An IPv4/IPv6 Traversal Scheme with Seamless Mobility Support over Heterogeneous Wireless Networks

Kyoung-Hee Lee^{1,*}, Hyun-Woo Lee² and Youn-Hee Han³

¹Dept. of Computer Engineering, Pai Chai University, Daejeon, Korea ²Broadcasting & Telecommunications Media Research Lab., ETRI, Daejeon, Korea ³Dept. of Computer Science & Engineering, Korea Univ. of Technology and Education, Cheonan, Korea

leekhe@pcu.ac.kr, hwlee@etri.re.kr, yhhan@kut.ac.kr

Abstract

This paper proposes a new IPv4/IPv6 traversal scheme based on a scalable network-based IP mobility management system, called Access Independent Mobile Service (AIMS), which can provide MNs with high-quality mobility services over various wireless access networks. The proposed AIMS with IPv4/IPv6 Dual Stack Support (AIMS-DS) scheme can support an MN moving continuously across the IPv4/IPv6 coexisting networks by IPv4/IPv6 address binding and dynamic transport control based on the IP-in-IP tunnel method. It inherits the novel features of the AIMS system including complete separation control and data planes in the core network and cross-layer (layer2 and 3) interworking method for handover control optimization. The performance evaluation results from our simulation study show that the proposed scheme properly handles a dual stack MN's handovers across IPv4/IPv6 coexisting networks. It is also shown that the proposed scheme outperforms the existing approach in some performance factors including packet delivery latency and handover latency.

Keywords: IPv4/IPv6 Traversal, Dual Stack, Handover, Mobility, Network-based

1. Introduction

Research interests in advanced networking technology to provide mobile users with continuous high-quality communication environment are ever increasing as demands of various multimedia convergence services grow at an astonishing rate over wired/wireless access networks. One of major challenges in this research area is how to make the mobile users do not suffer from service disruption or degradation during moving across heterogeneous networks.

To satisfy this requirement, a lot of researches have been introduced to propose fast and efficient mobility management protocols based on the IP-based Internet architecture. Those researches standardized by Internet Engineering Task Force (IETF) can be divided into two categories, which are host-based [1-7] and network-based [8-12] approaches. The Mobile IPv4 (MIPv4) [1] and the Mobile IPv6 (MIPv6) [3] are well-known host-based approaches to support global mobility of a mobile node (MN). They allow an MN to move across different IP domains while maintaining the MN's network reachability and ongoing sessions with a permanent home address (HoA). In the approach, an MN is directly involved in the mobility control procedure with the home agent (HA) whenever it moves between different networks.

^{*} Corresponding Author

On the other hand, a network-based mobility management approach, called Proxy Mobile IPv6 (PMIPv6) [8], provides a control framework which does not require an MN's participation in the mobility control procedure. In the PMIPv6, some mobility support nodes residing in the network recognize an MN's movement and perform the control procedure on behalf of the MN. Compared to the host-based approach, the network-based approach generally has several advantages, such as faster handover control, lower signaling overhead over wireless links, and little changes of an MN's protocol stack.

With those mobility management approaches, we can consider a situation that an MN moves between IPv4 and IPv6 networks. However, the existing approaches mainly address mobility within a single IP addressing architecture such as IPv4-only or IPv6-only network. Thus the IPv4/IPv6 traversal scheme could be another important research issue to support seamless mobility in the IPv4/IPv6 coexisting network environments. Though many researchers prospect that IPv6 will replace IPv4 in the future, the IPv6 is not widely deployed yet. It is expected that the migration from IPv4 to IPv6 will take a considerable time so that the changes do not cause much inconvenience and confusion of the users. During the period of migration, it is expected that both IPv4 and IPv6 addresses would coexist over various types of networks and MNs will move among networks configured with different IP addressing systems. It is reasonable to assume that a MN will need a support for both IPv4 and IPv6 addresses to be used by the upper layer protocols according to the purpose and circumstance. Many researchers have interests in this IPv4/IPv6 traversal issue with mobility support [13, 14].

In this paper, we propose a new IPv4/IPv6 traversal scheme based on a scalable networkbased IP mobility management system, called Access Independent Mobile Service (AIMS), which can provide MNs with high-quality mobility services over various wireless access networks. The AIMS system is another well-known IP mobility management approach introduced in several ITU-T Next Generation Network (NGN) standards [15-17]. Since the AIMS system was designed for IPv4-only networks, in this paper, we address some enhanced issues to extend it to support an IPv4/IPv6 dual stack MN moving across the IPv4/IPv6 coexisting networks. Those issues include IPv6 HoA mobility support, IPv6 transport support and IPv4/IPv6 traversal in the IPv4/IPv6 coexisting networks.

2. Related work

2.1. Dual stack Mobile IPv6

The dual stack MIPv6 (DS-MIPv6) [14] extends the MIPv6 capability to allow an IPv4/IPv6 dual stack MN to request its HA to forward IPv4/IPv6 packets destined to the MNs' HoAs to their IPv4/IPv6 Care-of-Addresses (CoAs). In the DS-MIPv6, an MN and the HA are considered as IPv4/IPv6 dual stack nodes. That is to say, an MN configures both IPv4 and IPv6 HoA/CoAs and registers those addresses to the HA, which is connected to both IPv4 and IPv6 networks. As shown in Figure 1, the DS-MIPv6 considers three scenarios according to the type of an access network: IPv6 network, IPv4 network and private IPv4 network.

The DS-MIPv6 defines two new options, which are IPv4 HoA option in Binding Update (BU) message and IPv4 address acknowledgement (ACK) option in Binding ACK (BA) message. When visiting an IPv6 network, an MN configures its CoA with a global unique IPv6 address and sends a BU message to the IPv6 address of its HA. This BU message includes an IPv4 HoA option. When receiving the BU message, the HA creates two binding cache entries, one for the MN's IPv4 HoA and the other for the MN's IPv6 HoA. Both HoAs point to the MN's IPv6 CoA. Therefore, the MN and the HA establish two different tunnels, one for its IPv4 traffic (IPv4-in-IPv6) and the other

for its IPv6 traffic (IPv6-in-IPv6) as shown in Figure 2. Whenever a packet is addressed to the MN's IPv4 or IPv6 HoA, the HA will forward them via those bi-directional tunnels to the MN's IPv6 CoA. After binding cache entries are created, the HA sends the BA message to the MN. This includes an IPv4 address ACK option. This option informs the MN whether the binding was accepted for the IPv4 home address.





Figure 2. Packet delivery of DS-MIPv6

When visiting an IPv4 network, an MN configures its CoA with a global IPv4 address sends a BU message to the HA using IPv6-in-UDP-in-IPv4 encapsulation. This BU message includes two options, which are IPv4 HoA option and IPv4 CoA option. After accepting the BU message, the HA updates its binding cache entries related to the MN or creates a new binding cache entry if such an entry does not exist. Then both IPv4 and IPv6 binding cache entries will point to the MN's IPv4 CoA. Thereafter, the MN and the HA establish two different bi-directional tunnels, one for its IPv4 traffic (IPv4-in-IPv4) and the other for its IPv6 traffic (IPv6-in-IPv4). All packets destined to the MN's IPv4 or IPv6 HoAs will be forwarded to the MN's IPv4 CoA via these bi-directional tunnels. After those binding cache entries are updated, the HA sends a BA message to the MN. This message includes IPv4 address ACK option and Network Address Translation (NAT) detection option. The NAT detection option is used to indicate whether a NAT was in the path between a MN and the HA.

2.2. Dual stack Proxy Mobile IPv6

Several network-based mobility management schemes have been introduced to minimize the functional changes on an MN. The PMIPv6 defines a Localized Mobility Management (LMM) domain and specifies the architecture and protocol to handle mobility within an LMM domain with a network-based manner [8]. An LMM domain is composed of the Local Mobility Anchor (LMA) and some Mobility Access Gateways (MAGs). An MAG initiates an IP handover procedure and performs a registration of an MN's location. The LMA manages the location information of an MN while it is moving among MAGs. A data tunnel is established between the LMA and each MAG to forward packets for MNs. When an MN enters an MAG's area, the MAG registers its own IP address with the LMA as the MN's CoA. The MN's HoA does not change in a single LMM domain. By managing the binding information of each MN's HoA and CoA, the LMA can properly forward packets from the outside of the LMM domain to MNs.



Figure 3. IPv4 support in PMIPv6 Figure 4. Packet delivery of DS-PMIPv6

The network-based control architecture significantly reduces functional updates required to an MN and shortens the latency to handle an IP handover. However, since it is designed for a managed area, *i.e.*, LMM, there are some limitations to be applied to the wide-area network such as Internet. If an LMM domain is configured too widely, it is difficult to escape the inherent problems of the current host-based IP mobility approaches: triangle routing and bottleneck at the LMA. On the contrary, if the size of an LMM domain is too small, there would be quite frequent handovers between different LMM domains. Those inter-domain handovers will require another scheme (*e.g.*, MIPv6) to support global mobility over the Internet. This may trivialize the advantages of PMIPv6, especially in case of vertical handovers across heterogeneous networks.

The dual stack PMIPv6 (DS-PMIPv6) [13] extends the PMIPv6 to add IPv4 support. As shown in Figure 3, the scope of IPv4 support in the PMIPv6 is two-fold: IPv4 HoA mobility support and IPv4 transport network support. To support an IPv4/IPv6 dual stack MN, the DS-PMIPv6 enables the MN to obtain an IPv4 address and uses it as a HoA in any of access networks in the PMIPv6 domain. That is, an MN does not need to be newly allocated or assigned with an IPv6 address to enable IPv4 HoA mobility support. To do this, the mobility entities in the PMIPv6 domain (MAGs and LMA) need to exchange the PMIPv6 signaling messages over an IPv4 transport. With considering the existence of an NAT device in the path between an MAG and the LMA, they also have a function of UDP and IPv4 encapsulation for IPv6 packets containing the Proxy BU and the Proxy BA messages. The IP traffic delivered between an MAG and the LMA is encapsulated according to the IP address type of transport network between them, as shown in Figure 4.

3. Access Independent Mobile Service

The Access Independent Mobile Service (AIMS) system [11] is another network-based IP mobility management framework which harmonizes well with wide-scale heterogeneous networks. It was designed to provide an MN using an IPv4 address with a fast and reliable mobility service over the Next Generation Network (NGN). The AIMS system has some novel features including the network-based mobility control, the complete separation method of control and data plane, and the cross-layer (layer2/layer3) interworking for handover control optimization.

Figure 5 shows the AIMS system architecture. It consists of three functional entities: Mobility Information Control Server (MICS), Handover Control Agents (HCA), and point of attachment (PoA). To separate a signaling path from the other data paths, we assume that a core network is based on the Multi-Protocol Label Switching (MPLS) architecture and mobility control messages are delivered through Label-Switched Paths



(LSPs). This architecture has been standardized in the ITU-T Y.2807, Q.1708 and Q.1709 [15-17].

Figure 5. AIMS system architecture

The MICS manages the binding information of an MN's L2 identifiers (IDs), HoA and CoA. When an MN performs a handover between different access networks, the MICS updates its binding information and controls the IP-in-IP tunnels among HCAs to adjust the data path to the MN's new location. The MICS periodically collects the status information of access networks (*i.e.*, available resources, link cost, handover latency, *etc.*) and then supports an MN's network selection procedure based on this information.

An HCA is located at a gateway router connecting a core network and each AN. It is in charge of detecting an MN's movement and supporting handover signaling with the MICS on behalf of an MN. When the HCA detects an MN's L3 handover, it allocates the MN's CoA and informs the MICS of an MN's movement with handover information including the MN's CoA and L2 ID. In addition, the HCA performs a location query procedure with the MICS to deliver packets between two MNs staying in different access networks. With the location query procedure, the HCA obtains the information of a destination MN's CoA (*i.e.*, the corresponding HCA's IP address) from the MICS and establishes an IP tunnel between those two HCAs.

In the AIMS system, a PoA has two functionalities, one is to report an MN's access network attachment to the HCA and the other is to cache and to send Router Advertisement (RA) messages delivered from the HCA. When an MN is newly associated with a PoA, the PoA immediately informs an upper HCA of the MN's attachment. This enables the HCA to detect the MN's handover and initiates the relevant control procedure accordingly. In addition, a PoA caches the RA message delivered from the HCA and passes it to an MN immediately after an MN's L2 handover to reduce the gateway address configuration latency.

4. AIMS with IPv4/IPv6 Dual Stack Support

Based on the AIMS architecture, this paper proposes a scheme to provide seamless mobility support to an IPv4/IPv6 dual stack MN over the IPv4/IPv6 coexisting networks, called AIMS with IPv4/IPv6 Dual Stack Support (AIMS-DS). Some considerations to design the AIMS-DS system are as follows.

- IPv4/IPv6 address configuration: When a dual stack MN first initiates network access, the HCA in the AIMS-DS system allocates both IPv4 and IPv6 HoAs to the MN.
- Transport of RA messages: An HCA managing an access network provides a dual stack MN with IPv4 or/and IPv6 RA messages according to the network policy and the IP address type of an MN.
- IPv4/IPv6 HoA mobility support: The AIMS-DS system should provide mobility support for a dual stack MN as well as an MN with only a single IPv4 or IPv6 address. To do this, the AIMS-DS system manages information of the IP address type of an MN from the beginning of its first network access.
- Mobility binding information management: The MICS and HCAs have their own binding cache entries including an MN's information of L2 IDs, HoA(s), CoAs and so on. To support two types of IP addresses, they manage binding cache entries of an IPv4 HoA and an IPv6 HoA separately.

4.1. Network attachment and initial registration

Figure 6 shows the procedure of an MN's network attachment and initial registration with the AIMS-DS system.



Figure 6. MN's initial registration of AIMS-DS

- (1) An MN first attaches to a target PoA through the layer 2 (L2) association. Then the PoA starts an authentication process for the MN with an authentication, authorization and accounting (AAA) server, called Converged User Profile Server (CUPS).
- (2) After the MN's authentication is completed, an L2 event trigger, called Link_Up, is immediately generated in the PoA. This triggering can be implemented with the Media Independent Handover functions specified in the IEEE standard 802.21 [18]. Then the PoA extracts the MN's L2 ID information from the trigger and sends a *Location_Report* message containing the MN's L2ID to the upper HCA. This initiates the network-based L3 registration procedure.
- (3) In addition, the PoA immediately sends the MN cached RA messages which are periodically delivered from the gateway routers (i.e., HCA). RA messages are IPv4 and/or

IPv6 messages. Based on these two types of RA messages, the MN configures its default gateway router information with little latency after initial attachment.

- (4) When the HCA receives a *Location_Report* message from the PoA, it looks up its Mobility Binding Table (MBT). If a binding entry for the MN is not found, the HCA knows that the MN is just attached to the network (initial registration case) or has moved from another access network (L3 handover case). Then, the HCA creates a new binding entry for the MN and updates the MBT with information of the *Location_Report* message.
- (5) Subsequently, the HCA sends a *Location_Registration* message to inform the MICS of the MN's attachment or handover. This message contains the MN's L2 ID and CoA (i.e., HCA's IP address). The type of this CoA depends on whether a core network is configured with an IPv4 or IPv6 address.
- (6) When the MICS receives the Location_Registration message, it checks its Global Binding Table (GBT) used to store binding information of each MN's HoA, CoA and L2 IDs. If the binding entry for the MN does not exist, the MICS knows that this is MN' s first network access (initial registration case). The MICS creates a new binding entry for the MN and updates the GBT with information of the Location_Registration message.
- (7) Then the MICS requests MN's information by sending an *Information_Query* message to the CUPS. The CUPS responds to the MICS with an *Information_Query_ACK* message which carries the MN's information of L2 ID list and IP address type (i.e., IPv4, IPv6 or both). Accordingly, the MICS updates a binding entry for the MN in its GBT according to this message.
- (8) To reply the *Location_Registration* message, the MICS sends the HCA a *Location_Registration_ACK* message. This message includes the MN's HoA field set to NULL, which enables the HCA to perceive the MN's initial registration. It also includes the information to show the IP address type of the MN's HoA to be supported by mobility management.
- (9) On receiving the Location_Registration_ACK message, the HCA allocates the MN's HoA depending on the information from the message and updates the MN's entry in the MBT. Then the HCA sends HoA update messages to the MICS and the MN respectively, to notify the MN's newly allocated HoA. With this message, the MICS updates MN's entry in the GBT and the MN configures its new IP address. Finally, they responses to the HCA with an HoA_Update_ACK message.

4.2. Handover control



Figure 7. Handover control of AIMS-DS

When an MN moves between different access networks, the HCA in the AIMS-DS system detects the MN's layer 3 (L3) handover and performs mobility control signaling on behalf of the MN. The procedure of an L3 handover is quite similar to the procedure of initial registration, as shown in Figure 7. Some differences between two procedures are as follows.

- (1) An MN's HoA allocation is omitted because the MN has already obtained its HoA during the initial registration procedure. The HoA is used without any changes until the MN finally disconnects a network access. The MN's HoA is informed to the HCA through a Location_Registration_ACK message.
- (2) The MICS maintains the MN's L2 ID list and IP address type support information (IPv4, IPv6 or both) through the initial registration procedure. Thus the MICS does not need to send an *Information_Query* message to the CUPS.
- (3) A localized and proactive authentication process for the MN can be applied since the MN's L2 ID does not need to be registered again with the CUPS. The authentication cache information of the MICS may further accelerate the handover control procedure.
- (4) During the initial registration procedure, a *Location_Registration_ACK* message explicitly includes the information to show the IP address type of the MN's HoA to be supported by mobility management. However, during the handover control procedure, the HCA knows an MN's IP address type information by implication through the MN's HoA list (IPv4, IPv6 or both) in the *Location_Registration_ACK* message.

4.3. Data packet transport

Besides mobility control signaling, one of main functions of the HCA is to configure a data path for the delivery of an MN's packets heading for another MN in the different access networks, which is denoted as a correspondent node (CN). Through the location query procedure with the MICS, the HCA obtains the information of the CN's CoA (i.e., the correspondent HCA's IP address) and establishes a bi-directional IP tunnel between the correspondent HCA and itself. The IP address type of the core network decides the type of IP tunnel between those two HCAs. That is, if the core network is an IPv4 network, IPv4-in-IPv4 or IPv6-in-IPv4 tunnels will be created between HCAs. Otherwise, the IPv4-in-IPv6 or IPv6-in-IPv6 tunnels will be established for data delivery between HCAs. Figure 8 shows the data packet transport procedure in the AIMS-DS network.



Figure 8. Data packet transport of AIMS-DS

- (1) When an MN residing in the HCA#1's domain transmits packets to a CN in the HCA#2's domain, these packets are first delivered to HCA#1 which is a gateway router of the MN's network. These data packets can be delivered to HCA#1 by either IPv4 or IPv6 sessions.
- (2) The HCA#1 looks up its Packet Forwarding Table (PFT) to check whether there already exists a forwarding entry (*i.e.*, an existing IP tunnel) for packets' destination (CN's HoA). If the forwarding entry exists in the PFT, the HCA#1 immediately encapsulates the packets and sends them to the HCA#2 through the existing IP tunnel. Otherwise, the HCA#1 temporally stores the packets in its buffer and sends a *Location_Query* message to the MICS to obtain the information of the CN's CoA (HCA#2's IP address).
- (3) On receiving the *Location_Query* message, the MICS looks up the GBT to obtain a CoA (HCA2's IP address) bound to the CN's HoA. And then, the MICS sends a *Location_Response* message containing the information of a CN's CoA (HCA#2's address) to the HCA#1. Subsequently, the MICS sends a *Location_Notification* message to inform HCA#2 of the need of a new IP tunnel establishment between the HCA#1 and the HCA#2. This notification message contains the MN's HoA and CoA information.
- (4) According to the CN's CoA information in the *Location_Query_Response* message, the HCA#1 builds a new IP tunnel for a CN's HoA and adds a new entry coupled with a CN's HoA in its PFT. The new IP tunnel can be one of IPv4-in-IPv4, IPv6-in-IPv4, IPv6-in-IPv6 and IPv6-in-IPv6 tunnel, depending on the IP address type of a core network and the packet delivery session.
- (5) With the *Location_Notification* message, the HCA#2 also establishes a new IP tunnel for an MN's HoA and adds a new entry coupled with an MN's HoA in its PFT. After that, the HCA#2 replies to the MICS with a *Location_Notification_ACK* message.
- (6) Through above procedures, the HCA#1 and the HCA#2 have a bi-directional IP tunnel between them for packet delivery for the MN and the CN. After completion of IP tunnel establishment, the HCA#1 encapsulates and forwards packets being temporally stored in its buffer through the IP tunnel.

4.4. Downlink traffic delivery during a handover

Figure 9 illustrates a handover control procedure of the AIMS-DS system in the aspect of continuity of downlink packet delivery to an MN moves across different access networks (*i.e.*, from HCA#1's domain to HCA#2's domain).



Figure 9. Handover data flow of AIMS-DS (downlink traffic)

- (1) After moving to a new access network (*i.e.*, HCA#2's domain), an MN attaches to a target PoA through the layer 2 (L2) association. Then the PoA immediately sends the MN cached RA messages. These messages could be IPv4, IPv6 or both. According to the currently active IP stack, the MN configures its IPv4 or IPv6 default gateway router information with those RA messages.
- (2) When receiving a *Location_Report* message from the PoA, the HCA#2 sends the MICS a *Location_Registration* message containing the MN's L2 ID and CoA (*i.e.*, HCA#2's IP address). The CoA type depends on whether the core network is configured with IPv4 or IPv6 addresses.
- (3) When the MICS receives a *Location_Registration* message, it searches its GBT to find a CN's location (i.e., HCA#3's IP address) and sends a *Location_Notification* message to the HCA#3. The notification message informs the HCA#3 of a new CoA of the MN (i.e., HCA#2's IP address). Then the HCA#3 changes the IP tunnel's endpoint so that data packets destined to the MN can be delivered to the HCA#2.
- (4) Simultaneously, the MICS informs the HCA#2 of the need of an IP tunnel for the MN by sending a *Location_Registration_ACK* message. Then the HCA#2 establishes a new IP tunnel endpoint connected to the HCA#3.
- (5) While updating the IP tunnel, some packets over the old IP tunnel between the HCA#1 and the HCA#3 could be lost by dropping at the PoA or wireless link. The new IP tunnel between the HCA#2 and HCA#3 can be one of IPv4-in-IPv4, IPv6-in-IPv4, IPv4-in-IPv6 and IPv6-in-IPv6 tunnel, depending on the IP address type of a core network and the packet delivery session.

4.5. Uplink traffic delivery during a handover

The overall procedure for handover control to provide continuity of uplink packet delivery in the AIMS-DS system is not much different with that for downlink packets described in the previous section. Figure 10 shows the control message flow to update a data tunnel for an MN's handover.



Figure 10. Handover data flow of AIMS-DS (uplink traffic)

- (1) After attaching to a new access network (*i.e.*, HCA#2's domain), an MN configures its IPv4 or IPv6 default gateway router information using the RA messages from the PoA. This process is quite similar with the downlink case. The only difference is that the packets generated by the MN are lost before the change of default gateway router is completed.
- (2) When receiving a *Location_Report* message from the PoA, the HCA#2 sends the MICS a *Location_Registration* message and then buffers the data packets from the MN since it recognizes the MN's handover. The buffering is maintained until a data tunnel is updated successfully to handle the MN's handover.
- (3) Simultaneously, the HCA#2 sends the MICS a *Location_Registration* message containing the MN's L2 ID and CoA (*i.e.*, HCA#2's IP address). The CoA type depends on whether the core network is configured with IPv4 or IPv6 addresses.
- (4) The subsequent procedure is equivalent with the downlink case. When receiving a *Location_Notification* message from the MICS, the HCA#3 changes the IP tunnel's endpoint so that data packets destined to the MN can be delivered to the HCA#2. Also the HCA#2 creates a new IP tunnel endpoint connected to the HCA#3 when receiving a *Location_Registration_ACK* message from the MICS.
- (5) The new IP tunnel between the HCA#2 and HCA#3 can be one of IPv4-in-IPv4, IPv6-in-IPv4, IPv4-in-IPv6 and IPv6-in-IPv6 tunnel, depending on the IP address type of a core network and the packet delivery session.

5. Performance evaluation

In this section, we present the performance evaluation results of the AIMS-DS system from our simulation study. We first analyzed the proposed scheme's performance in the IPv4 network environment and compared them with those of the PMIP. The measured performance metrics are packet delivery latency, handover latency and packet loss. In addition, we also present some performance measurement results of the AIMS-DS system over various IPv4/IPv6 network environments.

5.1. Simulation study in IPv4 networks



Figure 11. IPv4 network topology for simulation study

Figure 11 shows the network topology configured for our simulation study of both AIMS-DS and PMIP in the IPv4 networks. The MICS (LMA in case of PMIP) and three HCAs (MAGs in case of PMIP) are located at the boundary of the core network. All intermediate routers are MPLS Label-Switched Routers (LSRs) to establish LSPs in the core network. We consider only one PoA is connected to each HCA and 10 fixed hosts are attached to each PoA. In the simulation, a CN resides in the HCA3's access network while an MN continuously moves between the PoA1 connected to the HCA1 and the PoA2 connected to HCA2 with an L2 handover latency of 50 milliseconds.

Background traffic	# of sessions	Traffic volume
Case 1	0	No traffic
Case 2	228	91.2 Mbps
Case 3	250	100 Mbps
Case 4	280	112 Mbps

Table 1. Background traffic

Table 2.	Simulation	parameter	configuration
----------	------------	-----------	---------------

Parameters	values
Link bandwidth between an MN and a PoA	10 Mbps
Link bandwidth between a PoA and a HCA	100 Mbps
Link bandwidth in a core network	100 Mbps

To make our simulation configuration more realistic, we considered four different cases of background traffic with UDP data packets of 400 kbps per session, as shown in Table 1. Under the background traffic described above, the MN and the CN exchange UDP data packets with each other with the rate of 512 Kbps. The network configuration parameters for simulation are summarized in Table 2.



Figure 12. Performance comparison in IPv4 network

Figure 12 presents the performance results of AIMS-DS and PMIP simulated over the IPv4 network topology shown in Figure 11. Figure 12(a) shows the comparison of packet delivery latency of the AIMS-DS system and the PMIP derived from four cases of background traffic. As shown in the figure, it can be seen that the packet delivery

latency of the proposed scheme is quite less than that of PMIP. Also it shows that the packet delivery latency of the proposed scheme is not much influenced by diverse volumes of background traffic while that of PMIP increases considerably with the volume of background traffic. It is analyzed that this advantage of the AIMS-DS system is due to the route optimization feature which establishes a direct IP tunnel between two HCAs for packet delivery. Thus data packets are delivered along the shortest routing path in the core network. Moreover, this feature of the AIMS-DS system can address a bottleneck problem in a specific node such as the LMA in the PMIP network.

Figure 12(b) depicts the comparison of average handover latency for downlink packets of the proposed scheme and PMIP. From the simulation results, as the network becomes congested, the handover latency of PMIP increases rapidly. It becomes 2~3 times higher than that of the AIMS-DS in the Case 3 and 4. On the other hand, the AIMS-DS system does not suffer from such network congestion as Figure 12(b) shows that the handover latency is not much changed with the volume of background traffic. We understand that this is because the AIMS-DS system does not have a single bottleneck point problem which can arise at the LMA in the PMIP network.

5.2. Simulation study in IPv4/IPv6 coexisting networks



Figure 13. IPv4/IPv6 coexisting network topology for simulation study

Figure 13 shows the network topology for the simulation study to measure the performance of the proposed AIMS-DS system over various IP network environments. In the simulation, we considered four IP network configurations according to the IP address types, which a core network and an access network uses IPv4/IPv4, IPv4/IPv6, IPv6/IPv4, and IPv6/IPv6 addresses, respectively (see Table 3). In this simulation, we did not consider the L2 handover latency because it does not affect the performance evaluation results of the proposed L3 mobility management scheme. We assumed that no background traffic exist in the network because the performance in the congested network is presented in the previous section. We configured that the MN and the CN exchange UDP data traffic with an inter-arrival time of 0.1 milliseconds and with each packet's payload size of 128 bytes. The network configuration parameters for simulation are the same with those in Table 2.

	Access Network	Core Network
Case 1	IPv4	IPv4
Case 2	IPv4	IPv6
Case 3	IPv6	IPv4
Case 4	IPv6	IPv6

Table 3. IPv4/IPv6 coexisting network configuration

The packet delivery latency of the AIMS-DS system according to different IP address types are shown in Figure 14(a). Each latency value was measured as a time from when an MN sends UDP data packet to when another MN (i.e., CN) receives the packet in our 4 network configuration scenarios in Table 3, respectively. As shown in the figure, the packet delivery latency values do not have much difference in 4 different cases. It is obvious that the packet delivery latency appears higher in the IPv6 network because an IPv6 packet size is bigger than that of an IPv4 packet. It is interesting that packet delivery latency of the Case 3 is higher than that of the Case 2. Though a total size of encapsulated IPv4-in-IPv6 packet in the core network is equivalent with that of IPv6-in-IPv4 packet, the packet size processed in the access network is different in those two cases. This affects the total transmission delay and, accordingly, the packet delivery latency in the Case 3 appears higher than the Case 2.



Figure 14. Packet delivery latency in IPv4/Ipv6 networks

Figure 14(b) shows the packet transmission delay derived from both statistical analysis and simulation study. In this experiment, we considered the transmission delay as a main factor of packet delivery latency, which consists of processing delay, queuing delay, transmission delay and propagation delay. It is notable that the results from two analysis methods are considerably identical.

Figure 15 shows the average handover latency and packet loss for downlink/uplink packets of the proposed AIMS-DS system in 4 cases of Table 3. In our simulation study, the downlink handover latency is defined as a time from when an MN receives the last data packet in the old access network to when the MN receives the first data packet in the new access network after a handover. On the other hand, we defined the uplink handover latency as a time from when a CN receives the last data packet from an MN in the old access network to when the CN receives the first data packet from the MN's new access network after a handover.

International Journal of Multimedia and Ubiquitous Engineering Vol.9, No.1 (2014)



Figure 15. Handover latency in IPv4/IPv6 networks

From the simulation results, it is shown that the handover latency and packet loss values in 4 different cases are not so different. As previously examined with the results in Figure 14, the difference of packet size according to the IP version in the access network can also affect the results of handover latency and packet loss because the delivery latency of signaling packets for handover control becomes higher in the IPv6 access network. It is also notable that the handover latency and packet loss values measured from the uplink packets are quite less than those of downlink packets. This difference comes from the loss of downlink packets moving along the old IP tunnel during a handover, which was described in Section 4.4. Since those packets are delivered to the old HCA and lost at the PoA or wireless link. This causes the additional loss of downlink packets and increases the handover latency accordingly.

6. Conclusions

In this paper, we proposed a new IPv4/IPv6 traversal scheme based on a scalable networkbased IP mobility management system, called Access Independent Mobile Service (AIMS), which can provide MNs with high-quality mobility services over various wireless access networks. The proposed AIMS with IPv4/IPv6 Dual Stack Support (AIMS-DS) scheme can support an MN moving continuously across the IPv4/IPv6 coexisting networks by IPv4/IPv6 address binding and dynamic transport control based on the IP-in-IP tunnel method. It also inherits the novel features of the AIMS system including complete separation control and data planes in the core network and cross-layer (layer2 and 3) interworking method for handover control optimization.

The performance evaluation results from simulation study show the superiority and practicality of the proposed AIMS-DS scheme in the aspects of handover latency, packet loss and packet delivery latency. The performance comparison in the IPv4 network verifies that the proposed scheme outperforms the existing PMIP approach. The advantage appears more evidently as the network becomes congested. The simulation results over the IPv4/IPv6 coexisting networks show that our scheme properly handles an IPv4/IPv6 dual stack MN's handovers among different access networks configured with IPv4, IPv6 or both addresses. It is also notable that the L3 handover latency of the proposed scheme appears in the bound of requirements for various realtime multimedia services over Internet. For future work, a mobile QoS guarantee scheme interworking with the AIMS-DS scheme will be studied.

Acknowledgements

This research was supported by the research grant of Pai Chai University. This paper is a revised and expanded version of a paper entitled "A Network-based IP Mobility Management Scheme with IPv4/IPv6 Dual Stack Support" presented at the International Conference on Future Information & Communication Engineering, Shenyang, China, June 2013.

References

- [1] C. Perkins, "IP mobility support for IPv4", RFC 5944 on IETF, (2010).
- [2] K. El Malki, "Low-latency handoffs in Mobile IPv4", RFC 4881 on IETF, (2007).
- [3] C. Perkins, D. Johnson and J. Arkko, "Mobility support in IPv6", RFC 6275 on IETF, (2011).
- [4] R. Koodli, "Mobile IPv6 fast handovers", RFC 5568 on IETF, (2009).
- [5] E. Fogelstroem, A. Jonsson and C. Perkins, "Mobile IPv4 regional registration", RFC 4857 on IETF, (2007).
- [6] H. Soliman, C. Castelluccia, K. El Malki and L. Bellier, "Hierarchical Mobile IPv6 (HMIPv6) mobility management", RFC 5380 on IETF, (2008).
- [7] H. Jung, E. Kim, J. Yi and H. Lee, "A Scheme for supporting fast handover in hierarchical Mobile IPv6 networks", ETRI Journal, vol. 27, no. 06, (2005), pp. 798-801.
- [8] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury and B. Patil, "Proxy Mobile IPv6", RFC 5213 on IETF, (2008).
- [9] K. Kong, W. Lee, Y. Han, M. Shin and H. You, "Mobility management for all-IP mobile networks: Mobile IPv6 vs. Proxy Mobile IPv6", IEEE Wireless Communications, vol. 15, no. 2, (2008), pp. 36-45.
- [10] I. Ali, A. Casati, K. Chowdhury, K. Nishida, E. Parsons, S. Schmid and R. Vaidya, "Network-based mobility management in the evolved 3GPP core network", IEEE Communications Magazine, vol. 47, no. 2, (2009), pp. 58-66.
- [11] K. Lee, H. Lee, W. Ryu and Y. Han, "A scalable network-based mobility management framework in heterogeneous IP-based networks", Telecommunication Systems Journal, vol. 52, issue 4, (2013), pp. 1989-2002.
- [12] D. Kim and K. Kim, "A scenario for enhanced network-based localized mobility management", Journal of information and communication convergence engineering, vol. 6, no. 3, (2008), pp. 245-248.
- [13] R. Wakikawa and S. Gundavelli, "IPv4 support for Proxy Mobile IPv6", RFC 5844 on IETF, (2010).
- [14] H. Soliman, "Mobile IPv6 support for dual stack hosts and routers", RFC 5555 on IETF, (2009).
- [15] ITU-T SG13, "MPLS-based mobility and QoS capabilities for NGN services", ITU-T Recommendation Y.2807, (2009).
- [16] ITU-T SG13/19, "Framework of location management for NGN", ITU-T Recommendation Q.1708/Y.2805, (2008).
- [17] ITU-T SG13/19, "Framework of handover control for NGN", ITU-T Recommendation Q.1709/Y.2806, (2008).
- [18] K. Taniuchi, Y. Ohba, V. Fajardo, S. Das, M. Tauil, Y. Cheng, A. Dutta, D. Baker, M. Yajnik and D. Famolari, "IEEE 802.21: media independent handover: features, applicability, and realization", IEEE Communications Magazine, vol. 47, no. 1, (2009), pp. 112-120.

Authors



Kyoung-Hee Lee received his M.S. and Ph.D. degrees in Korea Advanced Institute of Science and Technology (KAIST) in 2000 and 2006, respectively. From 2006 to 2013, he worked for Electronics and Telecommunications Research Institute (ETRI). Since 2013, he has been a faculty member of Department of Computer Engineering in Pai Chai University. He has expertise in international standardization on mobility management technology area as a Rapporteur of Q.22/SG13 in ITU-T. His research interests include mobile communications, Internet QoS, real-time multimedia service and cloud computing.



Hyun-Woo Lee received the B.S., M.S. and the Ph.D. degree in the School of Electronics, Telecommunication and Computer Engineering at Korea Aerospace University, Korea in 1993, 1995 and 2005 respectively. From 1995, he has joined Electronics and Telecommunications Research Institute (ETRI). From 2009, he is a team leader in the Smart Screen Convergence Research Department in ETRI. His research interests include IPTV service, service control and traffic congestion control.



Youn-Hee Han re received his M.S. and Ph.D. degrees in Computer Science and Engineering from Korea University in 1998 and 2002, respectively. From March 4, 2002 to February 28, 2006, he was a senior researcher in the Next Generation Network Group of Samsung Advanced Institute of Technology. Since March 2, 2006, he has been a Professor in the School of Computer Science and Engineering at Korea University of Technology and Education, CheonAn, Korea. His primary research interests include theory and application of mobile computing, including protocol design and performance analysis. Since 2002, his activities have focused on mobility management, media independent handover, and cross-layer optimization for efficient mobility support on IEEE 802 wireless networks. International Journal of Multimedia and Ubiquitous Engineering Vol.9, No.1 (2014)