A MIPv6, FMIPv6 and HMIPv6 handover latency study: analytical approach

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ABSTRACT

Enhancement of basic Mobile IPv6 as IP based mobility management with respect to handover latency it's being studied within the framework of the EU IST project Moby Dick. This analytical study compares the handover latency of different IP mobility management schemes, considering the different approaches and combinations of them, as currently discussed within the IETF: basic MIPv6, FMIPv6 as support for fast handover and HMIPv6 as an approach allowing hierarchies of mobility agents. This study has been performed to assess the most appropriate approach for the functional specification and the implementation, specially with respect to the implementation for the project's field trial.

I. INTRODUCTION

The IST project Moby Dick [1] will define, implement, and evaluate an IPv6-based mobility-enabled end-to-end QoS architecture starting from the current IETF models for: QoS, IP based mobility management and AAA. In this framework, the deployed IPv6 mobility management is of significant importance, in order to provide uninterrupted real-time services to the user (e.g., VoIP or real time video streaming) and at the same time combine QoS and AAA to offer a secure and QoS-enabled mobility. This combination constitute the main challenge in the Moby Dick project.

This paper provides an analytical study, comparing the handover latency of different IPv6 mobility management proposals, which are currently discussed within the IETF: MIPv6 [2], FMIPv6 [3] and HMIPv6 [4]. While the basic Mobile IPv6 enables mobility in the IPv6 protocol stack, the extensions FMIP and HMIP are enhancements that help to speed up the handover latency and provide uninterrupted services for roaming users.

This analytical study about the handover latency comparison of the different approaches and combinations of them provides the basis for the functional specification within the Moby Dick project. The decision for the implementation of the IPv6 mobility management scheme in the project's field trial is based on the results of this analysis.

II. BACKGROUND

This section provides a brief overview of the differences to be taken in account when considering the different approaches to compute the handover latency. We assume a basic previous knowledge of the different drafts.

A. Basic Mobile IPv6

The latency due to a handover using basic MIPv6 is directly proportional to the minimum round-trip time necessary for a binding update (BU) to reach either the home agent (HA), the correspondent node (CN) or the previous access router (PAR) in case forwarding from PAR is allowed. The interruption time starts in the moment that the mobile node (MN) does not listen to the PAR anymore and finishes when the first packet arrives via the new route either from the HA, CN or PAR. For more details see [2].

B. Fast Mobile IPv6 (Anticipated FMIPv6)

Using anticipated FMIPv6 the handover is prepared in advance. Assuming we receive the fast binding acknowledgement (F-BAck) via the PAR, i.e, the overlapping area is designed considering the mobile speed to make it possible, and then we perform the handover, the latency will be proportional to the difference between receiving the F-BAck and the reception of the first packet forwarded to the new access router (nAR). For more details please refer to [3].

C. Hierarchical Mobile IPv6 (HMIPv6)

The handover latency in this case is the same as in the case of MIPv6 but instead of proportional to the minimum round-trip time between the MN and the HA or the CN or the previous AR, if forwarding from previous access router is enabled, it is proportional to the round-trip time between the MN and the mobility anchor point (MAP) or the previous AR. Please refer to [4] for details.

D. Anticipated FMIPv6+HMIPv6

The combination of both approaches introduce the difference of sending the fast binding update (F-BU) to the MAP instead of to the PAR. This means that the proxy router advertisement (PrRtAdv) and the handover initiate (HI) cannot be sent at the same time. The introduction of the hierarchy results in the forwarding performed by the MAP; in case of a symmetric topology this will result in an advantage, as we will see later. See details in [3] and [4].

III. STUDIED SCENARIO

This chapter introduces the scenario used for the study and presents the parameters and assumptions chosen in order to perform the analysis.

A. Scenario

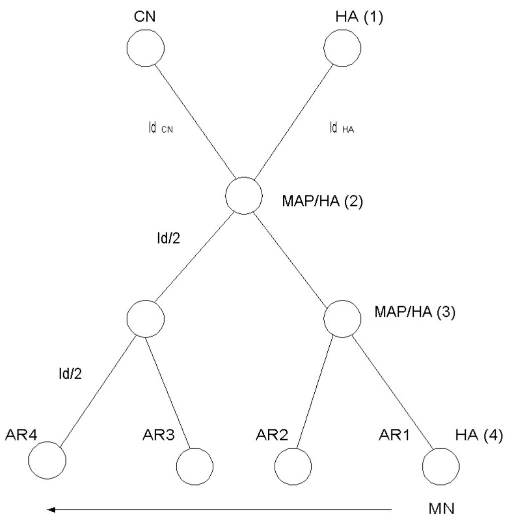

Figure 1. Studied scenario

In figure 1 we can observe the considered scenario. The scenario presents a hierachical topology. We assume a mobile node (MN) initially located in AR1 that moves from AR1 to AR4. The MN receives data packets sent by the correspondent node (CN). The study will cover the cases of the home agent (HA) located in 1), 2), 3) or 4). When HMIPv6 is considered we study two possible locations for the mobility anchor point (MAP): 2) or 3). The wired link delays are referred as 'ld'.

B. Assumptions

The handover latency will be analysed considering the mobile node initiated handover case. HMIPv6 and FMIPv6 studies are based on draft versions 05 and 04, respectively. For the care-of-address (*coa*) configuration we consider stateless address autoconfiguration, without DAD, relying on the uniqueness of the identifier of the cards or assuming that a unique identifier can be build [5]. We assume that the processing delays are negligible compared to access to the channel and transmission delays. For the wireless delay we assume the same value for the uplink and dowlink case.

IV. HANDOVER LATENCY STUDY

A. Basic Mobile IPv6

In order to compute the handover latency we have to consider the latency introduced by the wireless and the wired part. For example, considering the case where the HA, in our scenario, is in 1), the latency would be the time required to send the BU through the wireless medium, plus the time required by the BU to reach the closer entity (HA, CN or PAR) who has a packet for the MN, plus the time required by the forwarded packet to arrive to the current AR and plus the delay introduced by the wireless part to send the packet to the MN.

Handover latency performing a handover from AR1 to AR2:

- AR1->AR2

In case that the HA is located in:

1) $\#BU_{MIPv6} \cdot Wd + 2\,(ld + \min(ld_{HA}^{*}, ld_{CN}, 0^{*})) + Wd$ (1)
2)4) $\#BU_{MIPv6} \cdot Wd + 2 \cdot ld + Wd$ (2)
3) $\#BU_{MIPv6} \cdot Wd + ld + Wd$ (3)

where $\#BU_{MIPV6}$ corresponds to the number of BU sent. It can be two or three depending on whether previous access router forwarding is allowed or not. We have chosen the worst case where the minimum round-trip time corresponds to the last BU since there is no sending order indication in MIPv6. *Wd* symbolizes the delay introduced by the wireless part.

- AR2->AR3

1) $\#BU_{MIPv6} \cdot Wd + 2\,(ld + \min(ld_{HA}^{*}, ld_{CN}, ld^{*})) + Wd$ (4)
2) $\#BU_{MIPv6} \cdot Wd + 2 \cdot ld + Wd$ (5)
3) $\#BU_{MIPv6} \cdot Wd + 2\,(ld + \min(ld/2^{*}, ld_{CN}, ld^{*}) + Wd$ (6)
4) $\#BU_{MIPv6} \cdot Wd + 2\,(ld + \min(ld^{*}, ld_{CN}, ld^{*}) + Wd = \#BU_{MIPv6} \cdot Wd + 2\,(ld + \min(ld, ld_{CN}) + Wd$ (7)

(*) The latency is proportional to the round-trip time corresponding to the first packet received in the new link. Since the packets are sent by the CN either to the HA or to the PAR, depending on whether the entry in the binding cache for the old *coa* has expired or not, either the HA or the PAR receives the packets from the CN. Considering that forwarding from previous access router is allowed, the latency will be proportional to the minimum round-trip time between the MN and CN or HA if the binding cache entry has expired, or between the MN and CN or PAR if it has not expired.

B. Hierarchical MIPv6

The purpose of HMIPv6 is to reduce the amount of signaling to CNs and the HA and in some cases improve the performance of MIPv6 handovers. Therefore, the introduction of a hierarchy only makes sense if the MAP is located between the MN location and HA and CN locations. The numbers 2)3) correspond to MAP's position. Case 4) is not considered since then there is no hierarchy. In case 2) the cases of the location of the HA in 1) and 2) are covered. In case 3) the cases of the location of the HA in 1) and 2) and 3) are covered. The number of BU sent in HMIPv6 ($\#BU_{HMIPv6}$) is 1 or 2 depending on whether previous access router forwarding is allowed or not.

- AR1->AR2

2) $\#BU_{HMIPv6} \cdot Wd + 2 \cdot \min(ld^*, ld^*) + Wd = (\#BU_{HMIPv6}+1)Wd + 2 \cdot ld$ (8)
3) $(\#BU_{HMIPv6}+1)Wd + ld$ (9)

- AR2->AR3

2) $(\#BU_{HMIPv6}+1)Wd + 2 \cdot ld$ (10)
3) $(\#BU_{HMIPv6}+1) \cdot Wd + 2\,(ld + \min(ld_{HA}^*, ld_{CN}, ld/2^*)) + Wd$ (11)

C. Anticipated FMIPv6

Considering the reception of the F-BAck as the latency starting point and keeping in mind that the PAR starts to forward the packets to the new AR immediately after sending the F-BAck we obtain the following results:

- AR1->AR2

1)2)3)4) $|\, ld - Wd \,| \pm Wd + Wd$ (12)

The first Wd corresponds to the F-BAck, $\pm$ Wd to the F-NA and the third to the first packet received in the new link.

- AR2->AR3

1)2)3)4) $|\, 2ld - Wd \,| \pm Wd + Wd$ (13)

D. Hierarchical MIPv6+Anticipated FMIPv6

Assuming as in the case of Ant.FMIPv6 that the overlapping area is big enough to receive the F-BAck via the PAR and recalling that the F-BU is sent to the MAP, which is the forwarding entity, we obtain the following results:

- AR1->AR2

1)2)3) $Wd + Wd = 2 \cdot Wd$ (14)

The first Wd corresponds to the F-NA and the second to the first packet received in the new link.

- AR2->AR3

1)2) $2 \cdot Wd$ (15)
3) $|\, ld - Wd \,| \pm Wd + Wd$ (16)

Where the first Wd corresponds to the F-BAck.

The fact of waiting for the F-BAck via the old AR synchronizes the handover with the moment when the packets arrive to the new AR. This means that in case of having a symmetric path, in delay terms, between the MAP and the old and new AR, the wired latency part would be removed if the overlapping area allows us to wait for the F-BAck. This is very important since only with FMIPv6 we don't have any indication on which is the best moment to perform the handover, when can we expect that a forwarded packet waits in the new AR.

V. COMPARISON

A. Basic Mobile IPv6 – HMIPv6

Considering that the values of $\#BU_{MIPv6}$ and $\#BU_{HMIPv6}$ are comprised between 2 and 3, and 1 and 2, respectively, the result of ($\#BU_{MIPv6} - \#BU_{HMIPv6}$) = 1 for all cases.

- AR1->AR2

1) $Wd + 2 \cdot \min(ld_{HA}^*, ld_{CN}, 0^*)$ (17)
2)3) Wd (18)

- AR2->AR3

1) $Wd + 2 \cdot \min(ld_{HA}^*, ld_{CN}, ld^*)$ (19)
2) Wd (20)
3) $-Wd + 2\,((\min(ld/2^*, ld_{CN}, ld^*) - \min(ld_{HA}^*, ld_{CN}, ld/2^*))$ (21)

If we assume that the wired part introduces a much bigger delay compared to the wireless one:

- Assuming $ld >> Wd$
  - AR1->AR2
    1) $2 \cdot \min(ld_{HA}^*, ld_{CN}, 0^*)$ (22)
    2)3) 0 (23)
  - AR2->AR3
    1) $2 \cdot \min(ld_{HA}^*, ld_{CN}, ld^*)$ (24)
    2) 0 (25)
    3) $2\,((\min(ld/2^*, ld_{CN}, ld^*) - \min(ld_{HA}^*, ld_{CN}, ld/2^*))$ (26)
- Assuming $ld << Wd$
  - AR1->AR2
    1)2)3) Wd (27)
  - AR2->AR3
    1)2) Wd (28)
    3) –Wd (29)

As we can see, all the results are equal or bigger than 0, except in one case. HMIPv6 then, assures an equal or better performance, referring to handover latency, than basic MIPv6 for most of the cases.

B. Basic MIPv6 – Anticipated FMIPv6

- AR1->AR2

1) $\#BU_{MIPv6}\cdot Wd + 2(ld+\min(ld_{HA}^{*},ld_{CN}, 0^{*}))$ – ($|ld - Wd \pm Wd$) (30)
2)4) $\#BU_{MIPv6}\cdot Wd + 2\cdot ld$ – ($|ld - Wd| \pm Wd$) (31)
3) $\#BU_{MIPv6}\cdot Wd + ld$ – ($|ld - Wd| \pm Wd$) (32)

- AR2->AR3

1) $\#BU_{MIPv6}\cdot Wd + 2 \cdot\min(ld_{HA}^{*},ld_{CN}, ld^{*})$ – ($|2\cdot ld - Wd| \pm Wd$) (33)
2) $\#BU_{MIPv6}\cdot Wd + 2\cdot ld$ – ($|2\cdot ld - Wd| \pm Wd$) (34)
3) $\#BU_{MIPv6}\cdot Wd + 2(ld + \min(ld/2^{*}, ld_{CN}, ld^{*}))$ – ($|2\cdot ld - Wd| \pm Wd$) (35)
4) $\#BU_{MIPv6}\cdot Wd + 2(ld + \min(ld, ld_{CN}))$ – ($|2\cdot ld - Wd| \pm Wd$) (36)

- Assuming ld >> Wd
  - AR1->AR2
    1) $ld + 2\cdot\min(ld_{HA}^{*},ld_{CN}, 0^{*})$ (37)
    2)4) ld (38)
    3) 0 (39)
  - AR2->AR3
    1) $2 \cdot\min(ld_{HA}^{*},ld_{CN}, ld^{*})$ (40)
    2) 0 (41)
    3) $2 \cdot\min(ld/2^{*},ld_{CN}, ld^{*})$ (42)
    4) $2 \cdot\min(ld, ld_{CN})$ (43)

- Assuming ld << Wd
  - AR1->AR2
  - AR2->AR3
    $(\#BU_{MIPv6}-2)Wd \geq 0$ (44)
    for all $\#BU_{MIPv6}$ cases

As in the case of HMIPv6 we have an equal or better handover latency performance of Ant.FMIPv6 for all cases.

C. Basic MIPv6 – (Anticipated FMIPv6+HMIPv6)

- AR1->AR2

1) $(\#BU_{MIPv6}-1)Wd + 2(ld + \min(ld_{HA}^{*},ld_{CN}, 0^{*}))$ (45)
2) $(\#BU_{MIPv6}-1)Wd + 2\cdot ld$ (46)
3) $(\#BU_{MIPv6}-1)Wd + ld$ (47)

- AR2->AR3

1) $(\#BU_{MIPv6}-1)Wd + 2(ld + \min(ld_{HA}^{*},ld_{CN}, ld^{*}))$ (48)
2) $(\#BU_{MIPv6}-1)Wd + 2\cdot ld$ (49)
3) $\#BU_{MIPv6}\cdot Wd + 2(ld + \min(ld/2^{*},ld_{CN}, ld^{*}))$ – ($|ld - Wd| \pm Wd$) (50)

- Assuming ld >> Wd
  - AR1->AR2
    1) $2(ld + \min(ld_{HA}^{*},ld_{CN}, 0^{*}))$ (51)
    2) $2\cdot ld$ (52)
    3) ld (53)
  - AR2->AR3
    1) $2(ld + \min(ld_{HA}^{*},ld_{CN}, ld^{*}))$ (54)
    2) $2\cdot ld$ (55)
    3) $ld + 2\cdot\min(ld/2^{*},ld_{CN})$ (56)

- Assuming ld << Wd
  - AR1->AR2
  - AR2->AR3
    1)2)3) $(\#BU_{MIPv6}-1)Wd$ (57)

All the previous approaches present a better handover latency performance than basic MIPv6.

D. Anticipated FMIPv6 – HMIPv6

- Assuming ld >> Wd
  - AR1->AR2
    1)2) – ld (58)
    3) 0 (59)
  - AR2->AR3
    1)2) 0 (60)
    3) $-2\cdot\min(ld_{HA}^{*},ld_{CN}, ld/2^{*}))$ (61)

Under ld >> Wd assumption Ant.FMIPv6 assures equal or better performance than HMIPv6.

- Assuming ld << Wd
  - AR1->AR2
    1)2)3) $(3 - \#BU_{HMIPv6})Wd$ (62)
    value > 0 for all $\#BU_{HMIPv6}$ cases
  - AR2->AR3
    1)2) $(3 - \#BU_{HMIPv6})Wd$ (63)
    3) $(2 - \#BU_{MIPv6})Wd$ (64)

On the other hand, for ld << Wd , HMIPv6 assures equal or better performance than Ant.FMIPv6.

E. Antic. FMIPv6–(HMIPv6+Antic. FMIPv6)

- AR1->AR2

1)2)3) $|ld - Wd| \pm Wd - Wd$ (65)

- AR2->AR3

1)2) $|2\cdot ld - Wd| \pm Wd - Wd$ (66)
3) $|2\cdot ld - Wd| - |ld - Wd|$ (67)

- Assuming ld >> Wd
  - AR1->AR2
    1)2)3) ld (68)

- AR2->AR3
  1)2) $2 \cdot ld$ (69)
  3) ld (70)

- Assuming $ld << Wd$

  - AR1->AR2
    1)2)3) Wd (71)

  - AR2->AR3
    1)2) Wd (72)
    3) 0 (73)

It is important to observe that the introduction of HMIPv6 added to Ant.FMIPv6 assures an equal or better performance than Ant.FMIPv6 for all cases in latency terms.

F. HMIPv6 – (HMIPv6+ Anticipated FMIPv6)

- AR1->AR2

1)2) $(\#BU_{HMIPv6} - 1)Wd + 2 \cdot ld$ (74)
3) $(\#BU_{HMIPv6} - 1)Wd + ld$ (75)

- AR2->AR3

1)2) $(\#BU_{HMIPv6} - 1)Wd + 2 \cdot ld$ (76)
3) $(\#BU_{MIPv6} + 1 - (\pm) 1)Wd + 2 \cdot (ld + \min(ld_{HA}^{*}, ld_{CN}, ld/2^{*})) - | ld - Wd |$ (77)

- Assuming $ld >> Wd$

  - AR1->AR2
    1)2) $2 \cdot ld$ (78)
    3) ld (79)

  - AR2->AR3
    1)2) $2 \cdot ld$ (80)
    3) $ld + 2 \cdot \min(ld_{HA}^{*}, ld_{CN}, ld/2^{*})$ (81)

- Assuming $ld << Wd$

  - AR1->AR2
    1)2)3) $(\#BU_{HMIPv6} - 1)Wd$ (82)
    value ≥ 0 for all cases

  - AR2->AR3
    1)2) $(\#BU_{HMIPv6} - 1)Wd$ (83)
    value ≥ 0 for all cases
    3) $(\#BU_{MIPv6} - 1)Wd$ (84)

As we can see in the last case of $ld << Wd$ we could obtain a negative value, that means that in this case HMIPv6 would perform better than the combination of HMIPv6 and Anticipated FMIPv6. The reason is that due to the F-NA we get the security of no packet losses but we increase in one *Wd* the necessary signaling messaging. For all the other cases the combination of Ant.FMIPv6 and HMIPv6 performs better than HMIPv6 in latency terms.

VI. SUMMARY AND OBSERVATIONS

The following table compares the improvements introduced by the different approaches compared to basic MIPv6 in handover latency terms. We have taken the values corresponding to the case of having the HA in position 1) and considering an AR1 to AR2 handover. The values are compared for the case of a wired link delay much bigger compared to the wireless one ($ld >> Wd$) and for a wireless link delay much bigger compared to the wired one.

Basic MIPv6 handover latency compared to	HMIPv6	Anticipated FMIPv6	HMIPv6+ FMIPv6
$ld >> Wd$	$2 \cdot \min(ld_{HA}^{*}, ld_{CN}, 0^{*})$	$ld + 2 \cdot \min(ld_{HA}^{*}, ld_{CN}, 0^{*})$	$2 (ld + \min(ld_{HA}^{*}, ld_{CN}, ld^{*}))$
$ld << Wd$	Wd	$(\#BU_{MIPv6} - 2)Wd$	$(\#BU_{MIPv6} - 1) Wd$

Table 1. Comparison of handover latency values for different approaches.

A higher value in the table means a bigger saved difference in the handover latency with this approach compared to basic MIPv6. A priori it's surprising that HMIPv6 performs equal or better in the $ld<<Wd$ case than Ant.FMIPv6. However, this is due to the signaling packet (F-NA) that in Ant.MIPv6 is sent in order to inform the new AR that the transmission of packets can start. Therefore, packet losses are avoided in Ant.FMIPv6 providing a more seamless-like kind of handover but the price is an increase in the handover latency.

HMIPv6 was designed to reduce the signaling to CNs and the HA but it can also help to reduce the latency, as we have seen. The combination of HMIPv6 and Anticipated FMIPv6 presents the property of helping in the decision of the best moment to perform the handover plus the improvements that both add to basic MIPv6. The fact of waiting via the old AR for a signaling message (F-BAck) to perform the handover synchronizes the handover with the moment when the packets arrive to the new AR. This means that in case of having a symmetric path, in delay terms, between the forwarding point (MAP) and the old and new AR, the wired latency part would be removed. This is very important since only with Ant.FMIPv6 we don't have any indication on which is the best moment to perform the handover, when can we expect that a forwarded packet waits in the new AR.

As a conclusion, after analysing the results of this study, we can conclude that if only one option between HMIPv6 and Anticipated FMIPv6 should be implemented then the best option, considering handover latency and packet losses, would be Anticipated FMIPv6. However, using both together has proved to outperform, in latency terms, both approaches alone.Therefore, the best option in order to get the better performance would be to implement both HMIPv6 and Ant.FMIPv6. This would improve the signaling load, latency, packet losses and help in the handover decision. The following table summarizes the previous recommendations:

	HMIPv6 + FMIPv6	**Anticipated FMIPv6**	**HMIPv6**
Final reommendation	1	2	3

Table 2. Recommendation for the test-bed implementation.

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