A Proposal for Reducing Handover Latency and Improving Route Optimization in Proxy Mobile IPv6

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Abstract - **To reduce cost and complexity of mobile subscriber devices, it is desirable that mobility may be handled by network systems only. PMIPv6 relies on MIPv6 signaling and the reuse of the home agent functionality through a proxy mobility management agent in the network to transparently provide mobility services to mobile subscriber devices. Handover latency resulting from standard MIPv6 procedures remains unacceptable to real time traffic and its reduction can also be beneficial to non real-time throughput-sensitive applications as well. This paper proposes an optimized PMIPv6 that relies on a rich set of informational resources to reduce handover delays; and then a more efficient intra mobile access gateway routing scheme**

Keywords — **Mobile IP, Proxy Mobile IP, Handover Latency, Route Optimization**.

1. Introduction

Network-based mobility models [1]-[5] are models which allow mobile subscriber devices, which for convenience, we simply refer to as mobile nodes (MNs) in this paper, to continue their IP sessions as they move from one Point of Attachment (PoA) to another without the MNs getting involved in the signaling or management of their movement. In essence, the MN is unaware of its mobility. This reduces the complexity and cost of these devices. It also makes it possible for commodity subscriber devices that were produced before mobile IP came to light to be used on a mobile IP network. It therefore increases compatibility and interoperability between various systems and user equipment. In contrast, host-based mobility models [6], [7] are models that require sophisticated Mobile Nodes (MNs), in the sense that the mobile nodes need to be mobility aware, which implies having a mobility stack in the network protocol implementations. Because MNs are aware of their movement, they can inform the network entities providing them network services of their intention to move and also inform these network entities of new Access Networks (ANs) that they have discovered and will be connecting to. With this advance notification, the network entities can reduce the response time for managing a mobile node's movement especially as far as maintaining its ongoing communication is concerned.

Proxy Mobile IP (PMIP) is a network-based mobility management protocol solution that provides localized network-based mobility management by relying on MIPv6's signaling and the reuse of the home agent functionality through a proxy mobility agent in the network [1]-[5], [8]-[9]. Being localized in this sense means that the entire network (Proxy mobile IPv6 domain) within which the MN is authorized to roam is under the same administrative management and possibly the same service provider. This being the case, the network administrator can have a complete knowledge-set of the entire network and resources available at each of the PoAs as well as at their neighboring PoAs.

As described in the draft document of Ref. [1], PMIPv6 relies on the proxy mobility agents in the network to detect the MN's attachments and detachments and then signal this information, in the form of binding updates without the active participation of the MN itself. This scheme defines two core functional elements; Local Mobility Anchor (LMA) and the Mobile Access Gateway (MAG) as shown in Figure 1. All mobility management functions in a Proxy Mobile IPv6 domain are handled by the LMAs and the MAGs on behalf of the MN. These two systems are described in more detail, in subsequent sections. In [1], it is also proposed that when an MN moves and attaches to a new MAG, that MAG should detect the MN's attachment and initiate the necessary procedures to authenticate and authorize the MN, giving the MN access to the network. Accordingly, the MN continues its IP session.

We however, propose that the current MAG, that is the MAG of the PoA to which the MN is currently attached, should be capable of predicting the MN's movement to another PoA by detecting the MN's L2 trigger *Link-Going-Down*. When the current MAG detects this event, it should inform the MN's LMA initiating the proactive handover process we describe later in this paper. Because proxy mobile IPv6 domains are localized networks, we anticipate that an entity in the network, preferably the LMA will have complete knowledge of the entire network especially information regarding available as well as neighboring MAGs to the MN's current MAG, just as in [10]. With this information, we propose that on receiving the L2 trigger information from the MN's current MAG, the LMA should send Proxy Binding Updates (PBUs) to neighboring MAGs. This is so that when the MN finally attaches to any of its neighbors, that neighboring MAG would need to simply send a Proxy Binding Acknowledgement (PBA) and then data traffic transmission from the MN can continue through the new MAG, to the LMA and ultimately to the MN's Corresponding Node(s). This rather simple procedure as is shown in subsequent sections would significantly reduce handover latency, currently experienced in Proxy Mobile IP networks, especially as it relates to movement detection and binding updates.

The rest of this paper is organized as follows: In Section 2, background and related works are reviewed; in Section 3, we present the proposed scheme; in Section 4, we analytically evaluate the proposed scheme; in Section 5, we show results of the analysis of the proposed scheme, to show its benefits; and in Section 6, the paper is concluded.

2. BACKGROUND AND RELATED WORKS

2.1 Local Mobility Anchor (LMA)

The LMA is the Home Agent (HA) [8] of an MN in a Proxy Mobile IPv6 domain. It manages the MN's reachability state through Binding Cache entries and is the topological anchor point for the MN's home network. The LMA is also responsible for accounting, meaning that the LMA provides charging and billing services to the MN as the MN accesses and uses network resources and services. For this reason, every communication between an MN and its correspondent nodes must pass through the LMA, even in the case that they (MN and its corresponding node) may both be connected to the same MAG or PoA [1].

2.2 Mobile Access Gateway (MAG)

The MAG is the functional element that manages mobility related signaling on behalf of MNs attached to its access links (PoAs). It is responsible for detecting the MN's attachment or detachment from an access network and initiating signaling of these movements to that MN's LMA. It is a function that typically runs on an access router [1].

2.3 LMA Address (LMAA)

The LMAA is the address that is configured on the interface of the LMA that is connected to the MAG. It is the transport endpoint of the tunnel between the LMA and the MAG. It is also the address to which the MAG sends a PBU when it detects a MN's attachment to or detachment from its AN [1]. Based on our proposal, it is also the address to which an MAG will send a PBU when it detects that an MN is losing signal strength as a result of the MN's movement from its ANs towards the ANs of neighboring MAGs; or a PBA when an MN for which it (MAG) had earlier received a PBU from an LMA, finally attaches to its AN.

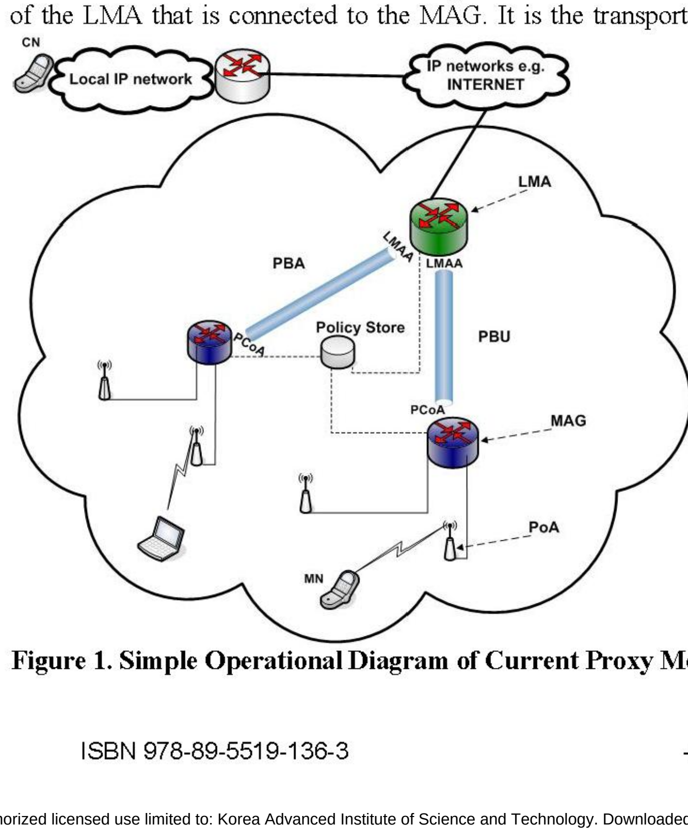

Figure 1. Simple Operational Diagram of Current Proxy Mobile IPv6

2.4 Proxy Care-of Address (Proxy-CoA)

The Proxy-CoA is the address that is configured on the interface of the MAG that is connected to the LMA. It is the transport endpoint of the tunnel between the LMA and the MAG. The LMA views this address as the Care-of Address of the MN, and registers it in the Binding Cache entry for that MN. It is the address to which the LMA will send a PBA for a PBU it had earlier received [1]. Based on our proposed scheme presented in subsequent sections, it is also the address to which an LMA will send PBUs for an MN when the MN's current MAG sends a trigger informing the LMA that the MN might soon be moving and attaching to the ANs of neighboring MAGs.

2.5 Proxy Binding Update (PBU)

The PBU is essentially a signaling message sent on behalf of a MN by an MAG to the MN's LMA for establishing or de-establishing a binding between the MN's MN-HoA and the Proxy-CoA. In this regard, the PBU is a signaling message that informs the MN's home agent (LMA) that the MN is now connected to or had just disconnected from the MAG that sent the signaling message. It is also a signaling message sent on behalf of an MN by its MAG to request that the LMA increases the lifetime of the binding already established for that MN [1]. Based on our proposed scheme, it is additionally a proactive signaling message sent by an MAG to inform the MN's LMA that the MN might be moving to neighboring ANs. Also based on the proposed scheme we present in subsequent sections, it is a proactive message, sent by an LMA to MAGs that are neighbors to the MN's current MAG informing them that the MN is on the move and might be attaching to their ANs soon. This will reduce handover delays due to movement detection and binding updates.

2.6 Proxy Binding Acknowledgment (PBA)

A PBA is a response message sent by an LMA in response to a PBU that it (LMA) earlier received from the corresponding MAG. A success or positive response indicates to the MAG that it can start transmitting data packets on behalf of the MN through the responding LMA to the MN's Corresponding Node(s). A success could also mean that the MAG's request to extend the lifetime of an existing binding has been accepted or that the MN's request that a binding earlier established between the MAG and the MN be deleted since the MAG had now lost its connection with the MN [1].

Based on our proposal, it is also a response message sent by an MAG informing the LMA that the MN for which the LMA had earlier sent a proactive PBU, has now arrived and attached to the sending MAG's AN and so data transmission to and from the MN, can now continue via the sending MAG.

2.7 Policy Store

This Policy Store is a database containing the policy profiles of all mobile and fixed nodes authorized to access the Proxy Mobile IPv6 domain. It typically contains provisioned network-based mobility service characteristics and other related parameters such as Service Level Agreement, a MN's Identifier, its LMA Address, permitted address configuration modes, roaming policy and others, necessary for providing network-based mobility services in the Proxy Mobile Ipv6 domain. It can be indexed and accessed by the MAG using the MN's MN-Identifier to obtain information specific to the MN and necessary for enabling the MAG emulate the MN's home agent. The LMA also accesses this policy store to obtain necessary information on the MN, such as the MN's roaming policy and service level agreements amongst others [1].

2.8 Proxy Mobile IPv6 Operation

Gundavelli et al. [1], [2], specify that every MN, in a proxy mobile IP domain is assigned an MN-Identifier [9] which it (MN) presents as part of access authentication when it attaches to an AN connected to an MAG in the domain. With this identifier, both the MAG and the LMA can obtain the MN's policy profile from the policy store. The moment an MN enters its Proxy Mobile IPv6 domain and is authenticated and assigned a home link (address), the network ensures that this home link conceptually follows the MN as it roams within the domain. The network ensures that the MN always sees this link with respect to the L3 network configuration, on any access link that it attaches to while it roams within the same Proxy Mobile IPv6 domain. The MAG uses this MN-Identifier to look up the MN's policy profile from the policy store so as to obtain the MN's LMA address. Upon obtaining this address, the MAG will generate and send a PBU message on behalf of the MN to the MN's LMA via the obtained address. This PBU message is intended to update the LMA with the current location of the MN. Obtaining the MN's policy profile also provides the MAG with parameters necessary for emulating the MN's home agent [8]. This means making the MN believe that it's still connected to its HA. After authenticating the request, the LMA will send a PBA response message back to the MAG. If the response that the LMA sent is positive, the LMA will also set up a route for the MN over a tunnel to the MAG. The MAG on receiving the PBU would establish a bi-directional tunnel with the LMA, add a default route through the tunnel to the LMA and finally grant the MN permission to transmit data. All traffic from the MN as well as all other MNs connected to the same MAG and LMA will be routed through this tunnel to the LMA and then to their CNs. On receiving the PBA, the MAG also sends a Router Advertisement to the MN advertising the MN's home network prefix. If the MN has not obtained an IP address by this time, it will generate one using the obtained home network prefix. The method of obtaining or generating an IP address can be by either stateless or stateful auto configuration and is determined by the MN's stored policy profile. The established tunnel hides the topology and enables an MN to use an IP address that is topologically anchored at the LMA, from any attached access link in the proxy mobile IPv6 domain.

An LMA also ensures that only authorized MAGs send PBUs on behalf of MNs. MAGs do not only send PBUs when they detect the presence of an MN on their ANs, they also send PBUs when they detect that an MN has left their AN or when the lifetime of the binding update for an MN that is still attached to it, expires. The MAG can detect this detachment of an MN from its AN via an *L2 Link Down* trigger; the MN's complete silence over a period of time exceeding a defined threshold (usually the binding update lifetime); or by any other access specific methods. When the LMA receives such a PBU message with the lifetime set to 0, it deletes the Binding Cache entry it had earlier created for reaching this MN through the sending MAG. It also brings-down the established tunnel. Before bringing down the tunnel, it will first check (for shared tunnels only) to confirm that other active MNs are not still reachable through the tunnel. Then it will generate and send a PBA in response to the MAG's binding request. Upon receiving this, the MAG in turn, deletes the entries it had created for the MN in its tables and also takes-down the tunnel from its end. This is similarly done if, and only if, no other MNs are currently using the tunnel. These bring-up and take-down of tunnels also only applies to non-static tunnels.

Lee et al. [4], proposed a scheme for handling inter-mobility which they described as mobility of an MN from one LMA to another. They proposed a scheme for handling a scenario where one MAG is connected to two LMAs in which case, the

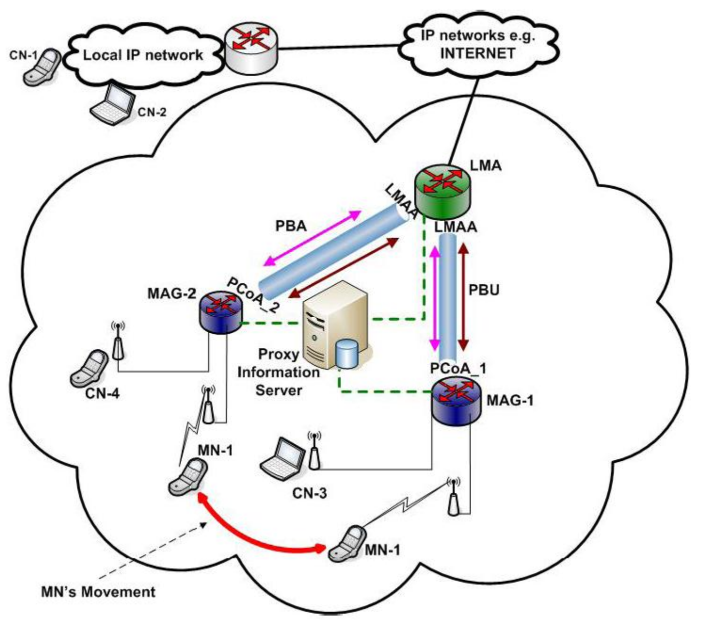

Figure 2. Operational diagram of Proposed Optimized Proxy Mobile IPv6

MN receives two MN-HoAs; one from each LMA but because both LMAs can communicate directly with the MAG, handover is easily managed. They termed this, the overlapped scenario and another, an un-overlapped scenario in which case the MN moves from one MAG, to another which are both connected to different LMAs so the MN loses its previous MN-PoA and obtains a new MN-PoA from the new LMA.

Damjan Damic [5] evaluated and compared network-based mobility solutions and confirmed that much more still needs to be done especially in route optimization and fast handover. He went further to propose some optimization mechanisms which revolve around creating a communication link between the current MAG and the new MAG so data packets tunneled to the current MAG can be forwarded to the new MAG before the LMA is informed of the MNs movement. These schemes all rely on the new MAG first detecting the MNs attachment which is reactive unlike our proposed proactive scheme. More so, in [5] direct connectivity between the MAGs is recommended but this is not part of the standard document yet.

3. THE PROPOSED SCHEME

In this section, we present our proposed scheme. First, we summarize the basic understandings upon which it is based.

- That Proxy Mobile IPv6 domains are restricted and localized so they are under a single administrative management. Thus, obtaining and maintaining a complete central database of the features and location of all MAGs and LMAs in the domain is feasible. This database would ensure that when an LMA selects at random any MAG, it can access the central database and obtain information on which MAGs are the randomly selected MAG's neighbors in all directions.
- All MNs have signal strength indicators (RSSI). This usually indicates if signal strength is Excellent, Very Good, Good, Low or Not-Connected (Disconnected), etc. A *Not-Connected* signal indicator directly maps to the L2 trigger *Link Down* while the *Low* signal indicator on the other hand directly maps to the L2 trigger *Link Going Down* [10]. The others basically map to the L2 trigger *Link Up*

With the above in mind, we propose that the Policy Store be upgraded, and renamed the Proxy Information Server (PIS) as shown in Figure 2. The PIS should now contain additional information such as available MAG neighbor maps and their complete features as described in [10]. It should thus contain information necessary for enabling an LMA to obtain necessary information such as the Proxy-CoA of all neighboring MAGs to any randomly selected MAG. Neighboring MAGs are candidate new-MAGs to which an MN which roams away from its current MAG will roam to. The PIS will also, now have the full capability of operating as an AAA cache server for the proxy mobile IPv6 domain and should be accessible by both the MAGs and the LMAs in the domain. With the PIS providing AAA service to the domain, MAGs can access the PIS and thus provide accounting services to their MNs. With this, it will no longer be necessary, for an MAG to pass traffic destined for MNs that are both connected to its access network through the LMA as [1] currently prescribes. Surely, the MAG will update the LMA as usual that the nodes are connected to it but when it receives packets from a MN connected to it, destined for another node that is also connected to the same MAG, the MAG will route these packets directly between the nodes without getting the LMA involved. Then, the MAG will update the AAA cache server with the billing information as required for services rendered to the MNs. This will reduce the transmission delay that, otherwise, these packets would have experienced; reduce the processing burden on the LMA; and also save the bandwidth on the tunnel between the LMA and the MAG that these packets would have consumed. This procedure is shown in Figure 5.

For handover latency reduction, we propose that an MAG should not only monitor its ANs so as to only detect when an MN attaches or detaches from them as specified in [1], but also to monitor so as to know when its signal strength (RSSI value), is decreasing, that is, going down. This should be triggered by the *Link Going Down* L2 trigger. An optimum signal strength threshold value that would trigger this state will depend on the speed with which the MN is moving and the handover preparation time of the proxy mobile IP network. By preparation time, we are referring to the total time it will take for an MAG to inform the LMA of this event, and for the LMA to compose and send the necessary PBUs to the current MAG's neighboring MAGs informing them that the roaming MN might be attaching to their ANs anytime soon. Therefore, the trigger should be in time to ensure that all necessary signaling and preparation for the MN's movement takes place before the MN finally moves. A slow moving MN shall therefore, trigger this state at a much lower threshold than a faster moving MN will. The rate of decrease of the RSSI value will be used to determine if a roaming MN is moving fast or slow.

When an MAG detects this state, in other words, upon this trigger, the MAG should send a PBU to the MN's LMA. To differentiate this PBU from the normal ones as described in [1], we propose the introduction of an additional flag D into the message formats defined in [1], [2], [8], and [11]. The *Link Going Down flag D*, as shown in Figure 3 and Figure 5, would be set to 0 in the PBU to indicate that the link is going down initiating the proactive handover procedure. Under this scheme, PBUs from an MAG will always have the D flag set to 1 except in this special condition when an MN has been observed to be in motion. On receiving this signaling message with the D flag set to 0, the LMA should look up its network information database from the PIS and locate all neighboring MAGs (candidate new-MAGs) to that which sent the message. By "all" we mean in all 360^0 direction from the current MAG. This is because of the difficulties and additional complexity involved with correctly predicting the direction in which the MN is moving or will move. Upon obtaining this information, the LMA should send PBUs with the D flag set to 1 to all these

MAGs informing these candidate new-MAGs that they should be expecting the roaming MN. Thereafter, the LMA initiates tunnels towards these candidate new-MAGs [1], if tunnels towards them do not already exist. Surely data transmission to and from the MN will continue through its current MAG until the LMA gets a positive response from any of the candidate new-MAGs it had informed of the MN's possible movement to their ANs or until it receives a PBU from the current MAG with the Binding lifetime for the MN set to 0 indicating that the current MAG has finally lost connectivity with the MN. While the LMA still sends data to the MN through its current MAG, it will also buffer these data and delete only those for which it receives acknowledgment. This is to minimize packet loss should the MN finally move away from its current MAG to a new MAG.

When any of the candidate new-MAGs that had received the binding update detects the presence of the MN at its ANs, it bypasses the usual authentication procedures, creates an entry for the MN in its tables and sends a PBA to the LMA, with the D flag set to 1 informing the LMA that the roaming MN has now attached to its' AN. Thereafter the new MAG sets up a bi-directional tunnel towards the LMA as in [1]. When the LMA receives this PBA, it will first check its records to confirm that it is genuine; by this we mean that it checks to confirm that the PBU in response to which this acknowledgement message has been sent, originated from it. If it is genuine, it proceeds to delete the previous binding cache for the MN, terminates the tunnel if necessary and creates a new entry for the MN. Data transmission to and from the MN then continues with the transmission first, of already buffered data through the new-MAG. We propose that the binding updates sent from the LMA to the MAGs be time stamped so they expire if the MN does not arrive after a specified time period.

As described, intuitively, it is clear that our proposal is feasible and easily applicable. It will also ensure routing optimization of traffic between nodes connected to the same MAG and will reduce handover delays caused by movement detection and binding update signaling.

0 1	2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5	6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
	SEQUENCE #
A H L K M R P D RESERVED	LIFETIME

Figure 3. Proposed Proxy Binding Update Message Format

0 1	2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5	6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
	STATUS K R P D RSVD
SEQUENCE #	LIFETIME

Figure 4. Proposed Proxy Binding Acknowledgement Message Format

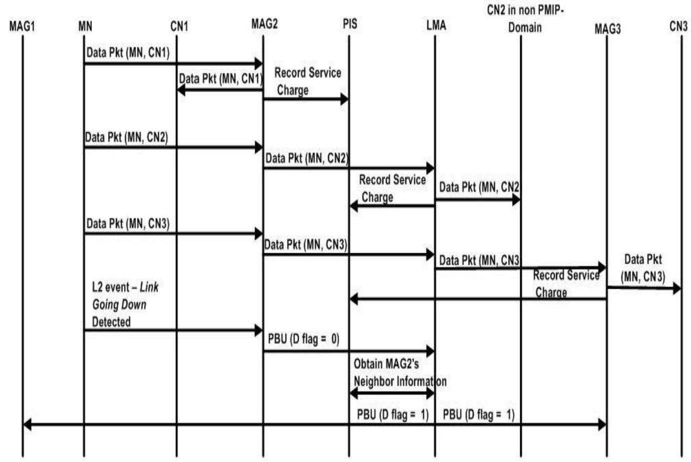

Figure 5. Proposed Route Optimization and Proactive Handover Procedure

4. ANALYTICAL EVALUATION

In this section we present an analytical evaluation of the performance improvement our proposed scheme brings to Proxy Mobile IPv6 as specified in [1]. We remind that the handover latency in [1] is our reference point and so we evaluate the the time it takes for a node to handover between two MAGs (total latency) based on [1] on the one hand and based on our proposed scheme on the other hand. We then compare values to show the benefits of our proposed scheme.

We evaluate the overall total handover latency based on [1] as T_{PMIP} and that based on our proposed scheme as T_{OPT}. We identify the individual latency entities for [1] as: time for L2 handover between the MAGs t_{L2}, time for new MAG to look up policy store and authenticate MN $t_{NMAG\text{-}PA}$, time for the new MAG to compose and transmit a PBU to the MN's LMA on behalf of the MN $t_{NMAG\text{-}PBU}$, time for the LMA to authenticate the MAG and the MN as $t_{LMA\text{-}AAA}$, time for the LMA to compose, send a PBA and then create a tunnel towards the new MAG for routing packets to the MN as $t_{LMA\text{-}PBA}$, time for the new MAG to create a reverse tunnel towards the LMA and then allow the MN resume data transmission as $t_{NMAG\text{-}MN}$. This gives the total handover latency based on [1] as;

$$T_{PMIP} = t_{L2} + t_{NMAG\text{-}PA} + t_{NMAG\text{-}PBU} + t_{LMA\text{-}AAA} + t_{LMA\text{-}PBA} + t_{NMAG\text{-}MN}$$

We remind that based on our proposed scheme, most of the mobility signaling and preparation for handover takes place even before the MN moves (that is, changes its MAG). Therefore, when the MN finally moves, the latency entities that are relevant, based on our proposed scheme are: time for L2 handover between the MAGs t_{L2}; time for the new MAG to compose and send a PBA to the MN's LMA informing it that the MN has now attached to its AN, create a reverse tunnel towards the LMA, and then authorize the MN to resume data transmission. We assume this to be at most $[t_{NMAG\text{-}PBU} + t_{NMAG\text{-}MN}]$. In reality however, we know that it will be less than this.

For simplicity however, we assume that it is equal to [$t_{NMAG\text{-}PBU}$ + $t_{NMAG\text{-}MN}$]. Hence we have for our proposed scheme,

$$T_{OPT} = t_{L2} + t_{NMAG\text{-}PBU} + t_{NMAG\text{-}MN}$$

Distinctly, latency is significantly reduced based our on proposed scheme. In the aspect of route optimization between a MN and its CN that are both connected to the same MAG, we recommended that the MAG forwards packets between these communicating entities directly without passing it through the LMA since the MAG now has access to the PIS and thus can render accounting services to the MN. In this case therefore the time saved, is the return propagation delay between the LMA and the MAG. That is the time it takes for a packet to be transmitted from the MAG to the LMA and back from the LMA to the MAG. If we denote this time as T and the number of packets as n; then data transmission delay will be reduced by [n*T]. Assuming a fiber cable link between the MAG and the LMA, T will depend on the length of fiber. On the other hand, if we consider a wireless interface between the LMA and the MAG, then T will depend on the distance between them, the number of MAGs connected to the same LMA, and other wireless channel sources of delay. Surely this route optimization proposal would also result in network resource (bandwidth on the tunnel) savings as traffic between nodes on the same MAG no longer have to transition through the tunnel.

5. ANALYTICAL EVALUATION RESULT

In this section, we show results to confirm the benefits of the proposed scheme. We assume that the links between the MAG, PIS and LMA are wired links and so propagation delay depends only on the length of cable. We assume that the PIS are centrally located between the MAGs and the LMA, so with a propagation delay between the LMA and MAG of say 20ms, it will be 10ms between the MAG/ LMA and the PIS. The delay on the wireless link between the MNs and their MAGs, varies due to mobility, increase in number of MNs, varying interference sources, and other unique properties of wireless channels. For simplicity, we assume that the L2 handover delay is twice the delay associated with an MAG authorizing an MN to commence data transmission, that is, $t_{L2} = 2^* t_{NMAG\text{-}MN}$. Figure 6 shows handover latency performance of the schemes as the average delay on the wireless channel increases. The result shows that latency of our scheme, T_{OPT} outperforms T_{PMIP}.

6. CONCLUSION

In this paper, we described the current status of the IETF draft document [1] and reviewed other efforts at improving Proxy Mobile IP protocol. We also presented and described our proposed scheme for improving the performance of the PMIP protocol. Our scheme targets to reduce handover latency due to movement detection and binding updates; and also to optimize routing of packets destined for nodes connected to the same

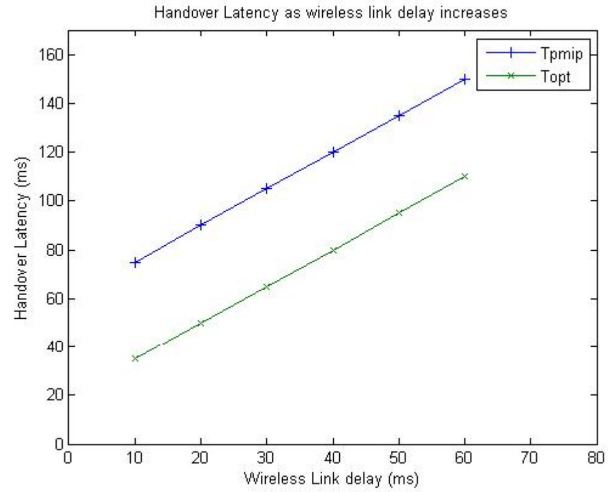

Figure 6. Handover Latency vs. Wireless Link Delay

MAG. To show the benefits of our proposed scheme, we presented analytical and simulation-based evaluations. As our future work, we plan to further improve and optimize PMIP's performance and especially obtain an optimum MN RSSI threshold for triggering the proposed proactive handover procedure. This threshold or trigger point depends on the speed with which the MN is moving and the preparation time of the proxy mobile IP network. It has to be chosen such that all the necessary signaling and handover preparations can take place before the MN finally moves.

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