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Distributed Mobility Anchoring
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Abstract

This document defines distributed mobility anchoring to meet diverse mobility needs in 5G Wireless and beyond. Multiple anchors and nodes with mobility functions work together to provide IP mobility support. A network or network slice may be configured with distributed mobility anchoring depending on the needs of mobility support. In the distributed mobility anchoring environment, multiple anchors are available for mid-session switching of an IP prefix anchor. Without an ongoing session, i.e., no IP session continuity required, a flow of a mobile node can be re-started using a new IP prefix which is allocated from a new network of the mobile node and is therefore anchored to the new network. With an ongoing session, the anchoring of the prior IP prefix may be relocated to the new network to enable IP session continuity.

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Table of Contents

1.	Introduction	3
2.	Conventions and Terminology	4
3.	Distributed Mobility Anchoring	6
3.1.	Configurations for Different Networks or Network Slices	6
3.1.1.	Network-based Mobility Support for a Flat Network	7
3.1.2.	Network-based Mobility Support for a Hierarchical Network	8
3.1.3.	Host-based Mobility Support	11
3.1.4.	NETwork MObility (NEMO) Basic Support	13
3.2.	Operations and Parameters	15
3.2.1.	Location Management	16
3.2.2.	Forwarding Management	18
4.	IP Mobility Handling in Distributed Anchoring Environments - Mobility Support Only When Needed	24
4.1.	No Need of IP Mobility: Changing to New IP Prefix/Address	25
4.1.1.	Guidelines for IPv6 Nodes: Changing to New IP Prefix/Address	27
4.2.	Need of IP Mobility	28
4.2.1.	Guidelines for IPv6 Nodes: Need of IP Mobility	30
5.	IP Mobility Handling in Distributed Mobility Anchoring Environments - Anchor Switching to the New Network	31
5.1.	IP Prefix/Address Anchor Switching for Flat Network	31
5.1.1.	Guidelines for IPv6 Nodes: Switching Anchor for Flat Network	32
5.2.	IP Prefix/Address Anchor Switching for Flat Network with Centralized Control Plane	33
5.2.1.	Additional Guidelines for IPv6 Nodes: Switching Anchor with Centralized CP	36
5.3.	IP Prefix/Address Anchor Switching for a Hierarchical	

Network	37
5.3.1. Additional Guidelines for IPv6 Nodes: No Anchoring Change with a Hierarchical Network	39
5.4. IP Prefix/Address Anchor Switching for a Hierarchical Network	39
5.4.1. Additional Guidelines for IPv6 Nodes: Switching Anchor with Hierarchical Network	41
6. Security Considerations	41
7. IANA Considerations	41
8. Contributors	41
9. References	42
9.1. Normative References	42
9.2. Informative References	44
Authors' Addresses	44

1. Introduction

A key requirement in distributed mobility management [RFC7333] is to enable traffic to avoid traversing a single mobility anchor far from an optimal route. Distributed mobility management solutions do not make use of centrally deployed mobility anchor for a data plane [Paper-Distributed.Mobility]. As such, the traffic of a flow SHOULD be able to change from traversing one mobility anchor to traversing another mobility anchor as a mobile node (MN) moves, or when changing operation and management requirements call for mobility anchor switching, thus avoiding non-optimal routes. This draft proposes distributed mobility anchoring to enable making such route changes.

Distributed mobility anchoring employs multiple anchors in the data plane. In general, control plane functions may be separate from data plane functions and be centralized but may also be co-located with the data plane functions at the distributed anchors. Different configurations of distributed mobility anchoring are described in Section 3.1. For instance, the configurations for network-based mobility support in a flat network, for network-based mobility support in a hierarchical network, for host-based mobility support, and for Network MObility (NEMO) basic support are described respectively in Section 3.1.1, Section 3.1.2, Section 3.1.3 and Section 3.1.4. Required operations and parameters for distributed mobility anchoring are presented in Section 3.2. For instance, location management is described in Section 3.2.1, forwarding management is described in Section 3.2.2.

An MN attached to an access router of a network or network slice may be allocated an IP prefix which is anchored to that router. It may then use an IP address configured from this prefix as the source IP address to run a flow with its correspondent node (CN). When there are multiple mobility anchors, an address selection for a given flow

is first required before the flow is initiated. Using an anchor in an MN's network of attachment has the advantage that the packets can simply be forwarded according to the forwarding table. Although the anchor is in the MN's network of attachment when the flow was initiated, the MN may later move to another network, so that the IP no longer belongs to the current network of attachment of the MN.

Whether the flow needs IP session continuity will determine how to ensure that the IP address of the flow will be anchored to the new network of attachment. If the ongoing IP flow can cope with an IP prefix/address change, the flow can be reinitiated with a new IP address anchored in the new network as shown in Section 4.1. On the other hand, if the ongoing IP flow cannot cope with such change, mobility support is needed as shown in Section 4.2. A network or network slice supporting a mix of flows requiring and not requiring IP mobility support will need to distinguish these flows. The guidelines for such network or network slice are described in Section 4.1.1. The general guidelines for such network or network slice to provide IP mobility support are described in Section 4.2.1.

Specifically, IP mobility support can be provided by changing the anchoring of the IP prefix/address of the flow from the home network of the flow to the new network of attachment. The basic case may be with network-based mobility for a flat network configuration described in Section 5.1 with the guidelines described in Section 5.1.1. This case is discussed further with a centralized control plane in Section 5.2 with additional guidelines described in Section 5.2.1. A level of hierarchy of nodes may then be added to the network configuration. Mobility involving change in the Data Plane Node (DPN) without changing the Data Plane Anchor (DPA) is described in Section 5.3 with additional guidelines described in Section 5.3.1. Mobility involving change in the DPN without changing the DPA is described in Section 5.4 with additional guidelines described in Section 5.4.1.

2. Conventions and Terminology

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 [RFC2119].

All general mobility-related terms and their acronyms used in this document are to be interpreted as defined in the Mobile IPv6 (MIPv6) base specification [RFC6275], the Proxy Mobile IPv6 (PMIPv6) specification [RFC5213], the "Mobility Related Terminologies" [RFC3753], and the DMM current practices and gap analysis [RFC7429]. These include terms such as mobile node (MN), correspondent node

(CN), home agent (HA), home address (HoA), care-of-address (CoA), local mobility anchor (LMA), and mobile access gateway (MAG).

In addition, this document uses the following terms:

Home network of an application session or a home address: the network that has allocated the HoA used for the session identifier by the application running in an MN. The MN may be running multiple application sessions, and each of these sessions can have a different home network.

IP prefix/address anchoring: An IP prefix, i.e., Home Network Prefix (HNP), or address, i.e., HoA, allocated to an MN is topologically anchored to an anchor node when the anchor node is able to advertise a connected route into the routing infrastructure for the allocated IP prefix.

Location Management (LM) function: managing and keeping track of the internetwork location of an MN. The location information may be a binding of the IP advertised address/prefix, e.g., HoA or HNP, to the IP routing address of the MN or of a node that can forward packets destined to the MN.

When the MN is a mobile router (MR) carrying a mobile network of mobile network nodes (MNN), the location information will also include the mobile network prefix (MNP), which is the IP prefix delegated to the MR. The MNP is allocated to the MNNs in the mobile network.

LM is a control plane function.

In a client-server protocol model, location query and update messages may be exchanged between a Location Management client (LMc) and a Location Management server (LMs).

Optionally, there may be a Location Management proxy (LMp) between LMc and LMs.

With separation of control plane and data plane, the LM function is in the control plane. It may be a logical function at the control plane node, control plane anchor, or mobility controller.

It may be distributed or centralized.

Forwarding Management (FM) function: packet interception and forwarding to/from the IP address/prefix assigned to the MN, based on the internetwork location information, either to the destination or to some other network element that knows how to forward the packets to their destination.

This function may be used to achieve traffic indirection. With separation of control plane and data plane, the FM function may split into a FM function in the data plane (FM-DP) and a FM function in the control plane (FM-CP).

FM-DP may be distributed with distributed mobility management. It may be a function in a data plane anchor or data plane node.

FM-CP may be distributed or centralized. It may be a function in a control plane node, control plane anchor or mobility controller.

Security Management (SM) function: The security management function controls security mechanisms/protocols providing access control, integrity, authentication, authorization, confidentiality, etc. for the control plane and data plane.

This function resides in all nodes such as control plane anchor, data plane anchor, mobile node, and correspondent node.

3. Distributed Mobility Anchoring

3.1. Configurations for Different Networks or Network Slices

The mobility functions may be implemented in different configurations of distributed mobility anchoring in architectures separating the control and data planes. The separation described in [I-D.ietf-dmm-deployment-models] has defined the home control plane anchor (Home-CPA), home data plane anchor (Home-DPA), access control plane node (Access-CPN), and access data plane node (Access-DPN), which are respectively abbreviated as CPA, DPA, CPN, and DPN here. Some configurations are described in [I-D.sijeon-dmm-deployment-models].

Different networks or different network slices may have different configurations in distributed mobility anchoring.

The configurations also differ depending on the desired mobility supports: network-based mobility support for a flat network in Section 3.1.1, network-based mobility support for a hierarchical network in Section 3.1.2, host-based mobility support

(Section 3.1.3), and Network MObility (NEMO) based support in Section 3.1.4.

3.1.1. Network-based Mobility Support for a Flat Network

Figure 1 shows two different configurations of network-based mobility management for a flat network.

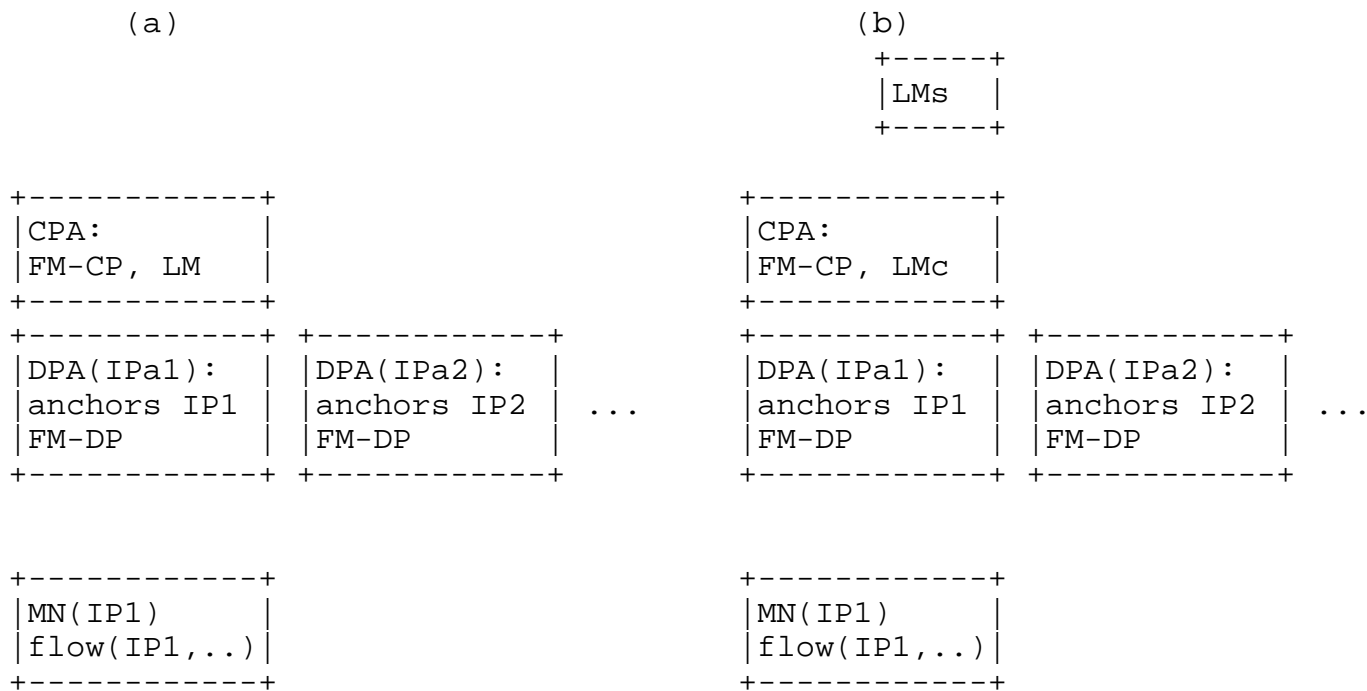


Figure 1. Configurations of network-based mobility management for a flat network (a) FM-CP and LM at CPA, FM-DP at DPA; (b) Separate LMs, FM-CP and LMc at CPA, FM-DP at DPA.

Figure 1 also shows a distributed mobility anchoring environment with multiple instances of the DPA.

There is an FM-DP function at each of the distributed DPA.

The control plane may either be distributed (not shown) or centralized. When the CPA co-locates with the distributed DPA there will be multiple instances of the co-located CPA and DPA (not shown).

There is an FM-CP function at the CPA.

An MN is allocated an IP prefix/address IP1 which is anchored to the DPA with the IP prefix/address IPa1. The MN uses IP1 to communicate with a CN not shown in the figure. The flow of this communication

session is shown as flow(IP1, ...) which uses IP1 and other parameters.

In Figure 1(a), LM and FM-CP co-locate at CPA.

Then LM may be distributed or centralized according to whether the CPA is distributed (not shown) or centralized.

Figure 1(b) differs from Figure 1(a) in that the LM function is split into a server LMs and a client LMc.

LMc and FM-CP co-locate at the CPA.

The LMs may be centralized whereas the LMc may be distributed or centralized according to whether the CPA is distributed (not shown) or centralized.

3.1.2. Network-based Mobility Support for a Hierarchical Network

Figure 2 shows two different configurations of network-based mobility management for a hierarchical network.

(a)

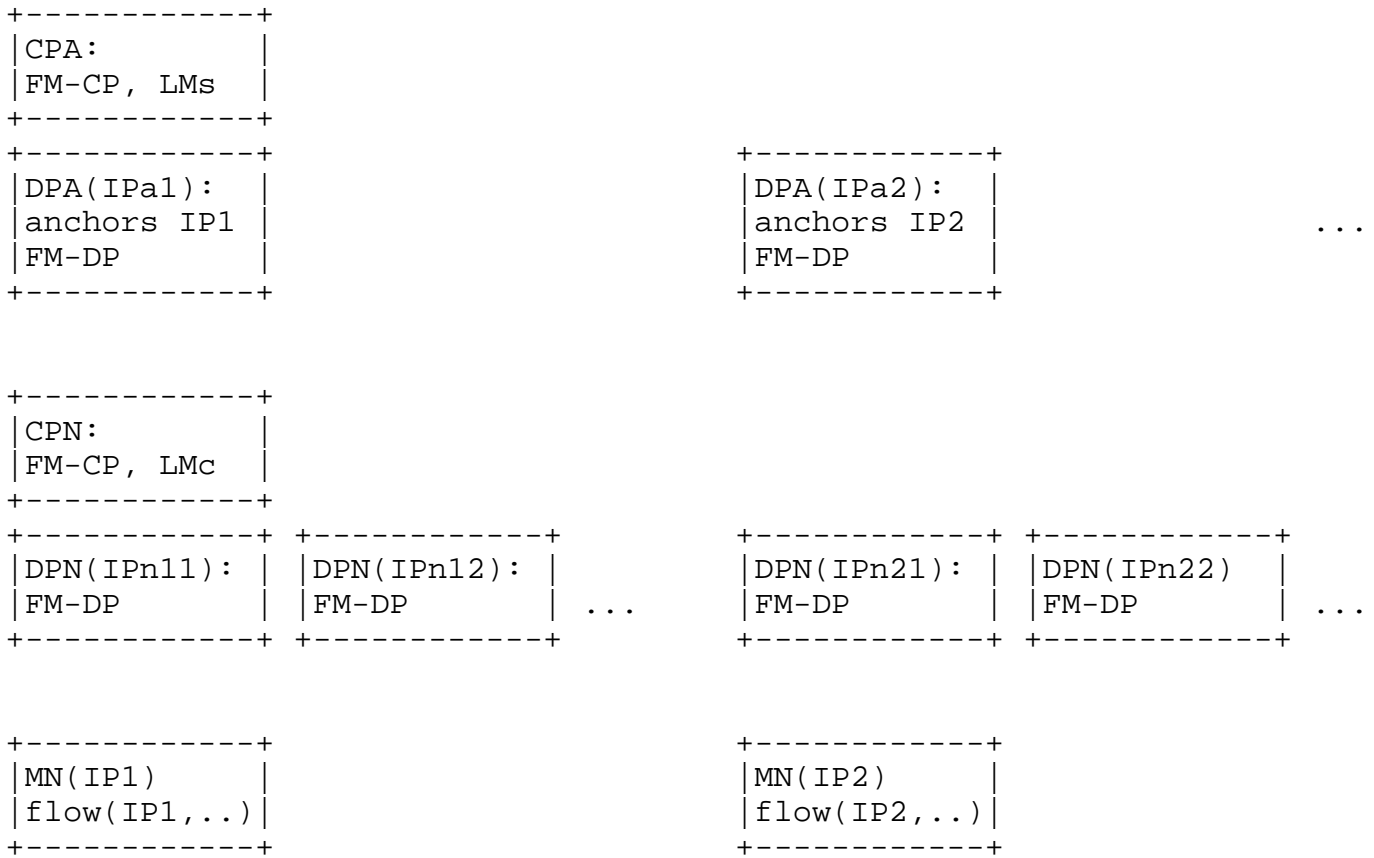


Figure 2(a). Configurations of network-based mobility management for a hierarchical network with FM-CP and LMs at CPA, FM-DP at DPA; FM-CP and LMc at CPN, FM-DP at DPN.

(b)

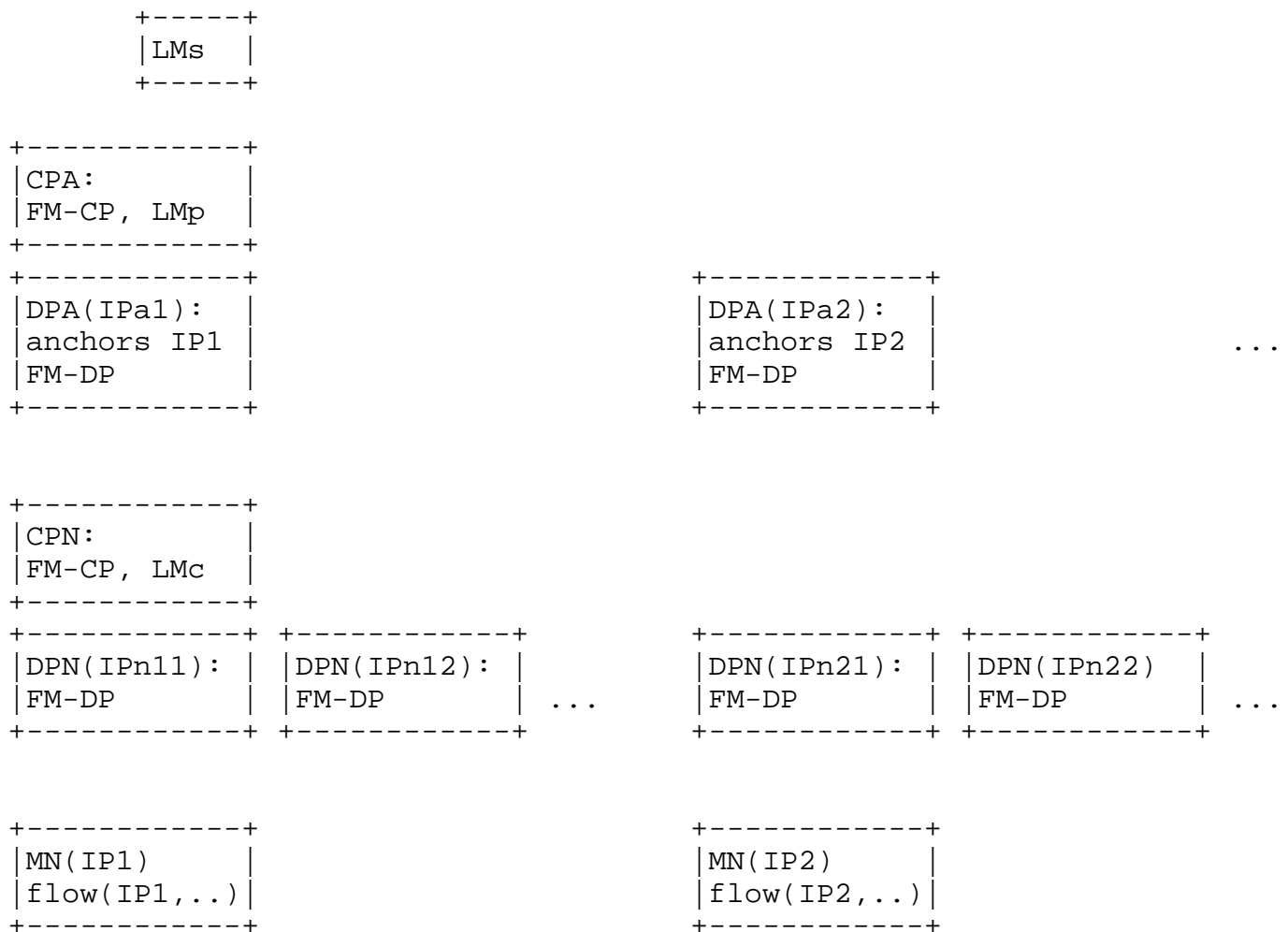


Figure 2(b). Configurations of network-based mobility management for a hierarchical network with separate LMs, FM-CP and LMp at CPA, FM-DP at DPA; FM-CP and LMc at CPN, FM-DP at DPN.

Figures 2 also shows a distributed mobility anchoring environment with multiple instances of the DPA.

In the hierarchy, there may be multiple DPN's for each DPA.

There is FM-DP at each of the distributed DPA and at each of the distributed DPN.

The control plane may either be distributed (not shown) or centralized.

When the CPA co-locates with the distributed DPA there will be multiple instances of the co-located CPA and DPA (not shown).

When the CPN co-locates with the distributed DPN there will be multiple instances of the co-located CPN and DPN (not shown).

There is FM-CP function at the CPA and at the CPN.

MN is allocated an IP prefix/address IP1 which is anchored to the DPA with the IP prefix/address IPa1. It is using IP1 to communicate with a correspondent node (CN) not shown in the figure. The flow of this communication session is shown as flow(IP1, ...) which uses IP1 and other parameters.

In Figure 2(a), LMs and FM-CP are at the CPA. In addition, there are FM-CP and LMc at the CPN.

LMs may be distributed or centralized according to whether the CPA is distributed or centralized. The CPA may co-locate with DPA or may separate.

Figure 2(b) differs from Figure 2(a) in that the LMs is separated out, and a proxy LMp is added between the LMs and LMc.

LMp and FM-CP co-locate at the CPA.

FM-CP and LMc co-locate at the CPN.

The LMs may be centralized whereas the LMp may be distributed or centralized according to whether the CPA is distributed or centralized.

3.1.3. Host-based Mobility Support

Host-based variants of the mobility function configurations from Figures 2(a) and 2(b) are respectively shown in Figures 3(a) and 3(b) where the role to perform mobility functions by CPN and DPN are now taken by the MN. The MN then needs to possess the mobility functions FM and LMc.

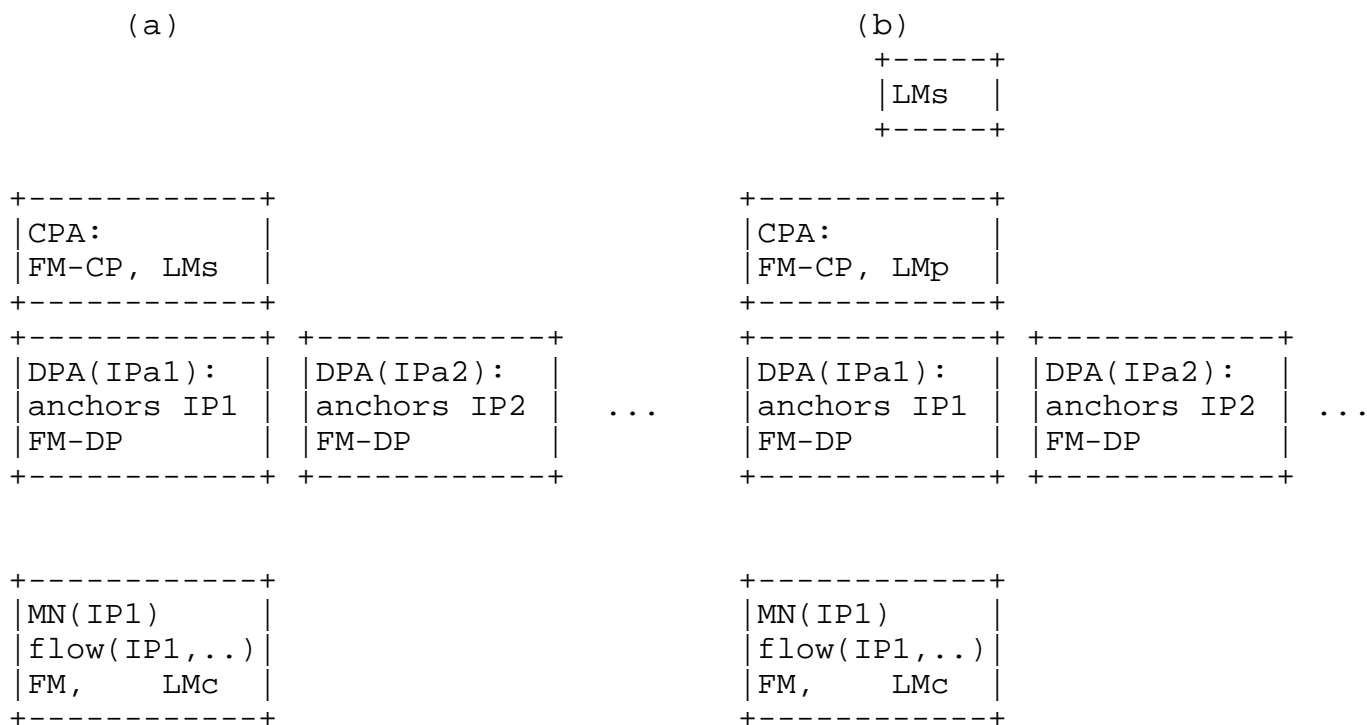


Figure 3. Configurations of host-based mobility management (a) FM-CP and LMs at CPA, FM-DP at DPA, FM and LMc at MN; (b) Separate LMs, FM-CP and LMp at CPA, FM-DP at DPA, FM and LMc at MN.

Figure 3 shows 2 configurations of host-based mobility management with multiple instances of DPA for a distributed mobility anchoring environment.

There is an FM-DP function at each of the distributed DPA.

The control plane may either be distributed (not shown) or centralized.

When the CPA co-locates with the distributed DPA there will be multiple instances of the co-located CPA and DPA (not shown).

There is an FM-CP function at the CPA.

The MN possesses the mobility functions such as FM and LMc.

The MN is allocated an IP prefix/address IP1 which is anchored to the DPA with the IP prefix/address IPa1. It is using IP1 to communicate with a CN not shown in the figure. The flow of this communication session is shown as flow(IP1, ...) which uses IP1 and other parameters.

In Figure 3(a), LMs and FM-CP co-locate at the CPA.

The LMs may be distributed or centralized according to whether the CPA is distributed (not shown) or centralized.

Figure 3(b) differs from Figure 3(a) in that the LMs is separated out and the proxy LMp is added between the LMs and LMc.

LMp and FM-CP co-locate at the CPA.

The LMs may be centralized whereas the LMp may be distributed or centralized according to whether the CPA is distributed (not shown) or centralized.

3.1.4. NETwork MObility (NEMO) Basic Support

Figure 4 shows two configurations of NEMO basic support for a mobile router.

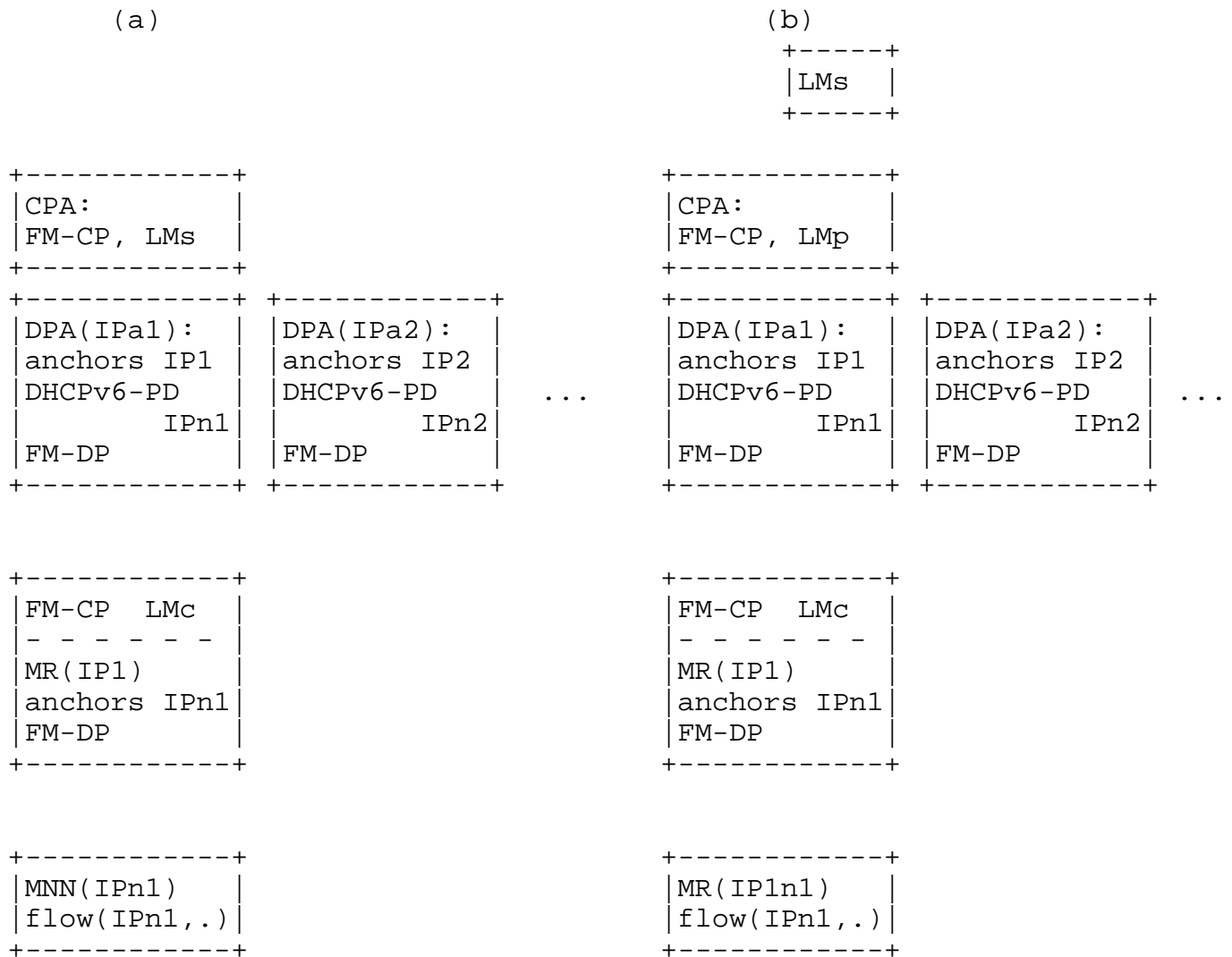


Figure 4. Configurations of NEMO basic support for a MR. (a) FM-CP and LMs at CPA, FM-DP at DPA, FM and LMc at MR; (b) Separate LMs, FM-CP and LMp at CPA, FM-DP at DPA, FM and LMc at MR.

Figure 4 shows 2 configurations of host-based mobility management for a MR with multiple instances of DPA for a distributed mobility anchoring environment.

There is an FM-DP function at each of the distributed DPA.

The control plane may either be distributed (not shown) or centralized.

When the CPA co-locates with the distributed DPA there will be multiple instances of the co-located CPA and DPA (not shown).

There is FM-CP function at the CPA.

The MR possesses the mobility functions FM and LMc.

MR is allocated an IP prefix/address IP1 which is anchored to the DPA with the IP prefix/address IPa1.

A mobile network node (MNN) in the mobile network is allocated an IP prefix/address IPn1 which is anchored to the MR with the IP prefix/address IP1.

The MNN is using IPn1 to communicate with a correspondent node (CN) not shown in the figure. The flow of this communication session is shown as flow(IPn1, ...) which uses IPn1 and other parameters.

In Figure 4(a), LMs and FM-CP co-locate at the CPA.

The LMs may be distributed or centralized according to whether the CPA is distributed (not shown) or centralized.

Figure 4(b) differs from Figure 4(a) in that the LMs is separated out and the proxy LMp is added between the LMs and LMc.

LMp and FM-CP co-locate at the CPA.

The LMs may be centralized whereas the LMp may be distributed or centralized according to whether the CPA is distributed (not shown) or centralized.

3.2. Operations and Parameters

The operations of distributed mobility anchoring are defined in order that they may work together in expected manners to produce a distributed mobility solution. The needed information is passed as mobility message parameters, which must be protected in terms of integrity. Some parameters may require a means to support privacy of an MN or MR.

The mobility needs in 5G Wireless and beyond are diverse. Therefore operations needed to enable different distributed mobility solutions in different distributed mobility anchoring configurations are extensive as illustrated below. It is however not necessary for every distributed mobility solution to exhibit all the operations listed in this section. A given distributed mobility solution may exhibit the operations as needed.

3.2.1. Location Management

An example LM design consists of a distributed database with multiple LMs servers. The location information about the prefix/address of an MN is primarily at a given LMs. Peer LMs may exchange the location information with each other. LMc may retrieve a given record or send a given record update to LMs.

Location management configurations:

LM-cfg: As shown in Section 3.1:

LMs may be implemented at CPA, may co-locate with LMc at CPA, or may be a separate server.

LMc may be at CPA, CPN, or MN.

LMP may proxy between LMs and LMc.

Specifically:

Location management operations and parameters:

LM-cfg:1 LMs may co-locate with LMc at CPA in a flat network with network-based mobility as shown in Figure 1(a) in Section 3.1.1.

LM-cfg:2 LMs may be a separate server whereas LMc is implemented in CPA in a flat network with network-based mobility as shown in Figure 1(b) in Section 3.1.1.

LM-cfg:3 LMs may be implemented at CPA, whereas LMc is implemented at CPN in a hierarchical network with network-based mobility as shown in Figure 2(a) in Section 3.1.2 or at MN for host-based mobility as shown in Figure 3(a) in Section 3.1.3.

LM-cfg:4 LMs may be a separate server with LMP implemented at CPA whereas LMc is implemented at CPN in a hierarchical network with network-based mobility as shown in Figure 2(b) in Section 3.1.2 or at MN for host-based mobility as shown in Figure 3(b) in Section 3.1.3.

LM-db: LM may manage the location information in a client-server database system.

Example LM database functions are as follows:

LM-db:1 LMc may query LMs about location information for a prefix of MN (pull).
Parameters:
- IP prefix of MN: integrity support required and privacy support may be required.

LM-db:2 LMs may reply to LMc query about location information for a prefix of MN (pull).
Parameters:
- IP prefix of MN: integrity support required and privacy support may be required
- IP address of FM-DP/DPA/DPN to forward the packets of the flow: integrity support required.

LM-db:3 LMs may inform LMc about location information for a prefix of MN (push).
Parameters:
- IP prefix of MN: integrity support required and privacy support may be required
- IP address of FM-DP/DPA/DPN to forward the packets of the flow.

This function in the PMIPv6 protocol is the Update Notification (UPN) together with the Update Notification Acknowledgment (UPA) as defined in [RFC7077].

LM-db:4 LMc may inform LMs about update location information for a prefix of MN.
Parameters:
- IP prefix of MN: integrity support required and privacy support may be required
- IP address of FM-DP/DPA/DPN to forward the packets of the flow: integrity support required

This function in the MIPv6 / PMIPv6 protocol is the Binding Update (BU) / Proxy Binding Update (PBU) together with the Binding Acknowledgment (BA) / Proxy Binding Acknowledgment (PBA) as defined in [RFC6275] / [RFC5213] respectively.

LM-db:5 The MN may be a host or a router. When the MN is an MR, the prefix information may include the MNP delegated to the MR.
Additional parameters:
MNP: integrity support required and privacy support may be required

LM-svr: The LM may be a distributed database with multiple LMs servers.

For example:

- LM-svr:1 A LMs may join a pool of LMs servers.
Parameters:
- IP address of the LMs: integrity support required
- IP prefixes for which the LMs will host the primary location information: integrity support required.
- LM-svr:2 LMs may query a peer LMs about location information for a prefix of MN.
Parameters:
- IP prefix: integrity support required and privacy support may be required.
- LM-svr:3 LMs may reply to a peer LMs about location information for a prefix of MN.
Parameters:
- IP prefix of MN: integrity support required and privacy support may be required
- IP address of FM-DP/DPA/DPN to forward the packets of the flow: integrity support required.

The parameters indicated above are only the minimal. In a specific mobility protocol, additional parameters should be added as needed. Examples of these additional parameters are those passed in the mobility options of the mobility header for MIPv6 [RFC6275] and for PMIPv6 [RFC5213].

3.2.2. Forwarding Management

Forwarding management configurations:

FM-cfg: As shown in Section 3.1:

FM-CP may be implemented at CPA, CPN, MN depending on the configuration chosen.

FM-DP may also be implemented at CPA, CPN, MN depending on the configuration chosen.

Specifically:

- FM-cfg:1 FM-CP and FM-DP may be implemented at CPA and DPA respectively in a flat network with network-based mobility as shown in Figure 1(a) and Figure 1(b) in Section 3.1.1.
- FM-cfg:2 FM-CP may be implemented at both CPA and CPN and FM-DP is implemented at both DPA and DPN in a hierarchical network

with network-based mobility as shown in Figure 2(a) and Figure 2(b) in Section 3.1.2.

FM-cfg:3 FM-CP and FM-DP may be implemented at CPA and DPA respectively and also both implemented at MN for host-based mobility as shown in Figure 3(a) and Figure 3(b) in Section 3.1.3.

Forwarding management operations and parameters:

FM-find:1 An anchor may discover and be discovered such as through an anchor registration system as follows:

FM-find:2 FM registers and authenticates itself with a centralized mobility controller.

Parameters:

- IP address of DPA and its CPA: integrity support required
- IP prefix anchored to the DPA: integrity support required

registration reply: acknowledge of registration and echo the input parameters.

FM-find:3 FM discovers the FM of another IP prefix by querying the mobility controller based on the IP prefix.

Parameters:

- IP prefix of MN: integrity support required and privacy support may be required

FM-find:4 when making anchor discovery FM expects the answer parameters:

- IP address of DPA to which IP prefix of MN is anchored: integrity support required
- IP prefix of the corresponding CPA: integrity support required

FM-flow:1 The FM may be carried out on the packets to/from an MN up to the granularity of a flow.

FM-flow:2 Example matching parameters are in the 5-tuple of a flow.

FM-cpdp: With separation of control plane function and data plane function, FM-CP and FM-DP communicate with each other. Such communication may be realized by the appropriate messages in [I-D.ietf-dmm-fpc-cpdp].

For example:

- FM-cpdp:1 CPA/FM-CP sends forwarding table updates to DPA/FM-DP.
Parameters:
- New forwarding table entries to add: integrity support required
- Expired forwarding table entries to delete: integrity support required
- FM-cpdp:2 DPA/FM-DP sends to CPA/FM-CP about its status and load.
Parameters:
- State of forwarding function being active or not: integrity support required
- Loading percentage: integrity support required
- FM-path:1 FM may change the forwarding path of a flow upon a change of point of attachment of a MN. Prior to the changes, packets coming from the CN to the MN would traverse from the CN to the home network anchor of the flow for the MN before reaching the MN. Changes are from this original forwarding path or paths to a new forwarding path or paths from the CN to the current AR of the MN and then the MN itself.
- FM-path:2 As an incoming packet is forwarded from the CN to the MN, the far end where forwarding path change begins may in general be any node in the original forwarding path from the CN to the home network DPA. The packet is forwarded to the MN for host-based mobility and to a node in the network which will deliver the packets to the MN for network-based mobility. The near-end is generally a DPN with a hierarchical network but may also be another node with DPA capability in a flattened network.
- FM-path:3 The mechanisms to accomplish such changes may include changes to the forwarding table and indirection such as tunneling, rewriting packet header, or NAT.

Note: An emphasis in this document in distributed mobility anchoring is to explain the use of multiple anchors to avoid unnecessarily long route which may be encountered in centralized mobility anchoring. It is therefore not the emphasis of this document on which particular mechanism to choose from.

FM-path-tbl:4 With forwarding table updates, changes to the forwarding table are needed at each of the affected forwarding switches in order to change the forwarding path of the packets for the flow from that originally between the CN and the home network anchor to that between the CN and the new AR.

Forwarding table updates may be achieved through BGP update as described in [I-D.templin-aerolink], [I-D.mccann-dmm-flatarch] and also for 3GPP Evolved Packet Core (EPC) network in [I-D.matsushima-stateless-uplane-vepc] when the scope and response time can be managed. Alternatively, a centralized control plane may be used.

When the control plane is centralized, forwarding table updates may be achieved through messaging between the centralized control plane and the distributed forwarding switches as described above (FM-cpdp) in this section.

Forwarding table updates may be triggered using DHCPv6-PD prefix delegation to change the role of IP anchoring from the home network anchor (with FM-DP) to the new anchor (with FM-DP) to which the MN is currently attached. The new anchor will then advertise routes for the delegated prefix.

With a distributed routing protocol, the updates spread out from neighbors to neighbors and will affect all the forwarding switches such that the packets sent from "any" node to MN will go to the new AR.

Yet the scope of such updates for a given flow may be confined to only those forwarding switches such that the packets sent only from the "CN" to MN will go to the new AR. Such confinement may be made when using a centralized central plane possessing a global view of all the forwarding switches.

FM-path-tbl:5 FM reverts the changes previously made to the forwarding path of a flow when such changes are no longer needed, e.g., when all the ongoing flows using an IP prefix/address requiring IP session continuity have closed. When using DHCPv6-PD, the forwarding paths will be reverted upon prefix lease expiration.

- FM-path-ind:6 Indirection forwards the incoming packets of the flow from the DPA at the far end to a DPA/DPN at the near end of indirection. Both ends of the indirection needs to know the LM information of the MN for the flow and also needs to possess FM capability to perform indirection.
- FM-path-ind:7 The mechanism of changing the forwarding path in [RFC6275] and [RFC5213] is tunneling. In the control plane, the FM-CP sets up the tunnel by instructing the FM-DP at both ends of the tunnel. In the data plane, the FM-DP at the start of the tunnel performs packet encapsulation, whereas the FM-DP at the end of the tunnel decapsulates the packet.
- Note that in principle the ends of the indirection path can be any pair of network elements with the FM-DP function.
- FM-path-ind:8 FM reverts the changes previously made to the forwarding path of a flow when such changes are no longer needed, e.g., when all the ongoing flows using an IP prefix/address requiring IP session continuity have closed. When tunneling is used, the tunnels will be torn down when they are no longer needed.
- FM-DPA:1 Recall from above that for the incoming packets from the CN, forwarding path change by FM is from the DPA at the far end which may be at any forwarding switch (or even CN itself) in the original forwarding path to the near end DPA/DPN.

It is necessary that any incoming packet from the CN of the flow must traverse the DPA (or at least one of the DPAs, e.g., in the case of anycast) at the far end in order for the packet to detour to a new forwarding path.

Therefore a convenient design is to locate the far end DPA at a unique location which is always in the forwarding path. This is the case in a centralized mobility design where the DPA at the far end is the home network anchor of the flow.

Distributed mobility however may place the far end DPA at other locations in order to avoid unnecessarily long route.

FM-DPA:2 With multiple nodes possessing DPA capabilities, the role of FM to begin path change for the incoming packets of a flow at the home network DPA at the far end may be passed to or added to that of another DPA.

In particular, this DPA role may be moved upstream from the home network DPA in the original forwarding path from CN to MN.

FM-DPA:3 Optimization of the new forwarding path may be achieved when the path change for the incoming packets begins at a DPA where the original path and the direct IPv6 path overlaps. Then the new forwarding path will resemble the direct IPv6 path from the CN to the MN.

FM-DPA-tbl:4 Forwarding table updates, such as that triggered using DHCPv6-PD to change the role of IP anchoring from the home network anchor (DPA with FM-DP) to the new anchor (DPA with FM-DP), may put the near end of the path change at the new DPA. Subsequent forwarding table updates may propagate upstream up to a far end where the original path and the direct IPv6 path overlaps.

When that far end is too far upstream the signaling of forwarding table updates may become excessive. An alternative is to use indirection (see FM-DPA-ind) from that far end to the new DPA at the near end.

Still another alternative is to combine forwarding table update with indirection.

FM-DPA-tbl:5 Changes made by FM to the following tables, which are IPv6 nodes, at the ends of the path change for a flow will be reverted when the mobility support for the flow is no longer needed, e.g., when the flows have terminated.

FM-DPA-ind:6 With indirection, locating or moving the FM function to begin indirection upstream along the forwarding path from CN to MN again may help to reduce unnecessarily long path.

FM-DPA-ind:7 Changes made by FM to establish indirection at the DPA and DPN, which are IPv6 nodes, at the ends of the path change for a flow will be reverted when the mobility

support for the flow is no longer needed, e.g., when the flows have terminated.

- FM-state:1 In addition to the above, a flow/session may contain states with the required information for QoS, charging, etc. as needed. These states need to be transferred from the old anchor to the new anchor.
- FM-buffer:1 An anchor can buffer packets of a flow in a mobility event:
- FM-buffer:2 CPA/FM-CP informs DPA/FM-DP to buffer packets of a flow.
Trigger:
- MN leaves DPA in a mobility event.
Parameters:
- IP prefix of the flow for which packets need to be buffered: integrity support required
- FM-buffer:3 CPA/FM-CP on behalf of a new DPA/FM-DP informs the CPA/FM-CP of the prior DPA/FM-DP that it is ready to receive any buffered packets of a flow.
Parameters:
- Destination IP prefix of the flow's packets: integrity support required
- IP address of the new DPA: integrity support required
- FM-mr:1 When the MN is a mobile router the access router anchoring the IP prefix of MR will also anchor the IP prefix or prefixes delegated to the MR.

4. IP Mobility Handling in Distributed Anchoring Environments - Mobility Support Only When Needed

IP Mobility Support Only When Needed:

IP mobility support may be provided only when needed instead of being provided by default. The LM and FM functions in the different configurations shown in Section 3.1 are then utilized only when needed.

A straightforward choice of mobility anchoring is for a flow to use the IP prefix of the network to which the MN is attached when the flow is initiated [I-D.seite-dmm-dma].

The IP prefix/address at the MN's side of a flow may be anchored at the access router to which the MN is attached. For example, when an

MN attaches to a network (Net1) or moves to a new network (Net2), it is allocated an IP prefix from the attached network. In addition to configuring new link-local addresses, the MN configures from this prefix an IP address which is typically a dynamic IP address. It then uses this IP address when a flow is initiated. Packets to the MN in this flow are simply forwarded according to the forwarding table.

There may be multiple IP prefixes/addresses that an MN can select when initiating a flow. They may be from the same access network or different access networks. The network may advertise these prefixes with cost options [I-D.mccann-dmm-prefixcost] so that the mobile node may choose the one with the least cost. In addition, these IP prefixes/addresses may be of different types regarding whether mobility support is needed [I-D.ietf-dmm-ondemand-mobility]. A flow will need to choose the appropriate one according to whether it needs IP mobility support.

4.1. No Need of IP Mobility: Changing to New IP Prefix/Address

When IP mobility support is not needed for a flow, the LM and FM functions are not utilized so that the configurations in Section 3.1 are simplified as shown in Figure 5.



Figure 5. Changing to the new IP prefix/address. MN running a flow using IP1 in a network Net1 changes to running a flow using IP2 in Net2.

When there is no need to provide IP mobility to a flow, the flow may use a new IP address acquired from a new network as the MN moves to the new network.

Regardless of whether IP mobility is needed, if the flow has terminated before the MN moves to a new network, the flow may subsequently restart using the new IP address allocated from the new network.

When IP session continuity is needed, even if a flow is ongoing as the MN moves, it may still be desirable for the flow to change to using the new IP prefix configured in the new network. The flow may then close and then restart using a new IP address configured in the new network. Such a change in the IP address of the flow may be enabled using a higher layer mobility support which is not in the scope of this document.

In Figure 5, a flow initiated while the MN was in a network Net1 has terminated before the MN moves to a new network Net2. After moving to Net2, the MN uses the new IP prefix anchored in Net2 to start a new flow. The packets may then be forwarded without requiring IP layer mobility support.

An example call flow is outlined in Figure 6.

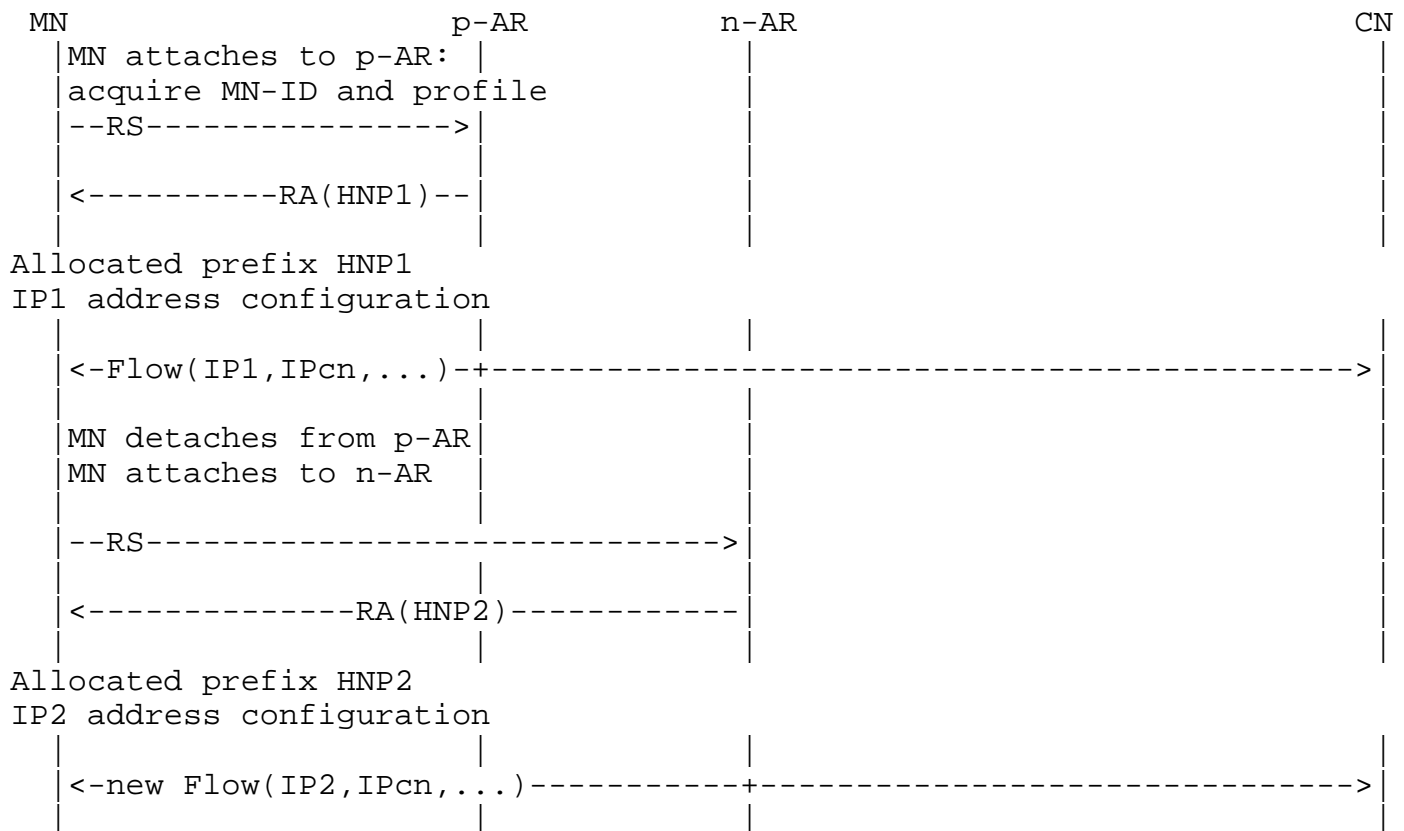


Figure 6. Re-starting a flow to use the IP allocated from the network at which the MN is attached.

4.1.1.1. Guidelines for IPv6 Nodes: Changing to New IP Prefix/Address

A network or network slice may not need IP mobility support. For example, a network slice for stationary sensors only will never encounter mobility.

The standard functions in IPv6 already include dropping the old IPv6 prefix/address and acquiring new IPv6 prefix/address when the node changes its point of attachment to a new network. Therefore, a network or network slice not providing IP mobility support at all will not need any of the functions with the mobility operations and messages described in Section 3.2.

The guidelines for the IPv6 nodes in a network or network slice supporting a mix of flows requiring and not requiring IP mobility support include the following:

- GL-cfg:1 A network or network slice supporting a mix of flows requiring and not requiring mobility support may take any

of the configurations described in Section 3.1 and need to implement in the appropriate IPv6 nodes the mobility functions LM and FM as described respectively in LM-cfg and FM-cfg in Section 3.2 according to the configuration chosen.

- GL-mix:1 These mobility functions perform some of the operations with the appropriate messages as described in Section 3.2 depending on which mobility mechanisms are used. Yet these mobility functions must not be invoked for a flow that does not need IP mobility support. It is necessary to be able to distinguish the needs of a flow. The guidelines for the MN and the AR are in the following.
- GL-mix:2 Regardless of whether there are flows requiring IP mobility support, when the MN changes its point of attachment to a new network, it needs to configure a new global IP address for use in the new network in addition to configuring the new link-local addresses.
- GL-mix:3 The MN needs to check whether a flow needs IP mobility support. This can be performed when the application was initiated. The specific method is not in the scope of this document.
- GL-mix:4 The information of whether a flow needs IP mobility support is conveyed to the network such as by choosing an IP address to be provided with mobility support as described in [I-D.ietf-dmm-ondemand-mobility]. Then as the MN attaches to a new network, if the MN was using an IP address that is not supposed to be provided with mobility support, the access router will not invoke the mobility functions described in Section 3.2 for this IP address. That is, the IP address from the prior network is simply not used in the new network.

The above guidelines are only to enable distinguishing whether there is need of IP mobility support for a flow that does not. When the flow needs IP mobility support, the list of guidelines will continue in Section 4.2.1.

4.2. Need of IP Mobility

When IP mobility is needed for a flow, the LM and FM functions in Section 3.1 are utilized. The mobility support may be provided by IP prefix anchor switching to the new network to be described in Section 5 or by using other mobility management methods

([Paper-Distributed.Mobility.PMIP] and [Paper-Distributed.Mobility.Review]). Then the flow may continue to use the IP prefix from the prior network of attachment. Yet some time later, the user application for the flow may be closed. If the application is started again, the new flow may not need to use the prior network's IP address to avoid having to invoke IP mobility support. This may be the case where a dynamic IP prefix/address rather than a permanent one is used. The flow may then use the new IP prefix in the network where the flow is being initiated. Routing is again kept simpler without employing IP mobility and will remain so as long as the MN which is now in the new network has not moved again and left to another new network.

An example call flow in this case is outlined in Figure 7.

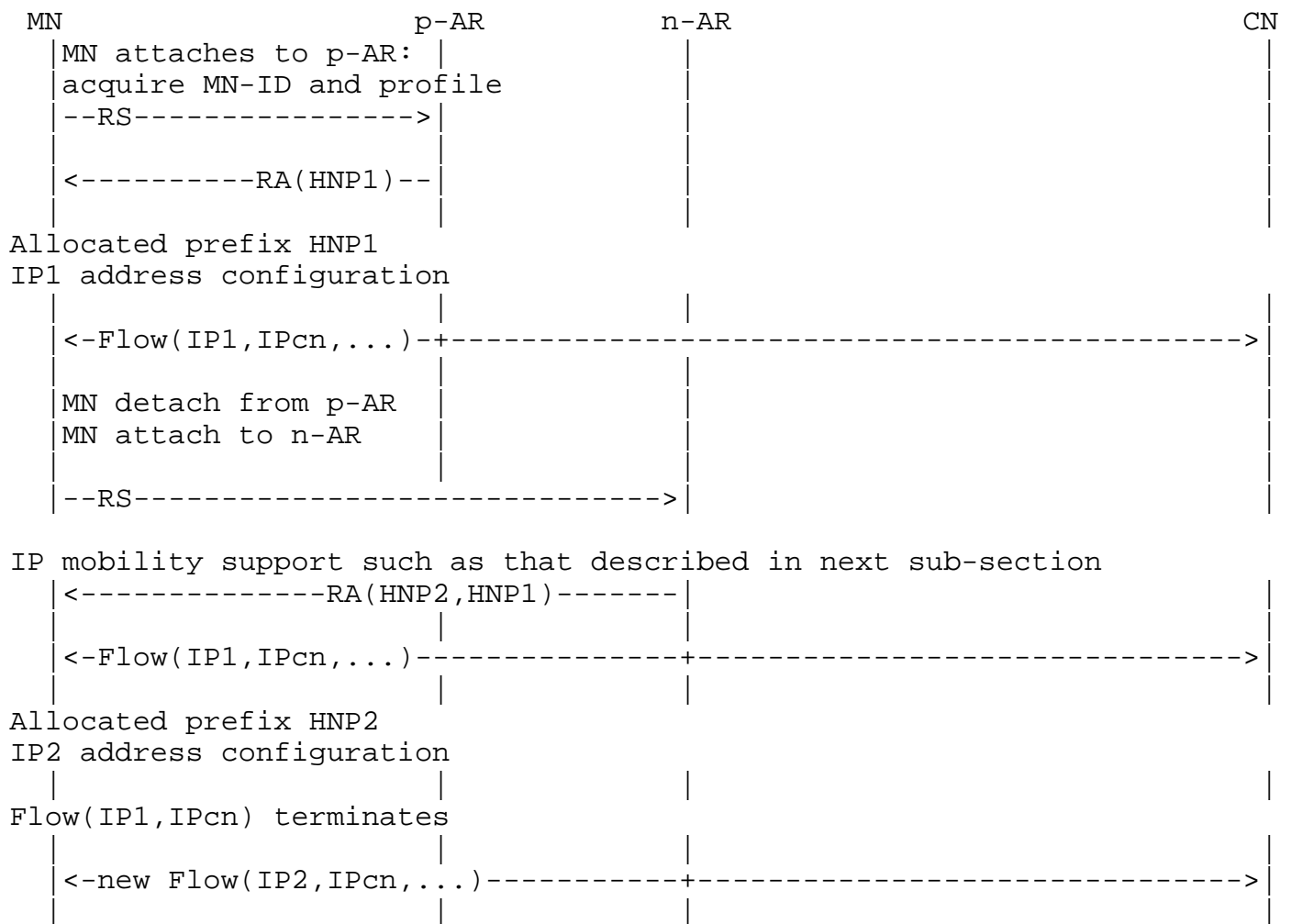


Figure 7. A flow continues to use the IP from its home network after MN has moved to a new network.

4.2.1. Guidelines for IPv6 Nodes: Need of IP Mobility

The configuration guidelines of distributed mobility for the IPv6 nodes in a network or network slice supporting a mix of flows requiring and not requiring distributed mobility support are as follows:

GL-cfg:2 Multiple instances of DPAs (at access routers) which are providing IP prefix to the MNs are needed to provide distributed mobility anchoring in an appropriate configuration such as those in Figure 1 (Section 3.1.1) for network-based distributed mobility or in Figure 3 (Section 3.1.3) for host-based distributed mobility.

The appropriate IPv6 nodes (CPA, DPA, CPN, DPN) are to be implemented the mobility functions LM and FM as described respectively in LM-cfg and FM-cfg in Section 3.2 according to the configuration chosen.

The guidelines of distributed mobility for the IPv6 nodes in a network or network slice supporting a mix of flows requiring and not requiring distributed mobility support had begun with those given as GL-mix in Section 4.1.1 and continue as follows:

GL-mix:5 The distributed anchors may need to message with each other. When such messaging is needed, the anchors may need to discover each other as described in the FM operations and mobility message parameters (FM-find) in Section 3.2.2.

GL-mix:6 The anchors may need to provide mobility support on a per-flow basis as described in the FM operations and mobility message parameters (FM-flow) in Section 3.2.2.

GL-mix:7 Then the anchors need to properly forward the packets of the flows as described in the FM operations and mobility message parameters (FM-path, FM-path-tbl, FM-DPA, FM-DPA-tbl) in Section 3.2.2.

GL-mix:8 If there are in-flight packets toward the old anchor while the MN is moving to the new anchor, it may be necessary to buffer these packets and then forward to the new anchor after the old anchor knows that the new anchor is ready. Such are described in the FM operations and mobility message parameters (FM-buffer) in Section 3.2.2.

5. IP Mobility Handling in Distributed Mobility Anchoring Environments
 - Anchor Switching to the New Network

IP Prefix/Address Anchor Switching to the New Network:

IP mobility is invoked to enable IP session continuity for an ongoing flow as the MN moves to a new network. Here the anchoring of the IP address of the flow is in the home network of the flow, which is not in the current network of attachment. A centralized mobility management mechanism may employ indirection from the anchor in the home network to the current network of attachment. Yet it may be difficult to avoid unnecessarily long route when the route between the MN and the CN via the anchor in the home network is significantly longer than the direct route between them. An alternative is to switch the IP prefix/address anchoring to the new network.

5.1. IP Prefix/Address Anchor Switching for Flat Network

The IP prefix/address anchoring may move without changing the IP prefix/address of the flow. Here the LM and FM functions in Figures 1(a) and 1(b) in Section 3.1 are implemented as shown in Figure 8.

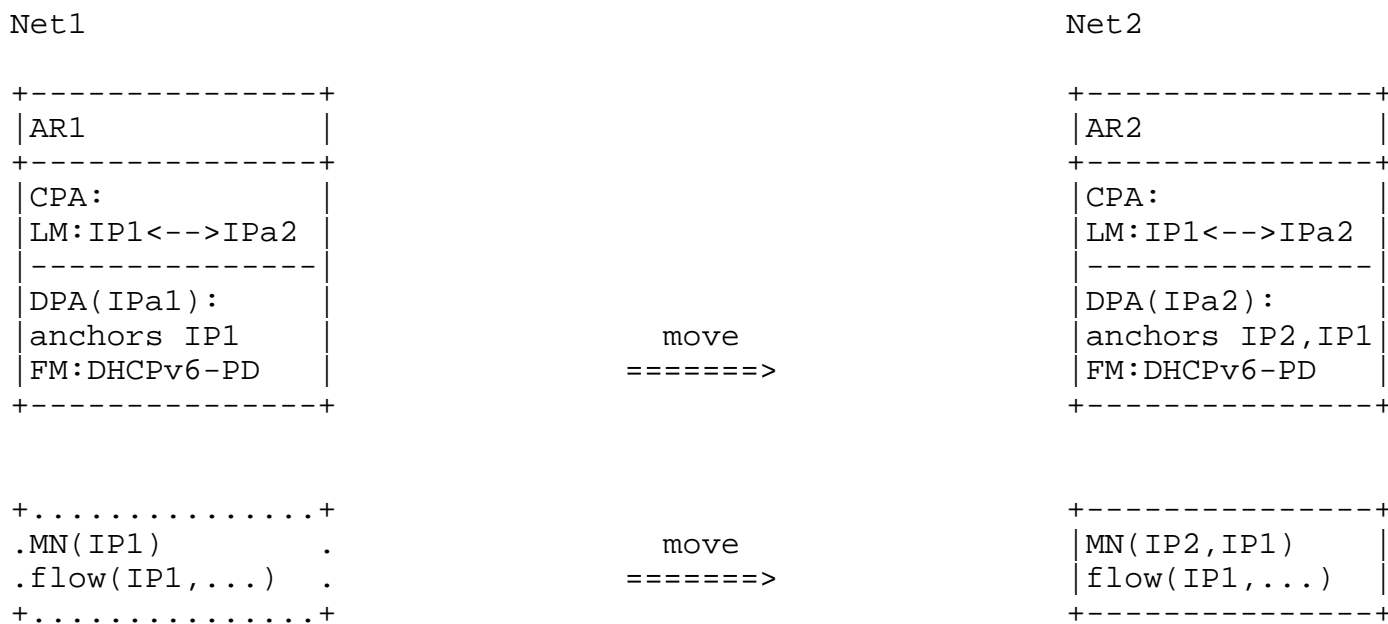


Figure 8. IP prefix/address anchor switching to the new network. MN with flow using IP1 in Net1 continues to run the flow using IP1 as it moves to Net2.

As an MN with an ongoing session moves to a new network, the flow may preserve IP session continuity by moving the anchoring of the original IP prefix/address of the flow to the new network. BGP

UPDATE messages may be used to change the forwarding table entries as described in [I-D.templin-aerolink] and [I-D.mccann-dmm-flatarch] if the response time of such updates does not exceed the handover delay requirement of the flow. An alternative is to use a centralized routing protocol to be described in Section 5.2 with a centralized control plane.

5.1.1. Guidelines for IPv6 Nodes: Switching Anchor for Flat Network

The configuration guideline for a flat network or network slice supporting a mix of flows requiring and not requiring IP mobility support is:

GL-cfg:3 Multiple instances of DPAs (at access routers) which are providing IP prefix to the MNs are needed to provide distributed mobility anchoring according to Figure 1(a) or Figure 1(b) in Section 3.1 for a flat network.

The appropriate IPv6 nodes (CPA, DPA) are to be implemented the mobility functions LM and FM as described respectively in LM-cfg:1 or LM-cfg:2 and FM-cfg:1 in Section 3.2.

The guidelines (GL-mix) in Section 4.1.1 and in Section 4.2.1 for the IPv6 nodes for a network or network slice supporting a mix of flows requiring and not requiring IP mobility support apply here. In addition, the following are required.

GL-switch:1 The location management provides information about which IP prefix from an AR in the original network is being used by a flow in which AR in a new network. Such information needs to be deleted or updated when such flows have closed so that the IP prefix is no longer used in a different network. The LM operations are described in Section 3.2.1.

GL-switch:2 The FM functions are implemented through the DHCPv6-PD protocol. Here the anchor operations to properly forward the packets for a flow as described in the FM operations and mobility message parameters in Section 3.2.2 FM-path, FM-path-tbl, FM-DPA, FM-DPA-tbl are realized by changing the anchor with DHCPv6-PD and also by reverting such changes later after the application has already closed and when the DHCPv6-PD timer expires. If there are in-flight packets toward the old anchor while the MN is moving to the new anchor, it may be necessary to buffer these packets and then

forward to the new anchor after the old anchor knows that the new anchor is ready as are described in Section 3.2.2 (FM-buffer). The anchors may also need to discover each other as described also in the FM operations and mobility message parameters (FM-find).

GL-switch:3 The security management function in the anchor node at a new network must allow to assign the original IP prefix/address used by the mobile node at the previous (original) network. As the assigned original IP prefix/address is to be used in the new network, the security management function in the anchor node must allow to advertise the prefix of the original IP address and also allow the mobile node to send and receive data packets with the original IP address.

GL-switch:4 The security management function in the mobile node must allow to configure the original IP prefix/address used at the previous (original) network when the original IP prefix/address is assigned by the anchor node in the new network. The security management function in the mobile node also allows to use the original IP address for the previous flow in the new network.

5.2. IP Prefix/Address Anchor Switching for Flat Network with Centralized Control Plane

An example of IP prefix anchor switching is in the case where Net1 and Net2 both belong to the same operator network with separation of control and data planes ([I-D.liu-dmm-deployment-scenario] and [I-D.matsushima-stateless-uplane-vepc]), where the controller may send to the switches/routers the updated information of the forwarding tables with the IP address anchoring of the original IP prefix/address at AR1 moved to AR2 in the new network. That is, the IP address anchoring in the original network which was advertising the prefix will need to move to the new network. As the anchoring in the new network advertises the prefix of the original IP address in the new network, the forwarding tables will be updated so that packets of the flow will be forwarded according to the updated forwarding tables. The configurations in Figures 1(a) and 1(b) in Section 3.1 for which FM-CP and LM are centralized and FM-DP's are distributed apply here. Figure 9 shows its implementation where LM is a binding between the original IP prefix/address of the flow and the IP address of the new DPA, whereas FM uses the DHCPv6-PD protocol.

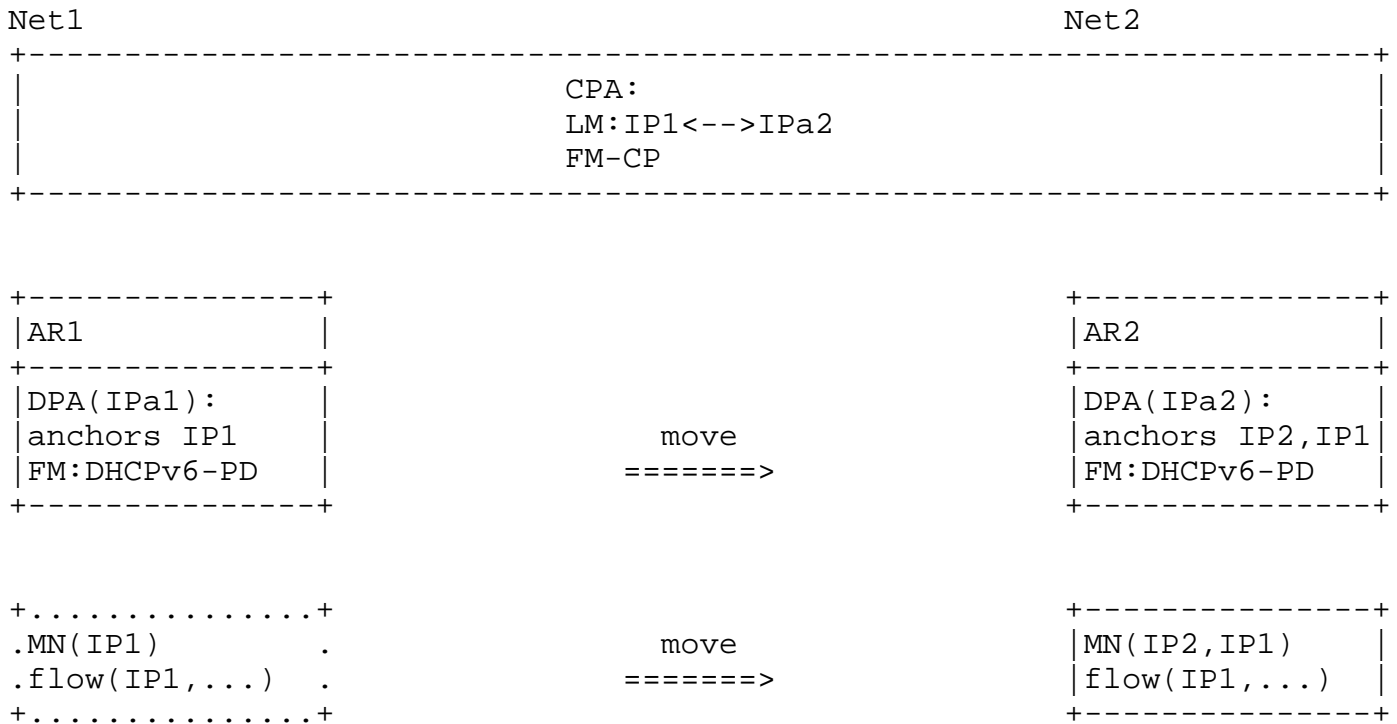


Figure 9. IP prefix/address anchor switching to the new network with LM and FM-CP in a centralized control plane whereas the FM-DP's are distributed.

The example call flow in Figure 10 shows that MN is allocated HNP1 when it attaches to the p-AR. A flow running in MN and needing IP mobility may continue to use the previous IP prefix by moving the anchoring of the IP prefix to the new network. Yet a new flow to be initiated in the new network may simply use a new IP prefix allocated from the new network.

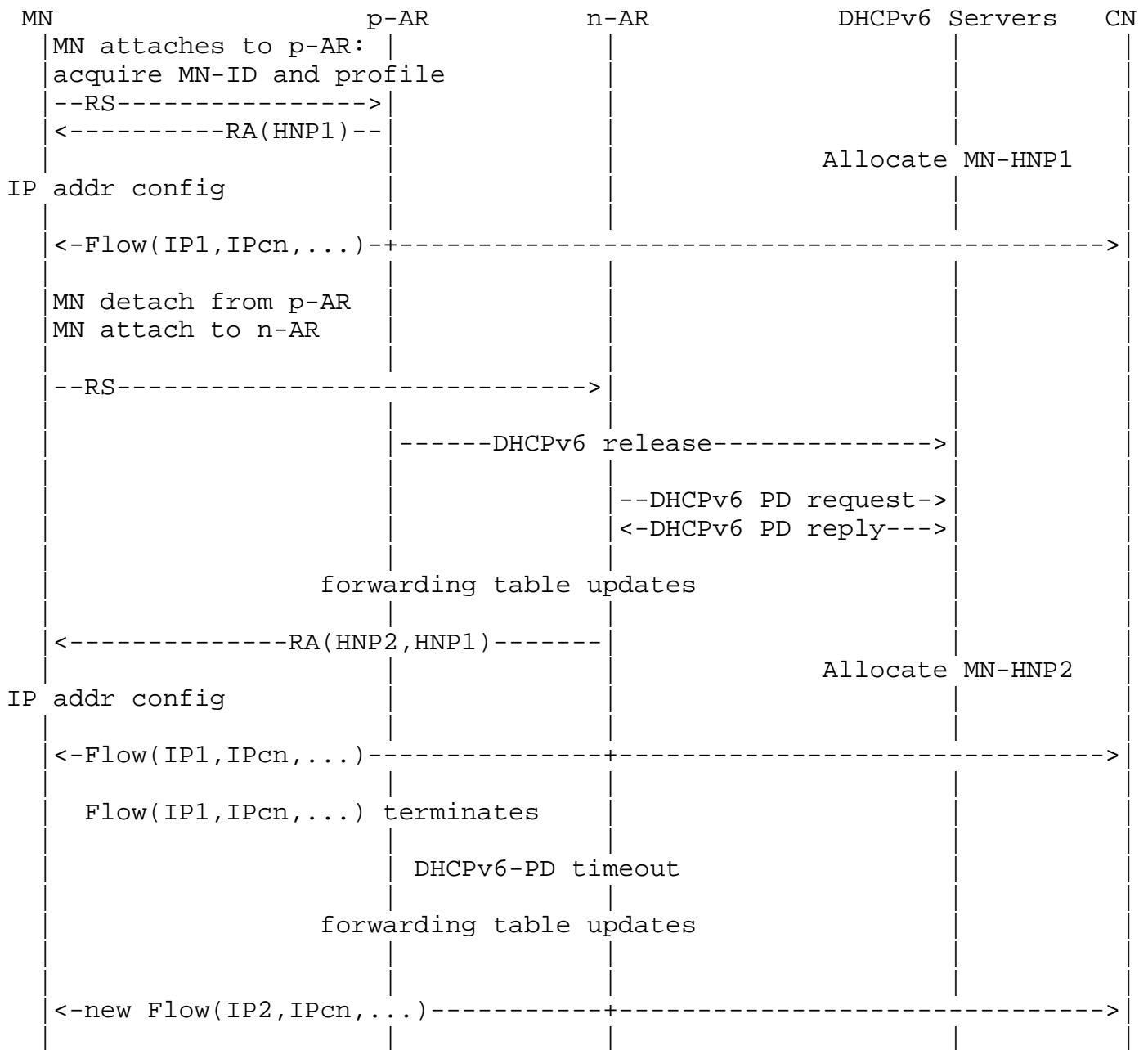


Figure 10. DMM solution. MN with flow using IP1 in Net1 continues to run the flow using IP1 as it moves to Net2.

As the MN moves from p-AR to n-AR, the p-AR as a DHCPv6 client may send a DHCPv6 release message to release the HNP1. It is now necessary for n-AR to learn the IP prefix of the MN from the previous network so that it will be possible for Net2 to allocate both the previous network prefix and the new network prefix. The network may learn the previous prefix in different methods. For example, the MN

may provide its previous network prefix information by including it to the RS message [I-D.jhlee-dmm-dnpp].

Knowing that MN is using HNP1, the n-AR sends to a DHCPv6 server a DHCPv6-PD request to move the HNP1 to n-AR. The server sends to n-AR a DHCPv6-PD reply to move the HNP1. Then forwarding tables updates will take place here.

In addition, the MN also needs a new HNP in the new network. The n-AR may now send RA to n-AR, with prefix information that includes HNP1 and HNP2. The MN may then continue to use IP1. In addition, the MN is allocated the prefix HNP2 with which it may configure its IP addresses. Now for flows using IP1, packets destined to IP1 will be forwarded to the MN via n-AR.

As such flows have terminated and DHCPv6-PD has timed out, HNP1 goes back to Net1. MN will then be left with HNP2 only, which it will use when it now starts a new flow.

5.2.1. Additional Guidelines for IPv6 Nodes: Switching Anchor with Centralized CP

The configuration guideline for a flat network or network slice with centralized control plane and supporting a mix of flows requiring and not requiring IP mobility support is:

GL-cfg:4 Multiple instances of DPAs (at access routers) which are providing IP prefix to the MNs are needed to provide distributed mobility anchoring according to Figure 1(a) or Figure 1(b) in Section 3.1 with centralized control plane for a flat network.

The appropriate IPv6 nodes (CPA, DPA) are to be implemented the mobility functions LM and FM as described respectively in LM-cfg:1 or LM-cfg:2 and FM-cfg:1 in Section 3.2.

The guidelines (GL-mix) in Section 4.1.1 and in Section 4.2.1 for the IPv6 nodes for a network or network slice supporting a mix of flows requiring and not requiring IP mobility support apply here. The guidelines (GL-mix) in Section 5.1.1 also apply here. In addition, the following are required.

GL-switch:5 The anchor operations to properly forward the packets for a flow as described in the FM operations and mobility message parameters in Section 3.2.2 FM-path, FM-path-tbl, FM-DPA, FM-DPA-tbl is realized by changing

the anchoring with DHCPv6-PD and undoing such changes later when its timer expires and the application has already closed. With the anchors being separated in control and data planes with LMs and FM-CP centralized in the same control plane, messaging between anchors and the discovery of anchors become internal to the control plane as described in Section 3.2.2 FM-cpdp. However, the centralized FM-CP needs to communicate with the distributed FM-DP as described as described in the FM operations and mobility message parameters (FM-find). Such may be realized by the appropriate messages in [I-D.ietf-dmm-fpc-cpdp].

GL-switch:6 It was already mentioned before that, if there are in-flight packets toward the old anchor while the MN is moving to the new anchor, it may be necessary to buffer these packets and then forward to the new anchor after the old anchor knows that the new anchor is ready Here, however, the corresponding FM operations and mobility message parameters as described in Section 3.2.2 (FM-buffer) can be realized by the internal operations in the control plane together with signaling between the control plane and distributed data plane. These signaling may be realized by the appropriate messages in [I-D.ietf-dmm-fpc-cpdp].

5.3. IP Prefix/Address Anchor Switching for a Hierarchical Network

The configuration for a hierarchical network is shown in Figures 1(c) and 1(d) in Section 3.1. With centralized control plane, CPA and CPN, with the associated LM and FM-CP are all co-located. There are multiple DPAs (each with FM-DP) in distributed mobility anchoring. In the data plane, there are multiple DPNs (each with FM-DP) hierarchically below each DPA. The DPA at each AR supports forwarding to the DPN at each of a number of forwarding switches (FW's). A mobility event in this configuration belonging to distributed mobility management will be deferred to Section 5.4.

In this distributed mobility configuration, a mobility event involving change of FW only but not of AR as shown in Figure 11 may still belong to centralized mobility management and may be supported using PMIPv6. This configuration of network-based mobility is also applicable to host-based mobility with the modification for the MN directly taking the role of DPN and CPN, and the corresponding centralized mobility event may be supported using MIPv6.

In Figure 11, the IP prefix allocated to the MN is anchored at the access router (AR) supporting indirection to the old FW to which the MN was originally attached as well as to the new FW to which the MN has moved.

The realization of LM may be the binding between the IP prefix/address of the flow used by the MN and the IP address of the DPN to which MN has moved. The implementation of FM to enable change of FW without changing AR may be accomplished using tunneling between the AR and the FW as described in [I-D.korhonen-dmm-local-prefix] and in [I-D.templin-aerolink] or using some other L2 mobility mechanism.

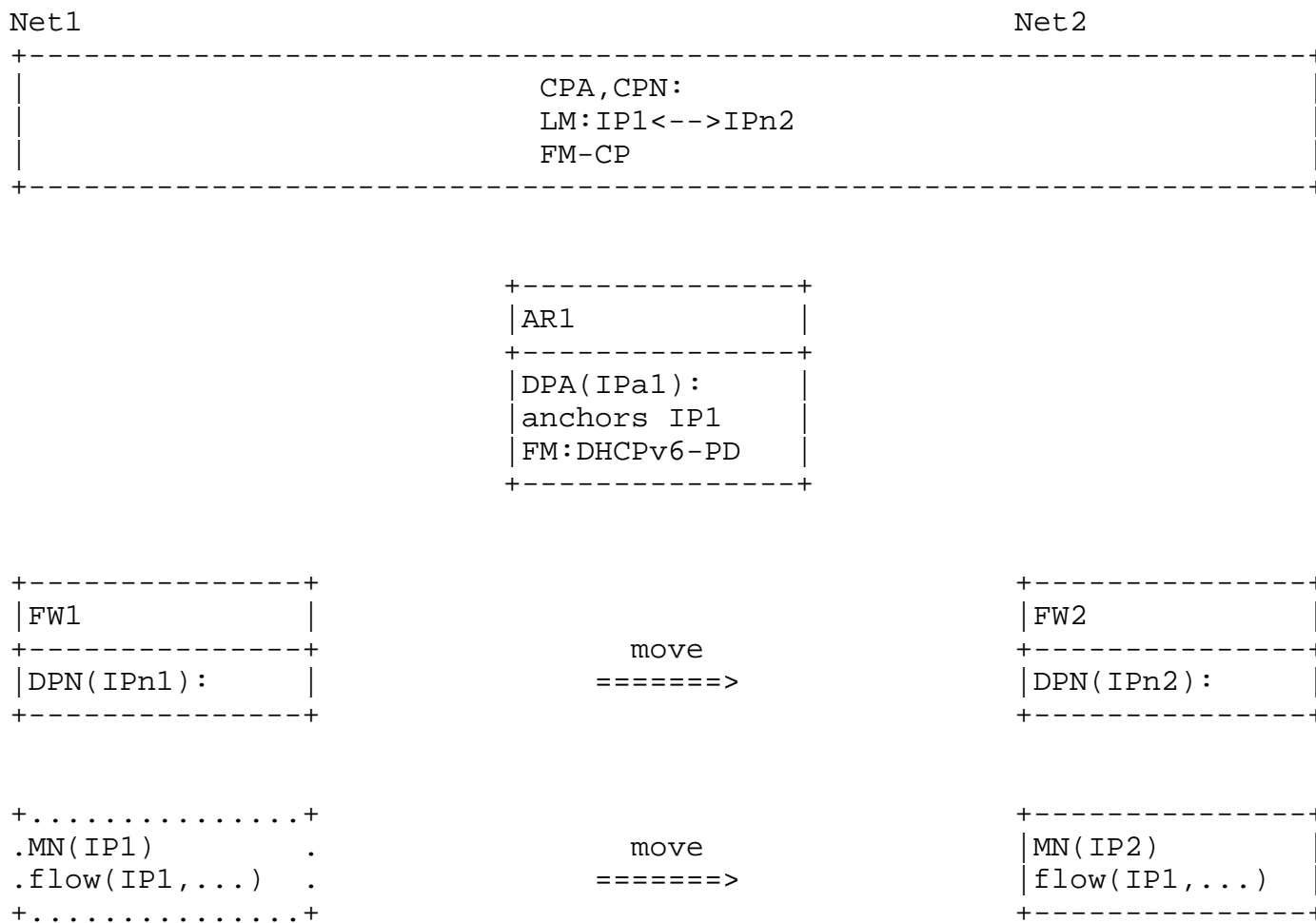


Figure 11. Mobility without involving change of IP anchoring in a network in which the IP prefix allocated to the MN is anchored at an AR which is hierarchically above multiple FWs to which the MN may connect.

5.3.1. Additional Guidelines for IPv6 Nodes: No Anchoring Change with a Hierarchical Network

The configuration guideline () for a hierarchical network or network slice with centralized control plane and supporting a mix of flows requiring and not requiring IP mobility support is:

GL-cfg:5 Multiple instances of DPAs (at access routers) which are providing IP prefix to the MNs are needed to provide distributed mobility anchoring according to Figure 2(a) or Figure 2(b) in Section 3.1.2 with centralized control plane for a hierarchical network.

The appropriate IPv6 nodes (CPA, DPA) are to be implemented the mobility functions LM and FM as described respectively in LM-cfg:3 or LM-cfg:4 and FM-cfg:2 in Section 3.2.

Even when the mobility event does not involve change of anchor, it is still necessary to distinguish whether a flow needs IP mobility support.

The GL-mix guidelines in Section 4.1.1 and in Section 4.2.1 for the IPv6 nodes for a network or network slice supporting a mix of flows requiring and not requiring IP mobility support apply here. The guidelines (GL-switch) in Section 5.1.1 and in Section 5.2.1 also apply here. In addition, the following are required.

GL-switch:7 Here, the LM operations and mobility message parameters described in Section 3.2.1 provides information of which IP prefix from its FW needs to be used by a flow using which new FW. The anchor operations to properly forward the packets of a flow described in the FM operations and mobility message parameters (FM-path, FM-path-ind, FM-cpdp in Section 3.2.2) may be realized with PMIPv6 protocol ([I-D.korhonen-dmm-local-prefix]) or with AERO protocol ([I-D.templin-aerolink]) to tunnel between the AR and the FW.

5.4. IP Prefix/Address Anchor Switching for a Hierarchical Network

The configuration for the hierarchical network is again shown in Figures 1(c) and 1(d) in Section 3.1. Again, with centralized control plane, CPA and CPN, with the associated LM and FM-CP are all co-located. There are multiple DPAs (each with FM-DP) in distributed mobility anchoring. In the data plane, there are multiple DPNs (each

with FM-DP) hierarchically below each DPA. The DPA at each AR supports forwarding to the DPN at each of a number of forwarding switches (FW's).

A distributed mobility event in this configuration involves change from a previous DPN which is hierarchically under the previous DPA to a new DPN which is hierarchically under a new DPA. Such an event involving change of both DPA and DPN is shown in Figure 12.

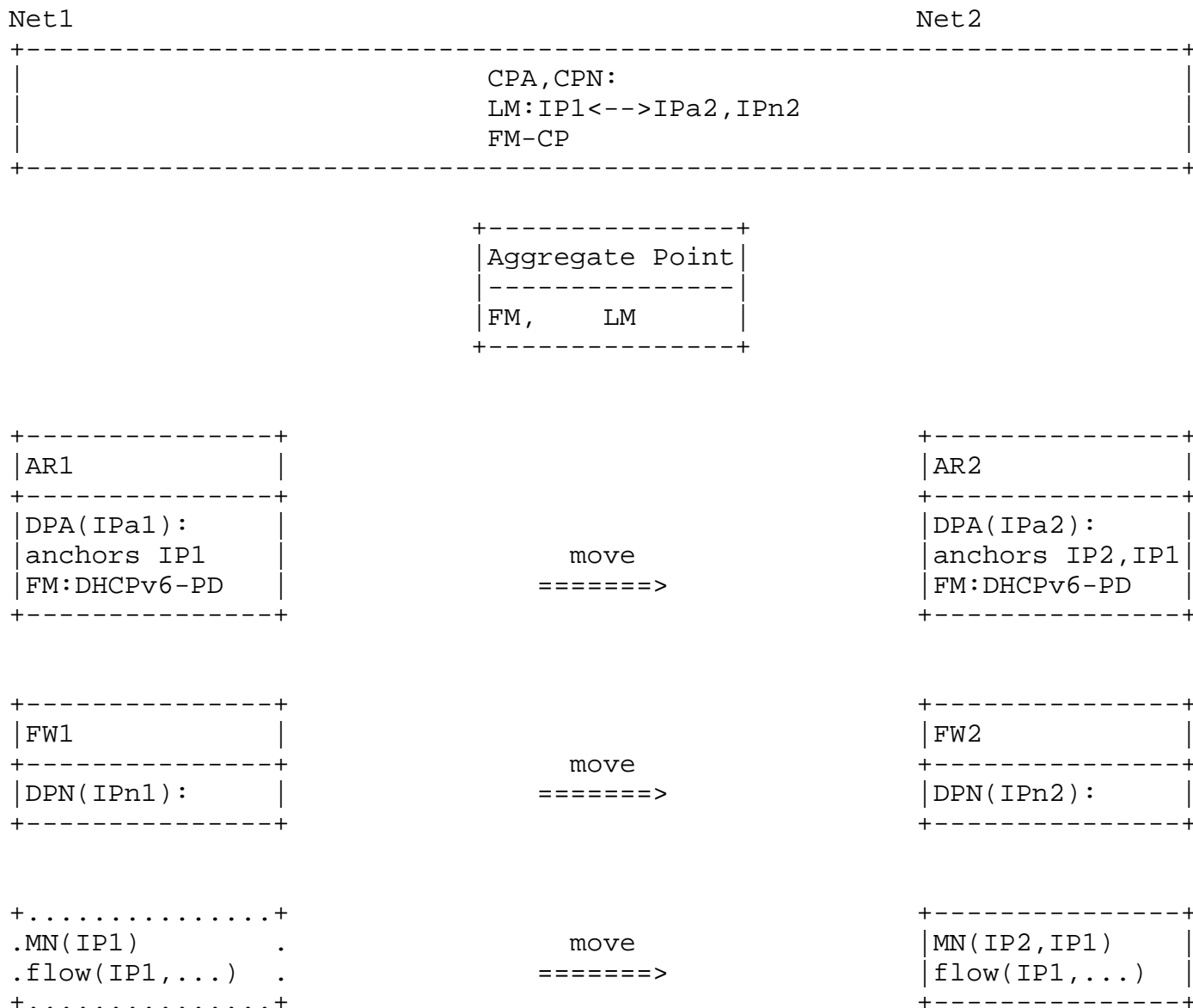


Figure 12. Mobility involving change of IP anchoring in a network with hierarchy in which the IP prefix allocated to the MN is anchored at an Edge Router supporting multiple access routers to which the MN may connect.

This deployment case involves both a change of anchor from AR1 to AR2 and a network hierarchy AR-FW. It can be realized by a combination of changing the IP prefix/address anchoring from AR1 to AR2 with the mechanism as described in Section 5.2 and then forwarding the packets with network hierarchy AR-FW as described in Section 5.3.

To change AR, AR1 acting as a DHCPv6-PD client may exchange message with the DHCPv6 server to release the prefix IP1. Meanwhile, AR2 acting as a DHCPv6-PD client may exchange message with the DHCPv6 server to delegate the prefix IP1 to AR2.

5.4.1. Additional Guidelines for IPv6 Nodes: Switching Anchor with Hierarchical Network

The configuration guideline (GL-cfg) for a hierarchical network or network slice with centralized control plane described in Section 5.3.1 apply here.

The GL-mix guidelines in Section 4.1.1 and in Section 4.2.1 for the IPv6 nodes for a network or network slice supporting a mix of flows requiring and not requiring IP mobility support apply here.

The guidelines (GL-switch) in Section 5.1.1 and in Section 5.2.1 also apply here to change the anchoring of the IP prefix/address with a centralized control plane.

In addition, the guideline for indirection between the new DPA and the new DPN as described in Section 5.3.1 apply here.

6. Security Considerations

TBD

7. IANA Considerations

This document presents no IANA considerations.

8. Contributors

This document has benefited from other work on mobility solutions using BGP update, on mobility support in SDN network, on providing mobility support only when needed, and on mobility support in enterprise network. These work have been referenced. While some of these authors have taken the work to jointly write this document, others have contributed at least indirectly by writing these drafts. The latter include Philippe Bertin, Dapeng Liu, Satoru Matushima, Peter McCann, Pierrick Seite, Jouni Korhonen, and Sri Gundavelli.

Valuable comments have also been received from John Kaippallimalil, ChunShan Xiong, and Dapeng Liu.

9. References

9.1. Normative References

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