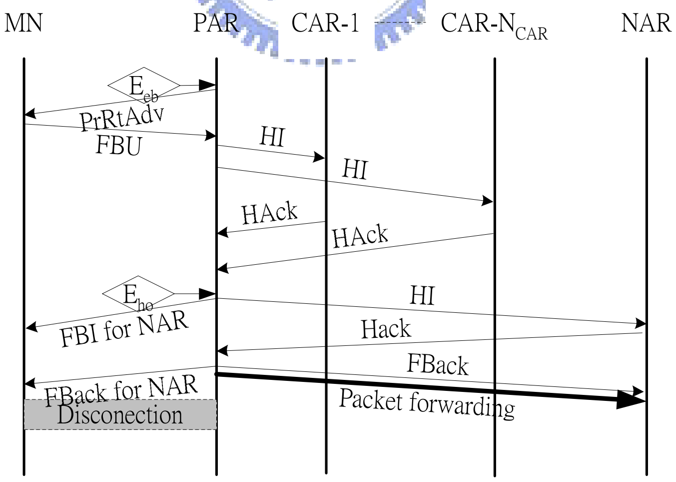

Figure 4-2. The Signal Flow of Predictive NEBFH for CAR Selection Failure

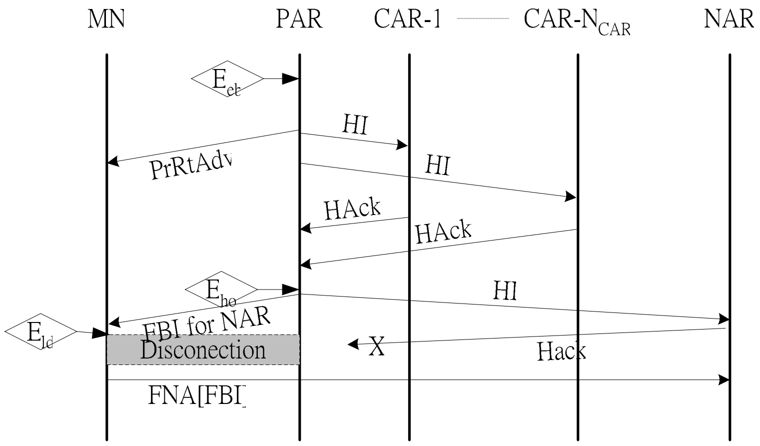

Figure 4-3. The Signal Flow of Reactive NEBFH for CAR Selection Failure

Figure 4-4 shows the flow chart of NEBFH. The early binding is initiated by E_{eb}. After triggered by E_{ho}, there are two cases, which are the CAR selection success or failure. The CAR selection success means the NAR has been predicted before link layer handoff trigger. However, the situation could be arisen that the binding between PAR and NAR has been not complete in case the HAck message does not be received by the PAR. The case that the HAck message has been received by the PAR is the early binding success. In this case, the mode of FMIP is predictive.

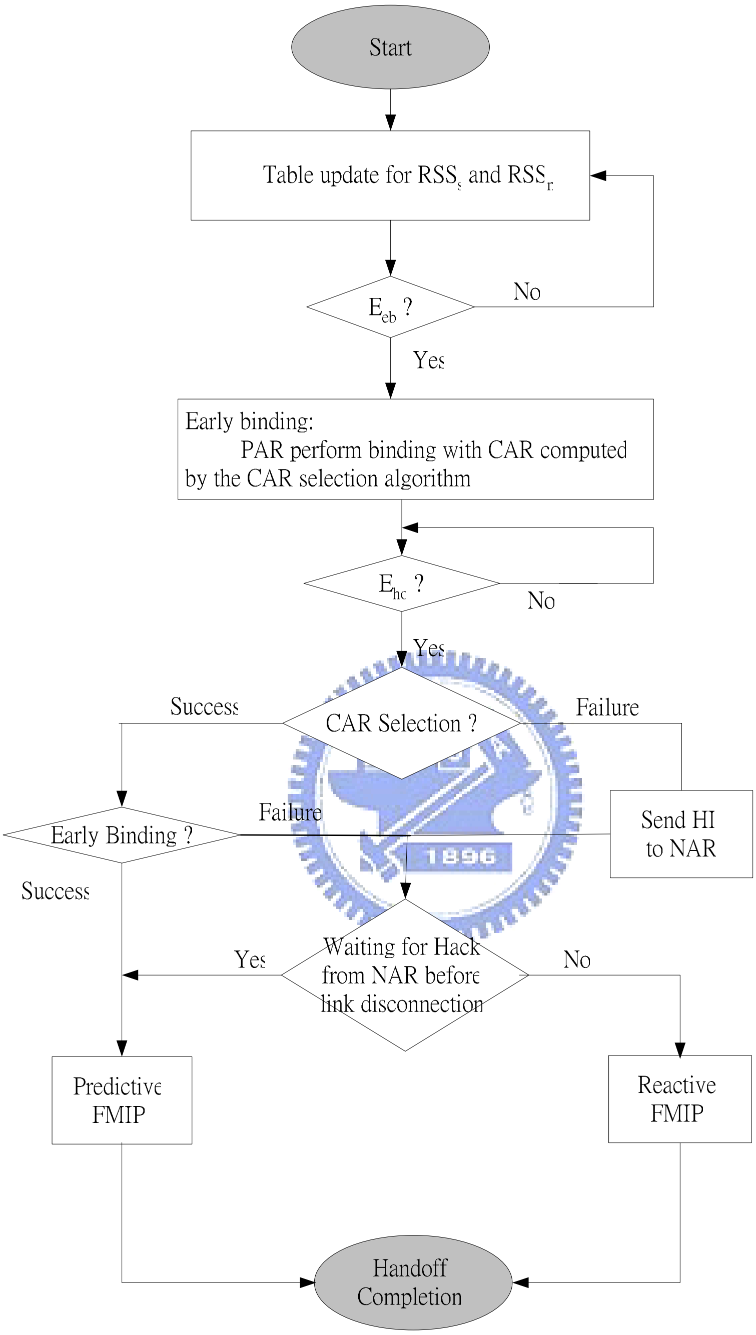

Figure 4-4. The Flow Chart of NEBFH

On the contrary, the case that the HAck message has been not received by the PAR is the early binding failure. If the HAck message can be received before the link disconnection, the mode of FMIP is predictive. Otherwise, the mode of FMIP is reactive. In brief, the predictive FMIP can be almost guaranteed to occur in the CAR selection success case.

For the CAR selection failure case, it means the failure of early binding and becoming back original fast handoff. Every signaling for early binding is in vain. Therefore, a proper candidate AR selection algorithm to boost the probability of candidate AR selection success case is critical for NEBFH.

4.2 Intelligent Candidate AR Selection (ICARS) Algorithm

A NAR is not determined before a L2 handoff trigger if using early binding method. Thus, a candidate AR selection algorithm is needed by the early binding method. The difference between the CAR and NAR may arise. In this case, the signaling cost foe early binding with CAR is in vain. The extra signaling cost of binding with NAR is consumed. In order to boost the rate of candidate AR selection success case, a simple method is choosing all the geographically adjacent AR to be included in CAR. However, the signaling cost is too high for this method. An intelligent candidate AR selection (ICARS) algorithm is proposed to provide not only high rate of CAR selection but also less signaling cost.

ICARS algorithm:

Let S_{CAR} denote the segment for candidate selection. We assume that all subnet of BS_n for *n* from 1 to N_s are different from the subnet of serving BS.

$$\text{CAR} = \text{The AR of } \{\, BS_n, \text{ whose } RSS_n \text{ locates at the range from } RSS_1 \text{ to } RSS_1 - \left(RSS_1 - RSS_{N_s}\right) / S_{CAR} \,\}, \quad (\text{n: } 1 \sim N_s) \qquad (4.1)$$

Figure 4-5 show an instance for ICARS algorithm. In this instance, let S_{CAR}=5 and N_s=6.

For the case <i> in the figure, RSS_1, RSS_2, and RSS_3 locate at the range from RSS_1 to $RSS_1 - (RSS_1 - RSS_{N_s})/S_{CAR}$ of RSS. Hence, the CAR= AR of { BS_1, BS_2, BS_3 }. N_{CAR}=3.

For the case <ii> in the figure, only RSS_1 locates at the range from RSS_1 to $RSS_1 - (RSS_1 - RSS_{N_s})/S_{CAR}$ of RSS. Hence, the CAR= AR of { BS_1 }. N_{CAR}=1.

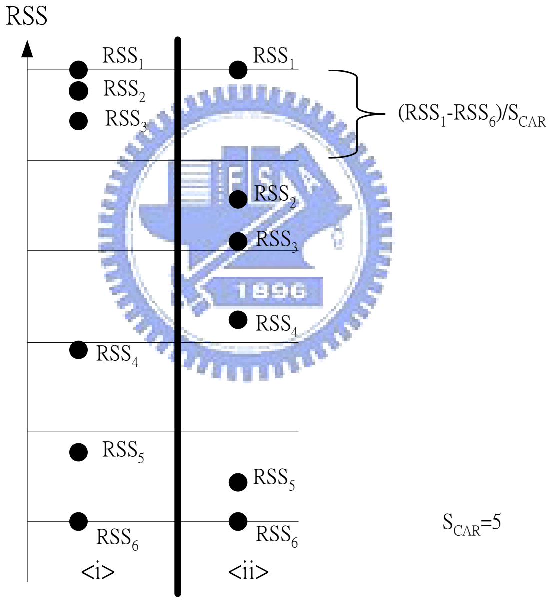

Figure 4-5. An Illustration of ICARS algorithm

It is possible that there are several CARs which MN possibly moves to. This may be arisen especially while MN locates among several these ARs. On the other hand, it is possible that there is only one AR which MN possibly moves to. This is may be arisen while MN locate at the cell boundary. Thus, selecting several CAR would be better in the former case; and selecting one CAR would be fine in the latter case. However, it is inefficient if selecting fixed number of CAR. It is efficient if number of selecting CAR changes adaptively. The ICARS algorithm is conducted according to this concept.

Chapter 5

Simulation Results and Discussions

5.1 Simulation Environment

In order to investigate the performance of proposed NEBFH scheme and ICARS algorithm under different conditions, a simulation was done using C++. Figure 5-1 shows the concatenated 19-cell layout in the simulation. Each cell has 1 km radius and the distance between BSs is $\sqrt{3}$ km. Moreover, a cell-wrapping technique has been adopted. Boundary cell are regards as neighbors of the boundary cells located almost directed opposite the cell layout. Only the 19 cells in the center really exist, the others are just copies of the cell having the same numbers.

The wireless fading channel consists of large-scale fading and small-scale fading. The large-scale fading comes from free space degrading and shadowing effect, while the small-scale fading is due to multipath reflection. In this thesis, the small-scale fading is neglected since the average of RSS is important for handoff issue. And it gets average out because of its rapid variation. The channel propagation model for received signal strength is given by : $RSS(d) = P_t - PL(d) + X_\sigma$,where P_t is transmit power, and $PL(d)$ is the pass loss at distance d between the BS and MN in meters, and X_σ is a zero-mean Gaussian random variable with standard deviation σ modeling shadow fading. On the other hand, the auto-correlation in time on the same link on the shadow fading is considered to approximate the real fading environment. As to the path loss, the model is : $PL(d) = 31.0 + 34.8\log(d)$ [12]. All system parameters are listed in Table 5-1. The values of the parameters defined in system model are shown in Table 5-2. The parameters of signaling cost is described in chapter 7. And the reference values of them defined in [13] are shown in Table 5-3.

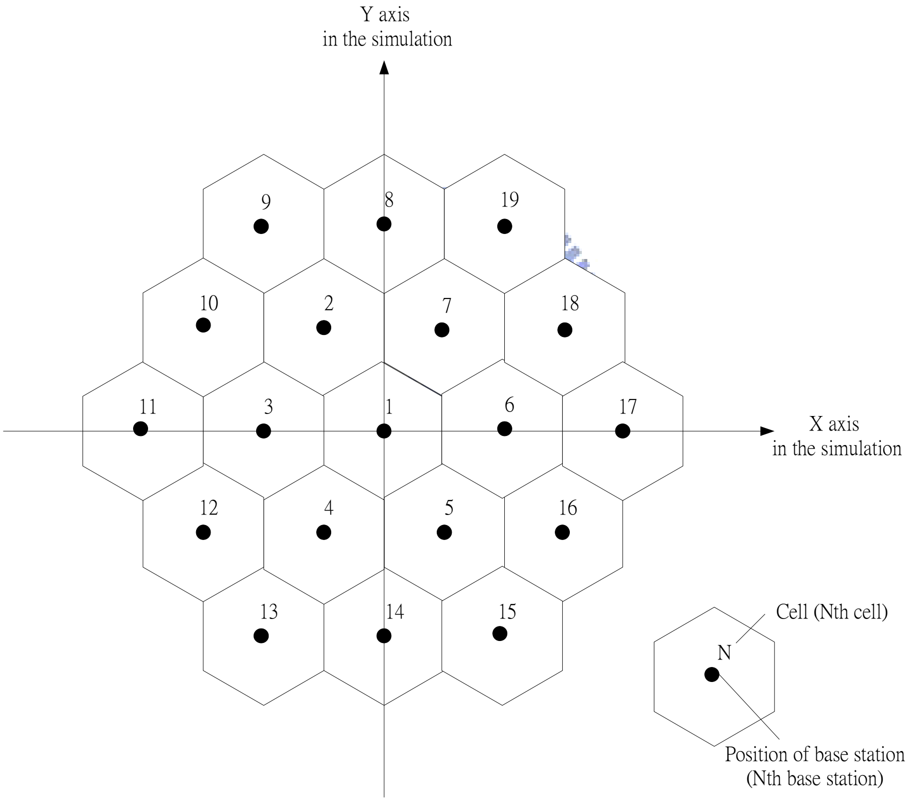

Figure 5-1. Cell Layout in the Simulation

Table 5-1. System Parameters in the simulation

Parameters	**Values**
Cell size	1000 m
Maximum transmit power (P_t)	44 dBm
Carrier frequency	2000 MHz
Thermal noise density	-174 dBm/Hz
Path loss model	$PL(d) = 31.0 + 34.8\log(d)$
Standard deviation of slow fading (σ)	8 dB

Table 5-2 The Parameters defined in System Model

Parameters	**Values**
V_{low}	20 km/hr
V_{upper}	120 km/hr
L_{dec}	20 m
$A°$	45
P_p	0.2
T_b	-70 dBm
T_{ho}	-80 dBm
T_{dis}	-90 dBm
S_{CAR}	5
t_b	0.1 sec
t_{ho}	0.5 sec

Table 5-3. The Parameters of Signaling Cost

Parameters	**Values**
TC_{mn_par}	1
TC_{mn_nar}	1
TC_{par_nar}	0.5
PC_{par}	5
PC_{nar}	5
SC_{eb}	$11\,N_{CAR}+7$
SC_{sf}	12
SC_{pre}	7.5
SC_{rea}	12

5.2 Simulation Result and Discussions

Figure 5-2 shows the handoff delay of FMIP and NEBFH with distinct CAR selection algorithms, which are *Fix-1 algorithm*, *Fix-2 algorithm*, *ICARS algorithm*, and *All algorithm*, respectively. The *Fix-1 algorithm* indicates that the CAR is to choose the adjacent AR of BS with the largest RSS. The *Fix-2 algorithm* indicates that the two CARs are the AR of BS with the largest RSS and the AR of BS with the second largest RSS. The *ICARS algorithm* is proposed by this thesis. The *All algorithm* indicates that the CAR is all geographically adjacent AR of PAR.

It can be found that the handoff delay of NEBFH is smaller than that of FMIP by 10% ~ 30% as the increase of velocity. The result shows that the handoff delay can be improve by the early binding method. For a high speed MN, it is possible that a PAR does not complete binding procedure until L2 handoff. As a result, the fast handoff becomes reactive mode fast handoff. As shown in Figure 5-3, the early binding method used in NEBFH decreases the rate of reactive fast handoff. That is because the binding procedure has been done before the L2 handoff trigger as soon as possible conducted by the early binding method. The method boosts the rate of the binding procedure completion before the handoff trigger and reduces the rate of reactive fast handoff. Therefore, the handoff delay is reduced.

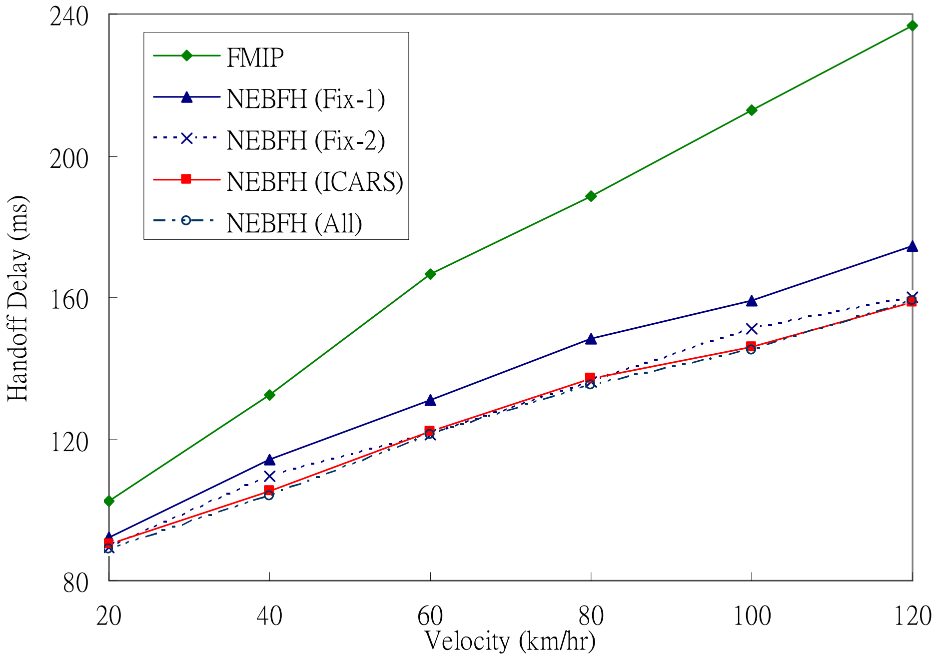

Figure 5-2. The Handoff Delay of FMIP and NEBFH with distinct CAR Selection Algorithm

The early binding method can improve the handoff performance but it consumes more signaling cost than FMIP as shown in Figure 5-4. The result shows that the signaling cost of NEBFH consumes more signaling cost than FMIP by at least 30%. More processing cost of NEBFH is consumed in comparison to FMIP. In FMIP, the handoff procedure is performed after handoff trigger. However, the handoff procedure has to be processed earlier than handoff trigger in NEBFH. Moreover it is possible for early binding failure. In this case, the signaling cost of early binding is in vain, and more signaling cost is consumed.

In addition, it can be found that there are distinct handoff performances of

NEBFH among distinct CAR selection algorithm. The handoff performance of NEBFH with *Fix-1 algorithm* is poorer than that of NEBFH with other three CAR selection algorithm. It can be found that the handoff delays of NEBFH used with *Fix-1 algorithm* is larger than that of NEBFH used with other there CAR selection algorithm with by 10~15 *ms* at high velocity. The result indicates the impact of CAR selection algorithm to handoff performance. As shown in Figure 5-5, the CAR selection failure rate of Fix-1 is 4.5%, and the CAR selection failure rate of other three CAR selection algorithm are less than 1%. This means that the improvement of CAR selection failure contributes to 8% in handoff delay under this system model. The CAR selection failure is caused by the scenario that the binding AR at the early binding phase is not the AR which MN switches to. This causes from the uncertainty of mobility, especially when MN locates between two ARs. Selecting more than one CAR is a solution to reduce the CAR selection failure rate. This can be seen from the result shown in Figure 5-5. It is worth noting that the scenario of uncertainty does not always exist. The scenario arises under the rate of 4.5%. Thus, always selecting more than one CAR is unnecessary. The *ICARS algorithm* is conducted by selecting one or more AR adaptively. Thus, the signaling cost of ICARS algorithm can be reduced effectively. That is the reason why the signaling cost of ICARS is smaller than that of *Fix-2 algorithm* and *All algorithm* as shown in Figure 5-4. Note that the signaling cost of *All algorithm* is about 62, and not shown in Figure 5-4 due to out of the scale.

As for the effects of the early binding method and the ICARS algorithm, it can be summarized that former is a solution to reduce the handoff delay due to the reactive fast handoff and the latter is a solution to reduce handoff delay due to the CAR selection failure. The NEBFH improves the handoff performance of FMIP. The

ICARS algorithm provides an efficient CAR selection algorithm for NEBFH.

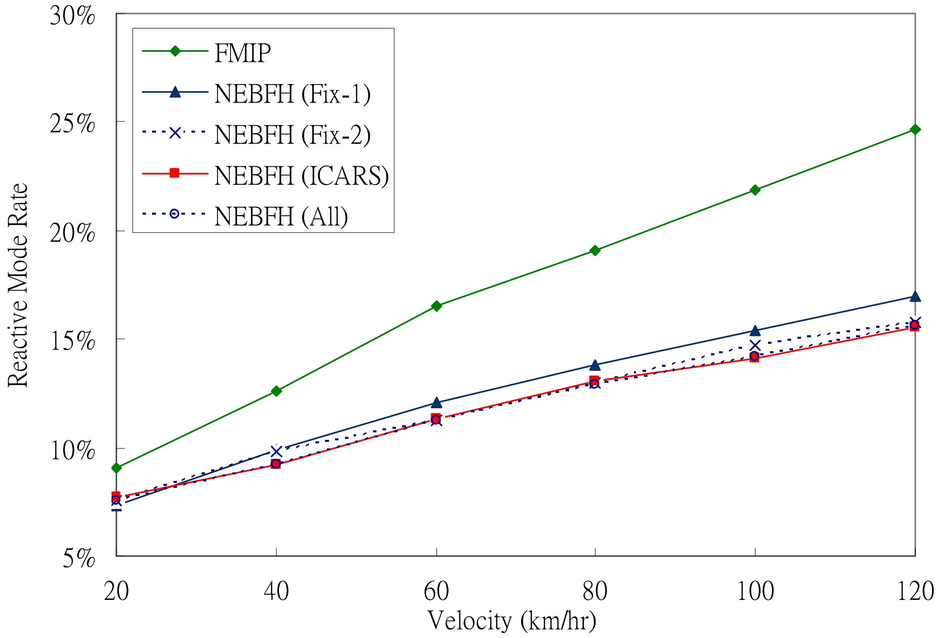

Figure 5-3. The Reactive Mode Rate of FMIP and NEBFH with distinct CAR Selection Algorithm

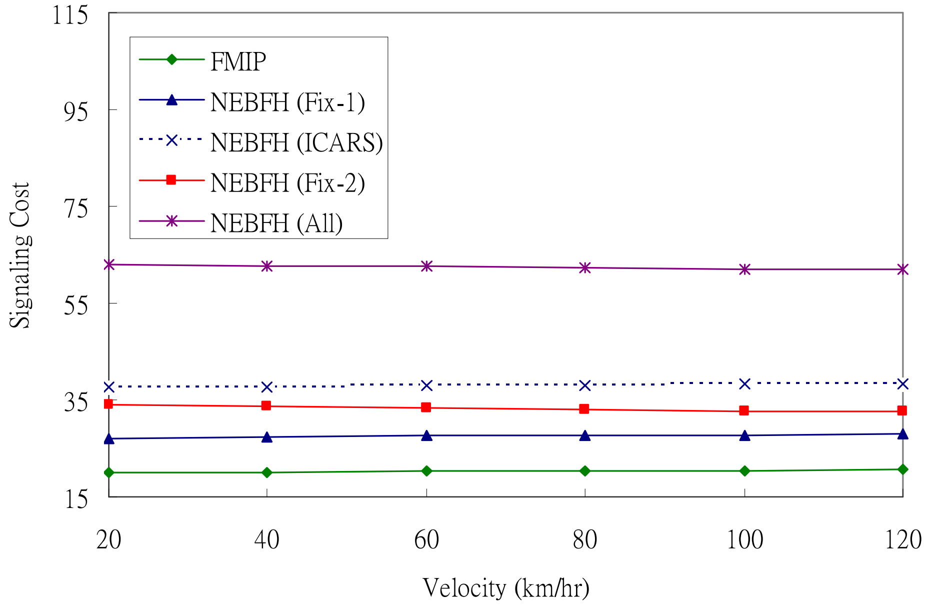

Figure 5-4. The Signal Cost of FMIP and NEBFH with distinct CAR Selection Algorithm

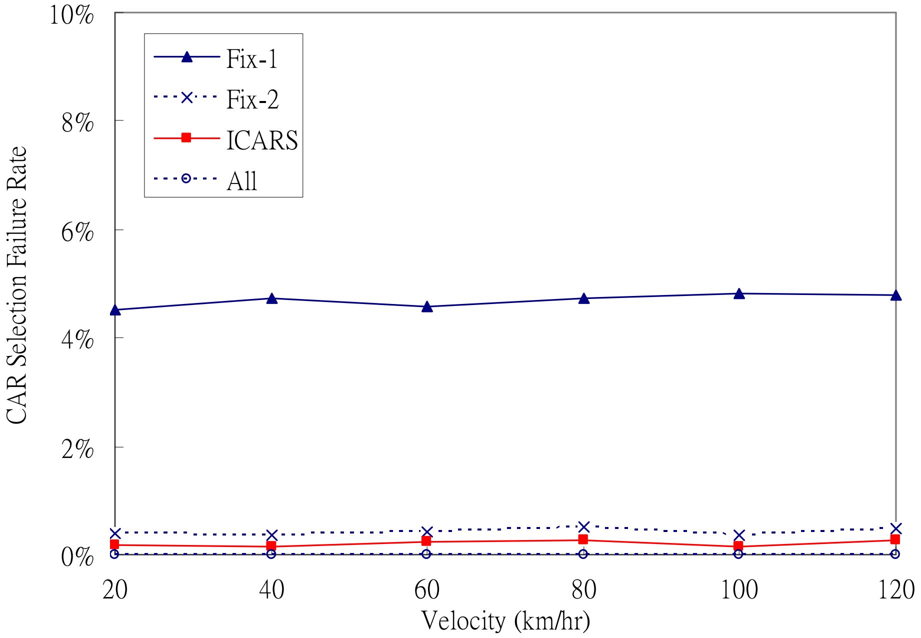

Figure 5-5. The CAR Selection Failure Rate of distinct CAR Selection Algorithm

Figure 5-6 illustrates the handoff delay of NEBFH with distinct early binding timer at binding threshold -80 *dBm*. The larger binding dwell timer indicates that the timing of early binding closes to the L2 handoff trigger. The timing of binding dwell timer 0.5 is the same with that of handoff trigger. In this case, the fast handoff is performed without using early binding method.

It can be found that the handoff delay increase as the increase of dwell timer especially for MN with high velocity. The result shows the impact of the timing of binding. The timing of binding is earlier than the handoff trigger as the decrease of dwell timer. The earlier binding means that there is possibly more time to perform binding before handoff trigger. This period from binding trigger to handoff trigger is long enough to complete the binding procedure. Therefore, the rate of early binding failure decreases, and the rate of predictive fast handoff increases. The handoff delay is reduced.

Figure 5-7 illustrates the handoff delay of NEBFH with distinct early binding threshold at binding timer 0.1 *sec*. The timing of binding is earlier as the increase of the binding threshold. It can be found that the handoff delay vary insignificantly as the increase of higher threshold above -70 *dBm*. The result shows that the binding threshold above some value does not have influence on the handoff delay. This is because the binding trigger event is satisfied after previous handoff if high binding threshold is set. If the binding threshold is set higher than the received signal strength after previous handoff, the binding condition is satisfied just after previous handoff. In this case, the timing of binding with higher binding threshold is almost the same. For higher threshold above specific value, the timing is just the timing after previous handoff. And that is the reason why the handoff delay is almost the same even the higher binding threshold is set.

As for the binding trigger event, the handoff delay is sensitivity to the dwell timer closed to the handoff trigger, but insensitive to the binding threshold above specific value. Furthermore, the handoff delay is affected by the factor such as early binding failure rate and CAR selection failure rate. The relation early binding failure rate of and CAR selection failure rate are shown in Figure 5-8 and Figure 5-9, respectively. The trigger event is defined in Table 5-4. The trigger event with larger number indicates the closer to the handoff trigger. In other words, the trigger event with small number represents the earlier timing of binding.

It can be found in Figure 5-8 that the timing of binding for trigger event 4 and 5 leads to the increase of early binding failure rate. This is because that there is not enough time to complete binding procedure while the timing of binding is close to the handoff trigger. Moreover, it can also be found that the CAR selection failure rate slightly decreases as the later binding trigger. This is because the CAR selection situation is more obvious while the timing is close to the handoff trigger. In this system model, however, the impact of the CAR selection failure to the handoff delay is less than that of the timing of binding. Therefore, it is better to let the timing of binding trigger early enough to complete the binding.

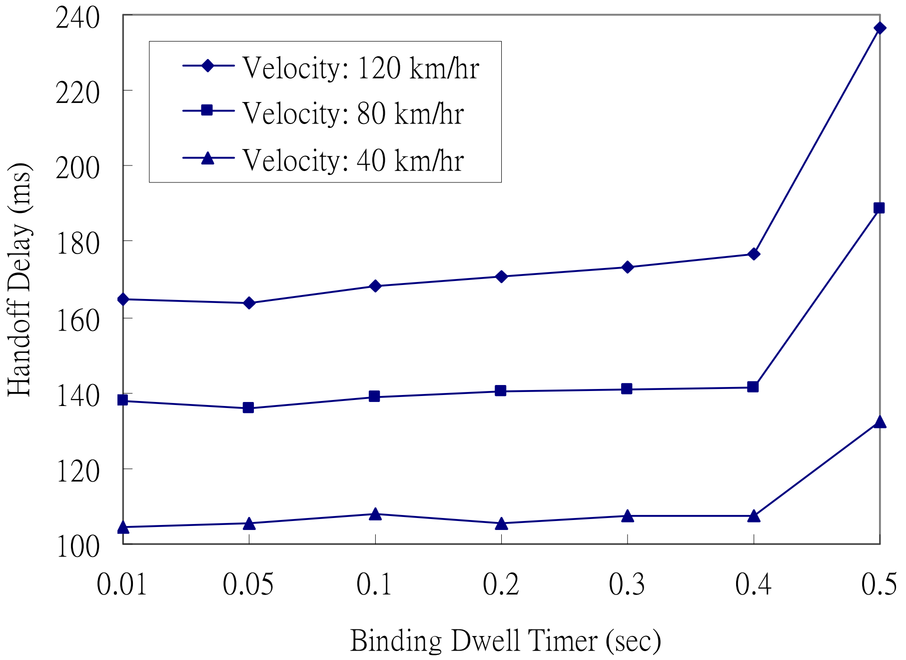

Figure 5-6. The Handoff Delay of NEBFH with Distinct Early Binding Dwell Timer at Binding Threshold -80 *dBm*

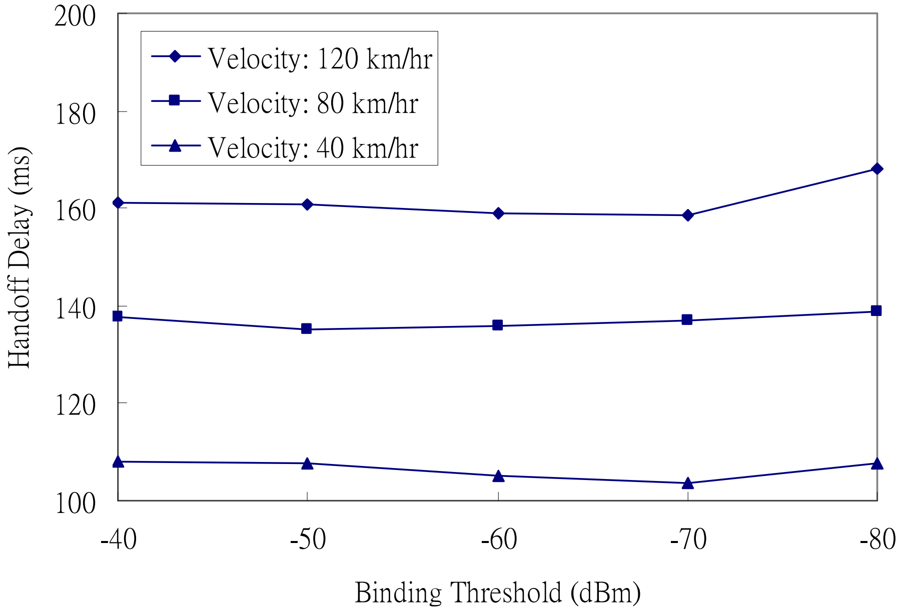

Figure 5-7. The Handoff Delay of NEBFH with Distinct Early Binding Threshold at Binding Dwell Timer 0.1 sec

Table 5-4. Trigger Event

Binding Trigger Event	1	2	3	4	5	6
Binding dwell timer	0.1	0.1	0.1	0.1	0.1	0.3
Binding threshold	-40	-50	-60	-70	-80	-80

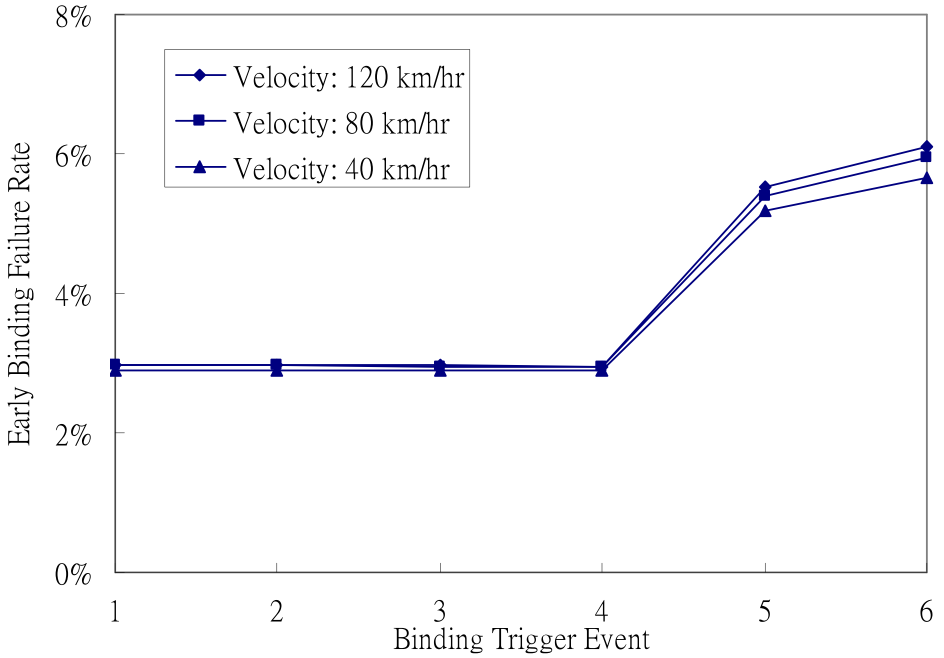

Figure 5-8. The Early Binding Failure Rate of Distinct Binding Trigger Event

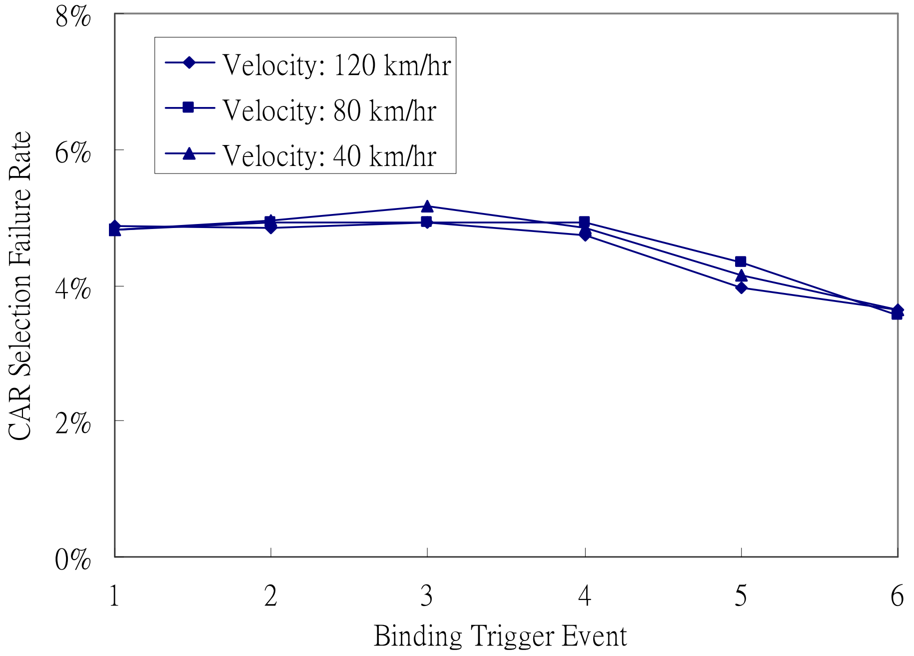

Figure 5-9 The CAR selection Failure Rate of Distinct Binding Trigger Event

Chapter 6

Conclusions

In IP-base mobile network, minimizing handoff delay is one of the most important issues. Compared with the existing protocols, The FMIP provides a practicable mechanism in terms of its ability to reduce handoff delay and support smooth handoff. For a high speed MN, however, the predictive fast handoff may fail because the signal strength goes down too fast to complete binding procedure and results in the increase of reactive handoff probability and handoff delay. The NEBFH provides a solution to boost the rate of predictive fast handoff by performing the binding procedure in advance. As for early binding method, two issues are analyzed further in this thesis: one is the candidate AR selection and the other is the timing of binding event trigger. We proposed an ICARS algorithm to accurately select candidate AR to reduce binding cost and the impact of binding event trigger timing was analyzed.

Simulation results show that early binding method is a significant solution to improve FMIP. It can reduce handoff delay of FMIP by 30% for high mobility case although it consumes more signaling cost. Moreover, the ICARS algorithm can reduce handoff delay of NEBFH by 8% compared with Fix-1 algorithm. The result also shows that the signaling cost of ICARS algorithm is the least while performing similar performance of handoff delay. The handoff delay of NEBFH would be close to that of FMIP while the timing of binding trigger event is close to handoff event trigger. The timing of binding trigger should be earlier than that of handoff event trigger by specific period, which is the longest period to complete the binding procedure.

Chapter 7

Appendix: NEBFH Performance Analysis

7.1 Handoff Delay Analysis of NEBFH

Table 7-1 shows all cases in NEBFH corresponding to the mode in the FMIP. The probability of each case is presented as follows:

- P_{css} : The probability of CAR selection success case in NEBFH.
- P_{csf} : The probability of CAR selection success failure case in NEBFH.
- P_{ebs} : The probability of early binding success in the CAR selection success case
- P_{ebf} : The probability of early binding failure case in the CAR selection success case.
- P_{ebfp} : The probability of prediction mode in early binding case of the CAR selection success case.
- P_{ebfr} : The probability of reactive mode in early binding failure case of the CAR selection success case.
- P_{csfp} : The probability of predictive mode in the CAR selection failure case.

- P_{csfr} : The probability of reactive mode in the CAR selection failure case.

Table 7-1. All Case in NEBFH Corresponding to the Mode in the FMIP

The Case in the NEBFH		**The Mode in the Fast Handoff**
CAR selection success case (CSS P_{css})	early binding success case (P_{ebs})	predictive mode (P_{ebs})
	early binding failure case (P_{ebf})	predictive mode (P_{ebfp})
		reactive mode (P_{ebfr})
CAR selection failure case(P_{csf})	original FMIP	predictive mode (P_{csfp})
		reactive mode (P_{csfr})

Moreover, all cases in NEBFH can correspond to predictive mode and reactive mode in FMIP, and the probability of the predictive mode and the reactive mode are denoted by P_{pre} and P_{rec}. The flowing formula can be obtained from Figure 4-4.

- $P_{css} = P_{ebs} + P_{ebf}$ (7.1)
- $P_{epf} = P_{ebfp} + P_{ebfr}$ (7.2)
- $P_{csf} = P_{csfp} + P_{csfr}$ (7.3)
- $P_{pre} = P_{eps} + P_{csfp} + P_{csfp}$ (7.4)
- $P_{rec} = P_{csfr} + P_{epfr}$ (7.5)
- $P_{pre} + P_{rec} = 1$ (7.6)

Therefore, the average handoff delay, $\overline{D_{ho}}$,is

$$\overline{D_{ho}} = P_{pre}\, D_{pre} + P_{rec}\, D_{rec} \tag{7.7}$$

7.2 Signaling Cost Analysis of NEBFH

In this section, the transmission cost between nodes and processing cost at the nodes are defended in order to analyze the signaling cost of NEBFH. The TC_{mn_par} and TC_{mn_nar} are transmission costs incurred in the wireless link between an MN and a PAR and between an MN and an NAR. The TC_{par_nar} is transmission cost incurred in the wired link between a PAR and NAR. The PC_{par} and PC_{nar} are processing cost at a PAR and an NAR. In NEBFH, the signal cost can be taken part as the following:

- SC_{eb}: The signaling cost of early binding. The SC_{eb} includes the procession cost for PAR to compute the candidate AR selection algorithm, the transmission cost sending the PrRtAdv message from the PAR and the MN, the transmission cost sending the HI message from the PAR to each CAR, the processing cost for each CAR to perform the DAD procedure, and the transmission cost sending the HI message from each CAR to the PAR. It can be referred to the signaling of upper gray block in Figure 7-1.

$$SC_{eb} = PC_{par} + 2 \cdot TC_{mn\_par} + N_{CAR}(PC_{par} + 2 \cdot TC_{mn\_nar} + PC_{nar}) \qquad (7.8)$$

- SC_{sf} : The signaling cost of selection failure. The SC_{sf} includes the transmission cost sending the FBI message from PAR to MAR, the transmission cost sending the HI message from the PAR to the NAR, the processing cost for NAR to perform the DAD procedure, and the transmission cost sending the HI message from each CAR to PAR. It can be referred to the signaling of lower gray block in Figure 7-1.

$$SC_{sf} = TC_{mn\_par} + PC_{par} + 2 \cdot TC_{mn\_nar} + PC_{nar} \qquad (7.9)$$

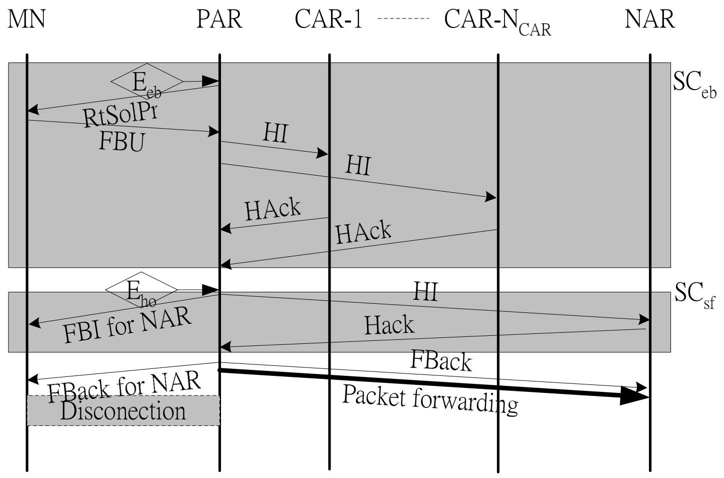

Figure 7-1. The Signaling Cost of NEBFH

- SC_{pre} : The signaling cost of predictive mode. The SC_{pre} includes the processing cost of PAR, the transmission cost to send the FBack message from the PAR to the MN and the NAR, and the transmission sending the FNA message from the MN to the NAR.

$$SC_{pre} = PC_{par} + TC_{mn\_par} + TC_{par\_nar} + TC_{mn\_nar} + PC_{nar} \quad (7.10)$$

- SC_{rea} : The signaling cost reactive mode. The SC_{rea} includes the transmission cost sending the FNA message, the processing cost for NAR to perform the DAD procedure, the transmission cost sending the FBU message from the NAR to the PAR, the processing cost of PAR, and the FBack message sending from the PAR to the NAR.

(7.11)

Table 7-2 shows the signaling cost of all cases in NEBFH. The signaling cost of each case in NEBFH can be presented by SC_{eb}, SC_{sf}, SC_{pre} and SC_{rea}.

Table 7-2. The Signaling Cost of All Cases in NEBFH

The Case in the NEBFH			**The Signaling Cost**
CAR selection success case	early binding success case	predictive mode	$SC_{eb} + SC_{pre}$
	early binding failure case	predictive mode	$SC_{eb} + SC_{pre}$
		reactive mode	$SC_{eb} + SC_{rea}$
CAR selection failure case	original FMIP	predictive mode	$SC_{eb} + SC_{sf} + SC_{pre}$
		reactive mode	$SC_{eb} + SC_{sf} + SC_{rea}$

Let $\overline{N_{CAR}}$, $\overline{SC_{eb}}$ and $\overline{SC}$ denote the average number of CAR computed by the CAR selection algorithm, average signaling cost for early binding and average signaling cost for NEBFH. The following formula can be obtain

$$\overline{SC_{eb}} = \overline{N_{CAR}}\,(PC_{par} + 2 \cdot TC_{mn\_nar} + PC_{nar}) + 2 \cdot TC_{mn\_par} + PC_{par} \tag{7.12}$$

$$\begin{aligned} \overline{SC} &= P_{ebs}\ SC_{ebs} + P_{ebfp}\ SC_{ebfp} + P_{ebfr}\ SC_{ebfr} + P_{csfp}\ SC_{csfp} + P_{csfr}\ SC_{csfr} \\ &= \overline{SC_{eb}} + (P_{csfp} + P_{csfr})\,SC_{sf} + (P_{eps} + P_{epfp} + P_{csfp})\,SC_{pre} + (P_{epfr} + P_{csfr})\,SC_{rea} \\ &= \overline{SC_{eb}} + P_{csf}\ SC_{sf} + P_{pre}\ SC_{pre} + P_{rec}\ SC_{rea} \end{aligned} \tag{7.13}$$

(7.13) can be obtained by the fact that the average signaling cost of NEBFH is sum of average signaling cost of early binding, the signaling cost of selection failure multiplied by the probability of CAR selection failure case, the signaling cost of predictive mode multiplied by the probability of predictive mode, and the signaling cost of reactive mode multiplied by the probability of reactive mode.

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Vita

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