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PMIP Based DMM Approaches
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Abstract

Proxy Mobile IPv6 (PMIPv6) is standardized by IETF to supply mobility management for mobile nodes (MN). For supporting Distributed Mobility Management based on current PMIP standard, enhanced Proxy Mobile IPv6 (ePMIP) with two new logic functions is introduced. (1) Location Management Function (LMF), (2) Distributed Anchoring Function (DAF), including Distributed Routing sub-Function (DRF) and Distributed Mobility sub-Function (DMF). Basic signalling procedures and considerations are also described in this document.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

Centralized mobility anchoring has several drawbacks such as single point of failure, routing in a non optimal route and etc. which are discussed in [I-D.draft-ietf-dmm-requirements]. For supporting Distributed Mobility Management to eliminate those drawbacks, enhanced Proxy Mobile IPv6 (ePMIP) with two new logic functions based on PMIP ([RFC5213]) is introduced in this document . (1) Location Management Function (LMF), maintaining the mappings between IP addresses and location information of mobile nodes. (2) Distributed Anchoring Function (DAF), including Distributed Routing sub-Function (DRF) which enables optimized routing between mobile node and its correspondent node and Distributed Mobility sub-Function (DMF) which guarantees mobile node's mobility with minimal packet loss when optimized routing is established.

DAF can be deployed in [RFC5213]specified MAG to constitute an eMAG, and LMF can be deployed in [RFC5213] specified LMA to constitute an eLMA. This document intends to provide approaches for eliminating those drawbacks by means of allowing mobile node can change its traffic anchor point dynamically. Besides, Distributed Mobility Management approaches are considered not only for communication between two mobile nodes, but also for communication between a mobile node and a fixed node (section 5.2). Further, an alternative implementation is also considered in section 7.

2. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC-2119 [RFC2119].

3. Overview of Ehanced Porxy Mobile IPv6

For supporting Distributed Mobility Management discussed in [I-D DMM], enhanced Proxy Mobile IPv6 (ePMIP) with two new logic functions is introduced in this document . (1) Location Management Function (LMF), maintaining the mappings between IP addresses and location information of mobile nodes (perhaps location information of fixed nodes are also included). (2) Distributed Anchoring Function (DAF), including Distributed Routing sub-Function (DRF) which enables optimized routing between mobile node and its correspondent node and Distributed Mobility sub-Function (DMF) which guarantees the mobile node's mobility when optimized routing is enabled.

3.1. Ehanced PMIP Networking Schematic

```
          Prefix A          Prefix B        Prefix C+D        Prefix X
          \  |  /           \  |  /          \  |  /       |  \  |  /
           \ | /             \ | /            \ | /        |   \ | /
           eLMA1             eLMA2            eLMA3        |    LMA
                                                           |
     (        )(        )(        ) (        )   (        )|(        )
     (  area1 )(  area2 )(  area3 ) (  area4 )...(  arean )|( arean+1)
     (        )(        )(        ) (        )   (        )|(        )
     (  eMAG1 )(  eMAG2 )(  eMAG3 ) (  eMAG4 )...(  eMAGn )|(   MAG  )
          |                             |
          |                             |               +-----+
          |                             |               | CN2 |
         MN1                           CN1              +-----+

                        PMIP Domain with ePMIP deployed
```

Figure 1. RFC[5213] specified PMIP Domain with ePMIP deployed

The ePMIP can be implemented in many ways. One is to extend Location Management Function in [RFC5213] specified Local Mobility Anchor (i.e. legacy LMA) and to extend Distributed Anchoring Function in [RFC5213] specified Mobile Access Gateway (i.e. legacy MAG). Legacy LMA with LMF is called as enhanced local mobility anchor (eLMA), and legacy MAG with DAF is called as enhanced mobile access gateway (eMAG) respectively in the context of this document.

Figure 1 illustrates a possible deployment for ePMIP, in which ePMIP is deployed within a PMIP domain. Mechanism specified by the ePMIP is enabled automatically for a mobile node when it attaches to an eMAG and without any of its awareness, therefore there is no additional requirement for a IPv6 mobile node. For fixed node considerations, please refer to section 5.2.

Clear boundary between ePMIP and PMIP is not necessary, however, deploying ePMIP in a continuous area is preferred. Distributed mobility management approaches will be applied only when correspondent node of this mobile node also attaches to an entity which supports at least DRF (e.g. an eMAG), otherwise [RFC5213] specified PMIP (say legacy PMIP) approaches will be applied (for more details, refer to section 5). For supporting distributed mobility management approaches, new signalling messages among the LMFs and DAFs are also proposed in this draft.

For other implementation considerations, please refer to section 7.

3.2. Functions of eMAG

The eMAG is fully compatible with legacy MAG with limited additional functions which are included in the distributed anchoring function. The general considerations of the eMAG (DAF is a part of eMAG) are described as following:

- If eMAG decides to route traffic from its attached mobile node in an optimized way, it should invoke the Distributed Anchoring Function (DAF), more specifically, the Distributed Routing Function (DRF), to enable distributed mobility management approaches.

- Optimized routing is realized by a direct tunnel between two DRFs of mobile node and its correspondent node. DRF is responsible for maintaining location information of mobile node's correspondent node.

- If correspondent node also attaches to an eMAG and is registered with an eLMA, the direct tunnel is established between two eMAGs and tunnel endpoints are IP addresses of these two eMAGs (or CoAs of these two communicating peers). For other scenarios, e.g. the correspondent node is a fixed node, refer to section 5.

- Optimized routing can only be enabled when location of correspondent node is determined. In case the location cannot be determined locally, DRF should initiate a query approach with a corresponding LMF. In case DRF is informed with the location (could be CN's new location in handoff scenario), it should update the location locally and forward any follow-up traffic based on that location. In case location of correspondent node cannot be determined by any means, common routing (e.g. PMIP routing) mechanism should be used.

- For supporting mobile node's handoff from previously attached eMAG (p-eMAG) to newly attached eMAG (n-eMAG), Distributed Mobility Function (DMF) of both eMAGs shall be enabled. The responsibility of n-DMF (n-eMAG) is to inform p-DMF (p-eMAG) with new location of that mobile node during handoff. The responsibility of p-DMF (p-eMAG) is to forward any received traffic which designated to that mobile node from DRF of correspondent node to n-DMF (n-eMAG) and to inform the DRF with new location for session continuity.

3.3. Functions of eLMA

The eLMA is fully compatible with legacy LMA with limited additional functions which are included in the Location Management Function. The general considerations of the eLMA (LMF is a part of eLMA) are described as following:

- The responsibility of LMF is to determine the location of a specified mobile node (perhaps a fixed node, please refer to section 5) identified by its IP address (e.g. HoA) when it is queried by DRF. Interface between LMFs for determining the location information is proposed, for other alternatives, please refer to section 4.4.

- The location information of a mobile node can be its CoA, and mechanisms for maintaining the mapping of mobile node's IP address and its location information (i.e. HoA-CoA correlation) can be based on Binding Cache Entry (BCE) which is specified in [RFC5213].

4. Overview of ePMIP Approaches

As described above, one implementation of ePMIP is to deploy LMF with legacy LMA to constitute an eLMA, and deploy DAF (including DRF and DMF sub-functions) with legacy MAG to constitute an eMAG. The sections including section 4 to 6 assume ePMIP adopts this implementation. Considerations for other alternative implementations, please refer to section 7.

The overall assumptions for section 4 are as following:

- The correspondent node is also a mobile node which attaches to an eMAG and is registered with an eLMA.

For other scenarios, such as correspondent node is a fixed station or not registered with an eLMA, please refer to section 5.

4.1. Initial Registration

The initial registration procedure for ePMIP is triggered when a mobile node is initialized and attaches to an access link on which there is an eMAG. The most likely procedures for initial registration are identical with those specified in [RFC5213].

When determining the mobile node is authorized for the network-based mobility management service, eMAG sends PBU to a selected eLMA for the mobile node to complete the registration. General, an eLMA is always preferred for the mobile node, unless there has other constraints.

For example, If the mobile node's policy profile includes a filed of mobile node's IPv6 home network prefix(es) assigned to the mobile node's connected interface, and if the HNP(es) is(are) managed by a legacy LMA, the eMAG shall send a PBU to that LMA. In this case, the eMAG shall act as a legacy MAG for this mobile node which means the DAF function in this eMAG shall be disabled for this mobile node.

When initial registration with eLMA is completed, the mobile node gets its HNP(es) and eLMA creates a binding cache entry for this mobile node to maintain the mapping of this mobile node's HNP(es) and Proxy-CoA.

4.2. Optimized Routing

As described in section 3.2, ePMIP leverages a direct tunnel between two eMAGs which are implemented with DRF to realize an optimized routing between mobile node and its correspond node. The effect is similar with the MAG-MAG tunnel specified in [I-D.ietf-netext-pmip-lr] but the principle is different, refer to section 9 for more information.

```
+-----+      +--------+    +-------+    +--------+     +-----+
| MN1 |      |  eMAG1 |    |  eLMA |    |  eMAG4 |     | MN2 |
+-----+      +--------+    +-------+    +--------+     +-----+
   |             |             |             |             |
   |  1.Attach and PMIP Reg.   |  1.Attach and PMIP Reg.   |
   |<------------|------------>|<------------|------------>|
   |             |             |             |             |
   |2.uplink Data|             |             |             |
   |===========>| 3. PBQR     |             |             |
   |             |----------->|             |             |
   |             | 4. PBQA     |             |             |
   |             |<-----------|             |             |
   |   +------------------+    |             |             |
   |   | 5.Record Location|    |             |            |
   |   |   of MN2         |    |             |             |
   |   +------------------+    |             |             |
   |             |  6.uplink data in tunnel |             |
   |             |========================>|             |
   |             |             |             |7.uplink data|
   |             |             |             |===========>|
   |             |   8. Ongoing traffic      |             |
   |<===========>|<========================>|<===========>|
   |             |             |             |             |
```

Figure 2. Optimized Routing

Figure 2 illustrates data delivery approaches of ePMIP for Distributed Mobility Management. Except for the general assumptions applied for section 4, two more assumptions are also applied as following:

- Mobile nodes (MN1 and MN2) attach to different eMAGs (eMAG1 and eMAG4) respectively.

- Mobile nodes are registered with a same eLMA.

For other scenarios, such as mobile nodes are registered with different eLMAs, refer to section 4.4.

After the initial registration, both mobile nodes get their HNPes. And eLMA maintains the mappings of HNP(es) and Proxy-CoAs of both mobile nodes in binding cache entries for them respectively .

The communication between MN1 and MN2 is initiated by MN1 sending IP packets to MN2 (i.e. uplink traffic). The destination IP address of the uplink traffic is set to HoA of MN2. Upon receiving the initial uplink traffic, eMAG1 should determine whether an optimized routing can be established by the support of DRF on it.

The eMAG1 (DRF) should determine whether it holds the location (i.e. CoA) of MN2 locally first. If not, eMAG1 (DRF) should determine the location by initiating a query (i.e. sending a PMIP Binding Query Request, PBQR) to eLMA (LMF) who holds the BCE for MN2. Based on HNP of MN2 provided in the PBQR, eLMA (LMF) could derive the location of MN2 (i.e. CoA) in a corresponding BCE and responses eMAG1 (DRF) with an answer (i.e. sending a PMIP Binding Query Answer, PBQA) carrying the location information. Upon receiving the PBQA, eMAG1 (DRF) records the location of MN2 locally.

Upon the location of MN2 is determined, eMAG1 (DRF) sets up its endpoint of a tunnel (e.g. IP in IP tunnel) to eMAG2 (DRF). And all follow-up uplink traffic will be encapsulated by eMAG1 (DRF) and sent to eMAG4 (DRF) in the established tunnel directly.

Before the optimized routing is established, eMAG1 could forward the first few packets of the uplink traffic to eLMA via bi-directional PMIP tunnel between the two as specified by legacy PMIP. In this case, the routing of the first few packets is non-optimized, and the delay of those packets may be a litter bit larger than the follow-up traffic. Another alternative is that eMAG1 buffers those packets until the optimized routing is set up. In this case, how to determine capacity of the buffer should be carefully considered.

Upon receiving encapsulated packet in the eMAG-eMAG tunnel, the eMAG4 (DRF) needs to decapsulate the packet and forwards the uplink traffic to MN2. As an alternative, eMAG4 (DRF) may parse the packet and record the location of MN1. The location of MN1 can be derived from the outer IP header of the encapsulated packet (i.e. the IP address of the tunnel entry point).

Upon receiving downlink traffic from MN2 to MN1, eMAG4 (DRF) should also set up its endpoint of a tunnel to eMAG1 (DRF) for the downlink

traffic when the location of MN1 is determined. At this moment, a bi-directional tunnel between two eMAGs has been established for all follow-up uplink and downlink traffic and an optimized routing for MN1 and MN2 is set.

4.3. Handoff when Optimaized Routing is Established

MN1 may change its point of attachment from previously attached eMAG (p-eMAG) to newly attached eMAG (n-eMAG) at any time after the optimized routing has been established as described in section 4.2. The routing shall still be remained optimized after handoff.

[I-D.ietf-netext-pmip-lr] also specifies a method for re-establishing optimized routing after the handoff which leverages another new trigger from LMA to both MAGs involved. The consequence is to make the routing non-optimized during the handoff, and optimized again after the handoff. The handoff approach specified here is much different from [I-D.ietf-netext-pmip-lr] specified approach and may provide less latency and jitter.

```
   +---+     +---------+  +---------+  +--------+ +---------+    +---+
   |MN1|     | p-eMAG  |  | n-eMAG  |  |  eLMA  | |  eMAG4  |    |MN2|
   +---+     +---------+  +---------+  +--------+ +---------+    +---+
     |            |            |           |           |           |
     |            |           1. Ongoing traffic       |           |
     |<==========>|<==================================>|<=========>|
     |            |            |           |           |           |
     |            | 2.attach and PMIP Reg. |           |           |
     |<----------------------->|<--------->|           |           |
     |            |  3.PBCI    |           |           |           |
     |            |<-----------|           |           |           |
     |            |  4.PBCA    |           |           |           |
     |            |----------->|           |           |           |
     |   5. Uplink traffic     |           |           |           |
     |========================>|           |           |           |
     |            |  +-----------------+   |           |           |
     |            |  | 6.Determine the |   |           |           |
     |            |  | Location of MN2 |   |           |           |
     |            |  +-----------------+   |           |           |
     |            |            |           |           |           |
     |            |      +--------------------------------------------+
     |            |      |   7. Process of uplink traffic is similar  |
     |            |      |      with the approaches in figure 2       |
     |            |      +--------------------------------------------+
     |            |            |           |           |           |
     |            |            | 8 . Downlink Traffic  |           |
     |            |<===================================|<==========|
     |            |===========>|           |           |           |
```

```
     |<=========================|           |           |           |
     |            |             | 9. PBCI   |           |           |
     |            |------------------------------------>|           |
     |            |             |           | +-----------------+   |
     |            |             |           | | 10. Update      |   |
     |            |             |           | | Location of MN1|   |
     |            |             |           | +-----------------+   |
     |            |             | 11. PBCA  |           |           |
     |            |<------------------------------------|           |
     |            |     12. Ongoing Downlink Traffic    |           |
     |<=========================|<=======================|<==========|
     |            |             |                       |           |
```

Figure 3. Handoff When Optimized Routing is Established

Figure 3 illustrates approach for handoff of MN1 from p-eMAG to n-eMAG. During handoff, legacy PMIP specified procedure is performed for MN1 to maintain its HNP(es) unchanged. The n-eMAG on new access link, upon detecting MN1 on the link, assigns a new CoA for MN1 and generates a PBU message to eLMA for updating the BCE for MN1. In sequence, eLMA responses a PBA message to n-eMAG with one additional new extension which includes the previous location of MN1 (i.e. CoA of MN1 assigned by p-eMAG).

Further, n-eMAG (DMF) initiates an inform message (i.e. PMIP Binding Change Inform, PBCI) to p-eMAG (DMF) with new location of MN1 (i.e. CoA assigned by n-eMAG) based on the acquired previous location of MN1. Sequencely, p-eMAG (DMF) updates the location of MN1 and responses with an acknowledge message (i.e. PMIP Binding Change Ack, PBCA) with all location information of the MN1's current correspondent nodes (in figure3, the current correspondent node is only MN2).

Upon uplink traffic arriving at n-eMAG instead of p-eMAG, n-eMAG (DRF) can derive the location of MN2 locally and forwards the traffic in an optimized way of routing (i.e. MN1->n-eMAG->eMAG4->MN2).

The most likely is that downlink traffic during the handoff is still forwarded by eMAG4 (DRF) to p-eMAG (DRF) before location of MN1 stored in eMAG4 (DRF) locally is updated (i.e. MN2->eMAG4->p-eMAG->MN1) and is discarded by p-eMAG (DRF).

For reducing packet loss, p-eMAG (DMF) is proposed to establish a directional tunnel to n-eMAG (DMF) and forward any received downlink traffic to n-eMAG (DMF) via the tunnel. Meanwhile, p-eMAG (DMF) is also proposed to update the location of MN1 stored in eMAG4 (DRF) by initiating a PBCI to eMAG4 (DRF) to indicate eMAG4 (DRF) to forward

follow-up downlink traffic to n-eMAG (DRF) directly:
MN2->eMAG4->n-eMAG->MN1.

4.4. Multiple eLMAs Consideration

As illustrated in figure 1, multiple eLMAs can be deployed. The most likely is that the mobile node and its correspondent node (i.e. another mobile node) are registered with different eLMAs. The approaches described in subsection 4.2 and 4.3 simply assume both mobile nodes are registered with the same eLMA (the same assumption applied to [I-D.ietf-netext-pmip-lr]), and this section considers multiple eLMAs.

```
Announce PA       Announce PB   Announce PC and PD
 \   |   /         \   |   /        \   |   /
  \  |  /           \  |  /          \  |  /
 +---------+       +---------+       +---------+
 |  eLMA1 |       |  eLMA2 |        |  eLMA3 |
 +-----+--+       +---------+       +---+-----+
      |                 _______________|
      /                |
 +---+-----+        +----+---+
 |  eMAG1 |         |  eMAG2 |
 +---+-----+        +---+-----+
     |                  |
  +--+-+              +-+--+
  | MN1|              | MN2|
  +----+              +----+
```

Figure 4. Mobile node and its Correspondent Node are Registered with Different eLMAs

As illustrated in figure 4, MN1 is registered with eLMA1 by eMAG1, and MN2 is registered with eLMA3 by eMAG2 respectively. Based on RFC[5213], only the LMA which is involved in PMIP registration for a mobile node holds this mobile node's Binding Cache Entry. Therefore, in figure 4, only eLMA1 holds the location information of MN1 and only eLMA3 holds the location information of MN2.

As described in section 4.2, before establishing optimized routing for the traffic, eMAG1 shall determine the location of MN2. In case the location can not be determined locally, eMAG1 shall determine to which eLMA it should send a PBQR message.

4.4.1. Determining eLMA Based on Configuration

As illustrated in figure 4, each eLMA manages a set of IPv6 prefixes with which it uses to allocate home network prefixes or HoAs to the MNs registered to that eLMA. For example, eLMA1 announces prefixes PA to routing system and eLMA3 announces prefixes PC+PD.

If eMAGs could be aware of the IPv6 prefixes configurations of each eLMA, e.g. from operator's management plane since they are in a same administrative domain. The eMAG (DRF) can determine the corresponding eLMA (LMF) to which it should send the PBQR, based on the destination IPv6 address of the traffic and the configured information.

For example, the destination IP address of the traffic from MN1 to MN2 is MN2's HoA. Based on configuration information, eMAG1 (DRF) can determine the HNP of MN2 is prefix PC and is managed by eLMA3. Therefore, eMAG1 (DRF) can determine the eLMA3 (LMF) should be queried when it wants to determine the location of MN2.

This solution looks simple, but it depends on static configured information on every eMAGs. If configuration of a eLMA is changed (e.g. add a prefix PE into eLMA1's IPv6 prefix set), the most likely is that the configured information in all eMAGs in same administrative domain needs update. It seems like that this solution works well for a administrative domain with small number of eMAGs.

4.4.2. Determining eLMA Based on IPv6 Hop-by-Hop Options Header

```
    Announce PA       Announce PB     Announce PC and PD
      \  |  /           \  |  /           \  |  /
       \ | /             \ | /             \ | /
       eLMA1             eLMA2             eLMA3
                                             +
                                            /!\
           ,------- Router1-------- Router2 .|
          |
          |
        eMAG1
```

eMAG1 initiates a query message (PBQR) carried in a IP packet whose destination IP address is HoA of MN2.
The packet will be intercepted, processed and terminated by eLMA3 who manages the prefix of the MN2's HoA based on the mechanism of the Hop-by-Hop Option Header.

Figure 5. Determining eLMA Based on Hop-by-Hop Options Header

When constructing a PBQR message, eMAG1 can use HoA of MN2 as destination IP address of this message and construct an appropriate IPv6 Hop-by-Hop Option Header as extension header ([RFC2460]). The HoA of MN2 is the destination IP address of the uplink traffic.

When IP packet which includes the PBQR message is sent into the routing system, standard routing mechanism ensures the packet can reach eLMA3 which manages the prefix of MN2's HoA. Depending on the mechanism of the Hop-by-Hop Option Header, each router including eLMA3 on the routing pass of this packet will intercept the packet and check the Hop-by-Hop Option Header.

Based on the indication carried by the options in Hop-by-Hop Option Header, eLMA3 determines whether the prefix of destination IP address belongs to its management. If it does, eLMA3 shall treat itself as destination of this message and let the LMF on it process the message.

It seems like that, all common routers on the routing pass of this packet will check the Hop-by-Hop Option Header and may cause some delay. Another disadvantage is that it will take relative longer time to make sure no location information of correspondent node can not be determined (refer to section 5.1 for more details).

4.4.3. Determining eLMA Based on Interface Between eLMAs

```
    +------------------------------+
    |            eLMA2             |
    |                              |
    |  eLMA1--------------> eLMA3  |
    |    /|\  further query        |
    +-----+------------------------+
          |
   query  |
          |
        eMAG1
```

Figure 6. Determining eLMA Based on Interface Between eLMAs

Interface between eLMAs which are located in a same administrative domain is introduced for determining location information of a particular mobile node.

When determining location of correspondent node, eMAG1 (DRF), in figure 6, could simply send a PBRQ message to any random eLMA (LMF) it considers convenient (e.g. eLMA1). The most likely is that the eLMA (LMF) queried does not hold the relevant location information.

But the eLMA (LMF) can determine which eLMA (LMF) holds the information (e.g. eLMA3).

For example, if IPv6 prefixes managed by each eLMA are awared of, the eLMA1 (LMF) can determine which eLMA (LMF) should be queried further and query it. It can be expected that the number of eLMA deployed in a administrative domain will not be large (as illustrated in figure 1), therefore, depending on configuration is applicable.

5. CN Considerations

The assumption of section 4 is that the correspondent node is also a mobile mode and is registered with eLMA by eMAG. Other scenarios, such as correspondent node is a fixed node, or a mobile node but is not registered with eLMA, are considered in this section.

5.1. CN Which is not Registered with eLMA

This section considers scenario that the correspondent node (e.g. CN2 in figure 1) is a mobile node but not registered with eLMA. For example, CN2 is registered with a legacy LMA by attaching to a legacy MAG. For another example, CN2 just locates in common IPv6 environment.

When mobile node (MN1 in figure 1) initiates uplink traffic to correspondent node (CN2 in figure 1), eMAG1 (DRF) to which MN1 attaches should initiate a query for determining location of CN2 as described in section 4.2.

According to section 4.4.1, eMAG1 (DRF) can not determine to which eLMA (LMF) it should send the query message, because CN2's prefix is out of the management of any eLMA. In this case, eMAG1 (DRF) can make sure no location information can be determined.

According to section 4.4.2, eMAG1 (DRF) should construct a query message and set message's destination to IP address of CN2. The query message will be routed to CN2 based on common routing mechanism and no response is excepted. The eMAG1 (DRF) should wait for the response until the related timer is timeout. Before eMAG1 (DRF) can make sure no location information can be determined, one or more query message may be re-sent by eMAG1 (DRF). Thus, it will take a relative longer time to make sure no location information can be determined.

According to section 4.4.3, eMAG1 (DRF) can send a query message to any one of those eLMAs (LMF) and the eLMA (LMF) queried performs the query among those eLMAs (LMF). In this case, eMAG1 (DRF) can make sure no location information can be determined.

As described above, the failed queries are excepted and location information of CN2 can not be determined by eMAG1 (DRF). In this case, eMAG1 should behavior as a legacy MAG for this session and PMIP specified routing mechanism shall be applied for the uplink traffic (i.e. no optimized routing), e.g. MN->eMAG1->E-LMA->common router->CN.

Of course, if the correspondent node itself is a fixed node, same rules described above are also applicable.

5.2. Routing Optimization Considerations when the CN is a Fixed Node

As described above, if correspondent node is a fixed node, eMAG1 will behavior as a legacy MAG and no optimized routing is enabled.

Most of correspondent nodes which are fixed nodes are deployed in a centralized manner in most deployment, e.g. CDN/IDC/Web Servers and etc. Those fixed nodes are generally converged by a couple of access routers, although the topology within those fixed nodes may be very complicate, to access operator's IP bearer network which is illustrated in figure 7. If mechanism which providing optimized routing cannot be applied when correspondent node are fixed nodes of these kind, effect of this mechanism will be very limited.

```
  __________
 /    CN     \             ,--------.
((CDN\IDC\Web )---Access Router     `.     _.----------.
(   Server)   )    ,--'               `-''    eLMA     :
 \___________/     \                _.-------.      ,--'
                     '--  eMAG-----''          `---'
                           |
                           |
                          MN1
```

Figure7. Correspondent Nodes are Fixed Nodes Cause Non-optimized Routing

Refer to figure 7, it seems like that non-optimized routing (e.g. between MN1 and CDN) will be a problem for this deployment as discussed in [I-D DMM Problem Statement]. For purpose of eliminating non-optimized routing, one implementation is to replace those common access routers in figure 7 with routers which are implemented with Distributed Routing Function (DRF). No Distributed Mobility Function (DMF) is needed, since nodes attached are all fixed nodes.

```
      ,-------.
    ,'         `-.
```

```
       (  CDN\IDC\Web )-.                 _.----.
       (  Server      )  \       ,--_.--''       `-.
        \____________'   AR+DRF-'                   `-------.
    ,-----------.          /  -.                             \
   ; Fixed User  :       ,'     `-                            \
   : Equipments  ;---AR+DRF ----LMF                    eLMA    :
    `-----------'        \     ,-                              ;
                      AR+DRF--'             ,----.            ;
        ,-----------.   / `\              eMAG    `--.        ;
       ; Fixed User  : /     -------------' |          `-----'
       : Equipments  ;/                     |
        `-----------'                       |
                                            |
                                           MN1
```

Figure 8. Applying Optimized Routing when Correspondent Nodes are fixed nodes

Additionally, one more LMF needs deployed as illustrated in figure 8. The responsibility of that LMF is to response any received PBRQ message with location of queried fixed node (e.g. IP address of one of those AR+DRF). Method specified in section 4.2.2 may not be applicable, because PBRQ will be routed to one of those AR+DRF directly. No response will be expected, except that the AR+DRF is also co-located with a LMF.

6. Handoff between eMAG and MAG

As illustrated in figure 1, ePMIP is deployed in PMIP domain (no clear boundary), and belongs to a same administrative domain, e.g. a same operator. The mobile node which is initial registered with eLMA by attaching a eMAG may handoff to a legacy MAG and vice versa. By supporting the handoff between eMAG and MAG , ePMIP can be deployed in manner of incremental when assuming PMIP is well deployed.

As described above, eLMA is a legacy LMA implemented with LMF, and eMAG is a legacy MAG implemented DAF (DRF+DMF). When a mobile node which attaches to an eMAG handoff to a legacy MAG, the legacy MAG will perform PMIP registration to the eLMA and establish a bi-directional tunnel with the eLMA. In this case, PMIP routing mechanism will be applied (i.e. no routing optimization). On the other hand, when a mobile node which attaches to a legacy MAG handoff to an eMAG, the eMAG will perform PMIP registration to the legacy LMA and establish a bi-directional tunnel with the legacy LMA. In this case, PMIP routing mechanism will also be applied (i.e. no routing optimization).

7. Considerations for Other Implementation

As described in section 3.1, ePMIP can be implemented in many ways. Section 3.1 also indicates one of those implementations, i.e. deploying LMF in legacy LMA, and DAF in legacy MAG. This section considers one alternative implementation.

7.1. One Alternative Implementation

One alternative implementation is to deploy DAF in legacy LMA, and deploy LMF independently. When multiple LMFs are deployed, interfaces between those LMFs are necessary as illustrated in figure 10.

```
                 _.--------------------.
           ,---''       LMF2             `--- ,
         ,'       _..-''    ``-.._             ;
      ,-'        LMF1 --------- LMF3            \
     /                                           : Prefix ePMIP
    /  ( area1 )( area2 )( area3 )...( arean )   |     /
   |   (       )(       )(       )   (       )   ;    /         ( arean+1)
   :   ( eLMA1 )( eLMA2 )( eLMA3 )...( eLMAn ) BG+DRF ---       (        )
    \      |        |       |                  /      \         (   LMA  )
     `-----+.       | _.----+--ePIMP Area-----'        \             |
           | `------|'      |                                        |
           |        |       |                                        |
          MAG1     MAG2    MAG3                                     MAG
           |                |
          MN1              CN1
```

Figure 10. One Alternative Implementation of ePMIP

For routing consideration, a clear boundary seems necessary if ePMIP takes this kind of implementation. A set of IPv6 prefixes which are used for allocating HNP(es) or HoA(s) to mobile nodes should be assigned to ePMIP area and each LMA manages part of them. The eLMAs don't announce any IPv6 prefix to routing system. Instead, a border gateway implemented with DRF (BG+DRF) which is located at the boundary of this ePMIP area announces those set IPv6 prefix(es) to outside as illustrated in figure 10.

The node inside ePMIP area could be a mobile node or a fixed node. When a correspondent node located outside of ePMIP area sends IP traffic to a node located inside ePMIP area, traffic will be routed to BG+DRF which announces the management of the prefix of the traffic's destination IP address.

7.2. Optimized Routing Consideration

Consider that a mobile node (MN1) is initiated in ePMIP area and attaches to a legacy MAG, legacy PMIP registration procedures will be performed. The MAG will select a local mobility anchor (e.g. eLMA1) for MN1 and send a PBU to it. Note that, the LMA selected by the MAG is actually an eLMA. MAGs cannot tell the distinguishes between LMAs and eLMAs.

After successful PMIP registration, MN1 acquires its HNP(es) and eLMA1 manages a binding cache entry for MN1 as specified by legacy PMIP. Further, eLMA1 (DRF) has to inform a corresponding LMF with the HNP(es) and location information of MN1 (i.e. IP address of eLMA1 itself). LMF will manage the mapping between HNP(es) and location. How to determine which LMF the eLMA1 (DRF) should inform, refer to section 7.4.

Consider that correspondent node (CN1) of MN1 is also a mobile node and is located in same ePMIP area (refer to section 7.3 for other scenarios).

Upon receiving uplink traffic from MN1 to CN1 via the bi-directional PMIP tunnel, eLMA1 (DRF) should determine whether it holds location information of CN1 locally. If not, a corresponding LMF should be queried by eLMA1 (DRF), and the required location (e.g. IP address of eLMA3) should be stored by eLMA1 (DRF) locally. Upon determining the location, eLMA1 (DRF) sets up a tunnel to eLMA3 (DRF) by using the location of CN1 as tunnel endpoint, and forwards uplink traffic to eLMA3 (DRF) directly.

Upon movement of MN1, a PMIP handoff from pMAG to nMAG will be triggered. [RFC6097] provides a mechanism for LMA discovery, and requires nMAG of a mobile node should discovery a same LMA with which the pMAG has discovered for that mobile node. The nMAG in this draft does not have to discover a same eLMA (i.e. eLMA1) but a best eLMA (e.g. eLMA2) for MN1 and performs PMIP registration. The implementation can take any method specified in [RFC6097] for discovering the best eLMA.

The eLMA2 (DRF) should update LMF with new location information of MN1 (e.g. IP address of eLMA2 itself) and eLMA2 (DMF) should also inform eLMA1 with the new location. The approaches are quite similar with those described in section 4.3.

7.3. Correspondent Node Consideration

The correspondent node may be located outside of ePMIP area (could be a mobile node or a fixed node). In this case, the prefixes or IP

address of CN are not managed by ePMIP. Actually, the set of IPv6 prefixes which are assigned to ePMIP can be configured in LMF. In this case, when eLMA1 (DRF) queries LMF CN's location, the LMF will response with IP address of BG+DRF. The routing will be: MN1 <-> MAG <-> eLMA <->BR+DRF <-> CN.

In the case of the correspondent node is a fixed node and is located inside ePMIP area, it seems like that the traffic from CN to MN1 cannot be routed correctly, because CN doesn't have any idea of MN1's location.

A simple approach is to let BG+DRF also announce the set of prefixes which are assigned to ePMIP to routing system in ePMIP area. In this case, traffic will be routed to BG+DRF and further forwarded by BG+DRF. But it seems that the BG+DRF could be overloaded easily and routing will be no-optimal.

Another approach is to deploy multiple routers implemented with DRF in ePMIP area and let them announce same set of prefix(es) which are assigned to ePMIP to routing system (as illustrated in figure 11). In this case, the anycast mechanism is used for attract traffic from CN and optimized routing is enabled: CN <->Access Router <-> Router+DRF <-> eLMA <-> MAG <-> MN

```
        ,--------------
       /  CN            `------------.
     ,'    |                LMF2       `---.
    /      |          _..-''    ``-.._      `.
   ;     Access      LMF1 --------- LMF3      `.
   +     Router                                 `.
   |                                              \
   |         \   |   /  Prefix ePMIP  \   |   /    \
   |          \  |  /                  \  |  /      \
   :         router+DRF              router+DRF      :
    :         /  |  \                  /  |  \       |     Prefix ePMIP
    |        /   |   \                /   |   \      |     /
    |                                                |    /
    +      ( area1 )( area2 )( area3 )...( arean )  BG+DRF---
     \     (       )(       )(       )   (       )   |    \
      \    ( eLMA1 )( eLMA2 )( eLMA3 )...( eLMAn )   |     \
       ` -------------------------------------------;
```

Figure 11. Anycast Mechanism for Attracting Traffic From CN

7.4. Location Management Consideration

As illustrated in figure 11, multiple LMFs can be deployed in ePMIP area. When a mobile node is registered with an eLMA, the eLMA (DRF) needs to update location of this mobile node in a corresponding LMF. And when eLMA (DRF) want to determine location information of a mobile node, it need to query a corresponding LMF.

Interface between those LMFs is proposed in this draft. One preferred LMF can be configured in every specific eLMAs (DRF). If eLMA (DRF) need to update or query location of a mobile node (or correspondent node), it can always sends a corresponding message to that preferred LMF. Upon receiving the message, that preferred LMF should determine which LMF is responsible for managing the location for that mobile (or correspondent node) and relay the message to that determined LMF.

Many methods can be used by preferred LMF for determining to which LMF it should relay the message. For example, Hash algorithm (hashing the HNP(es)), DHT algorithm and etc.

8. Security Considerations

This draft defines several new signaling messages among eMAGs and eLMAs for supporting Distributed Mobility Management. Security considerations for those messages are considered in this section for two implementation cases discussed in this draft.

For first implementation case, as described in section 3.1, deploying LMF in legacy LMA, and DAF in legacy MAG, respectively eLMA and eMAG. Basic assumption is that all those eMAGs and eLMAs belong to one same administrative domain (e.g. a same operator), other scenarios are out of scope of this draft.

The function of signaling messages PBQR/PBQA between eMAG and eLMA is for acquiring location information of a specific mobile node (or a fixed node). This draft uses the same security association mechanism which is defined in [RFC5213] to protect those PBQR\PBQA messages. The function of signaling messages PBCI/PBCA exchanged between eMAGs is for supporting mobile node's handoff when optimized routing has been established. This is an essential feature for supporting Distributed Mobility Management. The said PBCI/PBCA messages MUST be protected by using end-to-end security association(s) offering integrity and data origin authentication, the eMAGs is proposed to implement IPsec [RFC4301] or other equivalents for protecting PBCI\PBCA messages. E.g. IPsec Encapsulating Security Payload (ESP, [RFC4303]) in transport mode with mandatory integrity protection could be used for protecting those signaling messages.

Similar security considerations for protecting PBQR/PBQA and PBCI/PBCA messages which are described for the first implementation case above are also applied for the second implementation case which is described in section 7, i.e. deploying DAF in the legacy LMA to constitute eLMA, and deploying LMF independently.

9. Difference with Localized Routing

[I-D.ietf-netext-pmip-lr] (i.e. LR) allows mobile nodes attached to the same or different mobile access gateways to route traffic by using localized forwarding or a direct tunnel between the gateways. The core idea is to establish an optimized forwarding path between two mobile nodes. Such localized communication enables offloading traffic from LMAs and from the core network to the edge. Since traffic can be routed by MAGs directly, those MAGs can be considered as a kind of traffic anchor point. In this point of view, LR could be a potential solution for Distributed Mobility Management taken MAG as mobile node's dynamic anchor.

But LR cannot be used as a DMM solution directly, it still has some gaps, e.g. packet loss, scalability and etc. LR does not consider solution for scenario when two mobile nodes are attached to different MAGs and registered with different LMAs (i.e. scenario A22 described in [RFC6279]), because PMIPv6 does not define any interface between LMAs. But it is most likely that, in a real network, multiple LMAs are deployed. Because deploying a single LMA in same administrative domain (e.g. a same operator) is prone to single point of failure and low performance due to bottleneck. We can say that, a large part of MN-MN communications will fall into scenario A22. In this case, if scenario A22 is not considered, the usage of LR will be limited. This draft considers inter-LMA communications which is one of the main differences from LR.

In scenario when MN and CN attached to different MAGs but same LMA (i.e. scenario A21 described in section 5 of [I-D.ietf-netext-pmip-lr]) , if MN detaches from its current MAG and attaches to a new MAG the localized routing state needs to be re-established. During this period packets from CN will arrive at the old MAG, this will result in packet loss. The packet loss problem will be even more worse when MN handoffs from Scenario A12 to A22, in Scenario A22, neither LMA nor MAG has a means to determine and initiate LR , this can result in transient packet loss when routing switches between the localized path into the normal path through the LMAs as described in section 7 of [I-D.ietf-netext-pmip-lr]. Due to this limitation LR is not applicable for packet-loss-sensitive applications. This draft considers this issue and can guarantee minimal packet loss. This is another differences from LR.

MN and CN in LR MUST be PMIPv6 mobile nodes. However, in real deployment scenarios, a large part of communications between MN and its CN involve accessing fixed node by MN (e.g. access a web server). As described in section 5.2 (figure 7), non-optimized routing could be a problem for MN accessing fixed node. So if this scenario is not considered, the usage of LR will also be limited. This draft considers the routing optimization between mobile node and fixed node which is one another difference from LR.

In technical level, LR is established by utilizing Localized Routing Initiation (LRI) and Local Routing Acknowledgment (LRA) message between MAG and LMA. LMA provides one MAG with IP address of another MAG, and this approach will lead to so called race condition situation when both mobile nodes move and attach to a new access router simultaneously (refer to last bullet in section 3.2 of [RFC6279]). Solution specified in this draft utilize location information query mechanism to establish the optimized path which eliminates the race condition and also provides more flexibility in different deployment implementations(e.g. deploying LMF in LMA and DAF in MAG, deploying DAF in LMA and deploying LMF independently).

10. IANA Considerations

This document makes no request of IANA.

11. References

11.1. Normative References

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11.2. Informative References

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