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Inter-domain Mobility Support in Proxy Mobile IPv6 Using Overlap Function of Mobile Access Gateway

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Abstract. In this paper, we propose an inter-domain mobility support protocol in PMIPv6 networks using overlap function of Mobile Access Gateway. In the proposed protocol an MN maintain active communication sessions without mobility protocol stacks when the MN moves into another local mobility domain. Thus the proposed protocol retains the advantages of PMIPv6 for inter-domain mobility support. This protocol not only simplifies implementation and deployment, but also allows service providers to offer multi-services and communication ubiquity to customers with simple mobility hosts. We evaluate and compare network performance between our proposed solution and PMIPv6 and the main host-based mobility protocol, MIPv6 to demonstrate the advantages of proposed protocol.

Keywords: overlap-MAG, Network Based Hand Mobility, Proxy Mobile IPv6, Inter-domain Handover.

I. Introduction

Network-based mobility management protocol of PMIPv6 standardized by IETF NETLMM Working Group is applicable within the scope of a single administrative domain.

In this paper, we propose a solution for inter-domain mobility support in PMIPv6[2] networks. Here we introduce a new entity, called the overlap Mobile Access Gateway (overlap-MAG), which is a MAG located in the overlap area between coverage areas of two contiguous local mobility domains. Also on behalf of the MN, it can maintain the MN's communication sessions with the MN's CN during a inter-domain handover. In the proposed mechanism, when MN moves to another local mobility domain it is forced to use only its MIPv6 home address. Thus the MN is not involved in any IP mobility-related signaling.

When the MN moves from the pMAG towards the overlap-MAG, the overlap-MAG performs an intra-domain handover procedure in the pLMA. Then the overlap-MAG advertises the MIPv6-HNP in an RA message. After receiving the PBA message from pLMA, the overlap-MAG concurrently forwards packets, which are destined for the MN from the CN, to the MN and performs an intra-domain handover procedure in the nLMA domain. Finally, the overlap-MAG, on behalf of the MN, performs home and correspondent registration with the MN's LMAh (or the MN's HA) and CN.

2. Backgrounds and Related Works

PMIPv6 protocol standardized by IETF NETLMM Working Group does not support inter-domain mobility. To solve this problem, several drafts and papers [3-5] have introduced interactions between PMIPv6 and MIPv6, or between local mobility domains. However, in these scenarios, an MN can perform inter-domain handover only if the MN supports inter-domain mobility (for example, MIPv6 protocol).

The above proposals need to modify basic entities, such as the MAG, LMA, and even CN. But in our solution, we only need to supplement the MAG and LMA with a few more functions, and we do not need to modify or enhance any other entities.

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The purpose of this study is to propose a solution for network-based inter-domain mobility support in PMIPv6 networks. With this solution, the nature and advantageous characteristics of network-based mobility management of the PMIPv6 are retained, while inter-domain mobility management is still supported.

3. Inter-domain Mobility Support in Proxy Mobile IPv6

Fig. 1 shows basic operations of the proposed handover procedure. Here, we introduce a new entity, called the overlap Mobile Access Gateway (overlap-MAG), which is a MAG located in the overlap area between coverage areas of two contiguous local mobility domains such that it is connected with both of these domains.

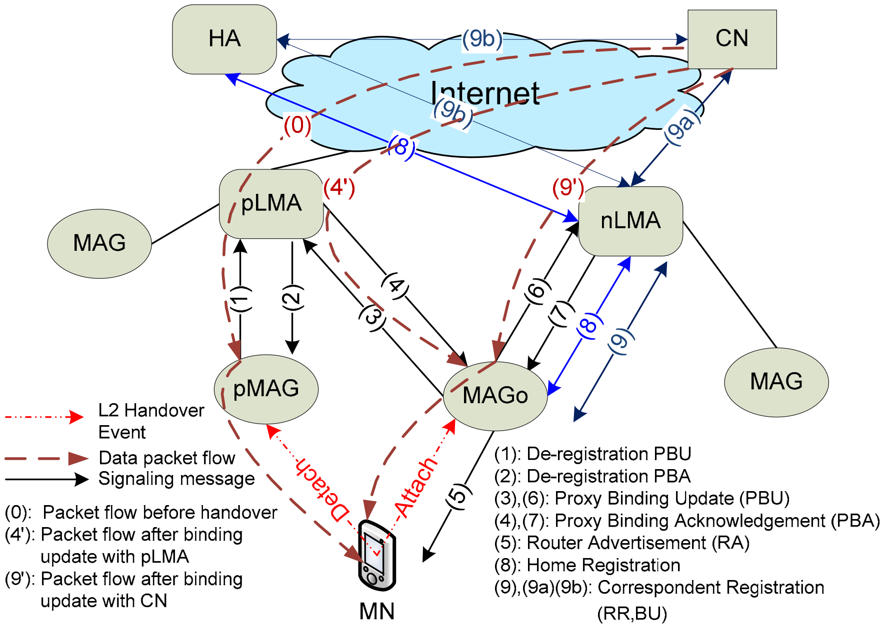

Fig. 1: Inter-Domain Handover Procedure in PMIPv6 with overlap MAGs

As shown in Fig. 1, pMAG and nMAG (i.e. overlap-MAGo) are always locally connected in the same domain.

When the MN moves towards the overlap-MAG, first, the pMAG performs de-registration by sending a PBU message to the pLMA to remove binding and routing states for the MN. In response to the PBU message, the pLMA sends a PBA message to the pMAG.

When the MN moves and attaches to the new link the overlap-MAG then performs binding registration with the pLMA for the MN. In the binding registration process described above, the pLMA updates binding and routing states for the MN, sets up a bi-directional tunnel to the overlap-MAG for the MN's data traffic.

Upon receiving confirmation from the pLMA, the overlap-MAG advertises the MIPv6-HNP in an RA message to the MN rather than the PMIPv6-HNP. After detecting no change of the network prefix due to the same MIPv6-HNP within the RA message, the MN continues using its HoA (i.e. MIPv6-HoA).

After the overlap-MAG completes the binding registration with the pLMA, the packet flow for the MN will be changed from Arrow (0) to Arrow (4') as shown in Fig. 1. Thus, the MN can receive packets after an intra-handover procedure for the case of inter-domain handover.

After receiving the PBA message from pLMA, the overlap-MAG concurrently forwards packets to the MN and performs binding registration with the nLMA. First, the overlap-MAG sends a PBU message to the nLMA. After receiving the PBU message from the overlap-MAG, the nLMA creates new PMIPv6-HNP for the MN. It then establishes an end-point of the bi-directional tunnel to the overlap-MAG and responds with a PBA message to the overlap-MAG. Finally, the overlap-MAG performs the route optimization process, including the home registration and the correspondent registration with the CN.

After completing the route optimization process, packets destined for the MN are routed directly to the new domain through the bi-directional tunnel between the nLMA and the overlap-MAG, then forwarded to the MN by the overlap-MAG.

4. Performance Analysis and Evaluation

We use the evaluation topology shown in Fig. 2 with following assumptions:

- A local mobility domain (LMD) consists of n MAGs with the same coverage area size of a_S. MNs move at an average velocity of v, and the direction of motion is uniformly distributed over [0, 2π].
- The CN is outside local mobility domains.

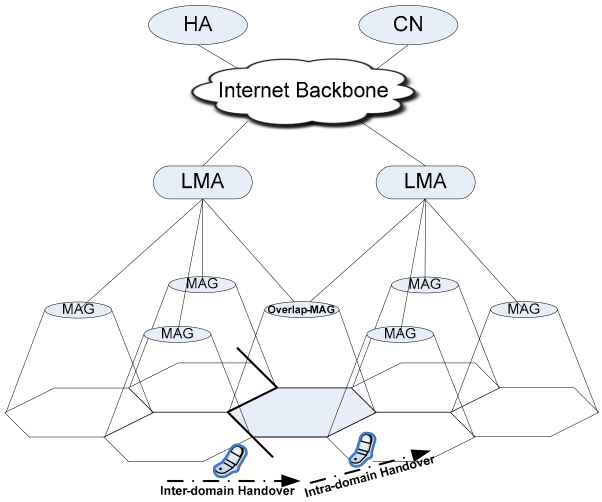

Fig. 2: Evaluation Topology

Table 1. List of evaluation parameters

Symbol	**Description**
λ_C	The subnet crossing rate
λ_S	The intra-domain handover rate
λ_D	The domain crossing rate (the inter-domain handover rate)
λ_I	The inter-session rate
λ	Packet arrival rate
SMR	The session-to-mobility ratio of an MN, defined as λ_I/λ_C [6]
D_{L2}	Layer 2 handover delay
T_{DAD}	Duplicated Address Detection delay
T_{MD}	The Movement Detection Delay in standard Mobile IPv6
T_{RA}	One-way transmission delay between MAG and MN to send an RA message
T_{NS}	Two ways transmission delay between MAG and MN to transmit a couple of NS and NA for a DAD process
$T_{A\text{-}B}$	One-way transmission delay and processing time of nodes between node A and node B
T_{PBU}	Binding update delay with LMA: $T_{PBU} = 2T_{MAG\text{-}LMA}$
$T_{D\text{-}PBU}$	The delay of a binding de-registration with LMA: $T_{D\text{-}PBU} = T_{PBU} = 2T_{MAG\text{-}LMA}$
$T_{FW\text{-}PBU}$	The delay of a request for forwarding packets between pLMA and nLMA
T_{BU*MN}	The delay of a binding update with HA and CN in Mobile IPv6 performed by MN
T_{BU*MAG}	The delay of a binding update with HA and CN in Mobile IPv6 performed by MAG
T_{BU*LMA}	The delay of a binding update with HA and CN in Mobile IPv6 performed by LMA
n	Number of subnets (MAGs) in a local mobility domain (LMD)
$T_{PROFILE}$	The time to obtain the MN's profile from context data transfer process between MAGs
T_{CTX}	The time to complete the MN's context data transfer process between MAGs in different LMDs

From [7] we obtain

$$\overline{D}_P = \frac{1}{SMR}\left(\left(1-\frac{1}{\sqrt{n}}\right)D_{P1} + \frac{1}{\sqrt{n}}D_{P2}\right) \quad (1)$$

$$\overline{C}_P = \frac{1}{SMR}\left(\left(1-\frac{1}{\sqrt{n}}\right)C_{P1} + \frac{1}{\sqrt{n}}C_{P2}\right) \quad (2)$$

where D_{P1}, and D_{P2} are handover delays of an intra-domain handover and an inter-domain handover in PMIPv6 and C_{P1}, and C_{P2} are packet loss costs of an intra-domain handover and an inter-domain handover in PMIPv6, respectively. The SMR (session-to-mobility ratio) of an MN is defined as λ_I/λ_C [6]

In the same way, we can formulate the average handover delay ($\overline{D}_O$), and the average packet loss cost ($\overline{C}_O$) in the proposed protocol as (3) and (4), respectively.

$$\overline{D}_O = \frac{1}{SMR}\left(\left(1-\frac{1}{\sqrt{n}}\right)D_{O1} + \frac{1}{\sqrt{n}}D_{O2}\right) \quad (3)$$

$$\overline{C}_O = \frac{1}{SMR}\left(\left(1-\frac{1}{\sqrt{n}}\right)C_{O1} + \frac{1}{\sqrt{n}}C_{O2}\right) \quad (4)$$

where D_{O1} and D_{O2} are the handover delays of an intra-domain handover and an inter-domain handover using overlap-MAG; and C_{O1} and C_{O2} are the packet loss costs of an intra-domain handover and an inter-domain handover using overlap-MAG .

In MIPv6, the MN has to perform the same handover procedure for an intra- and inter-domain handover. Thus, respective costs of an intra- and inter-domain handover are the same. We can formulate the average handover delay ($\overline{D}_M$), and the average packet loss cost ($\overline{C}_M$) in MIPv6 as (5), and (6), respectively.

$$\overline{D}_M = \frac{1}{SMR}D_M \quad (5)$$

$$\overline{C}_M = \frac{1}{SMR}C_M \quad (6)$$

where D_M is the handover delay of a handover in MIPv6; and C_M is the packet loss cost of an handover in MIPv6.

4.1. Handover Delay

The average handover cost includes both the delays of an intra and an inter-domain handover. In order to evaluate these averages, we need to calculate D_{P1}, D_{P2}, D_{O1}, and D_{O2}.

The delays of intra-domain handovers in both mechanisms are the same and given by (6).

$$D_{P1} = D_{O1} = D_{L2} + T_{PROFILE} + T_{PBU} + T_{RA} = D_{L2} + T_{PROFILE} + 2T_{MAG\text{-}LMA} + T_{MN\text{-}MAG} \quad (6)$$

where, $T_{PROFILE}$ is the time to complete the MN's context data transfer process between MAGs.

In the PMIPv6 mechanism, when the MN moves into another local mobility domain, host-based mobility must be activated. Thus, the MN must perform MIPv6 handover procedure.

$$\begin{aligned} D_{P2} &= D_{L2} + T_{PROFILE} + T_{PBU} + T_{RA} + T_{DAD} + T_{BU*MN} \\ &= D_{L2} + T_{PROFILE} + 2T_{MAG\text{-}LMA} + T_{MN\text{-}MAG} + T_{DAD} + 2T_{MN\text{-}HA} + 2max\{T_{MN\text{-}HA} + T_{HA\text{-}CN},\ T_{MN\text{-}CN}\} + 2T_{MN\text{-}CN} \\ &= D_{L2} + T_{PROFILE} + T_{DAD} + 7T_{MN\text{-}MAG} + 8T_{MAG\text{-}LMA} + 2T_{LMA\text{-}HA} + 2max\{T_{LMA\text{-}HA} + T_{HA\text{-}CN}, T_{LMA\text{-}CN}\} + 2T_{LMA\text{-}CN} \end{aligned} \quad (7)$$

In our mechanism, when the MN moves from the pMAG towards the overlap-MAG, the overlap-MAG performs an intra-domain handover procedure in the pLMA domain. Then, the overlap-MAG performs registration with the nLMA and registration with the MN's HA and CN. Therefore, inter-domain handover delay of our mechanism is the delay of the intra-domain handover from the previous domain, and thus it is given by (8).

$$D_{O2} = D_{O1} = D_{L2} + T_{PROFILE} + 2T_{MAG\text{-}LMA} + T_{MN\text{-}MAG} \quad (8)$$

In MIPv6, the MN must perform an MD, and a DAD process for its new CoA as well as home and correspondent. In particular, we compute this handover delay as follows.

$D_M=D_{L2}+T_{MD}+T_{DAD}+T_{BU*MN}=D_{L2}+T_{MD}+T_{DAD}+2T_{MN\text{-}HA}+2max\{T_{MN\text{-}HA}+T_{HA\text{-}CN},\ T_{MN\text{-}CN}\}+2T_{MN\text{-}CN}$

$$=D_{L2}+T_{MD}+T_{DAD}+6T_{MN\text{-}MAG}+6T_{MAG\text{-}LMA}+2T_{LMA\text{-}HA}+2max\{T_{LMA\text{-}HA}+T_{HA\text{-}CN},\ T_{LMA\text{-}CN}\}+2T_{LMA\text{-}CN} \quad (9)$$

4.2. Packet Loss

The average packet loss costs of each protocol include the packet loss costs of intra- and inter-domain handover. To evaluate these factors, we need to compute C_{P1}, C_{P2}, C_{O1}, and C_{O2}.

Since the LMA in the PMIPv6 always drops all packets destined for the MN after a binding de-registration from the pMAG, packets for the MN are lost until the LMA accepts the binding registration from the nMAG for the MN. Thus, the packet loss cost of an intra-domain handover in the PMIPv6 protocol, C_{P1}, can be calculated as in equation (10).

$$C_{P1}=\lambda(D_{L2}+T_{PROFILE}+½T_{PBU}=\lambda(D_{L2}+T_{PROFILE}+T_{MAG\text{-}LMA}) \quad (10)$$

where λ is the packet arrival rate.

In the proposed mechanism, packets arriving at the LMA after a binding de-registration are buffered, and then forwarded to the MN when a registration is bound from the nMAG for the MN. Nevertheless, packets for the MN may be lost after the MN detaches from the previous access link and before the binding de-registration with the LMA from the pMAG because the LMA still forwards packets to the MN until it receives the request for binding de-registration. Thus, the packet loss cost of an intra-domain handover in the proposed protocol, C_{O1}, can be computed as shown in equation (11).

$$C_{O1}=\lambda(½T_{PBU})=\lambda T_{MAG\text{-}LMA} \quad (11)$$

Packets for the MN in an inter-domain handover in the PMIPv6 protocol are lost after the MN detaches from the previous access link until the nMAG completes the binding registration with the nLMA and the MN completes the route optimization process with the CN. Therefore, the packet loss cost of an intra-domain handover in the PMIPv6 protocol, C_{P2}, can be calculated as equation (12).

$C_{P2}=\lambda(D_{L2}+T_{PROFILE}+T_{PBU}+T_{RA}+T_{DAD}+T_{BU*MN})$

$=\lambda(D_{L2}+T_{PROFILE}+2T_{MAG\text{-}LMA}+T_{MN\text{-}MAG}+T_{DAD}+2T_{MN\text{-}HA}+2max\{T_{MN\text{-}HA}+T_{HA\text{-}CN},T_{MN\text{-}CN}\}+2T_{MN\text{-}CN})$

$$=\lambda D_{P2} \quad (12)$$

In the proposed protocol, the packet loss cost in an inter-domain handover is the same as that in an intra-domain handover. Hence, C_{O2} is computed as equation (13).

$$C_{O2}=\lambda T_{MAG\text{-}LMA} \quad (13)$$

Packets for the MN in a handover (both intra- and inter-domain handover procedures are the same in MIPv6) in the MIPv6 protocol are lost after the MN detaches from the previous access link until the MN completes the binding registration with the HA and the CN on the new link. Therefore, the packet loss cost of a handover in the MIPv6 protocol, C_M, can be calculated as equation (14).

$C_M=\lambda(D_{L2}+T_{MD}+T_{DAD}+T_{BU*MN})$

$$=\lambda(D_{L2}+T_{MD}+T_{DAD}+2T_{MN\text{-}HA}+2max\{T_{MN\text{-}HA}+T_{HA\text{-}CN},T_{MN\text{-}CN}\}+2T_{MN\text{-}CN})\ =\lambda D_M \quad (14)$$

4.3. Numerical Results

We evaluate and compare handover delay, and packet loss cost of MIPv6, PMIPv6 and the proposed mechanism. The parameter values for the numerical analysis are shown in Table 2[6][8]. For simplicity, we set packet arrival rate (λ) as λ = 2,000packets/second. We assume that the packet size is 1000 octets. Thus, the required bandwidth can be calculated 2,000 packets/sec x 1KB/packet = **2MB/sec**. We also use the SMR value over [0.1, 100]. The SMR value of 0.1 means a high subnet-crossing rate and the SMR value of 100 means a low subnet-crossing rate. In order to show the handover performance of each protocol, we evaluate the influences of the session-to-mobility ratio (SMR), domain size (number of MAGs in a local mobility domain), number of CNs, and the possibility of inter-domain handover.

Table 2. Parameters used in Numerical Analysis

$T_{MN\text{-}MAG}$	$T_{MAG\text{-}LMA}$	$T_{LMA\text{-}HA}$	$T_{LMA\text{-}CN}$	$T_{HA\text{-}CN}$	$T_{pLMA\text{-}}$	D_{L2}	T_{DAD}	T_{MD}	$T_{PROFILE}$	T_{CTX}	λ

					nLMA						
5ms	3ms	5ms	6ms	6ms	5ms	10ms	1.5s	0.75s	6ms	8ms	2 packets/ms

where T_{MD} is the mean value of MAX_RTR_SOLICITATION_DELAY and MAX_RA_DELAY_TIME that are specified in [9] (1sec and 0.5 sec, respectively).

4.3.1. Handover Delay

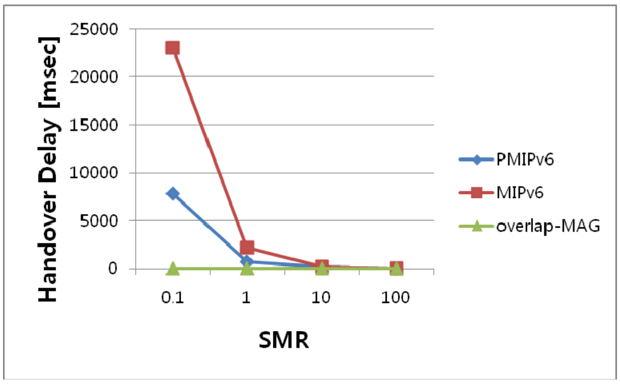

Fig. 3: Impact of SMR on Handover Delay(No. of CN = 4)

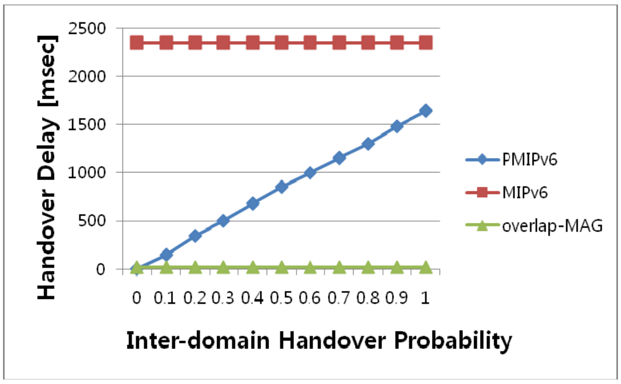

Fig. 4: Impact of Inter-domain Probability on Handover Delay

Fig. 3 shows the impact of the SMR parameter on the average handover delay. The graph shows that a lower SMR results in a higher handover delay in all protocols. The Fig. also illustrates that the handover delay of the proposed protocol is always significantly lower than that of the PMIPv6 and MIPv6 protocols, due to the significant reduction of mobility signaling in the proposed mechanism.

Fig. 4 shows the impact of the inter-domain handover probability on the average handover delay. Here, the number of subnets in a domain and the SMR are set to 4 and 1.0, respectively. Handover delay of the proposed protocol is always constant and is the lowest compared to all the others. When the probability is increased, the handover delay of PMIPv6 increases. As the delays of an intra-domain handover of PMIPv6 and that of the proposed protocol are the same, the increase of handover delay is caused mostly by inter-domain handover.

4.3.2. Packet Loss Cost

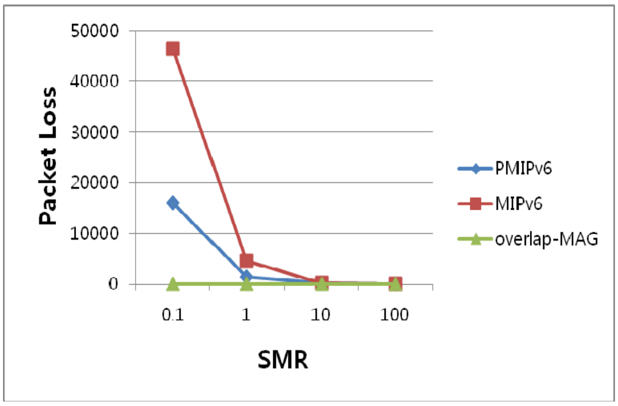

Fig. 5: Impact of SMR on Packet Loss Cost No. of CN = 4)

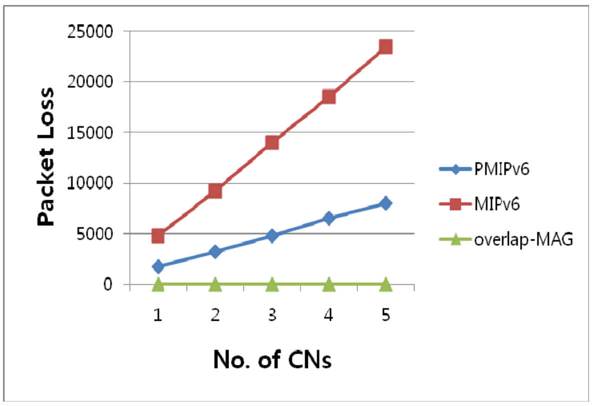

Fig. 6: Impact of Number of CNs on Packet Loss Cost

Fig. 5 shows the influence of the SMR parameter on the average packet loss cost of the protocols. The graph shows that the average packet loss cost in PMIPv6 is always much higher than that of the proposed protocol. The Fig. also shows that a lower SMR results in a higher than average packet loss cost in both protocols. In contrast, the higher the SMR, the lower the mobility, and packet loss cost in PMIPv6 and MIPv6 is thus lower. However, in our protocol, packet loss costs are always the same and negligible.

Fig. 6 shows the effect of the number of CNs on the average packets loss cost of the protocols. Here the session-to-mobility ratio (SMR) and the number of subnets in a domain (*n*) are set to values of 1.0 and 4, respectively. When the number of CNs increases, the average packet loss cost in PMIPv6 also increases, whereas the average packet loss cost in our protocol is unchanged and negligible. Thus, a greater number of CNs results in a larger gap between the average packet loss cost of PMIPv6 and those of the proposed protocol, demonstrating the superior performance of the proposed protocol.

The above analysis and evaluations show the superior performance of the proposed protocol.

5. Conclusion

In this paper, we proposed a solution for network-based inter-domain mobility support in Proxy Mobile IPv6 networks. Our solution maintains the communication session continuity of a mobility-unaware host when it moves between local mobility domains. However, only a few modifications to the mobile access gateway are needed.

Thus, handover delays and packet losses can be significantly reduced and host-based signaling avoided. With this solution, the nature and advantageous characteristics of network-based mobility management of PMIPv6 are retained, while inter-domain mobility management is added.

In our solution, we proposed a new entity, called the overlap mobile access gateway (overlap-MAG). This is a mobile access gateway located in the overlap area between the coverage areas of two contiguous local mobility domains. With this entity, inter-domain handover delays are analogous to those of intra-domain handovers.

Finally, we evaluated and compared the handover performance between the proposed protocol and the PMIPv6 protocol and a main host-based mobility protocol, MIPv6.

In order to show the advantages of the proposed solution, we evaluated the influence of the session-to-mobility ratio (SMR), domain size, number of CNs, and the probability of inter-domain handover. Numerical results demonstrate that the proposed protocol performs far better than the Proxy Mobile IPv6 and Mobile Ipv6 protocol when overlap mobile access gateways are used.

6. Acknowledgements

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