On the Performance of Enhanced Hierarchical Mobile IPv6

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***Abstract*—This paper defines a multi-hierarchical architecture of Mobile Anchor Points (MAP) in a micro mobility network to enhance the performance of Hierarchical Mobile IPv6 protocol. By deploying this multi-hierarchical architecture of MAPs the latency of IP handoffs is reduced significantly so that the traffic performance during handoffs can be improved. For this purpose a new multi-Binding Update signalling packet is developed to accelerate the handoff process using a new registration mechanism, with which the MAP can forward the multi-Binding Update message to the next hierarchical MAP level. The acknowledgement message for the multi-Binding Update message will be sent by the last MAP or the Home Agent. Moreover, a modified function for processing the data packets destined to mobile nodes is introduced in MAPs so that the packet overhead can still keep small by avoiding multi-tunnelling that can be resulted from the multi-hierarchy of MAPs without this modification. The investigated proposal is implemented in NS2 and the improvements of the traffic performance are verified by the simulation results.**

***Index Terms*—seamless mobility, smooth and fast handover, hierarchical mobility management, HMIPv6.**

I. Introduction

THE world is getting mobile and the desire for mobile services has rapidly grown recently. Wireless access networks and mobile devices offer the users a lot of possibilities for using the network services anywhere and anytime. The IPv4 protocol now is the basic communication protocol for transferring user data in the networks. IPv6 also will be a main protocol for the packet data networks of the next generation. Although the standardised IPv6 offers some features needed for mobile networking, special protocols still must be developed to support mobility as the IP protocol originally was developed for fixed networks with static nodes only.

Basic mobility support in IPv6 is realized by Mobile IPv6 (MIPv6) [1]. MIPv6 allows users to move within the IP network while connections between the mobile node and its corresponding nodes stay uninterrupted. However, this solution has some drawbacks for mobile nodes, which have time-critical sessions such as internet telephony or streaming video. This is because the MIPv6 cannot provide smooth and fast mobility as the time needed to update mobile node position increases significantly if the mobile node's Home Agent is far away from the visited network. This is the well-known problem with MIPv6 and a lot of solutions have been proposed to eliminate this problem. There are two handoff types – Layer 2 and Layer 3 handoffs. An Access Router may have a few access points connected over a L2 device. If a mobile node moves between two access points connected to the same access router, it has to process a L2 handoff. In case the access points are connected via the different access routers, they are in the different subnets and the mobile node operates a L3 handoff. It configures a new IPv6 address valid on the new wireless link and registers this one according to the MIPv6 functionality. Thus, a L3 handoff consists of L2 handoff and of two further phases (see Figure 1): the first one is to configure a new IPv6 valid on the new link and the second one is to register this address according to the mobility protocol used by the mobile node.

L3 Handoff	**2**. register the new IPv6 address according to the mobility protocol
	1. configure a new IPv6 address valid on the new link
L2 Handoff	**2**. associate with the new Access Point
	1. scan and choose a new radio channel

Fig. 1. Layer 2 and Layer 3 handoff phases

L2 handoff latency in passive scanning mode (up to 2sec. [4, 3]) might be unacceptable for real-time applications. The required time to process a L3 handoff may be even longer, which causes a noticeable disruption of the data connection. Although there are a lot of proposals to reduce L2 and L3 handover latency, none of them can provide an optimal mobility support and many of them must be further improved.

This paper investigates an improvement of the Hierarchical Mobile IPv6 (HMIPv6) protocol [2]. Default HMIPv6 has been further developed to be Enhanced HMIPv6 (eHMIPv6) to reduce the L3 handoff latency, namely to decrease the registration delay.

The paper is organized as follows: Section 2 gives a brief overview of the HMIPv6 protocol as specified by the drafts; in Section 3 the problems of current version of the protocol are presented. Section 4 explains our proposal, the performance comparison of HMIPv6 and eHMIPv6 in various mobile scenarios is presented in Section 5. Analysis and simulation results are discussed in Section 6, Section 7 concludes the paper and delivers an insight into the related future work.

II. Overview of HMIPv6

HMIPv6 is an extension to MIPv6 and IPv6 Neighbour Discovery that allows for local mobility handling. The protocol defines a micro mobility network by introducing a new node called Mobile Anchor Point (MAP), that essentially acts as a local Home Agent. A MAP aims to minimise the processing delay and the amount of signalling messages the mobile node has to send to its Home Agent and Corresponding Nodes. An access router broadcasts Router Advertisement signalling messages with the new MAP option carrying information about available MAPs through the AR. The boundaries of a micro mobility network are defined by the set of access routers sending information about the same MAP to the attached mobile nodes. A MN only registers with a MAP and informs its Home Agent (HA) and Corresponding Nodes (CN) about the Regional Care-of Address (RCoA, an IPv6 address on the MAP's subnet) instead of sending the particular Binding Updates (BU) with the on-link Care-of Address (current location on the AR's subnet) to these nodes. While moving between the ARs within the same micro mobility network the MN only needs to re-register with the MAP, while its RCoA stays unchanged. Thus, the MN sends just one BU to the MAP and thereby the handover processing delay is reduced as the MAP is generally closer to the MN's AR than its HA. A CN is also more distant from the MN than from the MN's MAP. However, a CN might be within the same micro mobility network and then the packet routing via the MAP is inefficient. Therefore, it is necessary to place more than one MAP in micro mobility networks for optimisation of the different mobility scenarios. The mobile node can register with various MAPs and use different RCoAs e.g. for communication to a certain sets of CNs. In the case of a distributed-MAP environment the selection of a MAP gets more challenging, however.

If there are more MAPs in the micro mobility network and the mobile node needs to change the MAP, it has to send a BU message at least to the HA and also to all CNs placed "above" the new MAP. Hence, frequent changing of the MAPs not only does not improve handoff performance, but reduces it significantly. Therefore fast mobile nodes should register with the highest MAP to avoid frequent re-registrations [2]. The problem is that the most distant MAPs can be relatively far away from the MN's AR. The delay to deliver the BU signalling message to the MAP is increased, the handover latency may become too much in this case. Therefore it is better for slow speed mobile nodes to register with the MAPs closest to the ARs. However, the lowest MAPs are connected to fewer ARs, and then the MN changes its MAP more frequently, that increases the handoff latency again.

The problem is even more critical if the mobile node is moving with a high speed and needs for a permanent global mobility. One possible solution would be to use a hierarchy of MAP nodes within the micro mobility network, however the basic version of the HMIPv6 offers some problems in supporting this approach.

III. Problems of HMIPv6 using a hierarchy of MAPs

The problems using a hierarchy of MAPs appear both during the forwarding data packets to the MN and with the registration of the MN at the MAPs.

Using a hierarchy of MAPs forces to route the data packets to the MN from the highest gateway MAP down through the MAP route. A MAP acts as a local Home Agent, it intercepts the packets destined to the MN's RCoA and tunnels them to the registered location of the MN. Thereby the IPv6-in-IPv6 encapsulation is used and every level of the MAP hierarchy adds an additional IPv6 header to the packet. Transmitting data packets using a MAP hierarchy is slower than that with only one MAP. The micro mobility network also is more loaded in this case. The packet delay through a MAP hierarchy may become huge in comparison to the packet delay by using the basic HMIPv6 with only one MAP. Because of the additional overhead due to the regular IPv6-in-IPv6 encapsulation the maximal Ethernet frame size may be exceeded, than the frame must be transmitted using fragmentation, that adds a large extra delay.

The purpose of using a MAP hierarchy is to decrease the second phase of a L3 handoff (see Figure 1) by defining a new node placed as close as possible to the access router of the MN. This allows to decrease the time needed to transfer Binding Update messages to the HA and CNs significantly. However, the MN may not register with the further MAP before it registered with the next MAP lower to the AR. In example shown on Figure 2 the MN must have been registered at the MAP_{AR} before it may register with the MAP_{GW}.

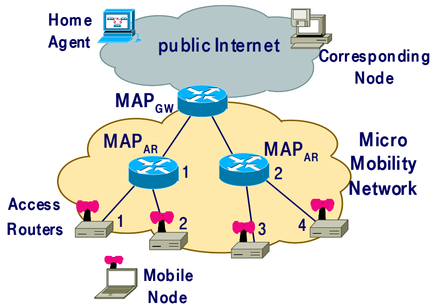


Fig. 2. Using a hierarchy of MAPs

If the MN sends the registration messages to all MAPs at once, the registration at the MAP_{AR} might not be accepted while the registration at the MAP_{GW} is successful. The route to the MN is not established and the data packets cannot be forwarded to the MN. Then the MN must re-register at the MAP_{GW} with the new address on the AR's subnet. Such process is much longer as if the MN used one MAP_{GW} only. To avoid this, the MN must wait for a Binding Acknowledgment (BA) signalling message from the MAP_{AR} at first and only then send a registration message to the next MAP. The registration process is slower if more hierarchies of MAPs are presented in the network. The registration delay using a multi-hierarchy of MAPs is even longer than that with only one MAP in the route. Using a hierarchy of MAPs does not work with the standard HMIPv6 functionality.

IV. ENHANCED HIERARCHICAL MOBILE IPV6 (EHMIPV6)

Although there are many problems as described above, using a hierarchy of MAPs shows a lot of benefits especially in the case where the high speed mobile nodes require permanent and global mobility. The second phase of the L3 handoff (see Figure 1) depends on the time needed to transport the Binding Update messages to the accordant nodes for registration. Packet loss is smaller if the registration process is faster completed. A micro mobility network with a multi-hierarchy of MAPs can be extended to allow the mobile nodes to re-register at the optimal crossover MAP. Therefore the transport delay for registration messages is as short as possible.

The default functionality of HAs and MAPs is to intercept the data packets destined to registered MNs and tunnel them to the Care-of Addresses registered in the Binding Cache. Thereby an IPv6-in-IPv6 encapsulation is used to avoid a corruption of the original packets [1]. However, a new encapsulating packet originated from the HA may include not only an additional IPv6 header for the IPv6-in-IPv6 encapsulation. In [1] a new Routing Header Type 2 is introduced to support packet forwarding without encapsulation that results in smaller overhead. According to [5] a packet with a Routing Header can be modified in flight without any corruption of the payload data. We propose to apply a modified function for processing the packets in MAPs. Figure 3 presents a data packet sent from a CN to the MN and tunnelled in the MN's HA. The HA has intercepted the packet and added two additional headers: standard IPv6 encapsulating header and a Routing Header Type 2.

IPv6 Hdr	RtgHdr 2		
IP_{DEST} = RCoA	IP = MN	IP_{DEST} = MN IP_{SRC} = CN	Payload

Fig. 3. Forwarded data packet structure

Assuming the example on Figure 2, the RCoA address is the Care-of Address (CoA) of the MN on the MAP_{GW}'s subnet. The MAP_{GW} intercepts the packet and finds in its Binding Cache a CoA corresponding to the RCoA, it is the CoA of the MN on the MAP_{AR}'s subnet. The MAP_{GW} changes the IPv6 header only and forwards the packet to the MAP_{AR}. The MAP_{AR} operates in the same way and addresses the packet to the current location of the MN, to its on-link CoA on the AR's subnet. The Routing Header 2 is used to carry the Home Address of the MN as specified in [1]. With the proposed operation mode no additional overhead has been added and the packet can be successfully routed through the hierarchy of MAPs.

Another challenge is the fast registration with all levels of MAPs in the MAP hierarchy. Before registering with a higher MAP the MN must wait for an acknowledgment from a lower MAP to know that its registration request is accepted. Without this confirmation the MN may not send any registration requests to further MAPs. If a MAP within a chosen route declines the MN's registration, the MN must choose another one anyway. One Binding Error only informs the MN about occurred errors. If a MAP accepts a binding request from the Mobile Node, the MN could send the next request to a higher MAP at once. This occurs only when the MN has received the acknowledgment from the first MAP. To speed up this procedure we propose to use a new multi-Binding Update signalling message, that carries registration information for all MAP levels, from the lowest to the highest. An example of such message is shown on Figure 4 for the network presented on Figure 2.

IPv6 Header	Routing Header		Mobility Header #1	Mobility Header #2	Mobility Header #3
IP_{DEST} = MAP_{AR}	IP = MAP_{GW}	IP = HA	Info for MAP_{AR}	Info for MAP_{GW}	Info for HA

Fig. 4. Structure of a multi-Binding Update signalling packet

The MN receives information about available MAPs within the Router Advertisement messages. The MN also chooses all the MAPs it will register with and builds a multi-Binding Update packet. Routing Header Type 0 [5] is used to force the signalling packet to be sent through each MAP chosen by the MN. Some modifications in the Routing Header and Mobile Header modules are requested to process such messages. Figure 5 shows a new algorithm for the operation of the Routing Header module.

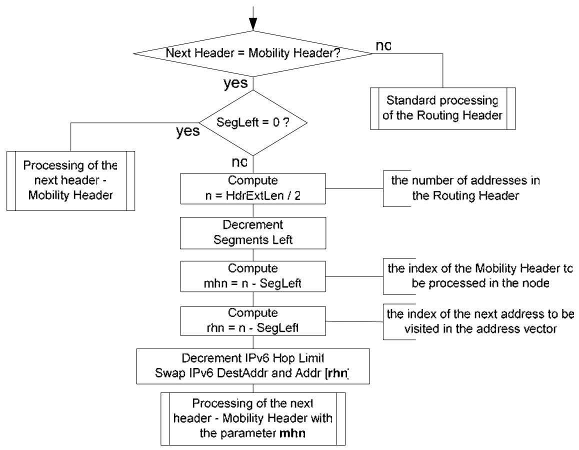


Fig. 5. Enhanced processing of the Routing Header Type 0

The multi-BU message is sent to the MAP_{AR}, that is the closest MAP to the MN's AR. In the MAP_{AR} the packet is processed in the Routing Header module at first. The packet should be processed with a default algorithm in case the next header is not Mobility Header. The following Mobility Header indicates the packet might be a multi-BU message. Swap of the IPv6 Header Destination address and an address from the routing header works as defined in [5]. The main issue is to choose the Mobility Header with the registration information to be processed at the node. The selection of an appropriate Mobility Header works like a choice of an address within the Routing Header to be swapped. The mobility header number, *mhn*, is equal to the routing header number. If the first address in the Routing Header must be swapped with the IPv6 header destination address, the first mobility header contains the information for the node, etc. The calculated value *mhn* is passed to the Mobility Header module so that the appropriate Mobility Header is chosen to process in the node. The functionality algorithm of the Mobility Header module must slightly be changed as shown in Figure 6. In the last node a multi-BU message is addressed to, Segments Left value is 0 [5]. The *mhn* parameter is not calculated, the Mobility Header module processes the last Mobility Header in the packet.

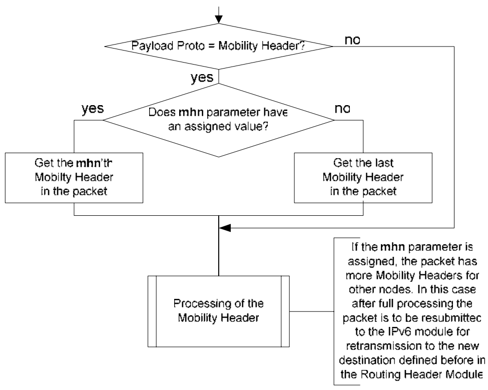


Fig. 6. Processing of the multi-Mobility Headers

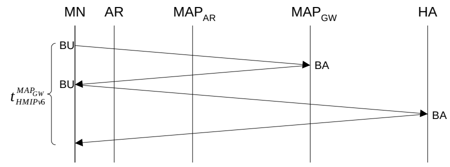
During the processing of the Mobility Header the node either accepts the registration request from the MN or declines it and sends a Binding Error to the MN. In case of successful registration in an intermediate MAP, the node needs not to send any acknowledgment message. The packet will be resubmitted to the IPv6 module to be forwarded to the next node chosen in the Routing Header module by swapping the IPv6 destination address. A Binding Acknowledgement must only be generated from the last node to confirm the registration at all nodes in the route. The registration process is substantially shorter in comparison to the default functionality of HMIPv6 while the benefits of using a multi-hierarchy of MAPs are adopted. Applying the above described operation method the registration process can be accelerated significantly because of reducing the second phase of a Layer 3 handoff.

V. eHMIPv6 vs. HMIPv6

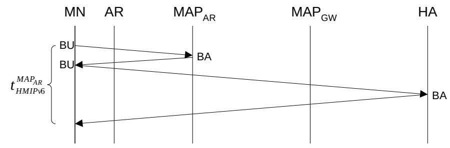
Upon arrival into the new micro mobility network the MN registers with a MAP (HMIPv6) or with a set of hierarchical MAPs (eHMIPv6) and subsequently with its HA to finish the handoff operation. Then if the MN changes its current address within a local MAP domain, it only needs to register the new address with its MAP. In all of the following operation diagrams the network is assumed as shown in Figure 2. The link delays are the same to transfer a signalling message between two adjusted nodes.

a. Arrival into the micro mobility network

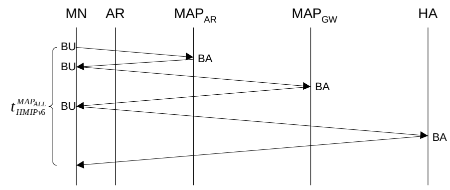
Using HMIPv6 the MN may choose to register either with a MAP_{AR} or with the MAP_{GW}. Then the MN binds its home address with its RCoA on the MAP's subnet at the MN's HA. Figures 7a and 7b show the operation sequence of HMIPv6 if the MAP_{GW} or MAP_{AR} is chosen to serve for the MN. Figures 7c and 7d present the registration delay in case the MN registers with all of the MAP levels using HMIPv6 and eHMIPv6 respectively.



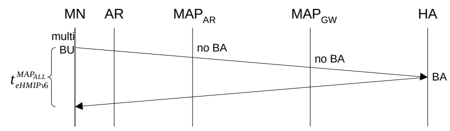
(a) HMIPv6, MN registers with the MAP_{GW}



(b) HMIPv6, MN registers with a MAP_{AR}



(c) HMIPv6, MN registers with all MAP levels



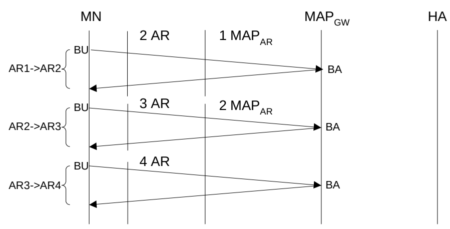
(d) eHMIPv6, MN registers with all MAP levels

Fig. 7. Operation sequences of HMIPv6 and eHMIPv6 at the first registration of MN

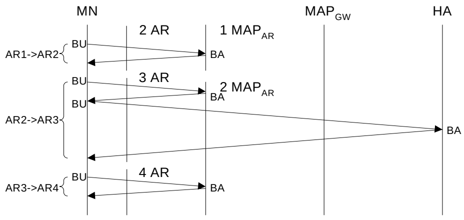
From the diagrams it can be seen that $t^{MAP_{ALL}}_{eHMIPv6} < t^{MAP_{AR}}_{HMIPv6} < t^{MAP_{GW}}_{HMIPv6} < t^{MAP_{ALL}}_{HMIPv6}$. Hence, the registration process with all MAPs using eHMIPv6 is even faster if the MN registers with a MAP_{AR} using HMIPv6. Figure 7c also shows that the HMIPv6 protocol is total insufficient if the MN registers with all MAP levels in the network. Above registration processes occur upon arrival of the MN into the network and by the updating of the timers in case the MN do not change it position. For the handoff efficiency it is more important to observe the registration delays after the MN has registered in the network while the MN changes its position.

b. Moving within the micro mobility network

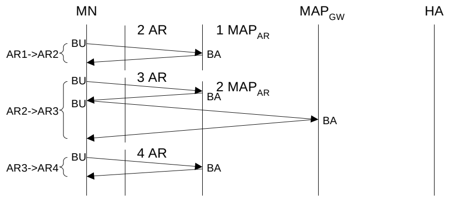
Figure 8 presents the operation sequences of HMIPv6 and eHMIPv6 in case the MN moves from the side left AR1 to the side right AR4. Three handoffs must be processed during the MN's moving, the first registrations shown on Figure 7 are assumed to be completed.



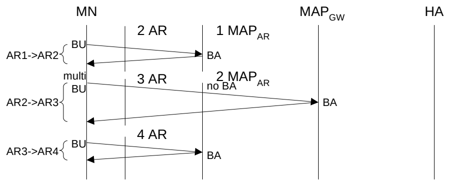
(a) HMIPv6, MN registers with the MAP_{GW}



(b) HMIPv6, MN registers with a MAP_{AR}



(c) HMIPv6, MN registers with all MAP levels



(d) eHMIPv6, MN registers with all MAP levels

Fig. 8. Operation sequences of HMIPv6 and eHMIPv6 during handoffs

Figure 8a shows the HMIPv6 operation if the MN registers with the MAP_{GW}. Only BU messages to this MAP must be sent during handoffs. However, every handoff delay is larger than this one if the MN registers with MAP_{AR}. But in this case (Figure 8b) the MN must re-register with its HA during a handoff between AR2 and AR3 as the MN changes its RCoA. The cumulative latency of three handoffs is the same in these cases. The registration time may be reduced by registering with all MAP levels using HMIPv6, see Figure 8c. Although the processing of a handoff between AR2 and AR3 is not optimal as the MN waits for a BA from the $MAP_{AR}2$ before it re-registers with the MAP_{GW}. Figure 8d shows an optimal registration process by using the eHMIPv6 protocol. No additional delay is added during registration with a hierarchy of MAPs due to the multi-Binding Update messages. The MN also re-registers at an optimal crossover MAP, which significantly reduces the handoff latency. Moreover no additional overhead is added to packets while data forwarding through the hierarchy of MAPs to the MN as described in Section 4.

VI. Evaluation of eHMIPv6

For the evaluation of our proposal we have implemented the developed protocol in the Network Simulator ns2 [6]. Figure 9 depicts the simulated network architecture. The micro mobility network has 3 levels of MAPs: MAPs closest to the ARs – MAP_AR, which are connected together via two intermediate MAP_IM. The gateway MAP_GW connects two MAP_IM. The Home Agent, Corresponding Node and MAP_GW are connected via the “public internet”, Router. Coverage areas of the MN and ARs are shown as circles around these nodes. The access network is built as a Wireless LAN hotspot consisting of “hexagonal” cells.

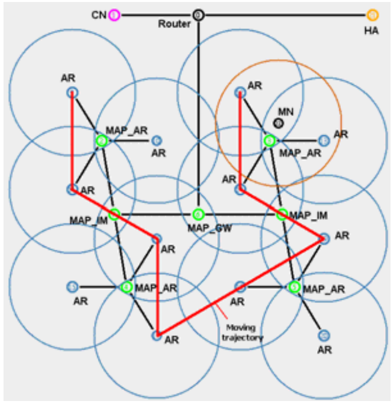


Fig. 9. Simulated network structure

The main objective of our experiments is to assess the benefit of using eHMIPv6 by introducing a hierarchy of MAPs. The eHMIPv6 protocol offers increased performance because of the reduced handoff latency. We have compared the performance of HMIPv6 and eHMIPv6. Thereby using HMIPv6 the MN registers either with the lowest level of MAPs – MAP_AR (HMIPv6 L), either with the intermediate MAP_IM (HMIPv6 M) or with the highest MAP_GW (HMIPv6 H). Using eHMIPv6, the MN registers at all MAP levels.

The performance of an incoming CBR traffic during the MN processes handoffs is presented in Figure 10. The moving trajectory of the MN is chosen in such a way that the MN consequently moves between all two ARs connected to each MAP_AR. The operation of every handoff depends on the applied protocol. It can be seen, that the handoff latency is minimal by handoff between two adjacent ARs connected to a MAP_AR using HMIPv6(L). However in this case the re-registrations with the MN’s HA is more frequent and the handoff latency is too large. By applying HMIPv6(M) the latency of every particular handoff becomes a little more but the MN re-registers with its HA only once. Using HMIPv6(H) no re-registration at the MN’s HA is needed, but the latency of other handoffs is slightly increased.

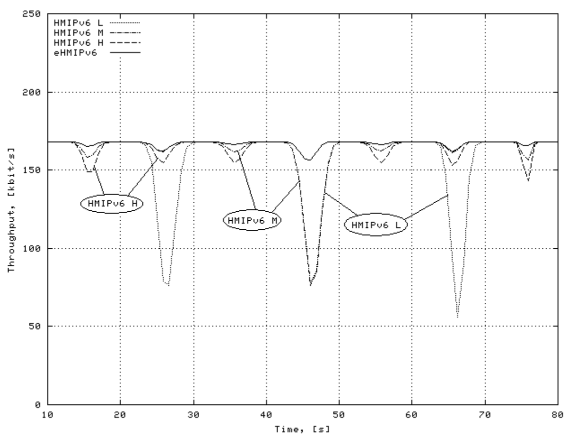


Fig. 10. CBR throughput during handoffs

The eHMIPv6 protocol comprises advantages of all possible HMIPv6 variations. The handoff latency is as short as possible as an optimal crossover MAP always is chosen. Thus the handoff performance is the same as by HMIPv6(L) if the MN processes a handoff between two ARs connected via a MAP_AR. If the MN moves between the ARs connected over a MAP_IM only, the handoff performance is the same as with HMIPv6(M) and if the ARs are connected over the MAP_GW only, the performance of eHMIPv6 is equal to this one of HMIPv6(H).

In the next experiments the MN randomly moves within the coverage area of the simulated WLAN, the performance of incoming FTP traffic is evaluated.

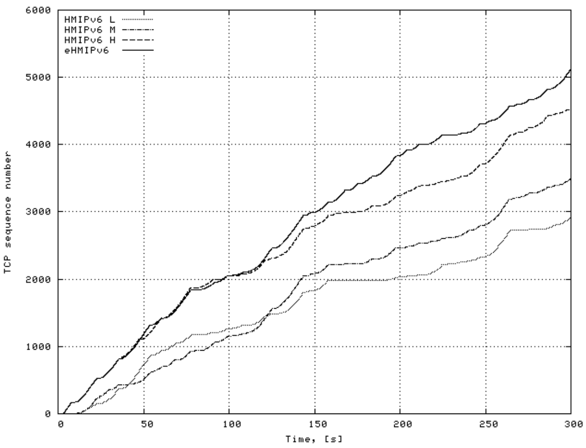


Fig. 11. TCP sequence while the MN moving

Figure 11 depicts the TCP sequence numbers during the MN's random movement. Long pauses in the growth of TCP sequence number are because of handoff processing. During these pauses no new packets are transmitted, TCP only retransmits the unacknowledged packets. The applied protocol impacts the TCP performance as the handoff latencies vary by using the different protocols. In this experiment we can also see that eHMIPv6 provides the best quality due to shortest handoff pauses. It can also be seen that until approx. 125 second the performance of eHMIPv6 and HMIPv6(H) is equal. The explanation is that in this period the MN essentially moves between the ARs connected over the MAP_GW only. In this case the provided quality of both protocols is the same. The performance of HMIPv6(L) and HMIPv6(M) till this point is also approx. equal, as re-registrations at the MN's HA occur by using both HMIPv6(L) and HMIPv6(M). However after 125 second the performance of each protocol differs significantly. The proposed eHMIPv6 protocol provides the best results due to the shortest handoff latencies.

Figure 12 shows the average throughput of FTP traffic depending on the MN's speed.

The results summarize the previous experiment by comparing the average throughput if eHMIPv6 or a variation of HMIPv6 is used. We see, that the worst results are provided by using HMIPv6(L). It validates that the data connections are disrupted at most due to the re-registrations at the MN's HA. The benefit of shortest handoff latencies by moving between two ARs connected via the same MAP_AR is insufficient to compensate these re-registration pauses. The higher the MN's speed the more handoffs are performed to be processed. Thus, the average throughput decreases with increasing speed of the MN.

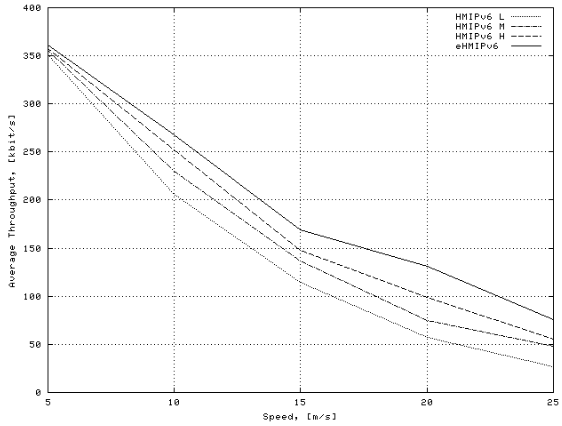


Fig. 12. The impact on FTP performance of MN's speed

Figure 12 also shows that eHMIPv6 provides better results for the high-speed mobile nodes, than any variation of HMIPv6. It verifies the benefits of applying our proposal again.

VII. Conclusion and Future Work

We have presented our proposal to speed up the registration phase of IP handoff by defining a multi-hierarchical MAP architecture in a micro mobility network. A new multi-Binding Update signalling packet was developed to support a new registration mechanism with which the MAP forwards the multi-Binding Update signalling message to the next hierarchical MAP level without acknowledging the accepted registration requests. Moreover, a mechanism for processing the data packets addressed to MNs was modified in MAPs so that the packet overhead that may be caused from the multi-hierarchy of MAPs is avoided.

The simulated results for CBR and FTP traffic show the benefits of our proposal. From these results it can be seen, that the handoff performance is much improved if the proposed eHMIPv6 protocol with a hierarchy of MAPs is used, especially in cases with high speed mobile nodes and more loaded larger mobility networks.

For our future work we plan to implement the developed protocol in our testbed to show the proposed functionality on the real hardware.

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