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Mobility Management Schemes in Wireless Mobile Networks

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Mobility Management Schemes in Wireless Mobile Networks

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Abstract

A large amount of research activities has been taken to address various design problems of the network architecture and effective methods of seamless mobility management, as Internet and mobile networks are rapidly activated. This thesis proposes and evaluates the mobility management schemes in cellular mobile networks and Mobile IPv6 networks. Specially, to provide seamless services to roaming mobile users, the location management has been critical research issues in wireless mobile networks. The first, in cellular mobile networks, reducing the location update cost has been a critical research issue since the location update process requires heavy signaling traffics. This thesis provides effective location management strategies to reduce the location update cost. The second, Mobile IPv6 has become an important protocol for providing Internet connectivity to roaming mobile nodes. There are two methods for communications between the mobile node and the correspondent node in Mobile IPv6. One is the bidirectional tunneling using tunneling all packets via the home agent and the other is the route optimization directly communicating without routing via the home agent. The conventional routing path using the former is often significantly longer than the optimal path using the latter. Therefore this thesis is to present the quantitative evaluation results which come from the performance comparison between two methods. That is, it proposes the route optimization scheme in Mobile IPv6. Reducing the handover latency has been one of the most critical research issues in Mobile IPv6. Such a research includes the fast handover, the hierarchical handover, the combined handover from them, and other variations. This thesis also proposes a variation of the handover scheme used in hierarchical Mobile IPv6 mobility management.

This thesis consists of five main schemes: a hierarchical scheme in cellular networks, an overlapping scheme in cellular networks, a route optimization scheme in Mobile IPv6, a route optimization scheme with security in Mobile IPv6, and a mobility support scheme in hierarchical Mobile IPv6.

The first part of this thesis proposes to employ hierarchical structure in cellular mobile networks to reduce the location update cost. Also, it provides the proposed analytical models to evaluate the performance of the proposed approach by comparing with the conventional scheme in cellular mobile networks. The evaluation shows that the proposed approach reduces the location update costs by reducing the update rate of the home location register. The reduction of the location update cost becomes larger when the degree of hierarchy is larger, the size of location area is smaller, and the average residual time of mobile users is smaller.

The second part of this thesis extends the above hierarchical scheme by introducing overlapping in cellular mobile networks. That is, it proposes an effective location management scheme not only to further reduce the location update cost in cellular mobile networks but also to distribute the location update rate which occurs in the boundary areas. In additional, it develops improved analytical models to evaluate the performance of the proposed scheme, the hierarchical scheme proposed in the first part, and the typical scheme, under various situations. The results of the evaluation show that the proposed scheme reduces the location update cost significantly.

The third part of this thesis proposes route optimization scheme in Mobile IPv6 as well as the analytical models to compare the performance of the bidirectional tunneling and the route optimization method. The proposed model takes into account several important factors such as the packet type (long or short term), the number of hops between end-to-end hosts, the network bandwidth, and the failure rate of the binding update procedure. It also presents the threshold values which help the interested readers to decide whether the proposed scheme is acceptable or not. The proposed model provides the approximate guideline when a network administrator is to implement mobile IPv6 with route optimization under the given network environments. In near future this thesis aims to help implement the smart mobile node which decides whether route optimization is needed or not by itself.

The fourth part of this thesis proposes route optimization scheme with Mobile IPv6 security. Note that the above scheme in the third part doesn't guarantee the security of the binding updates to the home agent or to the corresponding nodes. It proposes the advanced analytical models, considering Mobile IPv6 security authorizing the binding update, to compare the performance of route optimization scheme, and then presents the quantitative evaluation results which come from the performance comparison. The results show the threshold values to decide whether the mobile node had better use the route optimization or not. The proposed model provides the approximate guideline when network administrator is to implement route optimization mobile IPv6 with security under the given environment conditions. Moreover, it would help implement the smart mobile node autonomously deciding whether the route optimization is employed or not, by adding more functions to the mobile node and considering more detailed conditions.

The last part of this thesis proposes a variation of the handover scheme used in hierarchical Mobile IPv6. It also develops the analytical models to compare the performance of the proposed scheme with the standard handover scheme used in the hierarchical Mobile IPv6. The evaluation result shows that the proposed scheme is very effective regardless of the frequency of the packet transmission if

the mobile node moves fast. In particular, the proposed scheme can be adapted to Telematics environments where a user drives and sometimes receives the Web services using a telematics terminal in the car. It also gives readers the threshold value with which they can select an optimal handover scheme in the given application.

Keywords: Cellular Networks, Home Location Register, Visitor Location Register, Super Location Area, Location Management, Location Update, Mobile IPv6, Binding Update, Route Optimization, Bidirectional Tunneling, Return Routability Procedure, Hierarchical Mobile IPv6, Mobility Anchor Point, Handover, Macro Mobility Management, Micro Mobility Management

I. Introduction

This chapter describes the motivation and objectives of this thesis, specifically in regard of the location management in cellular mobile networks and Mobile IPv6.

1. Motivation and Objectives

This thesis addresses the mobility issues such as a hanover, network architecture, in wireless mobile networks.

The use of Internet has added another dimension to wireline communication field, and both voice and data are being processed extensively. An increased acceptance of mobile communication networks for conventional services has led to demands for high bandwidth wireless multimedia services. These growing demands require a new generation of high-speed mobile infrastructure network that can provide the capacity for high traffic volumes as well as flexibility in communication bandwidth or services. There is a need for frequent Internet access and multimedia data transfer. Wireless telephones are not only convenient but also providing flexibility and versatility. Thus, there has been a growing number of wireless phone service providers as well as subscribers. It is expected that third-generation (3G) wireless systems will have many subsystems, with different requirements, characteristics, and coverage areas. There are two methods of thought on the 3G cellular systems (Agrawal and Zeng 2003). In United States, people are inclined to use CDMA2000 as the basic technology, while in Europe and Japan, W-CDMA is being considered as the future scheme. In principle, both these schemes are similar, but there are difference in their implementations. There are basically design issues. Many researchers has consecutively concerned about diverse design architecture in cellular networks. Section 2 will deal with the basic cellular architecture and important issues in cellular networks .

Mobile IPv6 is a network layer protocol for enabling mobility in IPv6 networks. IP mobility technology has gained a significant amount of traction over traction over the last few years, driven by a number of factors. Among them are emergence of 3G wireless networks that support packet data services, deployment of high-speed wireless networks such as UMTS and CDMA2000, devices that are multifunctional and capable of services such as voice or test message (SMS), the increasing dependence of society on information, and the need to access it from any place and any time. Also, Mobile IPv6 is a protocol solution for achieving seamless mobility across heterogeneous access network types. Mobile IPv6 enables mobility of the devices has not been a major driver in the past. However, with the inclusion of IP stacks in PDAs, mobile phones, and various forms of notebook and tablet PCs, mobility is becoming an increasingly critical need. Mobile IPv6 has a long history n the Internet Engineering Task Force (IETF). Work on the protocol was started in the mid 1990s. It was approved for publication as an RFC (Request For Comments) only in July 2003. A lot of work has gone into this specification over the years. Moreover, a number of papers on Mobile IPv6 mobility has been published every year and the various standardization works of Mobile IPv6 also has been continuously made. The further information such as a basic architecture and the mobility support of Mobile IPv6 is described in detail in Section 3. Mobile IPv6 has some important requirements to satisfy and was designed to meet these requirements. The requirement is essentially to reduce the losses of IP packets due to Mobile IP handover which describes the movement of a mobile computer between different points of attachment to a network. It was not clear how much reduction was needed (Soliman 2004). Two main proposals following Mobile IPv6 protocol are the hierarchical Mobile IPv6 mobility management (HMIPv6) (Soliman et al. 2005) and the fast handover for Mobile IPv6 (FMIPv6) (Koodli 2005). And both protocols are working the standardization. HMIPv6 will be again detailed in Section 4.

2. Cellular Mobile Networks

One of the main issues in cellular mobile networks is the ability to deal with moving stations. In general, cellular networks have to address a task often referred to as mobility management. A mobile station (MS) may be moving whether it is communicating (in connection) or not (in an idle state). Handover in cellular mobile networks is a process that the mobile station changes its current base station during a connection. It is probably the most obvious and explored mobility management procedure. While a mobile station (MS) moves without any constraint, the system must be able to find the location of the mobile station in order to setup the connection properly. The task is called location management (Tabbane 1997, Bar-Noy et al. 1995, Madhow et al. 1995).

The location management involves two major operations – *location update* and *paging*. Location update is the procedure whereby the MS informs the network about its current location. And paging is the procedure whereby the network searches for exact MS's access port. Both operations are resource-consuming, since both of them involve signaling. Future cellular mobile networks will have to support a high service, so a high amount of signalling can be expected. With the increasing interest being shown in cellular mobile networks, location management has become a research topic and several location management proposals in the past years (Ali 2002, Kyamakya et al. 2005, Assouma et al. 2005, Morris and Aghvami 2006). And the location management methods are considerable related with the design of cellular mobile networks, because the amount of signaling can be changable according to the architecture of cellular mobile networks. Thus, many of researches has been made to address various design problems of cellular mobile networks (Cox 1995, Kim and Smari 2003, Fan and Zhang 2004).

3. Mobile IPv6

The mobility support in Mobile IPv6 (Johnson et al. 2004), one of the Internet standards founded by the Internet Engineering Task Force (IETF), bas been studied by many researchers. It specifies a protocol which allows the Mobile Node (MN) to remain reachable while moving around in the IPv6 Internet. One of the most important challenges to providing mobility at the IP layer is to route packets efficiently and securely. Mobile IPv6 protocol (Johnson et al. 2004, Osborne et al. 2005, and Aust et al. 2005) specifies that packets destined to the MN can either be always routed via the Home Agent (HA) or be delivered directly from the communicating Correspondent Node (CN) though the shortest path. The former is called the bidirectional tunneling, where the packets have to take a long detour due to the HA as well as be tunneled between the HA and the MN, and also had been called the well-known triangle routing (Perkins and Johnson 2001) in Mobile IPv4. The latter is called the route optimization to solve this triangle routing problem which has additional delays resulting from routing though the HA even when the MN is away from its HA and near to its CN. Support for the route optimization in Mobile IPv6 is a fundamental part of the protocol unlike Mobile IPv4 and optional (Johnson et al. 2004).

Mobile IPv6, especially focused on the route optimization, has researched. Hwang et al. (2003) proposes a new hierarchical scheme that enables any CNs to send packets to an MN without helps of the intermediate mobility agent, such as Mobility Anchor Point in (Castelluccia 2000 and Soliman 2005), using a subnet residence time in the profile. This scheme results in reducing delay in packet delivery and optimizing packet delivery routing. In another scheme (Park et al. 2005), an MN adapts the route optimization if the packet delivery cost is more dominant than the binding update cost. This scheme minimizes either the packet delivery cost or the binding update cost depending on the session-to-mobility of each CN. (Vogt 2006) proposes three integrated solutions for improved handover experience in surrounding with different preconditions: reactive handovers with unmodified routers, reactive handovers with router support, as well as movement anticipation and proactive handover management such as the fast handover in (Koodli et al. 2005, and Jung and Jeon 2006). Also, Vogt and Arkko (2006) describe and evaluate strategies to enhance Mobile IPv6 route optimization based on existing proposals in order to motivate and guide further research. Consequently, the route optimization acts a very important part in Mobile IPv6, on the basis of such researches. However, how effective is the route optimization? And will the route optimization capability be always needed when network administrators are to implement Mobile IPv6 under some conditions? There is no concrete answer for such questions so far (Soliman 2004). Most of the given works, including above mentioned schemes, did not present the exact quantitative results considering various factors such as the number of hops between end-to-end node, the network bandwidth, the amount of delivering packets, and the failure rate of the binding update. Therefore, this thesis proposes the analytical models to evaluate performance of the bidirectional tunneling and the route optimization, either considering the Mobile IPv6 security or not. The model presents the quantitative results of performance comparison.

4. Hierarchical Mobile IPv6

As mentioned above, the mobility support in Mobile IPv6 (Johnson et al. 2004) is one of the most important research issues to provide many mobile users with the seamless services. In the Internet environments, when a Mobile Node (MN) moves and attaches itself to another network, it needs to obtain a new IP address. Mobile IPv6 describes how the MN can maintain connectivity to the Internet when it changes its Access Router (AR) into another. The process is called handover. During this process, there is a time period when the MN is unable to send or receive the IPv6 packets due to link switching delay and IP protocol operations. This time period is called handover latency. Reducing the handover latency has been a critical research issue to support the seamless service for mobile users.

There have been many standardization works such as the Hierarchical Mobile IPv6 Mobility Management (HMIPv6) (Soliman et al. 2005), the Fast Handover for Mobile IPv6 (FMIPv6) (Koodli 2005), and the simultaneous bindings for fast handover (Malki and Soliman 2005). The hierarchical handover (HMIPv6) reduces the amount of signaling among the MN, its HA, and its CN using the Mobility Anchor Point (MAP). The fast handover (FMIPv6) is a method that an MN performs Layer 3 handover before the Layer 2 handover when the MN changes its location from one link-layer connection to another. Consequently, this scheme reduces the L3 handover delay. The simultaneous bindings for fast handover is to minimize packet loss at the MN while the fast handover is to minimize the amount of service disruption when performs L3 handover. The combined handovers of the HMIPv6 and the FMIPv6 have been proposed to improve the performance (hsieh et al. 2003, Jung and Koh 2004, and Jung et al. 2005). A number of researchers make a great effort to avoid packet loss during the handover simultaneously as well as to reduce the handover latency. This thesis focuses on the handover in the hierarchical mobile networks. As the HMIPv6 places the specific AR (MAP), it needs the Regional Care of Address (RCoA) which should be registered in the MAP. On the other hand, this thesis proposes a variation of the HMIPv6 which does not have to create the RCoA. It also develops an analytical model to compare the performance of the proposed scheme with that in HMIPv6. The performance comparison shows that the proposed scheme is very effective regardless of the frequency of the packet transmission if the MN moves fast. In particular, the proposed scheme is appropriate for Telematics services where a user drives and sometimes receives the Web services using a telematics terminal in the car. The result also gives readers the threshold value with which they can select an optimal hand over scheme in the given application.

5. Organization of the Thesis

The remaining portion of this dissertation is organized as follows.

Chapter 2 introduces the background of the proposed scheme and the related works in cellular mobile networks, Mobile IPv6, and hierarchical Mobile IPv6.

Chapter 3 proposes the hierarchical scheme in cellular mobile networks as well as analytical models to compare performance of the proposed scheme, and then shows the results how many location update cost does the proposed scheme reduce.

Chapter 4 proposes an improved location strategy adding the overlapping to the hierarchical scheme in Chapter 2. Also, it develops the advanced analytical models to compare new scheme and the existing schemes. Therefore the results of performance comparison shows how effective is the proposed scheme.

Chapter 5 proposes the route optimization scheme deciding whether a mobile node had better use the route optimization or not when network administrator is to implement mobile IPv6 with route optimization. And it develops analytical models to help the network administrator make such a decision.

Chapter 6 proposes the route optimization scheme with security and analytical models considering the Mobile IPv6 security. Also, the results of performance evaluation tell us when the route optimization with security is needed.

Chapter 7 proposes a handover strategy for fast moving users in hierarchical Mobile IPv6 and analytical models to compare performance of the standard handover and the proposed handover. And then it shows the results of performance comparison.

Chapter 8, finally concludes this thesis and mentions the future works of the proposed schemes.

II. Background and Related Works

This chapter deals with the following: the location management in cellular mobile networks; the underlying operations in the Mobile IPv6; Mobile IPv6 security considerations; hierarchical Mobile IPv6 mobility management.

1. Cellular Mobile Networks

This section introduces the standard location management scheme and the previous proposed location management scheme employing the hierarchical structure in cellular mobile networks.

1) The Standard Location Management Scheme

Figure 1 shows the architecture of cellular mobile networks (Kruijt et al. 1998). Cellular mobile networks comprises two types of databases: the home location register (HLR) and the visitor location register (VLR). The switching and control entities are called mobile switching centers (MSCs), which are associated with a specific VLR. An MSC is in charge of several base station controllers (BSCs), a lower control entity which in turn controls several base stations (BSs). Also, the MSCs are connected to the backbone wired network such as public switching telephone network (PSTN). The network coverage area is divided into smaller cell clusters called location areas (LAs) (Kruijt et al. 1998). The VLR stores temporarily the service profile of the mobile station (MS) roaming in the corresponding LA. The VLR also plays an important role in handing call control information, authentication, and billing. The HLR stores permanently the user profile and points to the VLR associated with the LA where the user is currently located. Each user is assigned unambiguously to one HLR, although there could be several physical HLRs.

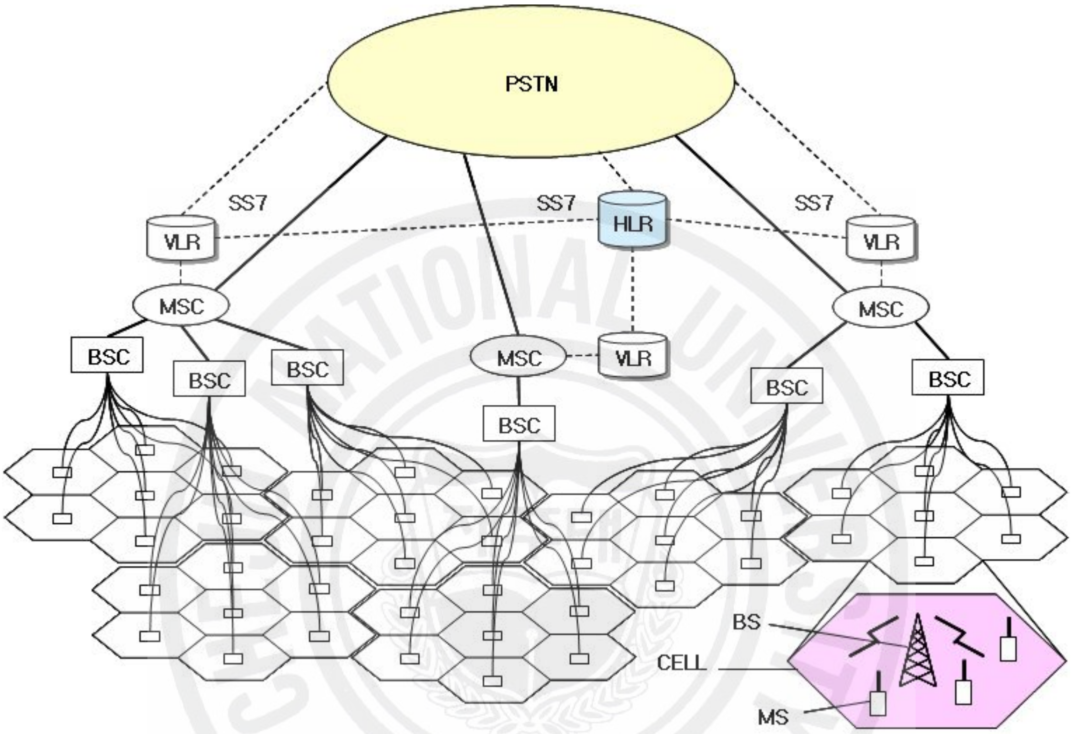

Figure 1 The architecture of cellular mobile networks

A base station periodically broadcasts its Location Area Identifier (LAI) which is unique for each LA. When a mobile station enters a new LA, the mobile station receives a different LAI. Then, the mobile station sends a registration message to a new VLR. The new VLR sends a registration message to the HLR. Then the HLR sends a registration cancellation message to old VLR and sends a registration confirmation message to the new VLR. Now the HLR points the new VLR that has service profile and location information of the mobile station. When a call to a mobile user is detected, the corresponding HLR is queried. Note that each mobile station is assigned unambiguously to one HLR, although there may be several physical HLRs in the network. Once the HLR corresponding to the mobile station has been queried, the VLR/MSC currently serving the mobile station is known. Then paging is simultaneously done through the LA where the MS is currently located. The larger the size of the LA be, the more the location update signaling become and the smaller the paging signaling do. Therefore the relationship of the paging and location update cost is actually trade-off. There have been made a lot of researches to reduce the location update cost, especially the HLR update cost. To reduce total location update cost, there are the given methods such as and grouping scheme (Weng and Huang 2000), overlapping schemes (Chu and Rappaport 1997 and Gu and Rappaport 1999), virtual layer schemes (Chung et al. 2001a and 2001b). First, this thesis proposes the new scheme employing the hierarchical structure for the system to reduce the location update cost of the HLR (Shin and Park 2003). However, even such a scheme, frequent updates are required for the boundary LAs between different Super Location Areas (SLAs). Thus, this thesis also proposes an advanced scheme in order to further reduce the location update cost as well as not to increase the paging cost.

2) The Hierarchical Location Management scheme

The hierarchical location management scheme (Shin 2002) employed a super location area (SLA) which is a group of LAs and the hierarchical Location Area Identifier (LAI). That is, this scheme applied LA-level hierarchy to cellular mobile networks and segmented the standard structure of the LAI. The size of an SLA may be various. Figure 2 shows not only the typical structure of LAI but also the new hierarchical structure of LAI. The conventional LAI was divided into three parts: the mobile country code (MCC), the mobile network code (MNC), and the location area code (LAC). The SLA scheme uses a hierarchical structure by dividing the LAC into two parts again: the super location area code (SLAC) and the location area identification code (LAIC). Adaption of such a hierarchical LAI in hierarchical cellular mobile network makes the hierarchical location management conveniently and effectively.

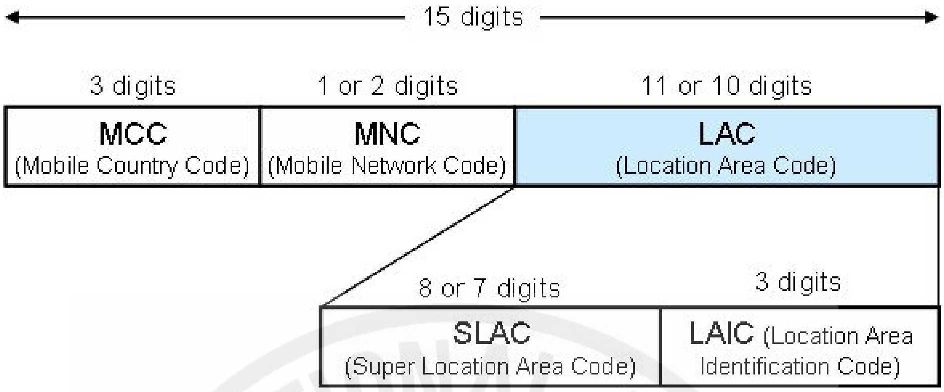

Figure 2. The hierarchical structure of the LAI

Figure 3 shows an example of the cellular architecture in which each LA contains 7 cells and an SLA, 19 LAs, employing the hierarchical structure.

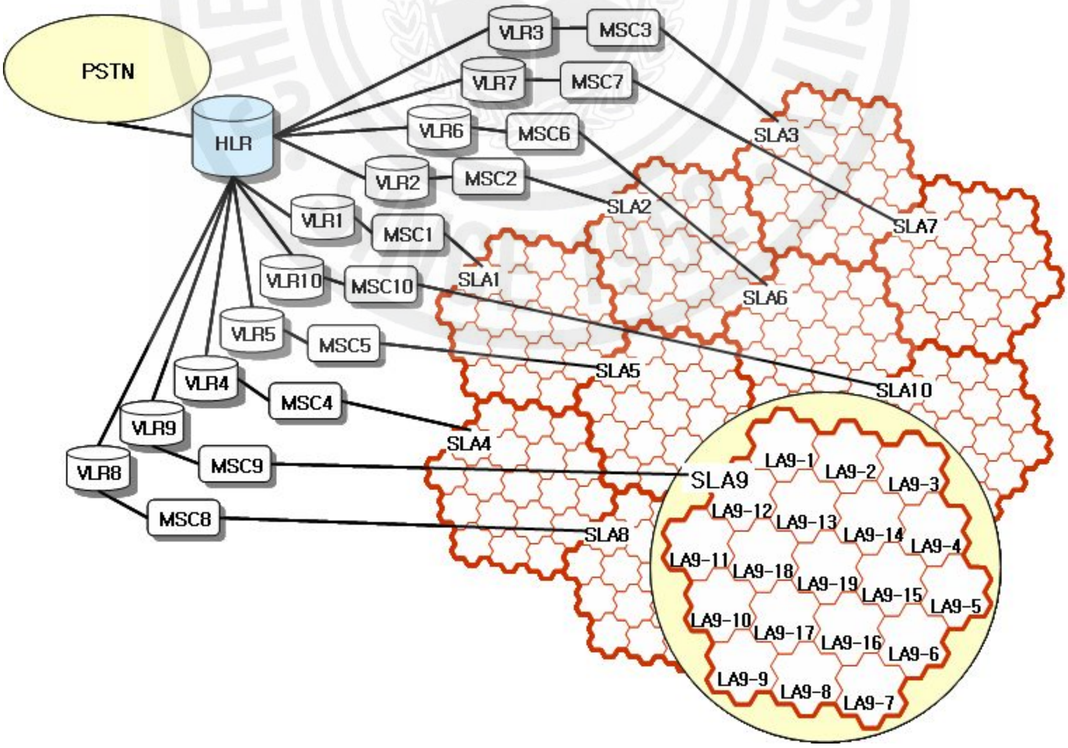

Figure 3. The cellular architecture employing the hierarchical structure

The notation LAi-j represents the cells belong to an LA j in an SLA i. Each MSC/VLR covers a specific SLA. As in the conventional system, the mobile station receives a different LAI when the station enters a new LA. The VLR is updated while a mobile station roams within an SLA, because two SLACs of the previous LAI and the current broadcasting LAI are equal but the LAIC of them is different. Both of the VLR and the HLR updates happen only when the mobile station enters a new SLA, since two SLACs of the previous LAI and the current broadcasting LAI are different without two LAICs of them. Interested readers may refer to (Shin 2002) for more details of the hierarchical location management scheme.

2. Mobile IPv6

This section describes overview of Mobile IPv6 and basic operations, especially the bidirectional tunneling and the route optimization, and the security considerations in Mobile IPv6.

1) The Standard Mobile IPv6

Figure 4 depicts the normal architecture and basic operations of Mobile IPv6. An MN is always expected to be addressable at its permanent home address, whether it is currently attached to its home link or is away from home. The home address is an IP address assigned to the MN within its home link while care-of address (CoA) is one to it within some foreign link. The MN can acquire both these addresses through conventional IPv6 mechanisms, such as stateless (Thomson and Narton 1998) or stateful (e.g., DHCPv6 (Droms et al.

2003)) auto-configuration. Typically, the home address and CoA of the MN are made by adding MN's link-layer address to its home subnet prefix and its foreign subnet prefix periodically broadcasted by the Router Advertisement Message (Narten et al. 1998) on the corresponding link, respectively. While an MN is at home, the packets addressed to its home address are routed to the MN's home link, using conventional Internet routing mechanisms.

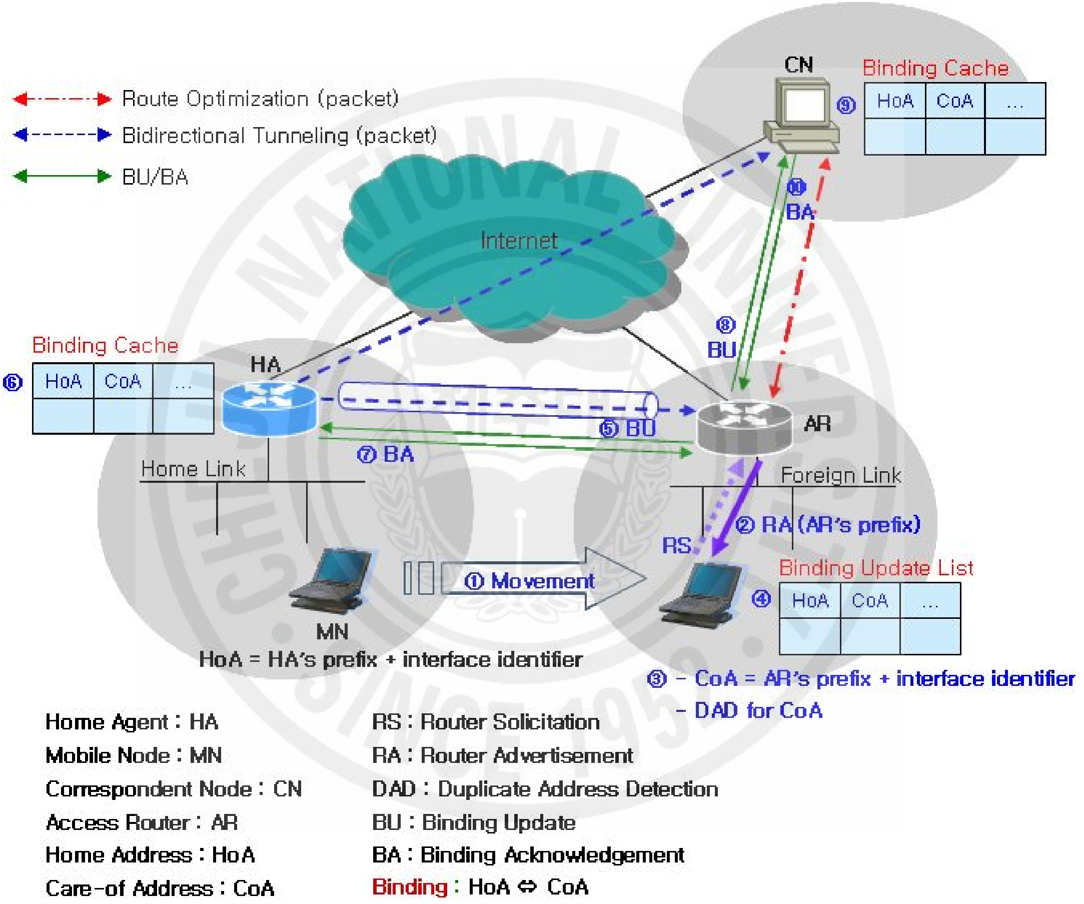

Figure 4. The architecture of Mobile IPv6

While an MN is at home, packets destined to its home address are routed to its home link, using conventional Internet routing mechanisms. On the other hand, while the MN is attached to a particular foreign link, packets addressed to its primary CoA (Johnson et al. 2004) will be routed to the MN either through it

HA (bidirectional tunneling) or not (route optimization). The association between an MN's home address and CoA is well-known as a binding for the MN. While away from home, an MN registers its primary CoA with its HA on its home link. The MN performs this binding registration by sending a Binding Update (BU) message (Johnson et al. 2004) to its HA, and then the HA replies to the MN by returning a Binding Acknowledgement (BA) message (Johnson et al. 2004). This process is called as the home registration. In the same manner, the MN also can provide information about its current location to the CN communicating with itself (the correspondent registration). The MN should register its current binding at both of its HA and the CN, whenever moving across a different foreign subnet.

2) The Bidirectional Tunneling and the Route Optimization

There are two possible modes for communications between the MN and the CN. The first mode, the bidirectional tunneling does not require the MN to register its current binding at the CN. Every packet destined to an MN will be intercepted by the HA first and be tunneled by it. This tunneling is performed using IPv6 encapsulation (Perkins 1996). And then the tunneled packets will be forwarded to the MN. The packet transmission from the MN to the CN is made by the reverse order using reverse tunneling (Johnson et al. 2004).

The second mode, the route optimization requires the correspondent registration. As a part of this registration procedure, a return routability test must be performed to authorize the establishment of the binding. The packets from the CN can be routed directly to MN without routing though the HA, using the shortest possible path. It eliminates not only additional delays for routing packets via the HA but also the congestion at the MN's HA and the home link. However, a new IPv6 Home Address Option (Johnson et al. 2004) should be added to the packet routed from the MN to the CN, while a new type of IPv6 Routing Header, Type 2 Routing Header (Johnson et al. 2004), should be used for the packet routed from the CN to the MN reversely, to carry its home address. Depending on the type of communication (long or short term), the MN may decide whether it should attempt to optimize the route between itself and the CN. An MN's implementation may decide to always use the route optimization or never use it. However, it is not yet clear which way is more appropriate under any conditions (Soliman 2004).

3) Mobile IPv6 Security Considerations

Mobile IPv6 security (Johnson et al. 2004) includes the protection of BUs both to the HA and the CN. The BU is protected by the use of IPsec Extension Headers, or by the use of the Binding Authorization Data option (Johnson et al. 2004). This thesis should employ Encapsulating Security Payload (ESP) Header (Kent and Atkinson 1998a) and the Authentication Header (Kent and Atkinson 1998b) for BU to the HA as well as run the Return Routability (RR) procedure (Johnson et al. 2004) for BU to the CN. The Binding Authorization Data option employs a binding management key (Johnson et al. 2004), Kbm, which can be established through the RR procedure as shown Figure 5.

The RR procedure enables the CN to assure that the MN is in fact addressable at its claimed CoA as well as at its home address. Only with this assurance is the CN able to accept the BU from the MN which would then instruct the CN to direct that MN's data packets to its claimed CoA. This is done by testing whether packets destined to two claimed addresses are routed to the MN. The RR procedure consists of the four messages, Home Test Init Message (HOTI), Care-of Test Init (COTI), Home Test (HOT), and Care-of Test (COT) Message as shown Figure 5. The RR address test procedure uses cookies and keygen tokens within these messages to generate Kbm. The HOTI and COTI messages are sent at the same time. After the MN has created Kbm, it can supply a verifiable binding update to the CN. As shown Figure 5, the transmission of the BU/BA messages is performed just after the RR procedure. The BU/BA messages include the Message Authentication Code (MAC) (Johnson et al. 2004) in the Binding Authorization Data option. The MAC is computed on message m with the created key Kbm and is the necessary encryption method for authorizing the binding update process.

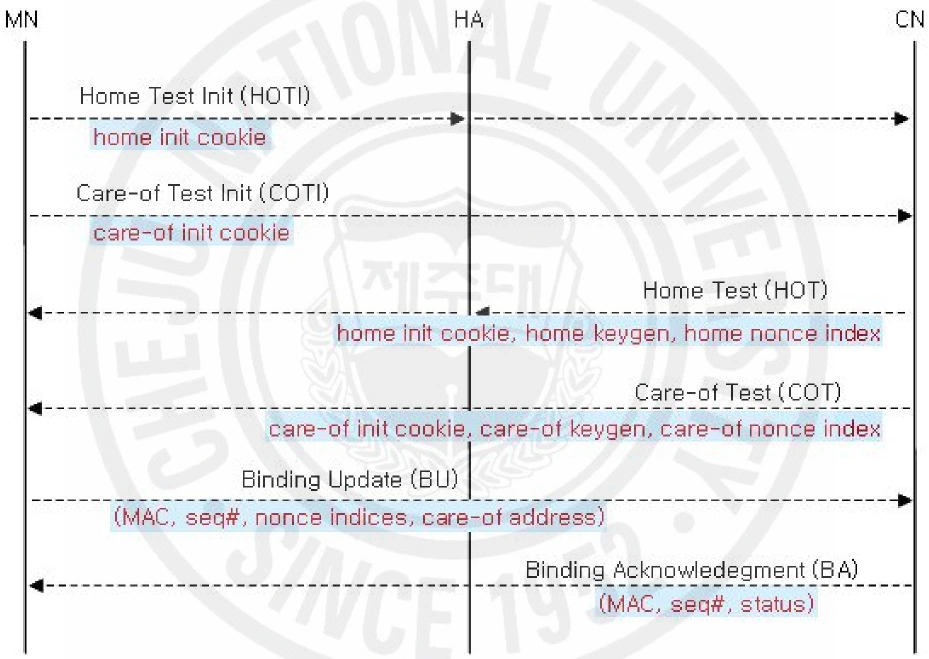

Figure 5. The message flow for the return routability procedure and BU/BA

3. Hierarchical Mobile IPv6 (HMIPv6)

A number of schemes have been proposed to reduce the handover latency in Mobile IPv6. Since this thesis focuses on HMIPv6, this section addresses the handover process in the HMIPv6 in detail. HMIPv6 divides mobility management into micro mobility management (intra-domain mobility) and macro mobility management (inter-domain mobility)(Soliman et al. 2005). HMIPv6 also introduces a new special entity called the MAP and minor extensions to the MN operation. It is normally placed at the edges of a network and is an aggregating router or a set of ARs, which constitute a larger network domain. The MAP, acting as a local HA, maintains bindings between itself and MNs currently visiting its network domain.

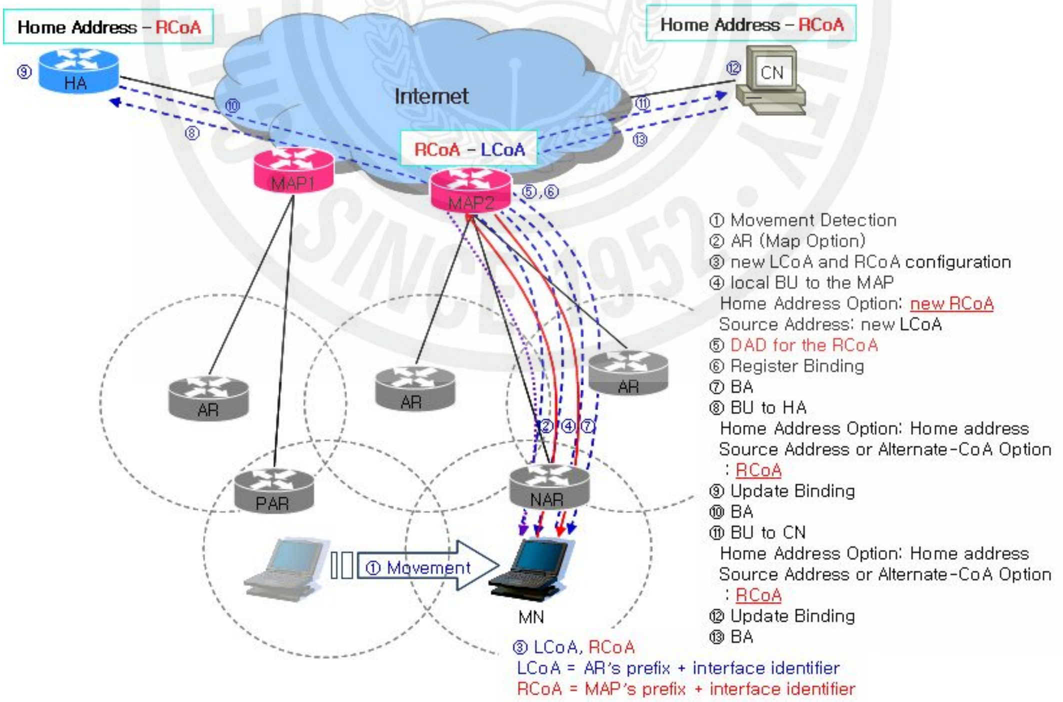

Figure 6. The standard handover process in macro mobility in the HMIPv6

Figure 6 illustrates the standard handover process supporting macro mobility in the HMIPv6. When an MN moves into a new MAP domain (i.e. its MAP changes), it needs to configure two CoAs: a Regional Care-of Address (RCoA) on the MAP’s link and an on-Link Care-of Address (LCoA) on the default AR′s link. These addresses are usually obtained using a stateless address autoconfiguration mechanism (Thomson and Narton 1998). The AR informs the visiting MNs of its presence by sending the Router Advertisement (RA) message including its prefix information (Narton et al. 1998). The MN configures the IPv6 addresses, as its LCoA and its RCoA, by appending its interface identifier (IEEE 1997, Crawford 1998) to the prefix sent by the RA message (Thomson and Narton 1998, Hidon and Deering 1998). Therefore, as soon as receiving the RA message, containing MAP Option (Soliman et al. 2005), broadcasted by the corresponding AR, the MN autoconfigures its LCoA and its RCoA by adding MN′s interface identifier to the new AR′s prefix and the new MAP′s prefix.

The Duplicate Address Detection (DAD) (Thomson and Narton 1998) is performed on these addresses prior to assigning them to an interface. The DAD process checks if the link-local address generated from the identifier is unique on the link. Thus after forming the LCoA, the MN performs the DAD of the LCoA on its link to verify the uniqueness of the LCoA. And then the MN sends a local Binding Update (BU) message to the MAP. The local BU message includes the MN’s RCoA (similar to a Home Address) in the Home Address Option (Johnson et al. 2004). The LCoA is used as the source address of the BU message. This BU process will bind the MN’s RCoA to its LCoA. The MAP will then perform DAD (when a new binding is being created) for the MN’s RCoA on its link and return a Binding Acknowledgement (BA) to the MN. This acknowledgement identifies the binding as successful or contains the appropriate error code. When the BA is received from the MN, the MAP must confirm the binding cache entry and continue forwarding packets for the lifetime of the binding. That is, the MAP intercepts all the packets addressed to the MN, and it serves and tunnels them to the MN's LCoA. After registering with the MAP, the MN must register its new RCoA with its HA by sending a BU message that specifies the binding between the RCoA and the Home Address. The Home Address Option is set to the Home Address while the RCoA can be found in the source address field or the Alternate Care-of Address Option (Johnson et al. 2004). The MN may also send a similar BU message that specifies the binding between the Home Address and the RCoA to its current CN.

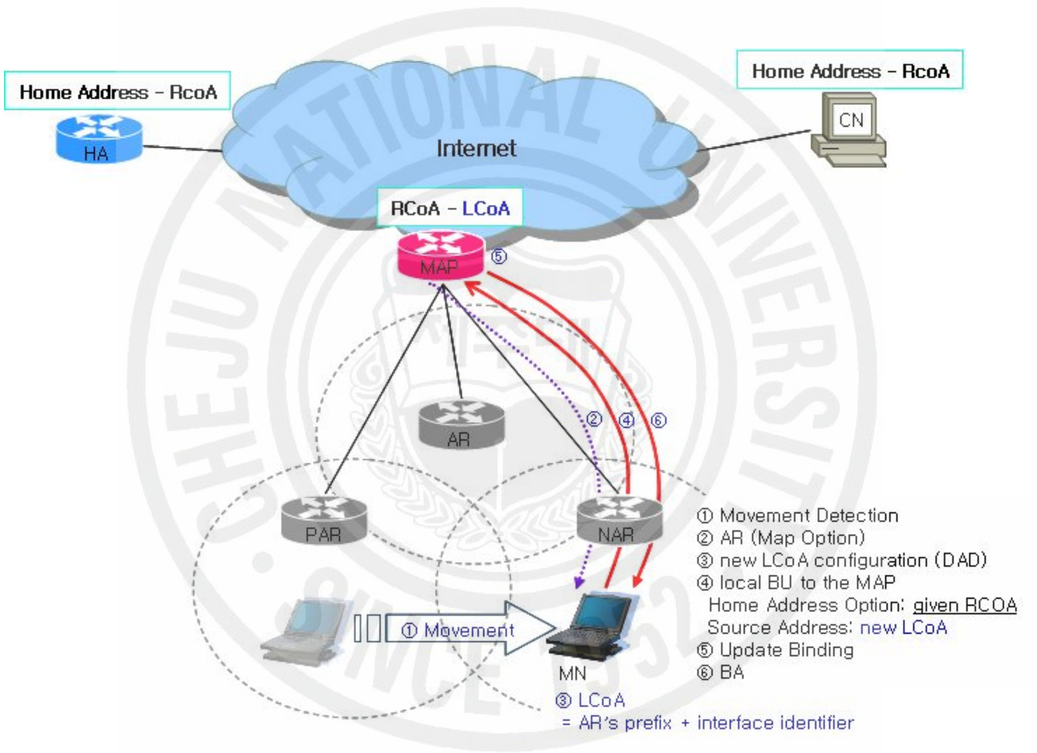

Figure 7. The standard handover process in micro mobility in the HMIPv6

Figure 7 shows the handover when the MN roams intra-domain. If the MN moves within the same MAP domain, new LCoA binding with the MAP should be only required. In this case, it is not required to configure the new RCoA because the MAP stays unchanged.

III. Hierarchical Scheme in Cellular Mobile Networks

This chapter introduces the hierarchical scheme, presents the analytical models, and shows the results of performance evaluation in cellular mobile networks.

1. The Proposed Scheme (Shin and Park 2003)

Shin (2002) does not inform readers how many does the size of an SLA affect the performance. The effect of the size of an SLA is evaluated in this Section. This thesis would call this scheme the SLA scheme, for convenience sake and for clear distinction from the previous scheme in (Shin 2002).

This section omits the basic architecture of cellular mobile networks, because the cellular architecture is the same as that in the Figure 3. Figure 8 shows an example of an MS roaming from A to V point in cellular mobile networks employing hierarchical structure. In the service area, the thickest line represents a boundary of an SLA while the second thickest line represents that of an LA. The thin line represents the boundary of the cell. Figure 8 shows seven SLAs each of which, in turn, contains 19 LAs. Each LA contains 7 cells. The configuration could be various and the evaluation on the configuration is done in Section 2. The MSC/VLR covers each SLA. The notation LAi-j represents the cell belonging to LA j in SLA i. As in the conventional system, the mobile station receives a different LAI when the station enters a new LA. Then the station sends registration message to the corresponding MSC. The MSC reads the SLAC in the LAI and determines whether the new LA belongs to the same SLA or not. If the new LA belongs to the same SLA, only the VLR is updated to record the new LA where the mobile station is located. The proposed scheme requires the HLR updates only when the mobile station enters a new SLA.

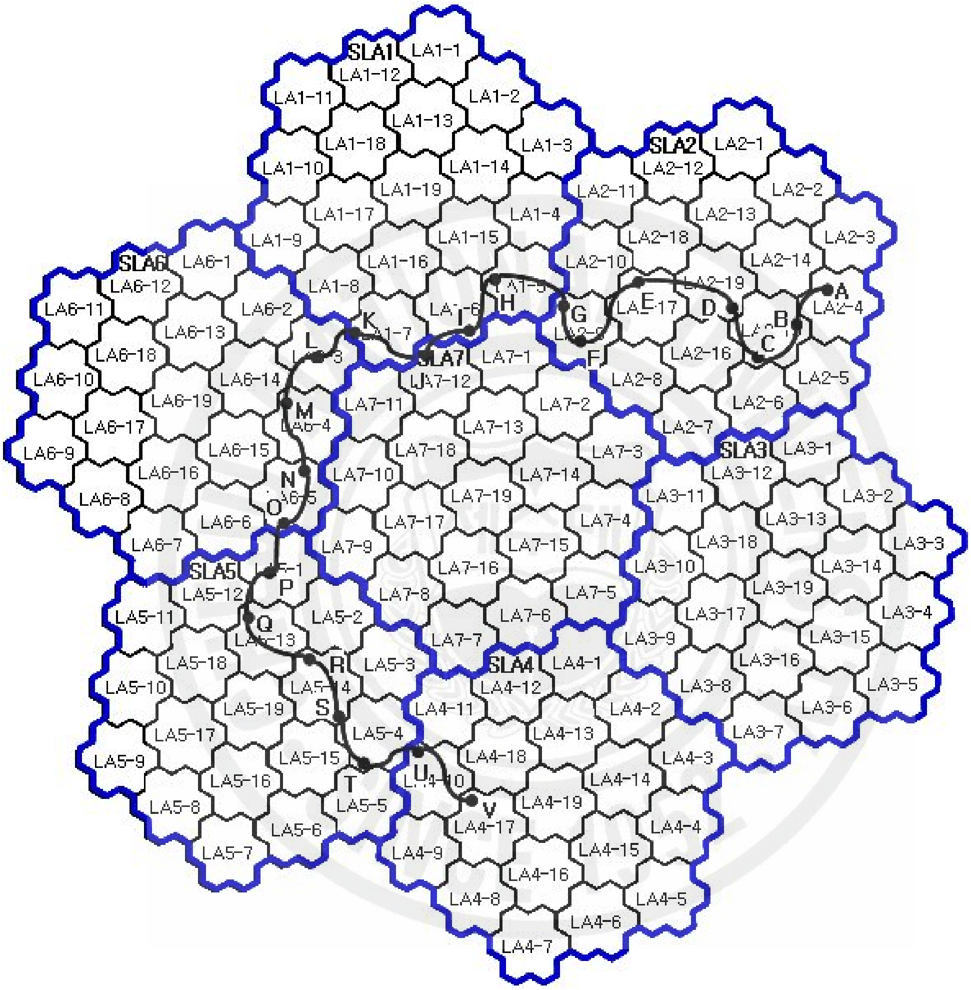

Figure 8. Moving Path of a mobile station in the SLA scheme

The station starts from location A belonging to LA2-4 which means the fourth LA in SLA 2. It moves to location D through B and C. The location of D is LA2-19 which is the 19th LA in SLA 2. Thus, the VLR is updated while the HLR is not. Since the conventional scheme does not employ any hierarchy, it should update not only the VLR but also the HLR. The whole update process is depicted in Table 1. The comparison depicted in Table 1 shows the reduction of the location update cost using the proposed architecture in this thesis.

Table 1. Comparison of the location update in terms of two schemes

	Path	Registered LA	Register Update	
			Typical	SLA
1	A→B	LA2-15	VLR, HLR	VLR
2	B→C	LA2-15	none	none
3	C→D	LA2-19	VLR, HLR	VLR
4	D→E	LA2-17	VLR, HLR	VLR
5	E→F	LA2-9	VLR, HLR	VLR
6	F→G	LA2-9	none	none
7	G→H	LA1-5	VLR, HLR	VLR, HLR
8	H→I	LA1-6	VLR, HLR	VLR
9	I→J	LA7-12	VLR, HLR	VLR, HLR
10	J→K	LA1-7	VLR, HLR	VLR, HLR
11	K→L	LA6-3	VLR, HLR	VLR, HLR
12	L→M	LA6-4	VLR, HLR	VLR
13	M→N	LA6-5	VLR, HLR	VLR
14	N→O	LA6-5	none	none
15	O→P	LA5-1	VLR, HLR	VLR, HLR
16	P→Q	LA5-13	VLR, HLR	VLR
17	Q→R	LA5-14	VLR, HLR	VLR
18	R→S	LA5-14	none	None
19	S→T	LA5-4	VLR, HLR	VLR
20	T→U	LA4-10	VLR, HLR	VLR, HLR
21	U→V	LA4-17	VLR, HLR	VLR
Total			17VLR, 17HLR	17VLR, 6HLR

2. The Proposed Analytical Model

This thesis has developed analytical models to compare the update cost of the proposed scheme with that of the conventional scheme used in PCS networks. The followings are assumed in the model.

1. The service area is divided into hexagonal cells of equal size.
2. A mobile user moves to one of neighboring cells with probability 1/6.
3. The movements of mobile users are probabilistic and independent of one another.
4. The dwell time in any cell for a mobile user is an exponentially distributed random variable with the average value, $\overline{T_d}$.

The size of an LA is represented by the number of rings of cells, d, forming the LA. The rings of this LA are numbered 1, 2, ⋯, *d* from innermost (the center cell) to outermost. This thesis uses the dwell time in (Madhow 1995, Yeung 1995) in the proposed model. Table 2 shows the notations used in the proposed analytical model.

Table 2. The notations used in the proposed analytical model of SLA scheme

Notation	Description
$\overline{K}$	The average number of mobile users in a cell
d	The size of an LA
s	The size of an SLA
$\overline{T_d}$	The average dwell time
N	The total number of mobile users in an LA
N_c	The total number of cells in an LA : $3d^2-3d+1$
N_{bc}	The number of boundary cells in an LA : $6(d-1)$
N_{Sla}	The total number of LAs in an SLA : $3s^2-3s+1$
N_{Sc}	The total number of cells in an SLA : $(3s^2-3s+1)(3d^2-3d+1)$
N_{Sbc}	The number of boundary cells in an SLA : $6\{3d-2+(s-2)(2d-1)\}$
N_S	The total number of mobile users in an SLA
$\overline{R_{LA}}$	The total location update rate for the given LA
$\overline{R_{SLA}}$	The total location update rate for the given SLA
$\overline{R_{MS}^{LA}}$	The average location update rate per a mobile user in the typical scheme
$\overline{R_{MS}^{SLA}}$	The average location update rate per a mobile user in the SLA scheme

Figure 9 shows the details to develop the models. The size of an SLA is represented by the number of rings of LAs, s, as shown in Figure 9-(b). The size of an LA is represented by the number of rings of cells, d, as shown in Figure 9-(a). Figure 9-(1), 9-(2), and 9-(3) show the cells from which a mobile user moves to boundary neighboring cells, causing the HLR update, with the probability of 3/6, 2/6, and 1/6, respectively, because a mobile user moves to a neighboring cell with probability 1/6.

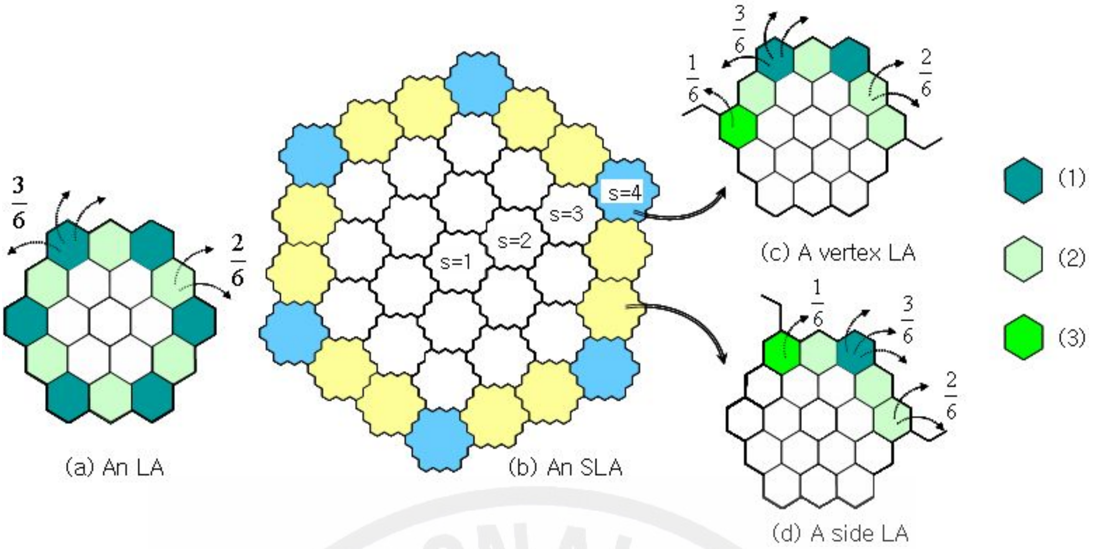

Figure 9. The structures of an LA and an SLA

The total number of mobile users in an LA is like Equation (1) obtained by multiply the total number of mobile users in an LA by the average number of mobile users in a cell.

$$N = N_c \times \overline{K} = (3d^2 - 3d + 1) \times \overline{K} \qquad (1)$$

Since only the users in the boundary cells of an LA contribute to the traffic for location update, the average location update rate is the average rate of departures of the users from the boundary cells in an LA. Thus, Equation (2) shows the average location update rate for an LA.

$$\overline{R_{LA}} = 6\left\{\frac{2}{6} \times (d-2) + \frac{3}{6} \times 1\right\} \times \overline{K} \times \frac{1}{\overline{T_d}} = (2d-1) \times \overline{K} \times \frac{1}{\overline{T_d}} \qquad (2)$$

The average location update rate per a mobile user in the conventional scheme is then obtained by Equation (3) by dividing the total location update rate for the given LA by the total number of mobile users in an LA.

$$\overline{R_{MS}^{LA}} = \frac{\overline{R_{LA}}}{N} = \frac{2d-1}{3d^2-3d+1} \times \frac{1}{\overline{T_d}} \tag{3}$$

Equation (4) show the total number of mobile users in an SLA and is computed by multiplying the number of cells in an SLA by the average number of mobile users in a cell.

$$N_S = N_{Sc} \times \overline{K} = (3s^2-3s+1)(3d^2-3d+1) \times \overline{K} \tag{4}$$

The number of boundary cells in an SLA can be segmented like Equation (5), according to a type of the LA as shown in Figure 9-(c) and 9-(d).

$$\begin{aligned} N_{Sbc} &= 6\left[(s-2)\times\left\{\frac{2}{6}\times N_{bc}+1\right\}+\frac{3}{6}\times N_{bc}+1\right] \\ &= 6\left[(s-2)\times\left\{\frac{2}{6}\times 6(d-1)+1\right\}+\frac{3}{6}\times 6(d-1)+1\right] \\ &= 6\{(s-2)(2(d-1)+1)+3(d-1)+1\} \\ &= 6\{(2s-1)(d-1)+(s-1)\} \end{aligned} \tag{5}$$

The average location update rate is the average rate of departures of the users from the boundary cells in an SLA, because the traffic for location update occurs only in the boundary cells of an SLA. Thus, Equation (6) shows the average location update rate per a mobile user for an SLA considering the probability as shown in Figure 9-(1), 9-(2), and 9-(3).

$$\begin{aligned}\overline{R_{SLA}} &= 6\left[\frac{2}{6}\{(2s-1)(d-2)+(s-1)\}+\frac{3}{6}\times s+\frac{1}{6}\times(s-1)\right]\overline{K}\cdot\frac{1}{\overline{T_d}} \\ &= \{(2s-1)(2d-1)\}\cdot\overline{K}\cdot\frac{1}{\overline{T_d}}\end{aligned} \tag{6}$$

As a result, the average location update rate per user in the SLA scheme is obtained by Equation (7) by dividing the total location update rate for the given SLA by the total number of mobile users in an SLA.

$$\overline{R_{MS}^{SLA}} = \frac{\overline{R_{SLA}}}{N_S} = \frac{(2s-1)(2d-1)}{(3s^2-3s+1)(3d^2-3d+1)}\cdot\frac{1}{\overline{T_d}} \tag{7}$$

3. The Results of Performance Evaluation

Figure 10 shows the HLR update rate according to the size of the SLA. In the figure, s represents the number of LAs belonging to the radius of the SLA. Thus, SLA with s value of 1 represents the SLA consisting of 1 LA, that with s value of 2, 7 LAs, that with s value of 3, 19 LAs, and so on. The figure shows that the HLR update rate decreases as the size of the SLA increases. Note that Td in the figure represents the average dwell time of mobile users.

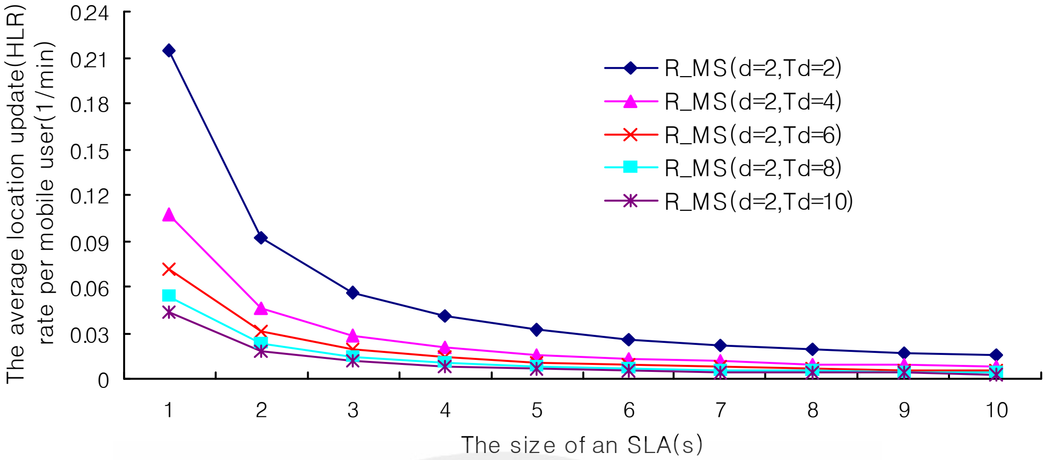

Figure 10. Update rate of HLR according to the SLA size

Figure 11 shows HLR update rate according to the size of the LA. In the figure, *d* represents the number of cells belonging to the radius of the LA. The relationship between the LA and the cell is similar to that between the SLA and the LA. The figure shows that reduction of the HLR update rate becomes larger when the size of LA is smaller. Also, the HLR update rate becomes smaller when the size of the SLA is larger.

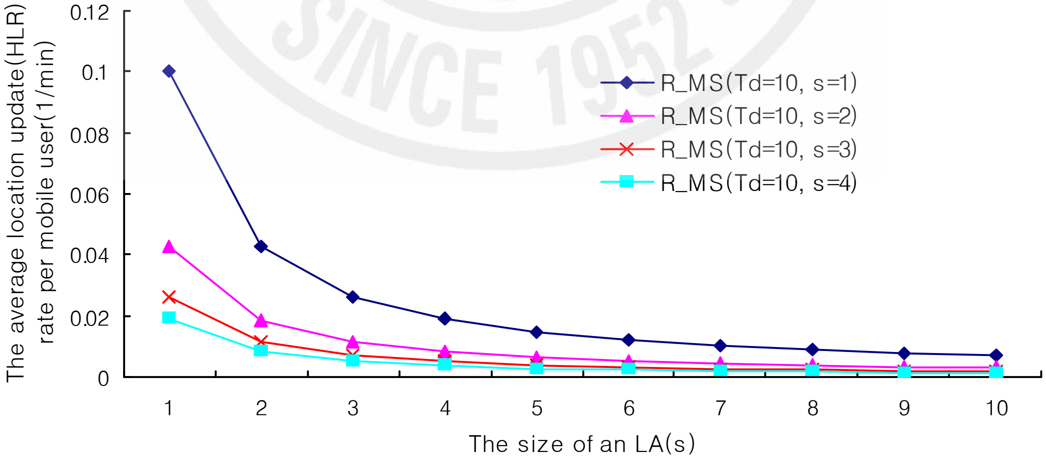

Figure 11. Update rate of HLR according to the LA size

Figure 12 shows the location update rates according to the average residual time of mobile users. The figure also shows that the proposed scheme outperforms the conventional scheme. Also, the difference becomes larger as the residual time becomes smaller.

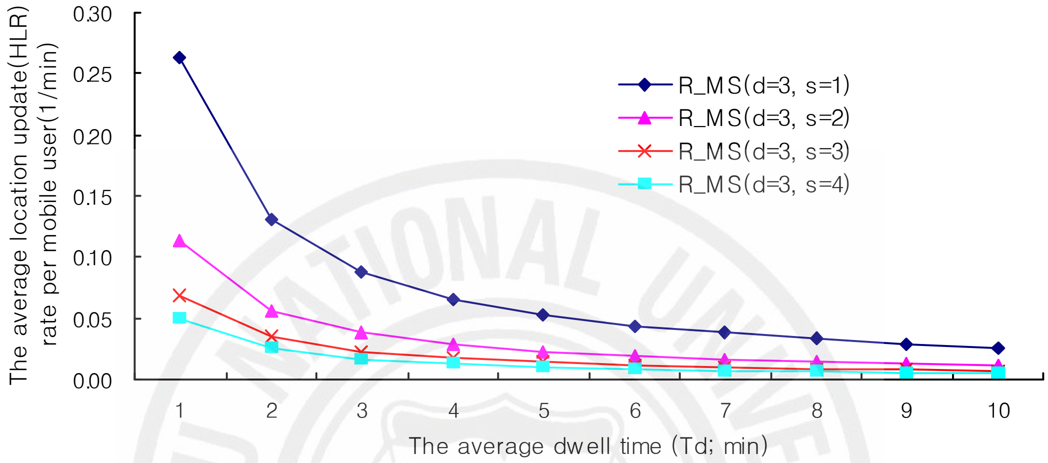

Figure 12. Update rate of HLR according to the dwell time

IV. Overlapping Scheme in Cellular Mobile Networks

This chapter introduces the overlapping scheme and shows the evaluation results resulting from the proposed analytical models in cellular mobile networks.

1. The Proposed Scheme (Shin et al. 2005)

The proposed approach employs overlapping location areas which are the common boundary LAs between different SLAs. That is, the proposed approach extends to the existing SLA scheme (Shin and Park 2003) in the previous section by employing LA-level overlapping. Thus this thesis would refer to this scheme as the OSLA (Overlapping Super Location Area) scheme. The modified cellular architecture for the proposed approach is depicted in Figure 13.

The overlapping LAs are colored areas in the figure. The overlapping borders consist of twofold or threefold overlapped LAs. The overlapping LAs belong to all SLAs associated with them. The two-fold overlapping LA is included in the two SLAs and two different LAIs are broadcasted in the LA. The three-fold overlapping LA is included in three different SLAs and three LAIs are broadcasted in the LA. Note that the overlapping LAs are duplicately managed by corresponding all MSCs/VLRs. As an example, the SLA9 out of SLAs shows an SLA with overlapping LAs in detail. When a mobile station enters to the overlapping LA, it must register only to one LA out of the overlapping LAs. This approach requires both of the VLR and the HLR updates only when an MS enters the LA that belongs to the new SLA while does not belong to the old SLA. The VLR update occurs when it roams a different LA within an SLA.

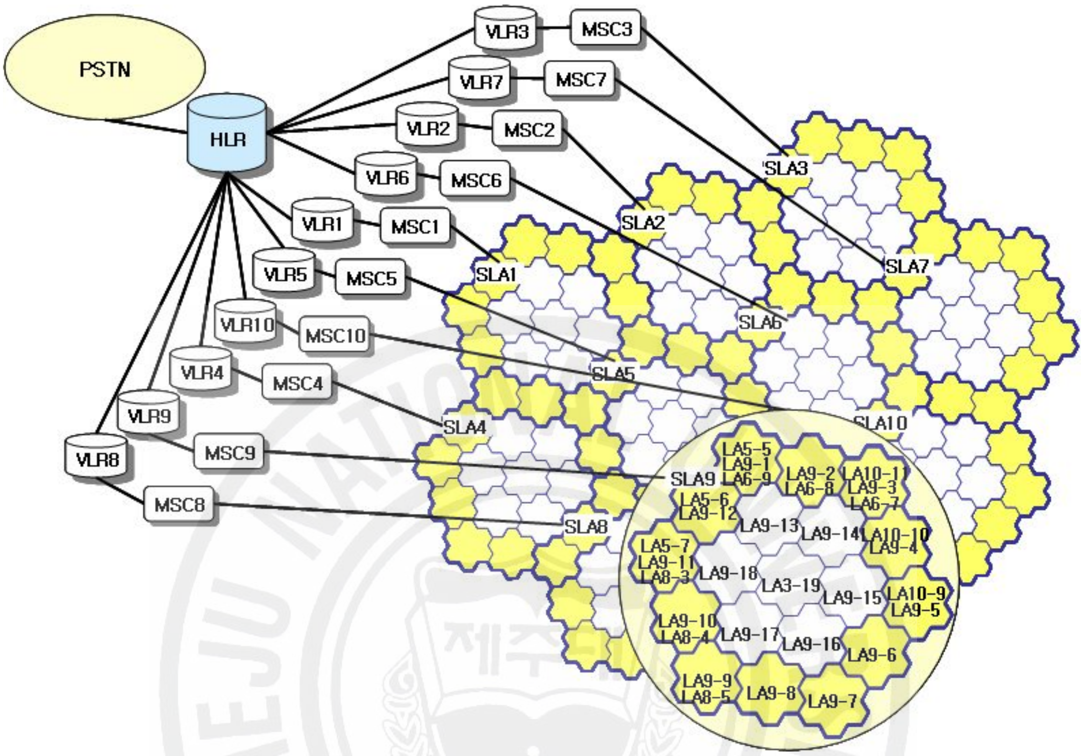

Figure 13. The cellular architecture employing the overlapping

Figure 14 shows an example of a mobile user path from location A to location U in the cellular architecture employing the SLA (Shin and Park 2003). It is out of question that the LAI employed in SLA, divided into four parts, could be used like the traditional LAI, divided into three parts. Thus, the location update procedure of the conventional scheme could be described in the figure. In the conventional system, both of the VLR and the HLR are updated whenever a mobile station enters a new LA. So the location updates tend to occur frequently in the boundary cells of LAs. In the SLA scheme, both of the VLR and the HLR updates occur when a mobile station moves to a different SLA like the path from location D to H in Figure 14. That is, the HLR updates also happen frequently in the boundary LAs of the SLAs.

Figure 14. Moving path of a mobile station in the SLA architecture

Figure 15 shows an example of a mobile user path in the cellular architecture employing the proposed approach. And Table 1 shows the whole update process while a mobile user roams from location A to U in terms of the typical scheme (Typical), the SLA scheme (SLA), and the proposed scheme (OSLA). The user path in Figure 15 is an identical line of that in Figure 14. Also, the two service areas are the same. In overlapping areas, if one out of the currently broadcasted LAI belongs to the same SLA as that of the previously registered LA, a mobile user registers to it. For example, if a mobile user arrives at location D and H, the user registers to LA4-3 out of two LAs and LA1-5 out of three LAs, respectively. In the proposed approach, both of the VLR and the HLR are updated only when a mobile user moves to the LA that belongs to the new SLA and does not belong to the old SLA at the same time. Particularly, in case of a path from location H to I, the mobile user has to register to either LA5-2 or LA2-8 as shown in the 8th row in Table 3. The decision of such registration is made by a random selection. According to the decision, the location update cost is different as shown in the 9th row in Table 3. Also, when the mobile user moves from location P to T, the HLR update is required only when the mobile user crosses the overlapping LAs like the path of P-Q-R or that of R-S-T. Thus, the HLR updates concentrated in boundary LAs are rather reduced and distributed.

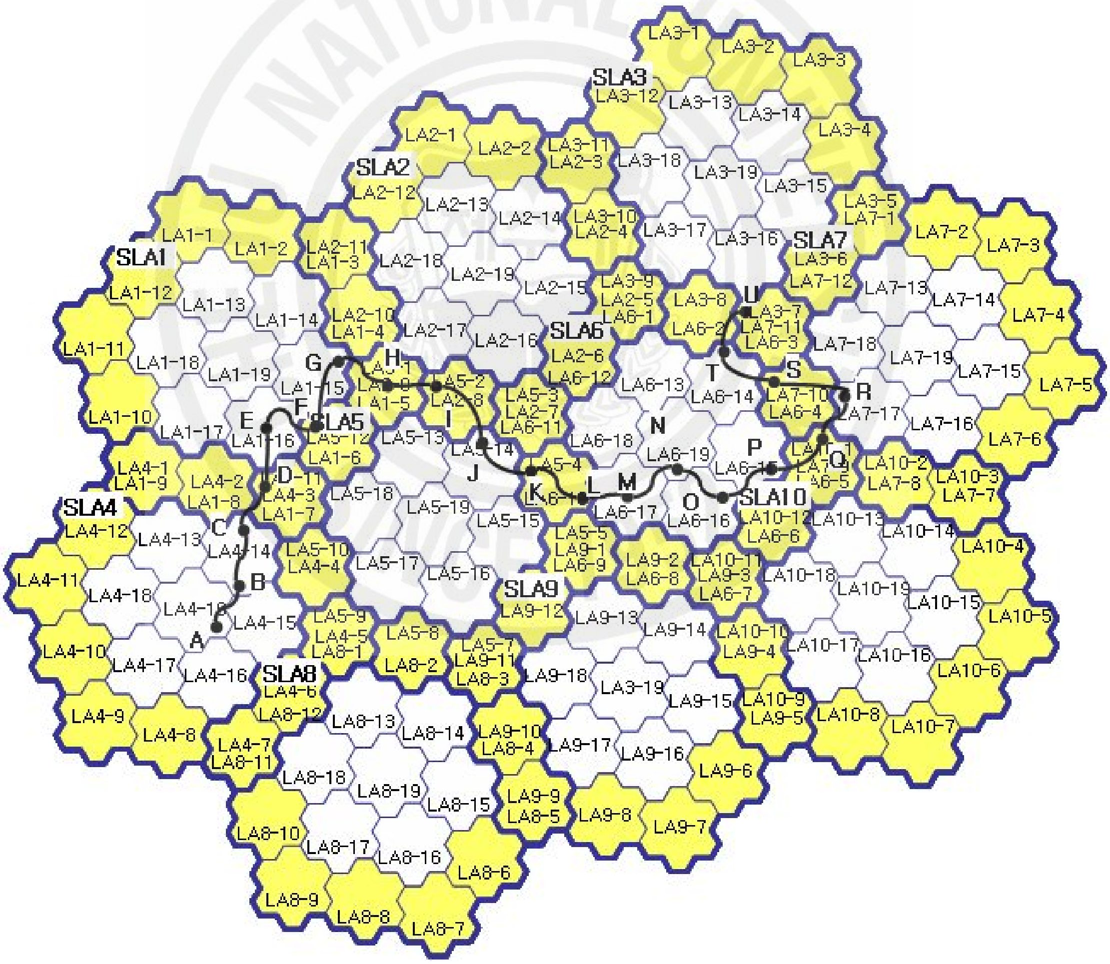

Figure 15. Moving path of a mobile station in the OSLA architecture

Table 3. Comparison of the location update in terms of three schemes

ID	The Path	The registered LA	The Register Update		
		(Typical, SLA) | OSLA	Typical	SLA	OSLA
1	A→B	LA4-14 | LA4-14	**VLR, HLR**	VLR	VLR
2	B→C	LA4-14 | LA4-14	None	None	None
3	C→D	LA4-3 | LA4-3	**VLR, HLR**	VLR	VLR
4	D→E	LA1-7 | LA1-16	**VLR, HLR**	VLR, **HLR**	VLR, **HLR**
5	E→F	LA5-11 | LA1-6	**VLR, HLR**	VLR, **HLR**	VLR
6	F→G	LA1-6 | LA1-15	**VLR, HLR**	VLR, **HLR**	VLR
7	G→H	LA5-12 | LA1-5	**VLR, HLR**	VLR, **HLR**	VLR
8	H→I	LA5-13 | (LA2-8 or LA5-2)	**VLR, HLR**	VLR	**VLR, HLR**
9	I→J	LA5-19 | LA5-14	**VLR, HLR**	VLR	VLR, **HLR** or VLR
10	J→K	LA5-15 | LA5-4	**VLR, HLR**	VLR	VLR
11	K→L	LA5-15 | LA5-4	None	None	None
12	L→M	LA5-5 | LA6-17	**VLR, HLR**	VLR	**VLR, HLR**
13	M→N	LA6-9 | LA6-19	**VLR, HLR**	VLR, **HLR**	VLR
14	N→O	LA9-1 | LA6-16	**VLR, HLR**	VLR, **HLR**	VLR
15	O→P	LA6-8 | LA6-15	**VLR, HLR**	VLR, **HLR**	VLR
16	P→Q	LA6-7 | LA6-5	**VLR, HLR**	VLR	VLR
17	Q→R	LA6-6 | LA7-17	**VLR, HLR**	VLR	**VLR, HLR**
18	R→S	LA6-16 | LA7-10	**VLR, HLR**	VLR	VLR
19	S→T	LA6-17 | LA6-14	**VLR, HLR**	VLR	**VLR, HLR**
20	T→U	LA6-19 | LA6-3	**VLR, HLR**	VLR	VLR
Total			18 VLR **18 HLR**	18 VLR **7 HLR**	18 VLR **6 or 5 HLR**

2. The Proposed Analytical Model

This thesis has developed analytical models in order to compare the performance of three schemes: the conventional scheme, the SLA scheme, and the proposed OSLA scheme. The notations used in the model are depicted in Table 4.

Table 4. The notations used in the proposed model to compare performance

Notation	Description
$\overline{K}$	The average number of mobile users in a cell
d	The size of an LA
s	The size of an SLA
$\overline{T_d}$	The average dwell time
N	The total number of mobile users in an LA
N_c	The total number of cells in an LA : $3d^2-3d+1$
N_{bc}	The number of boundary cells in an LA : $6(d-1)$
N_{Sla}	The total number of LAs in an SLA : $3s^2-3s+1$
N_{Sc}	The total number of cells in an SLA : $(3s^2-3s+1)(3d^2-3d+1)$
N_{Sbc}	The number of boundary cells in an SLA : $6\{3d-2+(s-2)(2d-1)\}$
N_S	The total number of mobile users in an SLA
$\overline{R_{LA}}$	The total location update rate for the given LA
$\overline{R_{SLA}}$	The total location update rate for the given SLA
$\overline{R_{OSLA}}$	The total location update rate for the given OSLA
$\overline{R_{MS}^{LA}}$	The average location update rate per a mobile user in the typical scheme
$\overline{R_{MS}^{SLA}}$	The average location update rate per a mobile user in the SLA scheme
$\overline{R_{MS}^{OSLA}}$	The average location update rate per a mobile user in the OSLA scheme

Since Equation (1)-(7) are equal to those in Chapter Ⅲ and then this thesis omits their description. Refer to analytical models in previous chapter.

$$N = N_c \times \overline{K} = (3d^2 - 3d + 1) \times \overline{K} \tag{1}$$

$$\overline{R_{LA}} = 6\left\{\frac{2}{6}\times(d-2)+\frac{3}{6}\times 1\right\}\times\overline{K}\times\frac{1}{\overline{T_d}} = (2d-1)\times\overline{K}\times\frac{1}{\overline{T_d}} \tag{2}$$

$$\overline{R_{MS}^{LA}} = \frac{\overline{R_{LA}}}{N} = \frac{2d-1}{3d^2-3d+1}\times\frac{1}{\overline{T_d}} \tag{3}$$

$$N_S = N_{Sc} \times \overline{K} = (3s^2-3s+1)(3d^2-3d+1)\times\overline{K} \tag{4}$$

$$\begin{aligned} N_{Sbc} &= 6\left[(s-2)\times\left\{\frac{2}{6}\times N_{bc}+1\right\}+\frac{3}{6}\times N_{bc}+1\right] \\ &= 6\left[(s-2)\times\left\{\frac{2}{6}\times 6(d-1)+1\right\}+\frac{3}{6}\times 6(d-1)+1\right] \\ &= 6\{(s-2)(2(d-1)+1)+3(d-1)+1\} \\ &= 6\{(2s-1)(d-1)+(s-1)\} \end{aligned} \tag{5}$$

$$\begin{aligned} \overline{R_{SLA}} &= 6\left[\frac{2}{6}\{(2s-1)(d-2)+(s-1)\}+\frac{3}{6}\times s+\frac{1}{6}\times(s-1)\right]\overline{K}\cdot\frac{1}{\overline{T_d}} \\ &= \{(2s-1)(2d-1)\}\cdot\overline{K}\cdot\frac{1}{\overline{T_d}} \end{aligned} \tag{6}$$

$$\overline{R_{MS}^{SLA}} = \frac{\overline{R_{SLA}}}{N_S} = \frac{(2s-1)(2d-1)}{(3s^2-3s+1)(3d^2-3d+1)}\cdot\frac{1}{\overline{T_d}} \tag{7}$$

As shown Figure 13, The boundary overlapping LAs consist of twofold or threefold overlapped LAs. The location update rate in twofold overlapped cells is a half of that in non-overlapped cells in the SLA scheme. And The location update rate in threefold overlapped cells is a third as small as that in non-overlapped cells in the SLA scheme. Thus, The average location update rate per mobile user in the OSLA scheme is obtained by Equation (8), considering twofold or threefold overlapped areas different from the non-overlapped areas.

$$\begin{aligned}\overline{R_{OSLA}} &= 6\left[(2s-1)\frac{1}{2}\left\{\frac{2}{6}(2(d-2)+1)+\frac{3}{6}\cdot 1+\frac{1}{6}\cdot 1\right\}\right]\overline{K}\cdot\frac{1}{\overline{T_d}} \\ &\quad +6\left[(2s-1)\frac{1}{3}\left\{\frac{2}{6}(3(d-2)+1)+\frac{3}{6}\cdot 2+\frac{1}{6}\cdot 1\right\}\right]\overline{K}\cdot\frac{1}{\overline{T_d}} \\ &= (s-1)(2d-1)\cdot\overline{K}\cdot\frac{1}{\overline{T_d}}\end{aligned} \tag{8}$$

Finally, the average location update rate per a mobile user in the OSLA scheme is like Equation (9) obtained by dividing the total location update rate for the given OSLA by the total number of mobile users in an SLA.

$$\overline{R_{MS}^{OSLA}}=\frac{\overline{R_{OSLA}}}{N_S}=\frac{(s-1)(2d-1)}{(3s^2-3s+1)(3d^2-3d+1)}\cdot\frac{1}{\overline{T_d}} \tag{9}$$

3. The Results of Performance Evaluation

Figure 16 shows the average HLR update rate according to the size of an SLA, when the size of an LA d = 3 and the average dwell time $\overline{T_d}$ = 6 minutes in terms of the traditional scheme, the SLA scheme, and the OSLA scheme. It shows that the proposed scheme (OSLA) outperforms both of the SLA and the conventional scheme.

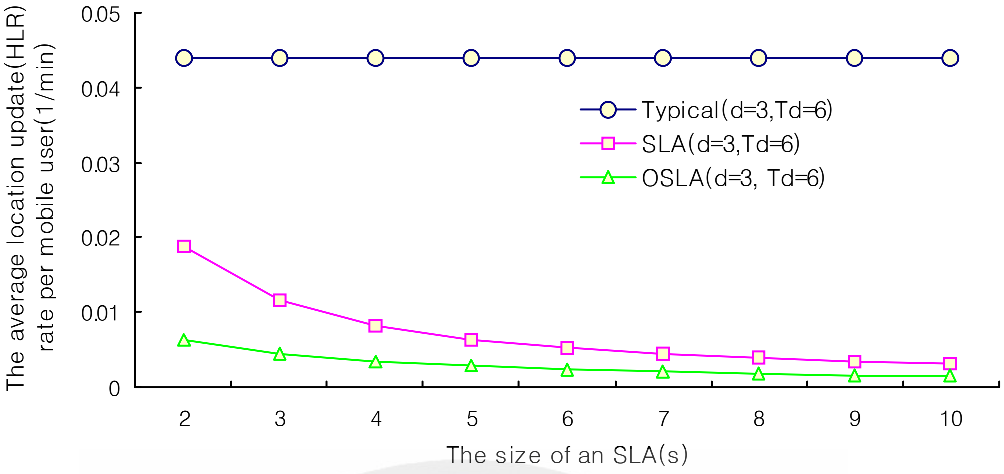

Figure 16. Comparison of HLR update rate according to the SLA size

Figure 17 shows comparison of the average HLR update rates of the conventional, the SLA, and the OSLA scheme according to the size of an LA, when the average dwell time $\overline{T_d}$ = 6 minutes and the size of an SLA s = 2. The average HLR update rate of OSLA scheme is smaller than those of the other schemes.

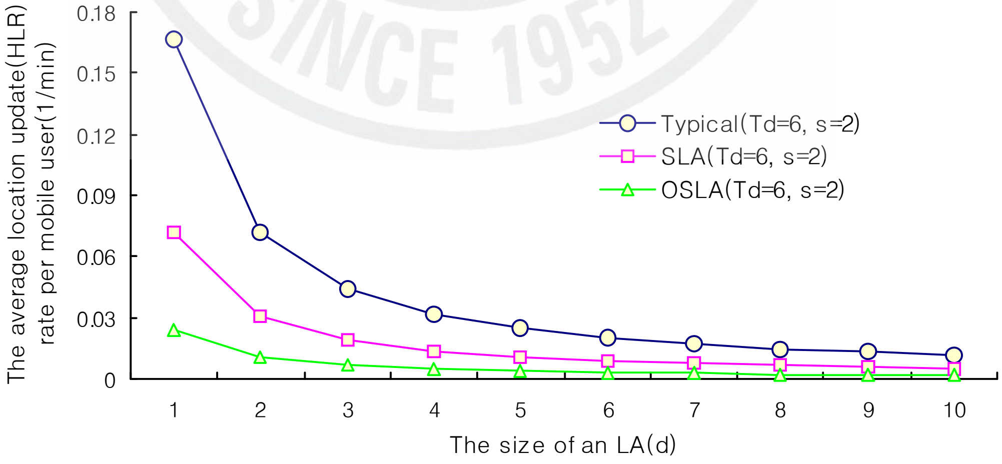

Figure 17. Comparison of HLR update rate according to the LA size

Figure 18 shows each average HLR update rate of three schemes according to the average dwell time, when $d = 3$ and $s = 2$. The OSLA scheme outperforms further than the other schemes like Figure 17.

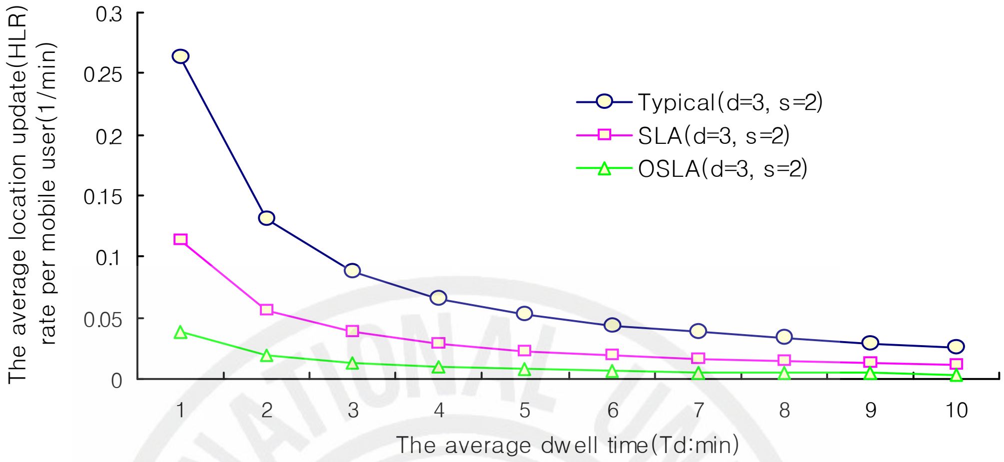

Figure 18. Comparison of HLR update rate according to the dwell time

Table 5 shows the total location update rates per a mobile user employing the SLA and the OSLA scheme. The total location update cost is obtained by adding the update cost of the HLR and that of the VLR. The performance evaluation so far has ignored the growing MSC loads resulting from the increase of the size of the SLA. While an MSC handles one LA in conventional scheme, an MSC handles the all LAs included in an SLA in the proposed approach. Thus the MSC may be overloaded as the size of the SLA increases. The threshold presented in Table 5 may play an important role of the performance comparison. That is, if the performance degradation due to the MSC overload is much larger than the performance gain in the table, the proposed scheme may not be accepted. On the other hand, if the performance degradation is smaller than the performance gain in the table, the proposed scheme may be effective. However, the proposed approach will be viable, considering that the cost of communication channel becomes more expensive while that of hardware becomes cheaper.

Table 5. Comparison of the location update cost in terms of three schemes

s=2 Td=6	SLA	OSLA	d=3 s=2	SLA	OSLA	d=3 Td=6	SLA	OSLA
d=1	0.238	0.190	Td=1	0.376	0.301	s=1	0.088	not applicable
d=2	0.102	0.082	Td=2	0.188	0.150	s=2	0.063	0.050
d=3	0.063	0.050	Td=3	0.125	0.100	s=3	0.055	0.048
d=4	0.045	0.036	Td=4	0.094	0.075	s=4	0.052	0.047
d=5	0.035	0.028	Td=5	0.075	0.060	s=5	0.050	0.047
d=6	0.029	0.023	Td=6	0.063	0.050	s=6	0.049	0.046
d=7	0.024	0.019	Td=7	0.054	0.043	s=7	0.048	0.046
d=8	0.021	0.017	Td=8	0.047	0.038	s=8	0.048	0.046
d=9	0.019	0.015	Td=9	0.042	0.033	s=9	0.047	0.045
d=10	0.017	0.013	Td=10	0.038	0.030	s=10	0.047	0.045

V. Route Optimization Scheme in Mobile IPv6

This chapter introduces the route optimization scheme by providing the threshold values coming the results from the proposed analytical models in Mobile IPv6.

1. The Proposed Analytical Model (Shin et al. 2007)

In this section, this thesis presents the new analytical models to evaluate the performance of the route optimization scheme. The security factor is not considered to keep the model simple. Figure 19 shows the flow of the packets required for the bidirectional tunneling and the route optimization when an MN communicates to a CN.

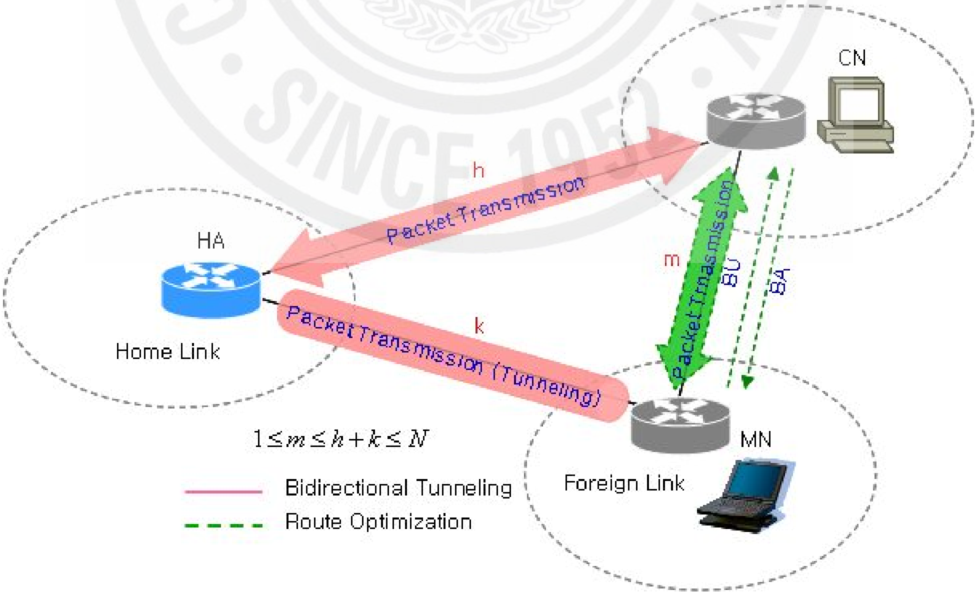

Figure 19. The model architecture of Mobile IPv6

For the bidirectional tunneling, every packet destined to an MN will be intercepted and tunneled by its HA. The tunneled packets will be forwarded to the MN as shown in Figure 19 (solid lines). On the other hand, for the route optimization an MN can not send directly the packets to the communicating CN until it should send the CN the BU and BA messages necessary for route optimization procedure as shown in Figure 19 (dotted lines).

Table 6 depicts the notations used in the proposed analytical models. The average bandwidth in wireless network is set to 1 (low), 10 (medium), and 100Mbps (high) and that in the wired network is 10 times (10, 100, and 1000Mbps) as high as the latter. The setting is reasonable considering the current trends of communication technologies. For example, Samsung Electronic Co., Ltd. showed 100 Mbps data transmission rate while moving and 1Gbps while not moving (maximum 3.5 Gbps) at the annual Samsung 4G Forum in Jeju Island, Korea 2006. The failure probability of BU is set from 10-2 to 10-3 because BER (Bit Error Rate) in the wireless network is typically 10-3 (Soliman 2004). The PMTU size for IPv6 packets is set to 1500 octets (McCann et al. 1996). This thesis assumes that both the size of the receiving and sending data (pkt) between the MN and the CN are equal just for convenience sake. The total size of the packet includes not only original data but also the IPv6 Basic Header and some of IPv6 Extension Headers such as Authentication Header, Fragmentation Header, Destination Option Header, and Routing Header. The other IPv6 Extension Headers are omitted due to the variety of their sizes and the optional preference.

Table 6. The notations used in the proposed analytical model in route optimization scheme

Notation	Description	Value
k	The Number of Hops from the MN to the HA	
h	The Number of Hops from the HA to the CN	
m	The Number of Hops from the MN to the CN using the Shortest Possible Path	
BW_{wl}	The Average Bandwidth in Wireless Network (Mbps)	1,10, 100
BW_{wd}	The Average Bandwidth in Wired Network (Mbps)	10,100, 1000
p	The Success Probability of the Binding Update Message	0.99, 0.999
pkt	The Size of Transfer Data (byte)	
$PMTU$	The Size of Path MTU (byte)	1500
IPH	The Size of IPv6 Basic Header (byte) (Deering and Hinden 1998)	40
$MobH$	The Size of Mobility Header (byte) (Johnson et al. 2004) : To include BU and BA message	
$AuthH$	The Size of Authentication Header (byte) (Kent and Atkinson 1998b)	20
$FragH$	The Size of Fragment Header (byte) (Deering and Hinden 1998): It is set to 0 if the size of packet is less than $PMTU$	8
$DOpH$	The Size of Destination Option Header (byte) (Deering and Hinden 1998): to include Home Address Option (Johnson et al. 2004)	20
$RoutH$	The Size of Routing Header (byte) (Deering and Hinden 1998): Type 2 Routing Header (Johnson et al. 2004)	24
$IPTun$	The Additional Size for IP-IP Tunneling (byte) (Perkins 1996): by adding IP Basic Header	40
M_{BU}	The Size of the Binding Update Message (byte) $= 40(IPH) + 12(MobH$ with MH Type $= 5) + 20(DOpH)$	72
M_{BA}	The Size of the Binding Acknowledgement Message (byte) $= 40(IPH) + 12(MobH$ with MH Type $= 6)$	52
T_{BU}	The Total Delay of BU Message (ms)	
T_{BA}	The Total Delay of BA Message (ms)	

T_{Msg}	The Total Delay of BU/BA Messages (ms)	
T_{ROpro}	The Total Delay of Route Optimization Procedure (ms)	
T_{RO}	The Total Delay of the Packets Transmission using Route Optimization (ms)	
T_{BT}	The Total Delay of the Packets Transmission using Bidirectional Tunneling (ms)	

Equation (10) and (11) show the delays for sending a BU message and receiving a BA message, respectively.

$$\begin{aligned} T_{BU} &= \frac{M_{BU}(Byte)}{BW_{wl}(Mbps)} + (m-1)\times\frac{M_{BU}(Byte)}{BW_{wd}(Mbps)} \\ &= \left\{\frac{M_{BU}}{BW_{wl}} + (m-1)\times\frac{M_{BU}}{BW_{wd}}\right\}\times\frac{8(bit)}{10^3\times 1024^2(bps)} \end{aligned} \tag{10}$$

$$\begin{aligned} T_{BA} &= \frac{M_{BA}(Byte)}{BW_{wl}(Mbps)} + (m-1)\times\frac{M_{BA}(Byte)}{BW_{wd}(Mbps)} \\ &= \left\{\frac{M_{BA}}{BW_{wl}} + (m-1)\times\frac{M_{BA}}{BW_{wd}}\right\}\times\frac{8(bit)}{10^3\times 1024^2(bps)} \end{aligned} \tag{11}$$

The total delay of both is obtained by Equation (12).

$$\begin{aligned} T_{Msg} &= T_{BU} + T_{BA} \\ &= \left\{\frac{M_{BU}+M_{BU}}{BW_{wl}} + (m-1)\frac{M_{BU}+M_{BA}}{BW_{wd}}\right\}\frac{8(bit)}{10^3\times 1024^2(bps)} \end{aligned} \tag{12}$$

The retransmission for BU message failure has exponential back-off time (1 second, 2 seconds, 4 seconds, and so on) and continues until the MN receives a BA or until a maximum timeout value (256 seconds) is reached (Soliman 2004). assume that the number of the BU message failure follows the geometric distribution. Consequently, the cost of the routing optimization procedure is obtained by Equation (13).

$$T_{ROPro} = pT_{Msg} + \sum_{i=2}^{10} p(1-p)^{i-1}(T_{Msg} + T_w), \quad 1 \leqq T_w = 2^{(i-2)} \leqq 256 \tag{13}$$

Equation (14), (15), and (16) are temporary variables to keep the ultimate formula simple.

$$\begin{aligned} g1 &= IPH + AuthH + FragH \\ g2 &= IPH + AuthH + DOpH + FragH \\ g3 &= IPH + AuthH + RoutH + FragH \\ g4 &= IPTun + IPH + AuthH + FragH \end{aligned} \tag{14}$$

$$\begin{aligned} r1 &= PMTU - (IPH + AuthH + FragH) = PMTU - g1 \\ r2 &= PMTU - (IPH + AuthH + DOpH + FragH) = PMTU - g2 \\ r3 &= PMTU - (IPH + AuthH + FragH) = PMTU - g3 \\ r4 &= PMTU - (IPTun + IPH + AuthH + FragH) = PMTU - g4 \end{aligned} \tag{15}$$

$$\begin{aligned} q1 &= \left\lfloor \frac{pkt}{r1} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r1} \right\rfloor \times r1 + g1 \\ q2 &= \left\lfloor \frac{pkt}{r2} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r2} \right\rfloor \times r2 + g2 \\ q3 &= \left\lfloor \frac{pkt}{r3} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r3} \right\rfloor \times r3 + g3 \\ q4 &= \left\lfloor \frac{pkt}{r4} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r4} \right\rfloor \times r4 + g4 \end{aligned} \tag{16}$$

Equation (17) and (18) are used for the routing optimization while Equation (19), (20), and (21) are for the bidirectional tunneling. Equation (17) shows the delay required when an MN sends the packets to a CN.

$$\begin{aligned} T_{MN:CN} &= \frac{q2(Byte)}{BW_{wl}(Mbps)} + \frac{(m-1) \times q2(Byte)}{BW_{wd}(Mbps)} \\ &= \left\{ \frac{q2}{BW_{wl}} + \frac{(m-1) \times q2}{BW_{wd}} \right\} \times \frac{8(bit)}{10^3 \times 1024^2(bps)} \end{aligned} \tag{17}$$

Equation (18) shows the delay required when the MN receives the packets from the CN.

$$\begin{aligned} T_{CN:MN} &= \frac{q3(Byte)}{BW_{wl}(Mbps)} + \frac{(m-1)\times q3(Byte)}{BW_{wd}(Mbps)} \\ &= \left\{ \frac{q3}{BW_{wl}} + \frac{(m-1)\times q3}{BW_{wd}} \right\} \times \frac{8(bit)}{10^3 \times 1024^2 (bps)} \end{aligned} \tag{18}$$

Equation (19), (20), and (21) are used for the bidirectional tunneling. Equation (19) shows the delay required when an MN sends the tunneled packets to its HA.

$$\begin{aligned} T_{MN:HA} &= \frac{q4(Byte)}{BW_{wl}(Mbps)} + \frac{(k-1)\times q4(Byte)}{BW_{wd}(Mbps)} \\ &= \left\{ \frac{q4}{BW_{wl}} + \frac{(k-1)\times q4}{BW_{wd}} \right\} \times \frac{8(bit)}{10^3 \times 1024^2 (bps)} \end{aligned} \tag{19}$$

Equation (20) shows the delay required when the HA does the law packets to a CN sequentially.

$$T_{HA:CN} = \frac{h\times q1(Byte)}{BW2(Mbps)} = \frac{h\times q1}{BW2} \times \frac{8(bit)}{1024^2 (bps)} \tag{20}$$

Finally, Equation (21) obtains the total delay required when the MN sends the packets to the CN through the HA.

$$\begin{aligned} T_{MN:HA:CN} = T_{CN:HA:MN} &= T_{MN:HA} + T_{HA:CN} \\ &= \left\{ \frac{q4}{BW_{wl}} + \frac{h\times q1 + (k-1)\times q4}{BW_{wd}} \right\} \frac{8(bit)}{10^3 \times 1024^2 (bps)} \end{aligned} \tag{21}$$

The delay for the packet transmission between an MN and a CN using the routing optimization and the bidirectional tunneling, are obtained by Equation (22) and (23), respectively.

$$
\begin{aligned}
T_{RO} &= T_{ROPro} + T_{MN:CN} + T_{CN:MN} \\
&= pT_{Msg} + \sum_{i=2}^{10} p(1-p)^{i-1}(T_{Msg} + T_w) \\
&\quad + \left\{ \frac{q2+q3}{BW_{wl}} + \frac{(m-1)(q2+q3)}{BW_{wd}} \right\} \times \frac{8(bit)}{10^3 \times 1024^2 (bps)}
\end{aligned}
\tag{22}
$$

$$
\begin{aligned}
T_{BT} &= T_{MN:HA:CN} + T_{CN:HA:MN} = 2 \times (T_{MN:HA:CN}) \\
&= \left\{ \frac{q4}{BW_{wl}} + \frac{h \times q1 + (k-1) \times q4}{BW_{wd}} \right\} \frac{16(bit)}{10^3 \times 1024^2 (bps)}
\end{aligned}
\tag{23}
$$

2. The Results of Performance Evaluation

In this section, this thesis would compare performance of bidirectional tunneling (BT) and routing optimization (RO) in terms of the total transmission delay for the messages using corresponding routing path and show the results. The most of specific values used in the graphs are ones mentioned in the previous section as shown in Table 6. Note that the difference of the numbers of hops between the MN and the CN with respect to two routing methods is relatively small as shown in the following figures. For example, m is 5 or 8, when h+k = 10. Consider the worst-case scenario that the MN move away from the HA and near to the CN. The case will provide a large difference. However, the difference can not be too large because the HA can be switched due to load balancing (Haley et al. 2006). Although the value of the average bandwidth in wired network is omitted in all over graphs, recall that it is set to 10 times as high as that in wireless network.

Figure 20-41 show the case of BT with the number of hops from the MN to the CN via the HA (k=5, *h*=5, *k*+*h*=10) and those of RO with the number of hops from the MN to the CN (*m*=5 and *m*=8) directly.

Figure 20-25 show that the larger the size of data is, the larger both of the delays of BT and RO will become. The cases of the low bandwidth (1Mbps) show in Figure 20 and 23, ones of middle bandwidth (10Mbps) do in Figure 21 and 24, and ones of high bandwidth (100Mbps) do in Figure 22 and 25. Figure 20, 21, and 22 provide threshold values at the specific points in the case of the success probability of the BU message *p* = 0.99. On the other hand, in the case of *p* = 0.999, the delay of BT is always larger than that of OR at all points except for the first point in Figure 24 and 25. Figure 23 shows that the delay of BT is always larger than that of OR.

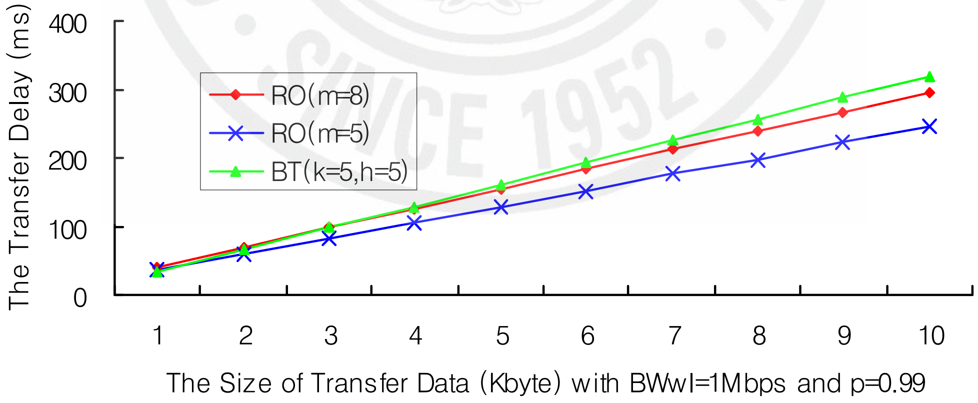

Figure 20. The delay comparison according to the size of transfer data with BW_{wl}=1Mbps and *p*=0.99

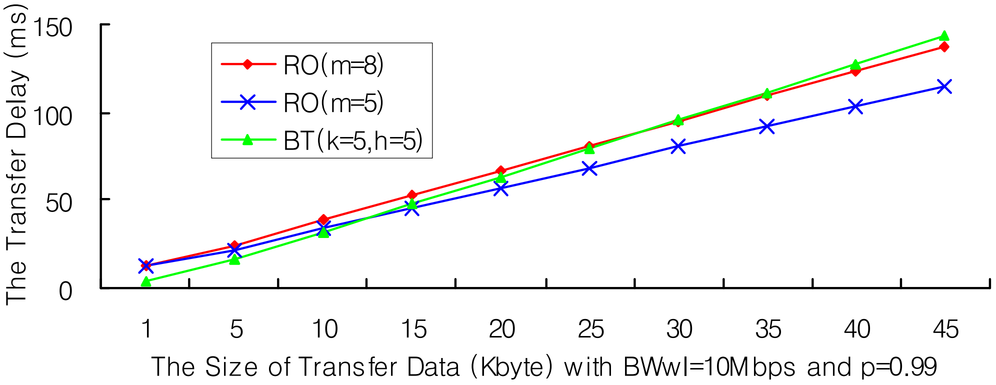

Figure 21. The delay comparison according to the size of transfer data with BW_{wl}=10Mbps and p=0.99

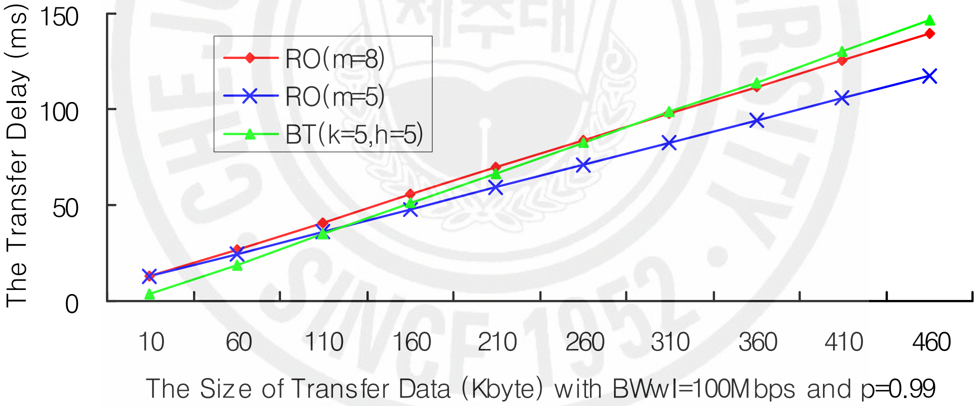

Figure 22. The delay comparison according to the size of transfer data with BW_{wl}=100Mbps and p=0.99

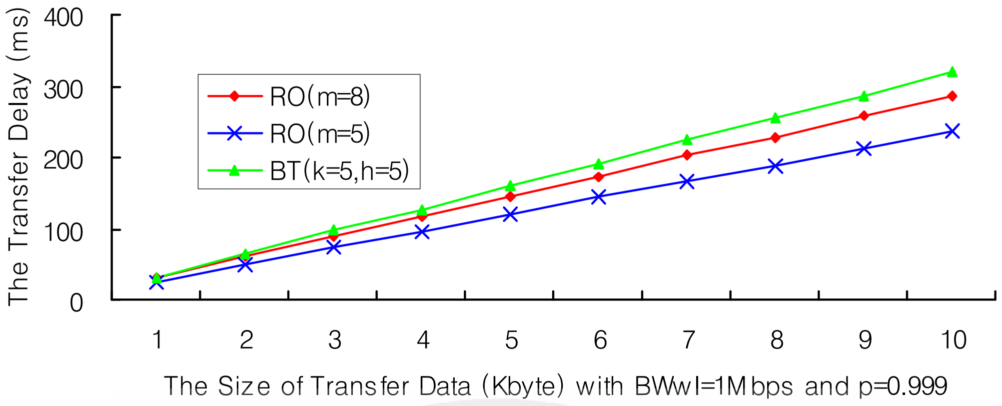

Figure 23. The delay comparison according to the size of transfer data with BW_{wl}=1Mbps and p=0.999

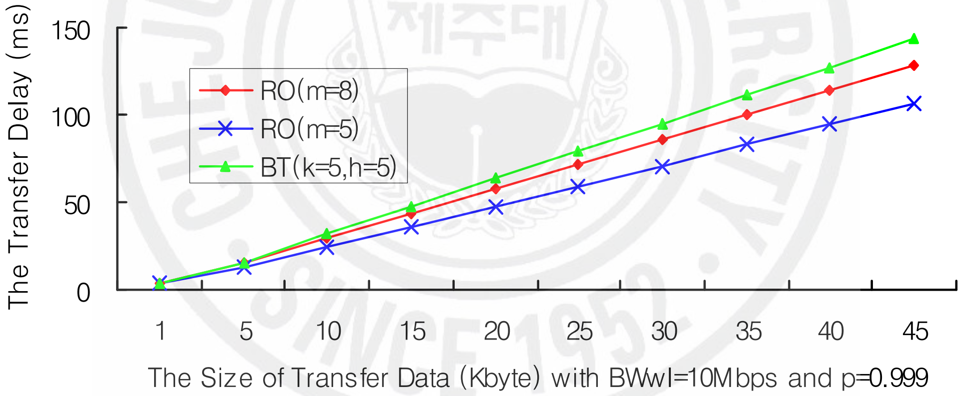

Figure 24. The delay comparison according to the size of transfer data with BW_{wl}=10Mbps and p=0.999

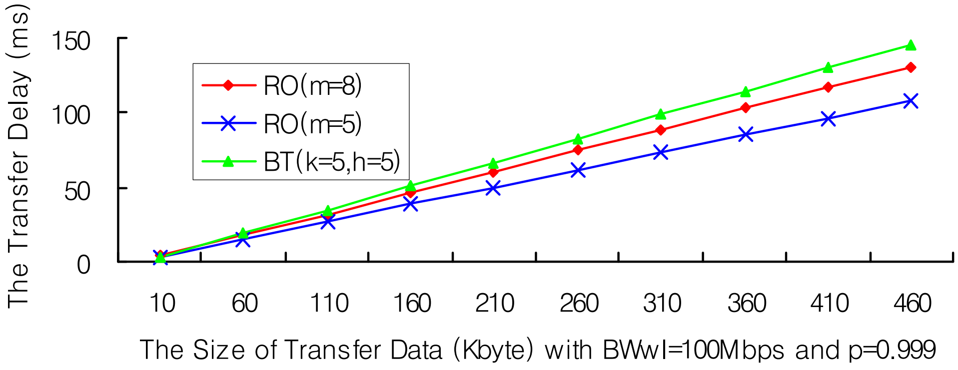

Figure 25. The delay comparison according to the size of transfer data with BW_{wl}=100Mbps and p=0.999

In Figure 26-29, as the success probability of the BU message (p) increases, the delay of OR decreases. Since the additional delay of BT does not contain the binding update process between an MN and the CN. The delay of BT is consistent no matter what the value of p is. Figure 26 and 29 provide the threshold values at the specific points. Figure 26 and 28 are the cases of the short term packets (1K) while Figure 27 and 29 are ones of the middle term packets (10K). Figure 26 and 29 provide the threshold values between BT and RO at the specific points. The delay of BT is always larger than that of and RO in Figure 27. And the former is always smaller than the latter in Figure 29.

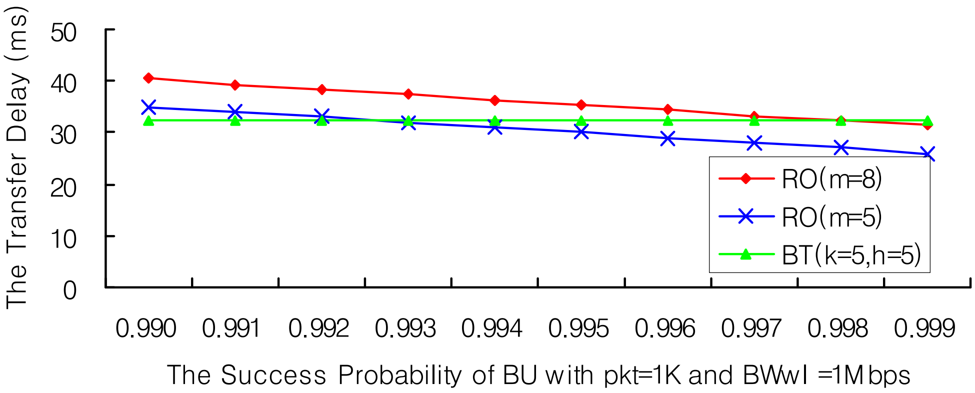

Figure 26. The delay comparison according to the success probability of the BU Message with *pkt*=1K and BW_{wl}=1Mbps

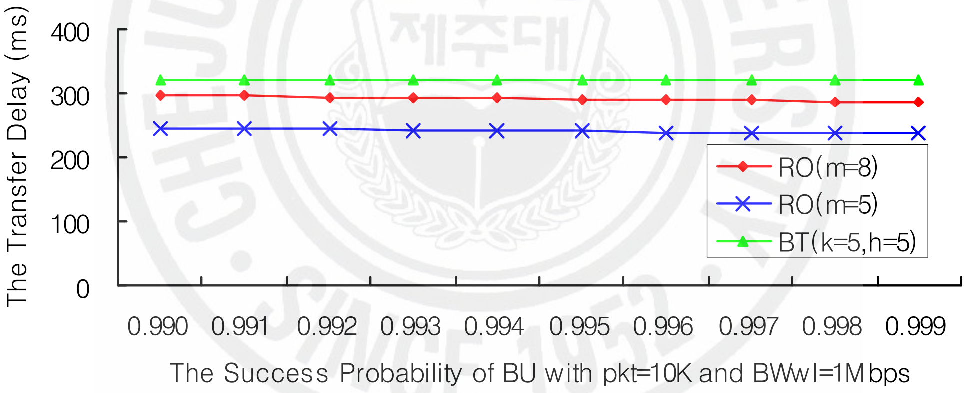

Figure 27. The delay comparison according to the success probability of the BU Message with *pkt*=10K and BW_{wl}=1Mbps

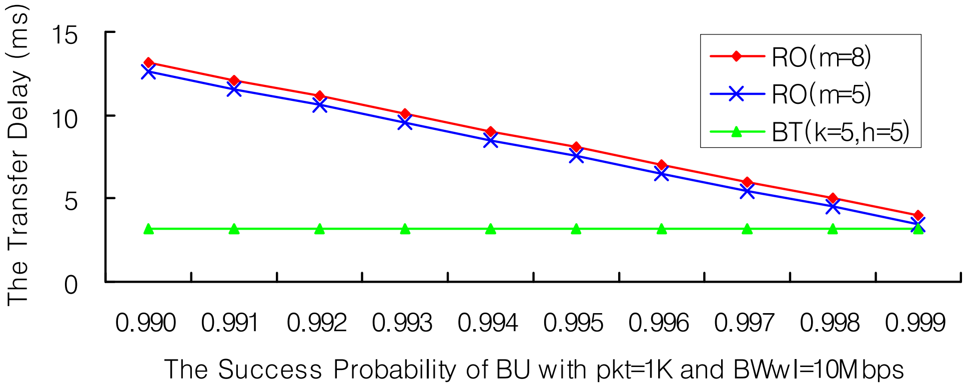

Figure 28. The delay comparison according to the success probability of the BU Message with *pkt*=1K and BW_{wl}=10Mbps

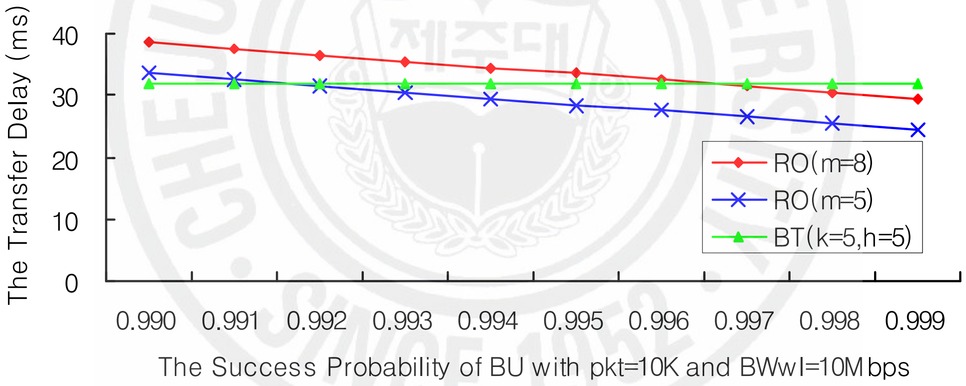

Figure 29. The delay comparison according to the success probability of the BU Message with *pkt*=10K and BW_{wl}=10Mbps

Figure 30-35 shows that the larger the size of the bandwidth is, the smaller the transmission delay becomes. Figure 30-32 are the cases of the success probability of the BU message p = 0.99, while Figure 33-35 ones of p = 0.999. The cases of the short term packets (1K) show in Figure 30 and 33, ones of the middle term packets (10K) do in Figure 31 and 34, and ones of the long term packets (100K) do in the other figures. The delay of BT has always the smallest at all points in Figure 30. On the other hand, the other figures show the threshold values between BT and RO at the specific points.

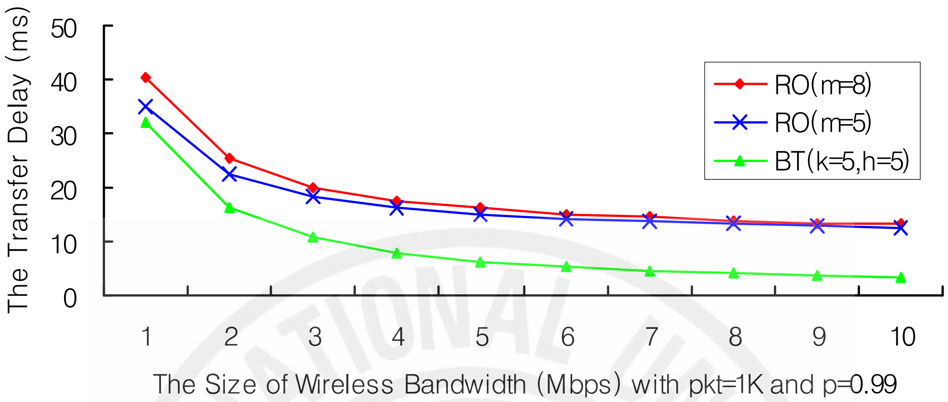

Figure 30. The delay comparison according to the bandwidth in wireless networks with *pkt*=1K and *p*=0.99

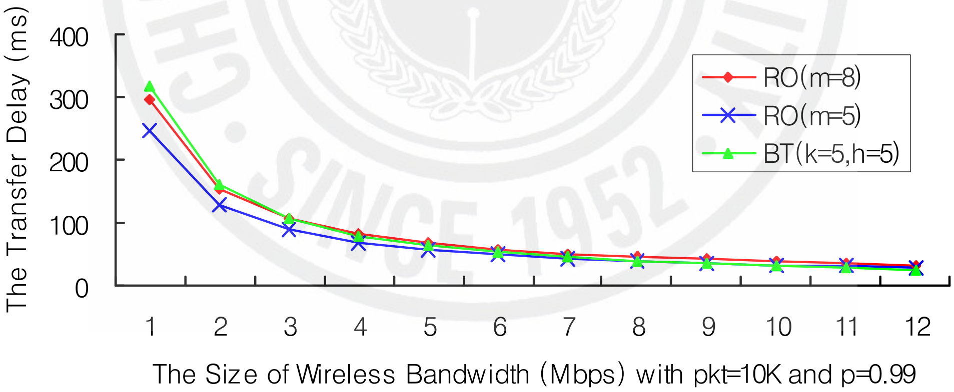

Figure 31. The delay comparison according to the bandwidth in wireless networks with *pkt*=10K and *p*=0.99

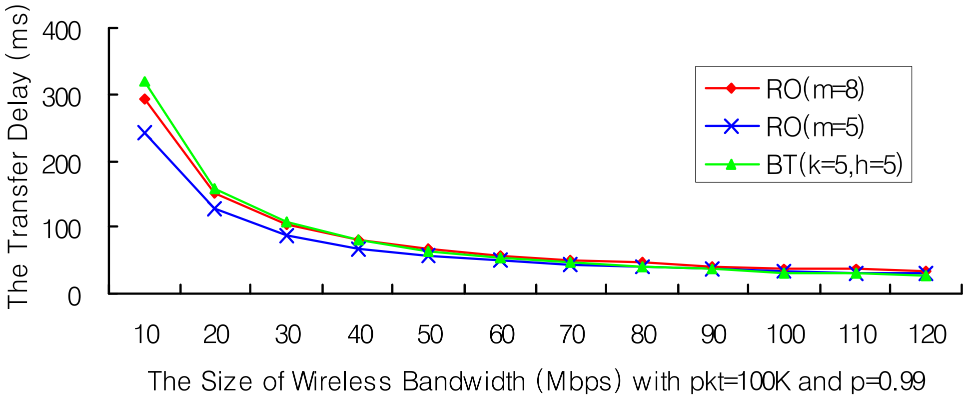

Figure 32. The delay comparison according to the bandwidth in wireless networks with *pkt*=100K and *p*=0.99

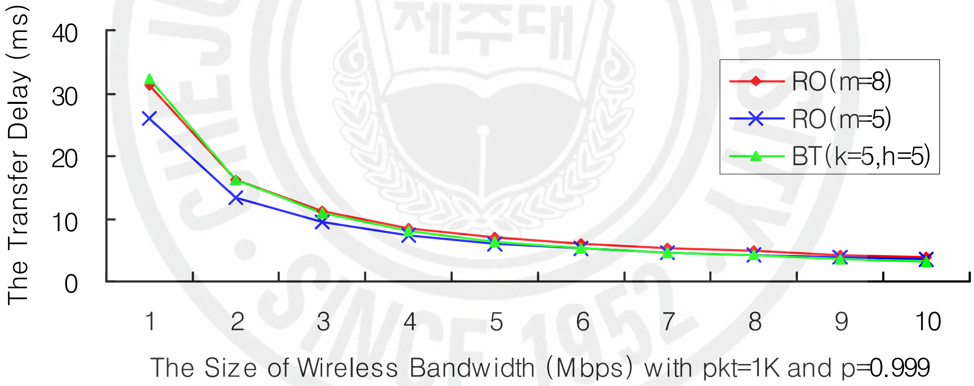

Figure 33. The delay comparison according to the bandwidth in wireless networks with *pkt*=1K and *p*=0.999

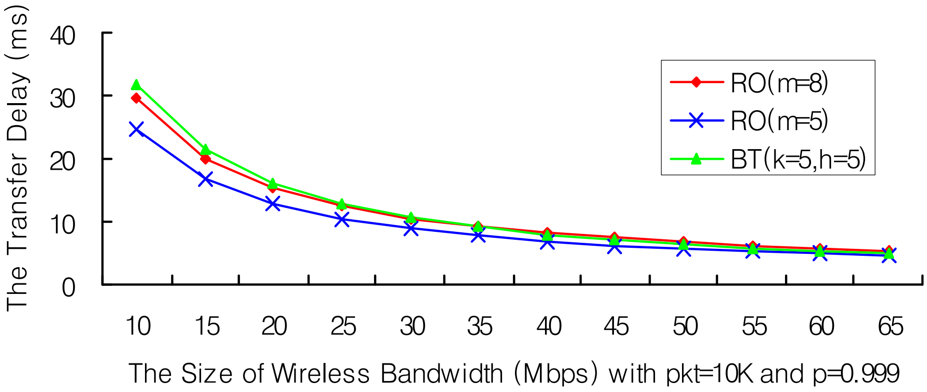

Figure 34. The delay comparison according to the bandwidth in wireless networks with *pkt*=10K and *p*=0.999

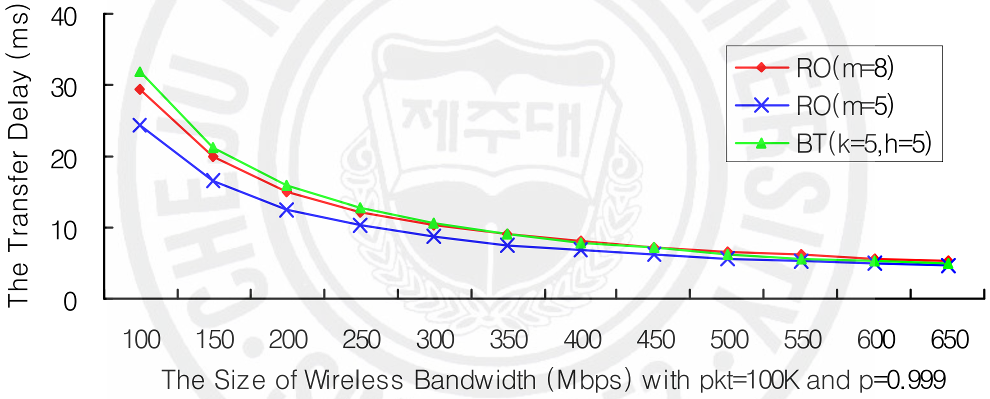

Figure 35. The delay comparison according to the bandwidth in wireless networks with *pkt*=100K and *p*=0.999

Figure 36-41 shows how much the change of the number of hops from the MN and to the HA (*k*) affects the total delay of BT when the number of hops from the MN to the CN (*k*+*h*) is fixed by 11. In all cases in Figure 36-41, as the number of hops between the MN and the HA, *k* increases (in other words, the number of hops between the HA and the CN, *h* decreases), the total delay of BT increases and those of RO are consistent, And the difference between the delay of BT and RO is not at most one hop.

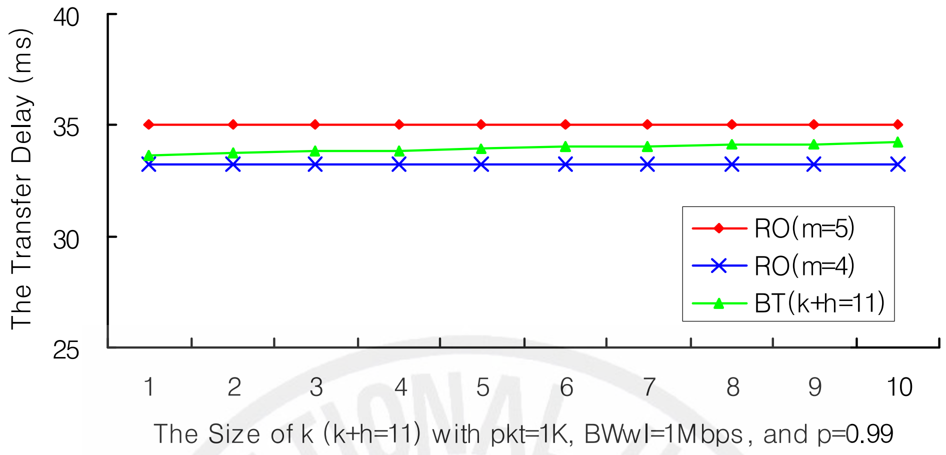

Figure 36. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=1Mbps and p=0.99

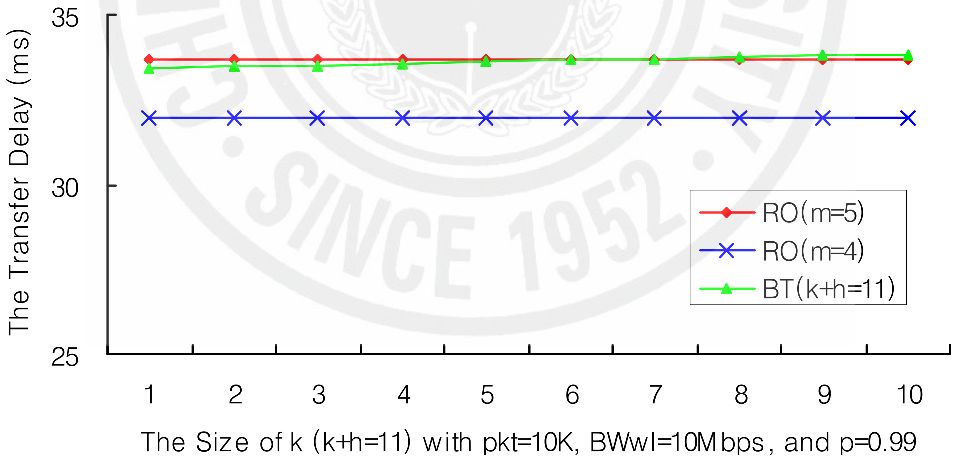

Figure 37. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=10Mbps and p=0.99

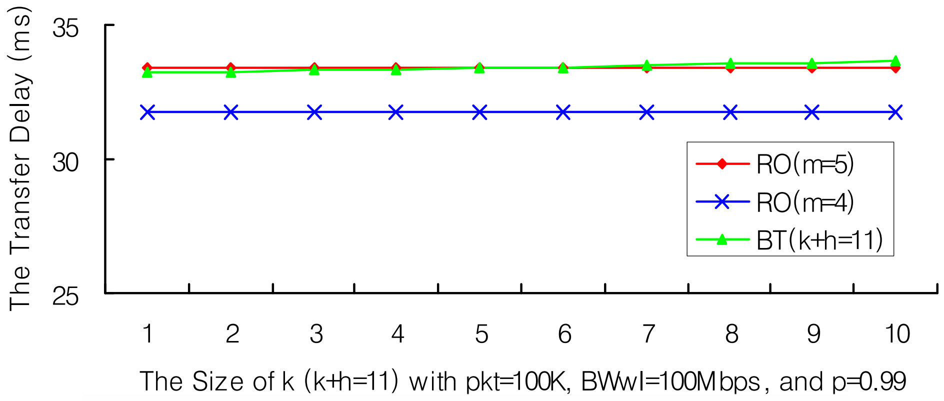

Figure 38. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=100Mbps and p=0.99

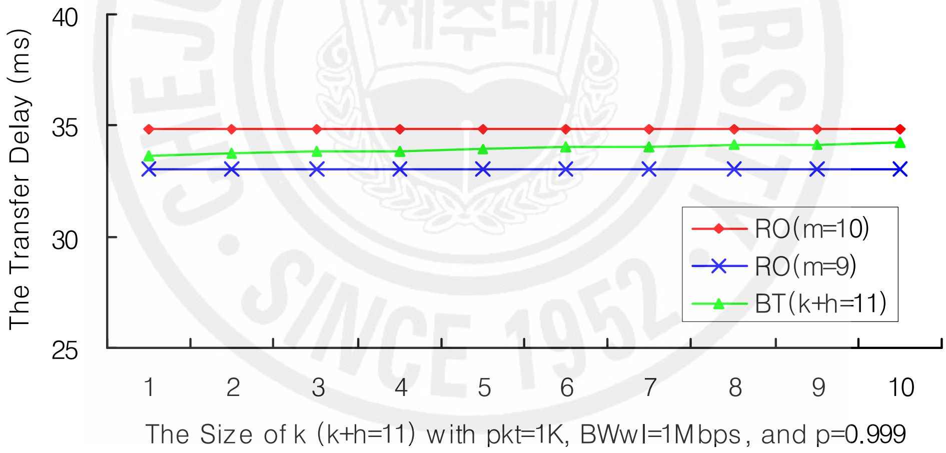

Figure 39. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=1Mbps and p=0.999

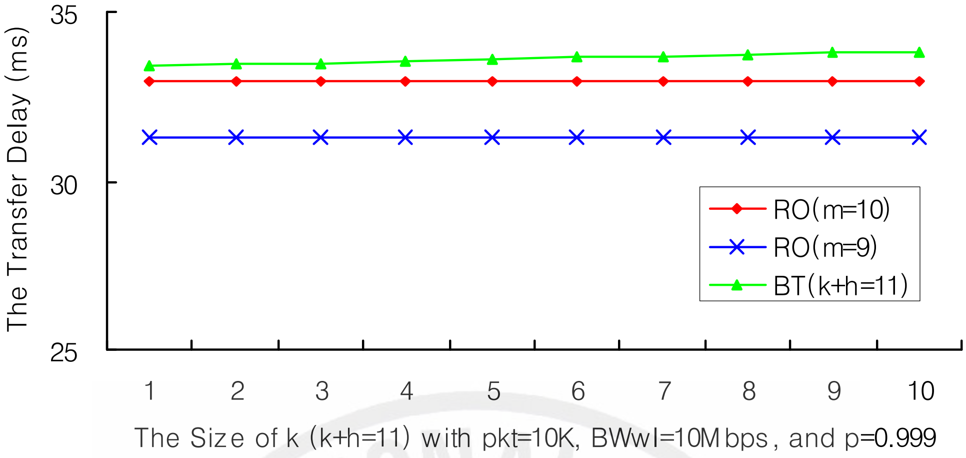

Figure 40. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=10Mbps and p=0.999

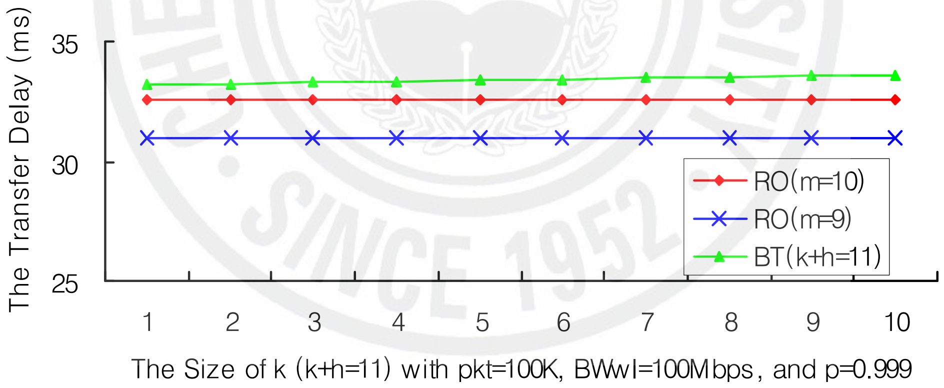

Figure 41. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=100Mbps and p=0.999

VI. Secure Route Optimization Scheme in Mobile IPv6

This chapter introduces the secure route optimization scheme considering the Mobile IPv6 security, by providing the threshold values coming the results from the proposed analytical models in Mobile IPv6 networks.

1. The Proposed Analytical Model

This section presents the new analytical models to compare the performance of the bidirectional tunneling and the route optimization. Figure 42 shows the flow of the data packets and messages required for two schemes. Note that this thesis takes account of only the different and additional delays between the schemes except the same delay such as the home registration procedure.

For the bidirectional tunneling, every packet destined to an MN will be intercepted and tunneled by its HA. The tunneled packets will be forwarded to the MN as shown in Figure 42. On the other hand, for the route optimization, the RR procedure to protect the integrity and authenticity of the BU and BA to the CN should precede the BU and BA messages as shown in Figure 42. An MN can not send directly the packets to the communicating CN until it should send the CN the BU/BA messages necessary for the route optimization procedure.

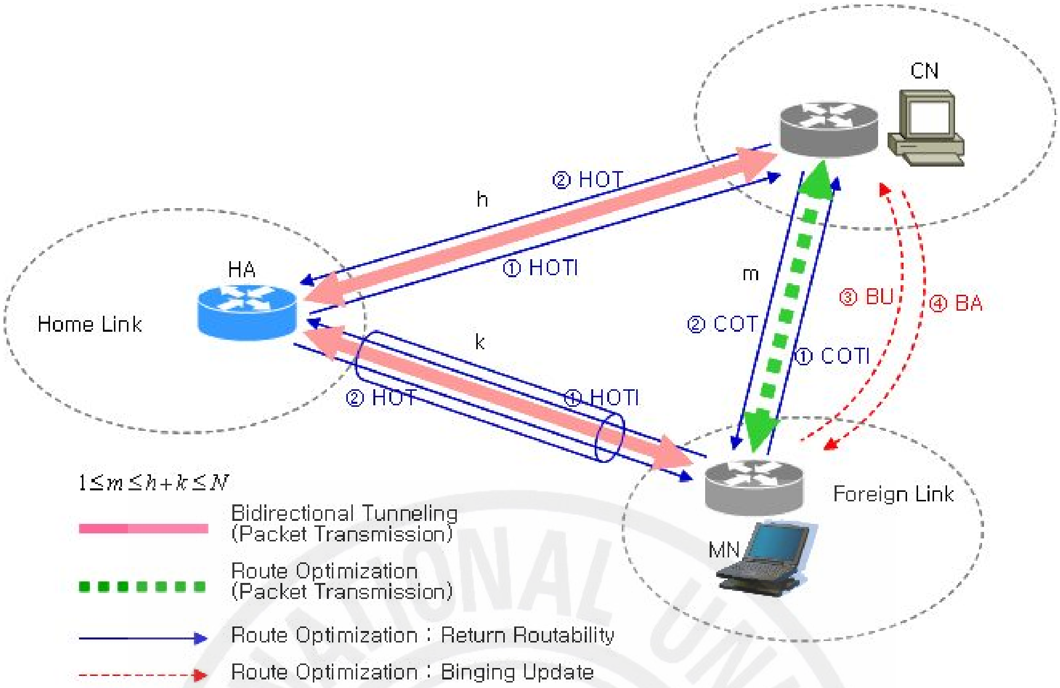

Figure 42. The bidirectional tunneling and the route optimization

Table 7 depicts the notations used in the proposed analytical models. Let′s see the new notations associated with Mobile IP security, since most of notations have already described in Table 6, Chapter Ⅴ. For the RR procedure, HOTI, COTI, HOT, and COT Message should be needed as shown Figure 3. To authorize binding management messages, Binding Authorization Data Option is mandatory in the BU and the BA sent by a CN. Also, Nonce Indices Option is required in the BU, to include home nonce index and Care-of nonce index (Johnson et al. 2004) as shown Figure 3.

Table 7. The notations used in the proposed analytical model in secure route optimization scheme

Notation	Description	Value
k	The Number of Hops from the MN to the HA	
h	The Number of Hops from the HA to the CN	
m	The Number of Hops from the MN to the CN using the Shortest Possible Path	
BW_{wl}	The Average Bandwidth in Wireless Network (Mbps)	1,10, 100
BW_{wd}	The Average Bandwidth in Wired Network (Mbps)	10,100, 1000
p	The Success Probability of the Binding Update Message	0.99, 0.999
pkt	The Size of Transfer Data (byte)	
$PMTU$	The Size of Path MTU (byte)	1500
IPH	The Size of IPv6 Basic Header (byte) (Deering and Hinden 1998)	40
$MobH$	The Size of Mobility Header (byte) (Johnson et al. 2004) (To include HOTI, HOT, COTI, COT, BU, and BA message)	
$BADOp$	The Size of Binding Authorization Data Option (byte) (Johnson et al. 2004)	16
$NIOp$	The Size of Nonce Indices Option (byte) (Johnson et al. 2004)	8
$AuthH$	The Size of Authentication Header (byte) (Kent and Atkinson 1998b)	20
$FragH$	The Size of Fragment Header (byte) (Deering and Hinden 1998): It is set to 0 if the size of packet is less than $PMTU$	8
$DOpH$	The Size of Destination Option Header (byte) (Deering and Hinden 1998) : To include Home Address Option (Johnson et al. 2004)	20
$RoutH$	The Size of Routing Header (byte) (Deering and Hinden 1998) : Type 2 Routing Header (Johnson et al. 2004)	24
$IPTun$	The Additional Size for IP-IP Tunneling (byte) (Perkins 1996) : By adding IP Basic Header	40
M_{HOTI}	The Size of Home Test Init Message (byte) (Johnson et al. 2004) = 40(IPH) + 16($MobH$ with MH Type = 1)	56
M_{THOTI}	The Size of Tunneled Home Test Init Message (byte) (Johnson et al. 2004) = 40($IPTun$) + 40(IPH) + 16($MobH$ with MH Type = 1)	96

M_{COTI}	The Size of Care-of Test Init Message (byte) (Johnson et al. 2004) = 40(IPH) + 16($MobH$ with MH Type = 2)	56
M_{HOT}	The Size of Home Test Message (byte) (Johnson et al. 2004) = 40(IPH) + 24($MobH$ with MH Type = 3)	64
M_{THOT}	The Size of Tunneled Home Test Message (byte) (Johnson et al. 2004) = 40($IPTun$) + 40(IPH) + 24($MobH$ with MH Type = 3)	104
M_{COT}	The Size of Care-of Test Message (byte) (Johnson et al. 2004) = 40(IPH) + 24($MobH$ with MH Type = 4)	64
M_{BU}	The Size of Binding Update Message (byte) = 40(IPH) + 12($MobH$ with MH Type = 5) + 16($BADOp$) + 8($NIOp$) + 20($DOpH$)	96
M_{BA}	The Size of Binding Acknowledgement Message (byte) = 40(IPH) + 12($MobH$ with MH Type = 6) + 16($BADOp$)	68
T_{HOT}	The Total Delay of HOTI/HOT Message (ms)	
T_{COT}	The Total Delay of COTI/COT Message (ms)	
T_{RR}	The Total Delay of Return Routability Procedure (ms)	
T_{BU}	The Total Delay of BU Message (ms)	
T_{BA}	The Total Delay of BA Message (ms)	
T_{Msg}	The Total Delay of BU/BA Messages (ms)	
T_{ROpro}	The Total Delay of Route Optimization Procedure (ms)	
T_{ROS}	The Total Delay of the Packets Transmission using Route Optimization with Security (ms)	
T_{BT}	The Total Delay of the Packets Transmission using Bidirectional Tunneling (ms)	

Equation (24) shows the delay for sending a BU message, including Binding Authorization Data Option and Nonce Indices Option , to the CN.

$$
\begin{aligned}
T_{BU} &= \frac{M_{BU}(Byte)}{BW_{wl}(Mbps)} + (m-1) \times \frac{M_{BU}(Byte)}{BW_{wd}(Mbps)} \\
&= \left\{ \frac{M_{BU}}{BW_{wl}} + (m-1) \times \frac{M_{BU}}{BW_{wd}} \right\} \times \frac{8(bit)}{10^3 \times 1024^2 (bps)}
\end{aligned}
\tag{24}
$$

Equation (25) shows the delay for receiving a BA message, including Binding Authorization Data Option, to the CN.

$$\begin{aligned} T_{BA} &= \frac{M_{BA}(Byte)}{BW_{wl}(Mbps)} + (m-1) \times \frac{M_{BA}(Byte)}{BW_{wd}(Mbps)} \\ &= \left\{ \frac{M_{BA}}{BW_{wl}} + (m-1) \times \frac{M_{BA}}{BW_{wd}} \right\} \times \frac{8(bit)}{10^3 \times 1024^2 (bps)} \end{aligned} \tag{25}$$

The total delay of both is obtained by Equation (26).

$$\begin{aligned} T_{Msg} &= T_{BU} + T_{BA} \\ &= \left\{ \frac{M_{BU} + M_{BU}}{BW_{wl}} + (m-1) \frac{M_{BU} + M_{BA}}{BW_{wd}} \right\} \frac{8(bit)}{10^3 \times 1024^2 (bps)} \end{aligned} \tag{26}$$

This thesis also assumes that the number of the BU message failure follows the geometric distribution. Equation (27) is the delay required for transmitting HOTI message from the MN to the CN via the HA while Equation (28) is one required for transmitting HOT message from the CN to the MN, reversely. HOTI/HOT messages should be tunneled between the HA and the MN.

$$T_{HOTI} = \left\{ \frac{M_{THOTI}}{BW_{wl}} + (k-1) \frac{M_{THOTI}}{BW_{wd}} + (h) \frac{M_{HOTI}}{BW_{wd}} \right\} \frac{8(bit)}{10^3 \times 1024^2 (bps)} \tag{27}$$

$$T_{HOT} = \left\{ \frac{M_{THOT}}{BW_{wl}} + (k-1) \frac{M_{THOT}}{BW_{wd}} + (h) \frac{M_{HOT}}{BW_{wd}} \right\} \frac{8(bit)}{10^3 \times 1024^2 (bps)} \tag{28}$$

And Equation (29) and (30) are the delay required for the direct transmission of COTI message from the MN to the CN and COT message from the CN to the MN, respectively.

$$T_{COTI} = \left\{ \frac{M_{COTI}}{BW_{wl}} + (m-1)\frac{M_{COTI}}{BW_{wd}} \right\} \frac{8(bit)}{10^3 \times 1024^2 (bps)} \tag{29}$$

$$T_{COT} = \left\{ \frac{M_{COT}}{BW_{wl}} + (m-1)\frac{M_{COT}}{BW_{wd}} \right\} \frac{8(bit)}{10^3 \times 1024^2 (bps)} \tag{30}$$

The total delay of the RR procedure is selected a maximum value out of the transmission delay of HOTI/HOT messages and one of COTI/COT messages like Equation (31), because the MN does not complete the RR procedure until it receives both HOTI and COTI messages.

$$T_{RR} = \mathrm{max}imum\{(T_{HOT} + T_{HOTI}) + (T_{COT} + T_{COTI})\} \tag{31}$$

Consequently, the delay of the route optimization procedure is obtained by Equation (32).

$$T_{ROPro} = T_{RR} + pT_{Msg} + \sum_{i=2}^{10} p(1-p)^{i-1}(T_{Msg} + T_w), \quad 1 \leqq T_w = 2^{(i-2)} \leqq 256 \tag{32}$$

Equation (33), (34), and (35) have no meaning as temporary variables to make the final formula simple.

$$\begin{aligned} g1 &= IPH + AuthH + FragH \\ g2 &= IPH + AuthH + DOpH + FragH \\ g3 &= IPH + AuthH + RoutH + FragH \\ g4 &= IPTun + IPH + AuthH + FragH \end{aligned} \tag{33}$$

$$\begin{aligned} q1 &= \left\lfloor \frac{pkt}{r1} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r1} \right\rfloor \times r1 + g1 \\ q2 &= \left\lfloor \frac{pkt}{r2} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r2} \right\rfloor \times r2 + g2 \\ q3 &= \left\lfloor \frac{pkt}{r3} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r3} \right\rfloor \times r3 + g3 \\ q4 &= \left\lfloor \frac{pkt}{r4} \right\rfloor \times PMTU + pkt - \left\lfloor \frac{pkt}{r4} \right\rfloor \times r4 + g4 \end{aligned} \tag{34}$$

$$\begin{aligned}
&r1 = PMTU - (IPH + AuthH + FragH) = PMTU - g1 \\
&r2 = PMTU - (IPH + AuthH + DOpH + FragH) = PMTU - g2 \\
&r3 = PMTU - (IPH + AuthH + FragH) = PMTU - g3 \\
&r4 = PMTU - (IPTun + IPH + AuthH + FragH) = PMTU - g4
\end{aligned} \tag{35}$$

Equation (36) and (37) are used for the route optimization. Equation (36) shows the delay required when an MN sends the packets to a CN, while Equation (37) does one required when the MN receives the packets from the CN.

$$\begin{aligned}
T_{MN:CN} &= \frac{q2(Byte)}{BW_{wl}(Mbps)} + \frac{(m-1)\times q2(Byte)}{BW_{wd}(Mbps)} \\
&= \left\{\frac{q2}{BW_{wl}} + \frac{(m-1)\times q2}{BW_{wd}}\right\} \times \frac{8(bit)}{10^3 \times 1024^2(bps)}
\end{aligned} \tag{36}$$

$$\begin{aligned}
T_{CN:MN} &= \frac{q3(Byte)}{BW_{wl}(Mbps)} + \frac{(m-1)\times q3(Byte)}{BW_{wd}(Mbps)} \\
&= \left\{\frac{q3}{BW_{wl}} + \frac{(m-1)\times q3}{BW_{wd}}\right\} \times \frac{8(bit)}{10^3 \times 1024^2(bps)}
\end{aligned} \tag{37}$$

Equation (38), (39), and (40) are used for the bidirectional tunneling. Equation (38) shows the delay required when an MN sends the tunneled packets to its HA.

$$\begin{aligned}
T_{MN:HA} &= \frac{q4(Byte)}{BW_{wl}(Mbps)} + \frac{(k-1)\times q4(Byte)}{BW_{wd}(Mbps)} \\
&= \left\{\frac{q4}{BW_{wl}} + \frac{(k-1)\times q4}{BW_{wd}}\right\} \times \frac{8(bit)}{10^3 \times 1024^2(bps)}
\end{aligned} \tag{38}$$

Equation (39) shows the delay required when the HA decapsulates the tunneled packets and then sends the law packets to a CN consecutively.

$$T_{HA:CN} = \frac{h \times q1\,(Byte)}{BW2\,(Mbps)} = \frac{h \times q1}{BW2} \times \frac{8\,(bit)}{1024^2\,(bps)} \tag{39}$$

Finally, Equation (40) obtains the total delay required when the MN sends the packets to the CN via the HA.

$$\begin{aligned} T_{MN:HA:CN} &= T_{CN:HA:MN} = T_{MN:HA} + T_{HA:CN} \\ &= \left\{ \frac{q4}{BW_{wl}} + \frac{h \times q1 + (k-1) \times q4}{BW_{wd}} \right\} \frac{8\,(bit)}{10^3 \times 1024^2\,(bps)} \end{aligned} \tag{40}$$

The delay for the packet transmission between an MN and a CN using the route optimization and the bidirectional tunneling, are obtained by Equation (41) and (42), respectively.

$$\begin{aligned} T_{ROS} &= T_{ROPro} + T_{MN:CN} + T_{CN:MN} \\ &= T_{RR} + pT_{Msg} + \sum_{i=2}^{10} p(1-p)^{i-1}(T_{Msg} + T_w) \\ &+ \left\{ \frac{q2+q3}{BW_{wl}} + \frac{(m-1)(q2+q3)}{BW_{wd}} \right\} \times \frac{8\,(bit)}{10^3 \times 1024^2\,(bps)} \end{aligned} \tag{41}$$

$$\begin{aligned} T_{TR} &= T_{MN:HA:CN} + T_{CN:HA:MN} = 2 \times (T_{MN:HA:CN}) \\ &= \left\{ \frac{q4}{BW_{wl}} + \frac{h \times q1 + (k-1) \times q4}{BW_{wd}} \right\} \frac{8\,(bit)}{10^3 \times 1024^2\,(bps)} \end{aligned} \tag{42}$$

2. The Results of Performance Evaluation

In this section, This thesis would compare performance of Bidirectional Tunneling (BT) and Route Optimization (RO) considering the security and then show the results. The most of values used in the figures are ones described in the previous chapter. Recall that the average bandwidth in wired network is 10 times as high as that in wireless network. Note that variables are able to be set the various values in addition to the fixed values in Table 7.

Figure 43-58 show the case of BT with the number of hops from the MN to the CN through the HA (k=4, h=6, $k+h$=10) and those of RO with the number of hops from the MN to the CN without routing via the HA (m=5 and m=8). In Figure 43-48, as the size of transfer data increase, both of the delays of BT and RO do. The cases of the low bandwidth (1Mbps) show in Figure 43 and 46, ones of middle bandwidth (10Mbps) do in Figure 44 and 47, and ones of high bandwidth (100Mbps) do in Figure 45 and 48. Figure 41, 44, and 45 provide threshold values at the specific points in the case of the success probability of the BU message p = 0.99. On the other hand, in the case of p = 0.999, the delay of BT is always larger than that of OR at all points except for the first point in Figure 46, 47, and 48.

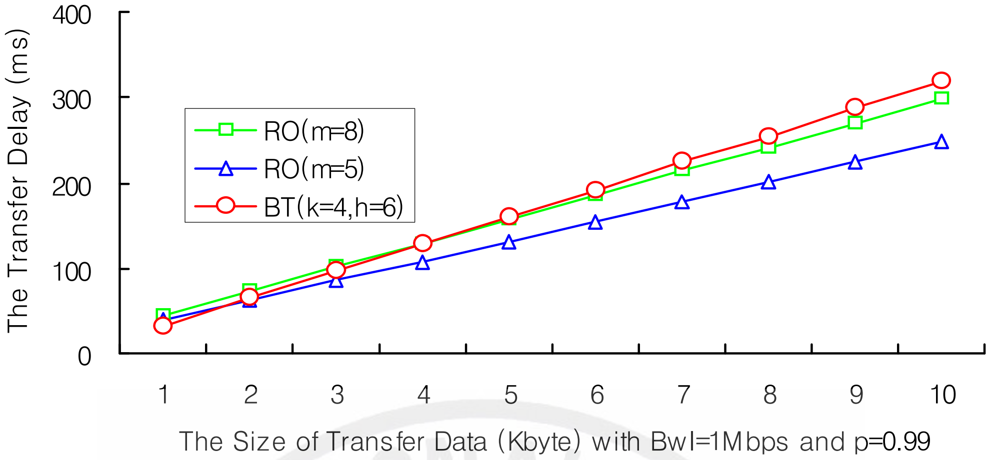

Figure 43. The delay comparison according to the size of transfer data with BW_{wl}=1Mbps and p=0.99

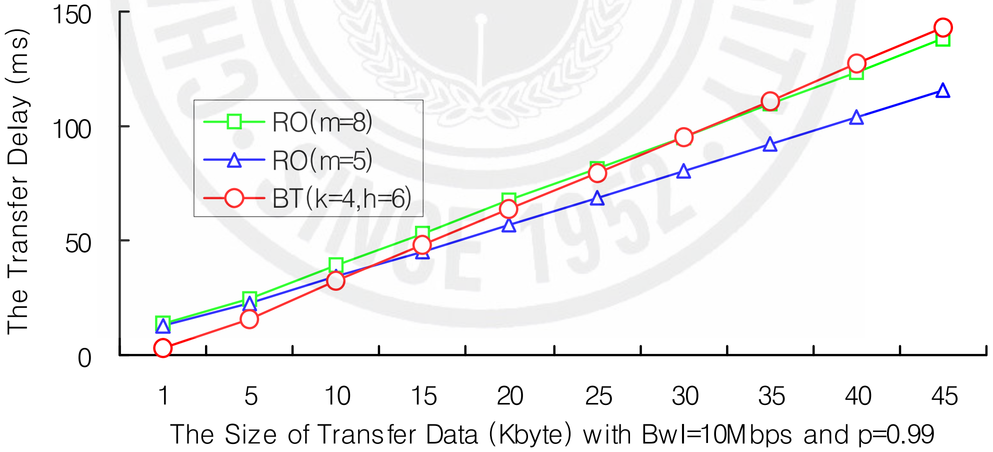

Figure 44. The delay comparison according to the size of transfer data with BW_{wl}=10Mbps and p=0.99

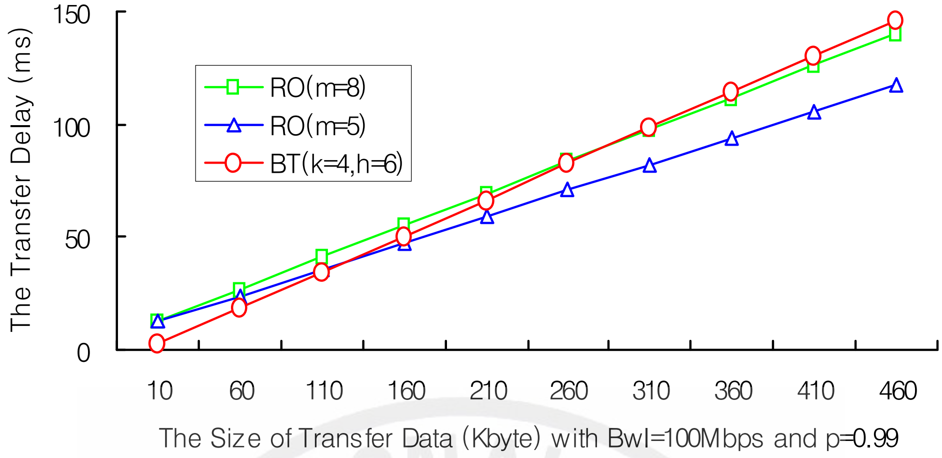

Figure 45. The delay comparison according to the size of transfer data with *BW_{wl}*=100Mbps and *p*=0.99

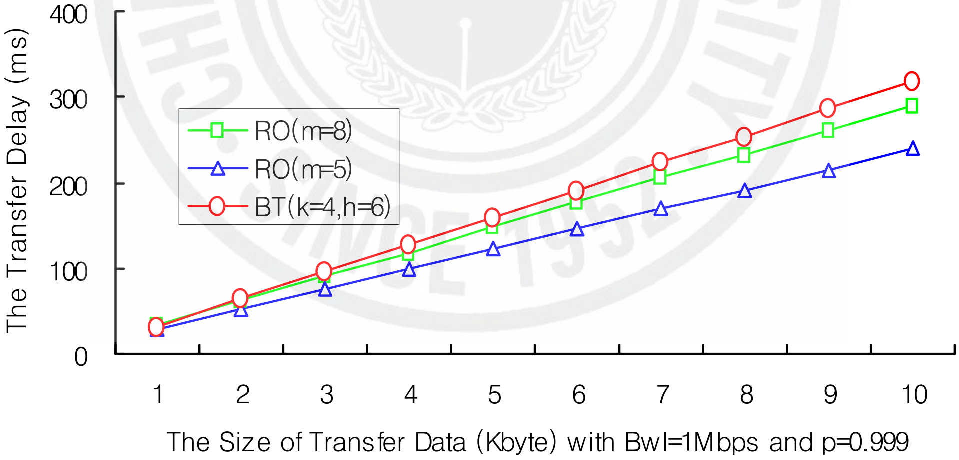

Figure 46. The delay comparison according to the size of transfer data with *BW_{wl}*=1Mbps and *p*=0.999

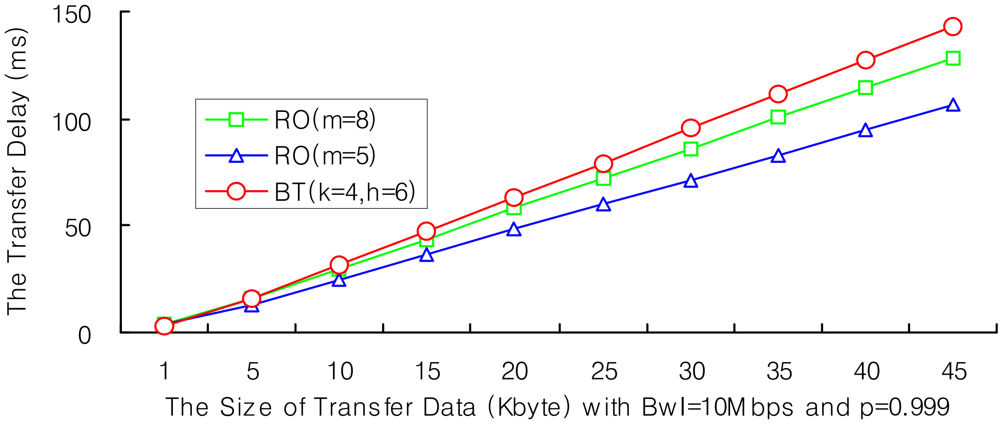

Figure 47. The delay comparison according to the size of transfer data with BW_{wl}=10Mbps and p=0.999

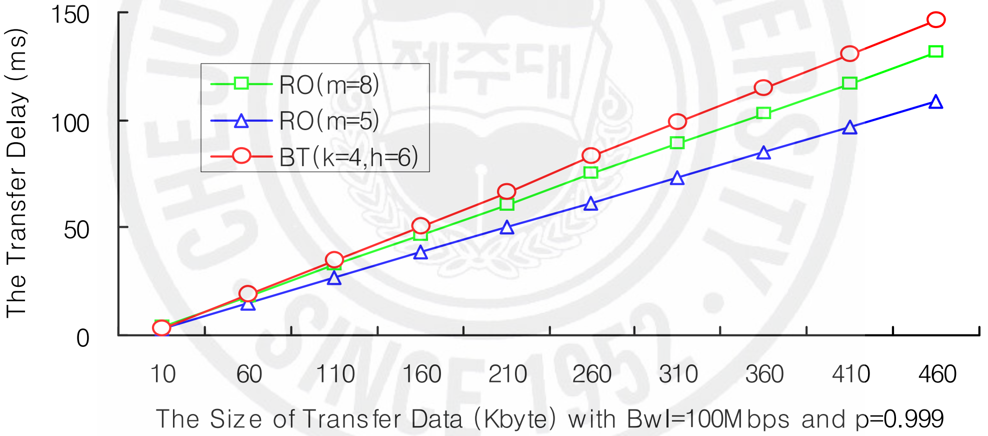

Figure 48. The delay comparison according to the size of transfer data with BW_{wl}=100Mbps and p=0.999

Figure 49-52 shows that the larger the success probability of the BU message p is, the smaller the delay of OR is. The delay of BT is consistent whatever the value of p is. Because the additional delay of BT does not contain transmission of the BU message. Figure 49 and 51 are the cases of the short term packets

(1K) while Figure 50 and 52 are ones of the middle term packets (10K). Figure 49 and 52 provide the threshold values between BT and RO at the specific points. The delay of BT is always smaller than that of and RO in Figure 51 while the former is always larger than the latter in Figure 50.

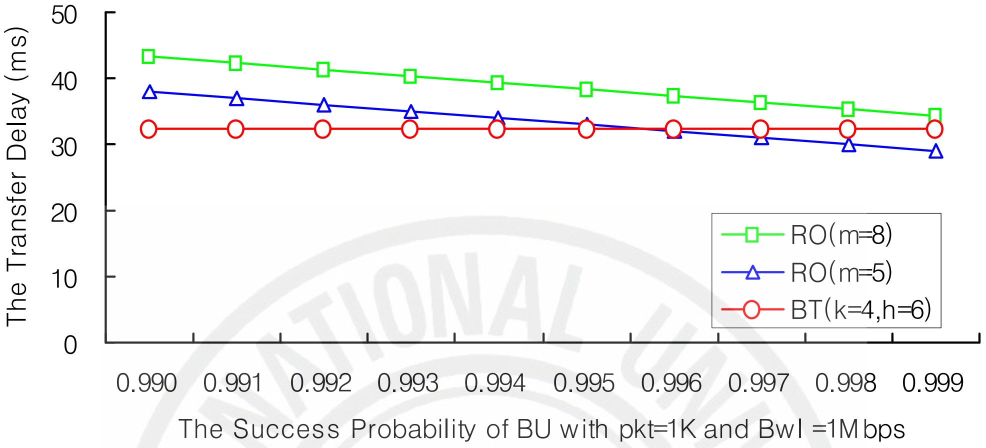

Figure 49. The delay comparison according to the success probability of the BU Message with *pkt*=1K and BW_{wl}=1Mbps

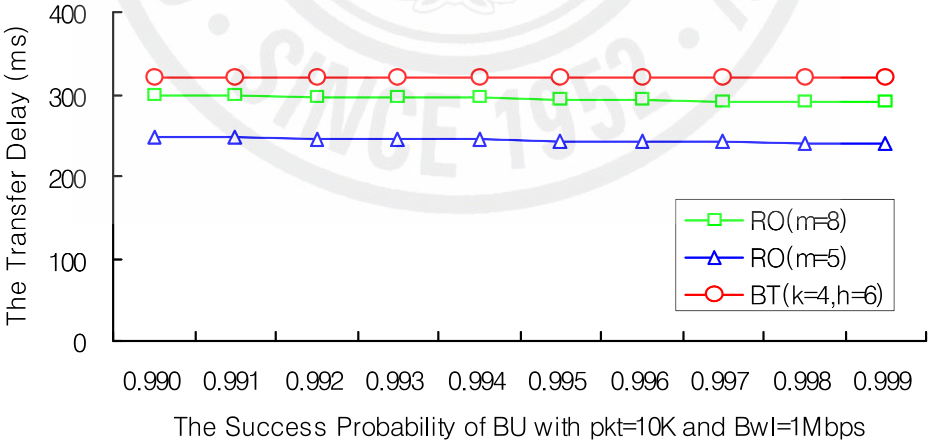

Figure 50. The delay comparison according to the success probability of the BU Message with *pkt*=10K and BW_{wl}=1Mbps

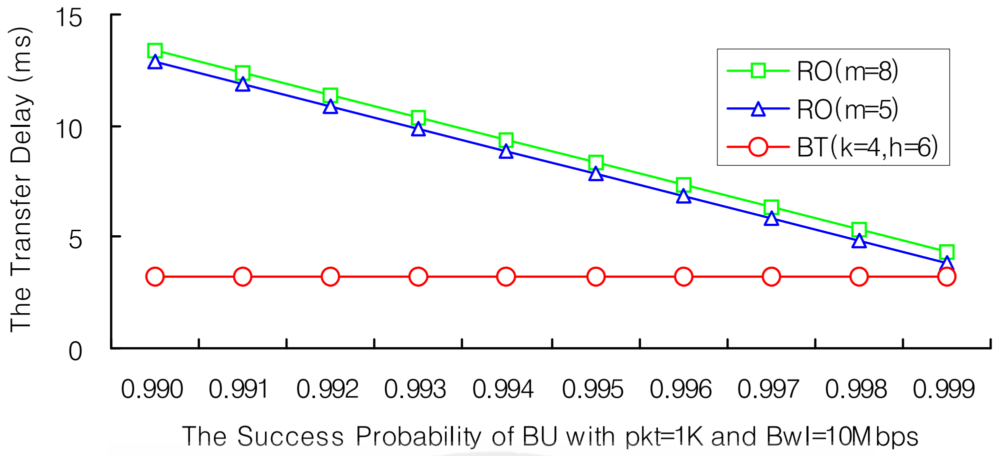

Figure 51. The delay comparison according to the success probability of the BU Message with pkt=1K and BW_{wl}=10Mbps

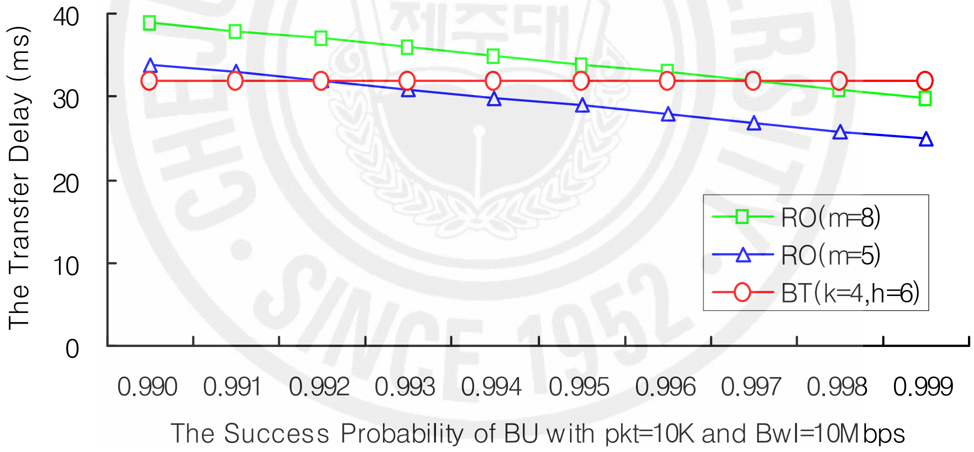

Figure 52. The delay comparison according to the success probability of the BU Message with pkt=10K and BW_{wl}=10Mbps

In Figure 53-58, the transmission delay decreases as the size of the bandwidth increases. Figure 53-55 are the cases of the success probability of the BU message p = 0.99, and Figure 56-58 are ones of p = 0.999. Figure 53 and 56 are the cases of the short term packets (1K), Figure 54 and 57 ones of the middle term packets (10K), and the other figures ones of the long term packets (100K). The delay of BT is the smallest at all points in Figure 53 while it is the largest at all points in Figure 57 and 58. The other figures show the threshold values between BT and RO at the specific points.

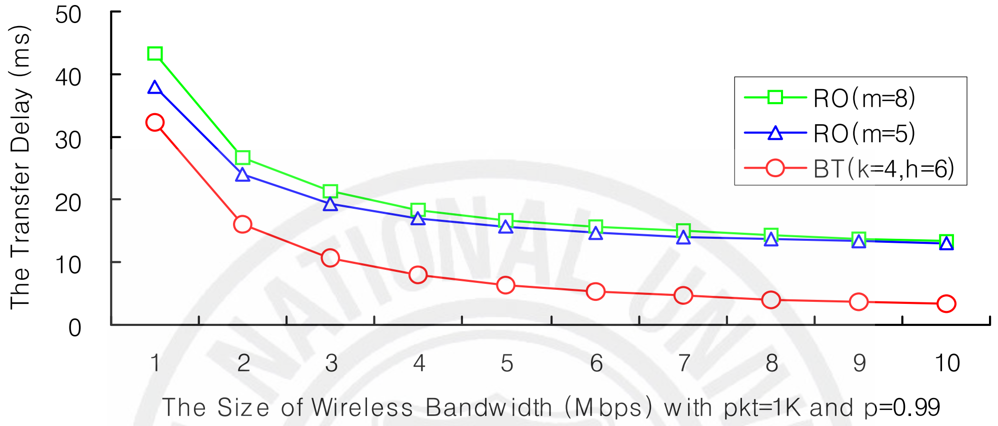

Figure 53. The delay comparison according to the bandwidth in wireless networks with *pkt*=1K and *p*=0.99

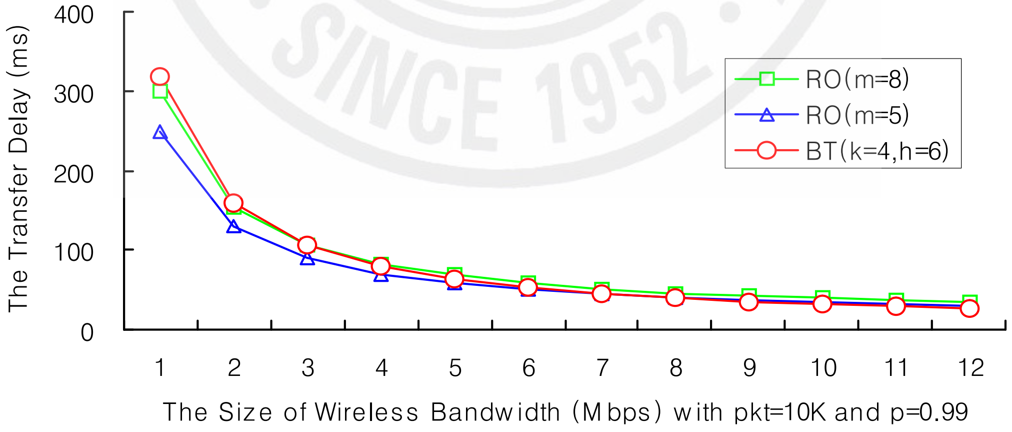

Figure 54. The delay comparison according to the bandwidth in wireless networks with *pkt*=10K and *p*=0.99

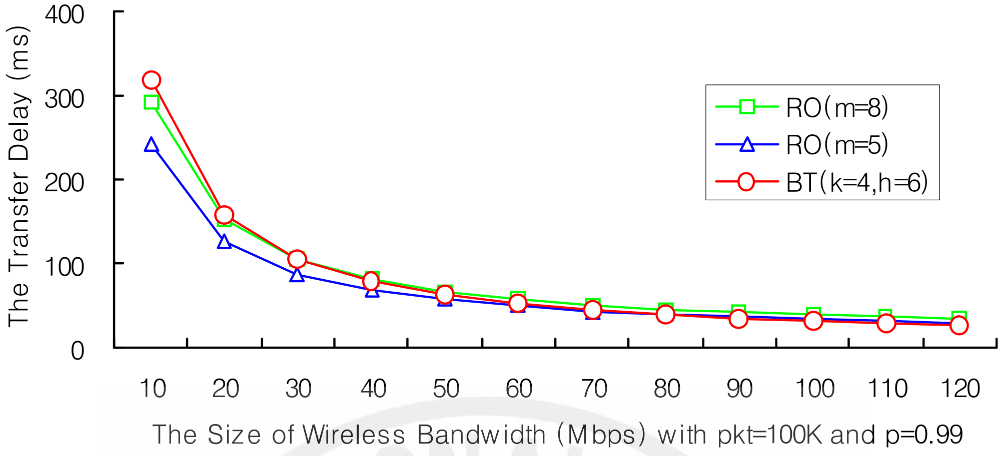

Figure 55. The delay comparison according to the bandwidth in wireless networks with *pkt*=100K and *p*=0.99

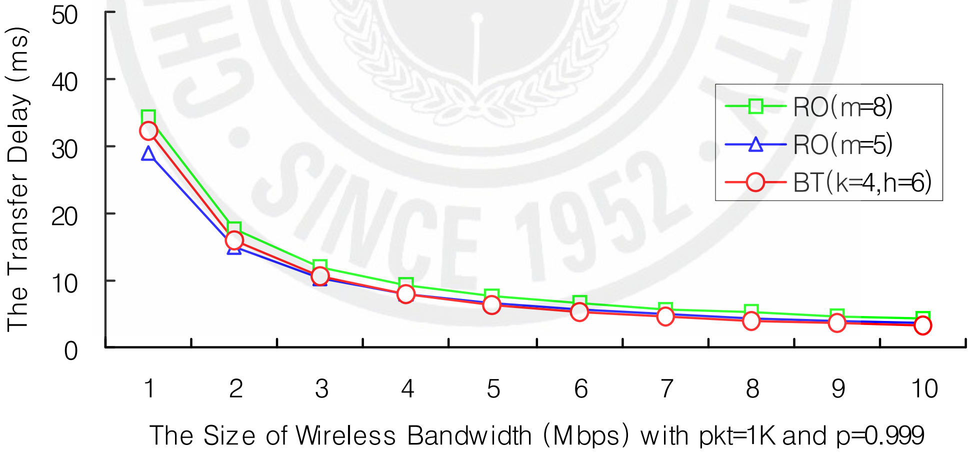

Figure 56. The delay comparison according to the bandwidth in wireless networks with *pkt*=1K and *p*=0.999

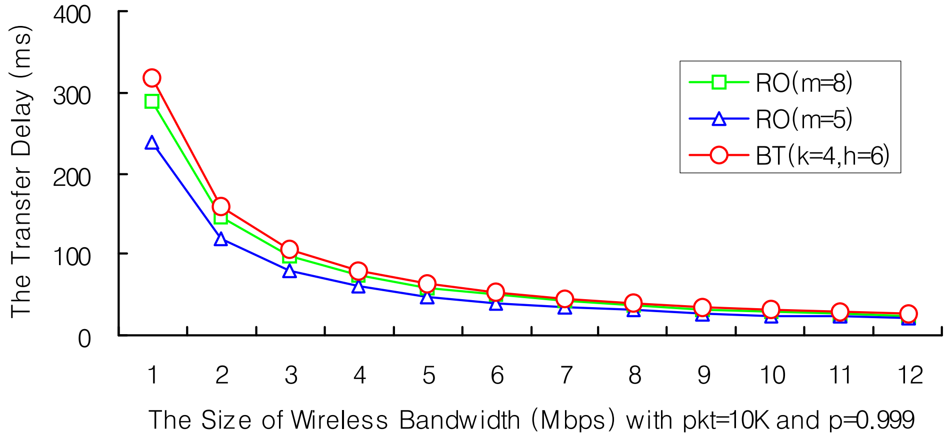

Figure 57. The delay comparison according to the bandwidth in wireless networks with *pkt*=10K and *p*=0.999

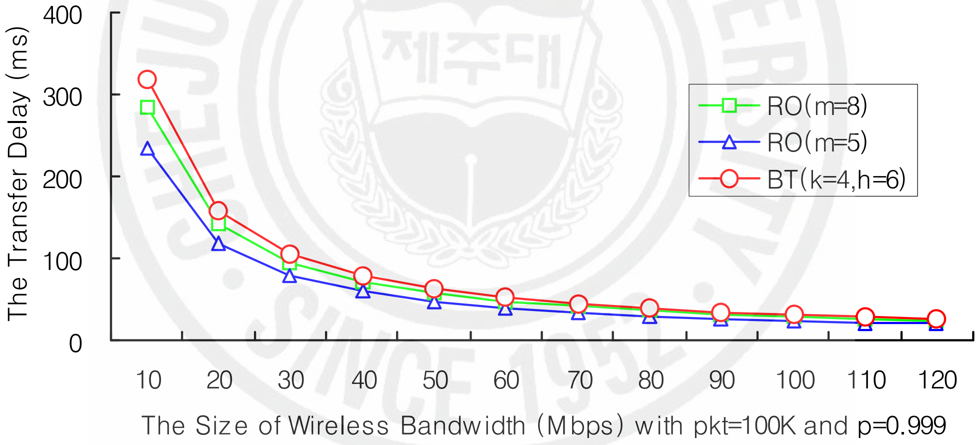

Figure 58. The delay comparison according to the bandwidth in wireless networks with *pkt*=100K and *p*=0.999

Figure 59-64 shows how much the change of the number of hops from the MN and to the HA, *k* affects the total delay of BT when the number of hops from the MN to the N, (*k*+*h*) is fixed by 11. The cases of the success probability of the BU message *p* = 0.99 are in Figure 59, 60, and 61 , while ones of *p* = 0.999

are in Figure 62, 63, and 64, in terms of the short, middle, and long term packets, respectively. In all cases in Figure 59 and 62, the larger the number of hops between the MN and the HA, *k* is, the larger both of the delays of BT and RO will become. The delay of BT than that of RO has a little more change according to *k*, but the difference is not at most one hop in all cases.

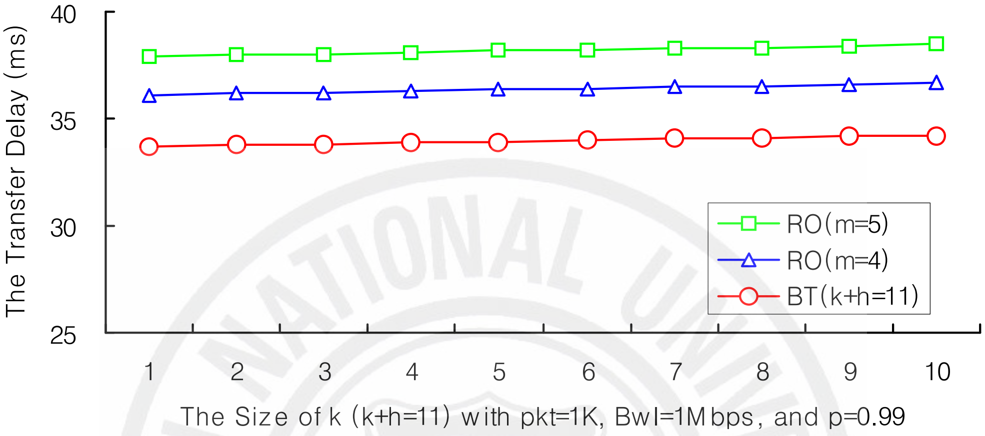

Figure 59. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=1Mbps and p=0.99

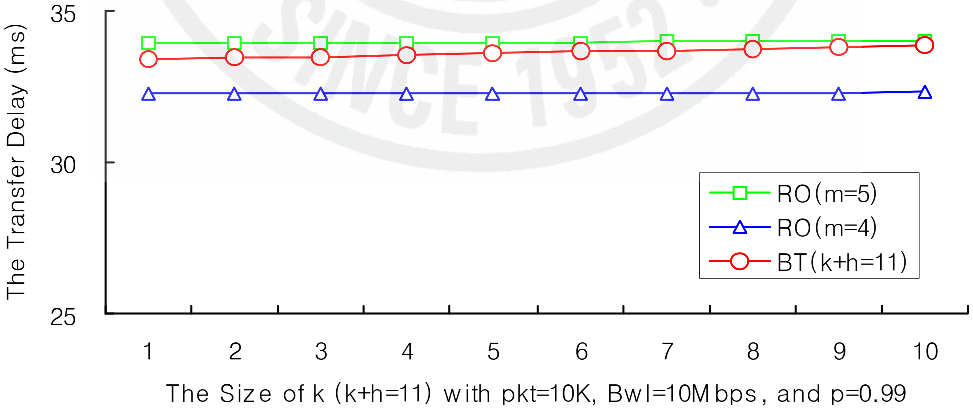

Figure 60. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=10Mbps and p=0.99

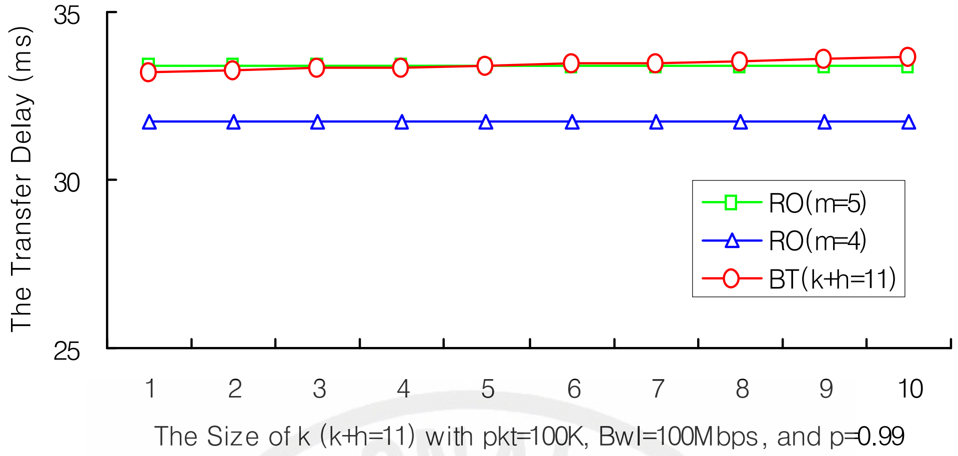

Figure 61. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=100Mbps and p=0.99

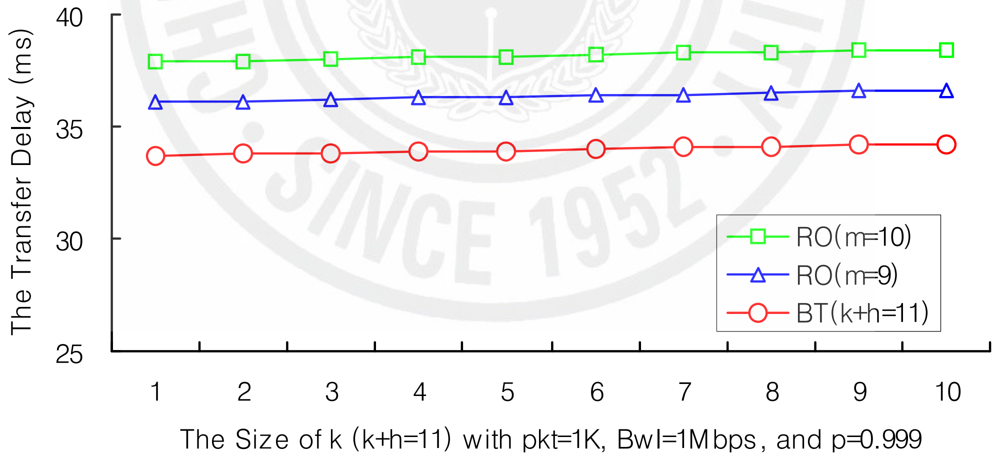

Figure 62. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=1Mbps and p=0.999

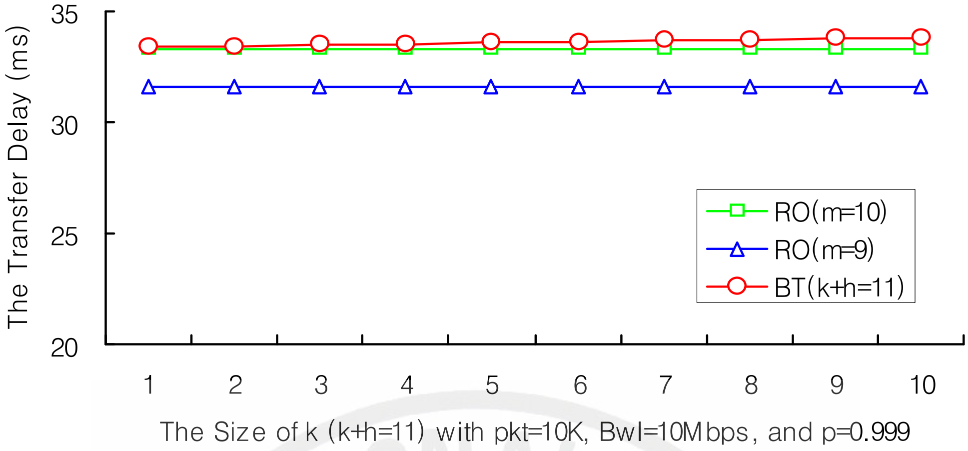

Figure 63. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=10Mbps and p=0.999

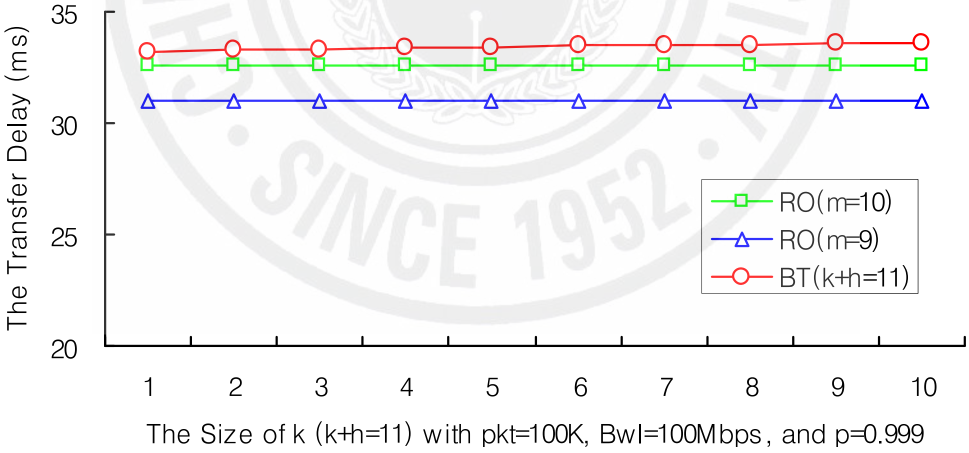

Figure 64. The delay comparison according to the number of hops from the MN to the HA with BW_{wl}=100Mbps and p=0.999

VII. Mobility Support Scheme in Hierarchical Mobile IPv6

This chapter introduces the mobility support scheme for fast moving objects and provides the threshold values resulting from the proposed analytical models in Hierarchical Mobile IPv6 (HMIPv6) networks.

1. The Proposed Scheme (Shin et al. 2006)

Figure 65 describes the basic operation of the proposed handover scheme. The main idea of the proposed scheme is that it carries out the MAP binding with an MN's home address instead of its RCoA. When an MN enters a new MAP domain as shown in Figure 65, it discovers a new MAP domain as receiving the MAP Option advertised by the MAP. And then it needs to configure only one CoA (LCoA) without configuring a new RCoA when it moves into the MAP domain. The MN initializes the MAP registration (a local BU) with its LCoA and its Home Address. The LCoA is used as the source address of the BU message as done in the HMIPv6 and home address is included in the home address Option. On the other hand, the MAP will bind the LCoA to the home address instead of the RCoA (required in the HMIPv6) Thus, the proposed scheme does not have to perform the DAD process for the RCoA any more. Note the fact that the MN's home address replaces its RCoA. The last process registering with the MAP is identical as done in the standard HMIPv6.

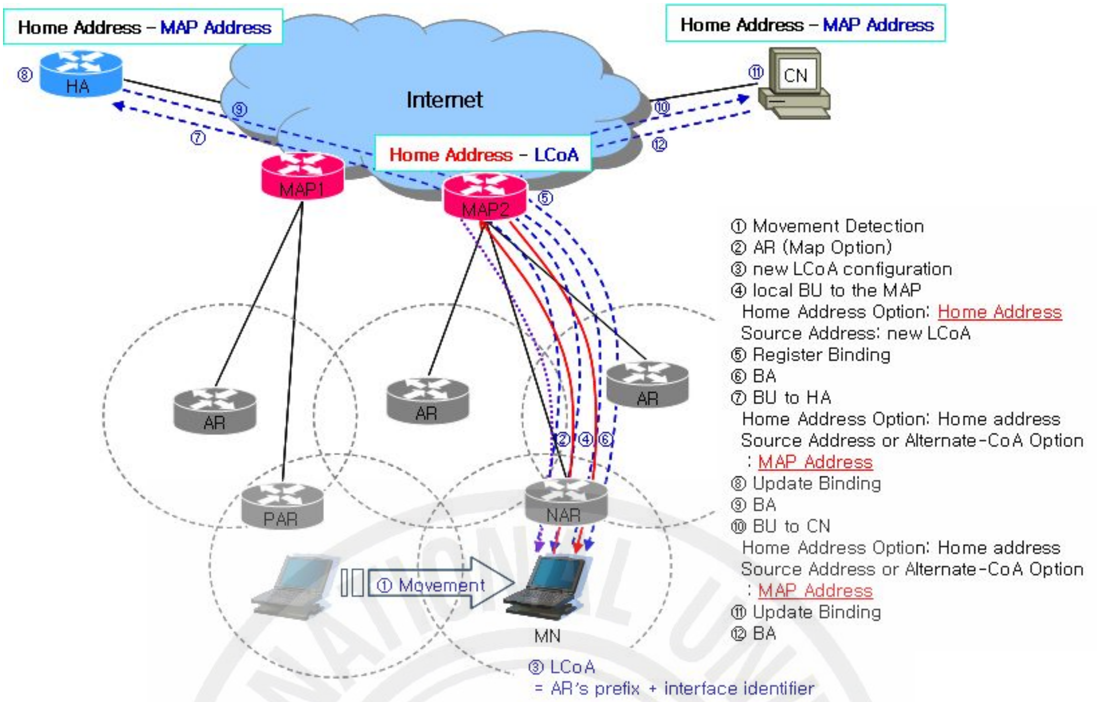

Figure 65. The proposed handover process in macro mobility in the HMIPv6

After the MAP registration, the MN must register its MAP's IP address, included in the MAP Option, with its HA or CNs by sending a BU message that specifies the binding of the MAP's IP address and its home address. The home address is put in the Home Address Option and the MAP's IP address can be involved in the source address field or the Alternate Care-of Address Option. Note that the IP address of the MAP is used instead of the RCoA.

In the case that an MN enters the same MAP domain as shown in the Figure 66, this scheme also performs the equal operation except that the MN performs a local BU with the home address instead of the RCoA. So the specification of this handover process is omitted in this thesis.

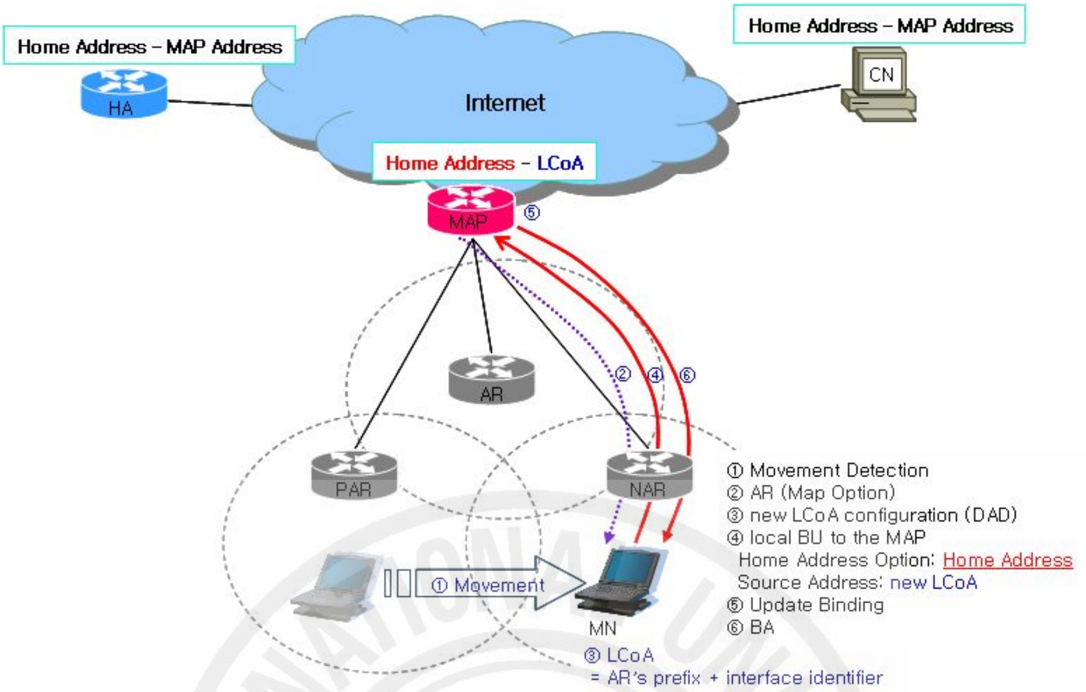

Figure 66. The proposed handover process in micro mobility in the HMIPv6

The most important difference between the proposed scheme and the normal scheme used in HMIPv6 is whether the RCoA is used or not. The proposed scheme does not need the RCoA configuration and the corresponding DAD procedure for the address. Instead, the HA and CNs should include the MN's home address in the packets if they will send the packets to any MN since they know only the location of the MAP (the MAP's IP address) and the MAP maintains the binding between the MN's home address and its LCoA.

The proposed scheme deletes the overhead of configuring the RCoA and the DAD procedure for the RCoA, while adding the overhead of the HA or CN due to the additional amount of the data packets which should include the home address. Thus, the proposed scheme will be appropriate for the application like Telematics where a mobile user moves very fast across MAP domains. The next section will show performance evaluation considering these costs.

2. The Proposed Analytical Model

This thesis assumes that an MN is a fast moving object which moves very fast across MAP domain. The fast moving object, such as a vehicle, is suitable in the environment like the Telematics.

The total of the handover latency is obtained by aggregating the delay during Movement Detection, New CoA Configuration, and Binding Update process. And the cost of the New CoA Configuration again consists of that of CoA generation and that of the corresponding DAD procedure. The delay of the CoA generation that is formed only by appending the interface identifier to the prefix, involved in the RA message, is small enough to be ignored. The procedure for the DAD uses Neighbor Solicitation (NS) message (Narton et al. 1998). The DAD must take place on all unicast addresses (CoAs) (Thomson and Narton 1998). Total necessary packet size for the DAD process is 84 bytes which consist of the IP Basic Header (40 bytes) (Deering and Hindon 1998), Authentication Extension Header (20 bytes) (Kent and Atkinson 1998), and the ICMP packet (24 bytes). The HMIPv6 has the additional delay to process the DAD procedure during the handover unlike the proposed scheme. On the other hand, in the proposed scheme, the HA should forward a larger size of packets to corresponding MAP in order to include the Home Address in the packet. To append the Home Address to the packet, the Home Address Option (Johnson et al. 2004) is used. The Home Address Option is a part of the Destination Options Header which is one of the IPv6 Extension Headers (Deering and Hindon 1998). The additional amount of the packets for the Home Address Option is 20 bytes. Therefore, the performance evaluation compares the proposed scheme with that in the HMIPv6 using the RCoA in terms of these costs, the DAD delay and the packet size, and excludes the identical parts.

Table 8 shows the notations used in the proposed analytical model. The MN's speed is decided by standardizing the moving speed of vehicles. The Maximum Transmission Unit (MTU) can restrict the size of packets without exceeding the link MTU [14]. The default MTU size for IPv6 packets on an Ethernet is 1500 bytes as specified in the (Narton et al. 1998) and (Crawford 1998). The network delay per an MTU (D_{Net}) means how long it takes to transfer an MTU. The total number of the MAP update (pkt) and that of the packet transmission (N_{MAP}) mean how often the MAP is updated and how often the packets are transferred during the simulation time, respectively. The delay for the DAD is set to the MAX_RTX_SOLICITATION_DELAY (1 second), the maximum transmission delay of the NS message (Narton et al. 1998, Dunmore 2004). The DAD procedure cannot be completed and should be again attempted in the case either that a node receives the Neighbor Acknowledgement (NA) message (the response of NS) informing the duplication of the required address or that the node receives the NS message containing the same address by another node. This thesis assumes that the node can successfully perform the DAD only if it does not receive these messages during at least 1 second. This thesis assumes that the network transfer speed (V_{Net}) is 50 Kbps. To calculate V_{Net} conveniently, its Kbps unit is converted into byte per second unit as shown in Table 8.

Table 8. The notations used in the analytical model to evaluate the proposed scheme

Notation	Description	Value
T_{sim}	The Total Simulation Time (min)	15
V_{MN}	The MN's Speed (km/min)	1
S_{MAP}	The Size of MAP (km)	1~16
N_{MAP}	The total number of Map Update $= \frac{T_{sim} \times V_{MN}}{S_{MAP}}$	
p	The Frequency of Packet Transmission (1/min)	1~30
N_{pkt}	The Total number of Packet Transmission	
V_{Net}	The Network Transfer Speed (byte per second) $= \frac{50(Kbps) \times 1024}{8}$	6400
D_{Net}	The Network Delay per $PMTU$ (s) $= \frac{p \times PMUT}{V_{Net}}$	
$PMTU$	The Size of Path MTU (byte)	1500
pkt	The Size of Transfer Data (byte)	
IPH	The Size of IP Header (byte)	40
$AuthH$	The Size of Authentication Header (byte)	20
$DOpH$	The Size of Destination Options Header (byte)	20
$FragH$	The Size of Fragment Header (byte)	8
D_{DAD}	The Delay for DAD (s)	1
D_{HMIPv6}	The Delay using the Standard Hierarchical Mobile IPv6 Scheme during T_{sim} (s)	
D_{Proposed}	The Delay using the Proposed Scheme during T_{sim} (s)	

The $\lfloor\ \rfloor$ and $\lceil\ \rceil$ refers the floor function and ceiling function, respectively. The result of the $\lceil\ \rceil$ means how many MTUs can the sending data be divided into. Here the total of the packet size includes the essential IPv6 Header and some of optional IPv6 Extension Headers (Deering and Hindon 1998), which are the Authentication Header, the Destination Options Header, and the Fragment Header. The other IPv6 Extension Headers is omitted due to the variety of its size and the optional preference. As a result, HMIPv6 and proposed mention the additional delay for the hierarchical handover and that for the proposed scheme, respectively.

The standard scheme in HMIPv6 and the proposed scheme need g1 and g2 in Equation (43), respectively in terms of IPv6 Headers during packet transmission.

$$\begin{aligned} g1 &= IPH + AuthH + FragH \\ g2 &= IPH + AuthH + DOpH + FragH \end{aligned} \tag{43}$$

Equation (44) is obtained by the total delay in normal HMIPv6 scheme, while Equation (45) is by one in the proposed scheme.

$$\begin{aligned} D_{HMIPv6} &= N_{MAP} + D_{DAD} + \left\lceil \frac{pkt}{PMTU - g1} \right\rceil \times D_{Net} \times T_{sim} \\ &= \left\lfloor \frac{T_{sim} \times V_{MN}}{S_{MAP}} \right\rfloor + D_{DAD} + \left\lceil \frac{pkt}{PMTU - g1} \right\rceil \times p \times \frac{PMTU}{V_{Net}} \times T_{sim} \end{aligned} \tag{44}$$

$$D_{\mathrm{Pr}oposed} = \left\lceil \frac{pkt}{PMTU - g2} \right\rceil \times p \times \frac{PMTU}{V_{Net}} \times T_{sim} \tag{45}$$

3. The Results of Performance Evaluation

In this section, this thesis is to compare the delay of the proposed scheme (Proposed) and that of the standard HMIPv6 scheme (HMIPv6) according to the size of transfer data, the size of the MAP, and the frequency of packet transmission.

Figure 67 shows the comparison of Proposed and HMIPv6 delay according to the size of transfer data. The proposed scheme is more effective than the HMIPv6 scheme at the all points except for pkt = 2860 bytes. The worst case means that the proposed scheme needs one more MTU than the standard HMIPv6 scheme by means of the packet transmission, due to the Home Address Option (20 bytes). The probability of these cases is very small. However it cannot be ignored. Such a case will be dealt with in the Figure 70 and 71 using the specific example.

According to the coverage size of the MAP with pkt = 2530 bytes, the delay of the proposed scheme is smaller than that of the HMIPv6 except one point with S_{MAP} = 16km as shown in Figure 68. The point means the case that the MN roams within an MAP domain and does not occur the MAP update resulting in the DAD procedure. The larger the size of MAP is, the smaller the difference between two schemes will become.

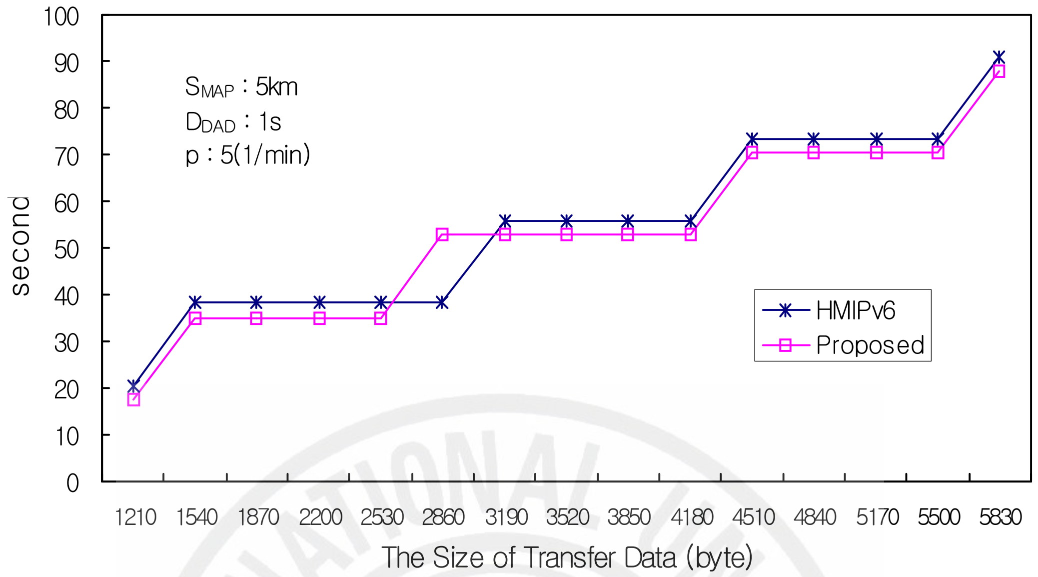

Figure 67. The delay comparison according to the size of transfer data

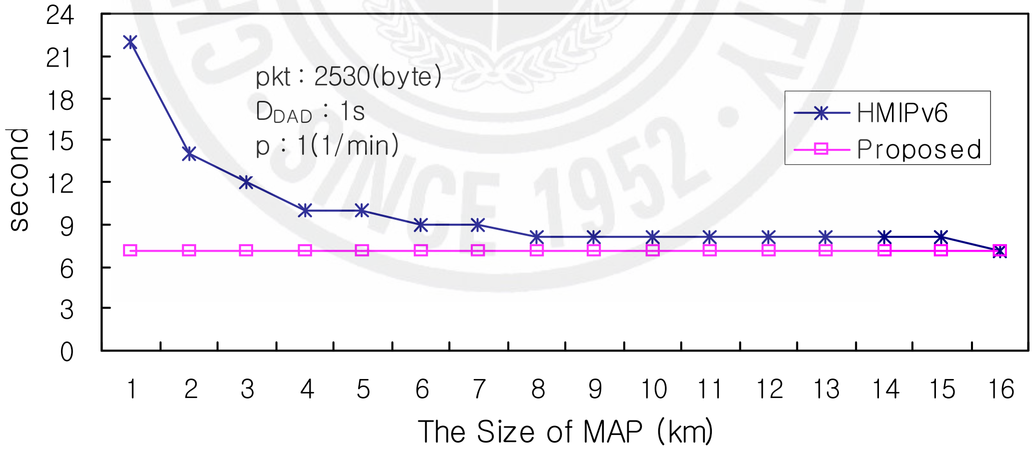

Figure 68. The delay comparison according to the size of MAP with *pkt*=2530bytes

Figure 69 shows that the delay of proposed scheme is less than that of HMIPv6 scheme at the same rate, in terms of the frequency of packet transmission, when *pkt* = 2530 bytes. This difference results from the DAD cost and is small in this case.

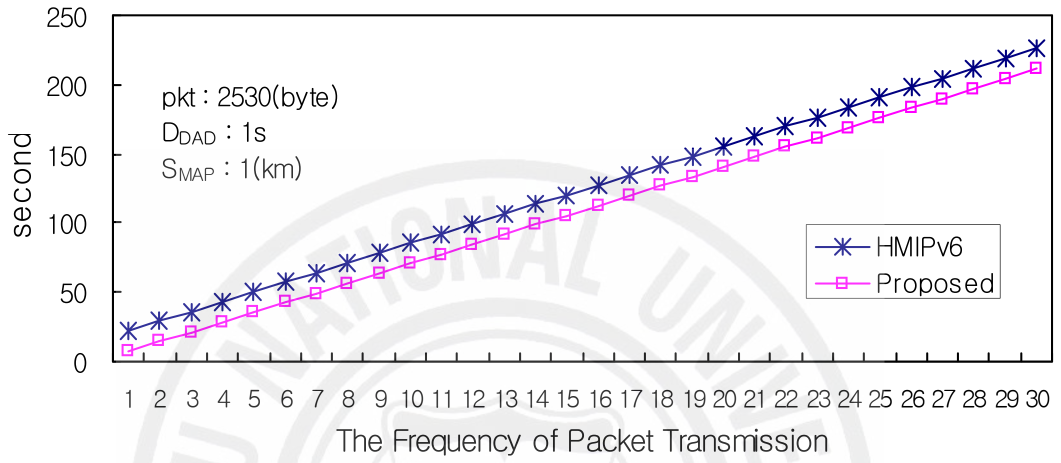

Figure 69. The delay comparison according to the frequency of packet transmission with *pkt*=2530bytes

Figure 70 and 71 show the delay according to the size of the MAP and the frequency of the packet transmission in the worst case that Data *pkt* = 2860 bytes as shown in Figure 67, respectively. Figure 70 provides the threshold value in the point, S_{MAP} = 4km or so, while Figure 71 in the point, p = 4(1/min) approximately. For these particular cases, the proposed scheme is most effective when both of the size of the MAP and the frequency of the packet transmission are small simultaneously.

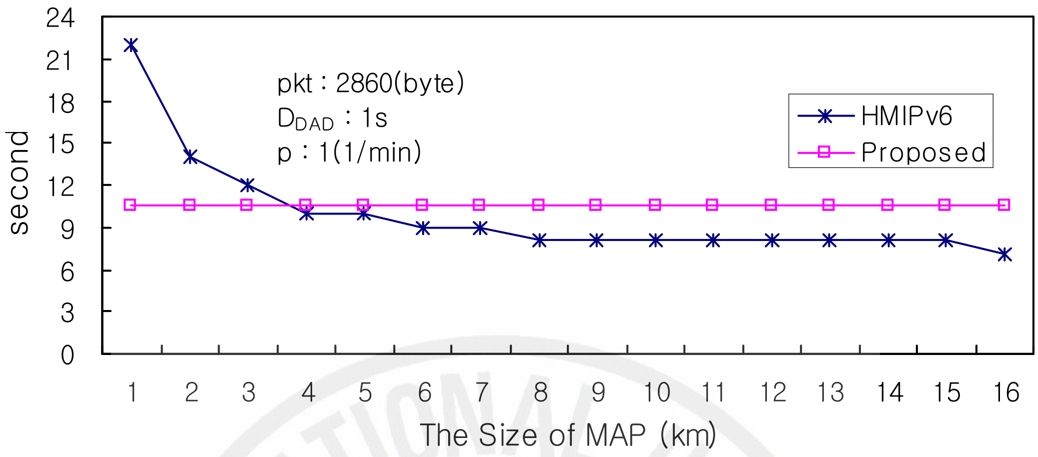

Figure 70. The delay comparison according to the size of MAP with *pkt*=2860bytes

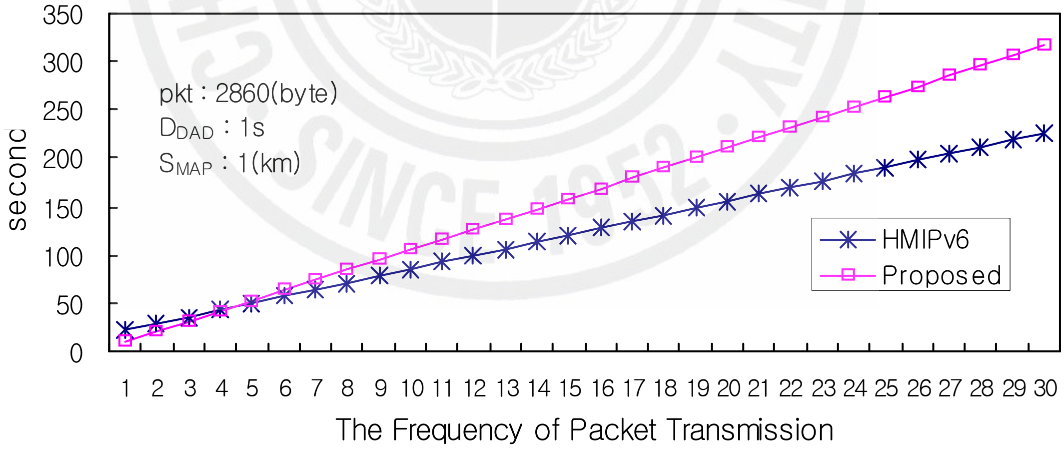

Figure 71. The delay comparison according to the frequency of packet transmission with *pkt*=2860bytes

VIII. Conclusion

This thesis will make a conclusion in cellular mobile, Mobile IP, and hierarchical Mobile IPv6 networks.

The First, in cellular mobile networks, since the location update process requires heavy signaling traffics, reducing the location update cost has been a critical research issue. First, this thesis proposed the SLA scheme employing hierarchical structure in the cellular architecture in order to reduce the location update rate of the HLR and developed analytical models to compare performance of the SLA scheme with that of the conventional scheme. The results obtained from the model show that the proposed scheme outperforms the conventional scheme in terms of the HLR update rate. Also, the difference in the performance becomes larger when the size of the SLA is larger, the size of the LA becomes smaller, and the residual time of the mobile user becomes smaller. However, even in the SLA scheme, the boundary location areas still cause the frequent location updates. Thus, this thesis proposed to apply overlapping location areas to further reduce the location update rates of the HLR. It also developed analytical models to evaluate the performance of the conventional scheme, the SLA scheme, and the proposed scheme (or the OSLA scheme). The results from the performance evaluation show that the proposed scheme outperforms the SLA scheme which, in turn, outperforms the conventional scheme. This thesis also evaluates the threshold values with which the OSLA scheme outperforms the conventional scheme. The proposed approach will be viable considering the fact that the cost of communication channel is being increased while that of hardware is being decreased.

The second, reducing the handover latency is a critical issue in Mobile IPv6. This thesis proposed the route optimization scheme which can decide whether an MN would rather route optimization method when it is to deliver packets the communicating CN. To make such a decision, this thesis develops the analytical models to compare the additional delays of the bidirectional tunneling method and the route optimization method, taking into account several important factors such as the packet type (long, middle, or short term packets) between the MN and the CN, the number of hops between them, the network bandwidth, and the failure rate of the binding update procedure. Note that this thesis puts focus on performance evaluation of the Mobile IPv6 route optimization with Mobile IP security or not. Specifically, Mobile IP security considerations are to authorize the binding update process which needs the additional options in BU/BA message as well as the RR procedure before the correspondent registration. Thus, it presents the threshold values to decide whether the MN should use the route optimization or not under various situations according to whether considering security or not. The proposed model also provides the approximate guideline when a network administrator is to implement mobile IPv6 with the route optimization capability, given the network environments such as the possible network bandwidth, the type of the packets, and the geographical location of the MN. In addition, the models would be extended or specified, by adding more detailed functions and capability to the MN as well as considering more detailed and diverse conditions, to enable them adapt to even the novel and variant schemes of standard Mobile IPv6 such that the improved models can present the affluent performance comparison among such schemes. In near future, the model aims to help implement the smart MN which decides by itself whether the route optimization is needed or not by adding more detailed functions and capability to the MN, considering diverse conditions.

The third, hierarchical Mobile IPv6 is an more improved protocol than the normal

Mobile IPv6 to reduce the handover latency. This thesis proposes a variation of the handover scheme used in the HMIPv6. The thesis develops the analytical models to compare the performance of the proposed scheme and the standard HMIPv6 scheme. The result shows that the proposed scheme is very effective regardless of the frequency of the packet transmission only if it enables the packet to transfer only by a PMTU and the MN moves fast. This thesis also gives many readers the threshold values with which they can select the optimal scheme under various situations. That is, this thesis can act as a guideline when anybody is to select one method out of the two, considering various network environments or various applications. In particular, the proposed scheme can be adapted to the Telematics services where a user drives fast and sometimes receives the Internet services using the terminal in the car.

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초록

인터넷과 모바일 네트워크가 급속도로 활성화됨에 따라, 네트워크 구조에 대한 디자인 문제라든지 단절되지 않도록 이동성 관리를 하기 위한 효과적인 방법들에 관한 연구 활동들이 많이 진행되어 왔다. 본 논문은 셀룰러 모바일 네트워크 (Cellular Mobile Network)와 모바일 아이피 버전 6 네트워크 (Mobile IPv6 Network) 에서 이동성 관리 (Mobility Management) 기법들을 제안하고 그 성능을 평가하고 있다. 특히, 무선 모바일 네트워크에서 움직이는 모바일 사용자들에게 단절되지 않게 서비스를 제공하기 위한 위치 관리 기법은 주요 연구 과제이다. 첫째, 셀룰러 모바일 네트워크에서 위치 업데이트 (Location Update)는 상당한 시그날링 트래픽을 소모하기 때문에, 위치 업데이트 비용을 줄이는 것이 매우 중요한 연구 쟁점이다. 본 논문은 위치 업데이트 비용을 감소시키기 위한 효과적인 위치 관리 전략들을 제시하고 있다. 둘째, 모바일 아이피 버전6은 모바일 사용자가 이동하는 동안 인터넷 서비스를 지속적으로 제공해주기 위한 중요한 프로토콜 중에 하나이다. 모바일 아이피 버전6에는 모바일 노드 (Mobile Node)와 상대 노드 (Correspondent Node)간의 두 가지 통신 방법이 있다. 하나는 모든 패킷들이 홈 에이전트 (Home Agent)를 거쳐 전송되어 지고 홈 에이전트에 의해 터널링되어지는 양방향 터널링 (Bidirectional Tunneling) 방법이고, 다른 하나는 홈 에이전트를 거치지 않고 직접 통신하는 경로 최적화 (Route Optimization)방법이다. 전자를 사용한 전형적인 전송 경로가 종종 후자를 사용한 최적 경로보다 확연히 길어진다. 그러므로 본 논문은 두 방법간의 성능 비교를 통해 얻어진 양적인 평가 결과를 제공한다. 다시 말해서, 본 논문은 모바일 아이피 버전6에서 경로 최적화 기법을 제안한다. 핸드오버 지연시간을 줄이는 것은 모바일 아이피 버전6에서 가장 중요한 연구 쟁점 중에 하나이다. 이러한 연구에는 빠른 핸드오버 (Fast Handover), 계층적 핸드오버 (Hierarchical Handover), 이 두 방법을 결합한 혼합 핸드오버, 그리고 또 다른 변형 기법들이 있다. 본 논문은 또한 계층적 모바일 아이피 버전6 이동성 관리 (Hierarchical Mobile IPv6 Mobility Management)에서의 핸드오버를 변형한 또 다른 기법을 제안한다.

본 논문은 크게 5가지 주요 기법, 즉 셀룰러 네트워크에서의 계층적 기법과 오버랩 기법, 모바일 아이피 버전6에서 경로 최적화 기법과 보안을 고려한 경로 최적화 기법, 계층적 모바일 아이피 버전6에서의 이동성 지원 기법으로 구성된다.

첫 번째 파트에서는 셀룰러 모바일 네트워크에서 위치 업데이트 비용을 줄이기 위해서 계층 구조를 고용한 기법을 제안하고 있다. 또한, 이 기법은 셀룰러 모바일 네트워크에서 전형적인 기법과 비교하여 성능을 평가하기 위한 분석 모델을 제안하고 있다. 평가 결과는 제안 기법이 홈 위치 레지스터 (Home Location Register)의 업데이트 비용을 줄임으로써 총 위치 업데이트 비용을 감소시킨다. 계층을 더 많이 하면 할수록 그리고 위치 영역 (Location Area)의 크기가 작아지면 질수록, 위치 업데이트 비용은 더 많이 감소된다.

두 번째 파트에서는 셀룰러 모바일 네트워크에서 위치 영역을 오버랩함으로써 위에서 언급한 계층 기법을 확장시키고 있다. 다시 말해서, 이 기법은 셀룰러 모바일 네트워크에서 위치 업데이트 비용을 계층적 기법보다 훨씬 더 줄일 뿐만 아니라 경계 영역에서 집중적으로 발생하는 위치 업데이트를 어느 정도 분산시키는 효과적인 위치 관리 기법을 제안하고 있다. 게다가, 이 논문은 다양한 조건하에서 전형적인 기법과 계층적 기법과 제안 기법의 성능을 평가하기 위한 향상된 분석 모델을 제시하고 있다. 성능 평가의 결과는 제안 기법이 위치 업데이트 비용을 상당히 감소시켰음을 보여주고 있다.

세 번째 파트에서는 모바일 아이피 버전6에서 경로 최적화 기법를 제안할 뿐만 아니라, 양방향 터널링 방법과 경로 최적화 방법간의 성능을 비교하기 위한 분석 모델을 제안하고 있다. 제안 모델은 패킷 형태 (장기 패킷, 단기 패킷), 호스트간의 홉 수, 네트워크 대역폭, 바인딩 업데이트 (Binding Update)의 실패율 등과 같은 여러 중요한 요소들을 고려하고 있다. 또한, 이 논문은 관심 독자들이 경로 최적화를 적용할 것인지 아닌지를 결정할 수 있도록 한계값을 제공한다. 제안 모델은 네트워크 관리자가 주어진 네트워크 환경 하에서 경로 최적화를 가능한 모바일 아이피 버전6을 구현하고자 할 때, 근사적인 가이드라인을 제공한다. 가까운 장래에, 이 논문은

경로 최적화가 필요한지 아닌지를 스스로 결정하는 스마트 모바일 노드를 구현하는데 보탬이 되고자 한다.

네 번째 파트에서는 모바일 아이피 버전6 보안을 고려한 경로 최적화 기법을 제안한다. 세 번째 파트에서의 이전 기법은 홈 에이전트와 상대 노드들에게 보내는 바인딩 업데이트의 보안을 보장하지 않았음에 주목하라. 이 기법은 경로 최적화 기법와의 성능비교에 있어서, 바인딩 업데이트를 인증하는 모바일 아이피 버전6 보안을 고려하여 좀 더 향상된 분석 모델을 제안하고 있고, 성능 비교로부터 나온 양적 결과를 제시하고 있다. 이 결과는 모바일 노드가 경로 최적화를 사용하는 것이 더 나은지 혹은 그렇지 않은지를 결정하기 위한 한계값을 보여준다. 제안 모델은 네트워크 관리자가 주어진 환경 조건하에서 보안을 고려한 경로 최적화 모바일 아이피 버전6을 구현하고자 할 때 대략적인 가이드라인 역할을 하고 있다. 게다가, 이 기법은 좀 더 상세 조건들을 고려하고 모바일 노드에 더 많은 기능을 추가함으로써, 자율적으로 경로 최적화를 사용해야 할 것인지 말아야 하는지를 결정짓는 스마트 모바일 노드를 구현하는데 도움을 줄 것이다.

마지막 파트에서는 계층적 모바일 아이피 버전6에서 사용되었던 핸드오버 방법을 변형한 새로운 기법을 제안하다. 이 기법은 역시 계층적 모바일 아이피 버전6에서의 표준 핸드오버 기법과의 성능을 비교하기 위한 분석 모델을 개발하였다. 성능 평가 결과는, 모바일 노드가 빠른 속도로 이동하는 경우에 전송 패킷의 횟수에 상관없이 제안기법이 매우 효과적임을 보여주고 있다. 특히, 제안 기법은 사용자가 운전하면서 자동차 안에서 텔레매틱스 단말기를 통해 때때로 웹 서비스를 이용할 수 있는 텔레매틱스 환경에 적용가능하다. 또한 이 논문은 독자들에게 기존 애플리케이션에서 최적의 핸드오버 기법을 선택할 수 있도록 한계값을 제공한다.

감사의 글

대학 초년부터 나의 가슴 한 켠에 막연하게 자리잡고 있었던 꿈들이 하나하나 현실화되어지는 순간을 맞이하면서 무한한 가능성과 그 열정을 키워왔습니다. 이제 이렇게 박사학위 논문을 그 결실의 하나로써 얻게 되었음을 깊이 감사하게 생각합니다. 단 한 걸음에 오를 수 있는 산이 없듯이, 나의 학문에 대한 길 또한 순탄치만은 않았지만, 그 힘들고 멀게만 느껴지던 길을 나를 격려하고 지켜봐주는 이들이 있어 포기하지 않고 묵묵히 걸어갈 수 있었던 것 같습니다. 내가 걸어온 그 길 한 고비 한 고비가 나에겐 소중한 추억이자 지금의 나를 있게 해준 밑거름입니다. 나의 과거를 돌이켜보니 작고 보잘 것 없이 보이는 한 소녀가 호기심 어린 눈으로 세상 앞에 우두커니 서 있습니다. 그 꿈 많지만 철없던 소녀가 여러분들에게 이 지면을 빌어 감사의 말씀을 드립니다.

우선 이 논문이 완성되기까지 덜렁거리고 성급한 저에게 많은 관심과 격려뿐만 아니라 진심어린 충고로 저를 오랜 시간 늘 변함없이 따뜻하게 지도해 주시며 저에게 항상 귀감이 되어 주신 박경린 교수님께 진심으로 감사드립니다. 제게 많은 기회를 주셨고 넓은 세상을 보게 해 주신 교수님의 은혜를 제 가슴속 깊은 속에 새겨 두겠습니다. 그리고 곁에서 늘 세심하게 보살펴 주신 이정훈 교수님께도 진심으로 감사의 말씀을 드리며, 또한 교수님을 대하는 편안함속에 무한한 존경심과 사랑이 있음을 잊지 마십시오. 또한 학부시절부터 줄곧 깊은 관심과 배려로 보살펴 주셨던 김철수 교수님, 김익찬 교수님, 이봉규 교수님께 감사드리며, 바쁘신 중에도 미흡한 저의 논문 심사를 기꺼이 맡아 주던 송왕철 교수님과 이윤정 교수님께도 감사를 드립니다.

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을 아끼지 않았던 학과 조교들, 그리고 학과 후배들에게도 고마움을 전합니다. 더불어 제가 힘들 때마다 저를 지켜봐 주신 많은 분들께 고마움을 전하며 기쁨을 함께 나누고 싶습니다.

가지 많은 나무에 바람 잘날 없는 시끌벅적한 가족사 속에서도 저를 위해 보이지 않는 곳에서 걱정하고 곁에 있는 것만으로도 저에게 힘이 되어주신 저의 소중한 부모님과 큰 언니가족, 둘째 언니 가족, 큰 오빠, 남동생을 비롯한 사랑하는 가족들에게 마음 깊이 감사드리고, 부족하지만 대학원 생활의 마지막 결실인 이 논문을 바칩니다.

씨앗이 혼자서 새싹이 되고 열매를 맺을 수 없듯이, 저에게 토양이 되어 주시고 태양이 되어 주시고 물이 되어주신 이 모든 분들에게 앞으로도 꾸준히 하루하루 노력하는 모습으로 보답하겠습니다. 그리고 앞으로 제가 일궈낼 소중하고 값진 열매를 진정 필요한 사람들에게 돌려드리겠습니다. 감사합니다.

2007년 6월

신 인 혜 올림