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RESEARCH ARTICLE

Performance Analysis of Various Mobility Management Protocols for IPv6 based Networks

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Abstract –Amount of Internet traffic has increased significantly in recent times. Penetration of mobile and handheld devices in the society is also remarkable. In order to address the user demands and seamless mobility in IP networks like the Internet, there is a need to have efficient mobility management protocols and architectures. This is required to address various issues that arise due to users' mobility. Such protocols and architectures should intend to provide better service quality to the end users. Protocols like Mobile IPv6 (MIPv6), Hierarchical MIPv6 (HMIPv6) and Proxy Mobile IPv6 (PMIPv6) have been established as widely accepted mobility solutions for IP based wireless networks which has also been standardized by the Internet Engineering Task Force (IETF). Three Layer MIPv6 (TLMIPv6) strives to provide seamless mobility management under mobile environment. In this paper, MIPv6, HMIPv6, PMIPv6 and TLMIPv6 are thoroughly surveyed. These protocols are also examined under different mobility models to evaluate respective performances. Three mobility models: (1) Random Walk Mobility Model, (2) Probabilistic Random Walk Mobility Model and (3) Gauss-Markov Mobility Model are exploited to model the mobility of users, in order to analyze the performance of the protocols. Future scope of the work has also been outlined.

Index Terms – Layered Architecture, Mobility Management, Performance Analysis, Mobility Models.

1. INTRODUCTION

Mobile data communication technology has undergone a great change in its architecture. It is now far different from the traditional wireless solutions as performed in last mile wireless access. The data produced by mobile network is growing tremendously and expected to reach an annual growth rate of around 42-45% with a compound expansion. Researchers have forecasted that the said mobile data will increase approximately by eight times of the current data by the end of 2023, with a total data of around 110EB per month. It is also forecasted that major part of these mobile data would be from smart-phones and it will dominate the network with a 90% of contribution [2]. It is due to the proliferation of mobile devices as well as popular mobile applications that make lives more sophisticated. Due to such popularity of the mobile communication technology and the demand of seamless mobility by users, there is an active trend in recent time in research activities of mobility management protocols and architecture that supports IP network. There are several mobility protocols for both cellular and IP based networks. However, research and development activities are still on in search of efficient solutions. The goal of such protocols and architectures is to support uninterrupted communication opportunity to the end users, a better service quality despite unpredictable changes in their attachment point during movements. It is a mandatory need of the mobility protocols to maintain connectivity during handover, even if the users move through heterogeneous networks.

Any layer in the TCP/IP protocol stack is capable of extending the support to the mobility management protocols. However, the mobility support provided in data link and the network layer are the most popular techniques. However, to provide seamless mobility, network layer solutions for mobility management are the most popular. The mobility management in network layer enables a mobile node to use the same IP address globally. The Mobile IPv4 (MIPv4) [4] or MIP is the first mobility management protocol to be standardized by IETF. The MIPv4 supported mobile users by integrating the Internet and communication on the go. It is a common scenario in wired and wireless environment where users want to communicate on the move. However, over time, the wireless network deployments have grown, and the uninterrupted connectivity to moving end users has become the primary requirement. To support such user demands several mobility management protocols have already been suggested. However, all these protocols are different in their performance with respect to the handoff latency and signaling cost. These two parameters are the most vital for a user who wants to roam and to have seamless connectivity and communication.

The performance analysis of any mobility management protocol is incomplete without evaluating the packet tunneling cost (or packet delivery cost) which is another vital metric in determining the network performance in IP based wireless mobile deployment scenario. The handoff latency is defined as the time taken by a mobile node (MN) to reestablish its connection during the change in attachment points [3]. It is expected to be minimum so that no data packets are lost due to handover. Signaling cost is the measure of the bandwidth utilized in exchanging signaling control packets between the mobility management agents in order to complete the handoff procedure. This cost is dependent on the number and size of the management packets and the distance traversed by them in the network. The packet tunneling cost, on the other hand, is the extra header bytes supplemented to the original packet, in order to deliver it to the visiting mobile device in its new location. Possible minimum values of these parameters identify a mobility management architecture and protocol as the efficient one.

Mobile IPv6 (MIPv6) [5] is an extension of IPv6 with mobile user support. Due to the shortage of address space, IPv4 is to be replaced by IPv6. As a result, the mobile version of IPv6 (MIPv6) is viewed as a suitable mobility management protocol to cater to the upcoming generations of wireless IP based networks. Despite being a standard solution, MIPv6 does not perform well in a situation where mobile users frequently change their location. Because in such a situation, they produce larger handover delay, and larger signaling overhead.

The Hierarchical MIPv6 (HMIPv6) [6], the extension of MIPv6 is a layered architecture for mobility management. Because of the hierarchically placed anchor agents, the incurred signaling cost and handoff latency in the network are comparatively less as that of MIPv6. HMIPv6 architecture divides the network into two categories (or domains); (1) internal network and (2) backbone. The backbone (or global domain) is constituted by connecting all border gateways (BGs) over the Internet. Whereas, the internal network, (or local domain) constitutes of all the routers which are under the coverage of single BG. In HMIPv6, the node (MN) mobility is divided into two types: (1) micro-mobility and (2) macro-mobility. When the mobile nodes move within subnets in the same local domain, this type of mobility is realized as micro-mobility. On the other hand, when the mobile nodes cross the local domain boundary, this type of mobility is realized as macro-mobility. The macro mobility results in the increase of the signaling load in the deployed network, as the MN crosses the local domain. HMIPv6 architecture introduces the concept of a Mobile Anchor Point (MAP) to be positioned at the boundary of the backbone and local domain in order to cater to the macro-mobility. Although, due to the placement of this agent the protocols work better in certain situations, it does not perform well in all scenarios. For example, in a scenario of a frequent micro-mobility, the signaling load produced in the local domain is quite significant. To address these issues, different proposals of multi layered model have been introduced in MIPv6. It is claimed and proved that the multilayer hierarchical models can significantly reduce the signaling load to be generated in the local domain.

In one side, multiple layers of anchor agents reduce the signaling load to be generated in the local domain, and in the other side, it increases the tunneling cost. So, the hierarchical layers in the hierarchical model cannot be augmented beyond a certain level. In [7, 8], it is shown mathematically and by simulation also, that a three-layer model provides an optimized solution for mobility management in hierarchical architecture with optimized values of handoff latency, optimized values of signaling overhead and optimized values of packet tunneling cost. Based on these works, a new Three Layer MIPv6 (TLMIPv6) model is proposed in [1, 9]. In this work, evaluation of TLMIPv6 is carried out with respect to its handoff latency, signaling overhead and packet tunneling cost. The performance analysis of TLMIPv6 is carried out with MIPv6 and HMIPv6 protocols. An exhaustive performance analysis of the TLMIPv6 is carried out under different mobility models. We aim at understanding the behavior of the new architecture (TLMIPv6) under the influence of various mobility patterns of the mobile users. The benefits of using this architecture in the upcoming generation of IP based wireless mobile networks are also to be understood.

The rest of the paper is organized as follows. The current research directions are discussed in section 2. Various mobility management protocols are reported in section 3. The network architecture with reference to [1] is explained in section 4. Few mobility models used for performance evaluation are described in Section 5. Parameters to be evaluated are discussed in section 6. Simulation setup in ns-2 simulator is presented in section 7. The simulation results and discussions on the results are presented in section 8. Finally, the paper is concluded in section 9.

2. CURRENT RESEARCH DIRECTIONS IN MOBILITY MANAGEMENT

Mobility management protocols have undergone considerable evolution in the last decade. The solution however, has been explored in many directions starting from distributed concept to recent software defined network concept but the problem still persists as no such work has been reported to find an optimum mobility management solution. This area of study has been active at present [29] [30]. In this section, few recent works in this area are highlighted.

The MIPv6 and PMIPv6 protocols are analytically evaluated in [10]. Authors have also provided some experimental results for comparison. A model for signaling load and handover latency is depicted in the research and the model has been evaluated analytically. Different network conditions are examined to show their impact on signaling and handover. In [11], authors have carried out an investigation on mobility management protocols. A comparison of existing solutions for mobility management is also provided. A list of pros and cons are highlighted. However, no new conclusion has been drawn by the authors in their work. Few mobility management issues in wireless mobile communication are highlighted in [12]. Major focus is on the relevance of mobility of nodes and mobility handling strategies in existing solutions and probable methods. Moreover, authors have elicited the handoff management taxonomy. A brief discussion about the security issues involved in various handover processes has also been presented. Furthermore, factors that affect the handoff delay are also studied. Finally, few recent open issues of research are highlighted.

The study in [13] is to examine the methods of mobility services in a flatter network architecture, and to understand how it is different from hierarchical network. Authors have centered on a few possible mobility handling solutions that have greater importance in current time. Authors have primarily focused on three most prominent solutions for mobility management that have been standardized by IETF. An analysis of their scalability characteristics is carried out using mathematical evaluation, as well as through experiments.

A secure mobility management protocol is proposed in [14]. The proposed mechanism is based on eXpressive Internet Architecture (XIA). This work describes an ID/locator decoupling based routing approach which is used for mobility support. The work suggests utilizing the self-certifying identifier, for binding management activities to address the issue of potential threats occurred due to mobility management. It provides mobility solution to outperform IP based solutions regarding efficiency and flexibility.

A comparative performance evaluation of HMIPv6 with PMIPv6 architecture is found in [15]. Three parameters, namely, the cost of location update, the packet delivery cost and the energy consumption for wireless transmission are compared. The impact and importance of the system parameters on the mobility model are highlighted. In [16], an analytical investigation has been carried out on the performance of the PMIPv6with respect toHMIPv6 architecture. The Random walk mobility model is considered to evaluate the performance. Since only one mobility model has been considered to understand the functioning of PMIPv6 and HMIPv6, the study remains incomplete. However, observations under other different mobility models are essential to have better insights and for wide deployment of the techniques.

There are few hierarchical solutions examined for optimum number of layers as described in [17], [18], [19] and [9]. Although the hierarchical architecture reduces handoff latency and signaling cost, it does not work well for reducing tunneling cost. Hence, finding optimal levels of hierarchy is a critical task. In the work presented in [17], MIPv6 is analyzed mathematically for finding an optimal hierarchy that gives better performance. Similarly, [18], [19] and [9] worked in the same direction. The work of [17] has evaluated the cost of packet delivery and the cost of location update and in multi-level HMIPv6 architecture. Optimal number of hierarchical layers for mobility management with minimized cost of handover management has been determined. In [18] the author focuses on providing a mobility management framework, and a solution in a layered IPv4 based network. Authors have proposed a pyramid like structure to form a hierarchical network and examined the network in search of an optimized solution. The work of [9] and [20] also performed similar observations but based on mathematical analysis. These studies indicate that the hierarchical model for mobility management cannot have indefinite numbers of layers due to the increased tunneling costs. In [9], it is concluded that a three-layer model is optimal for such a solution, in the layered and hierarchical model.

An optimized hierarchical solution for mobility management is reported in [17]. This work emphasizes on placing several anchor agents (AA). A reduced signaling load on the network is observed due to placing of such hierarchical anchors. Further, a border router is introduced in the network for the realization of route optimization. A means for fast handover in intra-domain and inter-domain has been adopted in the said proposal. The model combines the advantages of both HMIPv6 and FMIPv6. A reduced packet loss ratio is reported in the work and it is a result of multicasting as stated in the work. However, the protocol does not make any conclusion regarding the optimal hierarchy of layers. The work presented in [21] proposes a mobility anchor point (MAP) selection algorithm in a tree-based architecture of a hierarchical network. All MAPs are assumed to be intricately overlapping with each other. The algorithm allows an MN to appropriately select a MAP in the network to have a better impact on handover. Different MAP selection criteria are adopted for selection of MAPs and configured individually to use at a particular place.

The work reported in [8] is a three-layer mobility model for handoff management. In this work, the node movement is modeled as fluid flow. The performance analysis of the proposed hierarchical model has been carried out. This work also provides a comprehensive study on the signaling overhead generated for highly mobile MNs in the proposed model.

The layered architecture for mobility management has significant importance and one of the prominent solutions for seamless mobility provisioning. In this paper, a comprehensive performance analysis of TLMIPv6 model is reported. The TLMIPv6 model is observed under different mobility models in order to understand the respective behaviors. In the next section, we provide basic functionalities of some of the popular IPv6 based mobility management protocols.

3. VARIOUS MOBILITY MANAGEMENT PROTOCOLS

It becomes very important to extend the existing protocols to support seamless mobility with the ever increasing numbers of wireless mobile users. However, IPv6 [31] alone doesn't possess the capability of facilitating this extension of services. Also there are certain fundamental issues that need to be addressed while extending mobility support to the mobile nodes. Few of these certain issues [32] that may be experienced in the five functional layers, while mobile nodes change their locations between subnets are mentioned below.

Layer – 1: As a mobile node gets disconnected from one radio link to another, it is more than likely that the quality and support of the link changes.

Layer – 2: Media availability issues and frame loss issues may likely to affect the overall quality of services.

Layer – 3: IP address mismatch shall eventually lead to an overall inability of the visited network to service the IP packets sequenced from or destined to the visiting mobile node.

Layer – 4: Broken TCP session or degradation in quality of TCP session.

Layer – 5: A change in the network configuration, will lead to the malfunction of all the connection-unaware applications.

Mobility management protocols are in place in order to support such mobility of nodes. These protocols are in general categorized into two sub-classes based on their functionalities [33]. The one that provide services for tracking the location of mobile users known as location mobility management protocols and the other that provides handoff/handover services known as the handover mobility management protocols. Both these mobility management protocols need to be operational at tandem, that too in close coordination with each other for any given deployment scenario. This is because the methodology that maintains an active and seamless connection as the mobile users move from one geographical service area to adjacent geographical service area and the location of the mobile users in between communication sessions are both vitally important aspects of mobility management. Further there two sub categories of mobility management protocols: (1) network-based and (2) host-based. In the host-based one, the handover management is initiated by the roaming mobile node and carried forward by specialized designated mobility agents. However, in network-based mobility management protocols, the specialized designated mobility agents alone perform the task of handover management, making the handoff management imperceptible to the visiting mobile node. We have considered four IPv6 [31] based mobility management protocols in chronological order for our work; namely Mobile IPv6 [5], Hierarchical Mobile IPv6 [6], Proxy MIPv6 [22] and Three Layered MIPv6 [1]. All these mobility management protocols are extended versions of the IPv6 [31] protocol suite for wireless mobility support. Mobility support in IPv6 is principally important as we expect most of the Internet [3] users to be unwired and mobile during the lifetime of IPv6 and beyond. Primarily, in almost all the IPv6 based mobility management protocols, the entire network is categorized into two types: (1) home network-a subnet/LAN/ISP or any logical network where the mobile node originally belongs to and (2) foreign network- any other subnet/LAN/ISP or any logical network that supports any of the mobility management protocol which is other than the home network. It is of primary importance to know: how these mobility management protocols function when a mobile node switches location: (1) between home network and foreign network, and (2) between different foreign networks. In the following sub-section, a brief description of the handoff management that each of these mobility management protocols administer to the visiting mobile node in the event of a handover, is presented.

3.1. Mobile IPv6 (MIPv6) [5]

A mobile user in Mobile IPv6 (MIPv6) protocol (standardized by IETF), is permanently known by its home IPv6 address even if it detaches itself from its home network, and switches into a foreign network. Overall, MIPv6 protocol permits to sustain the ongoing communications of a roaming mobile user even if it moves from its home network into a foreign subnet having a dissimilar subnet prefix. Interestingly the ongoing communication persists despite of change in its physical connection and link-layer attachment point but without a change in the visiting mobile node's IPv6 address. Moreover, MIPv6 protocol specifies how the movement of a mobile node from home network to the foreign network is kept imperceptible to layer – 4 and above. It is done in such a way that the roaming mobile node is always routable using its home IPv6 address. Thus data packets may be routed to the visiting mobile node using its home IPv6 address regardless of the physical location or point of attachment of the mobile node to the Internet. In order to facilitate this process, three different IPv6 addresses need to be assigned to the different interfaces of each of the visiting mobile node: (1) home address, (2) current link-local-address and (3) care-of-address (CoA). The link-local-address is a layer-2, non-routable address which are unique, and at the same time reachable even without the help of the routers. The CoA is the IPv6 address which is globally routable and it also serves as the current temporary address of the visiting mobile node in a particular foreign subnet. In every event of a mobile node detaching itself from its home network to move to a foreign network, it is the responsibility of the of the visiting mobile node to configure the CoA in the current foreign MIPv6 network by virtue of the stateless address auto-configuration [34] feature of the IPv6 protocol suite or by some state-full auto-configuration with the help of PPPv6 [35] or DHCPv6 [36]. This configuration of CoAs by mobile nodes in the foreign network is carried out from the router advertisement messages advertised by the access routers present in the foreign network as specified in IPv6 protocol suite.

This essence of construction of globally routable CoA in a visited foreign network by a visiting mobile node categorizes MIPv6 as a host-based protocol. In order to enable the visiting mobile node to be addressable and reachable in a foreign network, MIPv6 protocol defines a home agent which is a router located in the mobile node's home subnet. The home agent, despite being connected to the Internet, and routing the IPv6 packets normally, carries an additional task of managing and tracking the movement of mobile nodes registered under it. MIPv6 also defines a so called correspondent node which is nothing but another mobile node. This node may be stationary or mobile that communicates with the mobile node under consideration using normal IPv6 addressing. Let us assume that one of the mobile nodes has moved to a foreign network. Suppose that an IPv6 packet destined for the mobile node's home address routes its way through to its home subnet. Now the MIPv6 protocol suggests that it is the responsibility of the home agent present in the home network to intercept this packet and tunnel this packet or perform IPv6 encapsulation [37] and re-route the said packet to the current CoA of the mobile node in its foreign network. To be able to do that, the home agent should have the knowledge of the current location (CoA) in its cache. After construction of the CoA and current link-local-address, the visiting mobile node then sends its first binding update to its home agent located in its home subnet.

This binding update has the new-CoA, current link- local-address and binding lifetime. The binding lifetime is the lifetime of the binding, till which the binding remains valid. If the mobile node chooses its stay in the same foreign network even after the expiration of the binding lifetime, it sends a binding refresh which is similar to sending a binding update. Upon receiving the binding update, the MIPv6 enabled home agent should send a binding acknowledgement (<ack>) back to the mobile node in its current-CoA after storing the binding information in its cache. Similarly, the home agent also enacts as the stand-in link layer interface in place of the detached mobile node in its home network so that any correspondent node located in the home subnet may use that particular link-layer to communicate with the detached mobile node. The exchange of binding updates and binding acknowledgements between home agent and its corresponding roaming mobile node can be carried out in two ways as defined in MIPv6: (1) like any other IPv6 packet carrying TCP [38] or UDP [39] payload and (2) separate IPv6 packet that does not carry TCP or UDP payloads but whose Next Header is set to express 'No Next Header' [40] in the Destination Options field. MIPv6 also addresses the triangle routing problem in such a way that every time a correspondent node does not need to send the packets destined to the same mobile node in its home address repeatedly. Once the home agent intercepts the first packet from a correspondent node just after a binding update/refresh, it shares the binding cache with the particular correspondent node thereby sharing the current CoA of the mobile node along with its current binding details. Therefore, from the next event onwards, the particular correspondent node routes the packet directly to the roaming mobile node in its current CoA thereby solving the triangular routing problem. The triangular routing problem solves the issue of single point failure of the home agent as precautionary measure. A schematic diagram showing Mobile IPv6 registration, signaling and data transfer is given in figure 1.

3.2. Hierarchical Mobile IPv6 (HMIPv6) [6]

MIPv6 protocol, although based on a mature IPv6 protocol with a well-defined structure, fails to be scalable when the number of roaming mobile users increases to a very large number leading to adverse impact on signaling overhead and handoff performance. This is because, the roaming mobile nodes or users (host, as per HMIPv6 terminology) need to send very frequent binding update/refresh messages to the correspondent nodes (host, as per HMIPv6 terminology) and to its home agent. As a matter of fact, it is seen that MIPv6 protocol manages the local mobility, the same way as it does with global mobility, although study suggest that 69% of all the movements of such mobile nodes are local (within the same subnet). [41]. HMIPv6 protocol also caters to this additional requirement by providing the much needed hierarchy among the mobility agents in order to handle the so called micro/local mobility and macro/global mobility separately. HMIPv6 protocol suggests that a correspondent host may be made aware only about the macro mobility of the mobile host instead of what has been suggested for MIPv6. The micro mobility (within the site) is kept transparent to the external hosts and managed locally. However, the process of sending binding updates/refresh upon the expiration of binding lifetime continues in HMIPv6, although in a hierarchical fashion, in this case. HMIPv6 also extends support for N-levels of hierarchical divisions of the site into N-sub-sites for mobility management on the basis of the N-levels of mobility of the mobile hosts. In HMIPv6, a mobility network [6] is deployed which is analogous to the home network for the case of MIPv6 network. The mobility network includes several mobility servers which are analogous to the home agent for the case of MIPv6 network. The difference between the mobility network and mobility server in HMIPv6 with their counterparts in MIPv6 is that the mobility network supports both fixed and mobile hosts including the mobility server. A border router [6] in HMIPv6 network is defined as the one that connects the mobility network to the Internet [3]. Very often, the border router and the mobility server are kept as different entities in HMIPv6 although possible to implement the mobility server on the border router for two reasons: (1) to avoid extra processing overhead and (2) to impart more robustness. The working of HMIPv6 is similar to MIPv6 except the way they process the handover management for the mobile hosts in a hierarchical manner. The process may be better explained in two phases as mentioned below.

3.2.1. Phase-I: Global Mobility or Inter-Site Mobility of Mobile Hosts

Unlike for the case in MIPv6, when a mobile host moves to a new site, it constructs two CoAs: physical CoA and Virtual CoA. The physical CoA is analogous to the link-local-address to that defined in MIPv6, whereas the virtual-CoA is analogous to the current-CoA defined in MIPv6. The number of virtual-CoAs depends on the level of hierarchy of the deployed HMIPv6 network. If N-level hierarchy is deployed, the number of virtual-CoAs constructed is N-1. A schematic diagram showing a Hierarchical Mobile IPv6 registration, signaling and data transfer for inter-site mobility of the visiting mobile host, is given in figure 2.

The following can be observed in figure 2.

a) The binding update sent to mobility server from the mobile host contains all virtual-CoA and physical-CoA. In response to this binding update, the mobility server, after performing admission and authentication control, sends back the binding acknowledgement to the mobile host maintaining reverse routing.
b) The binding update sent to the external correspondent host by the mobile host or mobility server contains all virtual-CoAs. The binding acknowledgement for this binding update has been kept optional in HMIPv6.
c) The binding update sent to the local correspondent host by the mobile host contains only physical-CoA. The binding acknowledgement for this binding update has been kept optional in HMIPv6.

The transfer of IPv6 packets between correspondent hosts, mobile hosts and mobility servers take place in a similar fashion as prescribed as in MIPv6 thereafter.

3.2.2. Phase-II: Local Mobility or Intra-Site Mobility of Mobile Hosts

Unlike MIPv6, HMIPv6 discriminates mobility management for inter-site mobility of a mobile host in such a way that this local mobility is kept transparent to the upper layers and eventually to the external correspondent hosts. In such a scenario, only the physical-CoA changes and the virtual-CoA (for that site) remains the same. A schematic diagram showing Hierarchical Mobile IPv6 registration, signaling and data transfer for intra-site mobility of the visiting mobile host is shown in figure 3.

The following can be observed in figure 3.

a) The binding update sent to the local correspondent host by the mobile host contains only physical-CoA.

b) The binding update sent to mobility server from the mobile host with its virtual-CoA and physical-CoA.

c) Binding updates are not sent over the Internet.

3.3. Proxy Mobile IPv6 (PMIPv6) [22]

Both MIPv6 and HMIPv6 protocols are host based protocols in a sense that in both the protocols, the responsibility of construction of CoAs lies with the visiting mobile node/host upon reception of empty IPv6 addresses advertised by the access router at the visiting sites. This puts extra processing overhead on the part of mobile host. Therefore, in PMIPv6, it is made possible to extend mobility for mobile nodes exclusive of any involvement of the visiting host in the mobility management process. In PMIPv6, the mobile node and its local mobility anchor (alias home agent) need not exchange signaling packets directly. This job is performed by a specialized mobility agent present in the foreign network known as mobile access gateway (MAG) on behalf of the visiting mobile node and hence the name Proxy Mobile IPv6. The MAG in a PMIPv6 protocol is also defined to detect the movements of the visiting mobile node within the access links and also to initiate and send binding updates to the corresponding local mobility anchor. The MAG, thus takes up the responsibility of mobility management in lieu of the visiting mobile node. As it is a Mobile IPv6 enabled network, the signaling and data transfers, post the handoff are carried out in a similar fashion as described for MIPv6. The equivalent schematic diagrams showing handoff signaling in PMIPv6 protocol when the visiting mobile node enters a foreign network is presented in figure 4.

As in figure 4, when a mobile node moves to a PMIPv6 domain, it gets attached to an access link. The corresponding MAG on that access link thereafter authenticates the visiting mobile node for the PMIPv6 mobility management service. After authentication, the MAG on behalf of the mobile node constructs the proxy-CoA and local-link-layer CoA similar to that in MIPv6 based network, with a network lifetime. A bidirectional tunnel is established between the mobile node and MAG, after authentication. Post the construction of CoAs and lifetime, a proxy binding update is delivered to the local mobility anchor by the MAG in lieu of the mobile node. The local mobility anchor acknowledges this binding update similar to that in MIPv6 and sends a proxy binding acknowledgement back to the current MAG. PMIPv6 also provisions a bidirectional tunnel to set-up between the local mobility anchor and the current MAG for the packet transfer. A similar transaction also takes place in chronological order between correspondent node and local mobility anchor and thereafter current MAG.

The schematic diagram presented in figure 5 shows the handoff signaling in Proxy Mobile IPv6 (PMIPv6) protocol when the visiting mobile node changes mobile anchor gateway. It can be seen that when the visitor mobile node moves to a new site, the proxy binding needs to be deregistered from the old MAG in the previous foreign network, before registering with the new MAG in the new foreign network. The process continues as described above after obtaining the appropriate acknowledgements for the same as shown in figure 5. It is worthwhile to note that, similar to HMIPv6, the inter site movement of mobile node has been kept under cover with the external correspondent nodes. Also as the MAG is involved in mobility management in place of the visiting mobile node, PMIPv6 exhibits improved handover performance and security.

3.4. Three Layered MIPv6 (TLMIPv6) [1]

Similar to that of HMIPv6 and MIPv6, the Three-layered MIPv6 also exhibits a host-based mobility management approach. It is a special case of HMIPv6 mobility management protocol, however, different in few functionalities. It was found that HMIPv6 fails to perform well when the visiting mobile nodes change their subnet very often, whilst remaining within the same local domain. Similar to local and global mobility in HMIPv6, the movement of a visiting mobile node in TLMIPv6 has been categorized into three types: (1) Local mobility, (2) Regional mobility and (3) Global mobility. Correspondingly, the mobility domains in TLMIPv6 based network is categorized into three domains local, regional and global. TLMIPv6 introduces three mobility anchor points (MAPs) as the mobility agents to monitor the mobility management in each of these domains in the TLMIPv6 enabled network. They are termed as the local MAP, regional MAP and the global MAP, respectively. Similar to MIPv6 and HMIPv6, on entering a foreign network, the mobile node constructs the CoAs from the router advertisement messages intercepted from the access routers present in the foreign network. In TLMIpv6, the three CoAs are constructed with their respective binding lifetimes: Global-CoA, Regional-CoA and the Local-CoA. The mobile node also constructs one link-CoA in a similar manner as described in MIPv6 and HMIPv6 protocols. A schematic diagram showing registration, signaling and data transfer in TLMIPv6 protocol for global mobility, regional mobility and local mobility of the visiting mobile node is shown in figure 6, figure 7 and figure 8, respectively. When a visitor mobile node switches from home network to a foreign network or from one foreign domain to another foreign domain, the binding update issued by the mobile node contains all the details of the link-CoA, its home address and the corresponding binding lifetimes associated with each of these addresses (figure 6). This binding information is passed on to the local-MAP which appends its local-CoA and associated lifetime to this binding, and tunnels an encapsulated binding to the regional-MAP.

The regional-MAP also does the same by appending its regional-CoA and its lifetime and tunnels an encapsulated binding to the global MAP. The global MAP appends its global CoA and lifetime to this binding and routes the binding update control signal to the corresponding home agent present in the home network. As described for MIPv6 and HMIPv6, the home agent routes the binding acknowledgement to the global MAP. The global MAP tunnels this binding acknowledgement after admission control at its level. Also, the TLMIPv6 maintains reverse routing as in case of HMIPv6. In similar fashion, the mobile node also sends binding updates to the external correspondent nodes in order to avoid triangle routing problem. The roaming mobile node’s communication protocol with the local correspondent nodes in the home network remains unchanged from the MIPv6 protocol. Figure 7 shows registration, signaling and data transfer in TLMIPv6 for regional mobility of the visiting mobile node. As we can see that for regional mobility, the signaling procedures are the same as above, except that the binding updates are not sent beyond global MAP. The binding updates are not sent over the Internet. This action imparts all the advantages of HMIPv6 protocol to the TLMIPv6 protocol.

The regional movement of the mobile node has hence been kept transparent from the correspondent node and the home network. Similarly, figure 8 shows registration, signaling and data transfer in TLMIPv6 for local mobility of the visiting mobile node. For local mobility, the signaling procedures are the same as above, except that the binding updates are not sent beyond regional MAP. This action imparts additional advantage of TLMIPv6 protocol over HMIPv6 protocol that does not allow additional signaling in case of frequent local movement of mobile nodes. Thus the local movement of the visiting mobile nodes has been kept transparent from the home network, and the global MAP. It is worthwhile to mention here that this protocol produces additional signaling overhead in case of binding timeout, at all levels as compared to MIPv6 and HMIPv6 protocols. This is because it involves additional addresses. However, optimization of binding lifetime is a separate issue and there is literature addressing this issue in TLMIPv6 [42].

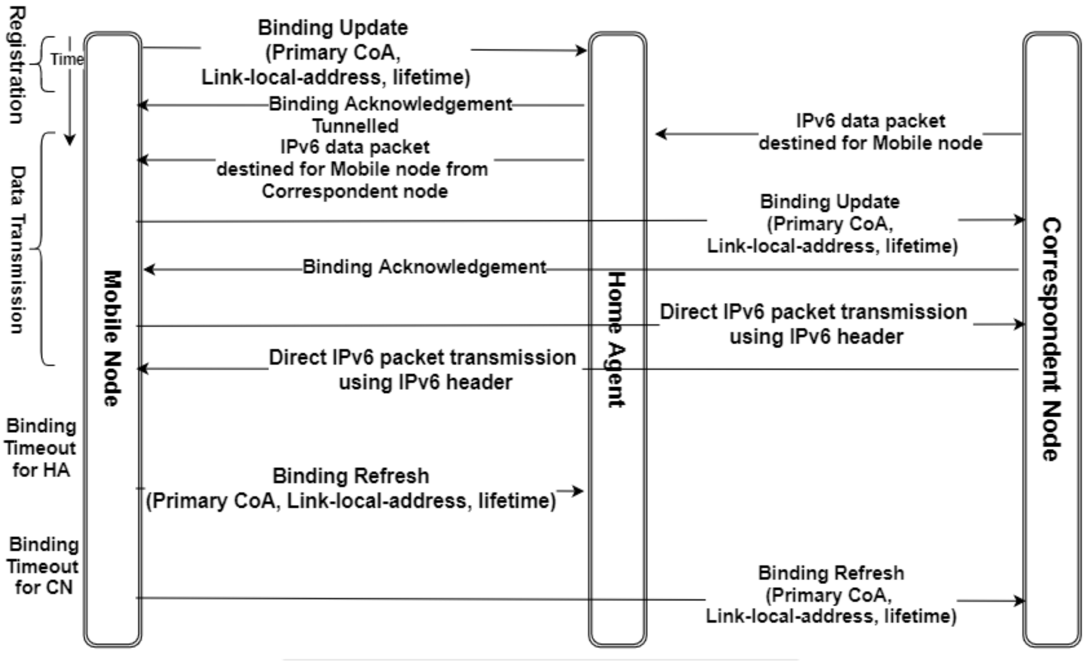

Figure 1 Registration, Signaling and Data Transfer in Mobile IPv6 Protocol.

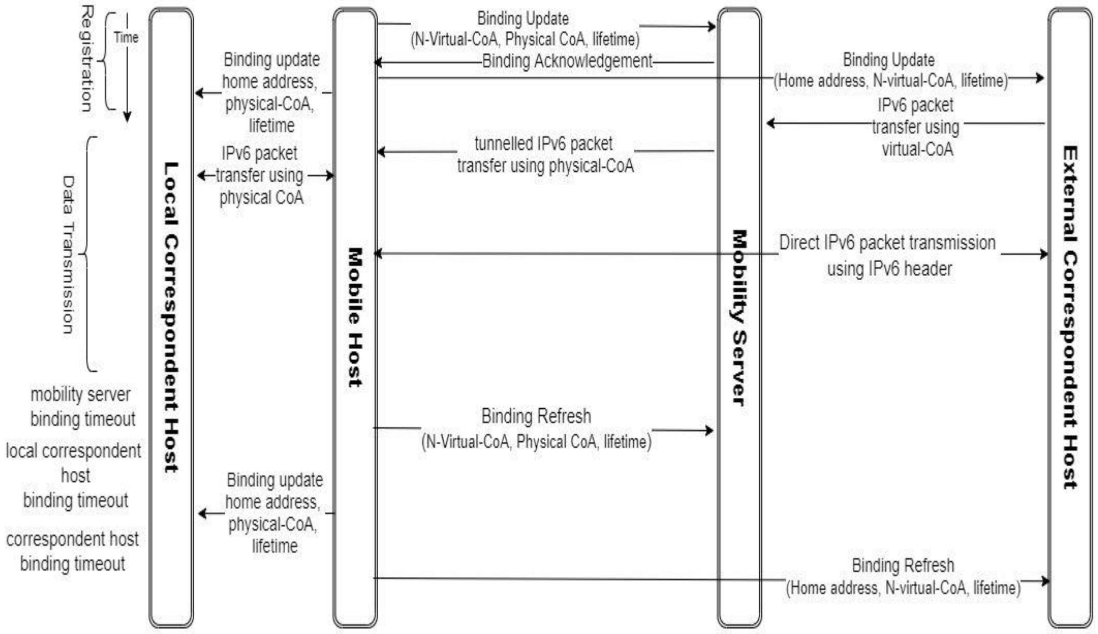

Figure 2. Registration, Signaling and Data Transfer in Hierarchical Mobile IPv6 Protocol for Inter-Site Mobility of the Visiting Mobile Host.

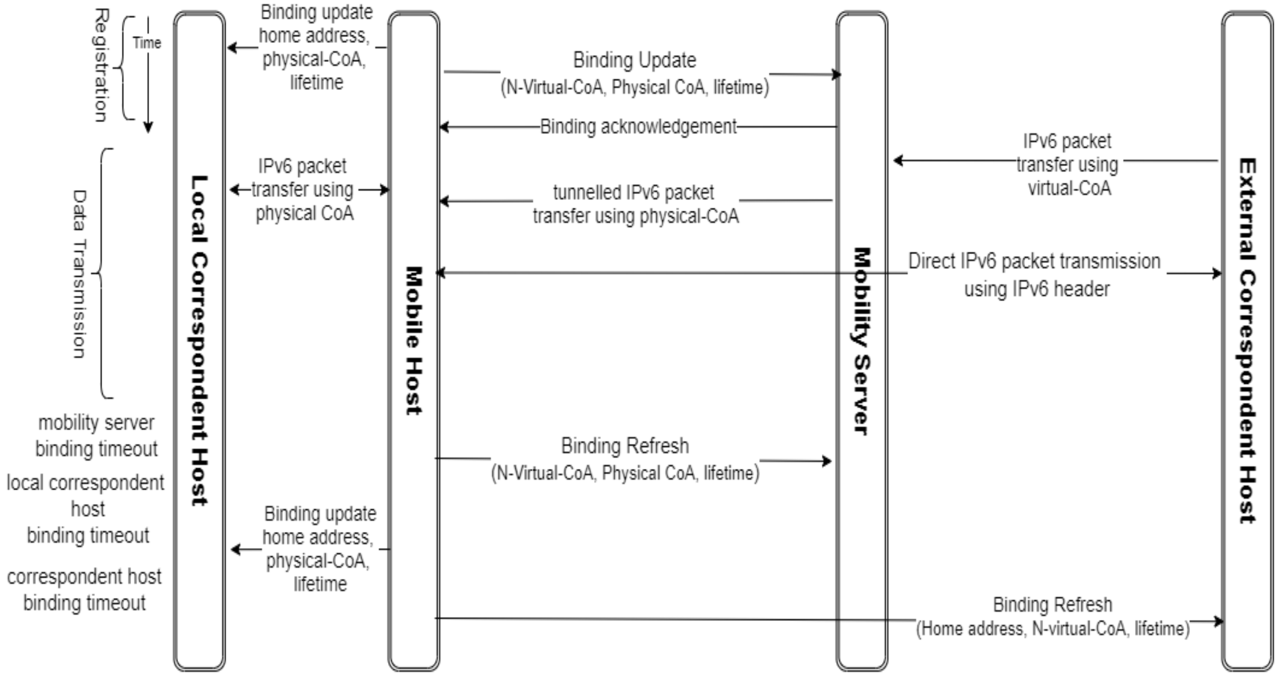

Figure 3. Registration, Signaling and Data Transfer in Hierarchical Mobile IPv6 Protocol for Intra-Site Mobility of the Visiting Mobile Host.

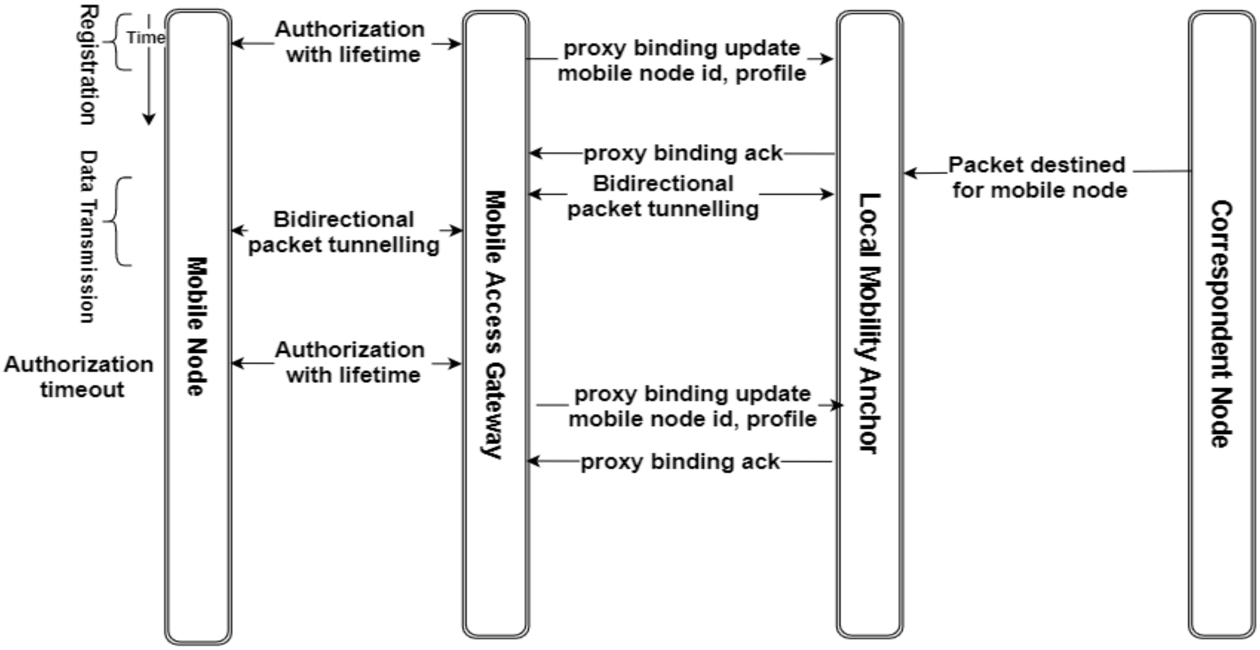

Figure 4. Registration and Signaling in Proxy Mobile IPv6 (PMIPv6) Protocol When the Visiting Mobile Node Enters a Foreign Network.

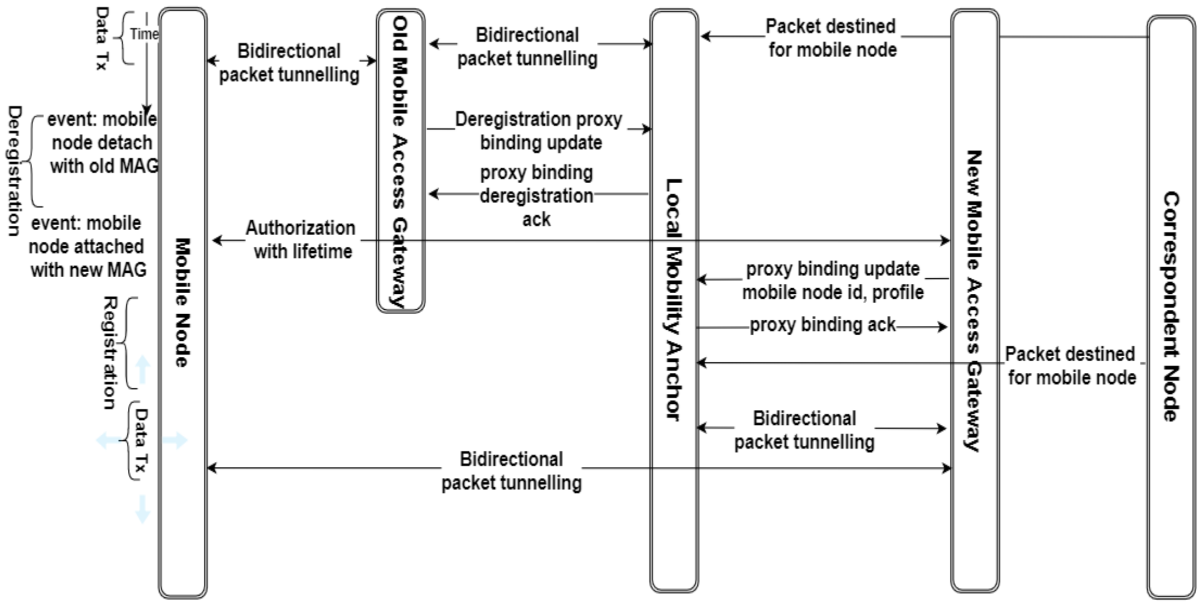

Figure 5. Handoff Signaling in Proxy Mobile IPv6 (PMIPv6) Protocol When the Visiting Mobile Node Changes Mobile Anchor Gateway

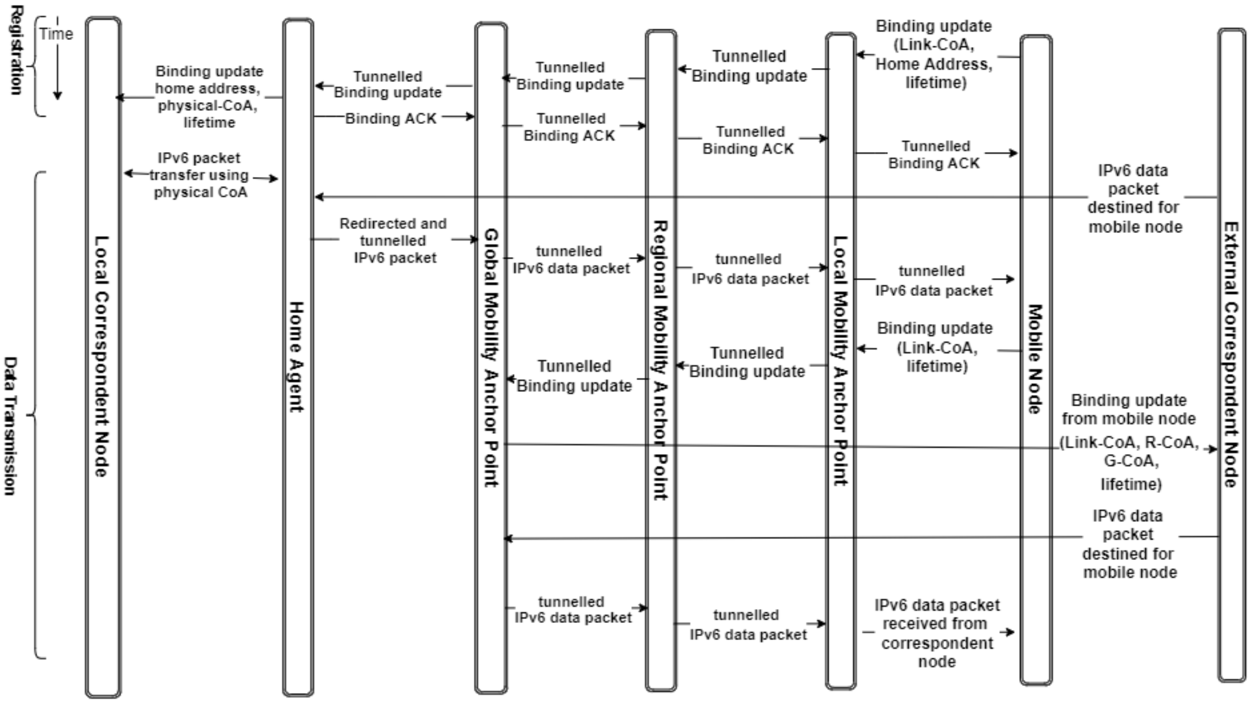

Figure 6. Registration, Signaling and Data Transfer in Three Layered Mobile IPv6 (TLMIPv6) Protocol for Global Mobility of the Visiting Mobile Node.

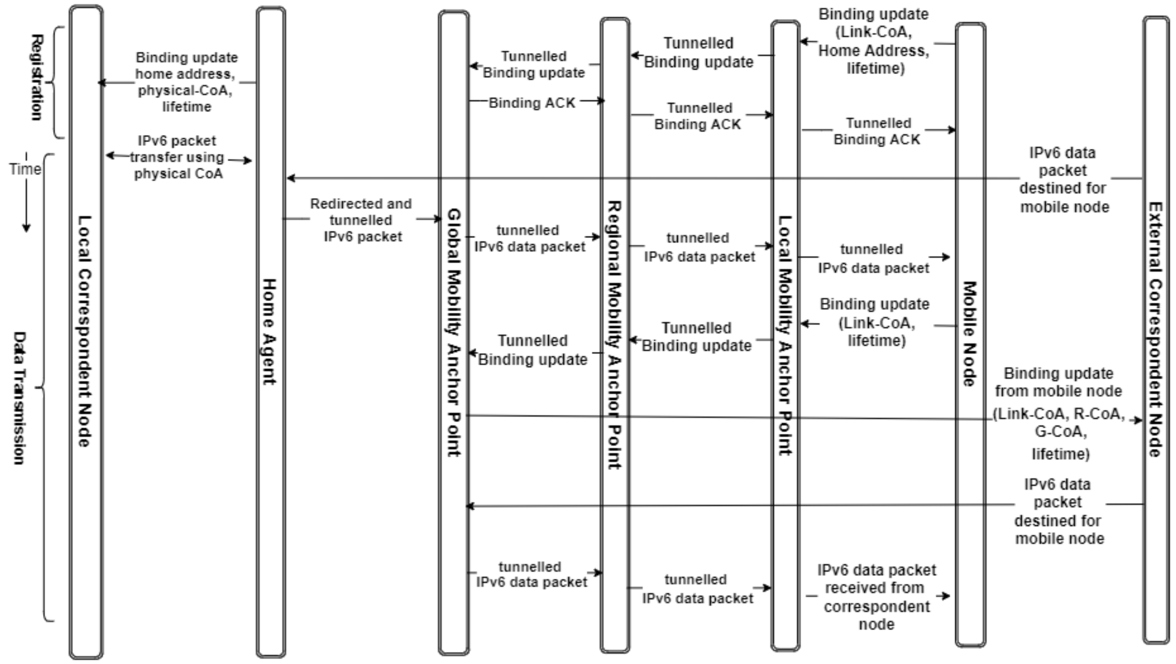

Figure 7. Registration, Signaling and Data Transfer in Three Layered Mobile IPv6 (TLMIPv6) Protocol for Regional Mobility of the Visiting Mobile Node.

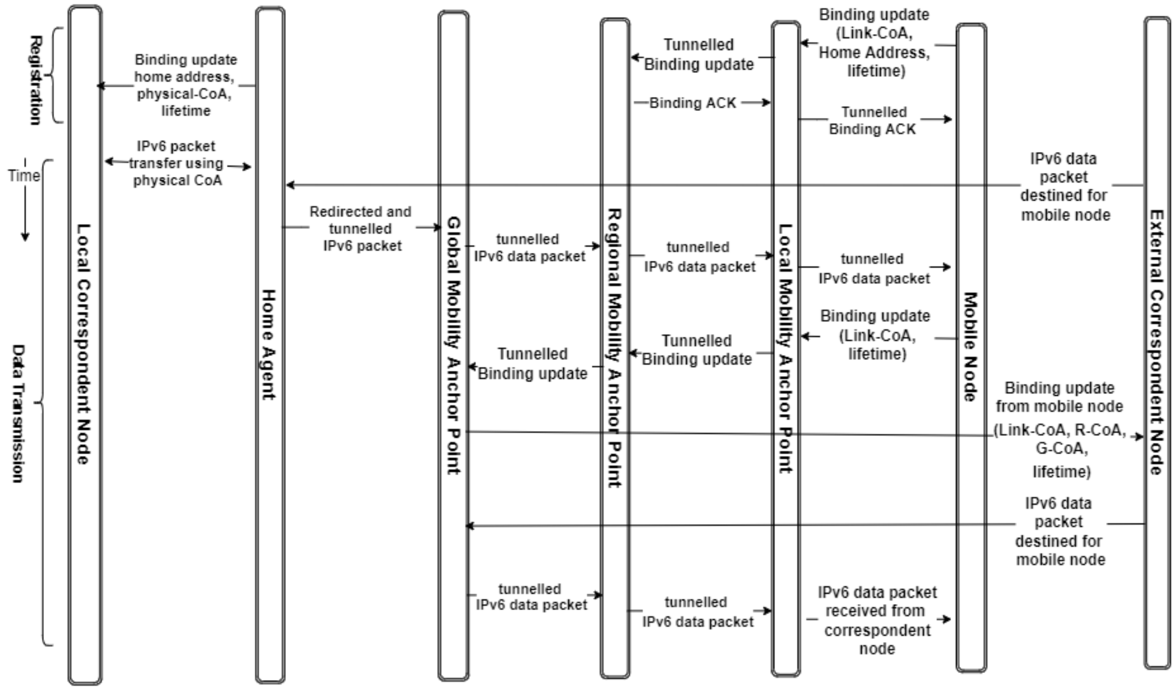

Figure 8. Registration, Signaling and Data Transfer in Three Layered Mobile IPv6 (TLMIPv6) Protocol for Local Mobility of the Visiting Mobile Node.

The mobility management protocols namely MIPv6, HMIPv6, PMIPv6 and TLMIPv6 are compared with respect to different attributes and the summary has been presented in Table 1.

TABLE 1: Comparison of MIPv6, HMIPv6, PMIPv6, and TLMIPv6

SL.No	**Attributes**	**Mobility Management Protocols**			
		Mobile IPv6 (MIPv6)	**Hierarchical Mobile IPv6 (HMIPv6)**	**Proxy Mobile IPv6 (PMIPv6)**	**Three Layered Mobile IPv6 (TLMIPv6)**
1	Underlying Mobility Management approach	Host based	Host based	Network based	Host based
2	Hierarchical level of mobility management	Undefined	N	Undefined	3
3	Mobility signaling between mobile node and home agent?	Yes	Yes	No	Yes
4	Initiation of remote registration by	Visiting mobile node	Visiting mobile host	Mobile access gateway in the foreign network	Visiting mobile node
5	Nomenclature of similar corresponding mobility agents	Mobile node, home network, foreign network, correspondent node	Mobile host, home network, foreign network (local and global), correspondent host	Mobile node, foreign network, local mobility anchor, correspondent node,	Mobile node, home network, foreign network (local, regional and global), correspondent node,
6	Mobility support	IPv6	IPv6	IPv4 and IPv6	IPv6
7	Change of address of mobile node/host while roaming across the same foreign network domain	All care-of-addresses change	Only physical care-of-address changes	Network prefixes remains unchanged	Address change depends on local, regional and global mobility
8	Mobility agent in the foreign network	Mobile node	Access router	Mobile access gateway	Access router
9	Mobility agent in the home network	Home agent	Mobility server	Local mobility anchor	Home agent
10	Intermediate mobility agent(s)	Not defined	Border routers	Not defined	Mobility anchor points (local, global and regional)
11	Types of mobility	Not defined	2 (intra-site and inter-site)	Not defined	3 (local, regional and global)
12	Binding update rate through the Internet	Very high	Low	High	Very low
13	Address associations of mobile node/host in a foreign network	Primary-care-of-address; link-local-address	N-virtual-care-of-addresses; physical-care-of-address	Local-mobility-anchor-address; proxy-care-of-address	Care-of-addresses (local, regional and global); link-local-address
14	Signaling load	Very high	Low	High	Very low
15	Route optimization by correspondent host/node	Addressed	Addressed for inter-site mobility only	Addressed	Addressed for global mobility only

4. INSIGHT TO THE THREE LAYER MIPV6 (TLMIPV6) NETWORK ARCHITECTURE

In [7], the author analyzed one n-layer network architecture to find a solution to an optimal hierarchy for handover management. The analysis shows that three layered hierarchical model provides an optimal solution for minimum handover delay, message overhead and packet delivery overhead. The work of [7] is verified through simulation [8]. Based on the results of [7] and [8] a three-layer model is proposed in [1]. The work presented in this paper is an exhaustive performance analysis of the proposed model reported in [1] under the influence of different mobility models. Description of Three Layer MIPv6 (TLMIPv6) architecture is presented in this section, for better understanding of the analysis carried out in this paper. However, for details about the model, readers may refer [1]. The proposed model is a special case of the network architecture depicted in [7] and [8].

The proposed network topology is segmented in to backbone and internal domains. The internal network (or domain) is further separated into three separate sub segments. They are known as a local, regional and global domain. Each of these domains is covered by different anchor agents (points) designated for the respective domains. The diagram depicted in figure 9 demonstrates the architecture. The MAP that covers the local domain is called LMAP (i.e., Local MAP). Similarly, the Regional MAP (RMAP) and Global MAP (GMAP) cover the regional and global domain respectively [1]. All these MAPs are entrusted with the responsibility of managing the mobility of nodes in their respective area of coverage. The proposed architecture suggests arranging the above mentioned anchor nodes in the domain internal network in a hierarchical fashion. The network topology forms a tree like structure GMAP as the root of the tree. The GMAP is in the top layer (layer 3), and it covers multiple RMAPs located in layer 2. Similarly, every RMAP covers a group of LMAPs located in layer 1.

Further, an LMAP is connected to multiple Access Routers (AR) that covers a single subnet. Every wireless subnet is covered by ARs, and it is connected to MAP. AR is configured to transmit Router Advertisement (RA) messages periodically. The RA contains Global Care-of-Address (GCoA), Regional Care-of-Address (RCoA) and Local Care-of Addresses (LoCoA) that represent the MAPs in respective layers. A visitor MN on entering to a foreign network constructs its Link Care-of-Address (LCoA) from the data available in the RA message. After construction of the LCoA, the visitor node communicates a binding update (BU) message to its MAP. The message indicates the visitor node's new address, its permanent IPv6 address and the address of the Home Agent (HA). The MAP then enters the received information in to a visitor's list and sends a BU packet to the RMAP above it. Similarly, the RMAP sends a BU to its higher layer GMAP. Finally, the GMAP sends the BU message containing the new location of the visitor MN to the concerned HA. On receipt of the BU, the HA records the information of the MN about its new location, and conveys the reception of the location information via binding acknowledgement (BACK) message back to the MN in the reverse path of BU message traversal. Similarly, every AR also maintains a list of the entire visitor MNs under its coverage.

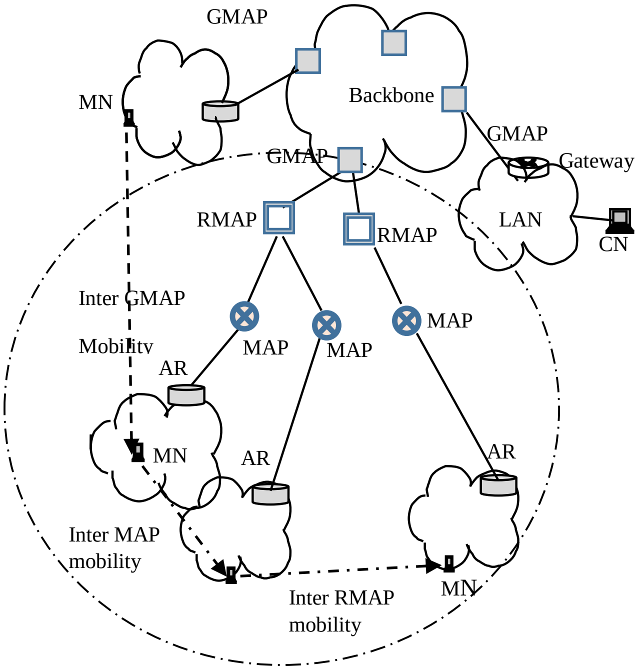

Figure 9 TLMIPv6 Architecture

The basic data flow of the model is as follows. A correspondent host communicates data to the mobile nodes' HA. The HA tunnels the packet to the nodes current location and informs the correspondent node. Afterwards, the sender sends packets directly to the GMAP under which the MN is located. The GMAP tunnels the packet to the RMAP and then to MAP and finally delivers to the MN, in turn, sends it to the RMAP, beneath which the MN is presently residing. The RMAP then sends it to the LMAP, and finally, the LMAP delivers to the corresponding MN. Each of the anchor agents including the Correspondent Node (CN) or HA tunnels the packet in order to deliver to the MN. If the global CoA is changed, then the MN has to resend the BU to the corresponding HA, as discussed earlier. Apart from the binding update, the visitor mobile node also refreshes its location with all the anchor agents including the home agent. The binding refresh cost is as large as the binding update cost. If a node stays under the same anchor agent longer than a pre-specified time interval, then the binding refresh process needs to be initiated. This time period is known as the binding life time. A short binding lifetime and generation of subsequent binding refresh process may affect the performance of the network architecture. In this paper, we have not considered the refresh cost.

The anchor agents in different levels of the proposed architecture control the mobility related activities and assist the visitor nodes in the handover process. The LMAP stops binding related messages from traversing beyond its coverage. Similarly, the RMAPs and GMAPs control the local and regional handover respectively. The architecture stops all the messages except those for performing global handover crossing a GMAP. It is already observed that the TLMIPv6 performed better than the MIPv6 and HMIPv6 protocol in terms of handoff delay, and signaling overhead. However, the models produce larger packet tunneling cost. This study aims at examining the TMIPv6 model under various mobility models. In order to accomplish this task, we have designed a simulation topology in ns-2 simulator, similar to the network topology stated in Figure 9. The simulation setup is described in section 6. The performance is also compared with that of MIPv6 and HMIPv6 for acceptability of the proposed model. We have briefly described the working of MIPv6 and HMIPv6 in section 3 above. For the detailed description of these two models, readers may refer [5] and [6] respectively.

5. INSIGHT TO THE THREE LAYER MIPV6 (TLMIPV6) NETWORK ARCHITECTURE

The individual mobility model estimates the movement pattern of mobile nodes over temporal progress. It depicts the location of individual users based on the speed and direction. Their movements are independent of each other. The movement adopted by nodes in an individual mobility model is either based on Brownian movement or based on traces. For the analysis of our proposed model, we have selected three different individual models as described in the next subsections.

5.1. Random Walk (RW)

This model is based on a mathematical principle where the next position in the path of the nodes' movement is determined by a stochastic process [23]. The next position is random in nature, and it doesn't depend on the previous location of the node. It is one of the oldest and highly used models for analyzing the wireless networks. The next position of the node over time, in this model is characterized by the randomly selected speed and movement direction. The speed and direction are randomly selected from the uniform range of speed [minimum speed, maximum speed] and [0, 2Π], respectively. Normally there is no pause time assumed between movements. However, the pause may occur after a certain time interval or after traversing a certain distance. Often such pauses occur on the completion of the movement. The node selects new random direction and speed on completion of one movement. This model does not suggest storing of speed or direction or any such related data regarding its previous movement. So, this model is considered as a memory less model. As the direction and speed are selected randomly by nodes, so its next position over time is unpredictable. If a node during its motion, reaches the simulation boundary, it restarts its movement from the border of the simulation area with an angle evaluated by the direction of the previous movement. There are many variations exist for this model. Few of them are the 1- D, 2- D, 3- D, and d- D walk models. In 1- D or 2- D model, the mobile node returns to its origin point with a probability of 1, once it reaches the end of the simulation boundary. Such restriction of the model makes sure that the node mimics the behavior of the real world by returning to the origin rather than going away to an uncertain place in the field.

In our analysis, we have used a 2- D model of random movement as depicted in [24]. It helps in realizing the movement of simulated nodes close to the real scenario. The2-D model best represents the Earth's surface in a simulated environment as well as in real scenarios. In this model, MN begins its movement around a central point (say x1, y1) within the simulated area of m x n (in our case it is 1000 x 1000). The MN is allowed to move for a certain time interval (2-3 sec) before it changes its direction and speed. However, in many implementations of this model, the MN is allowed to change its direction and speed after travelling a certain distance. However, we have used time as the deciding factor to change these values. In the simulation section, the behavior of the TLMIPv6 model is described with respect to this model.

5.2. Probabilistic Random Walk (PRW)

The Probabilistic Random Walk [25] is a probabilistic mobility model that is used for performance analysis of wireless protocol. It predicts the future position based on a set of probabilistic values. Unlike Random Walk, this model uses some stored information in the form of a matrix to trace the node movement. The matrix sores the nodes current and next position as sate 0 and state 1, respectively, to determine the expected future move probabilistically. The stored position information helps to predict the next expected position. Some variation of this model also suggests using a probability influenced matrix to find the location of the node in the coming time interval. In such cases, it takes three varying statistical values for current position (say state 0), three another statistical values for the next position (say state 1) to predict the next expected position of the node. The third parameter is the time component of the concerned MN.

However, this model does not give a clear picture of its predicted direction in advance. The stored state values (state 0 and state 1) specify that an MN may move in either of the directions front, back, left or right without taking a pause. Moreover, there is a high probability of moving in the same direction rather than changing the direction of the MN. Furthermore, this model depicts the probabilistic movement instead of random behavior of the observed node. It can best simulate the behavior of working people who travel through the same route daily to their work place and back. In such cases, it yields more realistic behaviors. They rarely turn around or trace back and their movement is predictable in every trip. If such a person follows random movement, it may lead him or her to eventually be in a wrong place other than his or her work place or home. Of course, it is true that predicting the exact steps is difficult, but it is possible to simulate the behavior of nodes over time, and up to a satisfactory level.

5.3. Gauss-Markov Model (GM)

In this model, the past velocity and direction of a node influence its future movements [26]. The nodes next speed of movement and direction (say at the nth instant of time) is dependent on the speed and direction of its previous time instant (say at the $(n\text{-}1)^{th}$ instant). Previous speed and direction also determine the next parameters. These values are random and taken from a set of values confined to a Gaussian distribution. At the beginning of the model, all nodes are located at a random place in the simulation space. Each node travel independently and there is no resemblance movement to each other. They have independent initial speed and movement of direction and do not interfere with each other. After a certain time, a node computes its own speed and movement direction which is determined by its parameters at its previous time instant. The degree of randomness plays a significant role in deciding the necessary parameters for determining the node’s next position. For each of the movement segment, the node is assumed to move with the pre calculated speed and direction for that duration [27]. The parameters necessary for movement is recomputed after each segment it moves accordingly. It is ensured that no node stays near the edge of the simulation topology for a longer period of time. A certain distance from the boundary is always tried to be maintained by the MNs. This is accomplished by manipulating the direction parameter used to simulate the motion of the node in this model. If an MN approaches boarder of the simulation region, its direction is changed by 180 degrees to allow the node to take more time to reach the other corner of the grid. In the random walk model, there exist some sudden stops and sharp turns. However, in Gauss–Markov model, such abnormal behaviors of nodes are avoided. It accomplishes this task by taking into account the previous attributes to determine the values of next segment.

6. PARAMETERS FOR PERFORMANCE EVALUATION

The protocols that are responsible to manage mobility in wireless networks are characterized by the performance in handoff management and signaling management. The handoff management defines the process of keeping track of MNs during their visit to foreign network away from home. Such tracking enables mobile devices to have uninterrupted connectivity on the go. The mobile node tracking involves the exchange of certain messages among coordinating nodes located in the network. The efficiency of handoff management is measured by handoff latency and performance of signaling management is measured by signaling cost. An efficient mobility management protocol enables users to receive data in any part of the network without changing its IP address. The protocol also helps in keeping track of nodes during its movement in efficient way, with the least possible message exchanges among anchoring nodes. The mobile users are not bothered about their location to communicate as the activities for connection management is done transparently to the end users. However, such responsibility is carried out in coordination with the mobile node, underlying network as well as some designated nodes in the network. Proper analysis of a mobility management protocol is essential to make it widely acceptable. In this paper, an evaluation of the proposed three-layer model is examined in terms of handover delay and signal transmission overhead under various mobility models. In this section, a brief introduction to the handoff frequency and handoff latency is given.

6.1. Handoff Frequency

It is the rate at which the MN changes its subnet. It specifies how frequently a node moves from one subnet to another subnet. The higher frequency of handoff generates more signaling load on the network. Moreover, the handoff frequency is directly proportional to the movement pattern of nodes. Hence, generated handoff frequency best represents the behavior and the applicability of a mobility model. A low handoff frequency is always a desirable parameter for the efficient performance of a network as it produces less signaling overhead. The work presented here is motivated by the importance of above mentioned parameters and unaddressed issues. We have studied the handoff frequency and the handoff latency experienced by mobile nodes in our proposed three-layer model. As the handoff count over time best represents the handoff frequency of the mobile nodes, that is why, handoff count has been computed to measure the frequency of handover.

6.2. Handoff Latency

When a mobile node changes its subnet from one to another, it has to register with the AR in the new subnet. Till it registers with the new AR, the node loses the connectivity. The underlying network and associated anchoring nodes in the network try their level best to complete the registration of the node at an early possible time. However, the process takes a considerable amount of time. This time duration is called handoff latency or handover delay. The visitor mobile node regains access to the network after waiting for the handoff delay period. So, for the seamless communication of a user, the least possible value of handoff latency is desired. Hence, handoff latency is one of the prime attributes to be considered to evaluate the performance of handoff management architectures. That is why all protocols proposed so far for mobility management have tried to minimize the handoff latency, incurred by end users in a wireless mobile environment deployment using different alternate methods.

7. SIMULATION SETUP FOR PERFORMANCE ANALYSIS

The protocols that are responsible to manage mobility in wireless networks are characterized.

Parameters	Value
The coveragearea of a node	50m
The distance of between cells	90m
Nodes communication range	100m
WLAN interface	Lucent DSSS Card with 802.11 at 914 MHz
MN's mobility pattern	Individual mobility
Data traffic modeled	CBR (Packet size 220 Bytes)

Table 2. Data Used in Experiments

A simulation scenario as shown in figure 10 is implemented in *ns-2* [28], for performance evaluation of the proposed three-layer architecture as depicted in figure 9. Entire simulation topology is divided into five domains. Two CNs (C_1 and C_2) and one HA (H) are deployed. There are 50 MNs deployed in the topology, however, for simple understanding, only a few of them are shown in the diagram. Multi-Layer Agents (MLA) is designed to mimic the activities of our proposed protocol by taking an extension of the Agent Class available in the *ns-2* library. This MLA possesses all the functionality of our TLMIPv6 architecture and the model is realized by attaching this agent into nodes of three layers. For example, the GMAP is attached to node N_1 and $N_2$to demonstrate two global networks. Similarly, the RMAPs are attached to nodes in the lower layer, for example, N_{21}, $N_{22,}$ and N23. The third layer agents (i.e., the MAPs) are placed in N_{31}, N_{32} $N_{33,}$ and N_{34}. All MNs visiting the foreign network uses stateless auto configuration method to constructs their Link CoA on arrival at the new subnet. There are six ARs that covers individual subnets in the simulated topology. An AR cover each of the subnets. The ARs are extended from the *BaseStation* class as available in the *ns-2* library. However, some additional functionality are extended to it for making the AR compatible with our architecture. To study the behavior of the TLMIPv6 architecture for different mobility models, deployed MNs are allowed to move within the simulation area as per the various mobility models defined earlier. The ARs are placed in a way to cover a region around*1000* x *1000* square meters. Each MN covers a transmission range of *50* meters. Random movements of nodes according to predefined mobility models are observed in the simulated environment. The mobile nodes use a Wireless LAN 802.11 DCF card for wireless physical specification with a transmission bandwidth of 2Mbps as modeled by the *ns-2* simulator. MN communicates data packets through designated AR located in the subnet.

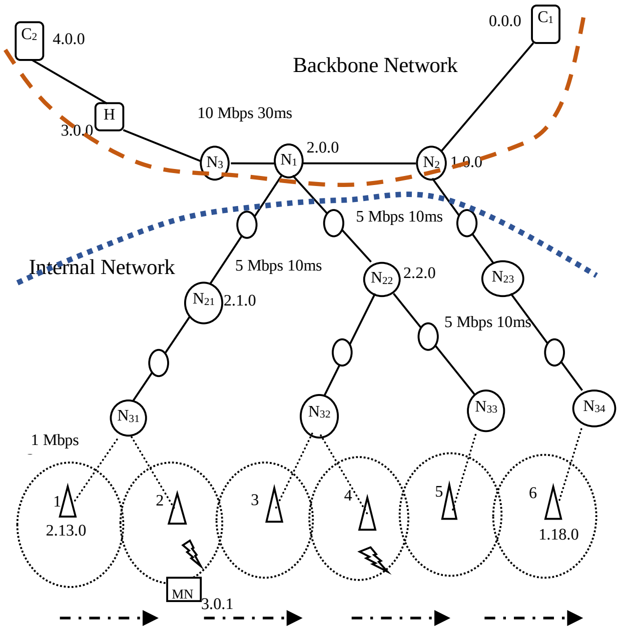

Figure 10 Topology in ns-2 for comparative evaluation

For any of the situation, transmission or reception, the MN has to compete for the transmission channel with other competing nodes in the same subnet. The data communicated to the MN by any correspondent node suffers queuing at the AR, whereas the data sent from the visitor node suffers channel access delay due to the underlying MAC specification. Since this simulation setup is mainly to observe handoff latency and signaling cost under various mobility models, we focus on the data communicated to MN from CN rather than data from MN to CN. There are three CNs configured outside the global domain to communicate packets with visiting mobile nodes. Each of the CNs are configured for different types of traffic. For example, one of them generates elastic FTP data with the characteristics of error sensitivity but delay tolerant. Two CNs configured to generate real time audio data. Audio data can tolerate errors due to the end systems characteristics. However, timeliness is of greater importance. Apart from these two applications, a user defined application derived from the *ApplicationClass* library of *ns-2* is utilized for observing the performance of the TLMIPv6 model. The *ApplicationClass* utility contains a special header to monitor the packets sent by a mobile node at any in-between router for some specific generated situation. A continual FTP source over TCP as a transport-layer protocol has been simulated to study the effect of IP mobility in TLMIPv6.

8. SIMULATION RESULTS

A simulator is a tool that provides the most detailed operational analysis for evaluating a theoretical design. Such simulated analysis enables designers to forecast the performance of their newly designed protocols and methods. It plays a vital role in allowing the designer to evaluate complex network traffic situations which would be difficult to analyze during implementation. MNs are allowed to move using various mobility models as discussed in Section 5. We have simulated three individual models for the performance analysis. Two parameters namely handoff frequency and handoff latency are examined, and the observations are analyzed in the forthcoming subsections. The simulation observation of the three-layer model under different mobility models with 50 MNs are deployed randomly in the simulation topology of dimension 1000 x 1000 square meters. The average speed of the MN is kept at 1.5 meters per sec. Other relevant simulation parameters are summarized in the Table 2, presented in Section 7. All results are recorded for varying simulation time in seconds and discussed in detail in following subsections.

8.1. Handoff Frequency / Handoff Count

Total handoff counts represent the handoff frequency during the entire simulation period. These values are taken separately for local, regional and global handoffs. Moreover, each of the results is compared for three mobility models. Simulated counts are plotted and shown in figure 11. Handoff count for the proposed TLMIPv6protocol helps in understanding the applicability of our model in various mobility scenarios. Total handoff count for three mobility models in terms of local domain, regional domain, and global domain are shown in figure 11(a), (b) and (c) respectively.

Observation shows that the TLMIPv6 behaves better for GM model compared to other two individual models RW and PRW. RW shows highest count in handoff for all simulation duration compared to other mobility models. The handoff count decreases from local to the regional domain and regional domain to the global domain. Moreover, with the increase in simulation time the rate of increase in handoff count is decreased gradually for regional and global handoff compared to local handoff count. This behavior of the handoff count is due to the placement of different layers to handle handoff. Moreover, RW produces the largest range of movements compared to other two mobility models. In figure 11(d), a comparison of average handoff count in MIPv6, PMIPv6, HMIPv6 and TLMIPv6 is shown. The simulation is made to run for 250 seconds, and other parameters are as stated earlier. Results depict that handoff count occurred in TLMIPv6 outperforms MIPv6, PMIPv6 and HMIPv6 for all the three mobility models. Since, MIPv6 has no intermediate anchor agents near between MN and the HA, every handover produces a global handoff. However, in TLMIPv6 such signals for local and regional handover is taken care by LMAP and RMAP.PMIPv6 shows similar behavior as MIPv6 because both the protocols do not handle handoff signals in the regional level. The HMIPv6 protocol on the other hand, includes the MAP to control the handoff signal in a domain. Therefore, HMIPv6 has lower handoff count compared to MIPv6 and PMIPv6.

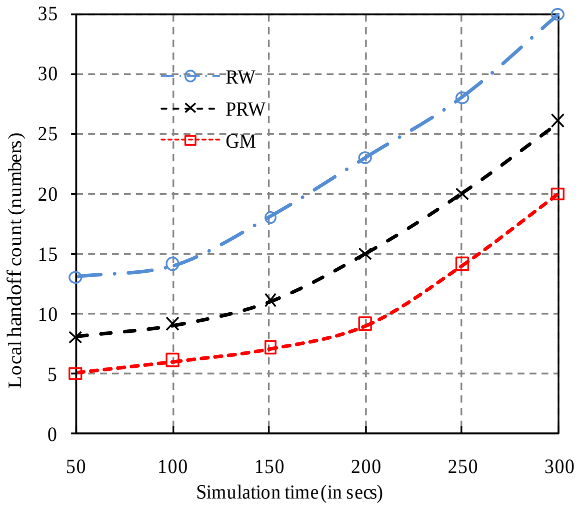

Figure 11 (a) Local Handoff Count

For the analysis of handoff latency, 50 MNs are allowed to move according to RW, PRW and GM mobility model keeping simulation time as 500 seconds. We have taken the average time consumed by five selected MNs to complete the handoff. Handoff latency for the local domain, regional domain, and global domain are taken, and in all these cases MNs with these three handoffs are observed. The simulated results for proposed TLMIPv6 are shown in figure 12. As in handoff frequency, here also, the parameters are compared for stated three models. Local, regional and global handoff latencies against MN speed are shown in figure 12(a), (b) and (c), respectively. Moreover, we have also computed the average handoff latency of the proposed model and compared with the HMIPv6 model. Results are shown in figure 12 (d).

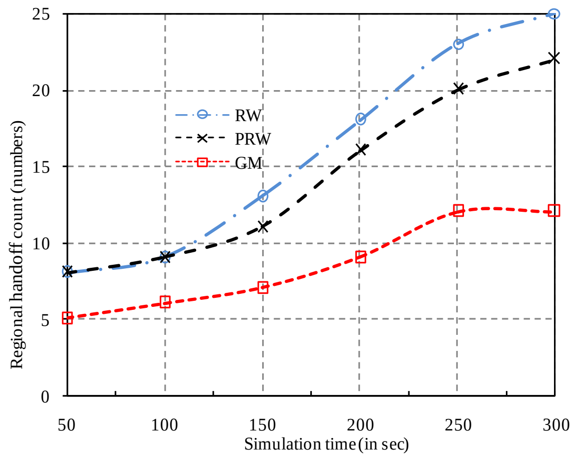

Figure 11 (b) Regional Handoff Count

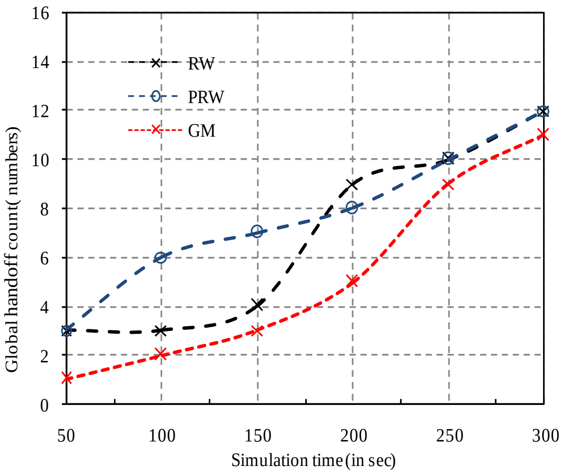

Figure 11 (c) Global Handoff Count

8.2. Handoff Latency

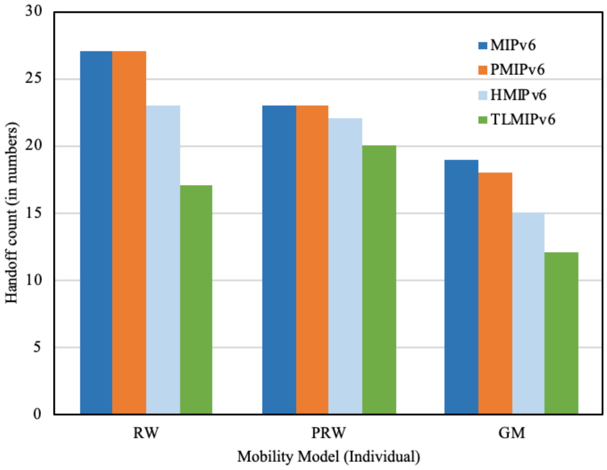

Figure 11 (d) Comparison of Handoff Count

Observation shows that handoff latency for all the three models are similar for low speed of MN. For higher speed of MN, the TLMIPv6 behaves better for GM model than RW and PRW. RW shows highest handoff latency for all simulation scenarios compared to other mobility models. Furthermore, handoff latency increases from local to the regional domain and regional domain to the global domain at same speeds. Moreover, with the increase in MN's speed, the rate of increase in handoff count decreases substantially for regional and global handoff compared to local handoff. Multiple layers in the proposed model influence the handoff latency for MN in a different region.

As mentioned earlier in section 2, TLMIPv6 is an enhancement to the MIPv6 model with provisioning of multiple layers. Needless to say, TLMIPv6 possesses characteristics inherited from HMIPv6. So, to understand the benefit of the proposed new model over HMIPv6 in terms of handoff latency, we have compared handoff latency of TLMIPv6 and HMIPv6. However, we are restricting our comparison only to the average handoff latency for both the protocols. In figure 12 (d), comparison of average handoff latency incurred by mobile users in MIPv6, PMIPv6, HMIPv6 and TLMIPv6 is shown. For the observation of these parameters, the simulation was executed for 500secs, and other parameters remain as stated earlier.

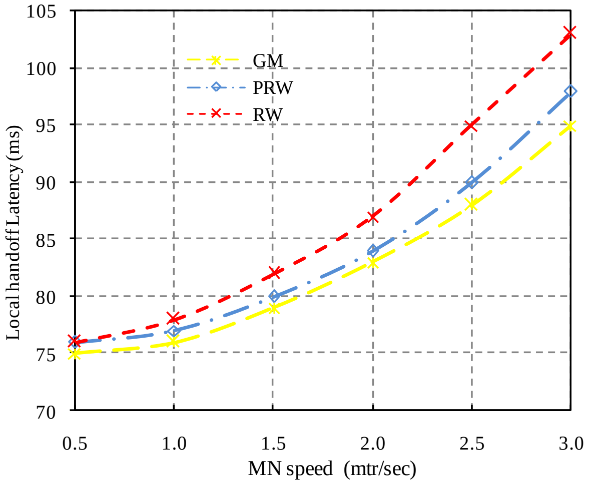

Figure 12 (a). Local Handoff Latency

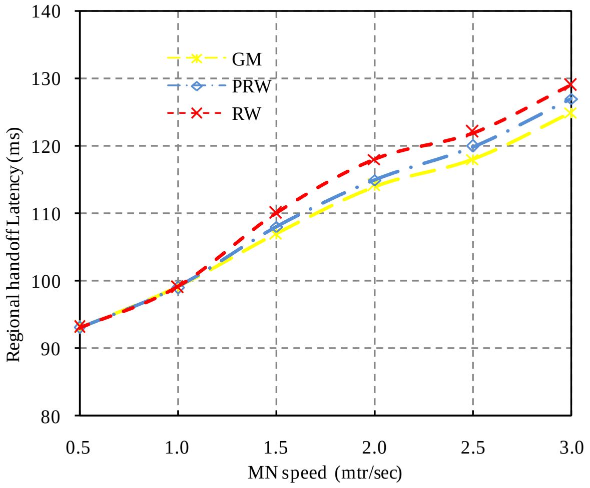

Figure 12 (b) Regional Handoff Latency

Results show that handoff latency suffered by nodes in TLMIPv6 outperforms MIPv6, PMIPv6, and HMIPv6, for all the individual mobility models under consideration. PMIPv6 shows similar behavior as MIPv6 because both the protocols do not handle handoff signals in the regional level. The HMIPv6 protocol on the other hand, includes the MAP to control the handoff signal in a domain. Therefore, HMIPv6 has lower handoff latency compared to MIPv6 and PMIPv6. Moreover, lack of layers in MIPv6 has incurred more handoff latency in the global handoff which is taken care of by the lower level MAPs in TLMIPv6.

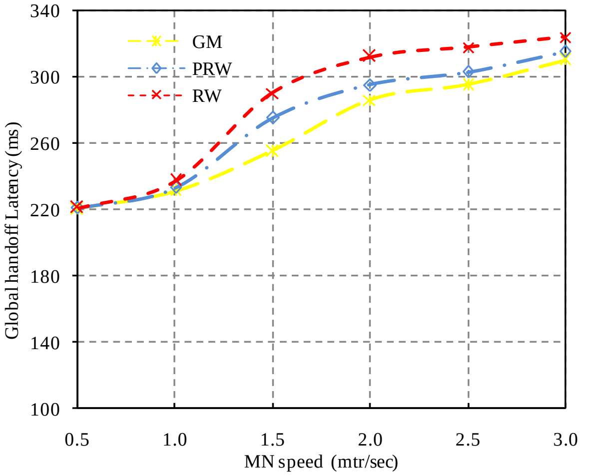

Figure 12 (c) Global Handoff Latency

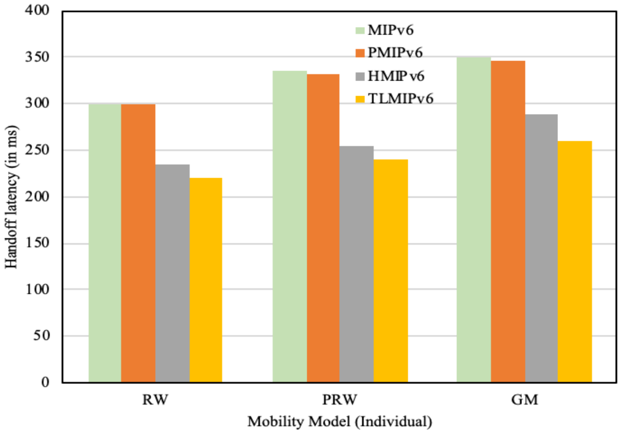

Figure 12 (d) Comparison of Handoff Latency

9. CONCLUSION

Performance analysis of a new Three Layer MIPv6 (TLMIPv6) is the prime concern of this paper. In [1] it has been stated that three layers of hierarchy of mobile anchor agents, in a mobility management architecture show optimal performance with respect to few parameters. Based on the results of [9], a TLMIPv6 model is proposed in [1]. In this paper, TLMIPv6 is analyzed under three different mobility models, (1) Random Walk Mobility Model, (2) Probabilistic Random Walk Mobility Model and (3) Gauss-Markov Mobility Model. The TLMIPv6 is implemented in ns-2 simulator. The Handoff Frequency (count) and Handoff Latency are observed in the simulation. The prime objective of this work is to understand how the TLMIPv6 architecture performs under the influence of different mobility models.

With the division of the network into local, regional, and global domain, this paper shows observations for these three domains separately. Results for the three models are compared. The model TLMIPv6 [1] performs the best for the Gauss Markov model, moderate for a Probabilistic Random Walk and less preferable for Random Walk model. The performance of TLMIPv6 has also been compared with that of MIPv6, and we observe that TLMIPv6 performs better under the influence of the three mobility models. However, the comparison is based on two parameters namely, handoff latency and handoff count. In future, a more comprehensive analysis of TLMIPv6 considering all the necessary parameters for handoff management, including signaling load and packet delivery cost may be planned. Furthermore, the performances of the proposed model need to be compared with that of both MIPv6 and HMIPv6 also with respect to other parameters as mentioned above.

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