Infrastructure-based Route Optimization for NEMO based on Combined Local and Global Mobility

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ABSTRACT
Global mobility management protocols have been standardized and are gaining more and more momentum for deployment. At the same time network-based local mobility management has been identified as an important cornerstone for an overall mobility management framework and is currently covered by PMIPv6. However, local and global mobility management are separated and serve different purposes with little interaction. In the light of the work on NEMO route optimization we propose to combine both approaches more tightly, reusing existing functionality. We show how PMIPv6 can be used to build a network-based route optimization procedure for NEMO/MIPv6 based on globally distributed Home Agents. We also show that this approach can directly benefit from future evolvements of the PMIPv6 protocol.

Categories and Subject Descriptors
C.2.1 [**Computer-communication Networks**]: Network Architecture and Design – *wireless communication*

General Terms
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Keywords
IPv6, MIPv6, NEMO, PMIPv6, Global HA to HA

1. INTRODUCTION
Mobile IPv6 (MIPv6) [8] is the well known global IP mobility management protocol relying on a Home Agent (HA) infrastructure. The NEMO Basic Support protocol [12] extends MIPv6 from a Mobile Host (MH) to support Mobile Routers (MR), but lacks a route optimization (RO) procedure, although many proposals exist [11]. New entities within the infrastructure are suggested, making them impractical. Nevertheless there is currently great interest in NEMO, especially from the side of the aeronautical and Car2Car communications community that have a great need for network mobility solutions. However, the lack of Route Optimization in the NEMO Basic support protocol has proved to be a major obstacle for its deployment.

In parallel, Proxy Mobile IPv6 (PMIPv6) [6] has been developed for local mobility management. So far the focus of PMIPv6 has been on the support of mobility within one network domain for nomadic nodes unaware of mobility signaling.

Convergence between both mobility approaches is, as of now, limited to using PMIPv6 to lower the number of handovers experienced by MIPv6. This is accomplished by the deployment of PMIPv6 within the access network and the use of MIPv6 for global mobility between different networks.

Hence, mobility management has been partitioned into four independent parts of two dimensions – local vs. global mobility and host vs. router mobility. MIP and NEMO are addressing global mobility for both hosts and routers whereas PMIPv6 provides local mobility for hosts only (as of now). We propose to combine these into an integrated solution with a special emphasis on NEMO that currently lacks of a RO solution.

Although the focus in this document is on a mobile router as in NEMO, our proposal is also valid for mobile nodes (MNs) as in MIPv6. This would be useful for cases where RO is necessary, but the Correspondent Nodes (CNs) do not implement the necessary functionality from [8]. For simplicity and clarity we will focus on MRs with a single mobile network prefix (MNP), although we explicitly want to mention that the proposed procedures for MNs as in MIPv6 are nearly equal.

The remainder of this document is structured as follows. Section 2 provides an overview of both PMIPv6 and the Global HA to HA protocol, the latter being an RO proposal for NEMO that serves as base line for Section 3 where we introduce the problem statement and discuss the context of our proposed solution. Sections 4 and 5 introduce RO for Mobile Routers that are attached to either PMIPv6 or non-PMIPv6 domains. In Section 6 we present how our proposal can be integrated more tightly with existing proposals for PMIPv6 RO mechanisms. Security aspects are investigated in Section 7 and we conclude with an investigation of the advantages/disadvantages of the suggested mechanisms in Section 8.

2. Existing Work
We provide an overview of Proxy Mobile IPv6 and the Global HA to HA protocol. We introduce the latter because its basic concept for performing NEMO RO is similar to our solution, although we provide a more comprehensive framework by making use of PMIPv6.

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2.1 Proxy Mobile IPv6

PMIPv6 [6] is a network based mobility solution. Its main intention is to eliminate the mobility signaling of the Mobile Hosts (MH) over the wireless link. A Proxy Mobile IPv6 domain comprises one or more Local Mobility Anchors (LMA) and one or more Mobile Access Gateways (MAG). The LMA is responsible for maintaining the mobile node's reachability and constitutes its topological anchor point (i.e. home network). Readers familiar with Mobile IPv6 will find it comparable to a MIPv6 Home Agent. The MAG is responsible for the mobility management and resides on the access link of the MHs point of attachment. Additionally the MAG is in charge of movement detection and serves as access router for the MH.

The functionality of PMIPv6 is achieved by extensions of the MIPv6 signaling protocol. After a MH enters a Proxy Mobile IPv6 domain, it attaches to an access link and authenticates itself to the visiting domain. The serving MAG sends a Proxy Binding Update (PBU) to the LMA. The LMA, after accepting the PBU, sends a Proxy Binding Acknowledgement (PBA) back to the MAG, that includes the mobile node's home network prefix. Additionally, the MAG and LMA establish a bi-directional tunnel (the tunnel is set up using IPsec mechanisms). The MAG can now advertise the MHs home network prefix on the access link. By this the MH is tricked into believing that it is attached to the same subnet. Thus, from the perspective of the MH, the entire Proxy Mobile IPv6 domain appears to be a single subnet, as the home network prefix appears to "follow" the MH through the PMIPv6 access network.

PMIPv6 does not require the MH to know anything of mobility protocols. Another advantage of this concept is the reduction of signaling overhead over the wireless link that is especially attractive for low-bandwidth aeronautical links. Additionally the mobility related signaling is sped up as PMIPv6 is used over the wired network (MAG to LMA), which can be assumed to be less error prone and to have lower latencies than the wireless link.

As of now, the PMIPv6 protocol as defined in [6] does not support MRs but only MHs. However this might change in the future.

2.2 Global HA to HA

The Global HA to HA protocol [1] has been devised to provide some extent of route optimization support for NEMO. The starting point of its development was the observation that the binding of the MR to a single fixed HA, regardless of its relative location, is in general not a satisfactory solution. With regard to the network performance the sub-optimal routing path of MRs in great distance from their HAs causes unnecessarily high latencies on the end-to-end path. Consequently, the solution envisaged by Global HA-to-HA relies on a distributed HA architecture that allows the MR to bind with its topologically closest HA. This feature is supported by the Dynamic Home Agent Address Discovery (DHAAD) procedure defined in MIPv6 using IPv6 *anycast* addressing. The introduction of a distributed solution helps overcoming the single point of failure of the (single) HA approach and offers a nearly optimized route between the Mobile Network and the Correspondent Nodes. It is noteworthy that this distributed approach does not prevent the introduction of additional route optimization procedures to benefit from a fully bidirectional optimized route. In addition, the approach is open to protocol extensions addressing the specific needs of nested networks issue with several levels of MRs.

The architecture makes use of another type of proxy, similar but different from the one defined by PMIPv6. This new type of proxy acts simultaneously as a classical HA from the MR point of view, and as a MR for the primary HA located in the MRs home network that manages and usually advertises the MRs reachability and route to the external network (i.e. to the Internet). Therefore, a binding for a MR attached to a foreign network is always performed in two separate steps: first the MR binds to the closest proxy HA, which in turns binds to the MR's primary HA.

The deployment of this architecture is accomplished by means of an overlay network constituted of bidirectional tunnels. These are between primary HAs (possibly belonging to different network providers), and between primary and proxy HAs within the same network provider infrastructure. These tunnels are organized prior to any transmission of data from and to the MR and are expected to remain relatively during the lifetime of the MRs network attachment.

3. Overview

This section outlines the basic idea of our *proxy-LMA* protocol.

3.1 Problem Statement

It seems reasonable to combine PMIPv6 and Global HA-to-HA as it would make sense for access networks, especially those spanning large geographical areas, to consist of more than one LMA and associated MAGs. These additional LMAs, already having most of the required functionality, could be used to serve as proxy HAs in the HA-HA context for MRs that are topologically close to them. Therefore we propose a new mechanism that allows MRs to bind to the closest LMA instead to the original one at the home link when they are in a foreign network. This LMA will then serve as a proxy HA and accepts traffic originating from and destined to the MR. As this proxy LMA is topologically close to the current point of attachment of the MR, nearly optimal routing is achieved. Similarly, later on we also investigate the case where a MR is attached to a PMIP-domain and mobility signaling is completely performed by the PMIP entities. In addition we propose additional signaling that combines route optimization within PMIP and HAHA.

Hence we assume that the MR is not agnostic of mobility signaling but is capable of using both PMIP and non-PMIP access networks. Especially in the latter case, the MR will have to make use of its NEMO functionality to achieve network mobility. This approach is comparable to 3GPP Release 8 where MNs are capable of both Dual Stack MIPv6 and Proxy MIPv6 operation [1].

3.2 Scenario

As shown in Figure 1, we are assuming two PMIPv6 domains A and B. Both are part of the same service provider network (called the *Extended Home Network* [3]), with each one LMA and two MAGs (domain A with LMA A, MAG A1, MAG A2 and domain B with LMA B, MAG B1, MAG B2) connected to each other via

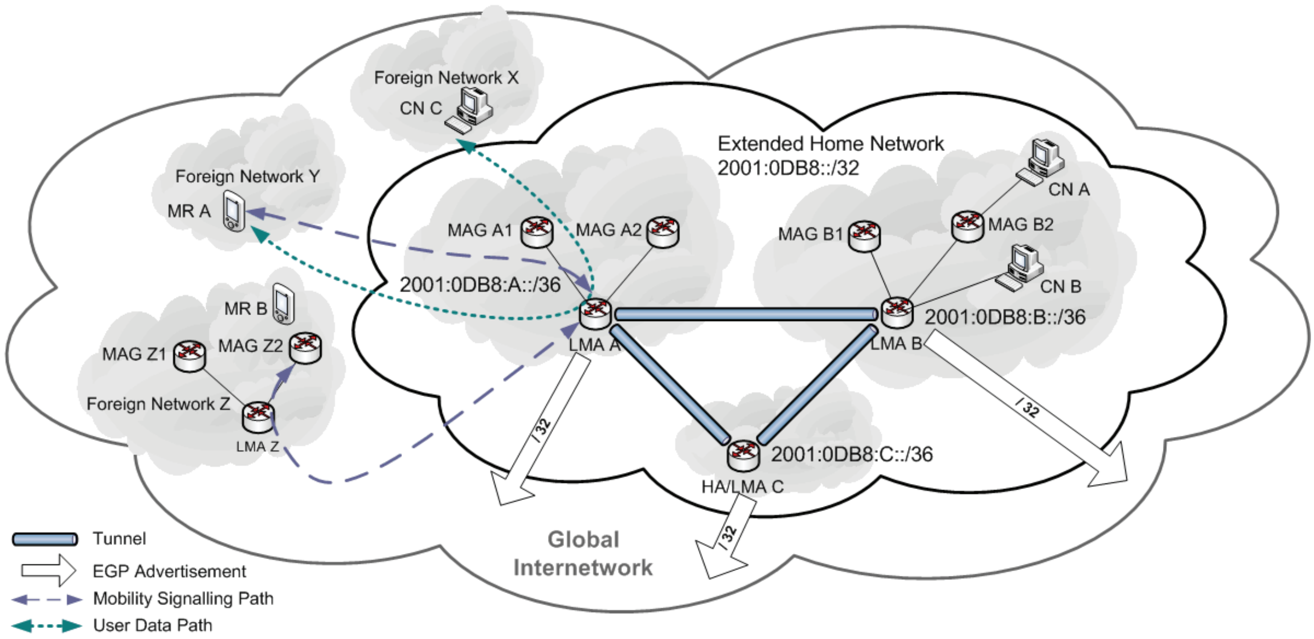

Figure 1 Example Topology

VPN tunnels. For example it is possible for a service provider to have different PMIP domains on different continents.

In addition, we have a Home Agent that is the primary HA (labeled HA/LMA C) for the MRs in question. It is located in a third subnet within the same operational domain as the PMIPv6 entities and is fully meshed with the PMIPv6 domains. From now on we call the HA of the MR the primary LMA (priLMA) and all other LMAs (potential) proxy LMAs (proLMA) of the MR.

MRs must have addresses configured from prefixes that are topologically anchored at one of the LMAs. These LMAs also work as normal HAs for nodes for whom they are the topological anchor. Therefore a MR always has a single primary HA/LMA whereas every other LMA can serve as proxy LMA. In our scenario that is depicted in Figure 1, HA/LMA C is the primary LMA for the MRs A and B that are currently attached to foreign networks.

MR A, attached to the non-PMIP foreign network Y, has to perform mobility signaling for itself with the closest LMA. In case of Figure 1 the MR binds with LMA A that accepts the binding of the MR and serves as a proxy LMA by forwarding traffic to and from the MR.

On the other hand (again referring to Figure 1), MR B is in the foreign PMIPv6 network Z. Under the assumption that a roaming agreement exists between the foreign and the home network of MR B, it is possible to restrict the mobility related signaling to the PMIP entities in these two networks. The MAGs of the foreign network Z advertise the home network prefix of MR B that therefore believes to be attached to the home link and hence does not perform mobility signaling on itself, except perhaps for a deregistration to the HA (if it previously was attached to a foreign network and performed mobility signaling on its own).

While MR A makes use of its NEMO implementation MR B does not have to do so as the MAGs and LMAs take care of the mobility. It should be noted that PMIPv6 does, as of now, only support MHs but not MRs although NEMO support for PMIP will hopefully be available in the near future.

All LMAs of the three example subnets announce their common /32 prefix (corresponding to the *Extended Home Network* [3]) via an Exterior Gateway Protocol (EGP) to the Internet, although in reality they only manage a local /36 prefix. Therefore, depending on the location of the MRs and CNs, traffic will be routed to the topologically closest LMA. Incoming traffic not destined to the local /36 managed by the receiving LMA has to be re-routed to the correct subnet that is the topological anchor for this prefix. For this reason, in addition the LMAs must have configured routes and tunnels between themselves. That is, e.g., LMA B must advertise a route for its own /36 to the other LMAs via an Interior Gateway Protocol (IGP). Because of this, LMAs advertising /32 prefixes to the Internet can forward packets to the correct /36 prefix owner (LMA) internally.

This scenario conforms to a specific type of distributed home network called partitioned home network as defined in [1].

In the following we present our proposed approach based on the same assumptions with regard to the network structure. We will consider the same two cases where the MR is attached to either a foreign non-PMIP network (Section 4) or a foreign PMIP network (Section 5).

4. MR in foreign non-PMIP domain

In this section we will focus on the scenario of MR A being attached to a foreign non-PMIP domain Y (cf. Figure 1). The MR uses mobility signaling as defined in [12] and the LMAs extensions and modifications to the proxy signaling defined in [6] for communication between the primary/proxy LMAs.

We start the discussion of this case considering how the MR can locate the closest LMA In the second step we show how the mobility signaling between the MR and the LMA is performed.

Finally we will discuss how the routing to and from the MR works inside the Extended Home Network and how it can be improved.

4.1 Locating appropriate LMA

The first step is to identify a mechanism that allows the MR to locate an LMA that is suitable for a binding. From the RO perspective this means that the LMA should be topologically close to the MR. There are several possible approaches to achieve this goal.

4.1.1 DHAAD

The Dynamic Home Agent Address Discovery (DHAAD) mechanism specified in [8] can be used to locate a suitable home agent. The current specification of DHAAD is based on /64 home network prefixes and therefore limited to discovering HAs on the physical home link. In addition it requires that the MN is preconfigured with the home prefix.

Using DHAAD in our case would require modifying the ICMP Home Agent Address Discovery Request message. The modification would be required to allow sending the message to the Mobile IPv6 Home Agents anycast address, constructed with a prefix that corresponds to the /32 extended home network instead of the /64 home subnet prefix (shown in Figure 1). All Home Agents have to be configured with this common 32-bit anycast address on one of their interfaces that can be used to route traffic to the closest Home Agent.

Using a /64 prefix would not work with PMIPv6 anyway, as it is based on a per-MN, per-technology prefix model – each MR has a unique home network prefix, different from the one on the home link of the primary LMA. Unmodified original DHAAD messages would therefore not be routed to the correct LMA. Using a common smaller prefix (/32 in our example) for the DHAAD request message solves this problem.

4.1.2 Limits and extensions of DHAAD

Extensions or alternate solutions to DHAAD could be envisaged. Indeed, the existing MIPv6 signaling related to the HA advertisement is quite limited, and currently comprises only few additional information: the HA preference, that can be used by the MN and the valid lifetime of the HA functionality, plus 2 bytes currently unassigned (referred to as *reserved*). Note that this limitation is not specific to NEMO but also addresses simple host mobility as in [8].

A suitable solution that remains in the field for investigation would be to organize an IP multicast group dedicated to the HA information signaling that would flow all over the Extended Home Network and in which any candidate LMA would advertise its main characteristics. Prior or after the handover, the MR would have to register to such a group and start discovering what could be its next candidate(s) LMA. However, given the number of LMAs and primary HAs present in the Extended Home Network, this could induce significant amount of signaling so that the LMA and HA information sending rates should be small in order to overcome congestion (especially if MRs constantly remain group members, in case handovers frequently occur).

The LMA information could also be advertised by lower layers according to the link technology deployed, or, preferentially, according to a standardized method as it is made possible in the 802.21 framework [7] where the different Points of Attachment (PoAs) or Points of Service (PoS) are able to communicate static configuration from their relative network domain, such as a list of possible (proxy) LMAs the MR could bind with.

At last, it should not be forgotten that a static solution can always be envisaged, for example assigning implicitly one LMA depending on the current geographical or topological position. Though this static approach has evident drawbacks, it also remains quite simple in case the Extended Home Network is not expected to be changed and reconfigured frequently.

While we think that this topic deserves further investigations in the future, for the purpose of this paper we will only rely on a modified DHAAD, as mentioned in Section 4.1.1, to locate the closest HA.

4.2 MR binding to HA/LMA

Assuming that the MR (while in a foreign non-PMIP network) is able to locate a suitable LMA, it is necessary to detect whether this responding LMA is a primary (priLMA) or a proxy (proLMA). It is assumed that the address of the priLMA is known to the MR, e.g. it can be obtained by a bootstrapping mechanism similar to [5]. Based on this information, the MR can determine whether it is connected to the primary LMA or a proxy LMA.

If the MR locates the priLMA as the closest MR, the Binding Update (BU) is constructed and sent to the address of the priLMA as specified in [12].

If the closest LMA is a proLMA, the MR extends its BU by adding the address of its primary Home Agent. This allows the proLMA to associate the MR with its priLMA that is the topological anchor. Without this additional option LMAs would require a database that maps MRs to their priLMAs. This database would even have to be integrated with the bootstrapping mechanism [5] and other mechanisms that allow a MR to switch its Home Agent and therefore perform renumbering. We argue that the proposed option is more convenient then this, but concede that the disadvantage of modifying the MR implementation could possible outweigh this advantage.

4.3 Basic LMA operation

Upon receiving a BU from the MR, the LMA checks whether it is the priLMA of this MR. This is accomplished by comparing the Home Address (HoA) of the MR with the prefix(es) the LMA serves.

In case the MR sent the BU to its priLMA, the binding is considered *primary* and subsequent operations are not different from [12].

If the BU is sent to a proLMA, the binding is *secondary*. In this case the LMA creates an appropriate entry in its binding cache. To allow differentiation between standard PMIPv6 proxy bindings and our proposed LMA proxy bindings, we add an *Extended Proxy* flag whose value is set to 1. Besides this, the binding cache entry at the proLMA is set up as specified in [12]. However, an additional field is added that contains the address of the MRs primary LMA, as learned through the additional information that the MR included in its BU.

4.4 LMA to LMA Synchronization

Within PMIPv6 [6] Proxy Binding Updates (PBUs) are sent from the MAG to the LMA to inform the LMA that this MAG now proxies the MH.

Similarly, if an LMA receives a BU from a MR for which it will act as a proxy (because it is not the primary LMA for this MR), it has to inform the priLMA that it currently proxies the MR. The proLMA sends an extended Proxy Binding Update (ePBU), comparable to the PBUs in PMIPv6, to the address of the priLMA. The differentiation between original PMIPv6 PBUs and the new ePBUs is achieved by an *Extended Proxy Registration Flag* E to indicate that this PBU is between a proLMA and a priLMA and not between a MAG and a LMA.

The priLMA stores all the information from the ePBU within its binding cache, including an extended proxy registration flag and the proLMA address for forwarding traffic destined to the MR/MNP to the proLMA that proxies the MR.

The proLMA will only create a binding cache entry and return a valid Binding Acknowledgement (BA) to the MR if the priLMA returns an Extended Proxy Binding Acknowledgement (ePBA) indicating success as a response to the preceding ePBU.

It is important for the priLMA to only consider the most recent binding updates (from the MR) and extended proxy binding updates (from proLMAs) and to ignore outdated BUs or ePBUs. To achieve this goal the sequence numbers within the Binding Updates [12] are reused by the LMA: the sequence number from the MRs BU is copied into the newly constructed ePBU. This way, the priLMA can check which binding update is the most recent one and discard the others.

In case the binding cache of the priLMA indicates that another proLMA is currently proxying the MR and the priLMA receives a valid BU from the MR or an ePBU from another proLMA it updates its binding cache with this new binding and informs the old proLMA that it should delete its binding with the MR (if the sequence number in the new binding is higher than the one stored in the binding cache of the priLMA).

As of now, the proLMA that currently proxies the MR has an appropriate binding cache entry and the priLMA of the MR knows with which proLMA the MR has a secondary binding with. The only remaining issue is forwarding of traffic within the Extended Home Network from and to the MR.

The MR tunnels its data to the LMA it currently has a binding with. In case of a primary binding (the LMA is the priLMA) operation is not different from [12]. If it is a secondary binding (LMA is a proLMA) then traffic is tunneled to this proLMA. The proLMA does not forward packets to the priLMA but instead directly routes the traffic to its destination, depending on the available IGP or EGP routes.

As all LMAs are announcing the /32 prefix via EGP (cf. Figure 1), traffic from the CNs to the MR/MNP can be attracted by any of the LMAs. In general, the LMA closest to the CN will usually receive all the traffic.

Hence, the following three cases for traffic forwarding are possible.

Case 1: traffic arrives at the current proLMA: As the MR has a secondary binding with this LMA, it can directly tunnel the traffic to the MR itself.

Case 2: traffic arrives at the priLMA: If the MR has a primary binding with the priLMA, then traffic can be directly tunneled to the MR. If the MR has a secondary binding with a proLMA, then priLMA forwards the traffic to this proLMA – the address of the proLMA was learned from the ePBU that the proLMA sent to the priLMA in the course of the synchronization process.

Case 3: traffic arrives at an LMA that is neither primary nor a proxy (MR has no binding with this LMA): The LMA does not know anything about the MR but is informed of the priLMA that advertises an aggregate prefix via IGP (cf. Section 3.2) to which the MR/MNP belongs to. Hence the LMA can forward the traffic to the priLMA which in turn knows of the current point of attachement of the MR (case 1 or 2 apply for further processing)

In the last case (3), the fully meshed structure of the partitioned PMIP domains allows routing the traffic destined for the MR to the primary LMA that announces the /36 subnet prefix aggregating the HoA/MNP of the MR. This is a kind of default route if no binding cache entries are available for a certain destination. Mobility signaling and forwarding of user data for this case is shown in Figure 2.

The synchronization time between the different LMAs is significantly influenced by their distances between each other. A large round-trip time also implies large delay for the transmission of ePBU and ePBA. As long as this delay is smaller then the values defined for the retransmission timers for the BUs at the MN, this should not become a problem though.

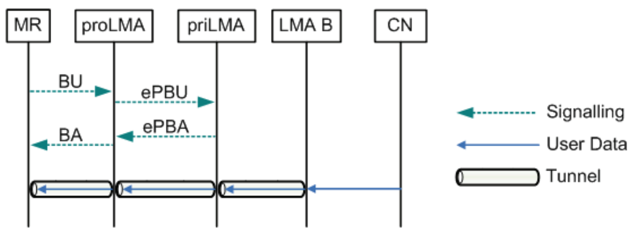

Figure 2 Signalling for and traffic forwarding after LMA synchronization.

4.5 Proactive/Reactive Synchronization

The synchronization mechanism in the previous section only covers signalling between the priLMA and proLMAs that have secondary bindings for the MR. Other LMAs that might attract traffic from CNs destined to the MR/MNP will send these datagrams first to the priLMA (because of the default /36 routes) that in turn sends it directly to the MR or to the current proLMA (Case 2 from above), depending on the MRs current point of attachment. In the latter case the path is not optimal as shown in Figure 2 (CN – LMA – priLMA – proLMA - MR). This problem can be solved by either a reactive or a proactive approach.

4.5.1 Reactive

When taking Figure 3 as an example, after having completed the Binding Update/Binding Acknowledgement exchange, traffic from the CN to the MR will be routed from LMA B via priLMA to proLMA. Upon receiving traffic destined to a MR, for which the priLMA knows that it has a secondary binding with a proLMA, it can detect that routing is sub-optimal and that the LMA could use the direct path to the proLMA.

The priLMA sends an ePBU to the LMA that received the traffic from a CN (e.g. LMA B in Figure 3), together with the address of the current proLMA as known by the priLMA as well as with HoA and MNP of the MR.

An LMA, upon receiving this ePBU, creates a new entry in its binding cache for the MR/MNP and stores the address of the proLMA in an appropriate field. Traffic destined to the MR will now be directly tunnelled to the current proLMA.

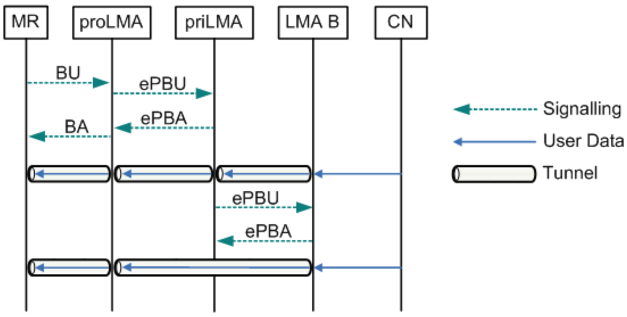

Figure 3 Reactive RO between LMAs

4.5.2 Proactive

In the proactive synchronization strategy, a proLMA receives a BU from the MR and sends an ePBU to the priLMA, just as before. However, during the final step when the priLMA sends the (positive) ePBA to the proLMA, the priLMA also sends ePBUs to all the other LMAs in the Extended Home Network. These ePBUs, similar to those in the reactive case, contain HoA and MNP of the MR as well as the address of the proLMA that currently proxies the MR.

An LMA upon receiving such an ePBU creates an appropriate binding cache entry just like in Section 4.5.1 and tunnels the traffic destined to the MR/MNP to the proLMA as learned from the ePBU. This is shown in Figure 4.

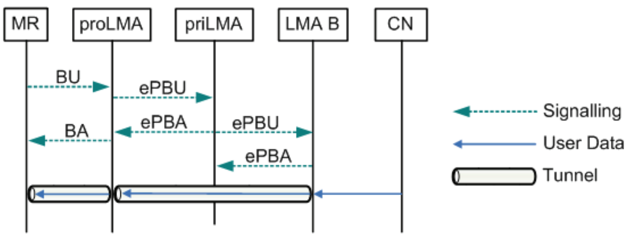

Figure 4 Proactive RO between LMAs

5. MR in foreign PMIP domain

In this section we discuss the case where the MR is attached to a foreign PMIPv6 domain (e.g. MR B in Figure 1).

The basic concept of route optimization for a PMIPv6 architecture is described in the IETF drafts [2] and [9]. The principle is that the two access routers, which are located at the first hop of each communicating partner, maintain state used to optimize the path. In case of movement to another access router the context of the previous access router has to be handed to the next access router. During this operation, the amount of lost packets should be kept to a minimum.

As baseline we refer to the case where MR B is attached to the foreign PMIPv6 domain Z and the CN A is the communication peer attached to MAG B2. Consecutively LMA B is an intermediate router for CN A. In this case and under the assumption that these two domains have set up roaming mechanisms between each other, it is possible to restrict the mobility signaling to the PMIPv6 entities. The foreign MAG can advertise the home network prefix of the MR, which will therefore not send any Binding Updates (except for deregistration if the MR was in a foreign non-PMIP network before) to any of the LMAs in the Extended Home Network. In this case the MR can remain mobility agnostic as signaling and tunneling is performed by PMIPv6, with a series of tunnels from the foreign MAG to the foreign LMA and from the foreign LMA to the home LMA that are always used for traffic forwarding to and from the MR. These routing paths are set up by the previously mentioned roaming mechanism [10].

Considering that the MR is initiating data transfer and binding cache entries are available at the foreign LMA and the home LMA as well as at the LMA of the CN itself, route optimization can be conducted in the following way (we now assume that the LMA of the CN is equal to the home LMA of the MR): Data traffic from the MR traverses through MAG and LMA of the foreign network through the backbone to the (home) LMA of the CN. The LMA forwards the data packet to the MAG and the CN receives the data packet. In order to enable route optimization for the incoming packets the LMA of the CN sends a Correspondent Binding Update (CBU) towards the LMA of the foreign network, where it is forwarded to the MAG the MR is currently attached to. This CBU associates the binding cache entries in the MAGs of CN and MR directly with each other. This means that the MR's MAG now does not need to transmit data packets via its LMA but directly due the MAG of the CN. All further data packets use this optimized path – see Figure 5. This technique may cause a short period where packets arrive out of order though.

In case the MR is moving to a different MAG under the same or a different LMA the same route optimization procedure as mentioned above has to be conducted. A different situation arises if the CN is moving toward a different MAG or the CN was initiating data transfer and the MR is moving to another MAG.

In this case the MR first has to attach to the next network and its MAG will send a Proxy Binding Update (PBU) to its LMA. This time the MR is associated with the next MAG and if CN is transmitting data packets they are still using the old route optimized path and will therefore be forwarded towards the previous MAG. The home LMA transmits a CBU to the CN's LMA, that forwards it to the CNs MAG where the binding cache will be updated and the MR will be associated with the next MAG. All packets that follow will use the newly optimized path. The existing IPsec Security Association (SA) between the MAGs need to be re-establishment; setting up a new SA would take too long and cannot be used to support seamless communication in case of handover, which favors the movement of the tunnel endpoint to the next MAG. However, no protocol for such a tunnel endpoint movement in this context exists today.

Note that CBUs always need some explicit form of an acknowledgment (CBA).

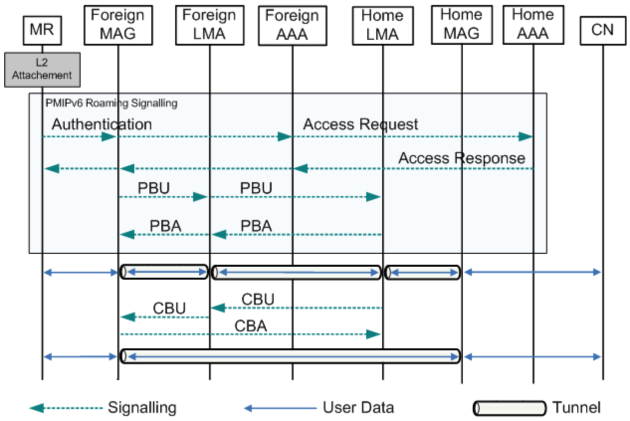

Figure 5 Signaling and user data flow for PMIPv6 based RO. PMIPv6 Roaming Signaling from [10].

6. LMA Synchronization with PMIPv6 RO

The scheme of PMIPv6 based RO can be extended to include the proxy-LMA synchronization mechanisms from Section 4.4.

It is now assumed that the CN is not anymore within the PMIPv6 home domain but in a foreign non-PMIP network (CN C in network X in Figure 1) and the MR still being attached to a foreign PMIPv6 domain (MR B in foreign network Z in Figure 1). The roaming mechanism from [2][10] is used to setup tunnels between foreign MAG, foreign LMA and the home LMA. Traffic between MR and CN will therefore be routed over both the foreign LMA and the primary LMA ("Home LMA") in the Extended Home Network as seen for the first user data flow that takes place after the roaming signaling in Figure 6.

As already mentioned previously the LMA within the Extended Home Network that is closest to the CN will usually attract the incoming traffic. Given that packets from CN flow to LMA A (cf. Figure 6), the traffic will be routed to the priLMA of the MR ("Home LMA") where it will be tunneled to foreign LMA and MAG and finally to the MR. The priLMA can notify LMA A with an ePBU of the foreign LMA and send a CBU to the foreign LMA after a corresponding ePBA from LMA A was received. The foreign LMA forwards the CBU to the foreign MAG that responds with a CBA to LMA A. Both entities establish a direct tunnel between each other that provides an optimized path for the two communication peers MR and CN.

It would also be possible to restrict the RO procedure to the involved LMAs, which means that based on the ePBU synchronization mechanisms presented in Section 5, instead of having a tunnel between foreign MAG and LMA A, a tunnel between foreign LMA and LMA A could be established. This is beneficial in case of frequent movements of the MR to different MAGs of the foreign network, as the tunnel does not have to be continuously reestablished.

In this case the ePBU sent by the priLMA to LMA A has to be extended so that LMA A is aware of the fact that a foreign LMA is proxying the MR. In addition LMA A has to wait for the CBA from the PMIPv6 entity in the foreign network that acknowledges that the RO state in the foreign PMIPv6 network was established.

In any case, for traffic from the CN to the MR the state within LMAs and MAGs is always per-MN with Binding Cache entries being based on HoA or MNP. On the reverse path from MR to CN the tunnel entry point at either MAG or LMA has to be per CN, which has to be considered as a scalability problem. Our primary use case for this RO procedure however is Air Traffic Services and Airline Operational Services where only a very limited number of CNs exist. Passenger communications is more problematic and a scalability problem has to be expected as the number of CNs in the public Internet is potentially large.

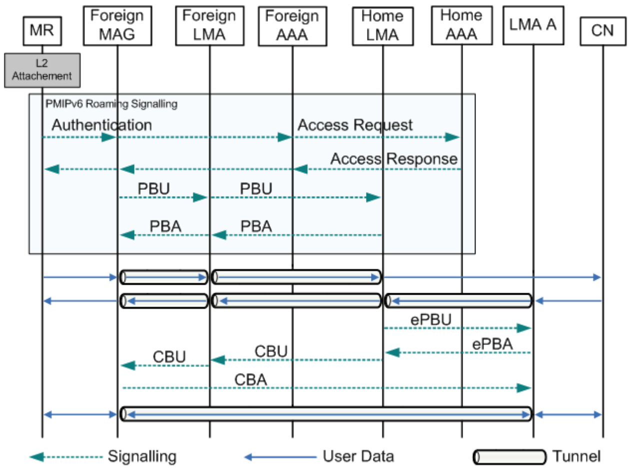

Figure 6 Route Optimization consisting of combined LMA Synchronization and PMIPv6 RO. PMIPv6 Roaming Signaling from [10].

7. Security Aspects

For a mobile router in a foreign PMIPv6 domain, locating a suitable LMA is the first vulnerable step in our proposed scheme. This is so mostly due to the fact that Security Associations are usually not yet established. The security concerns on DHAAD are known and also addressed in Section 15.5 of [8].

A potential weakness exists with the secondary binding that the MR uses to indicate its topological anchor (priLMA) to a proLMA (Section 4.2), as the MR might use a wrong address here. As the ePBU – ePBA message exchange between proLMA and priLMA implicitly involves a verification of the MR belonging to a priLMA, providing wrong HA/LMA addresses will be recognized and the associated original BU of the MR rejected. As the MR would only endanger its own communication and its identity is known (sending a BU to a proLMA requires a pre-established IPsec SA), this vulnerability does not seem critical. Nevertheless, in future investigations it would be necessary to confirm whether the overhead of such an attempted wrong registration is really negligible or not.

The synchronization mechanisms between the LMAs (Section 4.4) would allow creating wrong binding cache entries that e.g. could be used to redirect traffic to somewhere else. Yet as Section 4 only covers LMAs that are within the same network and operated by the same owner, it should be reasonable to assume that the LMAs trust each other to not intentionally provide wrong information and use protected tunnels between each other.

The PMIPv6 signaling in Sections 5 and 6 needs special security mechanisms as the signaling takes place between different operational domains (e.g. foreign LMA – home LMA). For the CBUs it is important to authorize the redirection of addresses or MNPs. It should not be possible for an arbitrary node to initiate a Route Optimization procedure by sending a CBU to a foreign LMA with a certain MNP, therefore either redirecting traffic to somewhere else or blocking traffic to the MR. A Return Routability like procedure as in [8] is the least necessary mechanism needed for protection.

The same holds for the ePBUs in Section 6 that are exchanged between LMAs of different operational domains (foreign LMA – home LMA).

8. CONCLUSIONS

This paper presented an approach to integrate network-based local mobility management provided by PMIPv6 more tightly with MIPv6/NEMO to provide network-based route optimization in global mobility, with an emphasis on NEMO. Reusing existing infrastructure for providing route optimization for aircraft would be valuable as its network-based structure keeps the amount of additional signaling messages over the wireless link to a minimum and, in case the MR is in a foreign PMIPv6 domain, the mobility signaling can be completely performed on the ground and the MR therefore remain mobility agnostic.

The synchronization between the current proxy-LMA of the MR and its primary LMA is always necessary to ensure proper routing inside the Extended Home Network, but the synchronization to other LMAs that are within the home PMIP domain (Section 4.5) is an additional optional but nevertheless important optimization cornerstone that can be based on two different approaches. Reactive synchronization incurs a higher delay at the beginning of MR-CN communication as it takes time to complete the optimization procedure when traffic is already flowing, but ensures that only those LMAs have additional entries in their binding caches that really have to. In the proactive case, optimized paths are always established to all LMAs and no additional delays for setting up RO exist, besides those incurred for the initial ePBU signaling on the fixed ground network. This comes at the cost of an increased binding cache load, as every LMA will have a binding cache entry for every MR that is attached to a foreign network.

Finding a good trade-off between proactive and reactive synchronization, e.g. depending on the amount of data traffic between a MR and CNs close to a certain LMA and the gained reduction of the end-to-end delay, will be investigated in more detail in the future, based on some realistic topology.

An implicit advantage of our proposed approach is the reuse of PMIPv6 that allows combining both proxy-LMA and PMIPv6 RO up to the level of a MAG. As presented in Section 6, this provides additional optimizations that are beneficial for eliminating the need for mobility signaling at the MR even for the case where the CN is in a foreign non-PMIP network.

Further work can be performed on support for multihomed MRs binding with different LMAs.

In addition mechanisms for authorizing and protecting the CBUs used within PMIP RO have to be defined as well. This is also necessary for ePBUs used for synchronization of LMAs that belong to different operational domains, as between foreign and home LMA in Section 6.

9. ACKNOWLEDGMENTS

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