DMM-based Inter-domain Mobility Support for Proxy Mobile IPv6

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***Abstract*—Proxy Mobile IPv6 (PMIPv6) takes advantage of the network-based mobility management that provides mobility support for moving nodes (MNs) without their involvement. However, the main drawback of PMIPv6 is that the inter-domain handover is not supported. That means when an MN moves to another PMIPv6 domain, the on-going sessions cannot be maintained. Although several proposals have been introduced for the inter-domain mobility support, they still have some limitations such as sub-optimal routing, signaling overhead, handover latency and lack of granularity on the mobility management service. In this paper, we propose the inter-domain mobility solutions based on the concept of the distributed mobility management (DMM) to overcome these limitations. Basically, DMM brings the mobility anchors closer to the users, thus avoiding such issues as sub-optimal routing, signaling overhead and dynamically providing the mobility service. Using the DMM concept, we have considered two approaches: partially or fully distributed. A performance analysis is studied based on a well-known factor, namely session-to-mobility which represents the relative ratio of session arrival rate to the user mobility rate. Numerical results show that the partially distributed solution gives a better performance than the existing inter-domain handover solutions (e.g. integration of MIPv6 and PMIPv6) in terms of handover latency, signaling cost and tunnel usage.**

***Index Terms*—Inter-domain mobility, Distributed Mobility Management, PMIPv6, Handover latency.**

I. Introduction

Recently, Proxy Mobile IPv6 (PMIPv6) [1] has been standardized by IETF, and widely adopted in 3GPP and WiMAX architecture. Taking advantage of the network-based mobility management, PMIPv6 enables IP mobility for moving hosts without their involvement. Compared to the host-based mobility management (e.g. Mobile IPv6, or MIPv6 [2]) PMIPv6 brings some benefits such as: (i) avoiding the complexity of protocol stack in the MN; (ii) supporting mobility without the involvement of the MN; and (iii) reducing tunneling overhead and decreasing handover latency. However, PMIPv6 fails to support inter-domain mobility. That means, even when an MN moves to another PMIPv6 domain, the session continuity cannot be maintained.

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In order to support the inter-domain mobility, several solutions have been proposed e.g. integration of MIPv6 and PMIPv6 (H-PMIP) [3], and I-PMIP [4]. Yet, they have such limitations as sub-optimal routing, signaling overhead and handover latency. Especially, due to the lack of granularity on the mobility management service, the mobility service is always provided even for the sessions that do not require mobility management support e.g. the sessions launch and complete while the mobile node connected to the same domain.

DMM [5] [6] is currently a quite hot topic in the IETF and 3GPP. The DMM concept has been introduced to overcome the limitations of centralized mobility management (e.g. MIPv6 and PMIPv6) [7] by placing the mobility anchors closer to the MN. In addition, the mobility service is dynamically provided when it is really needed.

In this paper, we propose inter-domain mobility solutions for PMIPv6 (called D-PMIP) based on the DMM concept. The solutions may be fully or partially distributed. Thus, they allow data packets to be routed via a near-optimal way by bringing the mobility anchors closer to the MN while the control management can be placed anywhere in the network. The numerical results show that the partially distributed solution (DP-PMIP) gives better performance than the existing inter-domain handover solutions e.g. MIPv6, H-PMIP and I-PMIP in terms of handover latency, signaling cost and tunnel usage.

The rest of this paper is organized as follows. Section II describes related work on the inter-domain mobility support and the DMM concept. In section III, two different proposals are presented with respect to theirs architecture and operations. Section IV provides performance analysis of signaling cost, handover latency and tunnel usage. Section V shows the numerical results taking into account the impact of different factors. Eventually, Section VI concludes this paper.

II. Related Work

A. Inter-domain mobility support

Several solutions have been proposed for inter-domain mobility support for PMIPv6. The common idea is using a global mobility anchor to keep the MN reachable when it moves to a visited PMIPv6 domain. In [3], the authors introduce a scenario in which PMIPv6 is used as an intra-domain mobility management whereas MIPv6 as a global mobility management (named H-PMIP). As a result, the complexity of the hosts is increased since they have to support both network-based and client-based protocol stacks. Another scenario is also considered, where PMIPv6 and MIPv6 are co-located at LMA/HA. Yet, there exist some problems due to the natural difference between the two protocols [3].

In [4], an extension to PMIPv6 (called I-PMIP) is proposed for the inter-domain mobility support by reusing the local mobility anchor as a global anchor point when the MN is away from home. Then the traffic is forwarded from/to the anchor which is called Session Mobility Anchor (SMA), to/from the current serving Local Mobility Anchor (S-LMA) where the MN is currently attached. Thus, two scenarios are suggested to find the corresponding SMA:

- Direct location: A common database, namely virtual mobility anchor (VMA), is introduced to store information about the established MN-SMA bindings from all domains.
- Indirect location: This scenario is based on the fact that the SMA is a topological anchor point of the MN. Hence, after inferring the MN's IPv6 address, the S-LMA sends a Proxy Binding Update (PBU) to this address. This PBU will obviously reach the SMA. However, this approach requires each SMA to analyze all of its incoming traffic to recognize the corresponding PBU. Consequently, the complexity of the LMA is increased, particularly when a lot of traffic passes the LMA.

One critical problem of this solution is that the mobility service is provided on a per user basis. Thus, the mobility service is always provided even for the sessions that do not require a mobility support (e.g. when the MN remains attached to the same domain during the lifetime of the sessions). Also, when the MN starts a new session at a new domain, it still has to use the SMA as the anchor point which may cause the sub-optimal routing and tunneling overhead problems.

Another proposal [8] is based on the idea that the home address (HoA) and Care-of-Address (CoA) are not only used for the MN, but also for the specific session. Every PMIPv6 entity maintains two Binding Cache entries (BCE) for each registered MN. One is Inner-domain BCE as normal BCE in the PMIPv6 domain, and the other is Inter-domain BCE which maintains the binding between HoA and CoA of the Corresponding Node (CN).

When an MN moves to another PMIPv6 domain, the S-LMA needs to communicate with the previous one to get the HoA of CN. It also interacts with the CN's home LMA to update the current location of the MN. The same process is executed when the CN changes its PMIPv6 domain. Though the traffic is routed via a near-optimal way (directly from the CN to the current location of the MN), this solution becomes too complex particularly when the MN communicates with many CNs at the same time. Moreover, this proposal can be applied only in the case where both the MN and the CN are attached to PMIPv6 domains.

B. Distributed Mobility Management

The centralized mobility management like MIPv6 and PMIPv6 has several drawbacks such as sub-optimal routing, scalability problems, reliability and signaling/tunneling overhead [7]. For overcoming these drawbacks, a novel approach, namely Distributed Mobility Management (DMM) [5] [6], has been introduced. The idea is that the mobility anchors are placed closer to the MN, the control and data plane are distributed among the network entities. In addition, this approach offers mobility support at a per-flow granularity, that is, only for the services that really require mobility support.

In a DMM domain, the MN gets a different set of IP addresses when changing its point of attachment, as compared to what happens in PMIPv6. The MN's flows are anchored (if necessary) at the mobility access router (MAR) in which the using MN's prefix is allocated. Hence, the packets can be redirected to the current location of the MN via the tunnel between the current MAR and the anchored one.

III. Description of the Solution

Based on the DMM concept, we introduce an inter-domain mobility support, called D-PMIP. This proposal brings some benefits: (i) the mobility anchors are placed very close towards the MN; and (ii) the mobility service is only provided for the sessions that really require service continuity.

Once the MN enters its PMIPv6 domain, it gets a set of prefixes. For simplicity, it is assumed that each MN is allocated with only one prefix. Based on the prefix allocated, the MN configures its IPv6 address. The MN then can use this address to initiate and maintain the sessions in a standard way while it remains attached to this domain. When the MN changes its domain, it gets another prefix and configures its address based on this prefix. This address can be used to set up the new sessions. Until the previous sessions are not closed, the old address should be kept. Thus, a tunnel is built between the anchored LMA (A-LMA) and the current one to redirect packets between two LMAs using the old prefix.

To enable the inter-domain mobility support, the BCE in the LMA is needed to extend with a field, called I-LMA which contains a list of the MN's prefixes and the previous/current LMA's address. Based on the DMM concept, two possible solutions for inter-domain mobility support are considered, namely the partially (DP-PMIP) and fully distributed (DF-PMIP) solution. The former solution relies on a common database for control plane, while in the latter one the mobility function is distributed in both data and control plane.

A. Partially Distributed Solution (DP-PMIP)

Similar to I-PMIP, this solution relies on the existing of a central entity called Inter-domain Central Mobility Database (ICMD) which stores the information of mobility sessions of all PMIPv6 domains. This common database can be established by the service level agreements between the operators. Unlike I-PMIP, the MN's prefix is used to distinguish between ICMD entries. The ICMD can also play the role of the LMA

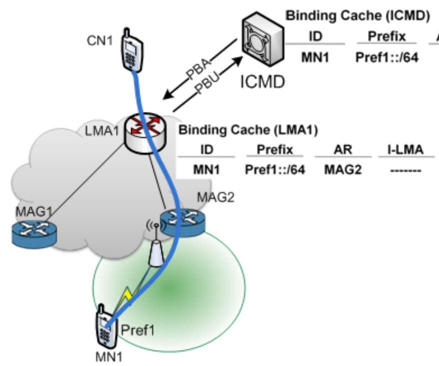

Fig. 1. Initial registration (partially distributed solution).

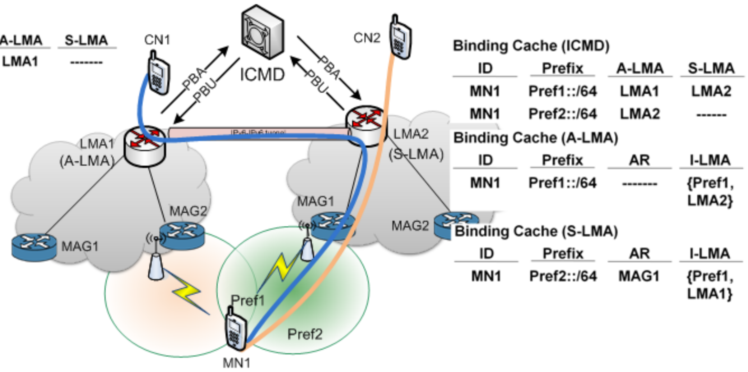

Fig. 2. Inter-domain handover signaling and BCE (partially distributed solution).

and the Mobile Access Gateway (MAG) to handle the PBU / Proxy Binding Acknowledgment (PBA) messages.

1) Initial registration: When an MN is attached to a PMIPv6 domain, the standard PMIPv6 operations are executed. The LMA (LMA1) then sends a PBU to the ICMD. This PBU includes the Mobile Node Identifier and Home Network Prefix options which are set to the MN's identifier (MN-ID) and the MN's prefix (Pref1), respectively. Since the session is new, the ICMD creates an entry which consists of the MN-ID, the Pref1 and the address of LMA1 in its BCE. The signaling process and the BCE of the ICMD are described in Fig. 1.

2) Inter-domain operations: This section describes the operations of DP-PMIP when the ICMD acts as a mobility signaling relay (DP-PMIP-R) [6] (see Fig. 2). When the MN moves to another domain, the current LMA (LMA2 or S-LMA) allocates another prefix (Pref2) to the MN. Then, the S-LMA sends a PBU to the ICMD for the new prefix registration. Upon receiving the PBU and searching the BCE table, the ICMD updates the current location to the existing entries for the MN. It also creates a new entry corresponding to the MN-ID and the new prefix. The ICMD then sends a PBU including the S-LMA's address to the A-LMA (LMA1) to update the current location of the MN. Upon reception of the PBU, the A-LMA sets up its endpoint for bi-directional tunnel to the S-LMA, updates its BCE and routing for Pref1. The A-LMA also replies with a PBA to ensure that the new location of the MN has been successfully updated. Using a PBA, the ICMD then indicates the address of A-LMA to S-LMA, which performs the same process as that of A-LMA. Afterwards, a bi-directional tunnel is established between the S-LMA and A-LMA to carry the traffic from/to MN using Pref1.

As a global anchor point of Pref1, the A-LMA, after receiving the packets destined to this prefix, forwards them through the bi-directional tunnel to the corresponding S-LMA. The packets then reach the MN at the current PMIPv6 domain.

When the MN transmits packets using Pref1 as the source address, the S-LMA, after receiving the packets, firstly checks their source address in the BCE. The S-LMA then forwards them through the tunnel to the corresponding A-LMA which routes them towards the destination. On the contrary, the packets using Pref2 as the source address are routed as a regular PMIPv6 routing.

To reduce handover latency, two possible methods can be used, depending on the role of ICMD as a mobility signaling locator (DP-PMIP-L) or a proxy (DP-PMIP-P) as described in [6]. In these methods, the data plane is kept as the same as the previous one while the control plane is changed as described in Fig. 3 and Fig. 4, respectively.

B. Fully Distributed Solution (DF-PMIP)

In this solution, the central database for inter-domain is removed from the architecture. Thus, the complexity of the handover procedures is increased as a result of the trade-off between the elimination of the central database and signaling cost. Since the S-LMA does not have knowledge of the LMAs in the other PMIPv6 domain, finding the A-LMA's address of the MN's prefix becomes a key challenge. There are several solutions to this issue:

- using a Layer 2 handover infrastructure e.g. IEEE 802.21;
- using a distributed LMA-discovery mechanism;
- relying on a distributed infrastructure that allows communicating between the domains.

In this paper, we introduce an example to illustrate how this approach works by using a distributed Authentication, Authorization, and Accounting (AAA) infrastructure [9] and RADIUS protocol for PMIPv6 [10]. The protocol operations can be briefly explained as follows (see Fig. 5).

After detecting the presence of a new MN, the current serving MAG (S-MAG) obtains the information of the MN (MN's IPv6 address) by exchanging Node Information (NI) Query/NI Reply messages [11]. If the MN's IPv6 address is not available, then the normal process is executed. Vice versa, the S-MAG, after extracting the prefix from MN's address, sends a RADIUS Access-Request message with PMIPv6-Home-HN-Prefix (Pref1) and Mobile-Node-Identifier (MN-ID) options, to the AAA server (S-AAA) to retrieve the MN's policy profile. If this prefix belongs to its domain, the S-AAA then continues with its regular operations. Otherwise, acting as a RADIUS client, the S-AAA sends a RADIUS message (including MN-ID and Pref1) to the AAA in the anchored domain (A-AAA), to get A-LMA's address. Upon reception of the reply message from A-AAA, the S-AAA sends an Access-Accept message which includes the prefix allocated to this MN (Pref2) to S-MAG. Afterwards, the standard PMIP operations

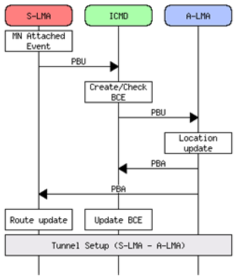

Figure 3. ICMD as mobility signaling locator (DP-PMIP-L).

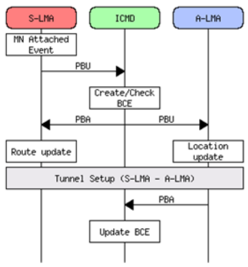

Figure 4. ICMD as mobility signaling proxy (DP-PMIP-P).

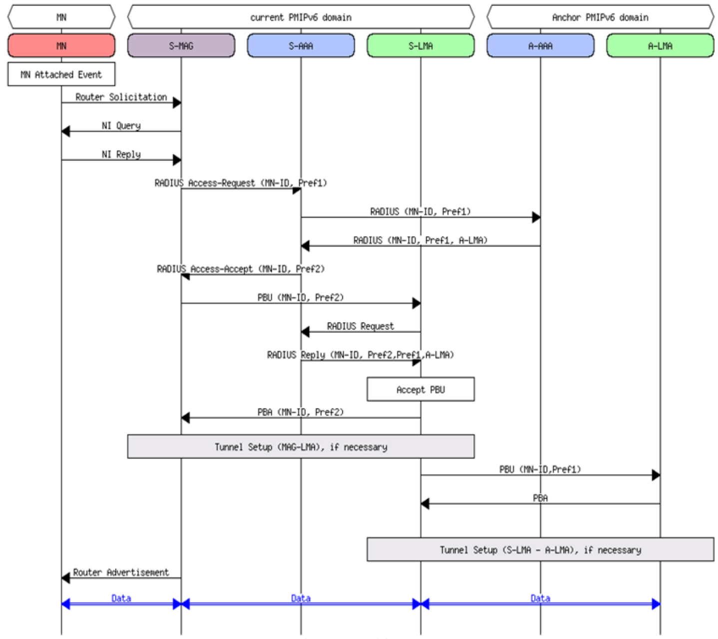

Figure 5. Signaling of fully distributed solution.

related to Pref2 are executed (e.g. location update and MN's address configuration). The S-LMA also obtains the A-LMA address from the S-AAA server. Then, the PBU/PBA messages are exchanged between the S-LMA and A-LMA to update their BCEs and routing related to Pref1.

C. Local routing considerations

After the receipt of the up-link packets from MN using Pref1 as the source address, the S-LMA will decide to forward them to the destination depending on the following cases: (i) if the CN is currently attached to its domain, the S-LMA simply forwards the packet to the corresponding MAG; and (ii) if the CN's address belongs to its domain but the CN is currently attached to another one, the S-LMA will forward the packets to the LMA where the CN is currently attached.

IV. Performance Analysis

In this section we analyze the performance of the proposed solutions in terms of signaling cost, handover latency and tunnel usage. We compare our solutions with the other ones for the inter-domain handover e.g. MIPv6, H-PMIP and I-PMIP. It is noted that the behavior of DP-PMIP-R resembles that of I-PMIP since they both rely on PMIPv6 for intra-handover and a central database for inter-handover (ICMD in DP-PMIP-R and VMA in I-PMIP). Thus, the handover delay and the signaling cost of I-PMIP and DP-PMIP-R are the same.

A. Reference model

Fig. 6 shows a reference topology for performance analysis. For simplicity, the average distance (number of hops) between the entities is defined as follows:

- The distance between the PMIPv6 entities in the same domain (local) is d$_l$ (e.g. between the MAG and LMA).
- The distance between two domains (region) is d$_r$ (e.g. between two LMAs or between LMA and ICMD).
- The distance between LMA/Access Router (AR) and Home Agent (HA) (global) is d$_g$.
- The distance between the MAG/AR and MN (wireless connection) is d$_{wl}$.

B. Signaling cost

Signaling cost of a mobility management protocol is defined as the transmission cost of location update signaling when an MN performs handover. To measure the signaling cost in the inter-domain context, the handoff frequency should be taken into account. As a result, we use a well-known factor, called session-to-mobility ratio (SMR) which represents the relative ratio of session arrival rate to the user mobility rate. It is assumed that the subnet residence time (MAG subnet) and session duration follow an exponential distribution with parameter η and μ, respectively. Hence, the SMR is calculated as $\rho = \frac{\mu}{\eta}$ [12]. Each LMA coverage area is supposed to be cir-

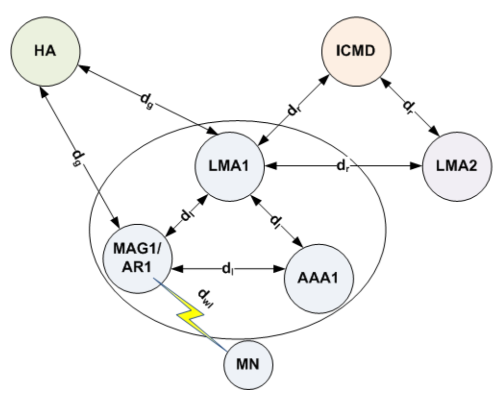

Fig. 6. Reference network topology for performance analysis.

cular with N subnets. According to [13], the intra-domain and inter-domain handoff probability are defined as $\rho_{intra} = \frac{1}{1+\rho}$, $\rho_{inter} = \frac{1}{1+\rho\sqrt{N}}$. And the expected numbers of intra-handoff and inter-handoff are $E_{intra} = \dfrac{1}{\rho}$, $E_{inter} = \dfrac{1}{\rho\sqrt{N}}$ Thus, the average location update signaling is given by:

$$C = (E_{intra} - E_{inter})\, C_{intra} + E_{inter} C_{inter}, \qquad (1)$$

where C_{intra} and C_{inter} are signaling update cost for intra-domain and inter-domain handover. Although different signaling messages have different size, we assume that they have the same size for simplicity. Also, the cost for transmitting a signaling message is supposed to be proportional to the distance between source and destination. The proportion is α for wired and $\alpha * \beta$ for wireless link. It is obvious that the signaling cost for three different methods of DP-PMIP (DP-PMIP-R, DP-PMIP-L and DP-PMIP-P) is equal and is calculated as:

$$C^{intra}_{DP-PMIP-R} = 2\alpha\beta d_{wl} + 2\alpha d_l, \qquad (2)$$

$$C^{inter}_{DP-PMIP-R} = 2\alpha\beta d_{wl} + 2\alpha d_l + 4\alpha d_r. \qquad (3)$$

Similarly, we can derive the equations of the signaling cost for DF-PMIP, MIPv6 and H-PMIP. It is noted that the signaling cost for intra-domain handover of DF-PMIP and H-PMIP is the same and equal to that of DP-PMIP (PMIP handover cost).

$$C^{inter}_{DF-PMIP} = 4\alpha\beta d_{wl} + 6\alpha d_l + 4\alpha d_r \qquad (4)$$

$$C^{inter}_{MIP} = C^{intra}_{MIP} = 4\alpha\beta d_{wl} + 2\alpha d_g \qquad (5)$$

$$C^{inter}_{H-PMIP} = 4\alpha\beta d_{wl} + 2\alpha d_l + 2\alpha d_g \qquad (6)$$

C. Handover latency

The Inter-domain handover latency (D_{inter}) is defined as the total time taken to complete all the operations before the traffic can be forwarded to the current location of the MN. Let D_{intra} denote intra-domain handover delay. Then, the average value of handover latency is

$$D = (\rho_{intra} - \rho_{inter})\, D_{intra} + \rho_{inter} D_{inter}. \qquad (7)$$

Since the delay between two nodes depends on the bandwidth, the propagation delay and the distance between them, for simplicity, we suppose that the delay is proportional to the distance. The proportion is τ for wired link and $\tau * \kappa$ for wireless link. Let t_{L2} denote the delay caused by Layer 2 handover. Thus, the intra-domain handover delay of DP-PMIP-R, DP-PMIP-L, DP-PMIP-P, DF-PMIP and H-PMIP is the same (PMIP handover delay) and is calculated as follows:

$$D^{intra}_{DP-PMIP-R} = t_{L2} + 2\tau\kappa d_{wl} + 2\tau d_l. \qquad (8)$$

Unlike the case of signaling cost, the inter-domain handover latency of three methods for partially distributed approach is different and given as follows:

$$D^{inter}_{DP-PMIP-R} = t_{L2} + 2\tau\kappa d_{wl} + 2\tau d_l + 4\tau d_r, \qquad (9)$$

$$D^{inter}_{DP-PMIP-L} = t_{L2} + 2\tau\kappa d_{wl} + 2\tau d_l + 3\tau d_r, \qquad (10)$$

$$D^{inter}_{DP-PMIP-P} = t_{L2} + 2\tau\kappa d_{wl} + 2\tau d_l + 2\tau d_r. \qquad (11)$$

Similarly, the handover latency of DF-PMIP, MIPv6 and H-PMIP is given by the equations below:

$$D^{inter}_{DF-PMIP} = t_{L2} + 4\tau\kappa d_{wl} + 6\tau d_l + 4\tau d_r, \qquad (12)$$

$$D^{inter}_{MIP} = D^{Intra}_{MIP} = t_{L2} + 4\tau\kappa d_{wl} + 2\tau d_g, \qquad (13)$$

$$D^{inter}_{H-PMIP} = t_{L2} + 4\tau\kappa d_{wl} + 2\tau d_r + 2\tau d_g. \qquad (14)$$

D. Tunnel usage

In this subsection, we will measure the tunnel usage ratio, called θ which is defined as the ratio between the number of sessions using the tunnel (between the anchored and the current domain) and the total number of sessions. Therefore, it can be used to show the advantage of using DMM in terms of dynamic provision of mobility service to avoid tunneling overhead (lower value is better).

Since in MIPv6, H-PMIP and I-PMIP the traffic always passes the tunnel between the global anchor point and the current one, θ is equal to 1.

To measure θ in case of D-PMIP, the sessions are separated into the new sessions and the handoff sessions. Thanks to DMM, the tunnel is used only for the handoff sessions. Let $N_n(t)$ and $N_h(t)$ respectively denote the numbers of the new sessions and handoff sessions up to time t. We suppose that $N_n(t)$ and $N_h(t)$ are a Poisson process with parameter λ_n and λ_h, respectively. Then, we have $\theta = \dfrac{N_h(t)}{N_n(t) + N_h(t)}$. According to [12] $\lambda_h = E[H] * \lambda_n$, where E[H] is the expected handoff number (in our case E[H] = $\frac{1}{\rho\sqrt{N}}$). We obtain:

$$\theta = \frac{1}{1 + \rho\sqrt{N}}. \qquad (15)$$

V. Numerical Results

This section presents the numerical results based on the analysis given in the previous section. The default parameter values for the analysis are introduced in TABLE I in which some parameters are taken from [13].

TABLE I
PARAMETERS FOR PERFORMANCE ANALYSIS

Parameters	Values	Parameters	Values	Parameters	Values
d_{wl}	1 hops	d_l	5 hops	d_r	5 hops
d_g	10 hops	τ	2	κ	5
N	32	α	1	β	5

Fig. 7 shows the signaling cost when SMR (ρ) is varying. We can observe that the signaling cost of the fully distributed solution is relatively high compared to the other. It is evident since more messages are required to get the address of the anchored LMA. The partially distributed solution and I-PMIP have lower signaling cost than that of the others. In highly mobile regimes ($\rho \ll 1$) the signaling cost difference between the protocols becomes more clearly.

Fig. 8 illustrates the handover latency as a function of SMR (when $t_{L2} = 100$ ms). The partially distributed solution when ICMD acts as a mobility signaling proxy (DP-PMIP-P) has better handover latency (lower is better) over the other solutions especially when ρ is small.

To measure the impact of the domain size on the handover latency, we assume that the architecture of the inter-domain is hierarchically formed as a tree structure with a d_r-layer, while the structure of a PMIPv6 domain as a binary tree with a d_l-layer [14]. The size of the network is supposed to be fixed e.g. the distance between the ICMD and MAG is 10 hops. Therefore, d_l and d_r are calculated as $d_l = log_2(N)$ and $d_r = 10 - log_2(N)$. Fig. 9 describes the impact of the domain size on the handover latency when the value of ρ

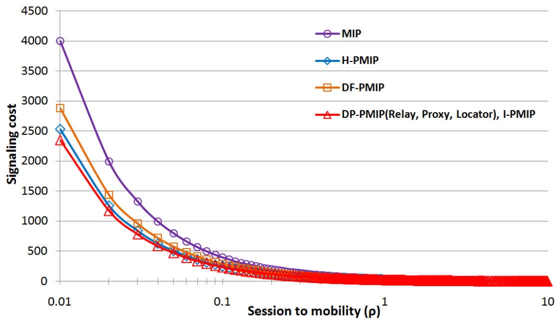

Fig. 7. Signaling cost variation with SMR (ρ).

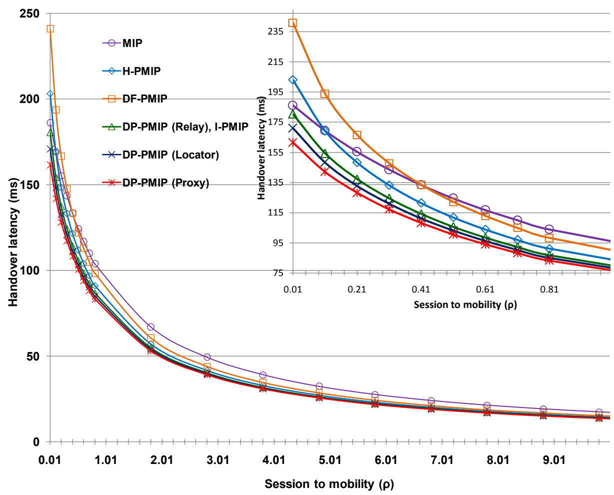

Fig. 8. Handover latency variation with SMR (ρ).

is set to 0.1. It is observed that when the domain size is small, the handover latency is high for all solutions. When the domain size is increased, the handover latency is decreased and then makes a bit increase. The enlargement of domain size makes the difference between three methods of the partially distributed solutions negligible.

Regarding the tunnel usage (see Fig. 10), in low mobility regimes ($\rho \gg 1$) the tunnel usage is significantly decreased in D-PMIP (DP-PMIP, DF-PMIP) compared to the others. The reason is that the number of new sessions in low mobility regimes is definitely higher than that of the handoff sessions.

VI. Conclusion

This paper proposes a solution (D-PMIP) that allows providing mobility service for the moving hosts between PMIPv6 domains. Based on the DMM concept, the proposal allows bringing the mobility anchors closer to the MN and dynamically providing the mobility service for only sessions which really need service continuity. The D-PMIP also retains the advantageous features of a network-based mobility management form PMIPv6 that provides mobility service without the involvement of the MN. A numerical analysis demonstrates that the partially distributed solution gives a better performance than the other solutions like MIPv6, H-PMIP, I-PMIP and the fully distributed solution in terms of signaling cost, handover

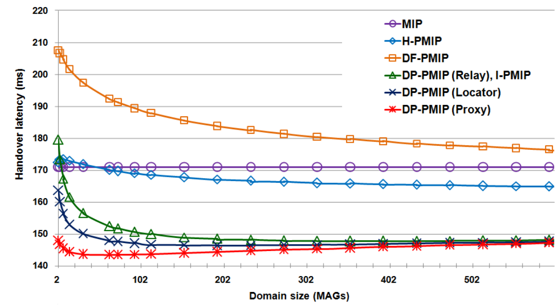

Fig. 9. Domain size effect.

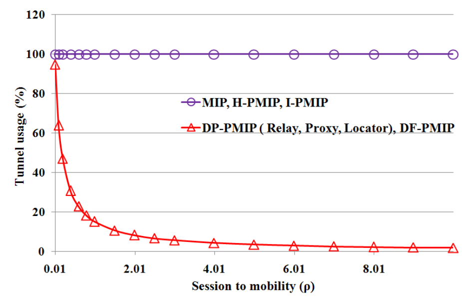

Fig. 10. Tunnel usage (θ) as a function of SMR (ρ).

latency and tunnel usage. Thus, at the moment the partially distributed solution seems to be more suitable than the fully distributed one.

In the future, the simulations will be made based on an open source PMIP (called OAI PMIP) and the Network Simulator NS-3 to provide a near-to-real experiment of inter-domain mobility support for PMIPv6.

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