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Transient Binding for Proxy Mobile IPv6

Abstract

This document specifies a mechanism that enhances Proxy Mobile IPv6 protocol signaling to support the creation of a transient binding cache entry that is used to optimize the performance of dual radio handover, as well as single radio handover. This mechanism is applicable to the mobile node's inter-MAG (Mobility Access Gateway) handover while using a single interface or different interfaces. The handover problem space using the Proxy Mobile IPv6 base protocol is analyzed and the use of transient binding cache entries at the local mobility anchor is described. The specified extension to the Proxy Mobile IPv6 protocol ensures optimized forwarding of downlink as well as uplink packets between mobile nodes and the network infrastructure and avoids superfluous packet forwarding delay or even packet loss.

Status of This Memo

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1. Introduction

The IETF specified Proxy Mobile IPv6 (PMIPv6) [RFC5213] as a protocol for network-based localized mobility management, which takes basic operation for registration, tunnel management, and deregistration into account. In order to eliminate the risk of lost packets, this document specifies an extension to PMIPv6 that utilizes a new mobility option in the Proxy Binding Update (PBU) and the Proxy Binding Acknowledgement (PBA) between the new Mobility Access Gateway (nMAG) and the Local Mobility Anchor (LMA).

According to the PMIPv6 base specification, an LMA updates a mobile node’s (MN’s) Binding Cache Entry (BCE) and switches the forwarding tunnel after receiving a Proxy Binding Update (PBU) message from the mobile node’s new MAG (nMAG). At the same time, the LMA disables the forwarding entry towards the mobile node’s previous MAG (pMAG). In case of an inter-technology handover, the mobile node’s handover target interface must be configured according to the Router Advertisement being sent by the nMAG. Address configuration as well as possible access-technology-specific radio bearer setup may delay the complete set up of the mobile node’s new interface before it is ready to receive or send data packets. In case the LMA performs operation according to [RFC5213] and forwards packets to the mobile node’s new interface after the reception of the PBU from the nMAG, some packets may get lost or experience major packet delay. The transient BCE extension, as specified in this document, increases handover performance (optimized packet loss and forwarding delay) experienced by MNs, which have multiple network interfaces implemented while handing over from one interface to the other. The transient BCE extension also increases handover performance for single radio MNs, which build on available radio layer forwarding mechanisms, hence re-use existing active handover techniques.

Some implementation-specific solutions, such as static configuration on the LMA to accept uplink packets from the old MAG in addition to accepting packets from the new MAG for a short duration during the handover and buffering at the new MAG, can help to address some of the issues identified in this document. Please see Appendix B for more details. A dynamic solution by means of the proposed protocol operation helps to optimize the performance for a variety of handover situations and different radio characteristics.

Additionally, this document specifies an advanced binding cache management mechanism at the LMA according to well-defined transient BCE states. This mechanism ensures that forwarding states at LMAs are inline with the different handover scenarios. During a transient state, a mobile node’s BCE refers to two proxy Care-of-Address (Proxy-CoA) entries, one from the mobile node’s pMAG, another from its nMAG. MAGs can establish settings of a transient binding on the LMA by means of signaling. An LMA can establish or change the settings of a transient binding according to events, such as a timeout, a change of the radio technology due to a handover, or a completed set up of a radio bearer or configuration of an MN's IP address. Such an event may also be triggered by other protocols, e.g., Authentication, Authorization, and Accounting (AAA) messages. This document specifies advanced binding cache control by means of a Transient Binding option, which can be used with PMIPv6 signaling to support transient BCEs. Furthermore, this document specifies forwarding characteristics according to the current state of a binding to switch the forwarding tunnel at the LMA from the pMAG to the nMAG during inter-MAG handover according to the handover conditions. As a result of transient binding support, handover performance can considerably be improved to smooth an MN's handover without introducing major complexity into the system.

2. Conventions and Terminology

2.1. 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 [RFC2119].

2.2. Terminology and Functional Components

- IF - Interface. Any network interface, which offers a mobile node wireless or wired access to the network infrastructure. In case a mobile node has multiple interfaces implemented, they are numbered (IF1, IF2, etc.).

- Transient Binding Cache Entry. A temporary state of the mobile node Binding Cache Entry that defines the forwarding characteristics of the mobile node forwarding tunnels to the nMAG and pMAG. This transient BCE state is created when the Transient Binding option is included in the PBU and PBA as specified in this document. The LMA forwards the mobile node traffic according to current transient BCE characteristics as specified in this document. The transient BCE state is transparent to the pMAG.

- Active Binding Cache Entry. A valid mobile node Binding Cache Entry according to [RFC5213], which is not in transient state.

3. Analysis of the Problem Space

This section summarizes the analysis of the handover problem space for inter-technology handover as well as intra-technology handover when using the PMIPv6 protocol as in [RFC5213].

3.1. Handover Using a Single Interface

In some active handover scenarios, it is necessary to prepare the nMAG as the handover target prior to the completion of the link-layer handover procedures. Packets sent by the LMA to the nMAG before the completion of the link-layer handover procedure will be lost unless they are buffered.

In some systems, the nMAG will be the recipient of uplink traffic prior to the completion of the procedure that would result in the PBU/PBA handshake. These packets cannot be forwarded to the LMA.

During an intra-technology handover, some of the MN’s uplink traffic may still be in transit through the pMAG. Currently, and as per the PMIPv6 base protocol [RFC5213], the LMA forwards the MN’s uplink traffic received from a tunnel only as long as the source IP address of the MN’s uplink traffic matches the IP address of the mobile node’s registered Proxy-CoA in the associated BCE. As a result, packets received at the LMA from the MN’s pMAG after the LMA has already switched the tunnel to point to the nMAG will be dropped.

3.2. Handover between Interfaces

In client-based mobility protocols, the handover sequence is fully controlled by the MN, and the MN updates its binding and associated routing information at its mobility anchor after IP connectivity has been established on the new link. On the contrary, PMIPv6 aims to relieve the MN from the IP mobility signaling, while the mobile node still controls link configuration during a handover. This introduces a problem during an MN’s handover between interfaces. According to the PMIPv6 base protocol [RFC5213], the Access Authentication and the Proxy Binding Update (PBU) are triggered in the access network by the radio attach procedure, transparently for the MN. In addition, a delay for the MN’s new interface’s address configuration is not considered in the handover procedure. As a consequence, the immediate update of the MN’s BCE after the PBU from the MN’s nMAG has been received at the LMA impacts the performance of the MN’s downlink traffic as well as its uplink traffic. Performance aspects of downlink as well as uplink traffic during a handover between interfaces are analyzed in the subsequent subsections.

3.2.1. Issues with Downlink Traffic

Delay of availability of an MN’s network interface can be caused by certain protocol operations that the MN needs to perform to configure its new interface, and these operations can take time. In order to complete the address auto-configuration on its new interface, the MN needs to send a Router Solicitation and awaits a Router Advertisement. Upon receiving a Router Advertisement from the new MAG, the MN can complete its address configuration and may perform Duplicate Address Detection (DAD) [RFC4862] on the new interface. Only then the MN’s new interface is ready to receive packets.

Address configuration can take more than a second to complete. If the LMA has already switched the mobile node tunnel to point to the nMAG and started forwarding data packets for the MN to the nMAG during this time, these data packets may get delayed or lost because the MN’s new interface is not yet ready to receive data. However, delaying the PBU, which is sent from the new MAG to the LMA after the MN’s new interface has attached to the network, is not possible, as the new MAG retrieves configuration data for the MN from the LMA in the PBA, such as the MN’s Home Network Prefixes (HNPs) and the link-local address to be used at the MAG.

The aforementioned problem is illustrated in Figure 1, which assumes that the HNP(s) will be assigned under control of the LMA. Hence, the HNP option in the PBU, which is sent by the new MAG to the LMA, is set to ALL_ZERO. An MN has attached to the network with interface (IF) IF1 and receives data on this interface. When the MN’s new interface IF2 comes up and is detected by the new MAG, the new MAG sends a PBU and receives a PBA from the LMA. If the LMA decides to forward data packets for the MN via the new MAG, the new MAG has to buffer these packets until address configuration of the MN’s new interface has completed and the MN’s new interface is ready to receive packets. While setting up IF2, the MN may not reply to address resolution signaling [RFC4861], as sent by the new MAG [A]. If the MAG’s buffer overflows or the MN cannot reply to address resolution signaling for too long, data packets for the MN are dropped and the MN can experience severe packet losses during an inter-access handover [B] until IF2 is ready to receive and send data [C].

```
       +------+                 +----+      +----+                 +---+
       |  MN  |                 |pMAG|      |nMAG|                 |LMA|
       +------+                 +----+      +----+                 +---+
       IF2 IF1                    |           |                      |
        |   |                     |           |                      |
        |   |- - - - - - - - - Attach         |                      |
        |   |                     |---------------PBU---------------->|
        |   |                     |<--------------PBA----------------|
        |   |--------RtSol------->|           |                      |
        |   |<-------RtAdv--------|           |                      |
        |  Addr.                  |           |                      |
        |  Conf.                  |           |                      |
        |   |<--------------------|==================data============|--
        |   |                     |           |                      |
        |- - - - - - - - - - - - - - - - - Attach                    |
        |   |                     |           |----------PBU-------->|
        |   |                     |           |<---------PBA---------|
        |   |                     |           |<-====data============|--
    [A]?|<-----------NSol---------------------|<-====data============|--
        |   |                     |      [B] ?|<-====data============|--
        |   |                     |          ?|<-====data============|--
        |-----------RtSol-------------------->|<-====data============|--
        |<----------RtAdv---------------------|            :         |
     Addr.  |                     |           |            :         |
     Conf.  |                     |           |            :         |
        |<-----------NSol---------------------|            :         |
        |------------NAdv------------------>[C]                      |
       !|<------------------------------------|======data============|--
        |   |                     |           |                      |
        |   |                     |           |                      |
```

Figure 1: Issue with dual radio handover

Another risk for a delay in forwarding data packets from a new MAG to the MN's IF2 can be some latency in setting up a particular access technology's radio bearer or access-specific security associations after the new MAG received the MN's HNP(s) from the LMA via the PBA signaling message.

In case an access network needs the MN's IP address or HNP to set up a radio bearer between an MN's IF2 and the network infrastructure, the access network might have to wait until the nMAG has received the associated information from the LMA in the Proxy Binding Acknowledgment. Delay in forwarding packets from the nMAG to the MN's IF2 depends now on the latency in setting up the radio bearer.

A similar problem can occur in the case in which the setup of a required security association between the MN's IF2 and the network takes time and such a setup can be performed only after the MN's IP address or HNP is available on the nMAG.

Both scenarios, as depicted above, can be found in [TS23.402], where the protocol sequence during a handover between different accesses considers a PMIPv6 handshake between the nMAG and the LMA to retrieve the MN's HNP(s) before access-specific operations can be completed.

3.2.2. Issues with Uplink Traffic

In the case of an inter-technology handover between two interfaces, the MN may be able to maintain connectivity on IF1 while it is completing address configuration on IF2. Such a handover mechanism is called "make-before-break" and can avoid uplink packet loss in client-based Mobile IP. However, in a PMIPv6 domain, the attachment of the MN on IF2 will cause the nMAG to send a PBU to the LMA, which will cause the LMA to update the BCE for this mobility session of the MN. According to Section 5.3.5 of the PMIPv6 base specification [RFC5213], the LMA may drop all subsequent packets being forwarded by the MN's pMAG due to the updated BCE, which refers now to the nMAG as a "Proxy-CoA".

A further issue for uplink packets arises from differences in the time of travel between the nMAG and LMA in comparison with the time of travel between the pMAG and LMA. Even if the MN stops sending packets on IF1 before the PBU is sent (i.e., before it attaches IF2 to nMAG), uplink packets from pMAG may arrive at the LMA after the LMA has received the PBU from nMAG. Such a situation can, in particular, occur when the MN's previous link has a high delay (e.g., a Global System for Mobile Communications (GSM) link) and is slow compared to the handover target link. This characteristic is illustrated in Figure 2.

```
      +------+              +-----+                  +---+
      |  MN  |              |nMAG|                   |LMA|
      +------+              +-----+                  +---+
      IF2 IF1                 |                        |
       |   |\                 |                        |BCE exists
       |   |    \             |                        | for pMAG
       |- -|- - - - \- - - - Attach                    |
       |   |           s\     |---------PBU----------->|BCE update
       |   |               l\ |<--------PBA------------| for nMAG
       |   |                   o\                      |
       |   |                  |    w\                  |
       |   |                  |        l\              |
       |   |                  |            i\          |
       |   |                  |               n \      |packet dropped
       |   |                  |                  k --->| as BCE has only
       |   |                  |                        | entry for nMAG
       |   |                  |                        |
       |   |                  |                        |
```

Figure 2: Uplink traffic issue with slow links

3.3. Need for a Common Solution

To reduce the risk of packet loss, some settings on an MN could be chosen appropriately to speed up the process of network interface configuration. Also, tuning some network parameters, such as increasing the buffer capacity on MAG components, could improve the handover performance. However, some network characteristics, such as access link delay or bearer setup latency, cannot be easily fine tuned to suit a particular handover scenario. Thus, a common solution that dynamically controls and enhances this handover complexity using a simple extension to the PMIPv6 base protocol is preferred.

This document specifies transient BCEs as an extension to the PMIPv6 protocol. Set up and configuration of a transient BCE can be performed by means of extended PMIPv6 signaling messages between the MAG and the LMA component using a new Transient Binding mobility option. The transient BCE mechanism supports three clearly distinguished sequences of transient states to suit various handover scenarios and to improve handover performance for both inter- and intra-technology handover. As a result of using transient BCEs, excessive packet buffering at the nMAG during the MN’s handover process is not necessary and packet losses and major jitter can be avoided.

4. Use of Transient Binding Cache Entries

4.1. General Approach

The use of transient BCE during an MN’s handover (HO) enables greater control on the forwarding of uplink (Ul) and downlink (Dl) traffic to harmonize handover performance characteristics with the capabilities of the handover source and target access networks. Updating of an MN’s BCE at an LMA is split into different phases before and after the radio setup and IP configuration being associated with the MN’s handover from a pMAG to an nMAG.

The use of a transient BCE during an MN’s handover splits into an initiation phase and a phase turning the transient BCE into an active BCE. Figure 3 illustrates the procedure to enter and leave a transient BCE during an MN’s handover. As a result of the MN’s attachment at the nMAG, the first PBU from the MN’s nMAG can turn the MN’s BCE at the LMA and the nMAG into transient state by including a Transient Binding option (Section 5.1). The LMA enters the nMAG as a further forwarding entry to the MN’s BCE without deleting the existing forwarding entry and marks the BCE state as ’transient’. Alternatively, in case the nMAG does not include a Transient Binding option, the LMA can make the decision to use a transient BCE during an MN’s handover and notify the nMAG about this decision by adding a Transient Binding option in the PBA. After receiving the PBA, the nMAG enters the MN’s data, such as the assigned HNP(s), into its Binding Update List (BUL) and marks the MN’s binding with the LMA as ’transient’, which serves as an indication to the nMAG that the transient BCE needs to be turned into an active BCE.

During the transient state, the LMA accepts uplink packets from both MAGs, the pMAG and the nMAG, for forwarding. To benefit from the still available downlink path from pMAG to MN, the LMA forwards downlink packets towards the pMAG until the transient BCE is turned into an active BCE. Such a downlink forwarding characteristic is denoted as "late path switch" (L). During a dual radio handover, an MN can receive downlink packets via its previous interface; during a single radio handover, the late path switch supports re-using available forwarding mechanisms in the radio access network. Appendix A describes both use cases.

Decisions about the classification of an MN’s BCE as transient during a handover can be made either by the nMAG or the LMA. Detailed mechanisms showing how an nMAG or an LMA finds out to use a transient BCE procedure are out of scope of this document.

A transient BCE can be turned into an active BCE by different means, such as a timeout at the LMA, a PBU from the nMAG, which has no Transient Binding option included, or a deregistration PBU from the pMAG. As soon as the MN's BCE has been initiated to turn into an active BCE, the LMA switches the forwarding path for downlink packets from the pMAG to the nMAG.

```
    +-----+            +----+    +----+               +-----+
    | MN  |            |pMAG|    |nMAG|               | LMA |
    +-----+            +----+    +----+               +-----+
       |                  |         |                    |[pMAG serves
       |                  |         |                    | MN as
       |                  |         |                    | Proxy-CoA]
       |                  |         |                    |
       |<-----------------|===============data tunnel=====|--->data
       |                  |         |                    |
   [Handoff               |         |                    |
     Start]               |         |                    |
       |                  |         |                    |
      e|-----------------------[MN Attach]                |
      x|                  |         |                    |
      e|                  |         |---PBU(transient)--->|[Add nMAG to
      c|                  |         |                    | MN's BCE,
      u|                  |         |<--PBA(transient)----| enter trans-
      t|                  |         |                    | ient state]
      i|                  |         |                    |
      o|<-----Dl+Ul-------|===============data tunnel=====|--->data
      n|--------Ul------------------|=====data tunnel=====|--->data
       |                  |         |                    |
    [Handoff/             |         |                    |
   Configuration          |         |                    |
    Completed]            |   [HO Complete]              |
       |                  |         |--------PBU--------->|[Activate
       |                  |         |                    | MN's BCE,
       |                  |         |<-------PBA ---------| update for-
       |                  |         |                    | warding path
       |                  |         |                    | to nMAG]
       |                  |         |                    |
       |<---------------------------|=====data tunnel=====|--->data
       |                  |         |                    |
```

Figure 3: General mechanism and forwarding characteristics during handover with transient BCE

This specification considers an optional state when turning the transient BCE into an active BCE of a transient BCE with a late path switch, which keeps the pMAG for some more time as the forwarding entry in the transient BCE, solely to ensure forwarding of delayed uplink packets from the pMAG. This optional activation state has a lifetime associated, and termination does not need any signaling.

Whether or not to enter this optional activation state is decided by the LMA. The LMA may take information about the access technology associated with the MN's pMAG and nMAG from the MN's BCE to decide if using the activation state is beneficial, e.g., since a slow link is associated with the pMAG and uplink packets from the pMAG may arrive delayed at the LMA.

The Transient Binding option allows configuration of the transient BCE late path switch and signaling of associated settings. Signaling of the Transient Binding option and the LMA's decision whether or not to use an optional activation state defines the sequence through the clearly defined transient BCE states, as illustrated and described in Section 4.4. Section 4.2 describes the required extension to an LMA's binding cache to support transient BCE operation. Section 4.3 provides a concise overview about the possible roles of the nMAG and the LMA to control a transient BCE handover sequence. Details about the Transient Binding option and its use are described in Sections 4.5 and 4.6.

4.2. Impact on Binding Management

The use of a transient BCE requires temporary maintenance of two forwarding entries in the MN's BCE at the LMA, one referring to the MN's pMAG and the other referring to its nMAG. Forwarding entries are represented according to [RFC5213] and comprise the interface identifier of the associated tunnel interface towards each MAG, as well as the associated access technology information.

Each forwarding entry is assigned a forwarding rule to admit and control forwarding of uplink and downlink traffic to and from the associated MAG. Hence, according to this specification, a forwarding entry can have either a rule that allows only forwarding of uplink traffic from the associated MAG, or a rule that allows bidirectional forwarding from and to the associated MAG. At any time, only one of the two forwarding entries can have a bi-directional forwarding rule. The interface identifier and access technology type info can be taken from the PBU received at the LMA and linked to each forwarding entry accordingly.

MAGs should maintain the status of an MN's binding and the lifetime associated with a transient BCE at the LMA in their binding update list. This is particularly important if the new MAG needs to explicitly turn a binding into an active BCE after the associated MN's new interface has proven to be ready to handle IP traffic.

4.3. Role of the LMA and nMAG in Transient State Control

This section provides an overview about the nMAG's and the LMA's possibility to control a transient BCE. Please refer to the Protocol Operations sections for a detailed protocol description (Sections 4.5 and 4.6).

4.3.1. Control at the nMAG

Initiate a late path switch - Since the nMAG needs to have knowledge about the nature of a handover to set the Handoff Indicator (HI) option in the PBU and whether or not the handover implies a change in the used radio interface or technology, the nMAG is a suitable entity to make the decision to delay the downlink path switch in a controlled manner by means of a transient BCE. The nMAG can make the decision to initiate a transient BCE handover for an MN only when it knows that the MN supports a delayed downlink path switch (Section 4.7) according to this specification. It may know this due to a number of factors. For instance, during dual radio handover, most cellular networks have controlled handovers where the network knows that the host is moving from one attachment to another. In this situation, the link-layer mechanism can inform the mobility functions that this is indeed a movement, not a new attachment and that the MN has sufficient control on its interfaces to support a transient BCE handover. Where no support from the link layer exists and no such indication can be provided to the nMAG by the network, the nMAG MUST assume that the host is incapable of this mode of operation and employ standard behavior as specified in [RFC5213]. In other words, the nMAG initiates a regular [RFC5213] handover.

The nMAG is also a suitable entity to estimate a maximum delay until the new connection can be used, as it knows about its locally connected radio network characteristics. Hence, the nMAG can set the maximum lifetime to delimit the transient BCE softstate at the LMA. The LMA may still override the proposed lifetime and notify the nMAG about the new lifetime in the Transient Binding option included in the PBA.

Activation of a transient BCE to perform a downlink path switch - During a transient BCE handover, the nMAG may get an indication that the MN's radio link can be used and the MN has completed the setup of the IP address to send and receive data packets via the new link. In this case, the nMAG can initiate turning a transient BCE into an active BCE before the expiration of the associated maximum transient BCE lifetime. To do that, the nMAG sends a PBU message without the Transient Binding option to the LMA. This results in a downlink path switch to the nMAG.

4.3.2. Control at the LMA

Initiate a late path switch - If the LMA has received a PBU without a Transient Binding option included, the LMA can take a decision to use a transient BCE to optimize the handover performance. The LMA indicates its selected settings for the late path switch (L) and the associated maximum lifetime in the Transient Binding option, which is included in the PBA and sent to the nMAG.

Decision to use an optional activation state - The LMA is a suitable entity to decide about the use of an optional activation state, as the LMA has the knowledge about the MN’s previous and new access technology. Hence, the LMA can make this decision to use an activation state to temporarily keep alive the forwarding of uplink packets from both MAGs, the pMAG, and the nMAG, even though the downlink path has been switched to the nMAG already. One reason to enter such an activation state may be a slow link between the pMAG and the LMA as described in Section 3.2.2.

4.4. LMA Forwarding State Diagram

The current specification of transient BCEs covers three clearly defined transient BCE states at the LMA, which can be used during an MN’s handover. Each state implies a dedicated characteristic regarding forwarding entries, in which forwarding rules for uplink traffic are maintained separately from downlink traffic. This section explains how the forwarding state sequentially changes during the optimized handoff. To suit different handover scenarios, different sequences through the forwarding states can be entered. Figure 4 depicts the possible cases, their sequence of forwarding states, and the triggers for the transitions. Two example use cases are described in detail in Appendix A to illustrate which sequence through the forwarding states suits a particular handover.

According to this specification, each BCE has a state associated, which can be either ’Active’ or any of the specified transient states ’Transient-L’, ’Transient-LA’, or ’Transient-A’. In the case that a BCE is in ’Active’ state, the information in a BCE and associated forwarding conforms to [RFC5213].

Any of the transient states imply that the transient BCE has two forwarding entries, which are denoted as pMAG and nMAG in the forwarding state diagram. The diagram includes information about the forwarding rule along with each forwarding entry. This rule indicates whether a forwarding entry is meant to perform forwarding only for Uplink (Ul) traffic or to perform bi-directional forwarding for Uplink (Ul) and Downlink (Dl) traffic.

State transitions can be triggered as a result of processing a received PBU or by a local timeout event on the LMA. In the forwarding state chart below, the presence of a Transient Binding option in a PBU is indicated by 'Topt' as an argument to a PBU or PBA, respectively. As a further argument to a PBU message, the source of the message is indicated, which can be either the MN's nMAG or pMAG. A PBA is always sent by the LMA and addressed to the originator of the associated PBU.

A handover with transient BCE is either triggered when the nMAG sends a PBU with a Transient Binding option or when the LMA decides to answer a normal PBU with a PBA after including a Transient Binding option. Figure 4 illustrates the possible transitions between an active BCE and a transient BCE from the LMA's point of view. It also shows the direct transition between two active BCE states during an MN's handover according to [RFC5213], bypassing any transient states.

The diagram refers to two timeout events. TIMEOUT_1 is set according to the Lifetime value in a Transient Binding option (see Section 5 for the format of the Transient Binding option), whereas TIMEOUT_2 is set to ACTIVATIONDELAY (see Section 8 for the default value).

The first sequence of a transient BCE handover is followed when the LMA decides not to use the optional activation state and is going through Transient-L state, in which the LMA continues forwarding downlink packets to the pMAG, whereas uplink packets are accepted and forwarded from both, the pMAG and the nMAG. On reception of a PBU without a Transient Binding option from the nMAG, a TIMEOUT_1 event, or the reception of a deregistration PBU from the pMAG, the forwarding entry of the pMAG is removed from the MN's BCE, and the BCE state changes to active.

If the LMA decides to use the activation state, the second sequence is used. In this case, the BCE state turns into Transient-LA. Forwarding characteristics in the Transient-LA state are the same as for the Transient-L state, but the Transient-LA state follows a Transient-A state when the LMA receives a PBU from the nMAG without a Transient Binding option included or a TIMEOUT_1 event occurs. In the Transient-A state, the LMA performs a downlink forwarding path switch from the pMAG to the nMAG, whereas uplink packets are still accepted and forwarded from both, the pMAG and the nMAG. The Transient-A state is terminated by a TIMEOUT_2 event, the forwarding entry of the pMAG is removed from the MN's BCE, and the BCE state turns to active. If the LMA receives a deregistration PBU from the pMAG while the associated MN's BCE is in Transient-LA state, the uplink forwarding rule of the pMAG is no longer valid and the transition through Transient-A state is skipped. In such a case, the BCE turns into active state immediately.

```
                                +----------------+              Before
          PBU(nMAG) & PBA(LMA)  |    Active      |              Handover
        +-----------------------|                |              --------
        |                       |  pMAG [Dl,Ul]  |                   .
        |                       *----------------*                   .
        |                               |                            .
        |                               |                            V
        |               PBU(nMAG, Topt) | PBU(nMAG) & PBA(LMA, Topt) .
        |                               |                            .
        |                               |                            .
        |                               V                      Handover
        |                           __________                 Procedure
        |                          /   LMA    \                      .
        |               _________ /  selects   \ _________           .
        |            No|          \ activation /          |Yes       .
        |              |           \_state_?__/           |          .
        |              |                                  |          V
        |              V                                  V          .
        |       +--------------+                  +--------------+   .
        |       | Transient-L  |                  | Transient-LA |   .
        |       |              |                  |              |   .
        |       | pMAG [Dl,Ul] |          +-------| pMAG [Dl,Ul] |   .
        |       | nMAG [Ul]    |          |       | nMAG [Ul]    |   .
        |       +--------------+          |       +--------------+   .
        |              |                  |               |
        |              |       PBU(pMAG,  |     PBU(nMAG) | TIMEOUT_1
        |              |       lifetime=0)|               |          .
        |              |                  |               V          .
        |              |                  |       +--------------+   .
        |              |                  |       | Transient-A  |   .
        |    PBU(nMAG) | TIMEOUT_1        |       |              |   .
        |              |                  |       | nMAG [Dl,Ul] |   .
        |              |PBU(pMAG,         |       | pMAG [Ul]    |   .
        |              | lifetime=0)      |       +--------------+   .
        |              |                  |               |
        |              |                  |   PBU(pMAG,   | TIMEOUT_2
        |              |                  |    lifetime=0)|          .
        |              |                  |               |          V
        |              |                  |               |    -------
        |              |                  |               |    Handover
        |              |                  |               V    Complete
        |              |                  |        +--------------+
        |              |                  +------->|    Active    |
        |              +-------------------------->|              |
        +----------------------------------------->| nMAG [Dl,Ul] |
                                                   +--------------+
```

Figure 4: Possible transient forwarding states during a handover

4.5. MAG Operation

In case of a handover, the MN's nMAG may decide to control the MN's handover at the LMA to perform a late path switch according to the transient BCE procedure. In such a case, the nMAG includes the Transient Binding option in the PBU and sets the L-flag to 1 to indicate a late path switch. Furthermore, the nMAG MUST set the Lifetime field of the Transient Binding option to a value larger than 0 to propose a maximum lifetime of the transient BCE and to delimit the delay of switching the downlink path to the nMAG. The chosen lifetime value for the Transient Binding option SHOULD be smaller than the chosen lifetime value for the PBU registration. Other fields and options of the PBU are used according to [RFC5213].

In case the nMAG does not include a Transient Binding option but the LMA decides to perform a handover according to the transient BCE procedure, the nMAG may receive a Transient Binding option along with the PBA from the LMA as a result of the PBU it sent to the LMA.

In case the nMAG receives a PBA with a Transient Binding option having the L-flag set to 1, it SHOULD link the information about the transient BCE sequence and the associated transient BCE lifetime with the MN's entry in the BUL. Since the L-flag of the Transient Binding option is set to 1 to indicate a late path switch, the nMAG MAY turn an MN's transient BCE into an active BCE before the expiration of the transient BCE lifetime (TIMEOUT_1), e.g., when the MN's nMAG detects or gets informed that address configuration and radio bearer setup has been completed. To initiate turning a transient BCE into an active BCE, the nMAG sends a PBU to the LMA without including the Transient Binding option. All fields of the PBU are set according to the procedure for the binding lifetime extension described in Section 5.3.3 of [RFC5213]. In case the lifetime of a transient BCE expires or the LMA approves turning a transient BCE into an active BCE as a result of a PBU sent by the nMAG, the nMAG MUST delete all information associated with the transient BCE from the MN's BUL entry.

In case the nMAG includes a Transient Binding option into the PBU, only one instance of the Transient Binding option per PBU is allowed.

A MAG, which serves the MN current Proxy-CoA while the LMA already has an active or transient binding for the MN pointing to this MAG, SHALL NOT include a Transient Binding option in any subsequent PBU to create or update a transient BCE for the MN's current registration with this MAG.

4.6. LMA Operation

4.6.1. Initiation of a Transient BCE

In case the LMA receives a handover PBU from an MN’s nMAG that does not include a Transient Binding option and the associated MN’s BCE is active and not in transient state, the LMA MAY take the decision to use a transient BCE and inform the nMAG about the transient BCE characteristics by including a Transient Binding option in the PBA. In such a case, the LMA should know about the nMAG’s capability to support the Transient Binding option. The configuration of the MN’s transient BCE is performed according to the description in this section and the selected transient state. Otherwise, the LMA processes the PBU according to the PMIPv6 protocol [RFC5213] and performs a normal update of the MN’s BCE.

In case the PBU from the nMAG has a Transient Binding option included, the LMA must enter the sequence of transient BCE states according to its decision whether or not to use an optional activation state. In case the LMA decides not to use an activation state, it configures the MN’s transient BCE and the forwarding rules according to Transient-L state. As a result, the LMA performs a late path switch and forwards downlink packets for the MN towards the MN’s pMAG, whereas uplink packets being forwarded from both Proxy-CoAs, the MN’s pMAG, as well as from its nMAG, will be routed by the LMA.

In case the PBU from the nMAG has a Transient Binding option included and the LMA decides to use an optional activation state, the LMA configures the MN’s transient BCE and the forwarding rules according to Transient-LA state. As a result, the LMA performs a late path switch and forwards downlink packets for the MN towards the MN’s pMAG, whereas uplink packets being forwarded from both Proxy-CoAs, the MN’s pMAG, as well as from its nMAG, will be routed by the LMA. In addition, the LMA marks the transient BCE to enter a temporary activation phase in Transient-A state after the LMA received an indication to turn a transient BCE into an active BCE.

The LMA sets the lifetime of the transient BCE according to the lifetime indicated by the nMAG in the Transient Binding option’s lifetime field or may decide to reduce the lifetime according to its policy. If the lifetime value in the Transient Binding option exceeds the lifetime value associated with the PBU message, the LMA MUST reduce the lifetime of the transient BCE to a value smaller than the registration lifetime value in the PBU message. In the case of a successful transient BCE registration, the LMA sends a PBA with a Transient Binding option back to the nMAG. The L-flag of the

Transient Binding option MUST be set to 1 in this version of the specification. The lifetime field is set to the value finally chosen by the LMA.

In any case where the LMA finds the L-flag of the received Transient Binding option set to 1, but the lifetime field of the Transient Binding option is set to 0, the LMA MUST ignore the Transient Binding option and process the PBU according to [RFC5213]. After the PBU has been processed successfully, the LMA sends back a PBA with the status field set to PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH.

In case the LMA receives a Transient Binding option with the L-flag set to 0, this version of the specification mandates the LMA to ignore the Transient Binding option and process the PBU according to [RFC5213]. After the PBU has been processed successfully, the LMA sends back a PBA with the status field set to PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH.

In case the LMA receives a PBU with a Transient Binding option included from a MAG that serves already as Proxy-CoA to the associated MN in an active or transient BCE, the LMA MUST ignore the Transient Binding option and process the PBU according to [RFC5213]. After the PBU has been processed successfully, the LMA sends back a PBA with the status field set to PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH. In case the MN's BCE was in transient state before receiving such PBU from the MAG, the LMA SHALL interpret this PBU as indication to turn a transient BCE into an active BCE and proceed with leaving the Transient-L or Transient-LA state, respectively.

In any case where the LMA includes a Transient Binding option in the PBA, only one instance of the Transient Binding option per PBA is allowed.

4.6.2. Activation of a Transient BCE

When the LMA receives a PBU from the MN's nMAG that has no Transient Binding option included but the MN's BCE is in a transient state or the LMA receives a local event trigger due to expiration of the MN's transient BCE, the LMA should check whether the forwarding rules for the associated MN are set to route the MN's downlink traffic to the MN's pMAG. If the forwarding entry for downlink packets refers to the MN's pMAG, the LMA must update the forwarding information to forward downlink packets towards the MN's nMAG. After the forwarding path has been switched, the LMA must update the MN's BCE accordingly.

If the transient BCE indicates that the LMA must consider an activation state Transient-A after leaving a transient BCE has been initiated, the LMA must keep both forwarding entries for the pMAG and the nMAG for uplink packets and perform forwarding of packets it receives from both Proxy-CoAs. If no activation phase is indicated, the LMA sets the state of the MN's BCE to active and deletes any forwarding entry referring to the MN's pMAG. The LMA must delete any scheduled timeout event for the MN that is associated with a transient BCE.

When the LMA receives a deregistration PBU from the MN's pMAG, which has the registration lifetime set to 0 and the MN's BCE is in transient state, the LMA must update the forwarding rules for the MN and switch the downlink traffic path from the pMAG to the nMAG. Furthermore, the LMA sets the state of the MN's BCE to active and removes any forwarding entry towards the pMAG from the MN's BCE, irrespective of whether or not the transient BCE was configured to enter an activation state of Transient-A.

When the LMA receives a local event trigger due to the expiration of a timer that has been set to ACTIVATIONDELAY and scheduled to terminate the activation state of an MN's transient BCE, the LMA sets the state of the MN's BCE to active and removes any forwarding entry towards the pMAG from the MN's BCE.

When the LMA receives a PBU for binding lifetime extension from the MN's pMAG while the MN's BCE is in transient state, the LMA must approve the lifetime extension to pMAG according to [RFC5213] and proceed with the transient BCE handover towards nMAG according to this specification.

When the LMA receives a PBU from pMAG or a (n+1)MAG, which indicates a handover, e.g., according to the indications specified in [RFC5213], while the MN's BCE is in any of the specified transient states, the LMA MUST terminate the transient state and perform a handover to pMAG or (n+1)MAG, respectively, according to [RFC5213]. After the PBU has been processed successfully, the LMA sends back a PBA to the MAG that sent the PBU. If the PBU included a Transient Binding option, the LMA must ignore the Transient Binding option and set the status code of the PBA to PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH.

4.7. MN Operation

For a single radio handover, this specification does not require any additional functionality on the mobile node, when compared to [RFC5213].

During dual radio handover, the MN benefits most from the transient BCE extension to PMIPv6 when it is able to keep communication on the previous interface while it is setting up its handover target interface with the configuration context that has been received as a result of the new interface's attachment to the nMAG. Various techniques enable support for such an operation, e.g., the use of a virtual interface on top of physical radio interfaces [NETEXT] or implementation-specific extensions to the MN's protocol stack. Details about how to enable such make-before-break support on the MN are out of scope of this document.

4.8. Status Values

This section specifies the following PBA status value (6) for transient binding cache entry support. This status value is smaller than 128 and has been added to the set of status values specified in [RFC5213].

PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH: 6

The LMA has processed and accepted the PBU, but the attached Transient Binding option has been ignored.

4.9. Protocol Stability

The specification and use of transient BCEs ensures that correct PMIPv6 operation according to [RFC5213] will not be broken in any case. Such cases include loss of signaling information and incompatibility between an nMAG and an LMA in case one or the other side does not support the transient BCE option. The following list summarizes such cases and describes how the PMIPv6 protocol operation resolves incompatibility or loss of a signaling message.

LMA does not support transient BCEs: In case the nMAG sends a PBU with a Transient Binding option included to an LMA but the LMA does not support transient BCEs, the LMA ignores the unknown option [RFC3775] and processes the PBU according to [RFC5213]. Since the nMAG receives a PBA that has no Transient Binding option included, it does not set any transient binding information in the MN's BUL entry and operates according to [RFC5213].

nMAG does not support transient BCEs: In case the LMA makes the decision to perform a handover according to any of the specified transient BCE sequences and includes a Transient Binding option in the PBA, the receiving nMAG ignores the unknown option [RFC3775] and processes the PBA according to [RFC5213]. As the LMA does not get any further indication or feedback about the incompatibility at the nMAG, the LMA enters the selected transient state, which will be terminated at the latest time after (TIMEOUT_1 + ACTIVATIONDELAY) seconds. During this period, the nMAG performs according to the PMIPv6 specification [RFC5213], whereas the LMA will accept all uplink packets for the MN, from the pMAG, as well as from the nMAG according to the transient BCE specification. It is transparent to the nMAG if the LMA forwards downlink packets to the pMAG during the transient BCE phase; thus, no protocol conflict occurs due to the different states on the nMAG and the LMA.

Loss of Transient Binding option: As the Transient Binding option is included in the PBU and PBA, recovery from signaling packet loss is according to the PMIPv6 protocol operation and associated re-transmission mechanisms [RFC5213].

Missing PBU to turn a transient BCE into an active BCE: According to this specification, a lifetime for TIMEOUT_1 is signaled in the Transient Binding option, and turning a transient BCE into an active BCE is initiated at the latest time after the timer TIMEOUT_1 has elapsed. In case PBU signaling is lost or the nMAG fails to initiate turning a transient BCE into an active BCE, the transient state of the MN’s BCE will be terminated after expiration of the set lifetime, i.e., stable operation of the PMIPv6 protocol [RFC5213] has reliably recovered.

Lost connection with pMAG during late path switch: In case an MN loses connectivity to its pMAG during a transient BCE phase with late path switch and the nMAG fails to initiate turning a transient BCE into an active BCE to perform the path switch to the nMAG, in a worst-case scenario, downlink packets are lost until the chosen TIMEOUT_1 expires. After TIMEOUT_1 seconds, the protocol operation has been recovered successfully. However, this case is very unlikely for two reasons: If the connectivity to the pMAG is lost, the pMAG will send a deregistration PBU for the MN to the LMA, which results in turning the transient BCE into an active BCE and in a path switch. Furthermore, the nMAG will initiate turning the transient BCE into an active BCE as soon as the setup of the data link between the MN and the nMAG has been completed (Section 4.4). Note that this case, in particular, affects downlink packets, whereas uplink packets can be sent through the new connection after a broken link to the pMAG has been detected.

Binding lifetime extension from pMAG while MN's BCE is transient: As the binding lifetime of the pMAG and the nMAG is not correlated, pMAG may send a PBU for binding lifetime extension to the MN's LMA while the MN's BCE is in transient state. In such a case, the LMA will approve the binding lifetime extension to pMAG according to [RFC5213] and proceed with the transient BCE handover towards nMAG according to this specification.

The specification of the transient BCE extension maintains stable operation of PMIPv6 in case the MN performs very frequent handover, e.g., movement while the MN's handover between the pMAG and the nMAG is still in progress. Such corner cases are summarized in the following list.

Handover to (n+1)MAG during transient BCE: In case the MN's BCE is transient due to a handover from the pMAG to nMAG and during the transient BCE, the MN performs a further handover to a MAG that is different from pMAG and nMAG, say to (n+1)MAG, the LMA terminates the transient BCE and performs a handover to (n+1)MAG according to [RFC5213].

Handover back to pMAG during transient BCE (ping pong): In case the MN's BCE is transient due to a handover from the pMAG to nMAG and the MN moves back from nMAG to pMAG during the transient BCE, the LMA terminates the transient BCE and performs a handover to pMAG according to [RFC5213].

5. Message Format

5.1. Transient Binding Option

This section describes the format of the Transient Binding option, which can be included in a Proxy Binding Update message and a Proxy Binding Acknowledge message. The use of this Mobility Header option is optional.

The Transient Binding option can be included in a PBU message, which is sent by an MN's nMAG as a result of a handover. In such a case, the nMAG controls the transient BCE on the LMA. Alternatively, the LMA may attach the Transient Binding option in a PBA for two reasons. Either it replies to a received PBU with an attached Transient Binding option to approve or correct the transient BCE lifetime, or it notifies the nMAG about its decision to enter a transient BCE without having received a Transient Binding option from the nMAG in the associated PBU beforehand.

The Transient Binding option has no alignment requirement. Its format is as follows:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Type       |     Length    | Reserved    |L|   Lifetime    |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type: Identifies the Transient Binding option (43).

Length: 8-bit unsigned integer indicating the length of the option in octets, excluding the Type and the Length fields. This field MUST be set to 2.

L-Flag: Indicates that the LMA applies late path switch according to the transient BCE state. If the L-flag is set to 1, the LMA continues to forward downlink packets towards the pMAG. Different setting of the L-Flag may be for future use.

Lifetime: Maximum lifetime of a Transient-L state in multiple of 100 ms.

6. IANA Considerations

This specification adds a new Mobility Header option, the Transient Binding option. The Transient Binding option is described in Section 5.1. The Type value (43) for this option has been registered in the Mobility Options registry, the numbering space allocated for the other mobility options, as defined in [RFC3775].

This specification also adds one status code value to the Proxy Binding Acknowledge message, the PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH status code (6). The PBU_ACCEPTED_TB_IGNORED_SETTINGSMISMATCH status code is described in Section 4.8. Its value has been assigned from the Status Codes sub-registry as defined in [RFC3775] and has a value smaller than 128.

7. Security Considerations

Signaling between MAGs and LMAs as well as information carried by PBU and PBA messages is protected and authenticated according to the mechanisms described in [RFC5213]. No new security considerations are introduced in addition to those in [RFC5213]. Thus, the security considerations described throughout [RFC5213] apply here as well.

In case the MAGs or LMAs make use of a further protocol interface to an external component, such as for support of transient BCE control, the associated protocol must be protected and information must be authenticated.

8. Protocol Configuration Variables

LMA values:

- o 'ACTIVATIONDELAY': This value is set by default to 2000 ms and can be administratively adjusted.

9. Contributors

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11. References

11.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC3775] Johnson, D., Perkins, C., and J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.

[RFC5213] Gundavelli, S., Leung, K., Devarapalli, V., Chowdhury, K., and B. Patil, "Proxy Mobile IPv6", RFC 5213, August 2008.

11.2. Informative References

[NETEXT] Melia, T., Ed. and S. Gundavelli, Ed., "Logical Interface Support for multi-mode IP Hosts", Work in Progress, October 2010.

[RFC4861] Narten, T., Nordmark, E., Simpson, W., and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", RFC 4861, September 2007.

[RFC4862] Thomson, S., Narten, T., and T. Jinmei, "IPv6 Stateless Address Autoconfiguration", RFC 4862, September 2007.

[TS23.401] "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access", <http://www.3gpp.org>.

[TS23.402] "Architecture enhancements for non-3GPP accesses (Release 9)", <http://www.3gpp.org>.

Appendix A. Example Use Cases for Transient BCE

A.1. Use Case for Single Radio Handover

In some systems, such as the 3GPP Evolved Packet Core, PMIPv6 is supported for providing network-based mobility between the Serving Gateway (i.e., MAG) and the Packet Data Network Gateway (i.e., LMA) and handover mechanisms are implemented in the access network to optimize handover for single radio mobile nodes [TS23.401].

In such a system, a well structured inter-MAG handover procedure has been developed and effectively used. In order to switch the data tunnel path between the LMA and the pMAG in a systematic way that reduces packet loss and delay, this inter-MAG handover sets up the uplink data path from the mobile node through the nMAG and to the LMA first. As soon as the uplink data path is set up, the mobile node is able to forward uplink data packets through the nMAG to the LMA.

Since the downlink data path between the LMA and the nMAG is not set up at the same time as the uplink data path, the LMA must continue to forward downlink data packets to the pMAG. Additionally, this system utilizes a layer 2 forwarding mechanism from the previous Access Network (pAN) to the new Access Network (nAN), which enables the delivery of the downlink data packets to the mobile node location while being attached to the nMAG.

In order for the LMA to be able to forward the mobile node uplink data packets to the Internet, the transient BCE mechanism is used at the nMAG to send a PBU with the Transient Binding option to allow the LMA to create a transient BCE for the mobile node with uplink forwarding capabilities while maintaining uplink and downlink forwarding capabilities for the Proxy-CoA that is hosted at the pMAG.

During the lifetime of the transient BCE, the LMA continues to accept uplink traffic from both previous and new MAG while forwarding downlink traffic to the pMAG only. While the MN is able to receive downlink traffic via the pMAG, the mechanism used in the pMAG’s access network to forward downlink traffic to the current location of the mobile node in the nMAG’s access network during an intra-technology handover is out of scope of this description.

When the nMAG receives an indication that the inter-MAG handover process has completed, the nMAG sends another PBU without including a Transient Binding option to update the mobile node’s transient BCE to a regular PMIPv6 BCE with bi-directional capabilities. This mechanism is used by the LMA as an indication to switch the tunnel to point to the nMAG, which results in a smoother handover for the MN.

An example of using a transient BCE for intra-technology handover is illustrated in Figure 5. When the nMAG receives the indication that the MN is moving from the pMAG's access network to the nMAG's area, the nMAG sends a PBU on behalf of the MN to the MN's LMA. In this PBU, the nMAG includes the MN-ID, the HNP, and the interface ID as per PMIPv6 base protocol [RFC5213].

Furthermore, the nMAG indicates an intra-technology handover by means of the HI option and includes the Transient Binding option to indicate to the LMA that this registration should result in a transient BCE with a late downlink path switch. The nMAG sets the value of the transient BCE lifetime to a value that is dependent on the deployment and operator specific [D].

After the nMAG receives an indication that the MN has completed the handover process and the data path is ready to move the tunnel completely from the pMAG to the nMAG, the nMAG SHOULD send a PBU to allow the LMA to turn the MN's transient BCE into a regular BCE and to switch the data path completely to be delivered through the new Proxy-CoA. In this case, the nMAG sends a PBU with the MN-ID, Interface ID, and HNP and at the same time indicates an intra-technology handover by means of the HI option. In this PBU, the nMAG MUST NOT include the Transient Binding option, as shown in Figure 5 [E].

In the event that the nMAG receives downlink traffic destined to the MN from the LMA after sending a PBU with the Transient Binding option included, the nMAG MUST deliver the downlink traffic to the MN. In this case, the nMAG SHOULD send a PBU to ensure that the transient BCE has been turned into an active BCE.

```
          +-----+      +----+       +----+                    +-----+
          | MN  |      |pMAG|       |nMAG|                    | LMA |
          +-----+      +----+       +----+                    +-----+
             |            |            |  bi-directional         |
             |            |<<<<<<<<======================>>>>>>>>|<-->
             |            |            |                         |
             |            |            |                         |
       [Handoff Event]    |            |                         |
             |      [MN HO Event]      |                         |
             |            |     [HO Event Acquire]               |
             |            |            |                         |
      [LL Attach to       |            |                         |
           nMAG]          |            |-----PBU(transient)----->|
             |            |            |                        [D]
             |            |            |<-----PBA(transient)-----|
             |            |            |                         |
             |            |          bi-directional              |
             |      |<--->|<<<<<<<<======================>>>>>>>>|<-->
             |     pAN    |            |                         |
             |      |----------->|     |                         |
             |            |     nAN    |                         |
             |<------------------|     |uplink only              |
             |------------------>|---->|>>>>>>===========>>>>>>>>|--->
             |            |            |                         |
             |            |      [HO Complete]                   |
             |            |            |----------PBU----------->|
             |            |            |                        [E]
             |            |            |<---------PBA -----------|
             |            |‘           |                         |
             |            |            |<<<<<<<<=========>>>>>>>>|<-->
             |            |            |                         |
```

Figure 5: Transient BCE support for an intra-technology handover

A.2. Use Case for Dual Radio Handover

During an inter-technology handover, the LMA shall, on the one hand, be able to accept uplink packets of the MN as soon as the MN has finalized address configuration at the new IF2 and may start using the new interface for data traffic, i.e., the PBU for the uplink shall be done before the radio setup procedure is finalized. But, to allow the MN to keep sending its data traffic on IF1 during the handover, uplink packets with the previously existing binding on IF1 shall still be accepted by the LMA until the MN detaches from pMAG with IF1 and the pMAG has deregistered the MN’s attachment at the LMA by means of sending a PBU with lifetime 0. This is of particular importance as sending the registration PBU from the nMAG is transparent to the mobile node, i.e., the MN does not know when the

PBU has been sent. On the other hand, switching the downlink path from the pMAG to the nMAG shall be performed at the LMA only after completion of the IP configuration at the MN's IF2 and after a complete setup of the access link between the MN and the nMAG. How long this takes depends on some interface-specific settings on the MN as well as on the duration of the target system's radio layer protocols, which is transparent to the LMA but may be known to MAGs.

Similar to the use case for single radio handover, a transient BCE can be utilized for MNs with dual radio capability. Such MNs are still able to send and receive data on the previous interface during the address configuration on the new interface. Forwarding between the nMAG and pMAG is not required, but the case in which the LMA immediately starts forwarding downlink data packets to the nMAG has to be avoided. This is enabled by a PBU that has the Transient Binding option included, so that it is not necessary that MN and LMA synchronize the point in time for switching interfaces and turning a transient BCE into an active BCE.

When the handover is finalized, the nMAG sends a second PBU without including the Transient Binding option and the LMA turns the MN's BCE into an active BCE. This PBU may overtake packets-on-the-fly from MN to LMA via pMAG (e.g., if the previous interface was of type GSM or Universal Mobile Telecommunications System (UMTS) with up to 150 milliseconds of uplink delay). The LMA has to drop all these packets from the pMAG due to the characteristics of the MN's active BCE. This can be avoided by entering another transient BCE state (Transient-A) during the activation phase and is characteristic for this use case. Whether or not to enter a Transient-A state is decided by the LMA.

The use of a transient BCE for an inter-technology handover is exemplarily illustrated in Figure 6. The MN attaches to the PMIPv6 network with IF1 according to the procedure described in [RFC5213]. The MN starts receiving data packets on IF1. When the MN activates IF2 to prepare an inter-technology handover, the nMAG receives an attach indication and sends the PBU to the LMA to update the MN's point of attachment and to retrieve configuration information for the MN (e.g., HNP). The LMA is able to identify an inter-technology handover by means of processing the HI option coming along with the PBU sent by the nMAG. As in this example, the nMAG includes the Transient Binding option in the PBU to control the transient BCE at the LMA, the LMA updates the MN's BCE according to the transient BCE specification described in this document and marks the state of the BCE as 'transient' [F].

As a result of the transient BCE, the LMA keeps using the previous forwarding information towards the pMAG binding as forwarding information until the transient BCE gets turned into active. The LMA acknowledges the PBU by means of sending a PBA to the nMAG. The nMAG now has relevant information available, such as the MN’s HNP, to set up a radio bearer and send a Router Advertisement to the MN. While the MN’s BCE at the LMA has a transient characteristic, the LMA forwards uplink packets from the MN’s pMAG as well as from its nMAG. The nMAG may recognize when the MN’s IF2 is able to send and receive data packets and sends a new PBU to the LMA without including the Transient Binding option to initiate turning the MN’s transient BCE into an active BCE [G]. As a result of successfully turning the MN’s transient BCE into an active BCE, downlink packets will be forwarded towards the MN’s IF2 via the nMAG [H].

```
    +------+                 +----+      +----+                 +---+
    |  MN  |                 |pMAG|      |nMAG|                 |LMA|
    +------+                 +----+      +----+                 +---+
    IF2 IF1                    |           |                      |
     |   |                     |           |                      |
     |   |- - - - - - - - - Attach         |                      |
     |   |                     |---------------PBU--------------->|
     |   |                     |<--------------PBA----------------|
     |   |--------RtSol------->|           |                      |
     |   |<-------RtAdv--------|           |                      |
     |  Addr.                  |           |                      |
     |  Conf.                  |           |                      |
     |   |<------------------->|==================data============|<--->
     |   |                     |           |                      |
     |- - - - - - - - - - - - - - - - - Attach                    |
     |   |                     |           |----PBU(transient)--->|
     |   |                     |           |<---PBA(transient)---[F]
     |------RAT Configuration--------------|                      |
     |   |<--------------------|==================data============|<---
     |-------RtSol-(optional)------------->|                      |
     |<-----------RtAdv--------------------|                      |
   Addr. |                     |           |                      |
   Conf  |                     |           |                      |
     |------------NSol-------------------->|---------PBU-------->[G]
     |   |                     |           |<--------PBA----------|
     |<------------------------------------|========data=========[H]<-->
     |   |                     |           |                      |
     |   |                     |           |                      |
     |   |                     |           |                      |
```

Figure 6: Late path switch with PMIPv6 transient BCEs

Appendix B. Applicability and Use of Static Configuration at the LMA

During the working group discussion of the functionality introduced by this document, it was mentioned that some current Home Agents are already handling some features and functionality introduced in this document via some static configuration. This Appendix captures the analysis that describes which functionality can be handled securely using a static configuration and which can not. In these cases where static configuration can be used, this section documents the possible disadvantages versus using the procedures captured in this document.

B.1. Early Uplink Traffic from the nMAG

This use case is related to the handoff scenario when the access network establishes the uplink tunnel to the LMA before the downlink portion is done. Consequently, when the mobile node is attached to the nMAG and in the case of active handoff, the UE will start sending uplink traffic to the LMA through the nMAG.

Since the LMA has a proxy BCE for this mobile node that points to the Proxy-CoA that is hosted at the pMAG, the LMA has a routing entry for the MN HNP that points to the pMAG-LMA tunnel. Any uplink packet coming from the nMAG will be dropped by the LMA.

Allowing the LMA to forward the received uplink traffic from the nMAG to the Internet while the MN BCE points to the Proxy-CoA hosted at the pMAG is a violation of all mobility protocols that require a secure signaling exchange between the nMAG and the LMA before forwarding such traffic to the Internet. Otherwise, the LMA will be modifying the mobile node's routing entry based on an unsecured data traffic packet coming from the nMAG.

Therefore, this case cannot be addressed by any statically configured information on the LMA. On the contrary, a secure signaling using Transient Binding option as detailed in this document is required to create a transient state for the mobile node BCE at the LMA. This transient state will allow a temporary routing entry of the mobile node to point to the nMAG Proxy-CoA.

B.2. Late Uplink Traffic from the pMAG

This case is a very common case where the mobile node is handing over to another MAG while there is still some uplink traffic in flight coming from the pMAG. In this case, the LMA has the MN BCE points to the mobile node location before the handoff, i.e., pMAG Proxy-CoA. Then the LMA receives a PBU from the nMAG over a secure signaling tunnel, e.g., IPsec tunnel, which indicates some type of handoff as per the value in the handoff indicator mobility option.

If the PBU received from the nMAG was sent using the secure tunnel and successfully processed by the LMA, the LMA according to [RFC5213] switches the IP-in-IP tunnel to point to the nMAG Proxy-CoA. However, as the LMA is fully aware of the mobile node movement via secure signaling from the nMAG and the content of the PBU, which, in particular, contains the Handoff Indicator mobility option, the LMA can process some intelligence to allow the mobile node's late in-flight uplink traffic coming over the pMAG-LMA tunnel to proceed to the Internet.

In order to handle all handoff circumstances, the activation mechanism as described in this document is preferable over a statically configured timer, and it would dynamically help in ending the late forwarding from the pMAG based on a protected signaling from the pMAG.

B.3. Late Switching of Downlink Traffic to nMAG

One main use case of transient bindings is the late switching of downlink traffic routing at the LMA. This allows IP mobility protocol signaling between nMAG and LMA to be performed decoupled from the setup of the new link-layer connectivity, e.g., for performing a handover to an interface with time-consuming link setup procedures or for a make-before-break handover between interfaces.

LMA behavior according to [RFC5213] does not allow for late path switching. The LMA, according to [RFC5213], can only act upon the Handover Indicator and has no information on the time of completion of link layer setup. Even if an LMA implementation would be configured to delay the path switching by a fixed time, which would violate [RFC5213], this would not lead to smooth handover performance but would even add latency to the handover. Only additional signaling as provided by this document provides the information that late switching is applicable and enables a synchronization of the handover sequence, i.e., the switching is adapted both to the finalization of the link between mobile terminal and nMAG and to the release of the link between mobile terminal and pMAG, whatever comes first. Stable handover performance is achieved using protected PMIPv6 signaling as per [RFC5213].

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