

# Reducing Handover Latency in Future IP-based Wireless Networks: Fast Proxy Mobile IPv6

Geert Heijenk<sup>1</sup>, Mortaza S. Bargh<sup>2</sup>, Julien Laganier<sup>3</sup>, and Anand R. Prasad<sup>3</sup>

<sup>1</sup> University of Twente, The Netherlands  
geert.heijenk@utwente.nl

<sup>2</sup> Telematica Instituut, The Netherlands  
mortaza.bargh@telin.nl

<sup>3</sup> DoCoMo Communications Labs Europe GmbH, Germany  
laganier@docomolab-euro.com

**Abstract.** Current IP-level mobility protocols have difficulties meeting the stringent handover delay requirements of future wireless networks. At the same time they do not give sufficient control to the network to control the handover process. This paper presents an extension to Proxy Mobile IP, which is the favorite IP level mobility protocol for the 3GPP System Architecture Evolution / Long Term Evolution (SAE/LTE). The extension, Fast Proxy Mobile IPv6 (FPMIPv6), aims at solving or reducing the control and handover problem. An elementary analysis shows that FPMIPv6 can significantly reduce the handover latency and the loss of packets during handover, especially if handovers can be predicted a few tens of milliseconds before they occur.

**Keywords:** Mobile IP, Handover

## 1 Introduction

Future wireless networks are assumed to fully integrate different wireless access technologies, in order to enable their users to exploit the advantages of the various technologies, depending on the momentary requirements and circumstances. Such access technologies are e.g., the 3GPP Long Term Evolution (LTE) [1] for wide area coverage at moderate data rates and (future) members of the IEEE 802.11 family of Wireless Local Area Networks (WLANs) [2] for high data rates at hotspots. To integrate the various access technologies, future wireless networks are assumed to be fully Internet Protocol (IP) -based. For instance, 3GPP is currently standardizing the System Architecture Evolution (SAE) [3], which will be IP-based. To enable the users of these future wireless networks to freely roam between various access networks, an IP-level mobility protocol is needed.

One of the problems with current IP-level mobility protocols is that they do sometimes not meet the stringent requirements for the handover latency. Ref. [4] states that in order to support real-time services such as Voice over IP (VoIP), "... the packet

transmission delay fluctuations are desired to be 30 ms or less, and interruption caused by packet losses should be 100 ms or less.” For handovers between different radio technologies, the first requirement is stretched to 50 ms.

An important aspect when designing mobility mechanism is the location of control. Traditional Mobile-IP-based approaches tend to locate the control of the handover in the mobile node, whereas current cellular networks use so-called mobile-assisted handovers, where the control of the handover is in the network, and the mobile node provides additional (measurement) information. Network controlled handovers (also when using (Mobile) IP-based protocols), enable the network operator to control the service and its quality provided to its customers, and to optimally utilize network resources. Therefore, a promising solution direction for handovers in future wireless networks is to give control of the handover process to the network. In this way the network can coordinate the entire handover process, making the most optimal decisions at the most optimal time, by using all information available. Thus, the network can improve the link quality for users, manage its radio resources, reduce interference, and enable fast and seamless handovers.

A promising proposal for an IP-level mobility protocol is Proxy Mobile IPv6 (PMIPv6) [5]. In PMIPv6, IP-level mobility is hidden from the mobile node. A special access router, called Mobile Access Gateway (MAG), enables a Mobile Node (MN) to continue to use its home address when attached. It is the MAG that detects and signals movement of the MN to the Local Mobility Anchor (LMA), which is the topological anchor point of the mobile node’s address. Typically, the handover latency of PMIPv6 equals the time needed to perform the handover at layer 2 (including authentication) plus a round-trip time between MAG and LMA. Packets sent during this period are typically lost.

In this paper we try to solve the control and the handover delay issue for PMIPv6. Our contribution extends PMIPv6 with ideas from Fast Handovers for Mobile IPv6 (FMIPv6) [6]. It will be referred to from now on as Fast Proxy Mobile IPv6 (FPMIPv6). Our extension to PMIPv6 aims to enable the network to control handovers with assistance from the mobile, while at the same time significantly reducing handover delays.

The outline of the paper is as follows. Section 2 describes related work. In Section 3, we describe the proposed extension to PMIPv6. The performance of the extension, FPMIPv6, is analyzed in Section 4. Section 5 presents conclusions and future work.

## 2 Related Work

The main problem with node mobility in IP networks is that the IP address functions both as the identifier as well as the locator of a MN in the routing hierarchy. In its role as identifier, the IP address has to be fixed in order to allow the MN to be identified by Correspondent Nodes (CNs) that want to initiate communication with it, and also because it is used by MNs to identify their ongoing Transmission Control Protocol (TCP) connections. In its role as locator, the IP address of a MN has to change when it moves to a different sub-network, in order not to disrupt the route aggregation in the Internet. IP-level mobility solutions address this problem by assigning a new IP ad-

dress to the MN, called Care-of Address (CoA). The CoA locates the MN, or the sub-network it is attached to, in the network. Typically tunneling is used to deliver packets carrying the identifier (e.g. home address) to the CoA, and hence to the MN.

In Mobile IPv6 (MIPv6) [7] a Home Agent (HA), located on the home (sub)network of the MN, tunnels packets addressed to the home address (i.e., identifier) of the MN to the CoA (i.e., current locator) of the MN. Note that in its role as an identifier for the MN, the home address also acts as a locator for the MN's sub-network (i.e. the MN's HA, or the MN itself when being at home). Additionally, CNs may be informed of the current CoA of the MN in order to enable route optimization, which allows packets to be exchanged directly between a MN and its CN without routing via the HA.

An extension to MIPv6 is Hierarchical Mobile IPv6 (HMIPv6) [8], which adds an indirection for locating a MN. The HA tunnels packets to a Mobility Anchor Point (MAP), which is addressed by a regional CoA. The MAP in turn tunnels these packets to the MN, addressed by a local CoA. The main advantage of this approach is that local handovers of the MN only have to be signaled to the MAP thus avoiding high latencies and overhead for the so-called local binding updates.

Another extension to MIPv6 is Fast Handovers for MIPv6 (FMIPv6) [6], which aims at reducing handover latencies by proactively executing the configuration of the MNs interface for the link to the target Access Router (AR) while the MN is still connected to the link to the serving AR. Further, FMIPv6 exploits forwarding of packets by the serving AR to the target AR during the critical phase of the handover and buffering of these packets at the target AR until the MN attachment is completed.

Recently, Proxy MIPv6 (PMIPv6) [5] has been proposed as a Network-based Localized Mobility Management (NetLMM) protocol to hide IP layer mobility from the MN. A special AR, called MAG, enables a MN to continue to use its home address when attached. The MAG emulates the MN's home link on the access link by advertising the MN's home network prefix to the MN. Upon handover, it is the new MAG that signals an LMA (being similar to a HA) regarding the MN movement. Packets are tunneled from the LMA to the MAG, using a proxy CoA.

In PMIPv6, which is the favorite IP level mobility protocol for SAE/LTE, control is loosely coordinated. There is limited coordination in the LMA, which replaces existing bindings with new ones, based on time-stamps provided in the proxy binding updates. In our extension, we propose to let the old MAG play a key role in coordinating the handover. In the proposal, the old MAG (or current MAG) will collect information regarding the current radio link (from MN and current Access Point (AP)), resource use (from local APs and other MAGs), and regarding potential new radio links (from MN, local APs, and other MAGs). Based on the collected info, it will trigger the handover. It does so both on the network side, by instructing the MAG aimed at to send a proxy binding update to the LMA, and on the radio side, by instructing the MN to connect to a new AP.

Recently, initial proposals have been issued to the IETF, to extend PMIPv6 with communication between old MAG and new MAG [9, 10]. However, as opposed to this paper, the proposals do not deal with handovers that are predicted wrongly or too late, and neither do [9, 10] present any analysis of the proposals.

### 3 Fast Proxy Mobile IPv6

In our description of FPMIPv6, we use the same terminology as used in PMIPv6 (see Fig. 1). Nodes in the FPMIPv6 domain that are involved in the handover process are the Mobile Node (MN), the current or old and the new Access Points (APold and APnew respectively), which provide link level wireless access to the MN, the old and the new Mobile Access Gateway (MAGold and MAGnew respectively), which are the first IP-level node as seen from the MN, and the Local Mobility Anchor (LMA), where the IP address that the MN uses resides.

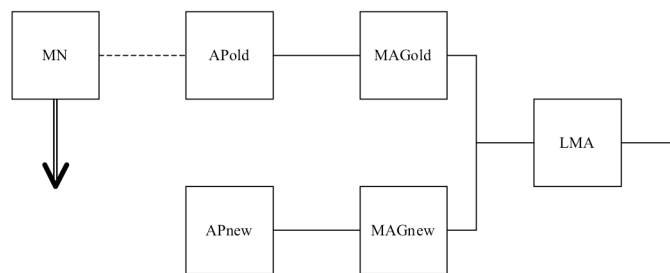


Fig. 1. Nodes in the FPMIPv6 domain.

#### 3.1 Protocol overview

The aim of FPMIPv6 is to (1) minimize the handover latency at the network layer and (2) minimize loss of packets due to the handover latency. The proposal is based on two main ideas:

- 1 A handover can be predicted.  
As a result of the prediction, the new MAG can be triggered to send a proxy binding update to the LMA, so that downlink traffic from LMA to MN can already be switched to the new MAG. The new MAG will buffer the traffic until the MN is connected.
- 2 Downlink traffic arriving at the old MAG after a MN disconnects will be buffered and redirected to the new MAG.  
To instruct the old MAG to redirect traffic, the new MAG will inform the old MAG of the handover by means of a Fast Binding Update (FBU) message.

The main coordination point of the handover is the old MAG. Based on information from MN, old AP (e.g., to predict that a handover will be needed), other APs, and other MAGs, it will take the decision to initiate a handover. The targeted new MAG is instructed to send a proxy binding update message to the LMA. As soon as this binding update is acknowledged, the new MAG will inform the old MAG. The old MAG will now instruct the AP and/or MN to release the radio link. Depending on the wireless interface capabilities of the MN, the MN will establish a radio link to the new AP before or after releasing the old one. A MN with multiple wireless interfaces can for instance already establish a new radio link as soon as the MAG initiates the handover.

To deal with mismatches in timing, the new MAG will buffer downlink packets if the MN has not yet attached to its AP. Similarly, the old MAG will buffer downlink packets if the MN has already disconnected and it still receives packets from the LMA. The new MAG will instruct the old MAG to forward buffered packets by means of a fast binding update message.

A critical issue in the operation of FPMIPv6 is the timely and correct prediction of a handover. In [11], simulation experiments using a simple handover prediction technique for 3GPP LTE indicate that it is indeed possible to predict handovers. In that paper, a timely prediction of approximately 70% of the handovers is obtained. Only a few percent of the predicted handovers had to be reversed, because the prediction was not accurate.

In the remainder of this section, we first present the basic operation of the protocol, in Section 3.2, followed by the case where the MN has two interfaces, in Section 3.3. We discuss the case that the prediction is not timely, i.e., the handover is premature, in Section 3.4. Finally, in Section 3.5, we discuss the case that the prediction is not correct.

### 3.2 Basic Operation

The basic operation of the FPMIPv6 proposal is illustrated in the Time Sequence Diagram (TSD) depicted in Fig. 2. Ideally, the old MAG receives a timely notification from L2 (from the old AP and indirectly the MN) that a handover is imminent, including the expected new Access Point to which the MN will connect (HOInfo). From that information the old MAG can easily derive the address of the new MAG. How exactly the address is derived is outside the scope of this paper. Each MAG can be provided with a table relating the APs of its neighboring MAGs to the relevant MAG address. Alternatively, the address of the MAG can be broadcasted by the connected APs on their pilot channel, so that the MN can inform the old MAG (HOInfo).

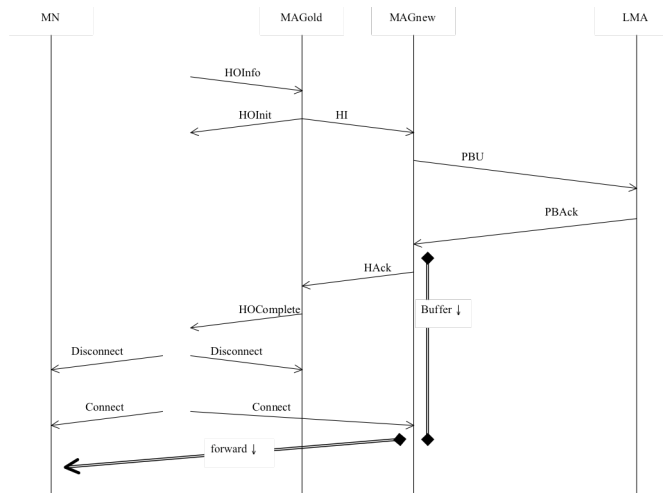


Fig. 2. Basic operation of FPMIPv6

If the old MAG decides to initiate a handover, it will inform the old AP (L2 message HOInit). Further, the old MAG will send a Handover Initiation (HI) message to the new MAG. This HI message includes a.o. a MN identifier and a timestamp.

Upon receiving the HI message, the new MAG will send a Proxy Binding Update (PBU) message to the LMA, using the timestamp received in the HI message. The LMA will install the new binding, return a Proxy Binding Acknowledgement (PBAck) message to the new MAG, and from now on forward all traffic for the MN to the new MAG.

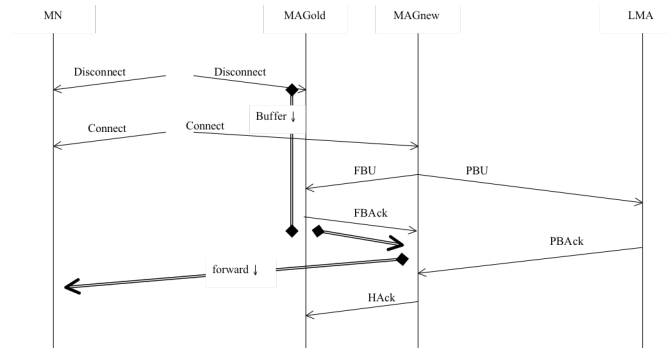
Upon receipt of the PBAck message, the new MAG will send a Handover Acknowledgement (HAck) message to the old MAG and start buffering traffic for the mobile node, until the MN connects to the new MAG (via the new AP), after which it will forward all traffic to the MN. The old MAG, upon receipt of the HAck message will send a L2 HOComplete message to the old AP, to instruct the MN to disconnect from the old AP, and connect to the new one, if it has not already done so. As we will see in Section D, some messages that are sent after the MN connects to the new MAG are omitted from the TSD in Fig. 2 in order to concentrate the description on the basic operation.

### 3.3 Operation with two interfaces

Depending on its implementation, a MN may be able to use two interfaces simultaneously. This may be because it uses two separate physical interfaces, e.g., to get access using different wireless technologies. The MN could also be using multiple virtual interfaces mapped onto a single physical interface [12]. Being able to connect to a new AP whereas the link to the old one will be maintained can significantly improve the handover performance. It also introduces new challenges, as the *network* should be able to (1) distinguish the interfaces, and (2) realize that the interfaces belong to the same node. We choose to introduce a shim layer in the MN that hides the presence of multiple interfaces from the IP layer. The MN only has a single globally routable IP address, and the shim layer should ensure that the MN is only using it on one interface at a time. Challenge (1) above is met because the different interfaces will use different hardware addresses. To meet challenge (2), the MN initially uses the MN identifier, and later the globally routable IP address. In case of multiple interfaces, the MN will use the HOInit that it gets forwarded from the AP to instruct its second interface to connect to the new AP. This way, the MN will already have a link to the new MAG available, at the moment it gets disconnected from the old MAG.

### 3.4 Premature Handover

Let us return to the single interface scenario. A handover cannot always be timely predicted. In order to avoid packet loss during an unexpected handover, the following reactive handover operation is proposed, illustrated by the TSD in Fig. 3.

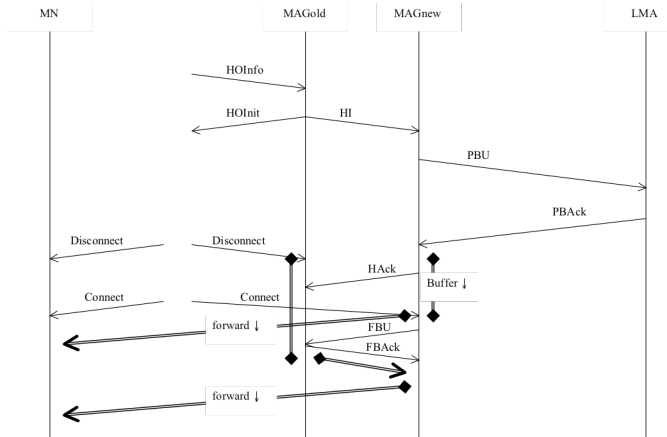


**Fig. 3.** Reactive handover operation

If the old MAG learns from L2 (APold) that the connection to the MN is lost, it starts buffering downlink packets that it receives for the MN. As soon as the new MAG learns from its L2 (APnew) that the MN has connected, it will send a PBU message to the LMA, and a Fast Binding Update (FBU) message to the old MAG. From this moment on, the new MAG will forward all downlink traffic it receives for the MN to the MN. The LMA will install the new binding, return a PBAck message to the new MAG, and from now on forward all traffic for the MN to the new MAG.

The old MAG upon receipt of the FBU message, acknowledges the message with a Fast Binding Acknowledge (FBAck) message, and redirects the traffic for the MN that it has buffered, or still receives to the new MAG.

The TSD depicted in Fig. 4 illustrates the case where the handover is predicted, but the MN is disconnected prematurely. The behavior of the nodes is the same as described above.



**Fig. 4.** Late prediction operation

### 3.5 Wrongly predicted handover

It can occur that a handover is predicted, but later on it appears that the MN has connected to a different AP and a different MAG. This requires that the old MAG corrects its HI message to the wrong MAG.

If the old MAG receives a FBU message for a MN from a MAG other than the new MAG where it has sent a HI message to, it will send the latter node also a FBU, so that it will start redirecting traffic for the MN back to the old MAG. The old MAG will redirect all traffic for the MN to the MAG it received the FBU from.

If a new MAG has initiated the handover, but before the MN connects, it receives an FBU message for that MN, it will start redirecting traffic for the MN to the sender of the FBU.

It can also occur that the old MAG has initiated a handover, but the MN is not able to perform the handover, and reconnects with the old AP / MAG. In that case, the old MAG will send a PBU message to the LMA, and also send an FBU message to the MAG the HI was sent to. In this situation, the old MAG carries out functions of a new MAG for the same MN simultaneously.

The detailed operation of the FPMIPv6 protocol is described in the finite state machines depicted in Fig. 5 and Fig. 6 for the old MAG and the new MAG respectively.

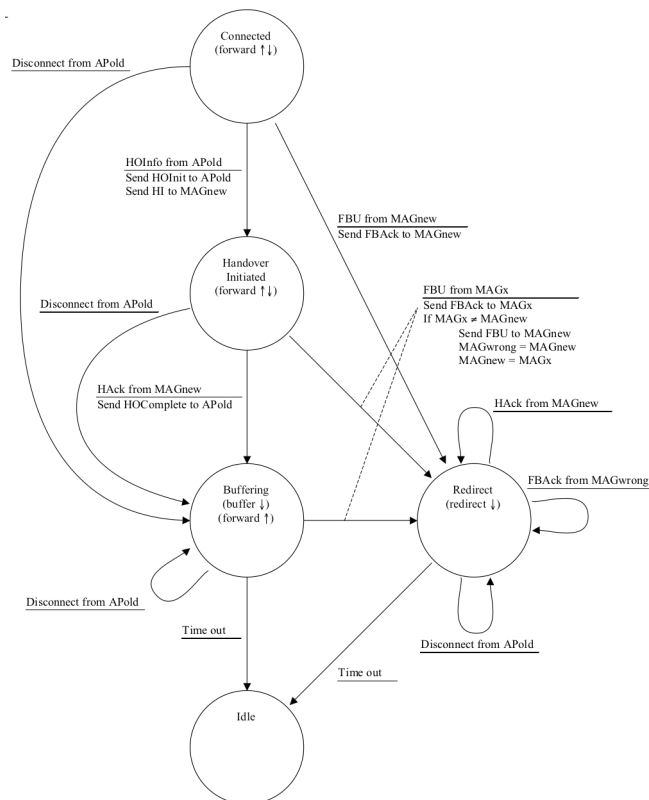


Fig. 5. Finite state machine of MAGold operation



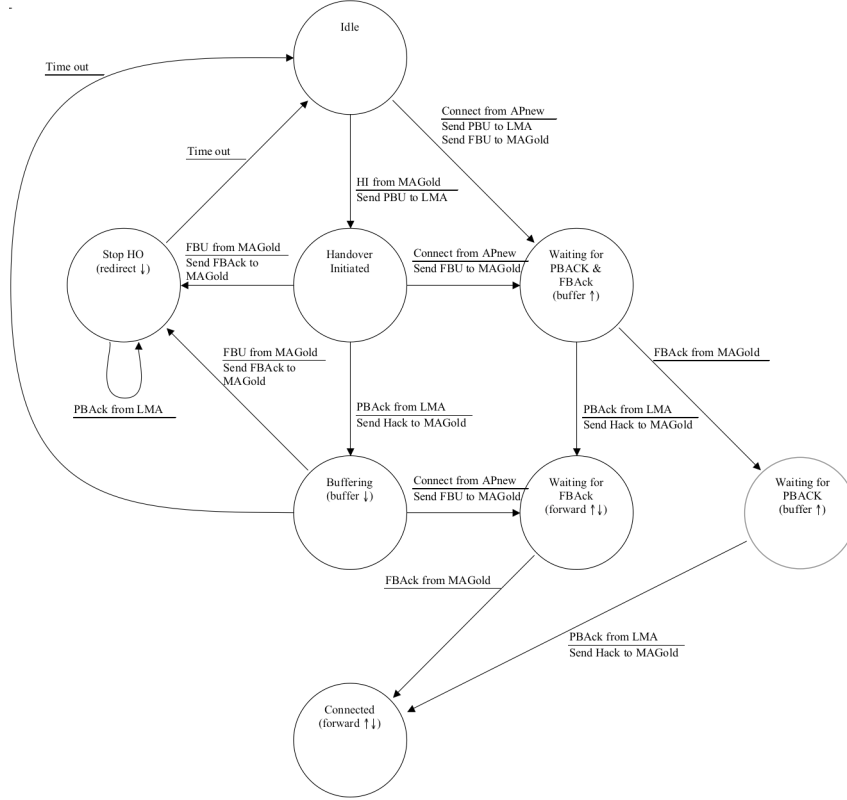


Fig. 6. Finite state machine of MAGnew operation

## 4 Analysis

In order to get insight into the handover latency ( $d_{HO}$ ) and packet loss due to handover ( $l_{HO}$ ), we construct a basic model to express these performance measures in terms of the round trip times (RTTs) between the various nodes.

### 4.1 Notation

We define  $d_{HO}$ , the handover latency, as the time during which no packets are received by the IP layer in the MN due to a handover. Further,  $l_{HO}$ , the handover loss period, denotes the number of packets that are lost because of the handover, measured as a time interval during which generated packets are lost. Finally,  $d_{add}$  denotes the maximum additional packet delay, i.e., the maximum delay that is experienced by packets during the handover due to buffering and redirection.

These performance measures will be expressed as a function of a number of network parameters. The first one is the prediction time,  $T_{pred}$ , which is the time that elapses between prediction of a handover and the possibly forced disconnection of the MN from the old AP. The layer 2 (L2) handover delay,  $D_{HO,L2}$ , denotes the time elapsing between the moment a MN is disconnected from the old AP until it has connected to the new AP, authenticated itself to the new AP, and notified the new MAG of its attachment. Finally we denote the RTT between MAG and LMA as  $RTT_{MAG-LMA}$ , the RTT between a MAG and an AP connected to it as  $RTT_{MAG-AP}$ , and the RTT between two neighboring MAGs as  $RTT_{MAG-MAG}$ .

## 4.2 Model

The model we are constructing to evaluate the handover latency and packet loss is an elementary one. We basically sum the delay components involved in the handover, and assume the individual components to be fixed. Our assumption is that processing delays can be neglected, and that the dominant delay components are those for the transfer of messages between the nodes involved. Which components have to be taken into account depends on the moment the handover is predicted, i.e. it depends on  $T_{pred}$ .

Let us first determine the packet loss during a handover. If the handover is predicted timely, no packets will be lost during handover, since all packets arriving at the old MAG can be delivered to the MN and packets arriving at the new MAG will be buffered until the MN has connected. If there is no timely prediction of the handover, packets that are already sent by the old MAG to the old AP before the old MAG gets notified of the disconnection get lost. This is at most the amount of data generated during one RTT between MAG and AP. It can be less, if the disconnection was predicted a little too late, but the LMA has already started redirecting the traffic from some point during the disconnection. The handover packet loss period can be summarized as

$$l_{HO} = \min(RTT_{MAG-AP}, \max(0, RTT_{MAG-AP} + RTT_{MAG-MAG} / 2 + RTT_{MAG-MAG} - T_{pred})) \quad (1)$$

The handover latency is a bit more difficult to determine. If the handover can be predicted timely, the handover latency is limited to the layer 2 handover latency plus the time needed for the new MAG to inform the old MAG that the binding in the LMA has been changed, i.e.,

$$d_{HO} = D_{HO,L2} + RTT_{MAG-MAG} / 2 \quad (2)$$

(for  $T_{pred} \geq RTT_{MAG-MAG} + RTT_{MAG-LMA}$ ).

The latter term may be reduced if the disconnection is just a bit earlier than predicted. This way, less time is wasted, where the LMA is already routing packets to the new MAG, and the new MAG is still informing the old MAG that it can disconnect the link,

$$d_{HO} = D_{HO L2} + T_{pred} - RTT_{MAG-LMA} - RTT_{MAG-MAG} / 2 \quad (3)$$

$$\text{for } \begin{cases} T_{pred} \leq RTT_{MAG-MAG} + RTT_{MAG-LMA} \\ T_{pred} > RTT_{MAG-MAG} / 2 + RTT_{MAG-LMA} \end{cases}$$

The handover latency is at its minimum if the old link disconnects prematurely, but the handover has been predicted a bit earlier, so that the new MAG has already sent a binding update to the LMA, and has already received packets from the LMA to forward to the MN, once it connects to one of its APs:

$$d_{HO} = D_{HO L2} \quad (4)$$

$$\text{for } \begin{cases} T_{pred} \leq RTT_{MAG-MAG} / 2 + RTT_{MAG-LMA} \\ T_{pred} > RTT_{MAG-LMA} + RTT_{MAG-MAG} / 2 \\ \quad -(D_{HO L2} - RTT_{MAG-AP}) \end{cases}$$

If the time between prediction and disconnection is even shorter, the handover latency will be increased, because after completion of the L2 handover, the MN has to wait until the new MAG has finished its binding update to the LMA and is receiving data from the LMA:

$$d_{HO} = RTT_{MAG-LMA} + RTT_{MAG-MAG} / 2 + RTT_{MAG-AP} - T_{pred} \quad (5)$$

$$\text{for } \begin{cases} T_{pred} \leq RTT_{MAG-LMA} + RTT_{MAG-MAG} / 2 \\ \quad -(D_{HO L2} - RTT_{MAG-AP}) \\ T_{pred} > RTT_{MAG-LMA} + RTT_{MAG-AP} \\ \quad -RTT_{MAG-MAG} / 2 - D_{HO L2} \end{cases}$$

The latter condition is included in Eq. 5 because if the disconnection occurs really early, just after, or even without prediction, the handover latency is determined by the time that is needed to perform the handover at L2 plus the time needed to request the old MAG to forward data to the new MAG. This results in the following handover latency:

$$d_{HO} = D_{HO L2} + RTT_{MAG-MAG} \quad (6)$$

$$\text{for } \begin{cases} T_{pred} \leq RTT_{MAG-LMA} + RTT_{MAG-AP} \\ \quad -RTT_{MAG-MAG} / 2 - D_{HO L2} \\ T_{pred} \geq 0 \end{cases}$$

Note that the handover latency will result in an additional packet delay. The maximum additional packet delay,  $d_{add}$ , is the difference between the handover latency and the packet loss (period), i.e.,

$$d_{add} = d_{HO} - l_{HO} . \quad (7)$$

If the mobile node has 2 interfaces, packets routed by the LMA towards the new MAG can be forwarded to the MN via the connected second interface right away. Therefore, for the 2 interface case, Eq. (2) – (4) can be replaced by

$$d'_{HO} = \max(0, RTT_{MAG-LMA} + RTT_{MAG-MAG} / 2 + RTT_{MAG-AP} - T_{pred}) \quad (8)$$

for  $T_{pred} > RTT_{MAG-LMA} + RTT_{MAG-AP} - RTT_{MAG-MAG} / 2 - D_{HO L2}$  .

The packet loss due to handover remains the same for the 2 interface case.

Finally, let us determine the handover latency in case a handover is wrongly predicted. If, after installing the binding with the new MAG in the LMA, the MN is not able to connect to an AP of the new MAG, and connects to a different MAG, the handover delay includes the L2 handover delay plus the time needed to either receive data from the LMA, or from the wrongly predicted MAG:

$$d''_{HO} = RTT_{MAG-MAG} / 2 + D_{HO L2} \quad (9)$$

+  $\min(RTT_{MAG-LMA}, 2RTT_{MAG-MAG}) + RTT_{MAG-AP} / 2$  .

Wrong prediction does not lead to additional packet loss. However, packets may experience an additional delay of up to the handover latency.

### 4.3 Numerical results

We will now provide some numerical results for the FPMIPv6 proposal. Values for network parameters are as much as possible taken from [13]. This implies that we take for the L2 handover delay  $D_{HO,L2} = 11$  ms, which was measured in [13]. For the various RTTs, we assume  $RTT_{MAG-LMA} = 30$  ms,  $RTT_{MAG-MAG} = 10$  ms, and  $RTT_{MAG-AP} = 5$  ms.

Fig. 7 shows the results obtained when varying  $T_{pred}$ . Apart from the handover delay and loss for the FPMIPv6 proposal, the same measures for the original PMIPv6 proposal are shown. For PMIPv6, the handover latency is simply the sum of the L2 handover delay and a round trip time between MAG and LMA. The PMIPv6 handover loss period lasts a full RTT between AP and LMA plus the L2 handover delay.

It can be observed from Fig. 7 that the performance of FPMIPv6 depends on the timely prediction of the handover. If the loss of the link to the old AP can be predicted at least 40 ms before the actual loss, the handover latency is limited to 16 ms, whereas packet loss can be avoided. If the handover comes totally unpredicted, the handover latency will be 21 ms, and 5 ms of packets will be lost. These figures are a significant improvement when compared to the 41 ms handover latency and 46 ms of packets lost for handovers in PMIPv6. It should be noted that FPMIPv6 might introduce an additional packet delay of up to 16 ms during handover. This could be compensated for by a play out buffer at the receiver.

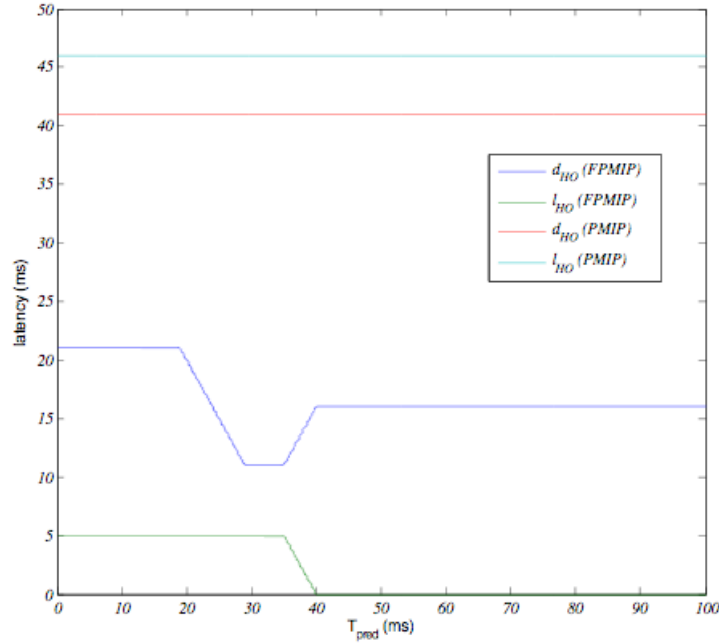


Fig. 7. Handover latency and packet loss

If 2 interfaces are used, performance is even better. If the loss of connection to the old AP is predicted at least 40 ms in advance, no noticeable handover latency and packet loss will be observed. In case a handover is wrongly predicted, the handover latency can be up to 38.5 ms. In order to deal with the additional packet delay, the receiver needs a considerable play-out buffer. Finally, it should be noted that in case of a premature handover, a series of packets might be delivered to the MN out of sequence. This will trigger TCP's fast recovery, but usually only once, as the delayed packets will usually arrive before a retransmitted packet.

## 5 Conclusions and future work

Two important issues when dealing with an IP-level mobility protocol for future wireless networks are (1) to give the network more control over the handover process, and (2) to reduce the handover latency and packet loss, compared to traditional approaches. In this paper we have proposed an extension to Proxy Mobile IPv6, which we have called Fast Proxy Mobile IPv6 (FPMIPv6).

Performance analysis reveals that the handover latency can be reduced to the time needed to perform the handover at layer 2 plus half a round trip time between two neighboring MAGs. Furthermore, if the handover is predicted correctly and timely, the loss of data can be avoided. To that end, handovers should be predicted a few tens of milliseconds in advance. Packets may experience an additional delay of up to the

L2 handover latency plus 1 or 2 round trip times between neighboring MAGs. The latter occurs in case the old MAG wrongly predicts a handover. However, this additional delay may be compensated for with a play-out buffer at the receiver. In case a mobile node is able to establish a new radio link before releasing the old one through the use of multiple (virtual) interfaces, performance can be further improved.

We are currently measuring the performance of FPMIPv6 using a prototype implementation. Future work includes the detailed specification and full implementation of the protocol, a study of layer 2 requirements from the protocol, especially in the presence of multiple interfaces. Finally, the end-to-end performance of the protocol for e.g., VoIP and TCP traffic needs to be investigated.

## References

- 1 3GPP TR 25.912, "Feasibility Study for Evolved UTRA and UTRAN", v7.2.0, June 2007.
- 2 IEEE 802.11, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", 1999.
- 3 3GPP TR 23.882, "3GPP System Architecture Evolution: Report on Technical Options and Conclusions", release 7, v1.11.0, July 2007.
- 4 Mobile IT Forum 4G mobile system requirements document (ver. 1.1), retrieved on 28/09/2007 from [http://www.mitf.org/public\\_e/archives/4G\\_req\\_v110E.pdf](http://www.mitf.org/public_e/archives/4G_req_v110E.pdf).
- 5 S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, B. Patil, Proxy Mobile IPv6, IETF NETLMM WG Internet-draft, draft-ietf-netlmm-proxymip6-06, September 23, 2007.
- 6 IETF RFC 4068, "Fast Handovers for Mobile IPv6", July 2005.
- 7 IETF RFC 3775, "Mobility Support in IPv6", June 2004.
- 8 IETF RFC 4140, "Hierarchical Mobile IPv6 Mobility Management (HMIPv6)", August 2005.
- 9 S. Park, J.E. Lee, J. Choi, Y. Kim, "Fast Localized Proxy Mobile IPv6 (FLPMIPv6)", IETF Internet-draft draft-park-netlmm-fastpmip-00, February 26, 2007.
- 10 F. Xia, B. Sarikaya, "Mobile Node Agnostic Fast Handovers for Proxy Mobile IPv6", IETF Internet-draft draft-xia-netlmm-fmip-mnagno-01, July 5, 2007.
- 11 T.-H. Kim, Q. Yang, J.-H. Lee, S.-G. Park, Y.-S. Shin, "A Mobility Management Technique with Simple Handover Prediction for 3G LTE Systems", in Proceedings of the 66<sup>th</sup> IEEE Vehicular Technology Conference, VTC-2007 Fall, September 30 – October 3, 2007.
- 12 R. Chandra, P. Bahl, and P. Bahl, "MultiNet: Connecting to multiple IEEE 802.11 networks using a single wireless card", in Proceedings of IEEE INFOCOM, 2004.
- 13 J. Laganier, M. Flege, A. Zugenmaier, A. Prasad, J., Kempf, J. Wood, "Travelling without Moving: 802.11 Access Points backed by Secure NETLMM", in Proceedings of 16th International Conference on Computer Communications and Networks 2007, ICCCN 2007, August 13-16, 2007.