Comparison of Signaling and Packet Forwarding Overhead for HMIP and MIFA

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Abstract. Handoff latency affects the service quality of real-time applications. In this paper we develop an analytical model to analyze the Mobile IP Fast Authentication protocol (MIFA) and compare it to Hierarchical Mobile IP (HMIP). The study compares the signaling costs of the protocols as well as the overall load for packet forwarding. Our study shows that MIFA minimizes the packet delivery cost compared to HMIP. Additionally, MIFA is more efficient when the arrival rate of the packets increases. Thus MIFA outperforms HMIP with respect to signaling cost. From the performance point of view MIFA performs similar to HMIP when the domain consists of two hierarchy levels only, and outperform HMIP otherwise. However, MIFA does not require a hierarchical network architecture as HMIP does.

1 Introduction

The real time applications are highly affected by the disruption in the communication during the movement from one cell to another. As the user mobility of IP-based mobiles increases and the cell size of the system decreases, handoffs will cause frequent service interruptions. Therefore, the development of fast mobility management solutions is a big challenge in future IP-based mobile networks.

When the **M**obile **N**ode (MN) notices that the current **A**ccess **P**oint (AP) is no longer reachable, it starts to scan the medium for other available APs. After that the MN authenticates and re-associates itself with the newly discovered AP. These procedures are called layer2 handoff. No additional procedures are required if the new AP belongs to the same subnet as the old one. However, the MN must discover the new **F**oreign **A**gent (FA) serving this subnet, register and authenticate itself with the **H**ome **A**gent (HA) or another special agent through this FA, if the new AP belongs to another subnet. These additional procedures are called layer3 handoff.

The rest of the paper is organized as following: In section 2 we provide the background and the related work. The MIFA protocol is described in section 3. The analytical model to derive the signaling cost and the analysis is given in section 4. After that we conclude with the main results and the future work in section 5.

2 Background and related work

In order to implement the layer3 handoff, several protocols have been proposed. With Mobile IP version 4 (MIPv4) [1], [2] or version 6 (MIPv6) [3], the MN has to be registered and authenticated by the HA every time it moves from one subnet to another. This introduces extra latency to the communication, especially when the HA is far away from the FA. Additionally, the generation of secret keys [4] for the security association is another reason for latency. Even though this is optional with MIP, it is highly recommended for security reasons. In addition, these keys are mandatory for some extensions of MIP, e.g. MIP with routing optimization [5]. Thus these two protocols are suitable for the management of global (macro) mobility.

In order to avoid these sources of extra latency, several approaches have been proposed to support local (micro) mobility. In [6] an approach to use an Anchor FA (AFA) has been proposed. If the MN is away from the home network, it will be initially registered by the HA. During this registration a shared secret between the MN and the FA is established. The FA then acts as an AFA. Thus, in subsequent registrations, the MN is registered at this AFA instead of the HA as long as it remains in the same domain. In this approach an additional tunnel from the AFA to the current FA is established to forward the packets to the MN. However, the forwarding delay on downlink as well as on uplink increases compared to MIP. An additional reverse tunnel is needed from the current FA to the AFA. Additionally a tunnel from the previous FA to the current FA is required in case the smooth handoff is supported [7].

In [8] a Regional Registration for MIPv4 and in [9] a Hierarchical Mobile IPv6 have been proposed. With these protocols the HA is not aware of every change of the point of attachment. This is due to the fact that the handoff procedures will be processed locally by a special node, e.g. a **G**ateway **F**oreign **A**gent (GFA) / **M**obility **A**nchor **P**oint (MAP), instead of the HA when the MN moves inside a certain domain. Thus, the MN communicates with the HA only if it changes this special node. However these protocols need a hierarchical network architecture.

Proposals for low latency handoffs use a trigger originating from layer2 (L2-trigger) to anticipate handoffs prior to a break of the radio link. In [10] methods for pre-registration, post-registration and a combined method have been proposed. Thus, a layer3 handoff is triggered by a L2-trigger. With the pre and post-registration method, the MN scans the medium for other APs if the strength of the signal received from the current AP deteriorates or if the error rate increases. If another AP is available and this AP belongs to another subnet, a L2-trigger is fired. This trigger contains the IP address of the new FA or another address from which the IP address can be derived, e.g. the MAC address. This prompts the MN, when employing pre-registration, to register with the new FA through the old one. Thus, the layer3 handoff is performed while the MN performs layer2 handoff. However, with post registration the MN performs only a layer2 handoff when the L2-trigger is fired. If the link between the current FA and the MN breaks down (receiving **L**ayer**2** **L**ink **D**own trigger (L2-LD) trigger), a bidirectional tunnel is established between the old FA and the new one. As a result the packets destined to the MN will be forwarded to the nFA through the old one. Thus, the MN receives the packets before the registration. With the combined method, the MN first tries to use the pre-registration method when a L2-trigger is received. If this fails, the MN employs the post-registration method.

Performance studies and an implementation of the pre-registration and post-registration method are described in [11] and [12] respectively. A comparison between the two methods is presented in [13]. The simulation results indicate that the timing of the trigger has a major influence on the handoff latency as well as the packet lose rate. Increased latency results if the L2-trigger for pre-registration is delayed. In case the **Reg**istration **Req**ue**st** (RegRqst) is dropped, it is possible that this method resorts to the standard layer3 handoff methods, e.g. MIP or HMIP. Even though post-registration is faster than pre-registration, the impact of delayed L2-triggers with post-registration is the same as with pre-registration. Due to the missing MIP registration with the post-registration approach, the packet delay is larger (uplink and downlink).

The **S**eamless **M**obile **IP** (S-MIP), proposed in [14] reduces the required registration time through the use of hierarchical network architecture. Additionally it uses the layer2 information to accelerate the layer3 handoff. S-MIP introduces a new entity called **D**ecision **E**ngine (DE) to control the handoff process. When the MN reaches the boundary of the cell, it informs the current **A**ccess **R**outer (AR) about the movement and about the addresses of the newly discovered ARs. The current AR informs the DE and the nARs about the movement. After that the movement of the MN will be tracked by the DE to decide accurately to which AR the MN will move. When the DE determines the new AR it informs the old AR and the other participating ARs about the decision. The packets will be forwarded then to the old and to the new AR until the DE is informed from the new AR that the MN has finished the handoff.

3 Mobile IP Fast Authentication Protocol

In order to avoid the problems of MIP without needing to insert intermediate nodes between the FA and the HA, **M**obile **I**P **F**ast **A**uthentication protocol (MIFA) [15] has been proposed. The basic idea of MIFA is that the HA delegates the authentication to the FA. As a result the MN authenticates itself with the FA and with the HA. However this authentication happens in the FA. Thus the MN sends RegRqst to the FA, which in turn directly replies by sending a **Reg**istration **Reply** message (RegRply) to the MN. After receiving the RegRply, the MN can resume the transmission on the uplink. In downlink a tunnel is established to forward the packets, arriving at the previous FA, to the current FA until the HA is informed about the movement and a tunnel from the HA to the current FA is established to forward the packets directly to the current FA. Thus the delay experienced from the communication between the current FA and the HA is eliminated, similar to the micro mobility protocols, see [16].

The local authentication by FAs relies on groups of neighbouring FAs. Each FA defines a set of neighbouring FAs called a Layer3 Frequent Handoff Region (L3-FHR) [17]. These L3-FHRs can be built statically by means of standard algorithms (e.g. neighbour graph [18] or others [17]), or dynamically by the network itself, by observing the movements of MNs. Every FA defines its own L3-FHR. There is a security association between the FAs in each L3-FHR. This security association can be established statically, e.g. by the network administrator, or dynamically, e.g. by the network itself as described in [4], [5].

Figure 1 depicts the basic operation of MIFA. While the MN communicates with the current FA, this FA sends notifications to all of the FAs in the L3-FHR the current FA belongs to. These notifications contain the security associations between the MN and the FAs in this L3-FHR on one side and between the FAs and the HA on the other side. These security associations are recorded in soft state and will be used by one FA at the future and deleted from the others. Additionally these notifications contain the characters of the HA and the authentication values (between the MN and the HA) the MN has to generate in the next registration with the next FA. These notifications are authenticated by means of the security associations established between the FAs, for more details see [15].

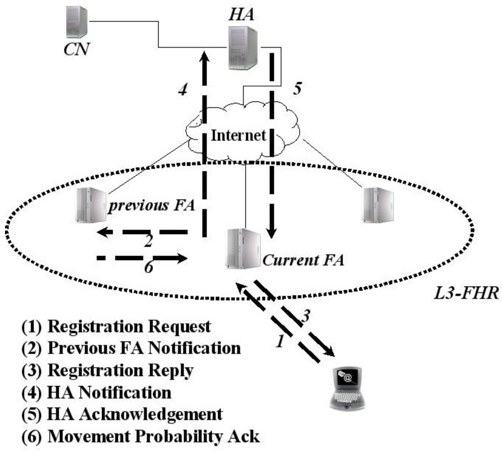

Fig. 1. Basic operation of MIFA

When the MN moves to one of the FAs in the L3-FHR, to which the previous FA belongs to, it sends RegRqst message to this FA. This current FA checks at first the authentication between it and the MN, this authentication will be checked by using the security association sent from the previous FA with the notification. After that the current FA checks the MIFA information, which presents the authentication information between the MN and the HA. The current FA then checks if the requirements requested from the HA can be satisfied, this can be achieved through the check of the HAs characters sent with the notification too. If the authentication succeeds, the FA builds a Previous FA Notification message to inform the previous FA that it has to forward the packets, sent to the MN, to the current FA. After that the current FA sends Registration Reply to the MN, at this time the MN can resume transmission in uplink. Additionally the current FA sends a HA Notification message to inform the HA about the new binding, the HA in turn establishes a new tunnel to the new FA, after that it intercepts the packets forwarded to the old binding and tunnels them to the new one. Thus the time to inform the HA about the new binding and to establish a new tunnel is eliminated.

In [16] an analytical model to evaluate the performance of MIFA compared to HMIP. This analysis shows that the handoff latency by MIFA is independent of the distance between the current FA and the HA. MIFA performs similar to HMIP when the domain consists of two levels of the hierarchy and outperforms HMIP otherwise.

The main advantage of MIFA is that MIFA does not require a hierarchical network architecture as HMIP does. Additionally, MIFA process the handoff procedures locally without introducing any intermediate node between the FA and the HA. Thus MIFA is a protocol to manage the global mobility, same as MIP, locally, same as HMIP.

4. Signaling cost function

In this section we will derive the signaling cost function to evaluate the impact of MIFA on the network and compare it to HMIP. The total signaling costs comprise the location update function and the packet forwarding function. We neglect the periodic bindings sent from the MN to refresh the cache in the mobility agents. The total cost will be considered as the performance metric.

4.1 Basic assumptions

In order to model the signaling cost function we suppose that the MN moves within two domains, domain a and b. Each domain contains 9 mobility agents. To model HMIP, these mobility agents are structured in hierarchical manner. To model the MIFA protocol, the mobility agents are divided into L3-FHRs. For simplicity we use a pre-defined mobility model for both cases, which presents the movement between the mobility agents in an active session. We assume that the MN moves along the path shown in Figure 2. The time that the MN will spend inside the region of each mobility agent is randomly with average T_a. Figure 3b depicts the network topology in the case of HMIP. Each domain contains 9 mobility agents where sets of three mobility agents are controlled by a **R**egional **F**oreign **A**gent (RFA). The RFAs are controlled by a GFA. Figure 3a plots the mobility agents divided into L3-FHRs for the case of MIFA.

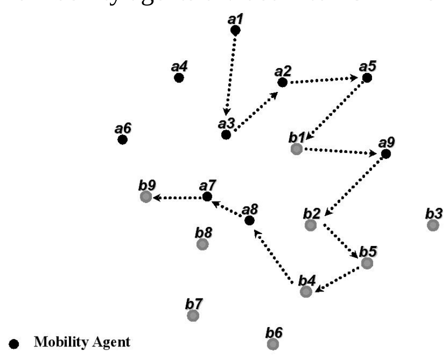

Fig. 2. Locations of the mobility agents

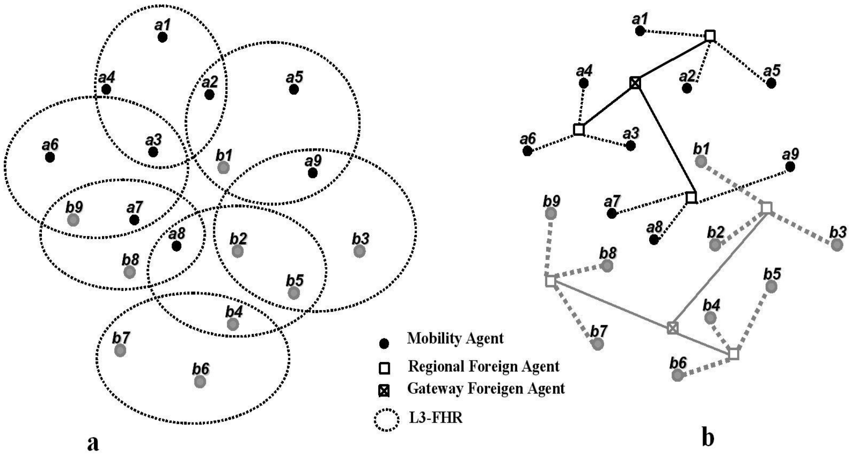

Fig. 3. Network topology

4.2 Location update cost

We define the following parameters to compute the location update cost: $C_{x,y}$ is the transmission cost of the location update between node x and node y. $D_{x,y}$ denotes the distance between the two nodes x and y with respect to the number of the hops. a_x represents the processing cost of the location update at node x.

4.2.1 Location update cost for HMIP

The location update cost function $C_{HMIP\text{-}LU}$ in case of HMIP is given in equation (1):

$$C_{HMIP\text{-}LU}=M^*\ C_{HMIP\text{-}LU\text{-}HA} + N^*\ C_{HMIP\text{-}LU\text{-}GFA} + G\ {}^*C_{HMIP\text{-}LU\text{-}RFA} \quad \textbf{(1)}$$

$C_{HMIP\text{-}LU\text{-}HA}$ is defined in equation (2) and denotes the location update cost when the MN registers with the HA. *M* represents the number of home registrations done by the MN while moving on the defined path. $C_{HMIP\text{-}LU\text{-}GFA}$ is defined in equation (3) and represents the location update cost when the MN registers with the GFA. *N* presents the number of times the MN has registered with the GFA. $C_{HMIP\text{-}LU\text{-}RFA}$ is given in equation (4) and expresses the location update cost when the MN registers with the RFA. *G* denotes the number of registrations with the RFA.

$$C_{HMIP\text{-}LU\text{-}HA}=2^*(C_{MN,FA}+C_{FA,RFA}+C_{RFA,GFA}+C_{GFA,HA})+2^*(a_{FA}+a_{RFA}+a_{GFA})+a_{HA} \quad \textbf{(2)}$$

$$C_{HMIP\text{-}LU\text{-}GFA}=2^*(C_{MN,FA} +C_{FA,RFA} + C_{RFA,GFA}) + 2^*(a_{FA} + a_{RFA}) +a_{GFA} \quad \textbf{(3)}$$

$$C_{HMIP\text{-}LU\text{-}RFA}=2^*(C_{MN,FA} +C_{FA,RFA}) + 2^*a_{FA} + a_{RFA} \quad \textbf{(4)}$$

The transmission cost $C_{x,y}$ on the wired network is proportional to the distance $D_{x,y}$ with proportional constant d_D. Thus we can write

$$C_{x,y} = d_D*D_{x,y} \quad (5)$$

while this cost on wireless link is *z* times more than on the wired one. Thus, we can derive this cost from equation (6):

$$C_{MN,FA} = z*d_D \quad (6)$$

4.2.2 Location update cost for MIFA

The location update cost $C_{MIFA\text{-}LU}$ using MIFA can be derived from equation (7):

$$C_{MIFA\text{-}LU}=B*(2*(C_{MN,FA} + C_{FA,oFA} + C_{FA,HA})+3*a_{FA} +a_{oFA} +a_{HA}) \quad (7)$$

where *B* denotes the number of the registrations the MN has executed.

4.3 Packet delivery cost

In order to evaluate the packet delivery cost, we assume the following parameters: $T_{x,y}$ denotes the transmission cost of the packet delivery between node x and node y. v_x represents the processing cost of the packet delivery at node x.

4.3.1 Packet delivery cost for HMIP

When using HMIP, the packets will be forwarded from the **C**orresponding **N**ode (CN) to the HA, which forwards them to the GFA. The GFA in turn forwards these packets to the serving RFA, which forwards them to the current FA. The current FA sends the packets then to the MN. Thus, there is extra cost for the packet delivery. We consider the packet delivery cost a packet incurs on its path from the CN to the MN. The packet delivery cost function $C_{HMIP\text{-}PD}$ is given in equation (8):

$$C_{HMIP\text{-}PD}=v_{HA}+v_{GFA}+v_{RFA} +v_{FA} + T_{CN,HA}+T_{HA,GFA}+T_{GFA,RFA}+T_{RFA,FA} \quad (8)$$

The transmission cost $T_{x,y}$ is proportional to the distance $D_{x,y}$ with proportional constant d_U. Thus we can write

$$T_{x,y} = d_U*D_{x,y} \quad (9)$$

The load on the GFA for the processing depends on the number of MNs in the domain and on the number of RFAs beneath it, while the load on the RFA depends on the number of MNs served from this RFA and on the number of FAs beneath it. Supposing the number of MNs in each subnet is *w*, the number of FAs served by each RFA is *k*, which equals the number of RFAs served by the GFA. The IP routing table lookup is based normally on the *longest prefix matching*. Thus, for the traditional *Patricia trie* [19], the packet processing cost functions in the GFA and the RFA can be computed from equations (10) and (11) respectively.

$$v_{GFA} = l_1 * k * L_a * (q_1 * w * K^2 + g_1 * \log(k)) \quad \textbf{(10)}$$

$$v_{GFA} = l_2 * k * L_a * (q_2 * w * K + g_2 * \log(k)) \quad \textbf{(11)}$$

where, L_a is the arrival rate of the MN. q and g are weighting factors of the router visitor list and the table lookups. l is a constant expressing bandwidth allocation cost.

The processing cost at HA and FA, which results from the encapsulation and decapsulation of packets, can be derived from the equations (12) and (13), respectively.

$$v_{HA} = y_1 * L_a \quad \textbf{(12)}$$

$$v_{FA} = y_2 * L_a \quad \textbf{(13)}$$

where, y_1, y_2 are constants expressing the packet delivery cost at HA and FA.

4.3.2 Packet delivery cost for MIFA

The packet delivery cost using MIFA can be computed from equation (14).

$$C_{MIFA\text{-}PD} = v_{HA} + v_{FA} + T_{CN,HA} + T_{HA,FA} \quad \textbf{(14)}$$

4.4 Total signaling cost

The total signaling cost is the sum of the location update cost and the packet delivery cost. Thus, we can write:

$$C_{HMIP} = C_{HMIP\text{-}LU} + C_{HMIP\text{-}PD} \quad \textbf{(15)}$$

$$C_{MIFA} = C_{MIFA\text{-}LU} + C_{MIFA\text{-}PD} \quad \textbf{(16)}$$

4.5 Analytical model

In order to analyze and to compare the two protocols, we assume that the costs for the packet processing at the mobility agents are available. a_{FA}, a_{RFA}, a_{GFA} and a_{HA} can be seen as the time required to process the location update message in FA, RFA, GFA and HA respectively. d_D and d_U present the delay required to send the location update message and the data message for a one hop. These values can be derived from the network by deploying certain measurements. l_1, l_2 ,k, q_1, q_2 , g_1, g_2 , y_1 and y_2 are designed values. Table 1 lists the used parameters in this model:

Table 1. The parameters used in this model

a_{FA}	a_{oFA}	a_{RFA}	a_{GFA}	a_{HA}	l_1	l_2	q_1	q_2	g_1	g_2	d_D	d_U	K
10 µsec	10 µsec	15 µsec	20 µsec	25 µsec	0,01	0,01	0,3	0,3	0,7	0,7	0,5 msec	1 msec	3

$D_{CN,HA}$	$D_{HA,GFA}$	$D_{GFA,RFA}$	$D_{RFA,FA}$	$D_{FA,oFA}$	$D_{HA,FA}$	T_a	w	y_1	y_2	z
10	10	2	2	2	10	10	25	10 µsec	10 µsec	10

We define *CMR* as the Call to Mobility Ratio, which expresses the ratio of the packet arrival rate to the mobility rate. Thus, we can write

$$CMR = T_f * L_a \quad (17)$$

Where, T_f is the residence time in the region of a certain mobility agent. Figure 4 depicts the packet delivery cost in a time unit as a function of *CMR*. The arrival rate L_a varies inside the range from 1 to 1000 packet per second. From this figure we notice that MIFA is more efficient than HMIP especially for large *CMR* values. Thus, MIFA is more adequate for real-time applications.

In the following, we will try to observe the total signalling cost of a session. We assume that the session will take 80 sec. The total signalling cost for the two protocols is depicted in figure 5. We can clearly see that MIFA outperforms HMIP.

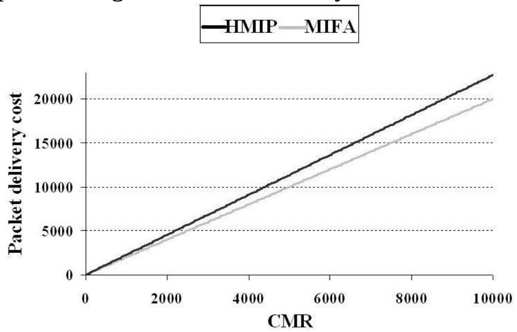

Fig. 4. Packet delivery cost

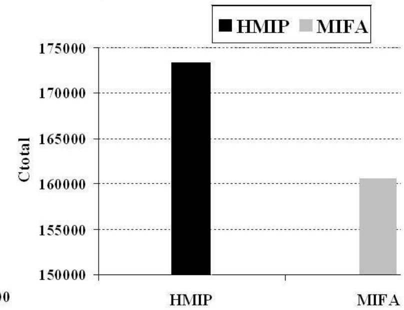

Fig. 5. Total signalling cost

5. Conclusion

In the paper we have designed an analytical model to evaluate the signaling cost of MIFA compared to HMIP. Our analysis shows that MIFA outperforms HMIP with respect to signaling cost. This is because MIFA eliminates the packet delivery costs resulting from the triangular routing by HMIP (from HA via GFA and RFA to the current FA). Additionally, the handoff latency using MIFA does not depend on the distance between the current FA and the HA, similar to HMIP. Thus MIFA performs similar to HMIP when the MN moves within a domain consisting of two hierarchy levels only and outperforms HMIP otherwise. Thus MIFA is more adequate for the real-time applications. Currently, we develop an analytical model to evaluate the signaling costs when using another mobility models and we try to determine the impact of the other parameters on the signaling cost.

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