Modeling Handover Latency in PMIPv6-based Protocols with Timed Petri Nets

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***Abstract*—Performance evaluation of networking protocols is generally related to metrics like latency, signaling overhead, packet loss, throughput, among others. Specifically for latency modeling, most of analytical modeling techniques involve considering the handover latency as a sum of all delays of each signaling message in the handover. However, it may not reflect the reality of various protocols based on *Proxy Mobile Internet Protocol version 6* (PMIPv6), which may consider asynchronous and parallel messages. Petri Nets are state-transition systems capable of expressing parallelism, synchronization, and allowing evaluation of properties of the systems modeled. The Timed Petri Net extension can additionally express time elapsing, which makes it a powerful tool for performance evaluation. This paper proposes to employ Timed Petri Nets to model PMIPv6-based protocols, and, therefore, to bring attention to the main advantages of this formalism for performance evaluation.**

***Keywords*–PMIPv6; Timed Petri Nets; Mobility; Modeling.**

I. INTRODUCTION

The Internet Engineering Task Force (IETF) has proposed the PMIPv6 [1] protocol to address issues related to energy saving and high latency found in Mobile IP (MIP). PMIPv6 considers two entities: the Mobile Access Gateway (MAG), which tracks the current Mobile Node (MN) location; and Local Mobility Anchor (LMA), which plays a similar role as the MIP's Home Agent for its domain. Signaling between MAG and LMA is responsible for the MN binding update. Several PMIPv6 extensions have been proposed to reduce packet loss during handover, as in *Fast Handovers for PMIPv6* (FPMIPv6) [2]. Other proposals handle localized routing as in *Optimized* PMIPv6 (O-PMIPv6) [3]. Multihoming aspects are considered by the *Transient Binding for PMIPv6* (TPMIPv6) protocol [4].

In order to evaluate these protocols, one may use measurements, simulation, or analytical modeling techniques. While measurements and simulation may give fine-grained details about network behavior, the use of analytical modeling may raise protocol design issues in earlier stages of the development in a shorter time than the other techniques.

This paper presents a proposal for modeling network-based mobile protocols at the IP layer using Timed Petri Nets. Petri Nets are a formalism generally employed to analyze the behavior of various types of systems, from product lines to programming languages. Petri Nets are capable of expressing parallelism and synchronization, and to check for possible deadlocks in systems [5]. Timed Petri Nets are an extension to that formalism that allows performance assessment [6]. Applying Timed Petri Nets to these protocols allows protocol designers to anticipate important issues about reliability, robustness and performance in an expressive and simple way.

The remainder of this paper is organized as follows. Section II presents some of the main PMIPv6-based protocols; in Section III, we discuss related work on modeling the handover latency for those protocols; in Section IV, we introduce a proposal for modeling some PMIPv6-based protocols using Timed Petri Nets, followed by the conclusion in Section V.

II. IPV6 MOBILITY MANAGEMENT

In order to accomplish handover between two different networks, in addition to link layer procedures, it is necessary to update routing tables, IP addressing, and handle authentication issues. These mobility management procedures are done by mobility protocols at the network layer. The most well-known mobility protocol is the MIP, which proposes the MN to keep the original IP address while moving beyond its original network, also known as *Home Network*. The *Home Agent* (HA) entity is the coordinator of the network. When the MN visits a foreign network, it receives a *Care-of address* (CoA) in order to be reachable by its HA in the foreign network. MIP has standards for both IPv4 and IPv6. Figure 1 presents the signaling for the MIP handover. After a new attachment, the MN receives the CoA information. Then, the *Binding Update* (BU) and *Binding Acknowledgment* (BA) messages are exchanged. They are responsible for the update of the HA's binding table.

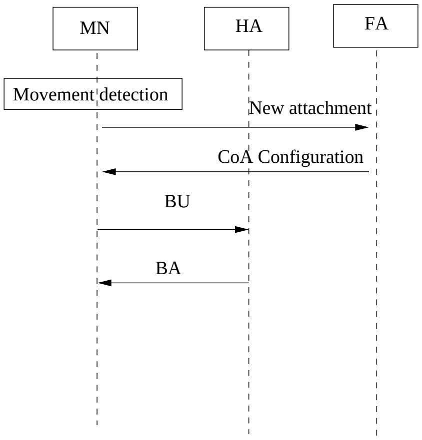

Figure 1. Mobile IP signaling flow.

The *MIPv6 Fast Handovers* (FMIP) [7] is a MIP extension that intends to reduce handover latency through anticipation of the address configuration step during the movement detection phase. The *Hierarchical MIPv6* [8] protocol seeks to reduce latency handling local and global mobility separately. This avoids unnecessary signaling overhead while there is intra-domain mobility with the help of a *Mobility Anchor Point*.

Since MIP requires that the MN has the protocol implementation in its operational system and, therefore, leads to an additional energy consumption, the IETF *Distributed Mobility Management* (DMM) working group proposed the PMIPv6 protocol [1]. PMIPv6 introduces two types of entities: MAG and LMA. A MAG detects movements of MNs and, thus, start binding update signaling. The LMA plays a similar role to the HA from MIP. Thus, PMIPv6 reduces the signaling overhead and the energy consumption on the MN side. Additionally, PMIPv6 does not require modifications in the operating system of the MN, being more adaptable to legacy devices. Figure 2 presents the PMIPv6 message flow for the handover. After the link layer handover, the previous MAG (PMAG) detects the detachment of the MN. Then, the MN asks the new MAG (NMAG) for a new route through the `Rtr Sol` message from the *Internet Control Message Protocol* (ICMP). Then, the NMAG requests the binding update to the LMA through the *Proxy Binding Update* (PBU) message. The LMA then responds with the *Proxy Binding Acknowledgment* (PBA) message. Finally, the NMAG may announce the new route to the MN sending the `Rtr Adv` ICMP message.

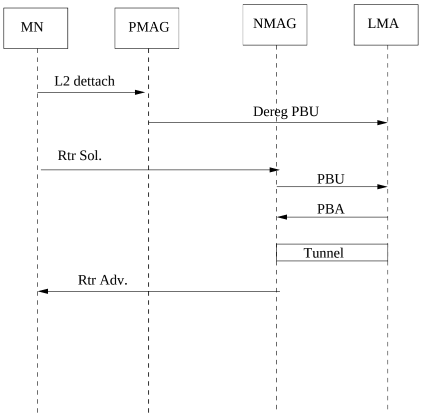

Figure 2. PMIPv6 signaling flow.

The FPMIPv6 protocol [2] adds a buffering scheme and a new tunnel between the PMAG and the NMAG while handover control messages are being exchanged. The main purpose of FPMIPv6 is to reduce packet loss during handover. FPMIPv6 may work in two modes: predictive or reactive. In the predictive mode, shown in Figure 3, PMAG sets up a tunnel with the NMAG through the `HI` (*Handover Indication*) and `HACK` (*Handover Acknowledgment*) messages as the link of the MN is about to be switched. After the node associates with the new network, NMAG exchanges signaling with the LMA, just like in PMIPv6. In the reactive mode, the tunnel setup occurs after the node connects to the link of the new network. In that case, the NMAG starts the signaling with the PMAG in order to configure the tunnel. This can be seen in Figure 4. The rest of the signaling is as in PMIPv6. Although FPMIPv6 may reduce packet loss, the signaling overhead introduced may increase the handover latency.

III. HANDOVER LATENCY MODELING AND RELATED WORK

Analytical modeling is a very powerful technique for performance evaluation of mobile network protocols. This is based on mathematical concepts and helps to predict systems behavior in a variety of scenarios in a short time.

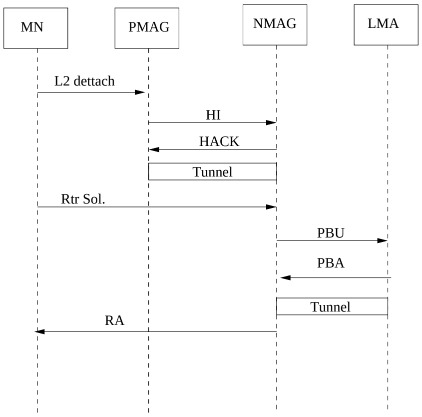

Figure 3. FPMIPv6 signaling flow in the predictive mode.

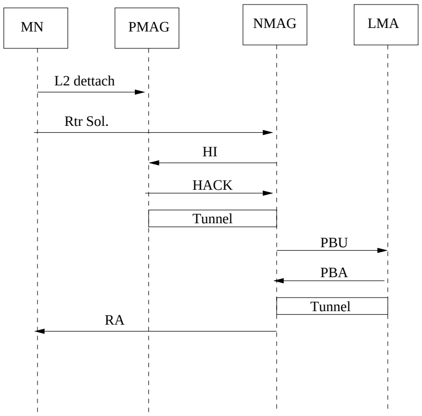

Figure 4. FPMIPv6 signaling flow in the reactive mode.

McNair, Akyildiz, and Bender [9][10] propose a framework to evaluate the performance of their proposal of two-path handover technique for MIPv6. The framework considers mathematical equations to calculate the specific operations of the proposed handover technique, bandwidth utilization and disruption time, that is, the time when the communication between nodes is interrupted because of the data path switch. These metrics are based on the latency measured between two network entities:

$$T = M + (T_w + M) \times \frac{q}{1-q}, \tag{1}$$

where M is the time to deliver a message, including processing, transmission, and propagation delays; q is the probability of link failure, and T_w is the waiting time to determine if a message is lost. Hussien *et al.* [11] utilizes that modeling to evaluate the performance of a Quality of Service (QoS) extension for MIPv6 (*DiffServ-MIPv6*) developed by the authors.

Hussain, Bakar, and Salleh consider equations to model handover latency to evaluate an intra-domain PMIPv6-based handover technique for vehicular network using Media Independent Handover (MIH) [12]. The latency equivalent to the signaling exchanged between MN and MAG (T_{RS}) and between MAG and LMA (T_{LU}^{PMIPv6}) is as follows:

$$T_{RS} = \frac{1+P_f}{1-P_f}\left(\frac{M_S^{RS}}{B_{wl}} + T_{wl}\right), \tag{2}$$

$$T_{LU}^{PMIPv6} = n_h\left(\frac{M_S^{PBU}}{B_{wd}} + T_{wd}\right), \tag{3}$$

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where P_f is the probability of link failure, M_S^{RS} and M_S^{PBU} are the size of the `Rtr Sol` and `PBU` messages, B_{wl} and B_{wd} are the wireless and wired bandwidths, T_{wl} and T_{wd} are the wireless and wired propagation delays, and n_h is the number of hops between the LMA and the MAG.

Makaya and Pierre [13] evolve the model in [9] considering the buffering aspects of FPMIPv6 and the queue delay in the handover latency equation. Thus, according to the authors, the latency of a signaling message exchanged between two nodes *x* and *y* (T_{x-y}) may be measured as follows:

$$T_{x-y} = \frac{1+q}{1-q}\left(\frac{M_{size}}{B_{wl}} + L_{wl}\right) + \\ H_{x-y}\left(\frac{M_{size}}{B_w} + L_w + T_q\right). \tag{4}$$

The first part of the sum is the wireless overhead and it must be excluded if neither *x* nor *y* is a wireless device. The second part is the overhead in the wired medium. The $H_{(x-y)}$ is the distance in hops between the two entities x and y. The parameter *q* is the probability of failure of the wireless link, M_{size} is the average length of a message, and B_{wl} and B_w are the wireless and wired bandwidths, respectively. The propagation delay in wireless and wired media are L_{wl} and $L_w, respectively$. The average queuing delay in each router is represented by T_q. Handover latency is the sum of the latency of all signaling messages exchanged during a handover. Taghizadeh *et al.* [14] apply the model in [13] to an analytical modeling framework for PMIPv6-based inter-domain protocols.

These contributions have in common the fact that the handover latency is calculated as the sum of all delays generated by each handover signaling message. This may seem appropriate for protocols like MIP and PMIPv6, where the signaling flow comprises synchronous messages. However, for PMIPv6-based protocols where there may be asynchronous messages, or messages that may be sent in parallel, these models may lead to incorrect assumptions. Thus, formal methods that are expressive enough to represent resource consumption and parallelism, like Petri Nets, may be the best suitable solution to model such protocols. Singh *et al.*[15] analyze several generations of mobile network systems, namely, GPRS, LTE and MANET using Petri Nets. The authors do not evaluate the performance of such technologies, however, they verify if they are robust and deadlock-free. Lakos [16] proposes to model MIPv4 networks in Mobile Petri Nets, a variation of Petri Nets that makes possible to represent the network divided into subsystems. Lakos does not present any performance evaluation, however, the author highlights the advantages of the graphical representation instead of a pure textual notation. Dutta *et al.* [17] use Timed Petri Nets to model the MIP binding update, including link-layer network association, CPU, memory, and bandwidth consumption. However, to the best of our knowledge, there are no studies about performance evaluation of PMIPv6-based protocols using Timed Petri Nets. It is important to fill that gap, since Petri Nets are a powerful mean to evaluate properties, resource management and synchronization in systems and, when associated to the cited mathematical models, it can help to predict systems performance.

IV. TIMED PETRI NET MODELING

In this section, the handover process in several PMIPv6-based protocols is represented as a Timed Petri Net. Each *place* in the Petri Net (represented by circles) reproduces a handover step achieved. Each *timed transition* of the Petri Net (represented by white rectangles) reproduces a signaling message exchanged between network entities with a delay calculated as in any latency modeling seen in Section III. The *token* (represented by a small circle inside a place) controls the state change. When there is a *token* in the first place of the Petri Net, it means that a new handover is about to start. The *arcs* in the Petri Net (represented by arrows) connect places to transitions and determine how many tokens a transition may produce to the subsequent place. Every time a *transition* is fired, it consumes a *token* from the previous *place* connected to it.

Figure 5 presents the Timed Petri Net for the PMIPv6 handover. This is equivalent to the signaling presented in Figure 2. At this time, the `T_L2Trigger` *transition* will fire after the link-layer handover time elapses. The `T_TxRtrSol` *transition* represents the ICMP message that the MN sends to its MAG. In that state, the `L3HOStart` *place* would have a *token* and the network layer handover could start. The `T_TxPBU` *transition* will fire after the delay equivalent to the delivery of the `PBU` message. The *token* would be removed from the `L3HOStart` *place* and a new *token* would appear in the `P1` *place*, representing that the LMA is in a state ready to send the `PBA` message. Then, the `T_TxPBA` *transition* waits the equivalent `PBA` signaling delay to fire. The Timed Petri Net is modeled as a directed circuit, that is, the last *transition* is connected to the first *place*. It may be helpful to simulate various iterations and, thus, to calculate average values.

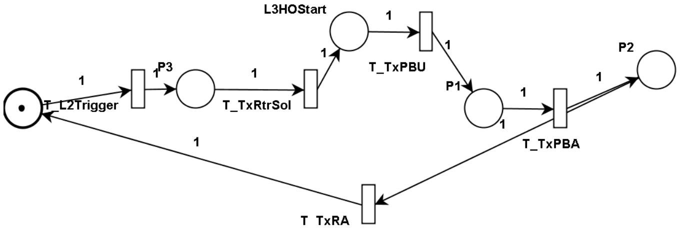

Figure 5. Timed Petri Net for PMIPv6 signaling.

Figure 6 presents the Timed Petri Net for the FPMIPv6 handover in the predictive mode. This is equivalent to the signaling presented in Figure 3. It is important to notice that the beginning of the tunnel setup depends only on the `T_L2Trigger` transition and the binding update may start only after the transition `T_TxRtrSol` fires. From this moment, the tunnel setup between MAGs and the binding update process may occur in parallel, as is expected in the FPMIPv6 predictive mode. That situation makes clear the advantage of using a Timed Petri Net model over modeling the handover latency as a sum of signaling delays. The parallelism is clearly expressed, which makes the model closer to the way the protocol is expected to work than with other modeling approaches.

Figure 7 presents the Timed Petri Net for the FPMIPv6 handover in the reactive mode. This is equivalent to the signaling presented in Figure 4. In that case, the tunnel setup

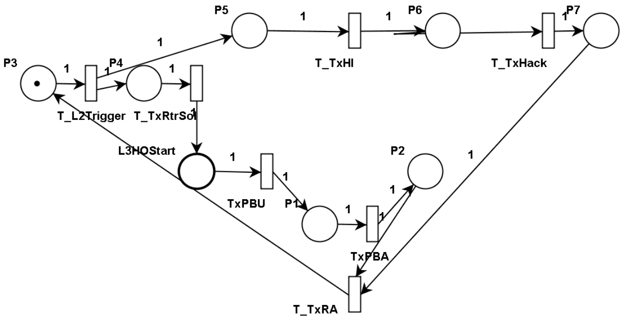

Figure 6. Timed Petri Net for FPMIPv6 signaling in the predictive mode.

between MAGs takes place after the `T_TxRtrSol` transition fires. In this model, the `T_TxPBU` transition may fire only after the `T_TxHI` fires, since it is sent by the same entity. This is represented by two arcs pointing to `T_TxPBU`. That dependency is not modeled in the predictive mode, since the tunnel setup occurs sooner, and, therefore, the `HI` message would always be sent before the `PBU` message.

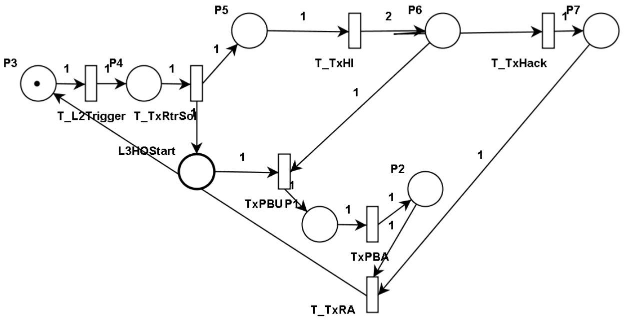

Figure 7. Timed Petri Net for FPMIPv6 signaling in the reactive mode.

It is important to notice that the use of Timed Petri Nets makes clear the main differences between PMIPv6 and FPMIPv6, and the FPMIPv6 proactive and reactive modes, due to its graphic features. It does not mean, though, that latency modeling as in related work may be discarded. Instead, the latency equations must be used to find a suitable value for each timed transition. With these two modeling techniques associated, one may obtain results that are closer to the ones that can be found in a real world environment.

V. CONCLUSIONS AND FUTURE WORK

This paper proposed Timed Petri Nets as a tool for modeling PMIPv6-based protocols. Timed Petri Nets are a formal language capable of representing resource consumption, parallelism, synchronization, and time elapsing. This makes Timed Petri Nets helpful when studying the differences among protocols in a simple and clear way. Thus, protocol designers can raise design issues before investing in a deployment environment for testing.

This paper described a work in progress. Therefore, as future steps, a study on the characterization of signaling delays is expected. This will make possible to infer the corresponding probability distribution function and to model these protocols using Stochastic Petri Nets [18], where steady state results may be collected. Buffering mechanisms and data flow may be as well considered in future work. Modeling of O-PMIPv6 and T-PMIPv6 are further expected.

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