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Enhanced analytical method for IP mobility handover schemes cost evaluation

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Abstract Seamless service delivery for mobile users complemented with Quality of Service provisioning for their real-time applications have a hot topic in the field of mobile communication in recent years. Seamless mobility goes hand in hand with Mobile IPv6 protocol. Since many different handover schemes trying to solve the Quality of Service issues have been developed a need for means for comparison has arisen. This paper presents an enhanced universal analytical method for comparison of handover schemes. The method focuses on two important aspects influencing the handover performance—binding update cost and packet delivery cost. The use of the proposed method is presented for comparison of four most common handover schemes—MIPv6, HMIPv6, FMIPv6 and F-HMIPv6.

Keywords Analysis · Cost · Handover evaluation · L3 handover · MIPv6 · Mobility · Performance

1 Introduction

The Quality of Services in wireless networks based on IPv6 protocol (including user mobility support—Mobile IPv6 protocol) derives mainly from packet loss ratio, layer 3 handover latency and protocol overhead [9]. The bandwidth limitation and end-to-end delay is extremely critical mainly for aeronautical datalink applications. For the air-ground communication the aircraft uses technologies (VDLm2, SATCOM, etc.) with very low throughput (tens of kbps) and high latency (hundreds of milliseconds). Therefore it is essential to analyze these parameters in context of handover schemes performance assessment, which could be an important starting point for a handover scheme implementation.

Two major factors influencing the overhead may be considered as the signalization messages exchange performed when the mobile node changes its point of attachment (i.e. location update) and the cost of delivering data packets to the mobile node during the process of handover. The latter one also utilizes available network resources and therefore shapes additional overhead that needs to be taken into account [8–11].

This paper proposes an enhanced analytical method allowing evaluation of Mobile IPv6 handover scheme performance. This topic has already been covered several times but none of the presented methods so far took such a universal approach as will be shown later on.

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.

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In MIPv6 protocol, a number of handover schemes already exist. Four of these schemes may be considered as the core L3 handover schemes—classical Mobile IPv6 (MIPv6) [4], Fast handovers for Mobile IPv6 (FMIPv6) [6], Hierarchical Mobile IPv6 (HMIPv6) [13] and Fast handovers for Hierarchical Mobile IPv6 (F-HMIPv6) [5]. 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 [4–6, 13].

2 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. From the signalization point of view it is the most complex handover scheme out of the four schemes mentioned above and therefore we focus right on it in this section. For detailed information about other schemes please refer to [4, 6, 13].

The F-HMIPv6 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 looses 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.

For the completeness of information and for the needs of the analysis, Table 1 shows the size of each signaling message complemented with the explanation of the message abbreviation.

3 Total handover cost

The total amount of handover signaling cost (C_{TOTAL}) may be expressed as a sum two main components—binding update signaling cost (C_{SIGNAL}) and packet delivery cost (C_{PACKET}).

$$C_{TOTAL} = C_{SIGNAL} + C_{PACKET} \tag{1}$$

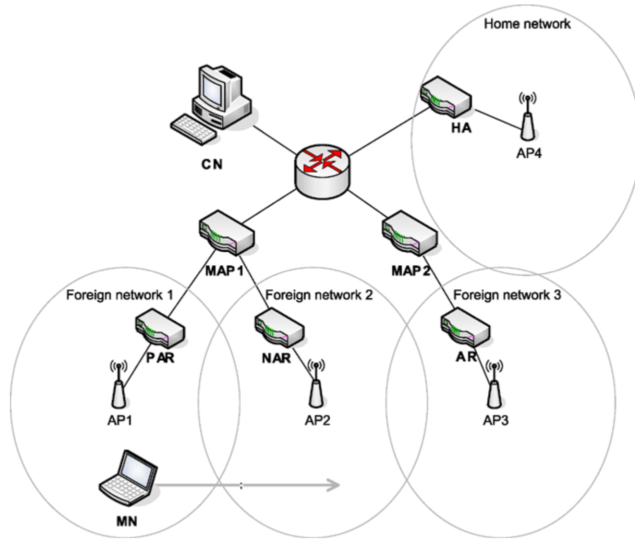

Fig. 1 Network structure supporting MIPv6 protocol with F-HMIPv6 handover scheme

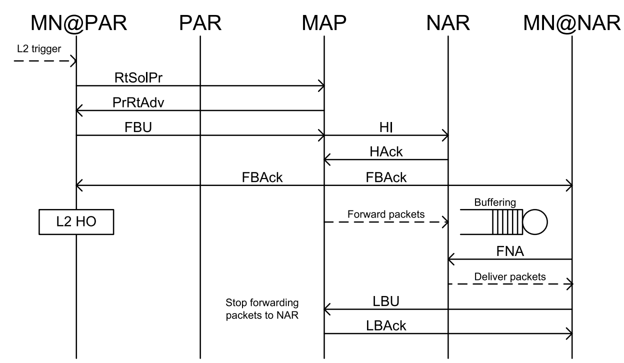

Fig. 2 Timing diagram for intra-MAP handover in F-HMIPv6

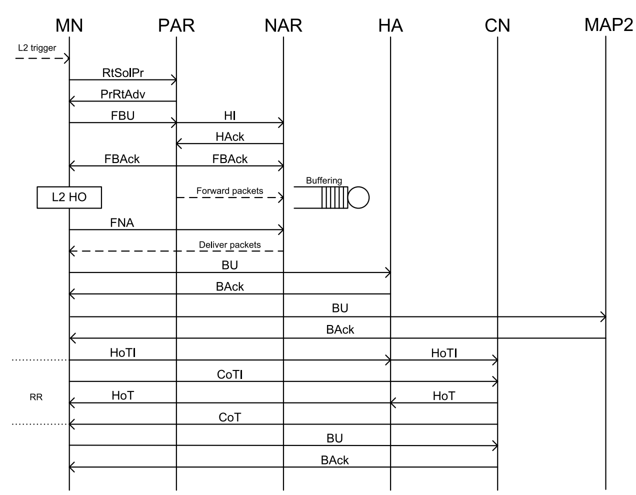

Fig. 3 Timing diagram for inter-MAP handover in F-HMIPv6

Table 1 Messages used in F-HMIPv6 handover scheme

Message	Meaning	Size of the message [Bytes]	Overall size (including IPv6 header) [Bytes]
BU	Binding Update		
	MN->HA	90 B[a]	136 B[a]
	MN->CN	26 B	72 B
BAck	Binding Acknowledgement		
	HA->MN	82 B[a]	128 B[a]
	CN->MN	26 B	72 B
HoTI	Home Test Init		
	MN->HA	82 B[a]	128 B[a]
	HA->CN	10 B	56 B
CoTI	Care-of Test Init	10 B	56 B
HoT	Home Test		
	CN->HA	18 B	64 B
	HA->MN	90 B[a]	136 B[a]
CoT	Care-of Test	18 B	64 B
RtSolPr	Router Solicitation for Proxy Advertisement	24 + 16n B[b]	64 + 16n B[b]
PrRtAdv	Proxy Router Advertisement	104 B	144 B
FBU	Fast Binding Update	72 B	118 B
HI	Handover Initiate	72 B	118 B
HAck	Handover Ack.	32 B	78 B
FBAck	Fast Binding Ack.	32 B	78 B
FNA	Fast Neighbor Advertisement	24 B	64 B
RS[c]	Router Solicitation	16 B	56 B
RA[c]	Router Advertisement	64 B	104 B
RS[d]	Router Solicitation	16 B	56 B
RA[d]	Router Advertisement	64 + 24n B[b]	104 + 24n B[b]
NS	Neighbor Solicitation	28 B	68 B
NA	Neighbor Advertisement	32 B	72 B
LBU	Local Binding Update	90 B[a]	136 B[a]
LBAck	Local Binding Ack	82 B[a]	128 B[a]

[a] Using IPsec is assumed (ESP header)
[b] n in number of access points (AP), that MN discovered during scanning (i.e. the message contains options with address of these APs)
[c] Intra-MAP handover
[d] Inter-MAP handover

3.1 Binding update signaling cost

Based on the way the mobile node (MN) changes its point of attachment and on the utilized mobility handover scheme it can perform two different binding update procedures—local binding update, involving just mobility anchor point MAP (for hierarchical handover schemes) and a standard (global) binding update in which the new Care of Address (NCoA) is reported in a standard way to the Home Agent (HA) and Correspondent Nodes (CN) [9, 11, 14]. The first variant occurs just in case of hierarchical handover schemes (HMIPv6, F-HMIPv6) when the MN roams between networks under control of a single MAP. In any other case, i.e. in MIPv6 and FMIPv6 for any handover and in HMIPv6 an F-HMIPv6 for inter-MAP handovers a standard (global) binding update procedure is performed.

Based on the above stated fact it is necessary for the proposed analytical method to take into account both of the variants when analyzing the signaling cost of a particular handover scheme unlike publications dealing purely with hierarchical protocols, like [8], or those analyzing just non-hierarchical protocols, like [10]. According to [9], an average signaling cost can then be expressed as:

$$C_{SIGNAL} = E(N_{INTRA}) \cdot C_{INTRA} + E(N_{INTER}) \cdot C_{INTER} \quad (2)$$

where $E(N_{INTRA})$ is an average number of subnetworks that the MN passes through during its ongoing data session with CNs, staying in coverage of a single MAP (in a single MAP domain). Similarly, $E(N_{INTER})$ covers MN's roaming among subnetworks in different MAP domains. C_{INTRA} and C_{INTRA} stand for signaling cost of binding update in intra-MAP and inter-MAP handover, respectively.

Generally, $E(N_{INTER})$ can be expressed as $\frac{\mu}{\lambda_S}$, in which μ is a MN's mobility rate (the frequency of MN's change of location) and λ_S is a session arrival rate (number of connection requests from CNs per second). Considering $E(N_{INTRA})$ to be mobility rate of a MN in bounds of a single MAP domain and $E(N_{INTER})$ to be mobility rate of a MN crossing boundaries of MAP domains, we can rewrite (2) as:

$$C_{SIGNAL} = \frac{1}{\lambda_S}(\mu_{INTRA} \cdot C_{INTRA} + \mu_{INTRA} \cdot C_{INTRA}) \tag{3}$$

For signaling cost analysis it is convenient, like in [9, 14] or [11], to introduce a parameter called SMR (Session to Mobility Ratio) which is an analogy to CMR (Call to Mobility Ratio) used in cellular networks for performance analysis. SMR is defined as a ratio of incoming data sessions λ_S and node mobility, defined as $\mu = \frac{1}{T_{SUB}}$, where T_{SUB} is an average time in which the MN remains in a particular subnetwork before roaming to a different one. Based on these assumptions we get $E(N_{INTER}) = \frac{1}{SMR}$.

Applying the above mentioned assumptions to (3) and taking into account results of [9] that give ratios of mobility as $\mu_{INTRA} = \mu\frac{\sqrt{M}-1}{\sqrt{M}}$ for intra-MAP handover and $\mu_{INTER} = \frac{\mu}{\sqrt{M}}$ for inter-MAP handover we get the fundamental equation for the binding update signaling cost analysis:

$$C_{SIGNAL} = \frac{1}{SMR \cdot \sqrt{M}}[(\sqrt{M}-1) \cdot C_{INTRA} + C_{INTER}] \tag{4}$$

where M stands for number of subnetworks in a MAP domain.

According to [9–11, 14], the signaling cost in IP-based networks is derived from the actual transmission of signaling messages (packets) through the network (packet transmission cost). The cost is proportional number of hops between the source and destination node. It is also assumed that the packet transmission cost of a wireless link is higher than the one of a wired link. This corresponds to the following definitions. The packet transmission cost of a wireless link between a MN and its access router (AR) is given as $C_{MN,AR} = \kappa$. The cost of delivering data between two end nodes X, Y by a wired link is counted as $C_{X,Y} = \tau \cdot d_{X,Y}$, where κ, τ is a cost of delivering a data unit through a wireless or wired link, respectively, and $d_{X,Y}$ is number of hops between nodes X and Y.

The final binding update signaling cost (C_{SIGNAL}) will then strongly depend on the handover scheme describing the exchanges of signaling messages during the handover procedure and on sizes of particular signaling messages (shown in Table 1). Additionally to this the final cost will also be influenced by the processing cost (PC_X) of each node involved in the communication chain.

3.1.1 Application to a particular handover scheme

Since applying the equation derived above to all basic handover schemes (MIPv6, FMIPv6, HMIPv6 and F-HMIPV6) would be out of scope of this paper, only the most complex case—F-HMIPv6—is presented here. F-HMIPv6 is a hierarchical mobility handover scheme and therefore we need to differentiate the intra-MAP handover from inter-MAP handover. As a consequence the signaling cost for these two variants is not equal. For intra-MAP handover a new Local CoA (LCoA) is registered just with the particular MAP (see Fig. 2). In the second case, except for registering new LCoA (with a new MAP) also new Regional CoA (RCoA) needs to be registered with the HA and all participating CNs—represented by C_{BU} (see (5)).

$$C_{INTER}^{F-HMIPv6} = C_{INTRA}^{F-HMIPv6} + C_{BU} \tag{5}$$

The binding update cost can be, with respect to Fig. 3, expressed as:

$$\begin{aligned} C_{BU} = {} & (BU_{MN,HA} + BAck_{HA,MN}) \cdot \underbrace{(C_{MN,AR} + C_{AR,HA})}_{MN\leftrightarrow HA} \\ & + PC_{HA} + H_{CN} \cdot \Bigg[(BU_{MN,CN} + BAck_{CN,MN}) \\ & \times \Bigg(\underbrace{(C_{MN,AR} + C_{AR,MN})}_{MN\leftrightarrow CN} \Bigg) + PC_{CN} + C_{RR} \Bigg] \end{aligned} \tag{6}$$

The first part of the equation is the process of registering the CoA at the HA. The second part describes performing the binding update at all the CNs. The number of CNs is given by NCN. CRR stands for signaling cost of Return Routability (RR) procedure (see Fig. 3 for details) and is expressed like:

$$\begin{aligned} C_{RR} = {} & (HoTI_{MN,HA} + HoT_{HA,MN}) \cdot \underbrace{(C_{MN,AR} + C_{AR,HA})}_{MN\leftrightarrow HA} \\ & + (HoTI_{HA,CN} + HoT_{CN,HA}) \cdot C_{HA,CN} \\ & + (CoTI + CoT) \\ & \times \underbrace{(CN_{MN,AR} + C_{AR,CN})}_{MN\leftrightarrow CN} + 2(PC_{HA} + PC_{CN}). \end{aligned} \tag{7}$$

Fast handover is mainly based on upcoming handover prediction. Therefore, according to [9] and [10], the total amount of signaling cost is derived from the probability of correct prediction of the upcoming handover. In reality, several situations may occur, when the predicted handover is in the end not executed. In such a case, all signaling messages that were exchanged remain unused. If we assume that the L3 handover is finished successfully whenever the MN receives the FBAck message, we may assume those unused messages to be all signaling messages sent prior to FBAck, i.e. RtSolPr, PrRtAdv, FBU, HI and Hack (see Fig. 3).

Based on what was stated above, the signaling cost of the intra-MAP handover (mentioned in (5)) is expressed like:

$$C_{INTRA}^{F-HMIPv6} = P_s \cdot H_s^{F-HMIPv6} + (1 - P_s) \cdot H_f^{F-HMIPv6}, \quad (8)$$

where P_s gives the correct L2 handover prediction probability and $H_s^{F-HMIPv6}$ and $H_f^{F-HMIPv6}$ is the cost of handover when the L3 handover is successfully finished (s—success) or when it fails (f—fail). The expression of $H_s^{F-HMIPv6}$ and $H_f^{F-HMIPv6}$ is with respect to Fig. 3 the following:

$$\begin{aligned} H_s^{F-HMIPv6} &= (RtSolPr + PrRtAdv + FBU + FBAck) \\ &\quad \times \underbrace{(C_{MN,PAR} + C_{PAR,MAP})}_{MN@PAR\leftrightarrow MAP} \\ &\quad + (HI + HAck + FBAck) \cdot C_{MAP,NAR} \\ &\quad + FNA \cdot C_{MN,NAR} + (LBU + LBACK) \\ &\quad \times \underbrace{(C_{MN,NAR} + C_{NAR,MAP})}_{MN@NAR\leftrightarrow MAP} \\ &\quad + 2PC_{AR} + 3PC_{MAP}, \qquad (9) \\ H_f^{F-HMIPv6} &= (RtSolPr + PrRtAdv + FBU) \\ &\quad \times \underbrace{(C_{MN,PAR} + C_{PAR,MAP})}_{MN@PAR\leftrightarrow MAP} \\ &\quad + (HI + HAck) \cdot C_{MAP,NAR} \\ &\quad + PC_{AR} + 2PC_{MAP} \qquad (10) \end{aligned}$$

By putting all the derived equations (5)–(10) to (4) we finally get the total signaling cost of the F-HMIPv6 handover scheme. The total signaling cost of other handover schemes may be easily derived from the expressions.

3.2 Packet delivery cost

The packet delivery cost stands for the cost directly connected with data traffic to the MN during the L3 handover procedure. The handover latency intervals are graphically represented in Fig. 4 [2, 7, 9, 10].

From the time the MN starts the handover procedure it is not able to receive any data on its "old" CoA anymore. Until it finishes the binding update procedure with its HA and all CNs the incoming data is either lost (discarded at the last point of attachment of the MN) or, in case of FMIPv6 and F-HMIPv6 protocols, intercepted and forwarded through a tunnel to the new MN's point of attachment. Similarly to [9, 10] and [8], we may express the packet delivery cost as:

$$C_{PACKET} = \delta \cdot C_{FORWARDING} + \epsilon \cdot C_{LOSS} \quad (11)$$

where $C_{FORWARDING}$ is the cost of transmission of the redirected packets and C_{LOSS} is the cost of transmission of the packets that are finally discarded. δ and ϵ are parameters describing and emphasizing the effect of redirecting or discarding the data.

3.2.1 Application to handover schemes

From the packet delivery cost point of view there are two basic handover schemes—the MIPv6 scheme, where packets are discarded during the handover procedure, and the FMIPv6, where the packets are redirected to the new point of MN's attachment. For that reason, and because of limited space of in the paper, only these two schemes will be covered. The other schemes can be derived easily from these.

3.2.2 MIPv6

Let λ_p be the packet arrival rate, defined as number of packets per time unit. Then we can compute the $C_{FORWARDING}$ and C_{LOSS} as a multiplication of the packet arrival rate, the overall time for which the packets need to be discarded or forwarded (i.e. the handover latency) and the cost of delivering these data through network infrastructure.

For MIPv6 we can easily set $C_{FORWARDING}^{MIPv6}$ to 0, because all the data is discarded, nothing is forwarded, which results in:

$$C_{FORWARDING}^{MIPv6} = \lambda_p \cdot (t_{L2} + t_{IP} + t_U) \cdot (C_{RO}^{MIPv6} + C_{nRO}^{MIPv6}). \quad (12)$$

C_{RO}^{MIPv6} and C_{nRO}^{MIPv6} stand for cost of data delivery using the Route optimization or tunneling through HA respectively and are expressed as:

$$C_{RO}^{MIPv6} = \omega \cdot \underbrace{(C_{CN,PAR} + C_{AR,MN})}_{CN\leftrightarrow MN}, \quad (13)$$

$$C_{nRO}^{MIPv6} = (1-\omega) \times \left[\underbrace{(C_{CN,HA} + C_{HA,PAR} + C_{PAR,MN})}_{CN\rightarrow HA\rightarrow MN} + PC_{HA} \right] \quad (14)$$

The parameter ω expresses the ratio between route-optimized traffic and non-route-optimized traffic.

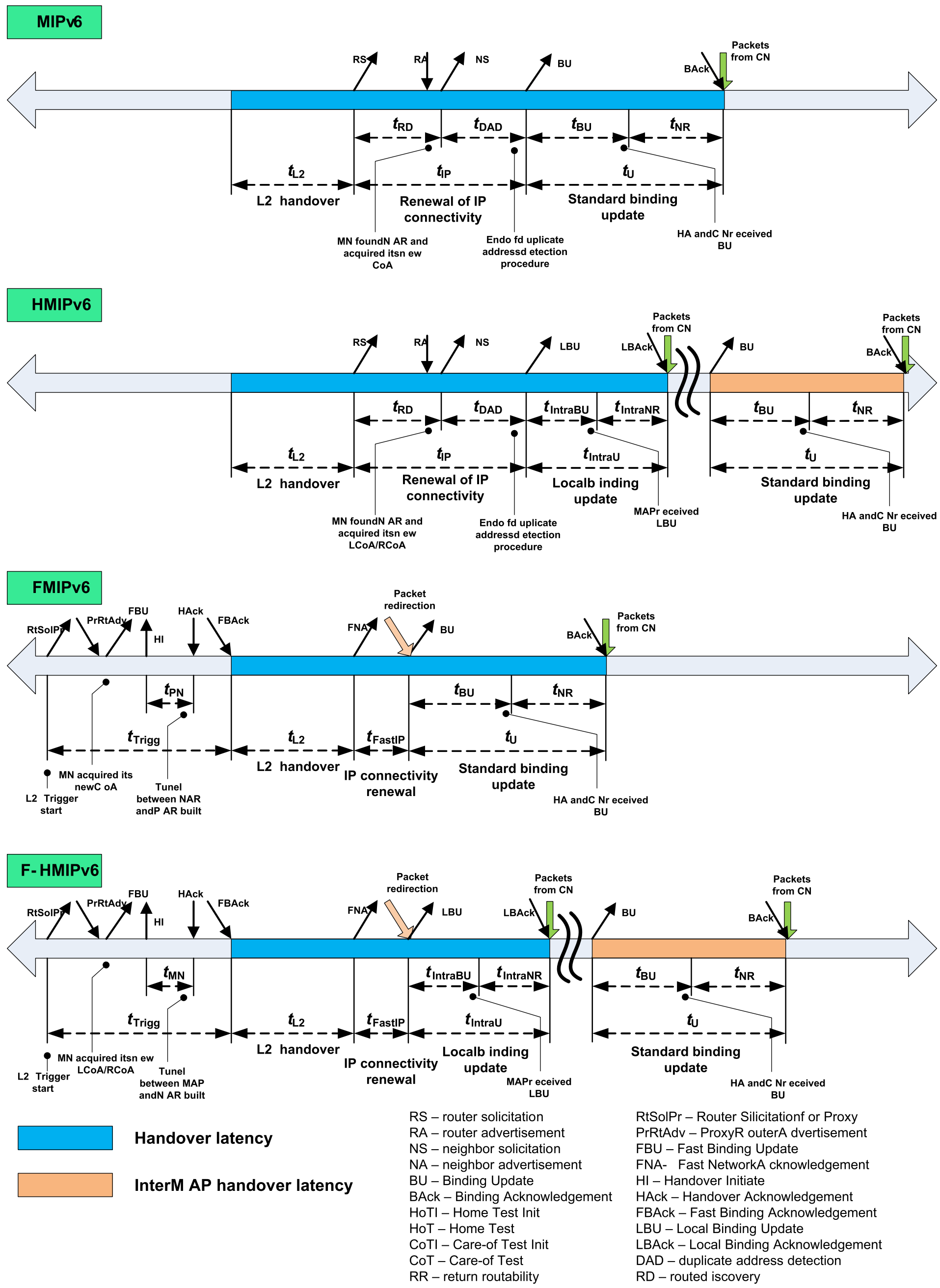

Fig. 4 Time diagrams of MIPv6 handover schemes

3.2.3 *FMIPv6*

In contrast with MIPv6 handover scheme there is the FMIPv6 scheme which has been developed to minimize the relatively high data loss during the handover procedure. In FMIPv6, the data is, during the handover procedure, tunneled to the new MN's expected point of attachment, buffered there and delivered to the MN as soon as it attaches to the new subnetwork.

Assuming the predictive mode of FMIPv6 and considering Fig. 4 we get:

$$C_{FORWARDING}^{FMIPv6} = \lambda_p \cdot (t_{L2} + t_{FastIP} + t_U) \times (C_{RO}^{FMIPv6} + C_{nRO}^{FMIPv6}) \quad (15)$$

Furthermore, the C_{RO}^{FMIPv6} and C_{nRO}^{FMIPv6} are expressed as:

$$C_{RO}^{FMIPv6} = \omega \cdot \Big[\underbrace{(C_{CN,PAR} + C_{PAR,NAR} + C_{NAR,MN})}_{CN \to PAR \to NAR \to MN} + PC_{AR} \Big], \quad (16)$$

$$C_{nRO}^{FMIPv6} = (1-\omega) \times \Big[\underbrace{(C_{CN,HA} + C_{HA,PAR} + C_{PAR,NAR} + C_{NAR,MN})}_{CN \to HA \to PAR \to NAR \to MN} + PC_{HA} + PC_{ARo} \Big] \quad (17)$$

Unfortunately, we cannot consider C_{LOSS} to be 0. This would be just an ideal case. For example if we consider the MN is moving too fast, then in Fig. 4 we get $t_{PN} > t_{Trigg}$ and therefore all the packets arriving in the timeframe $t_{PN} - t_{Trigg}$ would be lost. For successful FMIPv6 handover the condition $t_{PN} \leq t_{Trigg}$ needs to be true. Then we can identify:

$$C_{LOSS}^{FMIPv6} = \lambda_p \cdot \max\{(t_{PN} - t_{Trigg}), 0\} \times (C_{RO}^{FMIPv6} + C_{nRO}^{FMIPv6}) \quad (18)$$

4 Application of the framework and results

This section provides information about how the analytical framework provided above can be used for evaluation of a particular handover scheme. The goal of this section is to illustrate the application of the proposed method and provide results of performance assessment of the analyzed handover schemes.

4.1 Network model

For handover scheme evaluation we use the network topology which is depicted in Fig. 5 [8, 9, 14].

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.

In the Fig. 5, the access routers AR1–AR4 are grouped into two MAP domains (marked with the dashed line) driven by two MAPs. The topology illustrates a simple model in which the MN performs both the intra-MAP and inter-MAP handover. Links between the network nodes are marked with letters a–f that according to Table 2 show the number of hops on particular routes. This symbolizes a complex route through the network for each pair of nodes. The other values in the Table 2 are set according to [1, 7, 9, 10, 12, 14] and [3].

4.2 Schemes comparison

In this section we present some of the results that may be obtained by applying our method on the four main handover schemes that were mentioned earlier in this paper—MIPv6, HMIPv6, FMIPv6 and F-HMIPv6. The following text presents graphs that show the dependency of the handover cost on various parameters like session to mobility ratio, number of correspondent nodes etc.

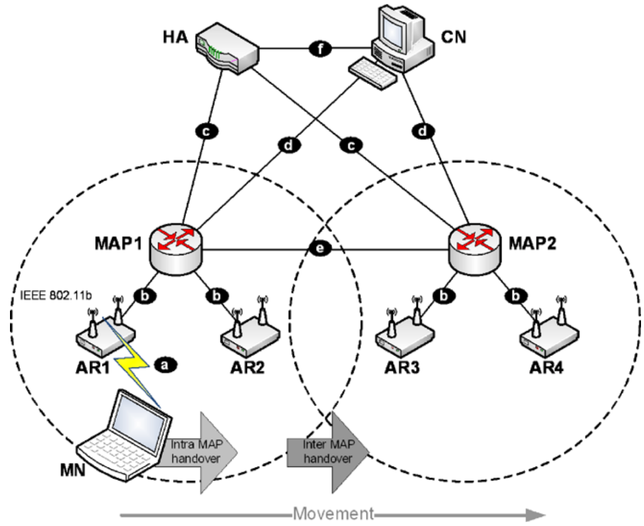

Fig. 5 Network topology used for handover scheme analysis

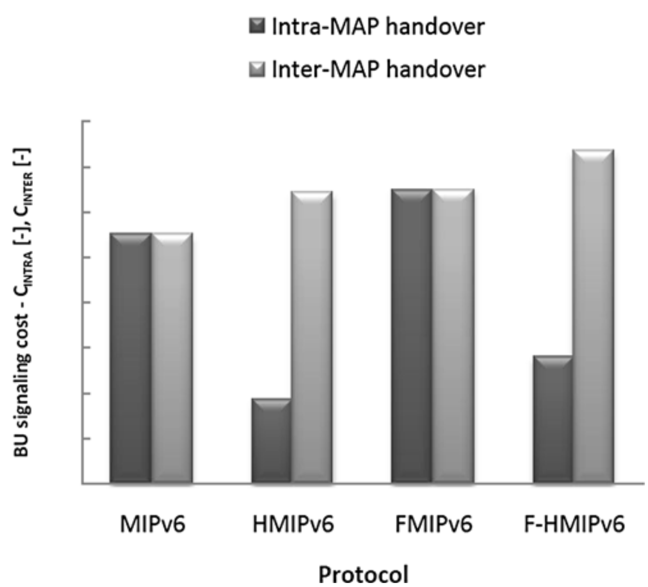

Fig. 6 Binding update signaling cost for different handover schemes—MIPv6, FMIPv6, HMIPv6 and F-HMIPv6

Figure 6 presents the comparison of the schemes based on binding update signaling cost. The graph shows that the best results (in terms of the lowest cost) are achieved the hierarchical handover schemes (i.e. HMIPv6 and F-HMIPv6) in the case of intra-MAP handover. This result is not really surprising, because the main reason for which the hierarchical schemes have been developed is to rapidly reduce the signaling for the intra-MAP handovers by enabling the mobile node to perform just local binding update to the active MAP. On the other hand, for the inter-MAP handover, the hierarchical schemes perform even worse than the respective

Table 2 Analytical model parameters

Parameter	Value	Description
a	1	Number of hops between MN and ARx (dMN.AR)
b	2	Number of hops between ARx and MAPx (dAR.MAP)
c	6	Number of hops between HA and MAPx (dHA.MAP)
d	4	Number of hops between CN and MAPx (dCN,MAP)
e	6	Number of hops between MAPI and MAP2 (dMAP1,MAP2)
f	6	Number of hops between HA and CN (dHA.CN)
M	2	Number of subnetworks (ARs) in a MAP domain
T	1	Packet delivery cost on a wired link
K	10	Packet delivery cost on a wireless link
PC_{AR}	800	Pakcet/message processing cost in ARx
PC_{HA}	2400	Pakcet/message processing cost in HA
PC_{CN}	400	Pakcet/message processing cost in CN
PC_{MAP}	1200	Pakcet/message processing cost in MAPx
P_s	0.9	Correct L3 handover prediction probability
δ	0.2	Parameter describing and emphasizing the effect of redirecting packets to MN
ϵ	0.8	Parameter describing and emphasizing the effect of discarding packets
ω	0.8	Parameter describing and emphasizing the effect of redirecting packets between MN and CN
λ_p	10 paket/s	Packet arrival rate for MN
λ_s	0.01	Session arrival rate for MN
T_{SUB}	10–250 s	A time interval for a MN to stay in a subnetwork
t_{L2}	100 ms	L2 handover latency
t_{RD}	120 ms	Router discovery interval
t_{DAD}	120 ms	Duplicate address detection (DAD) time interval
S	93 B	An average signaling message size
BW_{Wless}	11 Mbit/s	Wireless link bandwidth
BW_{Wired}	100 Mbit/s	Wired link bandwidth
l_{Wless}	2 ms	Wireless link transition delay
l_{Wired}	0.5 ms	Wired link transition delay
D_{Router}	0.001 ms	Router processing time

non-hierarchical schemes. The reason for this is that except for the binding update sent to home agent and correspondent nodes the mobile node needs to perform one more binding update—with the new MAP.

The graph in Fig. 7 presents the signaling cost in dependency on the session to mobility ratio (SMR) for handovers within one MAP domain. It actually shows the dependency of signaling cost on the mobile node's mobility. From the graph we can read that the tendency of intra-MAP handover cost (C_{INTRA}) is decreasing with increasing SMR. For small SMR the mobility rate of the mobile node (μ) is relatively higher than the amount of incoming data sessions (λ_S). This means that the mobile node changes its location quite often and therefore, caused by frequent handovers, the signal-

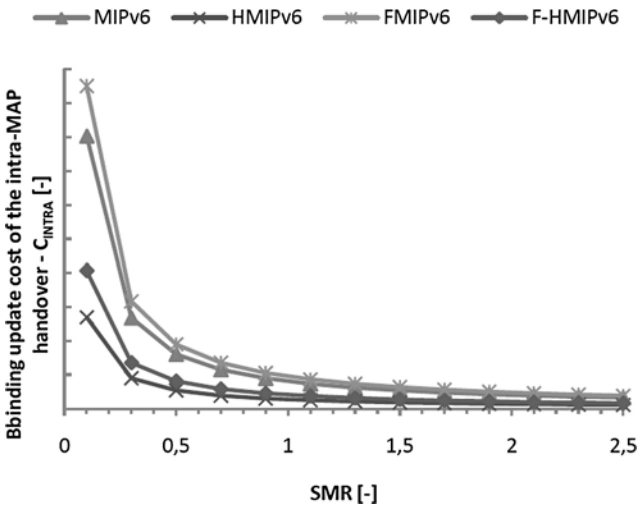

Fig. 7 The influence of SMR on the binding update cost of the intra-MAP handover

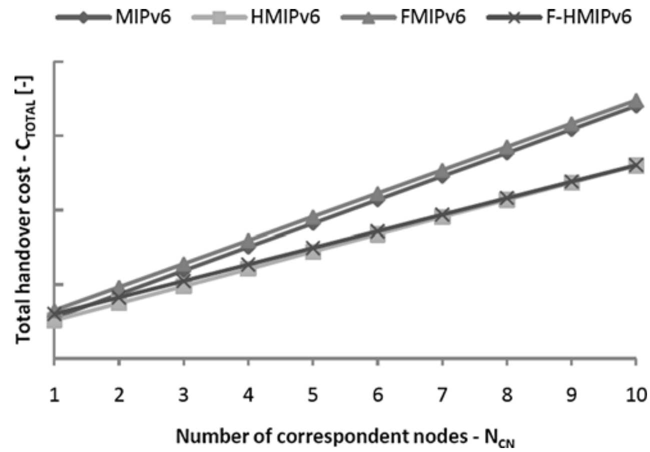

Fig. 8 Dependency of total handover cost on the number of correspondent nodes

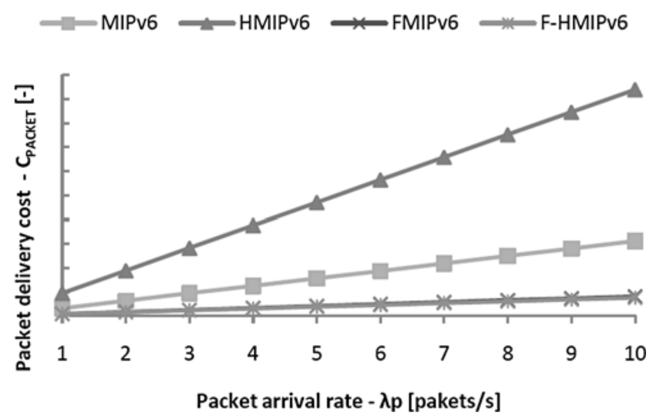

Fig. 9 Packet delivery cost dependency on the packet arrival rate

ing cost is high. But as the SMR ratio grows, the frequency of handovers decreases, the signaling cost rapidly decreases and asymptotically closers to zero (which would mean that the mobile node does not perform any handover).

For low SMR, i.e. for frequent handovers of the mobile, we can notice, that the difference between hierarchical and nonhierarchical schemes is quite significant. But as the ratio increases, the difference between these two kinds of handovers diminishes.

The graph in Fig. 8 presents the total signaling cost of all four analyzed handover schemes depending on the number of CNs that the MN communicates with. We can notice again that the hierarchical schemes suffer from lower cost than the other two analyzed schemes. More interesting observation is that for HMIPv6 and F-HMIPv6 the slope of the line is not as steep as for the other two schemes. Apparently the reason for this is the fact, that hierarchical protocol are not influenced by the number of correspondent nodes as far as the intra-MAP handovers are concerned. However, this is not valid for the inter-MAP handovers, for which the number of correspondent nodes plays as important role as for the nonhierarchical schemes.

The last figure (Fig. 9) depicts a graph showing the packet delivery cost influenced by the packet arrival rate. One important result that should be noticed is, that the HMIPv6 scheme suffers from the highest packet delivery cost. The main reason for this is interception of each packet by the mobility anchor point—the MAP. Since MAP needs to process every single packet, it increases the delivery cost by a great amount. The reason, why the other hierarchical scheme does not suffer from the same is the way the MAP deals with arriving packets during mobile nodes handover. In F-HMIPv6 the MAP does not try to deliver the packets (that would be lost a needed to be retransmitted in HMIPv6) but buffers them and delivers it to the mobile node after it finishes the handover procedure.

Furthermore the graph shows that FMIPv6 and F-HMIPv6 are much more effective for higher packet arrival rate than the other two and therefore more suitable for applications producing high continuous load, like voice over IP, for example.

5 Conclusion

The paper presents an enhanced analytical method for L3 handover cost evaluation. The proposed method takes into account all the key aspects of layer 3 handover, such as the signaling cost and packet delivery cost. The main contribution of this method is that it takes into account also the inter-MAP handovers that are specific for hierarchical mobility schemes (HMIPv6 and F-HMIPv6) although it is not strictly bounded to these schemes. This makes the proposed analytical method universal and suitable for other handover schemes that have been already developed or will be developed in the future.

Finally, the paper presents result of the comparison analysis of four most common handover schemes in IPv6 mobility—MIPv6, FMIPv6, HMIPv6 and F-HMIPv6. From the presented graphs we may derive a conclusion that from the signaling cost of view in conjunction with packet delivery cost the most effective schemes are the hierarchical ones—HMIPv6 and F-HMIPv6. This result should not be much surprising, because these schemes were developed for signaling cost reduction. The only weakness of HMIPv6 from the cost perspective can be seen in the packet delivery cost.

Moreover, the paper presents enough information for even more detailed analysis of the mentioned handover schemes and many others, existing or future ones. It also allows the analysis to be performed from other points of view that the reader of this paper may need.

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