Handover Optimization in Heterogeneous Wireless Networks: PMIPv6 vs. PMIPv6 with MIH

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Abstract – Next Generation wireless networks are expected to integrate and coordinate heterogeneous communication networks to enable network access ubiquity. Unfortunately, this integration of different networks results in performance degradation when handovers occur among the networks during a mobility event. Thus, there is a requirement for effective mobility management protocols to support ubiquitous network access by providing seamless handover. This paper examines the handover performance of Proxy Mobile IPv6 mobility management protocol when used with and without the IEEE 802.21 Media Independent Handover services in a heterogeneous wireless networks' environment. Our experimental analysis shows that Proxy Mobile IPv6 is an effective mobility management protocol for next generation wireless networks in terms of improving the handover performance metrics such as handover latency and packet loss particularly when used with the IEEE 802.21 MIH services in localized domain mobility scenarios.

Index Terms— Handover delay, Media Independent Handovers services, Proxy Mobile IPv6.

I. Introduction

FUTURE communication networks will consist of heterogeneous access technologies while mobile devices will be equipped with different interfaces to access the different networks. These networks will be inter-networked to realize a ubiquitous network environment. The network layer is the choice for convergence of the heterogeneous wireless networks in the all-IP vision [1]. Thus, mobile users will be able to move among these IP-based heterogeneous wireless networks' environment while maintaining their active connections. IETF has standardized protocols that can support session continuity when user changes location.

However, there is still a requirement to provide effective handover optimization mechanisms to ensure that ongoing sessions are kept active with little or no disruptions particularly to time sensitive applications during a handover process. More so, connections on higher layers such as TCP connections are defined with IP addresses and ports of the communicating nodes, thus the connection breaks if a node changes its IP address, for example, due to movement. Therefore, mobility resulting to handovers among heterogeneous networks disrupts active communications, due to delays and packet losses, which is unacceptable for time-sensitive applications.

For handovers to be seamless, timely information accurately characterizing the network conditions is needed in order for appropriate actions to be taken [2]. Hence, the National Institute of Standards and Technology (NIST) through IEEE recently published the IEEE 802.21 Media Independent Handover (MIH) services standard [3] to enhance handovers across heterogeneous networks.

MIH requires an effective mobility management protocol in order to further enhance the handover optimization performance, particularly in terms of facilitating seamless handover.

While Mobile IP, in particular, Mobile IPv6 (MIPv6) [4] is being considered to be the solution to support mobility in next generation networks (NGN) with IPv6 nodes, it has some weaknesses. For example, it has very high handover latency and packet loss hence not suitable for time-sensitive applications. In particular, as the user mobility increases such as in localized domains, frequent handovers are induced causing service interruptions especially when the user moves to another subnet [5].

Furthermore, MIPv6 is host-based as it involves the mobile node (MN) in mobility-related signaling hence introducing more delay especially when the Home Agent is far away from the MN. Various extensions [6] [7] have been proposed to enhance MIPv6 performance in terms of improving L3-handovers, in particular, for localized environments. Unfortunately, they all involve the MN in mobility-related signaling hence inherit some of MIPv6 weaknesses such as high handover latency, power consumption, high packet loss, and extensive MIPv6 functionality in the IPv6 stack of the MN [8].

The IETF NETLMM working group proposed Proxy Mobile IPv6 (PMIPv6) [9] for standardization as a network-based localized mobility management protocol. In PMIPv6 an MN can be provided service continuity without any mobility function [10] within the MN. If this protocol is intelligently integrated with MIH services, the handover process is improved.

This paper examines the performance of PMIPv6 when used with and without MIH services. In particular, it

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examines the handover delay and packet losses during handover among heterogeneous networks (WLAN and WiMax) in localized environments. Handover delay is the time that elapses between the moment the MN receives its last packet from its old point of attachment (PoA) and the moment it receives its first packet in the new PoA [11]. It is mainly comprised of delays due to network discovery, configuration, authentication, and binding update procedures associated with a mobility event [12]. Handover delay inherently determines the packet loss rate.

The rest of the paper is organized as follows: Related work is reviewed in Section II. Section III, briefly introduces PMIPv6. Section IV presents the simulation scenarios for PMIPv6 with and without MIH services, and discusses the obtained results. The paper is concluded in Section V.

II. Related Work

A lot of research has been done in the area of host-based mobility management among heterogeneous wireless networks recently. More so, next generation wireless networks are expected to interwork heterogeneous wireless networks in an All-IP infrastructure. Thus, network users should be able roam around these networks seamlessly with ongoing sessions. As such, Mobile IP, in particular MIPv6 and its extensions, is touted as the mobility management protocol to support mobility across these heterogeneous networks.

With the recent development by the IETF NETLMM working group towards standardizing a network-based localized mobility management protocol (PMIPv6), some considerable research is ongoing towards using this protocol to further optimize handover performance among heterogeneous wireless networks in localized domains. Also, the recent IEEE 802.21 MIH services are proposed to be used with various mobility management protocols to enhance the handover performance among heterogeneous networks.

Reference [13] proposes a proactive correspondent registration mechanism for PMIPv6 route optimization between a Mobile Access Gateway and a correspondent node (CN). This mechanism is claimed to reduce handover delay and hence enhances throughput degradation, caused by bidirectional tunneling via the Local Mobility Anchor (LMA), by performing correspondent registration before the actual handover. However, the paper is purely analytical and does not give experimental results.

A simple qualitative and quantitative analysis of mobility protocols is presented in [14]. The paper highlights the main desirable features and key strengths of PMIPv6 particularly those that enable it to optimize handover. Handover latency analysis is performed and PMIPv6 is found to perform better than other mobility management protocols. However, a simple analytical model for performance analysis is carried out with no experimental results.

Similarly, [15], [16] and [17] present analytical proposals where PMIPv6 is proposed to work with MIH services to improve handover performance particularly the movement detection and scanning times, which can be very significant during mobility. However, there are no experimental results. Furthermore, in [17], only homogeneous networks are considered. Reference [18] proposes to apply bi-casting in order to provide soft handover.

III. Proxy Mobile IPv6

PMIPv6 is based on MIPv6 as it extends MIPv6 signaling and reuses many concepts such as the Home Agent (HA) functionality. Figure 1 shows the relationship between PMIPv6 and non-PMIPv6 domains in terms of the flow of mobility-related signaling. It can be observed from the diagram that for a non-PMIPv6 domain, the MN is fully involved in mobility-related signaling. On the other hand, in a PMIPv6 domain, the mobility-related signaling is carried out by a network element on behalf of the MN.

The PMIPv6 domain introduces two new network functional entities called Local Mobility Agent (LMA) and Mobile Access Gateway (MAG). The LMA behaves like the HA of the MN in the PMIPv6 domain. Furthermore, it has additional capabilities required for network-based mobility management.

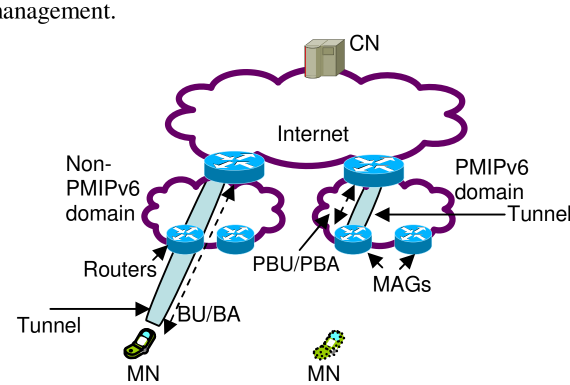

Fig. 1. Illustration of mobility-related signaling flow routes in PMIPv6 and non-PMIPv6 domains.

PMIPv6 is a network-based mobility management protocol that supports a MN in a topologically localized domain by utilizing a network entity called the MAG. The MAG handles all mobility-related signaling on behalf of the MN. It tracks the movement of the MN, authenticates it after attachment and initiates the required mobility signaling on behalf of the MN. A tunnel is established between the MAG and LMA to enable the MN to use the address from its home network prefix. Thereafter, the MAG emulates the MN's home network on the access network for each MN.

Basically, once the MN enters the PMIPv6 domain, the network ensures that the MN is always on its home network and can obtain its home address on any access network [16] in the domain. Thus, the serving network assigns a unique home network prefix to each MN, i.e. Per-MN-Prefix, and conceptually this prefix follows the MN wherever it moves within the PMIPv6 domain [9]. Consequently, it is not necessary to re-configure the care-of-address (CoA) at the MN for every change of PoA, hence handover delay is reduced, effectively. Furthermore, as observed in fig.1, PMIPv6 reduces the binding update delay component of handover delay by reducing the round-trip-time. Also, by the nature of its definition, PMIPv6 eliminates the delay component introduced by Duplicate Address Detection (DAD) in host based mobility management protocols, thus ultimately reducing handover delay.

IV. SIMULATION SCENARIOS AND DISCUSSION OF RESULTS

The simulation was carried out in the NS-2 simulator. One scenario setup implemented PMIPv6 as a mobility management protocol in the simulation of mobility across overlapping heterogeneous wireless access networks, WiMax and WLAN, in a localized administrative domain. The other scenario setup was the same as the previous one but further incorporated MIH functionality in the MN and the MAGs.

Thus, the simulation setup for both scenarios is as shown in fig. 2 below.

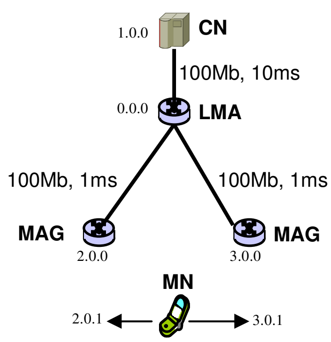

Fig. 2. NS-2 simulation setup

A flow of CBR traffic was simulated and transmitted from the CN to the MN using UDP. The CBR packet size was set to 1000 bytes while the interval between successive packets was fixed at 0.01 seconds.

Below is a table showing the network parameters of the scenario setup.

TABLE I
Network parameters

	CN to LMA	LMA to/from MAGs
Link delay(ms)	10	1
Bandwidth(Mb)	100	100

The MN's ID (assigned by the simulator during MN's creation) is added to the pool of prefixes in the LMA to enable the full MN's address to be used as if it were the MN's prefix as per PMIPv6. This, in turn, enables support for the change of PoA since currently in NS-2 a node's address cannot be changed even when MN changes its point of attachment.

The simulation time was 20 seconds for each of 30 random simulated handovers among the heterogeneous networks and all the outcomes averaged to the same results. For example, in one simulated handover the CBR traffic started to flow between the CN and MN at 0.5 seconds through MAG 1. As per PMIPv6 protocol, Proxy binding update (PBU) and proxy binding acknowledgement (PBA) messages were exchanged between MAG 1 and the LMA for registration purposes before the flow of the CBR traffic. At 1 second the MN started moving towards MAG 2 at a speed of 30m/s. At around 14.334 seconds the MN received its last packet from MAG 1. It next received its first packet from MAG 2 at around 14.776 after performing proxy binding to LMA through MAG 2 which had detected the MN attachment. Thus, the handover delay was about 0.4 seconds. The corresponding number of dropped packets during the handover period was about 38.

As mentioned earlier, the same simulation set-up as in fig. 2 above was used to simulate handover with the mobility management protocol PMIPv6 enhanced with the MIH services. Like in the previous scenario, the PMIPv6 client was installed on the network side, that is, in the MAGs and LMA. Furthermore, the MIH functionality was installed in the MN and the network.

The MIH services introduce various signaling, particularly for handover initiation and preparation, to help enhance the handover performance. Basically, MIH introduces **event services** which help to notify the MIH users such as PMIPv6 about events happening at the lower layers (link layers) such as *link down*, *link up*, *link going down*, etc., and essentially work as layer 2 triggers. It also provides the **command services** which enable the MIH users to control the lower layers, e.g., force change or handover of an interface. Finally, the MIH protocol provides the **information service** through a Media Independent Information Service (MIIS) which provides registered MIH users with the knowledge base of the network and its surroundings. By utilizing these services, the MIH users are able to enhance handover performance, e.g., through informed early decisions and signaling.

The simulation results of the performance comparison in terms of handover delay and packet loss obtained from the simulation of the two scenarios are as shown in fig. 3 below.

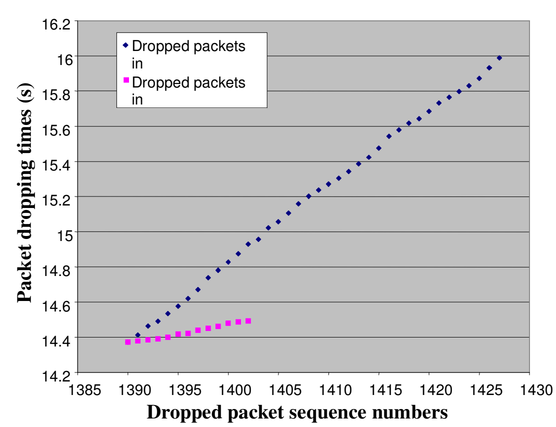

Fig. 3. Illustration of handover delay and dropped packets.

Fig. 3 illustrates the sequence numbers of the dropped packets as well as the times during which they were dropped. The handover delay, therefore, can easily be determined from the graph especially that of the PMIPv6 with MIH scenario. The figure, however, does not easily depict the handover delay due to the PMIPv6-only scenario for a reason that will be mentioned shortly. It can be observed that indeed PMIPv6 with MIH performs better than plain PMIPv6 in terms of handover delay and the number of dropped packets during the handover period. The handover delay in PMIPv6 with MIH was about 0.12 seconds while the number of dropped packets was 13 as observed from fig. 3 above.

In the PMIPv6 with MIH enhancement scenario, the new MAG (MAG 2) starts and finishes the necessary mobility-related configurations such as binding update exchanges earlier than in PMIPv6 without MIH. As a result, the PMIPv6 with MIH scenario completes handover much earlier resulting in shorter handover delay and fewer dropped packets. It is interesting to observe that packets are still being dropped even after the handover process has completed (after about 14.776 seconds) in the PMIPv6 scenario. That is because when the MN changes PoA to MAG 2, the CN would have already sent packets to the MN through the old PoA (MAG 1) and these packets would still be flowing in the network towards MAG 1 while the deregistration process is taking place. These packets, however, are dropped at MAG 1 because the MN would have detached and moved towards MAG 2. Thus, in the graph we observe packets still being dropped after MN has detached from MAG 1, hence the actual handover delay can not be easily read from the graph but can be determined from the ns-2 trace file resulting from the simulation.

By merely using the network-based PMIPv6 mobility protocol the handover delay is reduced when compared to that due to a host-based mobility management scheme [19] such as HMIPv6, for example because of reduced round-trip-time hence reduced binding update delay. The signaling overhead in the air interface is also reduced in PMIPv6 because the mobility-related signaling is exchanged between network elements.

The handover delay is further reduced when utilizing PMIPv6 that is enhanced by the MIH services compared to utilizing plain PMIPv6 without any handover optimizing scheme. With reduced handover delay, the packet loss is also reduced. However, as mentioned earlier, these improvements are obtained at the expense of extra signaling overhead between the network components as well as the MN, as can be observed in the following signaling call flow diagrams. Fig. 4 shows a typical handover operation of PMIPv6 while fig. 5 shows a simplified handover operation of PMIPv6 enhanced with MIH services.

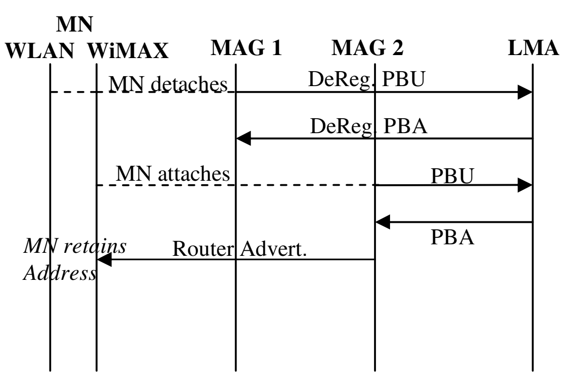

Fig. 4. PMIPv6 handover operation.

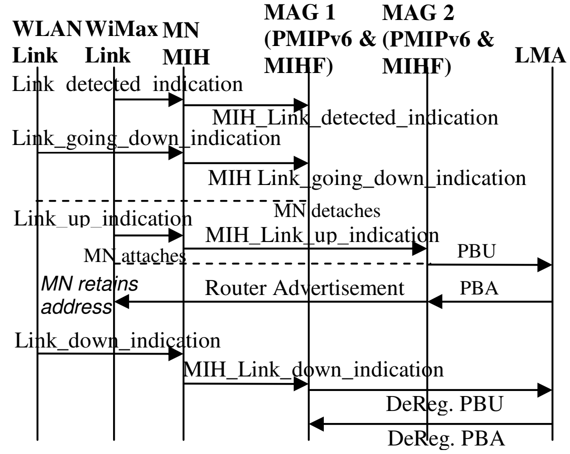

Fig. 5. PMIPv6 enhanced with MIH handover operation.

As can be observed from fig. 5 above, there is ongoing communication between the Media Independent Handover Functions (MIHFs) of all the MIH entities in the networks as long as they are within proximity of each other. This enables early detection of possible movements and link connections or disconnections which in turn enables early initiation and preparation of handover than in plain PMIPv6. For our simulation, we used a double-interface MN with WLAN and WiMax to move between a WLAN access point and a WiMax base station. The WiMax interface on the MN generates a '*link detect'* event when it gets in the vicinity of the WiMax base station. This notifies the MIHF in the MN which then uses the MIH protocol to relay the message to the MAG's MIHF. A '*link up'* event then triggers the PMIPv6 agent in the network to start performing the necessary proxy bindings. This happens immediately the MN senses the new point of attachment (WiMax base station) possibly before the link to the WLAN is disconnected.

Thus, before the MN was disconnected from MAG 1, intensive communication was ongoing between MAG 2 and the MN via the MIH protocol. The MN knew before hand that it would lose the connection with MAG 1 and also new that the next viable point of attachment was MAG 2.

V. CONCLUSION

In this paper we have examined PMIPv6 in terms of handover performance during mobility between heterogeneous wireless networks within the same administrative domain. We have shown that by enhancing PMIPv6 with MIH services, the handover performance in terms of handover delay and packet loss is even better. However, it was noted that there is a trade-off between some handover performance metrics when incorporating MIH services to enhance the handover performance of PMIPv6. That is, to obtain lower handover delay and packet loss, the signaling overhead is sacrificed.

Our future work involves efforts to further decrease the packet losses by designing effective handover schemes to add over the PMIPv6 with MIH scheme. We also intend to address other components of handover delay such as authentication and fetching of MNs policy profiles.

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