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Performance Evaluation of the Post-Registration Method, a Low Latency Handoff in MIPv4

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***Abstract*— In this paper we evaluate a low latency handoff protocol for MIPv4, the Post-Registration handoff method. This mechanism proposed by the IETF tries to improve the performance of Hierarchical Mobile IP by decreasing the handoff latency. We give a detailed description of the protocol behavior by means of an ns simulation and propose a simple queuing model to study the influence of various parameters on the protocol performance.**

I. Introduction

Mobile IP [7], the current support for mobility in IP networks, allows node mobility across media of similar or dissimilar types and delivers packets to a temporary address assigned to the mobile host at its current point of attachment. This temporary address is communicated to a possibly distant Home Agent (HA). This approach, applied to an environment with frequent handoffs, might lead to high associated signalling load and unacceptable disturbance to ongoing sessions in terms of handoff latency and packet losses. In such an environment, low-latency handoffs are essential to avoid performance degradation and signalling overhead.

Therefore, a hierarchical mobility management approach has been proposed where Mobile IP supports wide area mobility (e.g. mobility between different operators) while local mobility is handled by more optimised micro-mobility protocols. In that way a HA does not need to be aware of host movements within an access network and a Mobile Node (MN) will keep the same address until it moves to another access network, in which case it will have to notify its HA.

A number of micro-mobility protocols have been discussed in the IETF. These protocols should incorporate a number of important design features related to location management, routing and handoff schemes. They should fulfil requirements such as simplicity to implement, scalability with respect to the induced signalling, efficiency and performance with respect to packet loss and introduced delay.

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The aim of the Post-Registration handoff method proposed in [5] is to achieve low latency Mobile IP handoffs by minimising the period of time that an MN is unable to send or receive IP packets due to the delay in the Mobile IP registration process. This method can support both the normal Mobile IP model [7] in which the MN is receiving packets from a HA and the Hierarchical Mobile IP model [6] in which the MN receives packets from a Gateway Foreign Agent (GFA).

This paper focuses on the performance evaluation of this handoff scheme. We use an analytical model based on the ones developed to model Cellular IP, HAWAII and Smooth Handoff ([1], [2], [3]) that allows computing characteristic performance measures of the handoff schemes. These measures are related to packet loss and experienced delay. The models that are proposed are simple M/M/1 queuing networks that incorporate propagation delays between routers and processing times within routers. The models are not developed for dimensioning purposes, but mainly to investigate the influence of important design parameters and to compare the solutions. For this reason we have assumed Poisson background traffic and exponential processing times. The analytical model is validated through simulation showing the accuracy of the model. The simplicity of the model also allows the study of more general network topologies than the one considered in this paper.

The remainder of this paper is structured as follows. In Section II we describe the Post-Registration handoff scheme. In Section III we present the analytical model. In Section IV we give a detailed description of the protocol as implemented in the simulator using 802.11 as link layer and show the performance improvements achieved with it. In Section V we obtain some performance measures and we validate the analytical model. Finally Section VI concludes the paper.

II. The Post-Registration handoff method

The Post-Registration handoff method is based on a network-initiated model of handoff. It does not require any MN involvement until the actual Layer 2 (L2) connection with the new Foreign Agent (nFA) is completed. The name of this technique finds its origin in the fact that the registration occurs after the L2 handoff is complete. This approach uses bi-directional edge tunnels (BETs) to perform low latency change in the L2 point of attachment without the MN's involvement.

A handoff occurs when the MN moves from the oFA, where the MN performed a Mobile IP registration, to the nFA. Instead of making a new Mobile IP registration with the nFA, the MN delays it while maintaining connectivity using the BET between the oFA and nFA. In [5], two different Post Registration handoff schemes are defined: Source and Target Trigger Post Registration. The sequence of messages for both schemes is depicted in Figure 1.

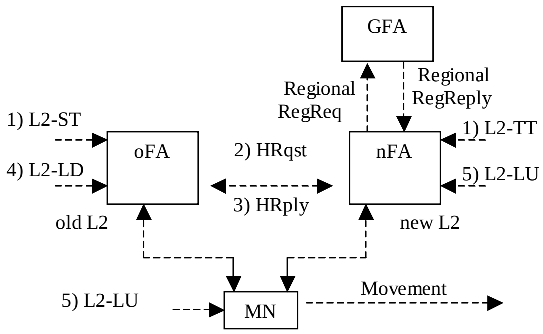

Figure 1. Post-Registration handoff

An FA becomes aware that a handoff is about to occur at L2 through the use of an L2 trigger. Two types of triggers can be received: (i) a source trigger at the oFA (L2-ST), (ii) a target trigger at the nFA. (L2-TT).

The FA receiving the trigger sends a Handoff Request (HRqst) to the other FA. The FA receiving the HRqst sends a Handoff Reply (HRply) to the other FA. This establishes a BET. The L2-LD (Link Down) trigger at the oFA and at the MN signals that the MN is not connected anymore with the oFA.

When the oFA receives the L2-LD trigger, it begins forwarding the MN packets through the forwarding tunnel to the nFA. When the nFA receives the L2-LU (Link Up) trigger, it begins delivering packets tunneled from the oFA to the MN and forwards packets from the MN. When the MN receives the L2-LU, it decides to initiate the Mobile IP Registration process with the nFA by soliciting an Agent Advertisement or continues using the BET. Once the Registration process is complete (through the exchange of a Regional Registration Request and a Regional Registration Reply with the GFA), the nFA takes over the role of oFA.

With optimal L2 trigger information, the FAs can set up the BET immediately after the L2 handoff is initiated, start tunneling MN data when the link to the MN goes down and the nFA can use the link up trigger to start delivering packets.

In the absence of optimal L2 trigger information, the HRply can act as the trigger to start tunneling MN data, but in this case, the period of packet delivery disruption to the MN could still be present and additional measures may be required to provide uninterrupted service.

III. Analytical model for source/target trigger Post-Registration handoff

In this section we present a mathematical model for the Post-Registration handoff scheme based on a queuing network, similar as in [1], [2] and [3]. For computational tractability reasons all routers are modeled as simple M/M/1 queues. The exponentially distributed service time of a packet in each router is assumed to both include the processing time and the transmission time. Denote the service rate of a router A by μ and the load by ρ, then its response time R_A is exponentially distributed with rate $\mu(1-\rho)$. In the remainder of this section we focus on the source trigger case, as the target trigger can be dealt with in a similar way.

Consider an MN moving from the oFA to the nFA, and suppose an overlapping area between the two subnetworks. We assume the L2 handoff starts when the MN enters the overlapping area, and denote this time instant by t_0. In order to model the handoff procedure we define the following variables

- D_{ST}, D_{LD}, D_{LU} : time needed, since t_0, to generate an L2-ST, L2-LD, L2-LU trigger respectively
- D_{MN} : time needed for a message from the nFA to reach the MN (and vice-versa)
- D_{HRqst}, D_{HRply} : time needed for the HRqst/HRply message to reach the nFA/oFA.
- D_{GFA} : time needed for a Regional Registration Request from the nFA to reach the GFA

We consider D_{ST}, D_{LD}, D_{LU} and D_{MN} to be constant positive values, and we have that $D_{ST} < D_{LD} < D_{LU}$. Due to the assumptions, the remaining variables are sums of constants and exponentially distributed variables. We have the following sequence of events:

- t_0 : an L2 handoff starts
- $t_0 + D_{ST}$: a trigger is sent to the oFA
- $t_1 := t_0 + D_{ST} + D_{HRqst} + D_{HRply}$: the oFA receives the Handoff Reply message and the BET is established between the oFA and the nFA
- $t_0 + D_{LD}$: the oFA starts tunneling packets for the MN to the nFA (provided the BET is established)
- $t_0 + D_{LU}$: the nFA starts delivering packets to the MN
- $t_2 := t_0 + D_{LU} + 3D_{MN} + D_{GFA}$: the GFA starts forwarding the packets for the MN via the nFA ($3D_{MN}$ accounts for the FA discovery).

Consider a constant bit rate UDP stream of packets originating from a CN destined to the MN. Assume that every T ms a packet arrives at the GFA. Then each packet of that stream belongs to exactly one of the following classes:

- *Class 0*: packets arriving at the oFA before $t_0 + D_{LD}$; these packets are forwarded directly to the MN
- *Class 1*: packets arriving at the oFA after $t_0 + D_{LD}$ and before t_1 ; these packets are lost

- *Class 2*: packets arriving at the oFA after $t_0 + D_{LD}$ and after t_1; these packets will be tunneled to the nFA via the oFA
- *Class 3*: packets arriving at the GFA after t_2; these packets are forwarded via the nFA

Remark that Class 2 packets are lost if they arrive at the nFA before $t_0 + D_{LU}$.

While travelling to the MN, each packet follows a specific path of routers, according to the class it belongs to. In our M/M/1 queuing model, this path is the sum of some exponentially distributed random variables and constants. Hence the delay distribution of each packet can be computed in a fairly straightforward way. Furthermore the M/M/1 model enables us to compute other performance measures such as the expected number of lost packets or the expected number of packets that need to be tunneled. Details of the computations are omitted in this paper.

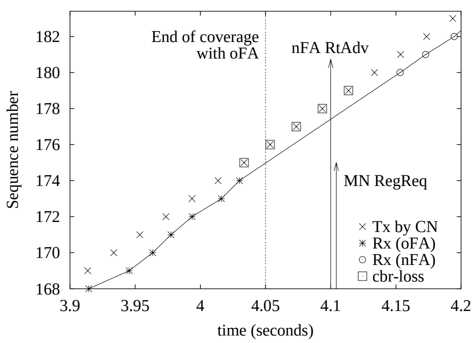

Figure 2: HMIP handoff.

IV. NS SIMULATION MODEL FOR TARGET TRIGGER POST-REGISTRATION HANDOFF USING 802.11 AS LINK LAYER

In this section we describe a possible implementation of the Target Trigger Post-Registration handoff using 802.11 as link layer (L2). We have added the implementation described in this section to the HMIP protocol currently available in the Network Simulator (ns) [8], [9]. In section V we shall use our implementation to validate the analytical model described in section III.

In the ns HMIP implementation given in [8] the handoffs are completely managed at layer 3 (L3). The implementation consists of the FA sending Router Advertisements that are used by the MNs to decide when to handoff to a new FA. However, a drawback of this implementation is that the Router Advertisement rate is rather low, e.g. the MIP specification [7] establishes a maximum rate of one Router Advertisement per second. Therefore, it may happen that the MN receives the Router Advertisement from the nFA that triggers the handoff when it has already moved out of coverage from the oFA. In this case, the packets tunneled to the oFA when the MN has moved out of coverage would be lost. This situation if depicted in Figure 2. The trace shown in this figure has been obtained using the ns with the network topology shown in Figure 3. Here the CN periodically sends UDP packets to the MN. The figure shows the instants when the CN sends the packets (indicated as Tx by CN), and the instants when the MN receives them. These reception instants are depicted differently depending from where the MN receives the packet: from the oFA or the nFA, indicated respectively as “Rx (oFA)” and “Rx (nFA)”. The figure also shows the instant when the nFA sends the Router Advertisement (indicated as nFA RtAdv) that causes the MN to perform the handoff to the nFA by sending a Regional Registration Request (indicated as MN RegReq). Finally, the figure shows the packets that are lost because they are sent by the oFA when the MN has moved out of coverage.

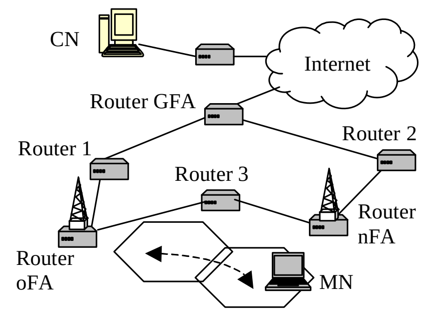

Figure 3: Network Architecture

The drawback of HMIP previously described may be avoided using Target Trigger Post-Registration handoff. This handoff scheme is managed at layer 3, but uses some handoff features of layer 2. As we shall see, the disadvantage of breaking the isolation between layers 2 and 3 is offset by an improvement of the handoff performance.

In 802.11 a layer 2 handoff mechanism has been specified [10]. In this standard the base stations are referred to as Access Points (AP). Before an MN is allowed to transfer data packets to an AP, it has to be associated with this AP. The MN initiates the association by sending an *Association Request* frame, which, in turn, is answered by an *Association Response* frame by the AP. The MN can only be associated with one AP. If the MN decides to handoff to another AP, then it sends a *Reassociation Request* to the new AP.

The APs send L2-beacons used for L2 synchronization purposes. Typically these beacons are sent every 100 ms. Furthermore, the MNs use these beacons to determine which AP would make the best connection, and thus, the *Association* and *Reassociation Requests* are sent to this AP.

By attaching an FA to every AP, we propose the following implementation of the Target Trigger Post-Registration handoff using 802.11: (i) the MN initiates the handoff using the 802.11 beacons as previously described. (ii) The *Reassociation Request* would be the *target trigger* at the nFA as described in section II. (iii) Upon receiving the HRply from the oFA, the nFA would send the *Reassociation Response* to the MN.

Since L2-beacons are sent at a rate much higher than the Router Advertisements, the losses illustrated in Figure 2 are likely to be avoided. This is shown in Figure 4, where we assume that the MN remains for a while under the coverage of both the oFA and nFA. When the MN approaches the nFA, the

L2-beacons sent by nFA triggers the L2-handoff at the MN, which sends a *Reassociation Request* (RAReq in the figure) to the nFA. Upon receiving this frame, there is a *target trigger* at the nFA, which sends the HRqst to the oFA. Upon receiving the HRqst, the oFA sends the HRply and establishes a tunnel with the nFA. In this way, the packets can reach the MN via the nFA after the coverage with the oFA has been lost. Finally, when the nFA sends the Router Advertisement, the MN makes a Registration with the nFA. Note that now no losses occur because the oFA sends the packets addressed to the MN along the tunnel established with the nFA. These packets are indicated in Figure 4 as *tunneled*.

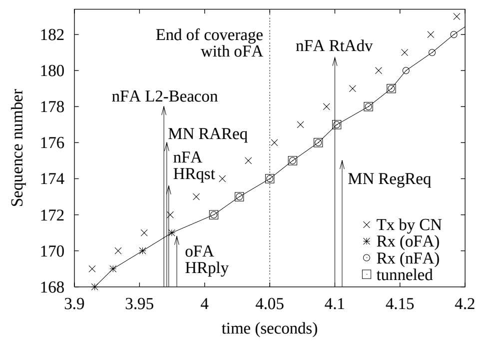

Figure 4: HMIP with Target Trigger-Post Registration handoff.

V. PERFORMANCE EVALUATION OF THE SOURCE/TARGET TRIGGER POST-REGISTRATION HANDOFF

In this section we validate our analytical model for the Target Trigger handoff by means of the ns simulation described in the previous section. Subsequently, the model will be used to illustrate the influence of different parameters (timing of L2 triggers , distance between routers) on the packet loss during a Source Trigger handoff. The results for Target Trigger handoff are very similar.

In order to compare the analytical results with the ns simulations, we have to adapt the model explained in Section III according to the comments made above about using 802.11 as link layer. We assume an overlap period of length D_{ov}. The arrival of the first 802.11 beacon since the beginning of the overlap initiates the handoff (and in that way the instant of arrival replaces the D_{TT} variable). The end of the overlap indicates the loss of connection with the oFA, so D_{ov} is used instead of D_{LD}.

The moment the HMIP Registration Request is sent, is not determined by D_{LU}, but by a variable τ_a which indicates the time between the initiation of the handoff and the nFA router advertisement. In this adapted model, there is no packet loss possible in the nFA. In the oFA, packets are lost if they arrive after D_{ov} and before the tunnel is established.

We assume the network topology as depicted in Figure 3 and we consider a CN that transmits 500 byte packets every T=20 ms. Furthermore, τ_1 represents the propagation delay on the links connecting the Gateway and the oFA and also on the links connecting the Gateway and the nFA, while τ_2 represents the propagation delay on the links connecting the oFA and the nFA.

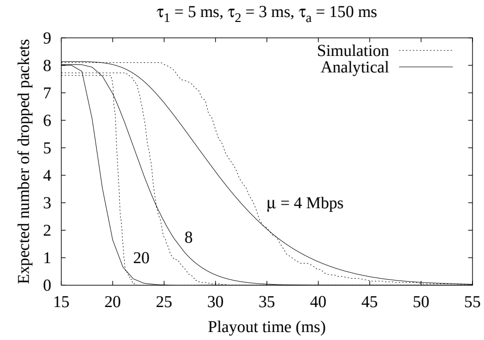

Figure 5: Expected number of dropped packets vs. playout time for variable transmission rate μ

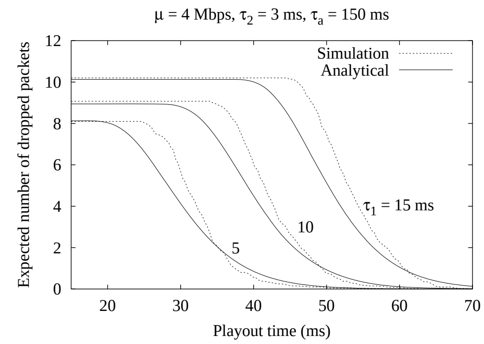

Figure 6: Expected number of dropped packets vs. playout time for variable link delays

The playout time is the maximum allowed end-to-end delay: if a packet's end-to-end delay exceeds this playout time, it will be dropped. The expected number of tunneled packets that are dropped due to expiration of playout time is shown as a function of the playout time, for different values of the transmission rate μ in the routers in Figure 5 and for different values of link propagation delay τ_1 between neighboring routers in Figure 6. We set D_{ov}=100 ms, which implies negligible packet loss probability.

The analytical results are compared against simulation results. One essential difference between the simulation and the analytical model is that we model the routers by means of an M/M/1 approximation, while in the simulation packets have constant length (i.e. they are equivalent to an M/D/1). To compare, we adapted the service rate in the model by matching the average resulting response time in each router.

We see that the simulation curves resemble the ones obtained by the analytical model. The difference between simulation and analytical results is due to the M/M/1 approximation resulting in exponential packet service times, and in particular resulting in response times with a higher variance. Remark that the number of packets in the origin is the average number of packets that use the BET, and that the curves tend to zero, indicating the zero loss probability.

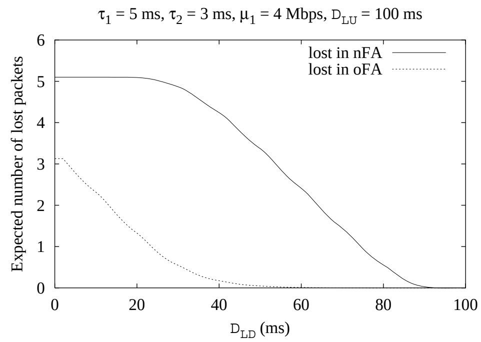

Figure 7: Expected number of packets lost in both oFA and nFA vs. D_{LD}

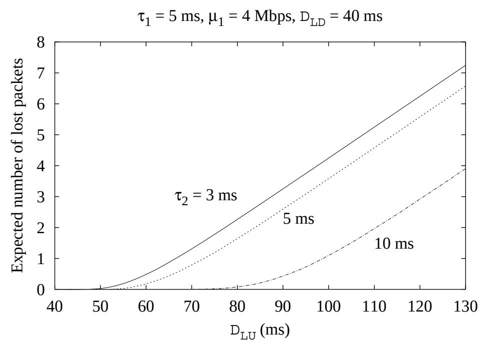

Figure 8: Expected number of packets lost in nFA vs. D_{LU}

Now that we have validated the model, let us compute some other performance measures, using the original model as described in Section III. We will show results for Source Trigger handoff, but similar results can be obtained with the Target Trigger model.

We now have two possible sources of packet loss. First there are Class 1 packets, i.e. packets arriving at the oFA after the L2-LD trigger and before the BET is established. Secondly we have those packets of Class 2 that arrive at the nFA, via the tunnel, before the L2-LU trigger.

Figure 7 depicts the expected number of packets lost in both the oFA and the nFA as a function of the timing of the L2-LD trigger, or D_{LD}. We considered a UDP stream transmitting 500 byte packets, now every T=10 ms. The service rate is set at μ=4 Mbps. Choosing τ_1=5 ms and τ_2=3 ms, the tunnel is established on average about 33 ms since t_0. That is why the expected number of lost packets at the nFA does not increase anymore when D_{LD} drops under 33ms. The number of lost packets at the oFA obviously depends almost entirely on D_{LD}, and converges rapidly to zero after 33 ms.

Figure 8 shows the influence of D_{LU} on packet loss in the nFA. Remark that packet loss in the oFA is not much influenced by the timing of the L2-LU trigger, except when this trigger occurs very early, in which case the HMIP registration can be completed before a tunnel is established. However in this example this possibility is negligible, so we only show the packet loss in nFA.

The service rate and τ_1 are the same as before, while τ_2 is varied. For a given value of D_{LU} the packet loss is higher for lower τ_2, since this means possibly more packets tunneled and certainly tunneled packets arriving earlier. Furthermore, it can be seen that there is an essentially linear relation between the timing of the L2-LU trigger and the number of packets lost.

The observed losses could be avoided using buffers in both the oFA and the nFA. The results of the analysis can be useful for dimensioning purposes.

VI. CONCLUSIONS

In this paper we have analyzed the Post-Registration handoff method proposed by the IETF by means of an analytical model. Furthermore, we have described a possible implementation of one of these protocols (the Target-Trigger Post-Registration handoff) in a 802.11 wireless network. We have added our proposal to the ns simulator in order to validate the analytical results.

The simulation shows how Post-Registration avoids the losses that can happen when using only HMIP and it can be used to obtain its detailed behavior when implementing the handoff method over 802.11.

The performance of the Source and Target Trigger Post-Registration handoff method for constant bit rate real-time (UDP) traffic is characterized by two measures: the expected number of tunneled packets that are dropped due to the expiration of the playout time together with the expected number of packets lost in the oFA and/or nFA depending on the triggers' timing. These losses could be avoided by using appropriately dimensioned buffers in both the oFA and the nFA.

As the results indicate, the timing of the triggers has a major impact on the packet loss rate.

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