Analytical method for L3 handover latency evaluation

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Abstract—Recent years in the field of mobile communications have brought two significant requirements – seamless service delivery and Quality of Service provisioning. Since seamless mobility goes hand in hand with Mobile IPv6 protocol and since various handover schemes of this protocol are trying to solve the QoS issue, there is a need for comparison of such handover schemes. In this paper we are presenting a method for evaluation of the Layer 3 handover schemes from the handover latency point of view. We are also providing results of this comparison for four most common handover schemes of Mobile IPv6 (MIPv6, FMIPv6, HMIPv6 and F-HMIPv6). However, the method is applicable to any other current or future handover scheme.

Keywords—analysis, evaluation, FMIPv6, F-HMIPv6, handover latency, HMIPv6, MIPv6, mobility

I. INTRODUCTION

In wireless networks based on IPv6 protocol (including user mobility support – Mobile IPv6 protocol) one of the major factors influencing the Quality of Service is, among others, the end-to-end delay. From the IP mobility point of view a big impact on keeping the end-to-end delay within acceptable boundaries during L3 handover has the choice of the handover scheme. The L3 handover brings to the communication additional overhead (handover cost) and delay (handover latency). Each handover scheme (e.g. MIPv6, FMIPv6, HMIPv6, and F-HMIPv6) provides a different trade-off between cost and latency. The cost of L3 handovers we have analyzed in [5]. In this paper we are presenting an analytical method for L3 handover latency evaluation. Results obtained by analytical comparing of existing or future handover schemes build an essential cornerstone for implementation of IP mobility to network solutions.

A good example of an application where the delay in communication is extremely critical would be the data-link communication between aircraft and ground Air Traffic Management (ATM) systems. During the design process of ATN/IPS technology by International Civil Aviation Organization (ICAO) [6] a validation of using MIPv6 and PMIPv6 for IP mobility was performed by actual implementation of these technologies in a real network. This is quite an inefficient way. By using an analytical method that we are proposing in this paper, the validation process would be much more efficient.

Currently, a research in the field of air-ground IP communication between an aircraft and ground ATM facilities in Europe is being done by SESAR (Single European Sky ATM Research) program. We assume our method to contribute to an efficient evaluation of handover schemes mainly in SESAR project 15.2.4, which is dealing with future mobile data link system definition.

II. MOBILE IPv6 BACKGROUND

A. General principles

The Mobile IPv6 protocol (MIPv6) is a layer 3 protocol that allows mobile services users (mobile nodes) to stay reachable independently on the mobile node’s movement in the IP environment. Without the mobility support in IPv6 protocol, the traffic destined to the mobile node could not be delivered as far as the mobile node was situated out of its home network. For keeping its connectivity in such case the mobile node would need to acquire a new IP address every time it changed its location. However, this would lead to breaking all transport and higher layer connections.

The Mobile IP protocol allows the mobile node (MN) to move among various subnets without changing its home address (HoA). This protocol makes this movement absolutely transparent to higher layers and packets destined to this node can routed through the network regardless its current location.

In Mobile IPv6 protocol, quite many handover schemes already exist. Four of these schemes may be considered as the core L3 handover schemes – classical Mobile IPv6 (MIPv6) [1], Fast handovers for Mobile IPv6 (FMIPv6) [2], Hierarchical Mobile IPv6 (HMIPv6) [3] and Fast handovers for Hierarchical Mobile IPv6 (F-HMIPv6) [4]. Since description of the schemes is out of scope of the paper, only a timing diagram of F-HMIPv6 scheme (the most complex one) will be presented for illustration purposes further on. Detailed information to Mobile IPv6 and all the handover schemes may be found in [1], [2], [3], [4].

B. F-HMIPv6 Fundamentals

For illustration we introduce a representative of the core Mobile IPv6 handover schemes. The Fast handovers for Hierarchical Mobile IPv6 handover scheme is a combination of two other handovers schemes, also previously mentioned –
FMIPv6 and HMIPv6. It makes use of the positive aspects of both schemes. The FMIPv6 scheme ensures a low latency of the handover by triggering the handover procedure before the mobile node loses connection with the current network (by utilizing information from layer 2). On the other hand, HMIPv6 reduces the signaling traffic of binding update by introducing some sort of local Home Agent (HA), called Mobility Anchor Point (MAP) and grouping subnetworks into clusters (MAP domains), each controlled by a single MAP. A typical network structure supporting MIPV6 protocol with F-HMIPv6 handover scheme is presented in Fig. 1.

To clarify the signaling procedures taking place in the F-HMIPv6 handover scheme, a timing diagram for inter-MAP handover is presented in the Fig. 2 and for intra-MAP handover in Fig. 3.

Fig. 1 Network structure supporting MIPV6 protocol with F-HMIPv6 handover scheme

Fig. 2 Timing diagram for intra-MAP handover in F-HMIPv6

Fig. 3 Timing diagram for inter-MAP handover in F-HMIPv6

III. LAYER 3 HANDOVER LATENCY

A. Method design

Handover latency is defined as a time interval between last reception of data on the current CoA and the moment when MN starts receiving packets at the new point of attachment. As handover latency we may consider a sum all particular delay intervals on L2 and L3 in the protocol stack which the mobile node experiences during both types of handover. It is obvious, that handover mechanisms on the link layer (L2) as well as the delay caused by these mechanisms do not have any impact on the Layer 3 handover mechanisms. For this reason, the Layer 2 handover time interval $t_{L2}$ (see Fig. 4) will not be further examined and will be considered as a constant for a given technology (see Table 1). Instead, the analysis focuses on the remaining time interval in Fig. XY - $t_{IP}$ (resp. $t_{FastIP}$ and $t_{U}$ (resp. $t_{intray}$) – which have a direct impact on the operation of Mobile IPv6.

Fig. 4 shows the sequence of signaling messages for all considered handover schemes in terms of their request-response time intervals. This figure, in case of F-HMIPv6, matches with Fig. 2 and Fig. 3, for example.

Values of each time interval in Fig. 4 depend on the delay that each signaling message experiences when being carried between its source and destination. According to [7] this delay is composed of a transmission delay and a link delay. For a message of size $S$ being carried on a wired link with bandwidth $BW_{Wired}$ and link delay $l_{Wired}$ between nodes X and Y we can write:

$$t_{X,Y}(S) = d_{XY} \cdot \left( \frac{S}{BW_{Wired}} + l_{Wired} + D_{Router} \right), \tag{1}$$

where $d_{XY}$ is number of hops between X and Y and $D_{Router}$ is a processing delay of each router on the way.
In case we consider one of the end nodes to be the wireless mobile node, we may reformulate the Equation (1) as:

\[
t_{MN,X}(S) = \left( \frac{s}{BW_{Wireless}} + l_{Wireless} \right) + (d_{MN,X} - 1) - \left( \frac{s}{BW_{Wired}} + l_{Wired} + D_{Router} \right),
\]

where \(BW_{Wireless}\) is a bandwidth of a wireless link and \(l_{Wireless}\) is the link delay. Hence we can see that the transport delay of a message travelling form a wireless mobile node to a wired end node depends mainly on the size of the message, on the bandwidth of both wireless and wired link, their link delay, on the number of hops the message performs on its way and on the processing delay of each router between two hops.

![Fig. 4 Time diagrams of MIPv6 handover schemes](image)

Fig. 4 Time diagrams of MIPv6 handover schemes

Based on the equation (2) we can analyze a transport delay of each particular signaling message in a given mobility scheme. The following text presents equations for analytical computation of handover latency. For hierarchical handover schemes we differentiate the latency for intra-MAP and inter-MAP handovers. For other schemes, we consider just one kind of handover.

B. MIPv6

For computation of handover latency of basic MIPv6 handover scheme we apply the equation (2) on each signaling message involved in the handover (see Fig. 4 and Fig. 5):

\[
D_{MIPv6} = t_{L2} + t_{RD} + t_{DAD} + (t_{MN,HA} + t_{MN,CN})_{BU} + (t_{HA,MN} + t_{CN,MN})_{BACK} + t_{RR},
\]

where \(t_{L2}\) is a latency of L2 handover, \(t_{RD}\) is a delay of Router Discovery procedure, \(t_{DAD}\) is a delay of Duplicate Address Detection, \(t_{RR}\) is a delay of Return Routability procedure, \(t_{MN,HA}_{BU}\) is a time interval for a Binding Update to get from MN to HA, etc. Equations for computation of \(t_{RD}\), \(t_{DAD}\) and \(t_{RR}\) are presented in the following sections.

C. FMIPv6

Analogically to basic MIPv6 handover scheme (Equation (2)) we can write an expression for latency of FMIPv6 handover scheme as follows:

\[
D_{FMIPv6} = t_{L2} + (t_{MN,NAR})_{FBU} + (t_{MN,HA} + t_{MN,CN})_{BU} + t_{HA}, MN+t_{CN,MN},_{NAR} + t_{RR}.
\]

D. HMIPv6

For hierarchical handover schemes the computation of handover latency is a little more complicated, since these schemes define two kinds of handovers – an intra-MAP handover and an inter-MAP handover. For the former one the mobile node stays in coverage of the same MAP, for the latter one the mobile node roams from one MAP to another.
We can compute the handover latency as follows:

\[ D^\text{HMIPv6}_{\text{INTRA}} = t_L + \frac{t_{RD}}{2} + t_{DAD} + (t_{MN,MAP})_{BU} + (t_{MAP,MN})_{L_B} + (t_{MAP,MAP})_{L_B} \quad (6) \]

\[ D^\text{HMIPv6}_{\text{INTER}} = D^\text{HMIPv6}_{\text{INTRA}} + (t_{MN,HA} + t_{MN,CN})_{BU} + (t_{HAMN} + t_{CN,MN})_{BU} + t_{RR} \quad (7) \]

The inter-MAP handover is basically composed of an intra-MAP-like handover, in which the mobile node makes a new binding with a new MAP, and a MIPv6-like handover, where the mobile nodes sends a binding update to its home agent and correspondent nodes.

E. F-HMIPv6

Fast handovers for hierarchical mobile IPv6 belongs, like HMIPv6, to hierarchical handovers family, and therefore we also need to compute both the intra-MAP handover delay, and inter-MAP handover delay:

\[ D^\text{F-HMIPv6}_{\text{INTRA}} = t_L + (t_{MN,NAR})_{RS} + (t_{MN,NAR})_{RA} + D_{RD} \quad (8) \]

\[ D^\text{F-HMIPv6}_{\text{INTER}} = D^\text{F-HMIPv6}_{\text{INTRA}} + (t_{MN,HA} + t_{MN,CN})_{BU} + (t_{HAMN} + t_{CN,MN})_{BU} + t_{RR} \quad (9) \]

F. Router Discovery and Duplicate Address Detection

For successful computation of previously mentioned handover delay we yet need to define the time intervals of RD and DAD.

For Router Discovery we can write:

\[ t_{RD} = (t_{MN,NAR})_{RS} + (t_{NAR,MN})_{RA} + D_{RD} \quad (10) \]

where \( D_{RD} \) is a processing time of NAR for router discovery procedure.

Similarly, for Duplicate Address Detection:

\[ t_{DAD} = (t_{MN,NAR})_{RS} + (t_{NAR,MN})_{NA} + D_{DAD} \quad (11) \]

where \( D_{DAD} \) is a processing time of NAR for duplicate address detection procedure.

G. Return Routability

The last time interval that has left to be defined is the time of return routability procedure. This procedure is used for securing binding updates between the mobile node and correspondent node in case the route optimization is enabled. The procedure consists of four signaling message, as depicted in Fig. 3. Please refer to [1] for more details. The return routability time interval is than defined as:

\[ t_{RR} = (t_{MN,HA} + t_{HACN})_{HOT1} + (t_{MN,CN})_{CAC1} + (t_{CN,HA} + t_{HAMN})_{HOT1} + (t_{CN,MN})_{CAC1} \quad (12) \]

IV. HANDOVER SCHEMES COMPARISON

A. Assumptions

For comparing handover latency we use the network topology which is depicted in Fig. 6, that was already presented in a paper dealing with handover cost analysis in [5].

It is assumed the access network is based on IEEE 802.11b and the transport (core) network is Ethernet – IEEE 802.3 100BaseT. The respective parameters of the networks are stated in Table 2.

![Network topology used for handover scheme analysis](image)

B. Numerical results

For numerical computation of previously presented handover delays we used values showed in Table 1 and Table...
2. Table 2 shows sizes of all signaling messages involved in the process of handover for all mentioned handover schemes, i.e. MIPv6, FMIPv6, HMIPv6 and F-HMIPv6. We took into account the values that include IPv6 header. Table 1 presents nominal values of variables that were used for the actual comparison of handover schemes.

As an output of the handover latency analysis we are presenting some of the graphs that we may get after application of the framework on real numbers.

The following graph in Fig. 7 shows the overall results for all previously considered handover schemes. The input values for the equations behind this graph are the ones stated in Table 1 and Table 2. From the graph we can read that the best results are achieved by the “fast” handover schemes, i.e. FMIPv6 and F-HMIPv6. This is quite obvious since these schemes were designed to make the handover period as short as possible. But what else we can read in the graph is, that these handover schemes are (in this network constellation) also usable for highly delay-sensitive applications like VoIP, which requires the overall latency not to exceed 150-200 ms.

What needs to be stressed is, that we were counting with L2 handover latency to be 100 ms. So if we subtract this value from the overall latency in Fig. 7 we get the pure L3 handover latency value.

The next graph, in we received by sweeping $l_{\text{Wireless}}$ from 2 to 400 ms. The rest of the parameters remain fixed. In the figure we show just the most interesting part – form 2 to 100 ms.

The link delay of the wireless link tends to be changing during the operation of mobile node so it is important to observe the reaction of handover schemes to this variation. It could be expectable, that handover latency will grow linearly with growing $l_{\text{Wireless}}$ for all schemes. But it may be important to observe how sever the change is. Each scheme provides a certain trade-off between the latency and signaling overhead (see [5]). When selecting a handover scheme for our application we may, based on this kind of results, choose the best solution.

To make the difference between the schemes more visible we combined the intra-MAP and inter-MAP handovers together with a predefined intra-MAP/inter-MAP ratio (see Fig. 9).
We can observe a very interesting phenomenon here – since the link delay crosses a certain value, the HMIPv6 starts performing better than FMIPv6.

By further investigation of this phenomenon we discovered that this value of link delay ($D_{\text{Wireless}}$) is dependent on the bandwidth of the wireless link in the following way (see Fig. 10).

The curve asymptotically approaches to a value which equals a sum of $D_{\text{RD}}$ and $D_{\text{DAD}}$ (i.e. processing time of NAR for router discovery procedure and duplicate address detection procedure).

V. CONCLUSION

This paper presents an analytical method for L3 handover latency evaluation. This method allows, based on analytical equations, to evaluate and compare various existing of future handover schemes without the need to implement it or edit complex simulation models. It is possible to easily adjust the method to the current needs simply by changing the assumptions or/and by performing some further refinements.

Together with an enhanced analytical method for L3 handover cost evaluation we published in [5] it makes an important framework for general L3 handover evaluation.

This framework will be contributed to the project 15.2.4 of the Single European Sky ATM Research (SESAR) program. Since one of the goals of the project is to design a mobility & multilink system, these methods will help to choose and/or design the most appropriate method of L3 handover.

REFERENCES


