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Research Article

Enhancing PMIPv6 for Better Handover Performance among Heterogeneous Wireless Networks in a Micromobility Domain

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This paper analyzes the reduction of handover delay in a network-based localized mobility management framework assisted by IEEE 802.21 MIH services. It compares the handover signaling procedures with host-based localized MIPv6 (HMIPv6), with network-based localized MIPv6 (PMIPv6), and with PMIPv6 assisted by IEEE 802.21 to show how much handover delay reduction can be achieved. Furthermore, the paper proposes and gives an in-depth analysis of PMIPv6 optimized with a handover coordinator (HC), which is a network-based entity, to further improve handover performance in terms of handover delay and packet loss while maintaining minimal signaling overhead in the air interface among converged heterogeneous wireless networks. Simulation and analytical results show that indeed handover delay and packet loss are reduced.

1. Introduction

The rapid expansion of mobile wireless communications over the last few years has spawned many different wireless communication networks. These networks will be interconnected and interworked with each other to offer access to Internet services for mobile users anytime anywhere. Also, the wireless mobile devices are becoming increasingly multimodal, containing multiple communication interfaces such as WLAN, WiMax, and UMTS [1] to access the different networks. Ultimately, the demands for users of the next generation networks to have ubiquitous and seamless access to internet services as they move around different access networks will be met. However, mobility management, in particular nonperceptible handover for active real-time applications such as VoIP, is still a challenge. The handover delay is still too large for time-sensitive services hence a lot of packets are lost during the handover procedures resulting in perceptible disruption to ongoing service sessions. Unfortunately, while mobility management protocols maintain the mobility bindings, they do not provide seamless handover in their current form [2].

Internet access ubiquity for mobile users requires seamless mobility management supported by effective handover mechanisms. These effective handover mechanisms ensure that ongoing communications are kept active with negligible perceptible disruptions during the handover procedures. Moreover, higher-layer connections such as TCP and UDP are defined with IP addresses of the communicating nodes, hence they break if a node changes IP addresses (e.g., due to mobility). Consequently, mobility resulting in handovers typically cause Layer 2 and/or Layer 3 IP mobility latencies and packet drops, thus disrupting current running services [3] and deteriorate quality of experience for the mobile user, particularly with time-sensitive services.

The early widely proposed handover delay reduction schemes are based on host-based mobility management schemes [4]. In particular, Mobile IPv6 (MIPv6) [5] extensions, Hierarchical MIPv6 (HMIPv6) [6] and Fast Handover for MIPv6 (FMIPv6) [7], have been proposed as experimental protocols by IETF to improve handover performance in the next generation networks with IPv6 nodes. HMIPv6 localizes handover binding registration while FMIPv6 performs address preconfiguration and tunnel pre-establishment in an effort to reduce handover delay and packet loss. When used on its own in an end-to-end approach, the basic MIPv6 suffers large handover latencies due to the end-to-end signaling. Thus, HMIPv6 and FMIPv6 are utilized to optimize MIPv6's performance in terms of reducing the handover delay and hence service degradation during the handover process. Generally, the main goal of localized mobility management protocols, for example, HMIPv6, is to reduce handover delay by localizing registration hence reducing end-to-end delay so that seamless service continuity can be achieved. Unfortunately, since host-based mobility management schemes involve the mobile node (MN) in mobility-related signaling, they introduce more delay especially when the home agent (or its peers) is far away from the MN. Furthermore, they result in high packet loss, signaling overhead, power consumption, and extensive MIPv6 functionality in the IPv6 protocol stack [4]. Thus, there are still some challenges pertaining to reducing handover delay with the widely proposed host-based localized mobility management schemes.

However, it has been discovered that for handovers to be seamless, timely information accurately characterizing the network conditions is needed in order for appropriate actions to be taken [3]. Hence, IEEE recently published the IEEE 802.21 Media Independent Handover (MIH) services standard [8] to enhance handovers across heterogeneous networks. Unfortunately, MIH is a bulky standard that has to be incorporated in the MN protocol stack and hence adds some signaling overhead in the air interface, particularly when used with a host-based mobility management protocol.

Recently, Proxy Mobile IPv6 (PMIPv6) [9] has been standardized by IETF [10] as a network-based localized mobility management protocol. Although PMIPv6 performs better than the popular host-based MIPv6 and its extensions in terms of handover performance [11], it still has a long handover delay that is not suitable for time-sensitive applications. In PMIPv6 an MN can be provided service continuity without any mobility function [12] within itself. This feature makes it possible for any MN to be able to get mobility support from any network that implements PMIPv6, as long as the MN has the relevant network access interface and is authorized to get mobility services from that network.

Previously proposed handover solutions, either host-based or network-based, that enhance mobility management protocols introduce new functional elements either at the source access or target access or both source and target accesses to optimize handover performance in terms of handover delay and packet losses. However, these solutions require packets to be buffered at the source access or target access until the MN completes handover procedures. This means that during the actual handover process there is no real-time delivery of packets to the MN. Furthermore, adequate buffer space is required to store the packets during handover. However, as the MN performs the handover, the packets queued in the buffers overflow or get misordered and hence get dropped. Also, some packets get misrouted towards the old path which the MN has detached from and get dropped. Basically, these implementations result in abrupt disconnections from the source network hence perceptible disruptions to ongoing time-sensitive applications during the handover period.

Thus, the contributions presented in this work are (1) the analysis of handover delay for an IEEE 802.21-assisted PMIPv6 architecture when compared with plain network-based PMIPv6 and host-based HMIPv6, (2) a complete enhanced handover process achieved through the introduction of a new network entity, called the handover coordinator (HC), to operate in the overlapping region of interworking heterogeneous wireless networks in a PMIPv6 domain. This HC ensures that packets are delivered to the MN as real-time as possible even during the execution of the handover procedures. Ultimately, the HC enhances the handover performance by further reducing the handover delay and packet loss while maintaining minimal signaling overhead.

This paper focuses on improving the handover performance in micromobility domains because user mobility is higher in these domains hence frequent handovers occur and cause service disruptions, especially when the user moves to another subnet [13].

The rest of the paper is organized as follows. Section 2 gives a brief overview of PMIPv6. Section 3 presents the analytical comparison of handover delay performance in PMIPv6, HMIPv6, and the IEEE 802.21-assisted PMIPv6 schemes. Section 4 presents and analyzes the PMIPv6 with Handover Coordinator architectural framework. The simulation scenario and results are presented in Section 5 while Section 6 concludes the paper.

2. Overview of Proxy Mobile IPv6

PMIPv6 extends MIPv6 signaling and reuses many concepts of MIPv6 such as the Home Agent (HA) functionality. Figure 1 below illustrates the relationship in terms of the signaling paths for mobility-related signaling in network-based PMIPv6 and host-based MIPv6 domains.

PMIPv6 introduces two new network functional elements called Local Mobility Agent (LMA) and Mobile Access Gateway (MAG) [9]. The LMA behaves like the HA of the MN in the PMIPv6 domain. It also has additional capabilities required for network-based mobility management.

PMIPv6 supports an MN in a topologically localized domain by utilizing the MAG entity. The MAG collocates with the access routers and handles mobility-related signaling on behalf of the MN. It tracks the movement of the MN, initiates the required mobility signaling, and ensures that the MN is authenticated before receiving network-based mobility services [9]. A tunnel is then established between the MAG and LMA so that the MN can be able 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.

While the MN is in the PMIPv6 domain, the protocol ensures that the MN is able to obtain its home address on any access network [14] as long as it roams in the domain. That is, the serving network assigns a unique home network prefix, Per-MN-Prefix, to each MN, and this prefix conceptually follows the MN wherever it goes within the PMIPv6 domain [14]. As a result, there is no need to reconfigure the address configuration at the MN every time it changes its point of attachment. This, in effect, optimizes the handover performance by reducing the latency

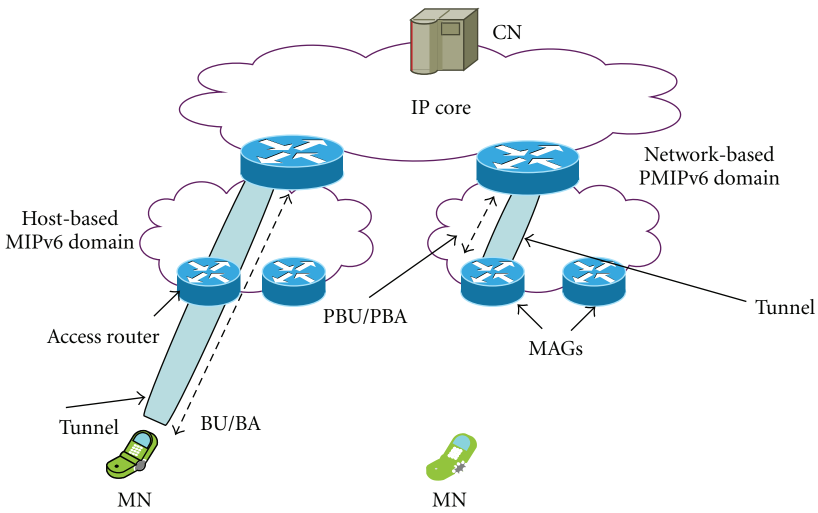

Figure 1: Illustration of mobility-related signaling paths in PMIPv6 and non-PMIPv6 domains.

due to address configuration. Also, since a network element performs mobility-related signaling on behalf of the MN, PMIPv6 reduces the binding update delay by reducing the round-trip time, thus reducing handover latency.

3. Analytical Comparison of Handover Delay Performance

3.1. Proxy Mobile IPv6. The typical signaling call flow diagram of handover in a PMIPv6 domain is shown in Figure 2. Notably, the binding registration messages are initiated from the MAG, which is in the network infrastructure, as opposed to host-based mobility management schemes such as HMIPv6 (as will be seen later) where the same signaling is initiated from the MN.

For clarity, the round-trip signaling call flow diagram showing the handover latency during MN handover to a new MAG in a basic PMIPv6 domain is shown in Figure 3. Evidently, the handover delay in PMIPv6 is due to many procedures that take place during handover: the attachment notification delay due to the event that informs the MAG of an MN's attachment D_{ATTACH}; the authentication delay (query(Q) and reply(R) messages) due to the MAG verifying if the attaching MN is eligible for network-based mobility management service $D_{\mathrm{AUTH}} = D_Q + D_R$; another authentication delay where the LMA verifies the authenticity of the MAG sending the proxy binding update $D_{\mathrm{AUTH\_2}} = D_{Q2} + D_{R2}$; the proxy binding registration delay $D_{\mathrm{BINDING(PMIPv6)}} = D_{\mathrm{PBU}} + D_{\mathrm{PBA}}$ where the MAG performs mobility-related signaling on behalf of the MN; the router advertisement delay D_{RA} where the MAG advertises the necessary information, some of which is obtained from the LMA, for the MN to know its default access router; the actual IP configuration delay D_{CONF}, and the duplicate address detection (DAD) delay D_{DAD}. DAD is for checking if the local address configured by the MN is not already configured by another MN in the same MAG link. In fact, D_{CONF} and D_{DAD} are not appreciable when the MN is already roaming in the PMIPv6 domain.

Delays are inevitable during vertical handover although they can be optimized or reduced (or made transparent to the active connections). The various delays during the handover process between MAGs in the PMIPv6 domain contribute differently to the overall handover latency. Hence, active real-time communication which an MN might be having with a correspondent node (CN) may be interrupted due to the handover latency which normally results in packet losses.

It should be appreciated that the handover delay is lower in PMIPv6 when compared to that in a host-based localized mobility management schemes by virtue of having the MN not getting involved in mobility-related signaling. That is, the binding update delay is shorter in PMIPv6 since it is carried out by a MAG (which is in the network infrastructure) instead of the MN which is usually further away from the LMA than the MAG is.

Also, since in a PMIPv6 domain the MN keeps its address configuration as long as it is inside the domain, the IP configuration and DAD process delays are negligible, unlike in host-based mobility management where these processes are performed completely anew every time an MN changes its point of attachment in the domain.

Thus, overall handover delay in basic PMIPv6 is the sum of the individual delay components:

$$D_{\mathrm{PMIPv6}} = D_{\mathrm{ATTACH}} + D_{\mathrm{AUTH}} + D_{\mathrm{AUTH\_2}} + D_{\mathrm{BINDING(PMIPv6)}} + D_{\mathrm{RA}}. \tag{1}$$

We assume that $D_{\mathrm{ATTACH}} \neq D_{\mathrm{RA}}$ since the router advertisement (RA) and MN attachment signals carry different messages hence are bound to encounter different delays.

Also, according to [9] the MAG can learn the MN's link-local address by snooping DAD messages sent by the MN for establishing the link-local address uniqueness on the access link. Subsequently, the MAG can obtain this address from the LMA at each handover to ensure link-local

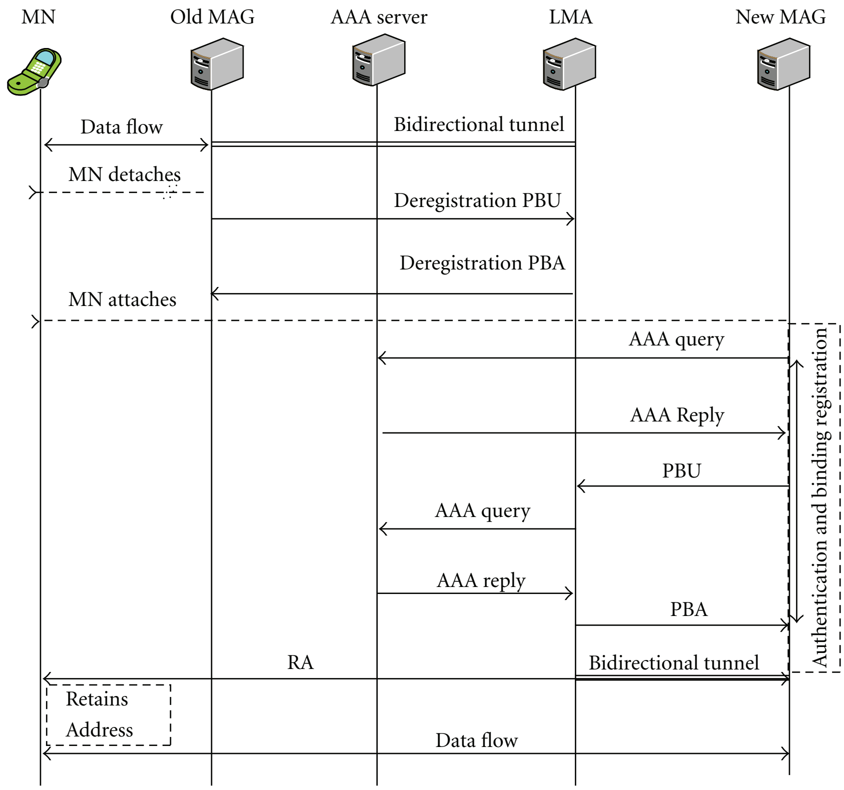

Figure 2: Signaling Call Flow of MN handover in PMIPv6 domain.

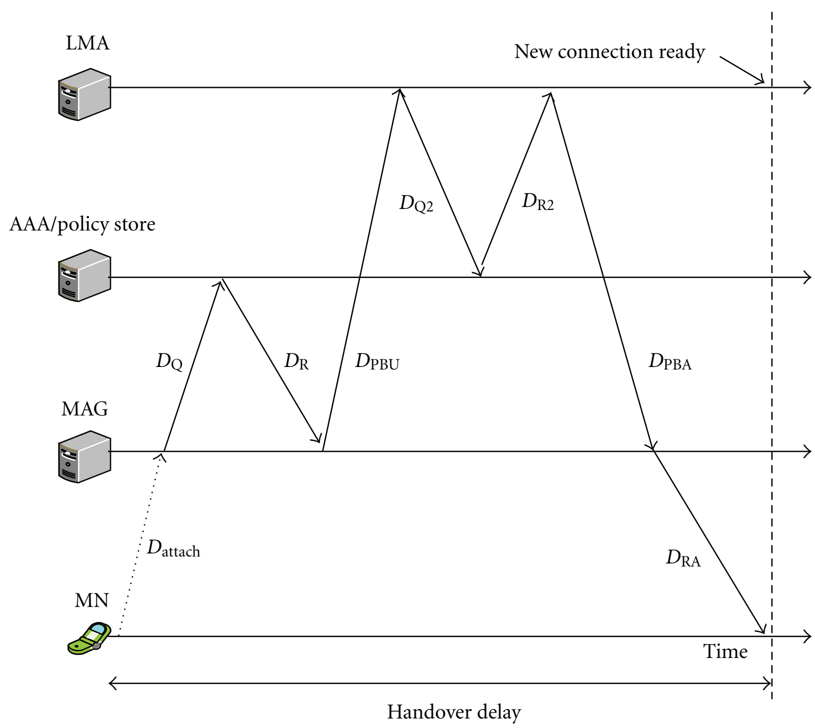

Figure 3: PMIPv6 signaling call flow showing handover delay components.

address uniqueness (LMA is assumed to have the overall knowledge of the PMIPv6 domain) and change its own link-local address if it detects a collision. Thus D_{DAD} is not appreciable.

3.2. Hierarchical MIPv6 (HMIPv6). Figure 4 shows a typical signaling call flow diagram for a host-based localized mobility management scheme, HMIPv6.

It is evident from the above figure that the MN is directly involved in mobility-related signaling. Therefore, the binding registration (BU and BA) time is longer in a host-based localized mobility management scheme than in a network-based localized mobility management scheme. We are assuming that both the PMIPv6 and HMIPv6 domains have single-level hierarchical structures, and only the MNs are mobile. Thus, $D_{\text{BINDING(HMIPv6)}} > D_{\text{BINDING(PMIPv6)}}$, where $D_{\text{BINDING(HMIPv6)}} = D_{\text{BU}} + D_{\text{BA}}$. Also, movement detection delay $D_{\text{MD}} = D_{\text{RS}} + D_{\text{RA}}$ and D_{DAD} are known to be long and time-consuming operations that can degrade handover performance significantly in host-based mobility management schemes as mentioned in [11]. Therefore, $D_{\text{MD}} > D_{\text{ATTACH}}$ where $D_{\text{ATTACH}} \approx D_{\text{RS}}(\neq D_{\text{RA}})$. The handover delay in HMIPv6 is

$$D_{\text{HMIPv6}} = D_{\text{MD}} + D_{\text{BINDING(HMIPv6)}} + D_{\text{AUTH}} + D_{\text{CONFIG}} + D_{\text{DAD}}. \tag{2}$$

Hence, in terms of PMIPv6 delay notation, $D_{\text{BINDING(HMIPv6)}} \approx D_{\text{PBU}}+D_{\text{PBA}}+D_{\text{ATTACH}}+D_{\text{RA}}$ and $D_{\text{MD}} \approx D_{\text{ATTACH}} + D_{\text{RA}}$. Of note is that according to [9] the MAG in PMIPv6 only sends the router advertisement (RA) after completing the binding registration with the LMA, unlike in HMIPv6 where RA is sent to MN before binding registration. The handover delay in HMIPv6 in terms of PMIPv6 delay notation is

$$D_{\text{HMIPv6}} = 2D_{\text{ATTACH}} + 2D_{\text{RA}} + D_{\text{BINDING(PMIPv6)}} + D_{\text{AUTH}} + D_{\text{CONFIG}} + D_{\text{DAD}}. \tag{3}$$

Furthermore, an HMIPv6 mobility stack is added in the MN's protocol stack as opposed to the PMIPv6 scenario where the addition of a mobility stack is not necessary as long as the MN roams within the PMIPv6 domain. This mobility stack adds complexity to the MN as well as signaling overhead in the air interface.

3.3. IEEE 802.21-Assisted PMIPv6 Scheme. The IEEE 802.21 MIH technology defines information exchanges that provide topological and location-related information of service networks; timely communications of wireless environment information; commands that can change the state on the wireless link. In fact, these functions are provided by the Media Independent Handover Function (MIHF) which employs three functional components, namely, Media Independent Information Service (MIIS), Media Independent Event Service (MIES), and Media Independent Command Service.

MIIS provides static information about characteristics and services of the serving and neighboring networks. With the necessary information, an MN may discover available neighboring networks and communicate with elements within these networks a priori to optimize handover. MIES offers services to upper layers by reporting dynamically changing lower layer events. These services are normally triggered by events which are based on reports on throughput, packet loss, signal strength, and so forth, of the lower layers. MICS is provided to the upper layers to enable them to control and manage the handover-related functions of the lower layers. In fact, the MICS commands are used to execute higher-layer mobility and connectivity decisions to the lower layers.

Thus, basically MIH services provide a report mechanism that conveys useful network status information to entities where a decision is made to cause a command to be executed at some specific network elements to facilitate seamless handover. Hence, the handover process is facilitated by the information provided from the network to the MN, in addition to the information that the MN collects from the lower layers. This cooperative information exchange enhances handover optimization.

With IEEE 802.21 MIH services, the MN and the PMIPv6 domain network entities, in particular the MAG in the access routers, are informed about the values of the relevant parameters necessary in handover decision making prior to the actual handover process. Furthermore, intelligent handover decisions to optimal subnets can be made with collaboration between the MN and the network entities. Thus, the MIH services enhance network discovery, preparation, and selection. The IEEE 802.21-assisted PMIPv6 scheme exploits the services of the MIHF, in particular MIIS to reduce handover delay, for example, the access authentication delay component which can cause significant delay in network-based mobility management handovers.

MIH services enable some operations to be performed prior to the handover process while the MN is still connected to the old MAG's link. Thus, when the handover is eventually performed, there will be fewer delay causing procedures executed. For example, the authentication delay is dealt with by enabling the new MAG to preauthenticate the MN ahead of time.

Utilizing the MIIS service, the MN and MAG get to know of their heterogeneous neighboring networks' characteristics by requesting from information elements at a centralized information or MIIS server (which may collocate with a policy store and AAA server). The information server is assumed to be collocated with the LMA in this paper as shown in Figure 5.

The information elements in the server provide information that is essential for making intelligent handover decisions, such as, general information and access network-specific information (e.g., network cost, security, QoS capabilities, service level agreements, etc.), point of attachment specific information (e.g., proxy care-of-address, data rates, MAC addresses, etc.), and other access network specific information.

Dynamic information such as attached MNs' policy profiles together with authentication information (with relevant cookies) and stable identities of the MNs is also included in

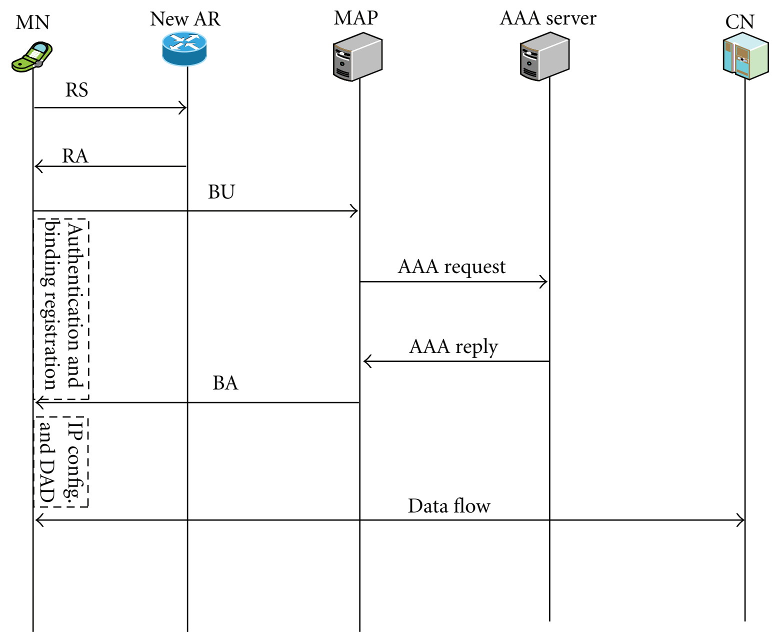

Figure 4: HMIPv6 domain handover signaling call flow.

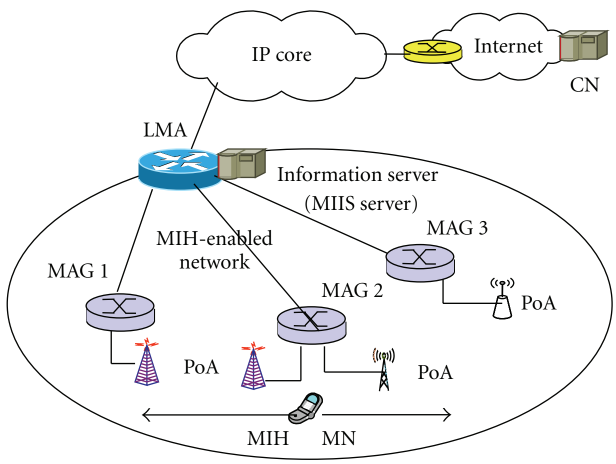

Figure 5: IEEE 802.21-enabled PMIPv6 domain and Mobile Node.

the information server. Consequently, every MAG is always aware of its neighboring environment by utilizing MIIS to get information by requesting from the information elements in the central information server.

The MIH services, that is, MIES and MICS, are triggered by different dynamic events such as the attachment or detachment events of an MN in a MAG and varying handover decision-related parameters exceeding predefined thresholds. In particular, the MIES service notifies relevant handover decision engines about imminent handover while also updating the information server. Maintenance of the information server is very feasible since the localized PMIPv6 domain is possibly administered by a single operator or by cooperating service providers.

Assuming a trust relationship between the MAGs in the IEEE 802.21-enabled PMIPv6 domain and through the utilization of proactive signaling deliberations via MIH services between the MAGs (on behalf of the attached MNs) and the Information server, a new MAG will immediately get information about MNs attaching to neighboring MAGs including authentication information. For example, when an MN is handing over from an old MAG (e.g., MAG 1) to a new MAG (e.g., MAG 2), then MAG 2 would already be having information about the MN ahead of time through the MIIS server. On obtaining the information from the server, MAG 2 authenticates the MN ahead of time in anticipation of a handover towards itself (MAG 2) in the near future. Thus, technically the MN is attached (hence, $D_{\text{ATTACH}} \to 0$) to MAG 2 if its service requirements pass some call admission control procedures. However, no resources are reserved until the actual handover happens, and the MN has literally attached to MAG 2's link. The assumption is

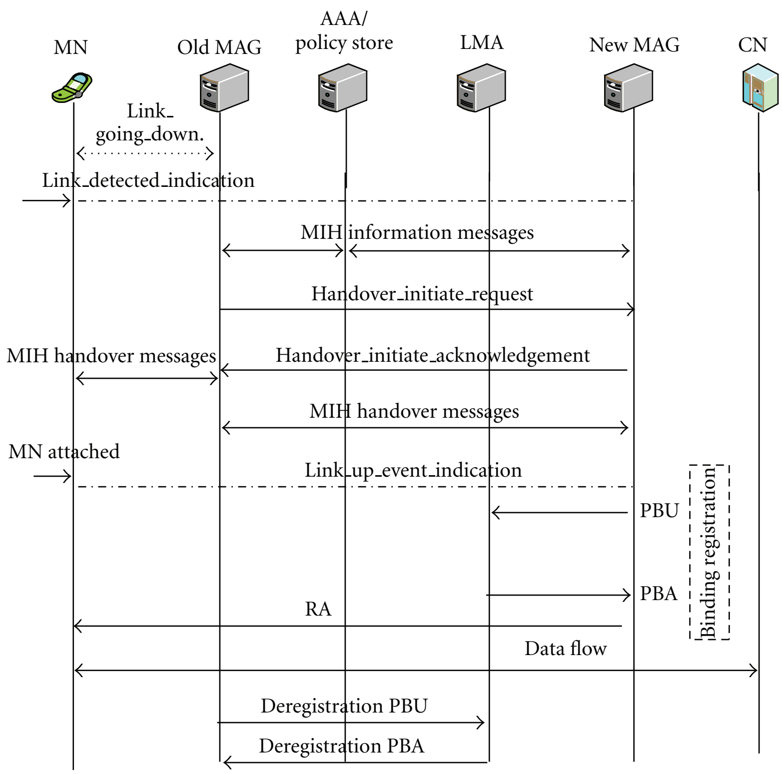

Figure 6: Signaling call flow for IEEE 802.21-assisted PMIPv6 handover process.

that MAG 1 has already authenticated the MN and sent the MN's authentication information (with relevant cookies) and policy profile to the information server through MIH services since it (MN) is already in the PMIPv6 domain and receiving as well as sending information to correspondent nodes (CNs) before the handover.

Ultimately, the authentication procedure, as well as the attachment notification phase is eliminated from the actual handover process hence reducing handover delay. In that way, the actual handover will not be impeded by authentication and attachment delays. However, the early authentication process comes with the expense of reduced security. To increase the security provision, the authentication procedure will have to be performed normally once the handover completes, and the MN has literally attached to the new MAG. To save resources, once an MN leaves the domain or becomes inactive for a certain predefined period, all its information is deleted from the information server.

Thus, from the above discussion we can deduce that the handover delay due to the IEEE 802.21-assisted PMIPv6 scheme is significantly reduced to

$$D_{\text{PMIPv6(802.21)}} = D_{\text{BINDING}} + D_{\text{RA}}. \tag{4}$$

A typical signaling call flow for the IEEE 802.21-assisted PMIPv6 is as shown in Figure 6. However, for clarity, the details of the involved specific MIH information messages and handover message primitives are not shown in the figure. Instead, they are collectively depicted as MIH information updates and MIH handover messages.

Thus, the reduced handover delay will ensure minimum service disruption for delay sensitive services.

In utilizing the MIH services, the authentication procedure is performed in the new point of attachment while the MN is still attached to its old MAG hence reducing handover delay which normally disrupts real-time service continuity during the actual handover. PMIPv6, on the other hand, reduces binding update delay hence ultimately reducing the handover delay. Unfortunately, signaling overhead in the air interface is sacrificed.

Having discussed an IEEE 802.21-assisted PMIPv6 scheme, which reduces handover delay and packet loss while trading-off signaling overhead during handover, we introduce a novel mechanism that enhances handover performance in terms of further reducing handover delay and packet loss while maintaining minimal signaling overhead.

4. PMIPv6 with Handover Coordinator (PMIPv6-HC)

Figure 7 below depicts the architectural framework of PMIPv6 with Handover Coordinator mechanism [15] to further improve handover performance.

4.1. Handover Coordinator (HC). The HC is an internetworking multiple-interface base station level entity operating in the overlap area of the interworking heterogeneous wireless networks in a PMIPv6 domain.

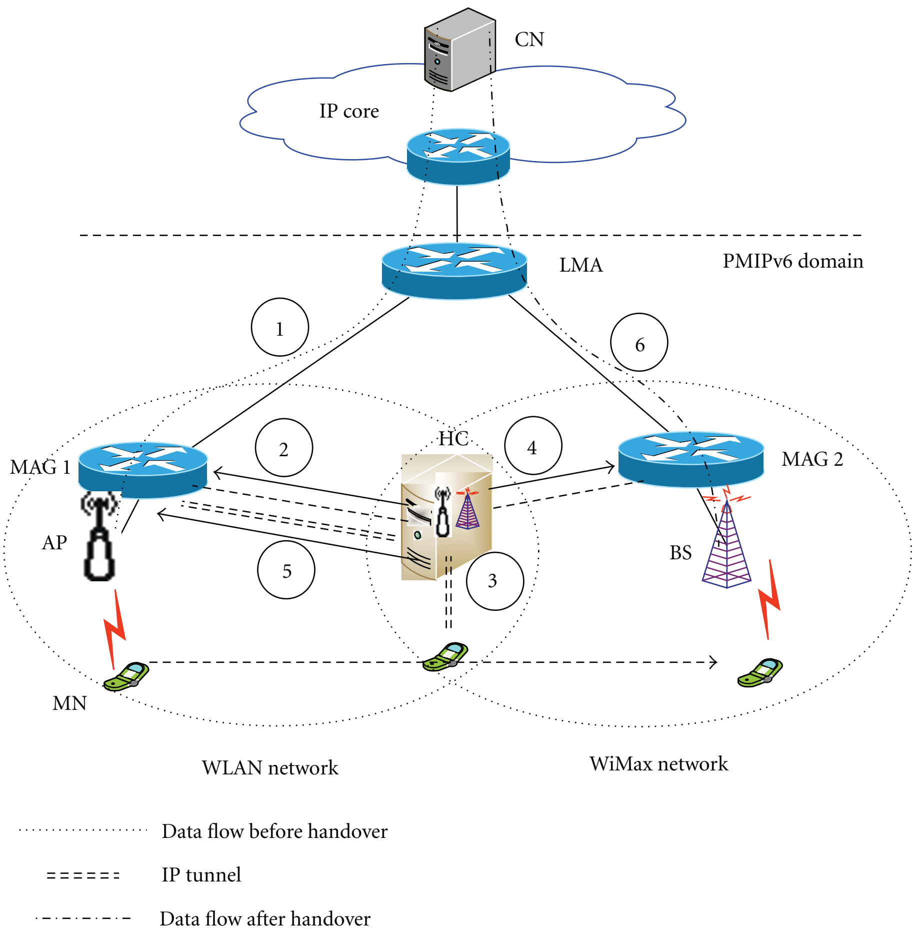

Figure 7: PMIPv6-HC architectural framework.

The HC has different functions that facilitate seamless handover with negligible handover delay and packet loss among the heterogeneous networks in the PMIPv6 domain. The functions include real-time data relaying, MN tracking in the overlap region, and facilitation of MN preauthentication and preregistration. Furthermore, the HC triggers relevant network elements in advance notifying them of imminent MN attachment or detachment. Thus, signaling steps during the actual handover are reduced hence reducing the handover delay and ultimately the packet loss.

Adding the HC as a stand-alone network entity is advantageous in that it reduces the impact of failure in the network. That is, the network will still run perfectly with its default mobility management protocol (e.g., PMIPv6) although with reduced handover performance if the HC fails. We assume that PMIPv6 is already implemented to support mobility among the heterogeneous networks in the domain. The HC is basically an added-value service that provides seamless and soft handover between the heterogeneous wireless networks. The partially overlapping networks utilize the services of this common network-based HC to achieve seamless handover between them.

Since the HC is network-based, it provides a handover solution that enables easier implementation of handover policies by operators and providers based on business and operational requirements. For example, network operators are able to easily manage handovers while ensuring proper traffic load balancing. After all, operators who have the ability to switch a user's session from one access technology to another can better manage their networks and better accommodate service requirements of their users [16].

The HC coordinates handover activities for the MN by communicating with both the old MAG (e.g., MAG 1) and new MAG (e.g., MAG 2) when the MN enters the overlap region. Thus, it performs handover functions on behalf of the MN. Normally, an MN attaches to a MAG through connecting to an access point (AP) or base station (BS). However, for simplicity, in this paper we omit the mentioning of AP or BS.

The implementation of the PMIPv6-HC handover scheme is focused mainly on the proof-of-concept in terms of demonstrating the capability of the scheme to reduce handover delay and packet loss without incurring extrasignaling overhead in the air interface. Thus, network discovery and selection, for example, in a scenario where there are more than two overlapping access networks (MAGs) in the heterogeneous network, have not been considered.

When the MN is attached to MAG 1, as shown in Figure 7, data packets from a CN (outside the domain) flow to the MN as shown by step 1. As the MN gets further away from MAG 1 and enters the overlap region, it starts observing a *link_going_down* event with respect to the signal strength from MAG 1 and hence realizes that a handover is imminent. At this predefined threshold (threshold 1), the MN generates a handover trigger signal which it sends to the HC via the currently attached network (the MN still has enough strength to send this signal). The IP address of the HC is either configured by the operator in the MN or is discovered through DHCP or obtained through periodic advertisements by the MN in the overlap region. The overlap region is the vicinity of operation of the HC.

The HC is carefully configured with specially set power levels to cover the overlap region. When the HC receives the signal from the MN via MAG 1, it automatically knows that the MN is about to handover to another access network (e.g., MAG 2's WiMax access). Thus, the HC requests MAG 1 (as illustrated by step 2) to send subsequent incoming packets destined to the MN via itself (HC). In effect, the HC can also be seen to extend the signal range of MAG 1 just enough for the MN to continue receiving packets as real-time as possible and without errors as it traverses the overlap region. The HC establishes a communication with the MN through an IP tunnel via the corresponding interface (e.g., AP) and uses PMIPv6 functionality to coordinate the initiation and preparation of handover procedures among the respective MAGs in the background. Subsequently, MAG 1 forwards the packets destined to the MN via the HC which relays them in real-time through the IP tunnel to the MN (step 3) in the overlap region. The HC continues to track the MN, through link-layer mechanisms, for packet delivery as long as the MN is in its vicinity of operation, that is, the overlap area.

As the MN decapsulates the received packets in the overlap region it realizes that it is receiving them via the HC, hence automatically assured that a handover has begun. Thereafter, within a predefined short period it momentarily switches on (wakes up) its other interface resulting to the activation of the corresponding interface (e.g., BS) in the HC. Thus, the HC generates an imminent attachment notification signal which it sends to the next MAG (step 4). Note that the MN is still receiving data packets as real-time as possible via the HC while handover procedures are concurrently happening in the background.

On receiving the notification, MAG 2 is able to determine the MN's identity (ID) based on the parameters in the received notification signal. Thus, MAG 2 uses the MN's ID to start pre-authenticating the MN to verify its credentials.

Thereafter, MAG 2 associates its proxy care-of-address with the MN. This proxy care-of-address will be used at the LMA to reach the MN after handover. However, the LMA is updated with this proxy care-of-address only after a certain predefined signal strength threshold of the MN in the overlap region has been reached. Also, at this threshold (threshold 2), the MN gets deregistered from the old MAG (MAG 1). This threshold is experienced when the MN starts detecting a *link_up* event at a certain predefined signal strength level from MAG 2. Ideally, this threshold should be reached as the MN leaves the HC's vicinity of operation. Thus, we have two predefined thresholds; one is experienced when the MN enters the overlap area while the other is experienced when the MN leaves the overlap area. Their roles are reversed when the handover is towards the other direction. These thresholds are preconfigured in coordination between the relevant elements based on network conditions. However, other types of parameters can be used as thresholds, for example, cost, QoS, and so forth.

Basically, in terms of real-time packet relaying to the MN, the HC emulates MAG 1 when the MN moves from MAG 1 to MAG 2 while it emulates MAG 2 when the MN moves from MAG 2 to MAG 1.

Now, after assigning the new proxy care-of-address to the MN and performing proxy binding registration, the new MAG (MAG 2) acknowledges receipt of the imminent attachment notification signal by informing the HC that it is ready for the MN's attachment. The HC receives the acknowledgement and waits for threshold 2 to be reached. Up until this point the MN receives data packets through its old interface via the HC. Once threshold 2 is reached, the HC quickly sends a signal to the old MAG notifying it to start performing the deregistration process of the MN from its binding list entries earlier than it would normally do without the HC, as illustrated in step 5. As MAG 1 deregisters the MN (and the old interface is switched off or put to sleep), MAG 2 and LMA simultaneously complete registration of the MN, and subsequently packet flow is redirected at the LMA as shown in step 6.

5. Simulation Environment and Results

5.1. Simulation Environment. The NS-2 network simulator with the NIST mobility package was used to carry out the simulations. Partially overlapping wireless access networks, IEEE 802.11 (WLAN) and IEEE 802.16 (WiMax), implementing PMIPv6, were simulated. An HC with carefully controlled power levels was placed in the overlap region of the networks and linked to the respective MAGs of these access networks. CBR traffic was transmitted using UDP to simulate real-time traffic, from a stationary CN outside the PMIPv6 domain to the MN through the LMA and MAG.

The packet size was set to 1000 bytes while the inter-packets duration was fixed at 0.001 s. The bandwidth (throughput) trace time at the MN was done every 0.01 s. Link delays and link bandwidth between LMA, MAGs, and HC were arbitrarily selected and kept constant throughout the simulation. The simulation was run for 20 s while the MN's speed was fixed at 25 m/s as it moved from WLAN to WiMax. Thus, the effect of varying MN speeds was not investigated in this paper. Furthermore, the MN was simulated to move in a linear fashion such that it definitely crossed the HC's vicinity as it moved from one access network to the other. The results presented in this paper are for a handover from WLAN to WiMax. As per the PMIPv6 protocol, the relevant proxy binding updates and acknowledgements were exchanged between the respective MAGs and LMA before the traffic flow to the MN.

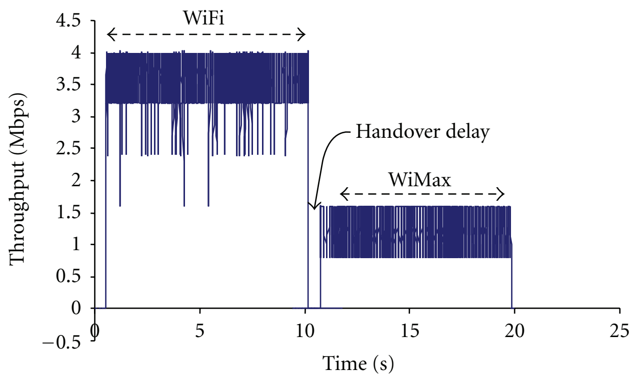

Figure 8: Throughput in ordinary PMIPv6 scenario.

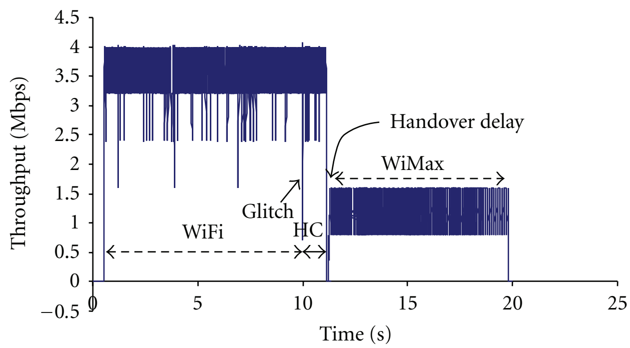

Figure 9: Throughput in PMIPv6-HC scenario.

The start time of traffic flow from CN to MN was randomly changed; thus the start and end times of the handover process were not constant for different simulated handovers. Even though the times for handovers were different, the handover duration was observed to be the same. Similarly, the number of lost packets was the same in all cases for the different scenarios.

5.2. Simulation Results. Figure 8 below illustrates the throughput in the ordinary PMIPv6 scenario before and after handover while Figure 9 illustrates the same for PMIPv6-HC scenario before and after handover. Obviously, the networks have different characteristics and simulator settings, hence offer different throughputs.

As can be observed from Figure 8, the signal gets disconnected from the MN around 10.3 s resulting in packet loss (0 Mbps throughput) as the MN enters the overlap area (i.e., leaves the old network for the new network). The discontinuity corresponds to the period when handover procedures are performed, and the MN is unable to send or receive ongoing communication.

Figure 9 below illustrates the behavior when the HC has been incorporated in PMIPv6 in the handling of handover procedures.

In Figure 9, as can be observed, the handover happens at around 10.8 s. That is because the HC acts as a real-time data relaying function or bridge of data packets destined to the MN when the MN is in the overlap area. Thus, because of the HC there is no abrupt disconnection from the old network hence no severe packet loss is experienced. The glitch or spike observed around 10 s is when the packets to the MN started being forwarded via the HC. We can observe that the discontinuity or handover delay is very short in PMIPv6-HC. Likewise, the packet loss is very low compared to that experienced in PMIPv6.

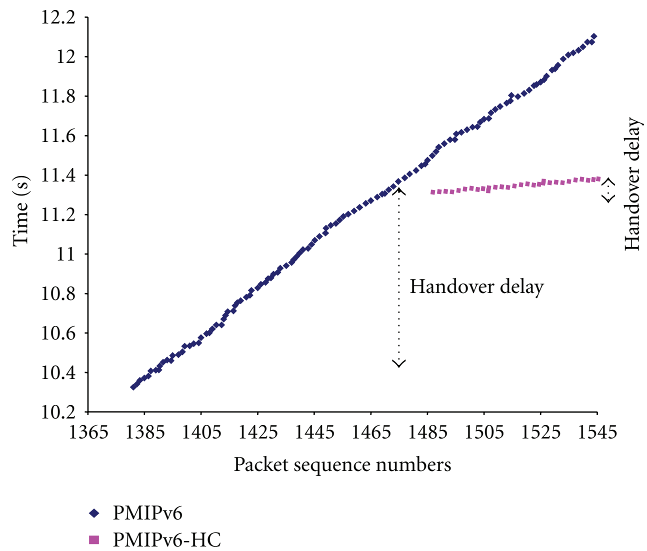

Figure 10: Handover performance comparison of PMIPv6 and PMIPv6-HC.

Figure 10 below compares the corresponding handover performance of PMIPv6 and PMIPv6-HC in terms of handover delay and packet loss as. Each point is an average of ten simulations.

As can be observed from Figure 10, PMIPv6-HC performs better in terms of both handover delay and packet loss. The HC ensures that packets continue to flow as real-time as possible towards the MN even during the handover process. The few packets that are lost are during the brief moment when the new MAG sends a router advertisement (RA) to the MN, basically enabling it to know its default proxy care-of-address. We have ignored packets that are lost due to overflowing queues since the CBR packet delivery rate remains constant yet the access networks differ. Thus, the graphs show packets that are lost during handover.

The handover delay in the PMIPv6 scenario is not easily determined from Figure 10 because packets from the CN to the MN continue to flow towards the old MAG as long as the MN is not deregistered from it (MAG) and the LMA is not yet updated with the new proxy care-of-address. Thus, packets are still being sent (or misrouted) and dropped at the old MAG even after the handover period. The handover delay was, therefore, determined from the NS-2 output trace file obtained after the simulation run. Thus, the handover delay as determined from the trace file was about 0.94 s while dropped packets were about 174 during that handover period. However, when HC is added in the PMIPv6 domain, the handover delay was reduced to about 0.1 s while the dropped packets were about 28.

The following diagram, Figure 11, basically gives a clear perspective of the handover period during which the packets observed in Figure 10 were dropped. We can observe from Figure 11 that the actual handover between the interworking heterogeneous wireless networks start later in the PMIPv6-HC scenario when compared to the PMIPv6 scenario. This is due to the fact that the HC continues to relay ongoing communication packets to MN in the overlap region while with the PMIPv6 scenario the disconnection is abrupt hence happens earlier than that in PMIPv6-HC.

The discontinuities in Figure 11 depict the handover period during which no packets were received by the MN.

The following figures depict the handover performance of PMIPv6 and our proposed PMIPv6-HC when the number of simultaneously handing over MNs increases.

We can observe from Figure 12 that PMIPv6-HC performs better than PMIPv6. However, in both mobility management scenarios, the handover delay increases with the number of MNs. In fact, the increase is slight at fewer MNs and becomes significant as the number of simultaneously handing over MNs gets bigger. We can attribute this behavior to that increasing the number of simultaneously handing over MNs increases the mobility-related signaling messages that must be handled at the same time by the relevant network elements. This scenario overloads the elements hence cause delays in the processing of these signaling messages. Furthermore, the increase of simultaneous signaling messages from the many different MNs increases the delay in the connection links due to the saturation in the channel. However, even in this situation the CN continues to send ongoing communication packets to the MN. Thus, Figure 13 below depicts the corresponding average packet loss.

The above figure shows the average packet loss experienced during handover as the number of MNs increases. As expected, the packet loss also increases with the number of MNs.

5.3. Signaling Call Flow. The signaling call flow diagram in Figure 14 shows the typical signaling involved during handover in the PMIPv6 with HC architecture. It can be observed that the no extrasignaling overhead is incurred in the air interface (between the MN and the network elements, i.e., MAGs and HC).

The data relaying capability of the HC ensures seamless and soft handover by enabling smooth disconnection from the old MAG hence very few packets are lost during the handover process. Furthermore, the proactive nature of the scheme in terms of preregistration, pre-authentication, and setting up the new PCoA ahead of time significantly reduces the effects of handover delay thus enhancing seamless service continuity.

To illustrate the handover delay improvement of the PMIPv6-HC scheme in terms of handover analytical performance modeling, we note that when PMIPv6-HC is used most of the handover activities that happen in ordinary PMIPv6 are initiated by the HC in the respective MAGs ahead of time on behalf of the MN while the MN is still directly connected to the old MAG or indirectly through HC,

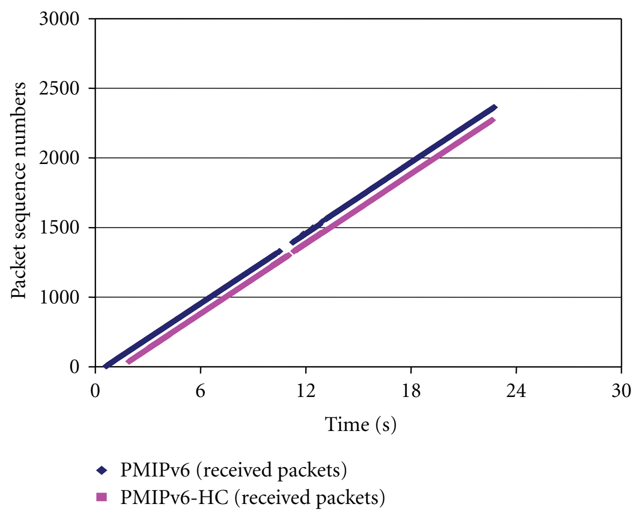

Figure 11: Handover delay in PMIPv6 and PMIPv6-HC.

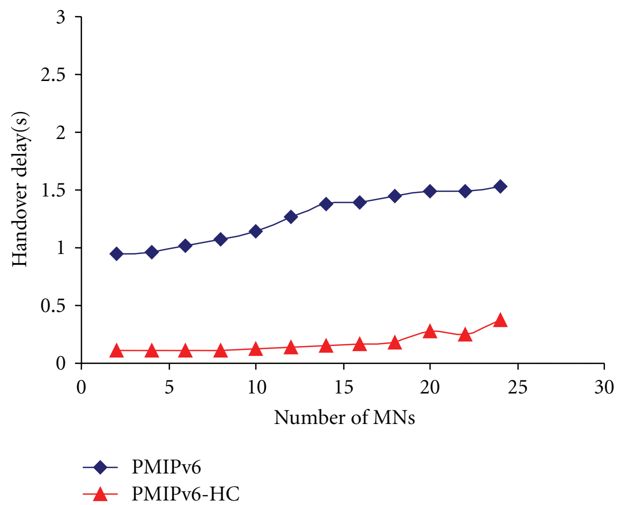

Figure 12: Impact of number of simultaneous handing over MNs on handover delay.

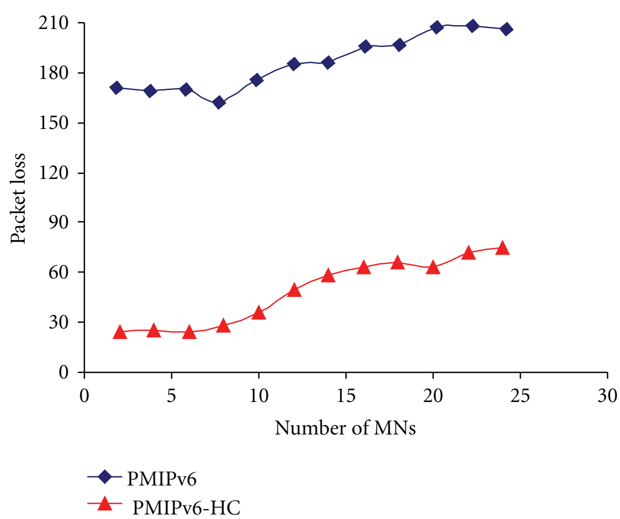

Figure 13: Impact of number of simultaneous handing over MNs on packet loss.

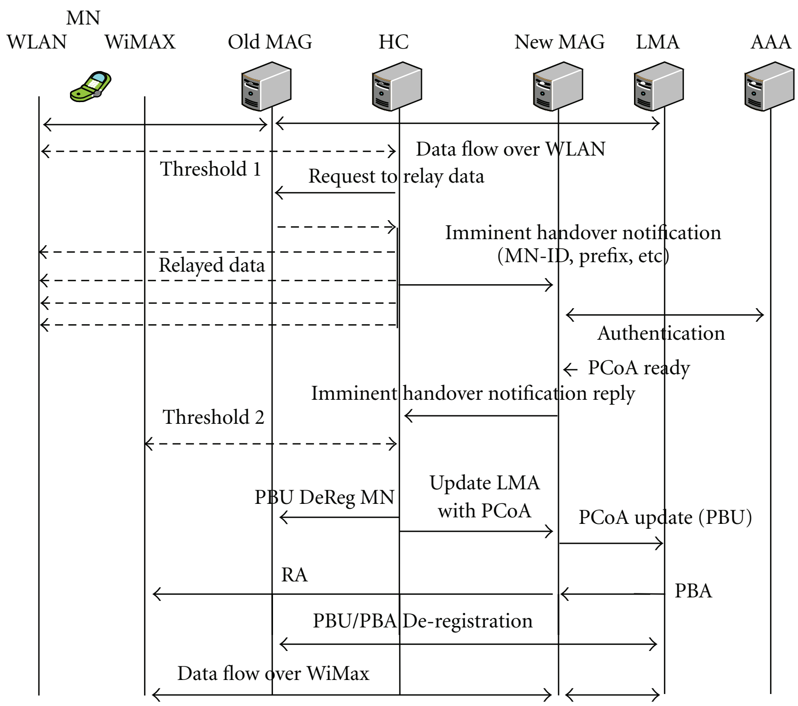

Figure 14: Typical Signaling call flow of PMIPv6-HC.

while moving towards the new MAG. Thus, the handover delay is substantially reduced to the time the MN receives its last packet from the HC until it receives its first packet in MAG 2, and this contribution is mainly due to the router advertisement delay, thus,

$$D_{\text{PMIPv6-HC}} \approx D_{\text{RA}}. \quad (5)$$

Note that by definition the handover delay is the time that elapses between the moment the MN receives its last packet from old access network (MAG 1) and the moment that it receives its first packet in the new access network (MAG 2), which is longer.

6. Conclusion

The paper first analyzed a handover mechanism that optimizes the PMIPv6 handover process with the assistance of the IEEE 802.21 MIH services. The analysis showed that PMIPv6, as a network-based mobility management protocol, performs better than host-based mobility management protocols such as HMIPv6. Thus, PMIPv6 performs even better when assisted by the MIH services by employing proactive signaling deliberations which help to reduce the signaling steps during the actual handover process. However, it was noted that handover delay and packet losses are reduced at the expense of more signaling overhead in the air interface.

Thus, we further introduced a novel handover process where PMIPv6 was enhanced with a handover coordinator (HC) to further enhance the handover performance. With the HC being a network-based entity that coordinates the facilitation of handover activities on behalf of the MN ahead of time, handover delay and packet loss were reduced without incurring extrasignaling overhead in the air interface. Furthermore, data packets were delivered to the MN as real-time as possible even during the actual handover period without any need for buffering either at the source or target access. The throughput rates observed during the handover period in the PMIPv6-HC scheme confirm the handover performance improvement of the scheme. Furthermore, the scalability of the proposed scheme in terms of its performance as the number of MNs that are involved in handovers at the same time increase was investigated.

For future work, the IEEE 802.21 MIH services may be incorporated to the HC to facilitate new target MAG discovery and network selection to further optimize the handover performance. To minimize signaling overhead in the air interface some of the MIH signaling may have to be delegated to the HC which would handle them on behalf of the MN.

References

[1] S.-J. Yoo, D. Cypher, and N. Golmie, "Predictive link trigger mechanism for seamless handovers in heterogeneous wireless networks," *Wireless Communications and Mobile Computing*, vol. 9, no. 5, pp. 685–703, 2009.

[2] A. Dutta, V. Fajardo, Y. Ohba, K. Tanuichi, and H. Schulzrinne, "A framework of media-independent pre-authentication (MPA) for inter-domain handover optimization," draft-irtf-mobopts-mpa-framework-05, work in progress, July 2007.

[3] S.-J. Yoo, D. Cypher, and N. Golmie, "Timely effective handover mechanism in heterogeneous wireless networks," *Wireless Personal Communications*, vol. 52, no. 3, pp. 449–475, 2008.

[4] J. Kempf, "Problem statement for network-based localized mobility management (NETLMM)," IETF rfc-4830, April 2007.
[5] D. Johnson, C. Perkins, and J. Arkko, "Mobility support in IPv6," IETF rfc-3775, June 2004.
[6] H. Soliman, C. Castelluca, K. El Malki, and L. Bellier, "Hierarchical mobile IPv6 mobility management (HMIPv6)," IETF rfc-4140, August 2005.
[7] R. Koodli, "Fast handovers for mobile IPv6," IETF rfc-4068, July 2005.
[8] IEEE Std 802.21-2008, "IEEE standard for local and metropolitan area networks—part 21: media independent handover services," January 2009.
[9] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy mobile IPv6," IETF rfc-5213, August 2008.
[10] The Internet Engineering Task Force (IETF), http://www.ietf.org/.
[11] K.-S. Kong, W. Lee, Y.-H. Han, M.-K. Shin, and H. You, "Mobility management for All-IP mobile networks: mobile IPv6 vs. proxy mobile IPv6," *IEEE Wireless Communications*, vol. 15, no. 2, pp. 36–45, 2008.
[12] K.-W. Lee, W.-K. Seo, D.-W. Kum, and Y.-Z. Cho, "Global mobility management scheme with interworking between PMIPv6 and MIPv6," in *Proceedings of the 4th IEEE International Conference on Wireless and Mobile Computing, Networking and Communication (WiMob '08)*, pp. 153–158, Avignon, France, October 2008.
[13] A. Diab, A. Mitschele-Thiel, and J. Xu, "Performance analysis of the mobile IP fast authentication protocol," in *Proceedings of the 7th ACM Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM '04)*, pp. 297–300, Venezia, Italy, October 2004.
[14] C. M. Mueller and O. Blume, "Network-based mobility with proxy mobile IPV6," in *Proceedings of the 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '07)*, Athens, Greece, September 2007.
[15] L. A. Magagula, H. Anthony Chan, and O. E. Falowo, "Handover coordinator for improved handover performance in PMIPv6-supported heterogeneous wireless networks," in *Proceedings of the IEEE Wireless Communications & Networking Conference, (WCNC '10)*, Sydney, Australia, April 2010.
[16] K. Taniuchi, Y. Ohba, V. Fajardo, et al., "IEEE 802.21: media independent handover: features, applicability, and realization," *IEEE Communications Magazine*, vol. 47, no. 1, pp. 112–120, 2009.