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A PERFORMANCE EVALUATION FRAMEWORK FOR NETWORK-BASED IP MOBILITY SOLUTIONS

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Abstract. *Modern wireless networks rely on mobile Internet Protocol (IP) technology to manage handovers among different subnets. However, the poor performance of traditional mobile IP protocols can affect negatively delay sensitive services. Recently, network-based IP mobility has been proposed as a potential solution. Although initial evaluations have already confirmed the practical advantages of this new approach, a proper investigation of existing methods has yet to be performed. In the present paper, an evaluation framework is proposed to investigate handover performance metrics in network-based IP mobility. The framework is subsequently employed to analyze prominent methods. Analytical results highlight the efficiency of each solution under different operating conditions and reveal the main factors that affect the performance. Unlike other comparative studies, this framework has been developed to assist IP mobility designers in analyzing the effects of system parameters on their proposed solutions. A new prediction-based mobility solution for metropolitan area networks is suggested, and its design parameters are analyzed by utilizing the proposed framework. The present study not only provides deeper insights into network-based IP mobility but also a framework for faster analysis of future solutions in this category.*
Keywords: Network-based IP mobility, Handover, Performance evaluation, Stochastic mobility model

1. **Introduction.** Handover control has always been one of the critical aspects of mobile wireless networks. Traditionally, handover refers to the process of transferring an on-going call from one access point to another caused by the mobile node movement beyond the range of first access point. By having Internet Protocol (IP) based wireless technologies such as Mobile WiMAX (IEEE 802.16e [1]) and 3GPP LTE [2], the handovers can lead to a change in IP subnet and address reconfiguration. Unlike efficient link-level handover techniques, IP-level handover can impose relatively long delay and huge signaling overhead to user's connectivity [3]. Reaching an optimized IP mobility solution in modern wireless networks is an important subject of research and investigation in the telecommunications industry [4].

Network-based IP mobility and its standard protocol, Proxy Mobile IPv6 (PMIPv6 [5]), are apparently promising solutions for the handover performance issue in modern cellular networks [6]. Network-based IP mobility removes IP address reconfiguration by separating the identifying role of IP address from its routing duty inside a predefined mobility domain. According to the existing performance evaluations [7, 8, 9], PMIPv6 has been proved to be an effective method of reducing handover signaling cost and latency, mainly because of its ability to exclude the mobile node and its radio connection from the IP mobility procedure. However, PMIPv6 operation is limited to the single mobility domain. This condition indicates that any handover beyond this domain has to be handled by a global mobility management protocol, such as Mobile IPv6 (MIPv6 [10]), which causes performance degradation and other technical issues as discussed in [11].

Several network-based schemes [12-16] have been suggested to achieve a global IP mobility without the intervention of MIPv6. To the best of the authors' knowledge, there is no in depth evaluation among these schemes. Supportive evaluations provided by the authors of each scheme only consist of some aspects of handover performance (e.g., handover latency, and signaling cost). A comprehensive evaluation should measure all performance metrics under different conditions. Developing an evaluation framework for handover performance in network-based IP mobility schemas is the main goal for the present study. Research in this area is still in progress, and conducting a proper analysis of design parameters can show the future direction toward new standard protocols. The current paper provides an analytical evaluation of all major network-based IP mobility schemes. The advantages and disadvantages of the schemes were comparatively examined. Furthermore, a general analytical evaluation framework that can accelerate the development of new solutions in the network-based IP mobility category is developed.

During this study, possible adaptation scenarios to extend network-based IP mobility schemes in wide area wireless networking will be initially identified. Then, each of existing schemes will be associated with one of adaptation scenarios. An analytical framework that includes mobility models, the operational formulas, and the equations for the performance metrics will be derived. The first stage of the proposed analytical framework utilizes existing mobility models (e.g., Random Walk [RW] and Fluid Flow [FF]) to estimate the user's dynamics. The operational formulas are uniform presentation of the general functions of each network-based IP mobility schemes. The final stage of the framework includes detailed equations of main handover performance metrics. The innovative aspect of the proposed framework is to develop a formulation technique that can be extended to accommodate any network-based IP mobility solution. The study also includes the outline of a new prediction-assisted proactive mobility session (PPMS), a network based IP mobility scheme designed to accelerate global handovers in metropolitan area networks. The performance evaluation of PPMS demonstrates the effectiveness of proposed framework.

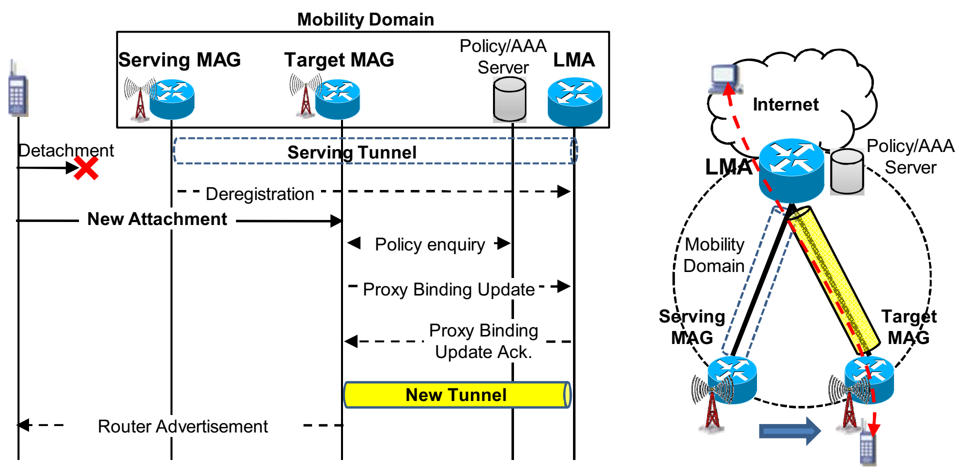
The current paper is organized as follows. A network-based IP mobility according to its published standard is described and the manner by which it has been adopted into mobile wireless networks is presented in Section 2. Section 3 introduces three global handover scenarios and discusses possible network-based IP mobility schemes in each scenario. Section 4 proposes the performance evaluation framework and develops its stages. The results of the evaluation of the different system parameters and user dynamics will be discussed in Section 5. Section 6 provides a practical example of the application of the proposed framework by a predictive network-based IP mobility scheme and evaluating its design parameters. Finally, Section 7 concludes the paper by highlighting its findings and contributions.

2. **Preliminaries.** Handover control enables a mobile device to keep its connectivity while changing its access point to the network. Ideally, the connection should be restored within a short time such that the user does not notice any interruptions. In IP-based wireless networks, the handover process can also changes the subnet and IP address of the node, which requires several extra steps to restore IP connectivity in addition to connection reestablishment. The rest of this section explores these two levels of handover process in mobile wireless networks.

2.1. **IP mobility protocols.** Internet Engineering Task Force (IETF) developed Mobile IPv6 (MIPv6 [10]) protocol to restore IP connectivity during node handover. However, MIPv6 imposes long latency to the connection that is not tolerable in delay sensitive services, such as VoIP [17]. Localized techniques, such as Hierarchical MIPv6 (HMIPv6 [18]), has been suggested to shorten the distance between mobility entities and reduce handover latency. Fast mobility (e.g., Fast MIPv6 [19]) improves handover performance using link-layer triggers. However, the common aspect of these host-based protocols is that the Mobile Node (MN) or host is still responsible for initiating the handover procedure. The problem is that the MN has to exchange handover signals through wireless links, that are generally less reliable and more expensive than wired links.

A network-based mobility protocol, such as PMIPv6 [5], follows the same fundamental rules of host-based protocols but with several important enhancements. This protocol removes the dependency on the IP address within a predefined mobility domain by utilizing a local identifier (MN-ID) and excludes the MN from mobility-related functions by dividing these functions between mobility agents inside the network. PMIPv6 introduces two kinds of mobility agents (Figure 1), as follows: the Local Mobility Anchor (LMA) that creates and updates binding record for each MN; and the Mobile Access Gateways (MAGs) that are responsible for tracking the movement of the MN and handling mobility functions on its behalf. Each PMIPv6 mobility domain needs at least a single LMA, but there are several MAGs distributed all over the domain (usually in each access router). Any packet sent to the MN or generated by the MN, is transferred through a bi-directional tunnel between MAGs and the LMA.

Figure 1(a) shows the message flow map of PMIPv6. Whenever the mobile node detaches from its serving MAG and reattaches to a new target MAG, the handover process is accomplished by exchanging Proxy Binding Update (PBU) message and Proxy Binding



(a) Message flow map (b) Topology

FIGURE 1. Local handover operation with PMIPv6

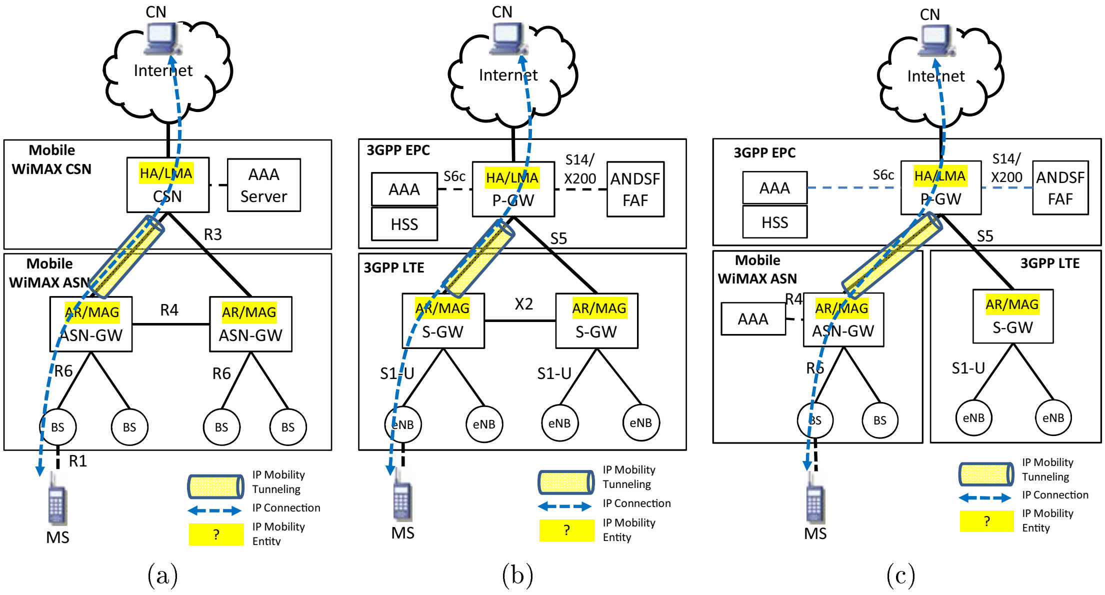


FIGURE 2. Handover architecture in (a) mobile WiMAX, (b) 3GPP LTE, (c) integrated LTE/WiMAX

Acknowledge (PBA) between the LMA and new MAG. By means of a unique MN-ID and after consulting the policy server, the mobility agents can recognize the registered MN and emulate its home link by advertising the home address prefix. Subsequently, the MN retains its home address and senses that it is still connected to its home network.

2.2. **Handover in mobile wireless technologies.** Link-level or layer 2 handover is the process of losing or releasing a link in one access point and establishing a new link with another access point. The exact process of link-level handover depends on the wireless technology, a typical procedure includes search and selection of proper target and re-route traffic toward it. Given the maturity of wireless technologies and numerous related studies [20], link-level handover imposes a short latency to the service. Mobile WiMAX [1] and 3GPP LTE [2] are the two most prominent examples of this condition. As illustrated in Figures 2(a) and 2(b), they have similar architectures concerning handover procedure despite the difference in network entities. Considering the pioneering role and dominant market of these two technologies, their handover architecture can be assumed to be applicable to other IP-based wireless networks.

2.2.1. *Handover performance in mobile WiMAX.* Mobile WiMAX is a mobility-enabled version of the original WiMAX technology. The architecture (Figure 2(a)) of this version consists of a Connectivity Service Network (CSN) that provides IP connectivity to several Access Service Networks (ASNs). The handover inside the ASNs could be handled through link-layer mechanisms. However, IP mobility protocols are needed to address mobility between ASNs. Mobile WiMAX standard suggests that the handover should not take more than 50 ms [21]. However, the IP level handover can violate this limitation if proper IP mobility scheme is not employed. The proposed configuration of IP mobility over Mobile WiMAX is shown in Figure 2(a), with LMA located in CSN and MAGs distributed inside each ASN.

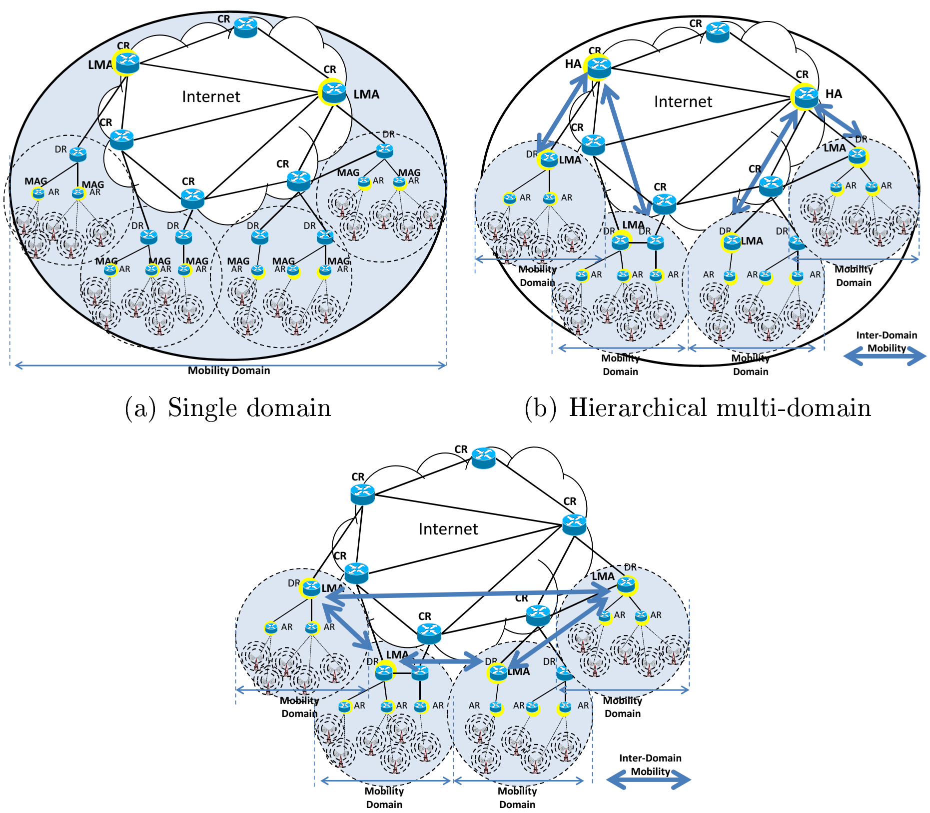
2.2.2. *Handover performance in 3GPP LTE.* The standards of LTE has been published within 3GPP release 8 [2], as a major revision of 3G wireless technology. Similar to Mobile WiMAX, 3GPP LTE architecture (Figure 2(b)) consists of two main parts, namely, the

Evolved Packet Core and the LTE access networks. Depending on the scale of the mobility, the handover can be addressed by link-layer or support from IP mobility protocols. The evaluation in [22] proved that the link handover in LTE does not compromise user experience of services by having interruption time of approximately 30 ms. Figure 2(b) shows one possible configuration of network-based IP mobility over LTE networks.

The coexistence of different access technologies is an important aspect of emerging IP-based wireless networks [3]. Accordingly, the integration of Mobile WiMAX and 3GPP LTE has been provisioned in 3GPP LTE/SAE architecture [23]. As illustrated in Figure 2(c), Mobile WiMAX can connect 3GPP Packet data Network Gateway and operates similar to a 3GPP wireless access network.

3. **Network-Based IP Mobility Scenarios.** According to [24], an effective handover control mechanism in wide area wireless networks should have minimum impact on standard architectures, cause minimum coupling between access technologies, and optimize performance. Following these design strategies and assuming that mobility domain is a logical representation of a wireless access network, three possible scenarios in adopting network-based IP mobility schemes are proposed, as follows:

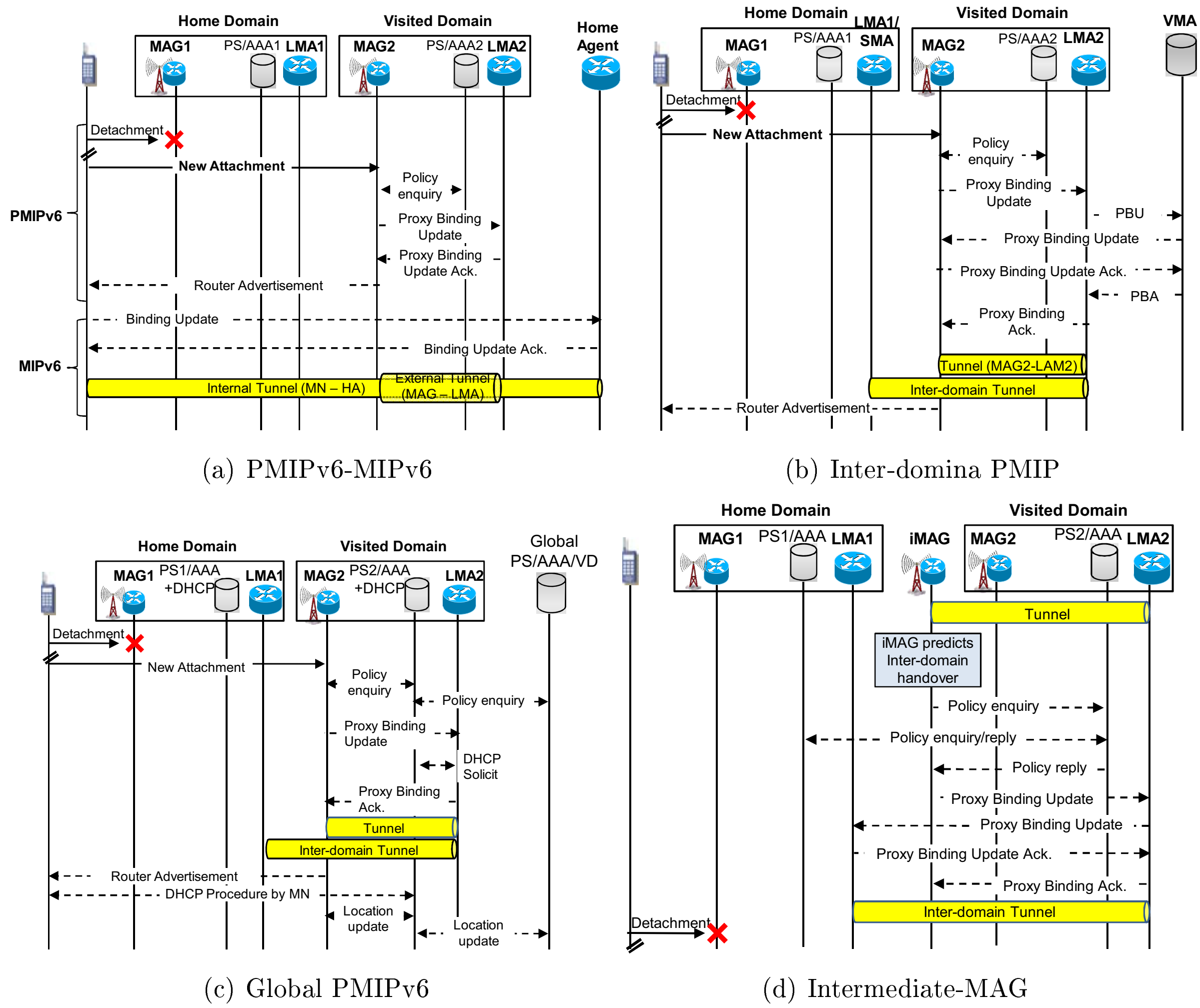
1. **Single domain scenario.** The scalability issue limits the domain size [5]. However, for the sake of investigation and as a benchmark for other options, the first scenario is considered as a single domain that covers the entire network (Figure 3(a)). This scenario can be implemented without any changes in the PMIPv6 protocol and is in accordance with existing recommendations of 3GPP for handover to non-3GPP wireless technologies [23].



(a) Single domain (b) Hierarchical multi-domain

(c) Peer multi-domain

FIGURE 3. Inter-domain network-based IP mobility scenarios



(a) PMIPv6-MIPv6

(b) Inter-domina PMIP

(c) Global PMIPv6

(d) Intermediate-MAG

FIGURE 4. Operation of inter-domain network-based IP mobility schemes

2. **Hierarchical multi-domain scenario.** Each access network has an independent mobility domain that is managed by a localized mobility scheme (e.g., PMIPv6). According to Figure 3(b), the inter-access handovers have to be handled by a global IP mobility protocol in a hierarchical manner. A feasible option to realize this scenario is the interconnection between MIPv6 and PMIPv6 [25]. Figure 4(a) shows the message flow map of this interconnection, which indicates that a mobile node is responsible for binding update with its home agent (HA) according the MIPv6 specification in each global handover to a new domain [10]. There are also two nested mobility tunnels. The outer tunnel is located between the LMA and MAG inside each PMIPv6 domain, whereas the inner tunnel belongs to MIPv6, which stretches from the HA to the mobile node. This scenario is not a pure network-based IP mobility solution because it requires the involvement of a mobile node. However, implementation can be performed with minimum changes in the existing systems, given that both protocols (PMIPv6 and MIPv6) are standard.
3. **Peer multi-domain scenario.** Similar to the second scenario, the handover inside each access network is managed by its local mobility protocol (PMIPv6). However, inter-access handovers rely on globally extended network-based schemes (Figure 3(c)). This condition can be achieved by at least three recently proposed schemes, I-PMIP [12], GPMIP [15] and iMAG [13].

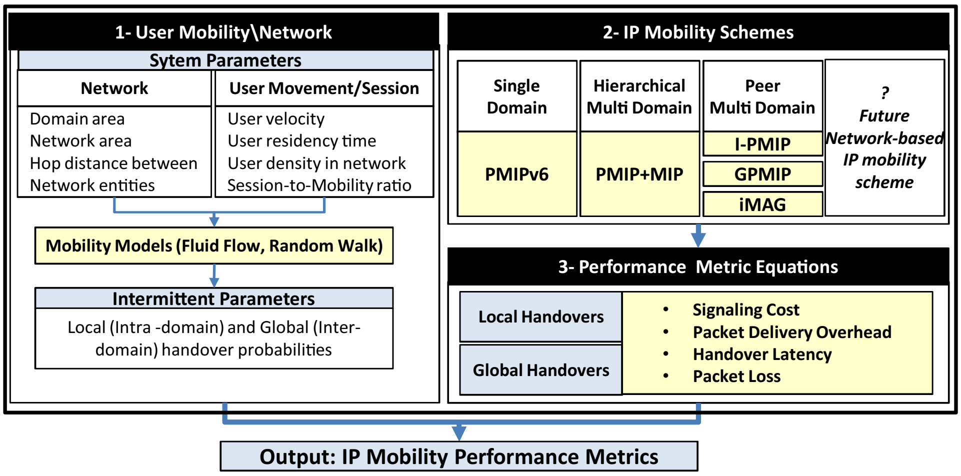


FIGURE 5. Main stages of proposed performance evaluation framework

3.1. **The proposed schemes for peer multi-domain scenario.** Inter-domain PMIP (I-PMIP [12]) is one of the original extensions of the PMIPv6 protocol. The most important advantage of this scheme is the preservation of the general procedure and features of PMIPv6. A couple of other recently proposed schemes such as Traffic Distributor [14] and Inter-domain roaming [16] operate similarly. Figure 4(b) illustrates the operation of I-PMIP [12] that utilizes the serving LMA (LMA1) as a Session Mobility Anchor (SMA) to direct the traffic of the mobile node to its new domain until the end of its current session. The traffic of the mobile node will reach the target MAG through two cascaded tunnels. However, I-PMIP requires a database (Virtual Mobility Anchor (VMA) in terms of this scheme) with global awareness of mobile nodes and their current mobility sessions. A simple performance evaluation by the authors shows that the I-PMIP could act faster than the interconnection between PMIPv6 and MIPv6.

A different approach is proposed in Global PMIPv6 (GPMIP) [15] by suggesting the separation of controlling and forwarding anchor points. The message flow map of this scheme is shown in Figure 4(c). GPMIP removes the handover control duty from LMA and places it on a hierarchical structure of Virtual Database (VD) servers. GPMIP also uses a stateful address configuration based on DHCP instead of stateless address configuration that is suggested in the original PMIPv6 protocol. The authors concluded that GPMIP reduces the total signaling cost in the range of 11.7% to 41.1% comparing the host-based IP mobility protocol, HMIPv6 [18]. However, the performance of GPMIP has yet to be compared against other network-based solutions.

Intermediate-Mobile Access Gateway (iMAG) as suggested by Lee in [13] relies on a third party (beside source and destination of handover) to accelerate the process. iMAG uses a common MAG in the overlapping area between two domains with connections to both serving and target LMAs. As illustrated in Figure 4(d), an inter-domain handover with iMAG will be accomplished while the mobile node is still connected to the common MAG. This condition occurs once iMAG detects the movement of MN toward its next target. Authors claim that the global handover by iMAG can be performed as fast as the local PMIPv6 handovers. However, this condition depends on the availability of the iMAG and its correct prediction of handover target that is apparently difficult as the prediction algorithm in iMAG only works for linear movements.

4. **Performance Evaluation Framework.** According to the schematic diagram in Figure 5, the proposed performance evaluation framework consists of the following stages:

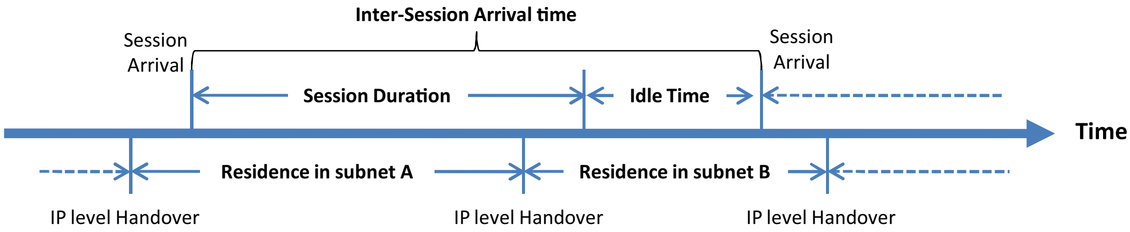


Figure 6. Typical nodes' mobility and session arrival timeline

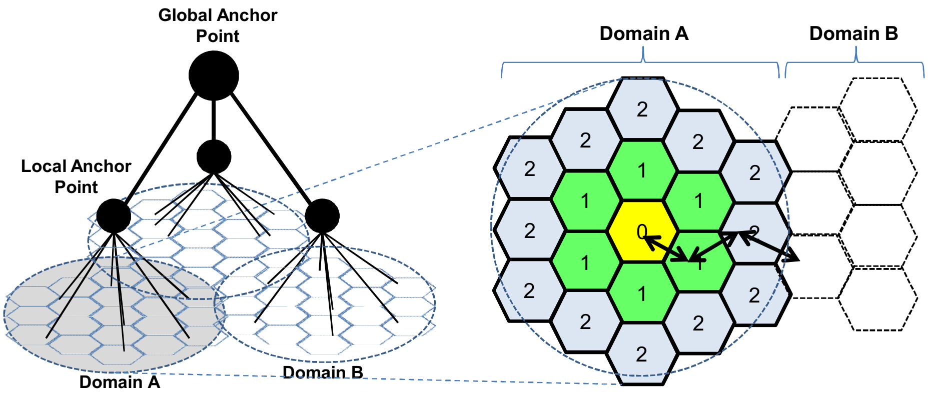


Figure 7. Hexagonal network model for mobility domains (R = 2)

1) modeling network and mobility, 2) formulation of network-bases IP mobility schemes and 3) deriving equations of performance metrics.

4.1. **Mobility and network models.** Subnet crossings and the session (call) arrivals are two effective events in the performance of mobile nodes' IP level handovers (Figure 6). Finding the exact occurrence time of these random events requires their distribution functions. The analytical studies have applied a verity of distribution functions for this purpose. However, for the sake of performance estimation of IP level handovers, the average effect of these two dynamics provides enough accuracy [26]. This effect can be expressed by the ratio of two averages, sessions arrival rate (λ_S) and subnet crossing rate (η_T), as follows:

$$SMR = \frac{\lambda_S}{\eta_T} \tag{1}$$

where SMR indicates Session-to-Mobility Ratio.

The likelihood that a mobile node crosses the border of its current domain can be estimated by utilizing network and mobility models. As illustrated in Figure 7, by choosing a hexagonal shape for each subnet (under control of a MAG), the mobility domain (area of an LMA) can be shown by a cluster of hexagons. Each domain includes a central subnet that is surrounded by R-rings (R = 2 in Figure 7) of equal-sized subnets. The hexagons have been employed initially in cellular network studies [27] as a regular representation of cells. Stochastic models predict handover probability to each neighbor more easily because of the six similar sides.

Two popular mobility models, RandomWalk (RW) and Fluid-Flow (FF), have been chosen in the current study as they resemble two different movement patterns [28]. RW characterized by limited range and speed has been widely deployed for pedestrian movement modeling. By contrast, the FF model is a proper presentation of the aggregated behavior of mobile nodes with semi-deterministic speed and direction, such as vehicular mobility.

The RW imitates a continuous series of movements, each one by randomly chosen direction and speed leads the mobile node to the next point. Using the RW model, IP mobility can be expressed as subsequent changes of subnet (MAGs) up to the point that mobile node reaches the border of its domain and goes beyond that (Figure 7). The probability of making global handovers can be determined by solving the RW model by one-dimensional Markov chain [29, 30]. Assuming that each state in the state space of Markov chain is equivalent to one ring of subnets, state transition probability can be expressed as the probability of movement from one ring to another. Considering that the probability of moving from one hexagon to any of its neighboring hexagons is equal to $(\frac{1}{6})$, the state transition probabilities (p) can be drived by following formulae:

$$p_{r\to r+1} = \begin{cases} (1-\varphi), & \text{if } r=0 \\ (1-\varphi)(\frac{1}{3}+\frac{1}{6r}), & \text{if } 1\le r\le R \end{cases} \tag{2}$$

$$p_{r\to r-1} = (1-\varphi)\left(\frac{1}{3}-\frac{1}{6r}\right) \tag{3}$$

where φ is the willingness of the mobile node to stay in its current location, $p_{r\to r+1}$ is the transition probability of movement form ring r to the outer ring $r+1$ and similarly, $p_{r\to r-1}$ is the probability of transition from the ring r to the inner ring $r-1$. By solving Markov Equations (2) and (3), steady-state probabilities of being in an specific state ($\pi_{r,R}$) can be expressed as follows:

$$\pi_{r,R} = \pi_{0,R}\prod_{i=0}^{r-1}\frac{p_{i\to i+1}}{p_{i+1\to i}} \text{ for } 1\le r\le R \tag{4}$$

Considering that the sum of steady-state probabilities should be equal to one, $\pi_{0,R}$ can be derived by the following equation:

$$\pi_{0,R} = \frac{1}{1+\sum_{r=1}^{R}\prod_{i=0}^{r-1}\frac{p_{i\to i+1}}{p_{i+1\to i}}} \tag{5}$$

According to the network model (Figure 7), the inter-domain (global) handover happens once the MN is located in the outermost ring of domain ($\pi_{R,R}$) and makes a movement our of the domain ($p_{R\to R+1}$). Therefore, the probability of making a global handover (p_g) can be expressed as follows:

$$p_g = \pi_{R,R}\times p_{R\to R+1} \tag{6}$$

Having the probability of making a global handover, local and global handover rates ($\overline{N}_l$ and $\overline{N}_g$) can be formulated as follows:

$$\overline{N}_l = \frac{(1-p_g)}{\overline{T}} = \frac{\lambda_S\times(1-p_g)}{SMR} \tag{7}$$

$$\overline{N}_g = \frac{p_g}{\overline{T}} = \frac{\lambda_S\times p_g}{SMR} \tag{8}$$

where $\overline{T}=\frac{1}{\eta_T}$ denotes the expected residency time of MN inside the subnet.

The FF is a simple mobility model, which is frequently utilized by IP mobility studies [8, 33]. In this model, the direction of the movement of each MN is a uniformly distributed random variable in the range of $(0,2\pi)$. Given ν as average velocity of MN inside the domain, L_M and A_M as perimeter and coverage area of a subnet, L_D and A_D as perimeter and coverage area of a domain, respectively. Then, subnet and domain crossing rates (μ_M and μ_D) can be expressed by the following equations:

$$\mu_M = \frac{\nu L_M}{\pi A_M} \tag{9}$$

$$\mu_D = \frac{\nu L_D}{\pi A_D} \tag{10}$$

Form μ_M and μ_D, the local and global handover rates, can be expressed by the following equations:

$$\overline{N}_l = \mu_M - \mu_D \tag{11}$$

$$\overline{N}_g = \mu_D \tag{12}$$

Considering cluster shape of domain model in Figure 7, domain perimeter (L_D), the coverage area of subnet (A_M) and domain area (A_D) can be calculated from the perimeter of each subnet (L_M), as follows:

$$L_D = (2R + 1) \times L_M \tag{13}$$

$$A_M = 2.6 \times \left(\frac{L_M}{6}\right)^2 \tag{14}$$

$$A_D = (3R \times (R + 1) + 1) \times A_M \tag{15}$$

where $(3R \times (R + 1) + 1)$ is the total number of subnets inside a domain with R rings.

4.2. **IP mobility schemes formulas.** The processes of network-based IP mobility schemes differ, particularly during global handovers. Consequently, deriving a general formula is the most challenging part of the proposed framework. To achieve this, the main activities can be categorized into four basic types:

1. Deregistration (**DReg**) is a request by a mobile node or its proxy MAG from a mobility anchor point to clear an old binding record.
2. Policy Inquiry (**PoInq**) is a request by mobility agents on the authenticity of a newly attached node, and the reply to this request includes the profile of mobile node. Depending on the scale of handover, a local or global server can handle the policy inquiry.
3. Binding Update (**BU**), Proxy Binding Update (**PBU**) and Database Binding Update (**DBU**). The main function of each scheme is a request by mobile node or its proxy MAG to update the respective binding record inside a local or global anchor point or its equivalent database.
4. Stateless or Stateful Address Configuration (**AddConf**) is a part of IPv6 protocol, including Route Solicitation (RS) and Route Advertisement (RA) messages exchanges between the mobile node and its access router. In a stateful mode, address configuration includes a request to DHCP server (or an equivalent database) by mobile node or its proxy to obtain a new IP address.

Following the present classification, operational formulae for all five schemes are listed in Table 1 as a sequence of activities and their participants. For example, $PBU(MAG \leftrightarrow LMA)$ shows a proxy binding update between MAG and LMA. The relative locations of mobility agents in each scheme are shown in a three-tier topology (core, distribution and access) in Figure 8.

4.3. **Equations of performance metrics.** The performance metrics in an IP mobility schemes show the efficiency of the scheme and its effects on data traffic. In this section, equations of the four main metrics (signaling cost, packet delivery overhead, handover latency and packet loss) are derived.

TABLE 1. Network-based IP mobility formulation

Scheme	1-Intra-domain (Local) Handover Procedure	2-Inter-domain (Global) Handover Procedure
Single Domain (PMIPv6) [5]	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.AddConf(MN ↔ MAG)	
Hierarchical Multi-Domain (PMIPv6+MIPv6) [11]	1.DeReg(MAG →LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.AddConf(MN ↔ MAG)	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.AddConf(MN ↔ MAG) 5.BU(MN ↔ HA)
Peer Multi-Domain (I-PMIP) [12]	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.AddConf(MN ↔ MAG)	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.AddConf(MN ↔ MAG) 5.PBU(newLMA ↔ VMA ↔ oldLMA)
Peer Multi-Domain (GPMIP) [15]	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.DBU(MAG ↔ VD) 5.AddConf(MN ↔ MAG) 6.AddConf(MN ↔ DHCP)	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PoInq(PS ↔ GPS) 4.PBU(MAG ↔ LMA) 5.DBU(MAG ↔ VD) 6.DBU(VD ↔ GVD) 7.AddConf(MN ↔ MAG) 8.AddConf(MN ↔ DHCP)
Peer Multi-Domain (iMAG) [13]	1.DeReg(MAG → LMA) 2.PoInq(MAG ↔ PS) 3.PBU(MAG ↔ LMA) 4.AddConf(MN ↔ MAG)	1.PoInq(MAG ↔ PS) 2.PoInq(newPS ↔ oldPS) 3.PBU(MAG ↔ LMA) 4.PBU(old LMA ↔ new LMA) 5.DeReg(MAG → LMA) 6.PoInq(MAG ↔ PS) 7.PBU(MAG ↔ LMA) 8.AddConf(MN ↔ MAG)

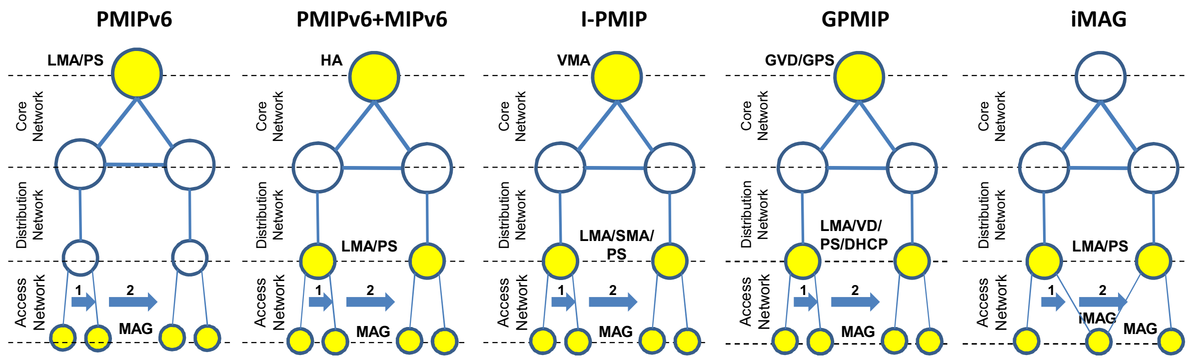


FIGURE 8. Placement of mobility agents in each scheme

4.3.1. *Signaling cost.* The cost is generally defined as the number of signal message exchanges needed to accomplish a handover. The unit of signaling cost represents a single message transmission between two adjacent nodes. Accordingly, a general formula to calculate the signal transmission cost between the node (x) and a mobility agent (y) is as follows:

$$C_{x-y} = \overbrace{\alpha(H_{x-y})}^{Wired\ transmission} + \overbrace{\beta}^{Wireless\ trasmission} \quad (16)$$

where H_{x-y} is the hop distance between two nodes inside the network, α and β are the coefficients of unit transmission costs (in message/hop) in wired and wireless links, respectively. It should be noted that, the cost coefficient for wireless links (β) is usually considered higher than wired links. It is assumed that node is in one hop distance from its access point. Similarly, the signal transmission cost between two mobility agents (y, z) inside the network can be expressed as follows:

$$C_{y-z} = \alpha(H_{y-z}) \quad (17)$$

The processing cost inside the mobility agent is usually small enough to be ignored in the performance studies. However, we adopt a simple normalizing method to include processing cost into the signaling cost. Assuming that a binding table lookup in the mobility agent includes at least one binary search, which increases logarithmically with increasing size of the table, the processing cost in mobility agent y can be expressed as follows:

$$PC_y = \zeta \log(N^y_{mn}) \quad (18)$$

where ζ is a normalizing constant equivalent to the bandwidth allocation cost [31] and N^y_{mn} is the number of binding records in y.

Following the operational formula of each scheme (Table 1) and the general Equations (16)-(18) we can derive the local (intra-domain) and global (inter-domain) handover cost equations for each designated network-based IP mobility schemes. For clarity sake, the abbreviations *SD*, *hMD*, *pMD-I*, *pMD-G* and *pMD-M* will be used as symbols for single domain PMIPv6, hierarchical multi domain PMIPv6-MIPv6 and peer multi domain I-PMIP, GPMIP and iMAG, respectively.

Single Domain: the local and global handover costs (C^{SD}_l and C^{SD}_g) are equal as follows:

$$\begin{aligned} C^{SD}_l = C^{SD}_g = &(\alpha H_{mag-lma} + PC_{lma}) + (2\alpha H_{mag-ps} + PC_{ps}) \\ &+ (2\alpha H_{mag-lma} + PC_{lma} + PC_{mag}) + 2(\alpha H_{ap-mag} + \beta) \end{aligned} \quad (19)$$

Hierarchical Multi Domain: the local handover cost (C^{hMD}_l) can be obtained from Equation (19). The global handover cost (C^{hMD}_g) has an extra MIPv6 binding update, which can be expressed by the following equation:

$$C^{hMD}_g = C^{hMD}_l + 2(\alpha H_{ap-ha} + \beta) + PC_{ha} \quad (20)$$

Peer Multi Domain with I-PMIP: again the local handover cost (C^{pMD-I}_l) can be obtained from Equation (19). For global handovers, one more binding update between home and visited LMAs through VMA is necessary. The equation is as follows:

$$C^{pMD-I}_g = C^{pMD-I}_l + (2\alpha H_{lma_2-vma} + PC_{vma}) + (2\alpha H_{vma-lma_1} + PC_{lma_1}) \quad (21)$$

where subscripts (1 and 2) refer to home and visited domains, respectively.

Peer Multi Domain with GPMIP: signaling cost equations for local and global handovers are as follows:

$$\begin{aligned} C^{pMD-G}_l = &(\alpha H_{mag-lma} + PC_{lma}) + (2\alpha H_{mag-ps} + PC_{ps}) + (2\alpha H_{mag-lma} + PC_{lma} \\ &+ PC_{mag} + 4(\alpha H_{ap-mag} + \beta) + (2\alpha H_{mag-vd} + PC_{vd}) \end{aligned} \quad (22)$$

$$C^{pMD-G}_g = C^{pMD-G}_l + (2\alpha H_{ps-gps} + PC_{gps}) + (2\alpha H_{vdb-gvd} + PC_{gvd}) \quad (23)$$

Peer Multi Domain with iMAG: the cost of each local handover with iMAG (C^{pMD-M}_l) can be obtain from Equation (19). However, global handovers in this case consists of

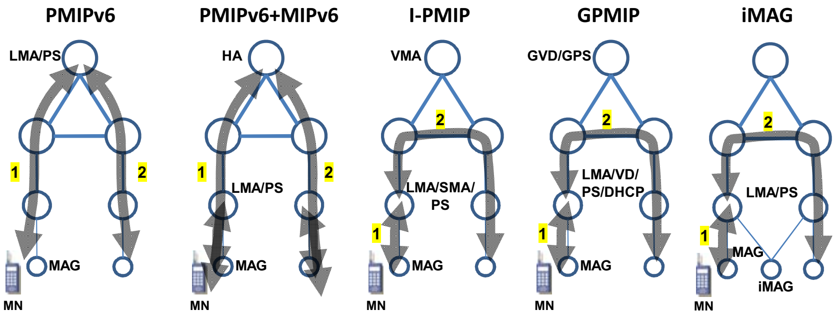


FIGURE 9. Mobility tunnel trajectory in 1) local, 2) global handovers

inter-domina message exchanges in addition to local handover operation. The equation is as follows:

$$\begin{aligned} C_g^{pMD-M} &= C_l^{pMD-M} + (2\alpha H_{mag-ps_2} + PC_{ps_2}) + (2\alpha H_{ps_1-ps_2} + PC_{ps_1}) \\ &\quad + (2\alpha H_{mag-lma_2} + PC_{lma_2}) + (2\alpha H_{lma_1-lma_2} + PC_{lma_1}) \end{aligned} \tag{24}$$

4.3.2. *Packet delivery overhead.* Packet delivery overhead (PD) is a direct result of extra header in IP-in-IP tunneling between mobility agents. A method to measure this overhead is expressed in the following equation:

$$PD^x = \frac{40 \times H_{tunnel}}{(40 + P_{size}) \times H_{mn-cn}} \tag{25}$$

where H_{tunnel} is the mobility tunneling length as shown in Figure 9, H_{mn-cn} is the length of routing trajectory from Correspondent Node (CN) to the mobile node and P_{size} is the average data packet size. Based on Equation (25), the specific equations for each scheme can be expressed as follows:

$$PD_l^{SD} = PD_g^{SD} = \frac{40 \times \alpha H_{mag-lma}}{(40 + P_{size})(\alpha H_{mn-cn} + 2(\beta - \alpha))} \tag{26}$$

$$PD_l^{hMD} = PD_g^{hMD} = \frac{40 \times (\alpha H_{mag-lma} + \alpha H_{ap-ha} + \beta)}{(40 + P_{size})(\alpha H_{mn-cn} + 2(\beta - \alpha))} \tag{27}$$

$$PD_g^{pMD-I} = PD_g^{pMD-G} = PD_g^{pMD-M} = \frac{40 \times \alpha(H_{lma_1-lma_2} + H_{mag-lma})}{(40 + P_{size})(\alpha H_{mn-cn} + 2(\beta - \alpha))} \tag{28}$$

Delivery overhead in local handovers with any peer multi domain scheme (PD_l^{pMD-x}) can be obtained from Equation (26).

4.3.3. *Handover latency.* By definition, total handover latency is the duration of time that a mobile node is unable to exchange packets with network. This includes the time to accomplish link switching (link-layer handover) and then execute IP mobility scheme (IP layer handover). The focus of this study is on the second part that is caused by message transmission delays between mobility agents. The processing time inside the agents is too short to be counted in the handover evaluation studies [32]. Similar to [26, 30] a general formula to calculate the signal transmission time between two arbitrary nodes x and y can be expressed as follows:

$$T_{x-y} = \overbrace{\left(\frac{1+q}{1-q}\right)\left(\frac{M_{size}}{B_{wl}} + L_{wl}\right)}^{Wireless\ transmission} + \overbrace{(H_{x-y})\left(\frac{M_{size}}{B_w} + L_w + T_q\right)}^{Wired\ transmission} \tag{29}$$

where q is the wireless link failure probability, M_{size} is the average message size, B_{wl}, B_w, L_{wl} and L_w are the bandwidth and propagation delay of the wired and wireless links, respectively and T_q is the average queuing time at each router. It is assumed that all the links inside the network are wired, and each mobile node's connection is through a wireless link with one hop distance from its access point. It is obvious that if both x and y were inside the network, Equation (29) can be rewritten as follows:

$$T_{x-y} = \overbrace{(H_{x-y})\left(\frac{M_{size}}{B_w} + L_w + T_q\right)}^{Wired\ transmission} \tag{30}$$

The handover latency equations for the network-based IP mobility schemes are as follows. Note that among main functions, the deregistration happens before handover and has no role in handover latency.

$$D_l^{SD} = D_g^{SD} = \overbrace{2 \times T_{mag-ps}}^{Policy\ Inquiry} + \overbrace{2 \times T_{mag-lma}}^{Binding\ Update} + \overbrace{2 \times T_{mn-mag}}^{Add.\ Conf.} \tag{31}$$

The local handover latency in hierarchical multi domain (PMIPv6-MIPv6) and peer multi domain (I-PMIP) can be obtained from Equation (31).

$$D_g^{hMD} = D_l^{hMD} + \overbrace{2 \times T_{mn-ha}}^{Global\ Binding\ Update} \tag{32}$$

$$D_g^{pMD-I} = D_l^{pMD-I} + \overbrace{2 \times (T_{lma_2-vma} + T_{vma-lma_1})}^{Global\ Binding\ Update} \tag{33}$$

$$D_l^{pMD-G} = \overbrace{2 \times T_{mag-ps}}^{Policy\ Inquiry} + \overbrace{2 \times (T_{mag-lma} + T_{mag-vd})}^{Binding\ Update} + \overbrace{2 \times (T_{mn-mag} + T_{mn-dhcp})}^{Add.\ Conf.} \tag{34}$$

$$D_g^{pMD-G} = D_l^{pMD-G} + \overbrace{2 \times T_{ps-gps}}^{Global\ Policy\ Inquiry} + \overbrace{2 \times T_{vd-gvd}}^{Global\ Binding\ Update} \tag{35}$$

iMAG scheme reduces the latency of the global handovers down to the local handovers by keeping the connection of the mobile node to an intermittent MAG. Hence, local and global handovers latency for this scheme (D_l^{pMD-M} and D_g^{pMD-M}) can be calculated by Equation (31).

4.3.4. *Packet loss.* Considering that there is no internal buffering for IP mobility solutions, the number of lost packet (PL) is proportioned to handover latency. The following equation shows the relation:

$$PL^x = D^x \times \lambda_p \tag{36}$$

where x indicates one of the network-based IP mobility schems and λ_p is the packets arrival rate. D^x can be obtained by one of Equations (31)-(35).

To estimate the combined effect of packet loss and packet delivery overhead, we define IP mobility goodput (GP^x) as the ratio of useful traffic as received by a mobile node to the overall traffic that is targeted to that mobile node during its residency time, indicated by (TOT_{data}):

$$GP^x = \frac{TOT_{data} - (P_{size} \times PL^x + TOT_{data} \times PD^x)}{TOT_{data}} \tag{37}$$

Using SMR, average duration of each session $\overline{S}$, packet rate λ_p and the size of each packet P_{size}, the TOT_{data} can be expressed as follows:

$$TOT_{traffic} = SMR \times \overline{S} \times \lambda_p \times P_{size} \tag{38}$$

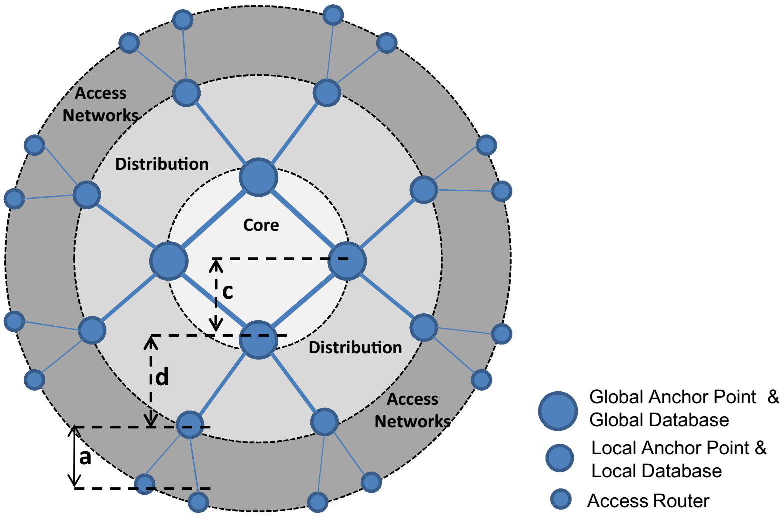


FIGURE 10. The reference topology

TABLE 2. System parameters

Model	Symbol	Description	Default Value
Mobility Models	ρ	Density of active MNs	200 per km^2
	ν	Average Velocity of MN	$5 \sim 40\ m/s$
	φ	Probability that an MN remains in its location	0.2
	$\overline{T}$	Average subnet residency time	100 s
Network Models	R	Number of the subnet Rings in each Domain	1
	L_M	Perimeter of each subnet area	6000 m
	B_{WL}	Bandwidth of wireless link	100 mb/s
	L_{WL}	Propagation delay of wireless link	50 ms
	q	Failure probability of Wireless link	0.2
	B_W	Bandwidth of wired link	1000 mb/s
	L_W	Propagation delay of wired link	0.5 ms
	T_q	Average queuing time at IP routers	5 ms
Sessions and Protocols	M_{size}	Average signal message size	80 $Bytes$
	P_{size}	Average data packet size	250 $Bytes$
	α	Unit transmission cost in wired link	1
	β	Unit transmission cost in wireless link	10
	ζ	Bandwidth allocation cost at each node	0.01
	λ_S	Average session arrival rate	0.001
	λ_p	Average packets arrival rate	50

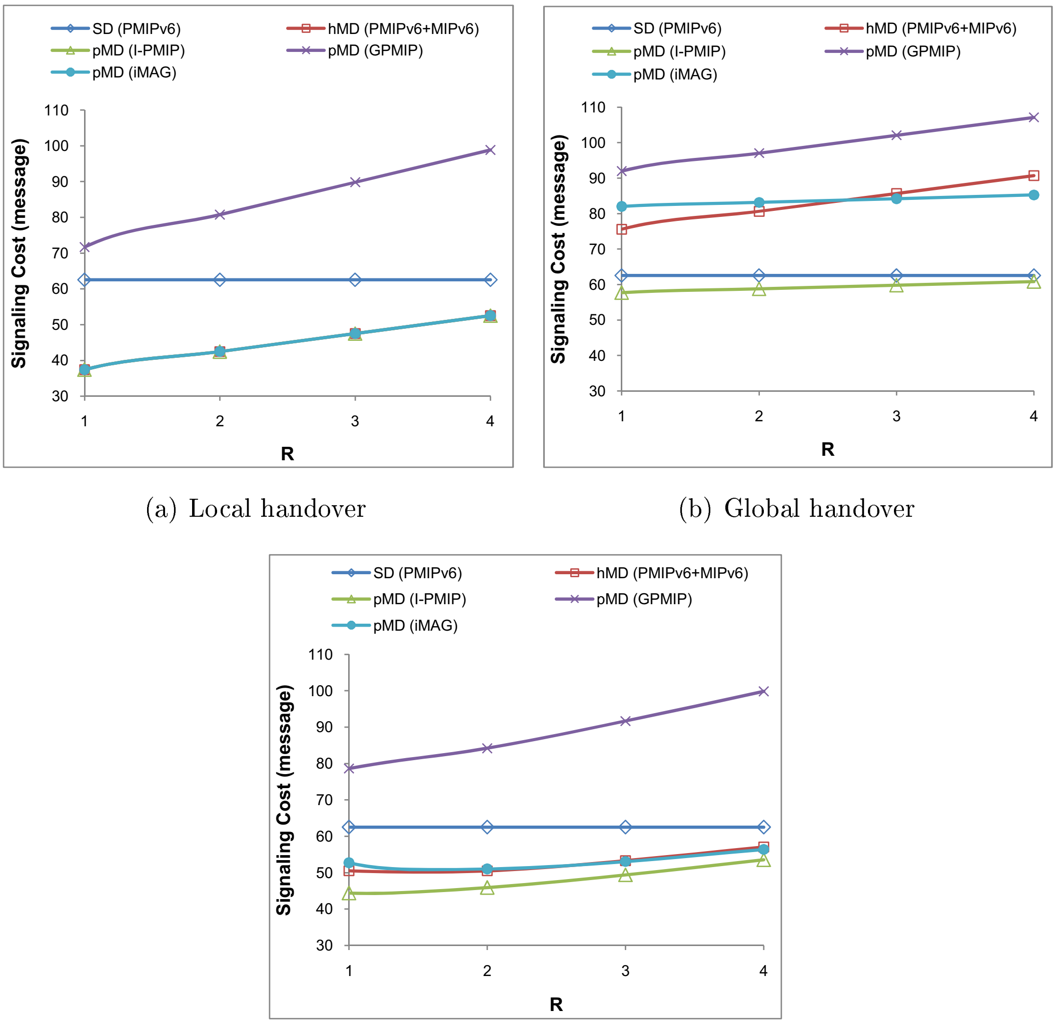
5. **Numerical Results and Discussion.** Having the global handover probability (p_g), the overall performance can be obtained as the weighted average of local and global metrics. The topology in Figure 10 has been used as a reference for hop distances (a, b and c) between mobility agents. Considering that the average distance of each two typical end points over the Internet are 10 hops, the distance from one access router up to the core $(a + d + c)$ is considered fixed and equal to 8 hops. The average distance between two core routers is 2 hops $(c = 2)$. The exact values of (a) depends on domain dimension, which is a function of R. Assuming that a binary tree resembles the hierarchical topology of access networks, the value of (a) and (d) can be calculated by following formula:

$$a = \lfloor \log(3 \times R \times (R + 1) + 1) \rfloor, \quad d = 6 - a \tag{39}$$

where $(3 \times R \times (R + 1) + 1)$ is the number of access routers in the base of topological tree (similar to the number of subnets in Equation (15)). The rest of the system parameters

TABLE 3. Topological configuration in different domain dimensions

R	Number of subnets inside the domain	Number of domains inside the Network	Topological Distances (a, d, c)	Inter-domain handover probability (p_g)
1	7	9	$(3, 3, 2)$	0.342857143
2	19	3	$(4, 2, 2)$	0.210526316
3	37	2	$(5, 1, 2)$	0.151351351
4	61	1	$(6, 0, 2)$	0.118032787



(a) Local handover

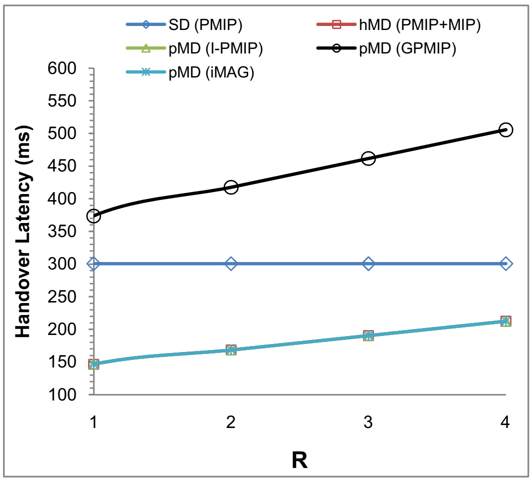
(b) Global handover

(c) Overall cost

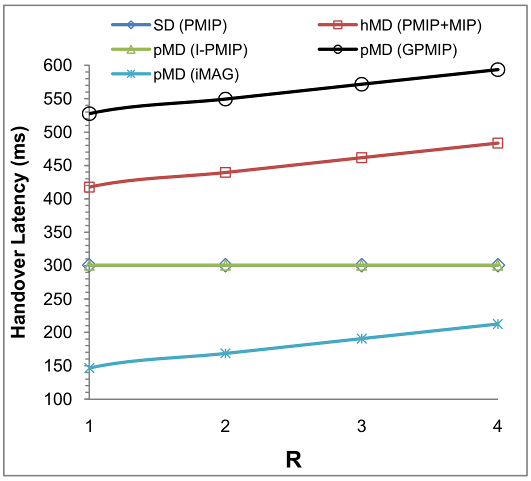
FIGURE 11. Handover signaling cost versus domain size (R)

are listed in Table 2, the default values have been chosen similar or close to the values in [9, 31].

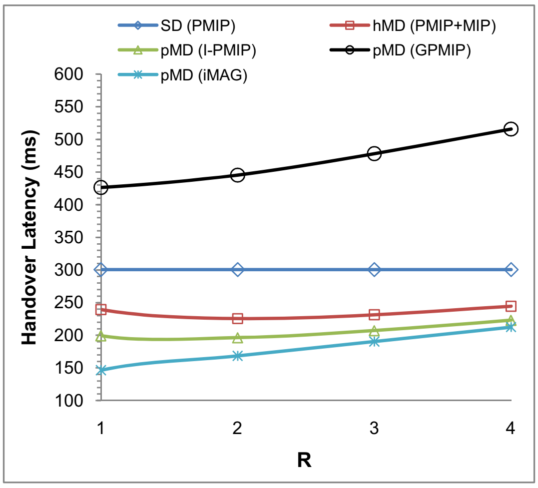
5.1. **Domain size effect.** Mobility domain dimension could influence performance metrics in multi-domain scenarios. This effect was studied by four different topological configurations by changing the number of subnet rings (R) inside each domain varying from 1 to 4, while the size of network is fixed (equal to 61 subnets). The number of domains and distances in each configuration are listed in Table 3. The probability of global handover in each case has been calculated using the RW model (Equation (6)). The plots in



(a) Local handover



(b) Global handover

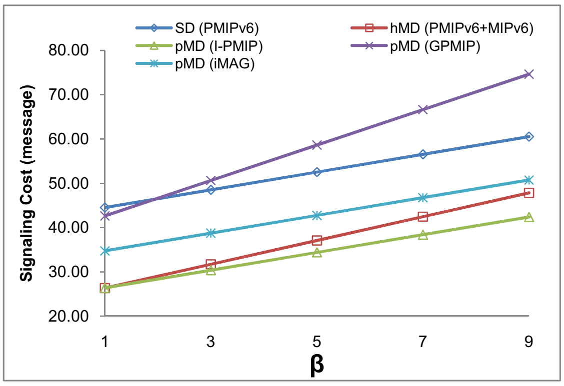


(c) Overall latency

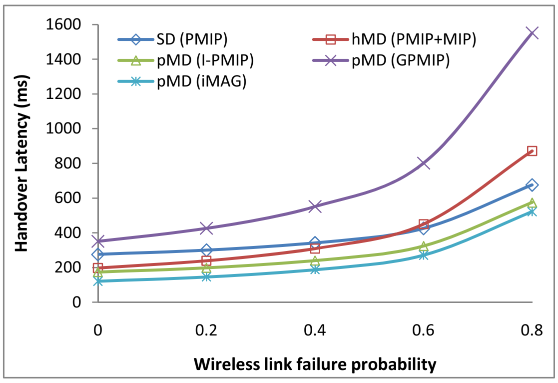
FIGURE 12. Handover latency versus domain size (R)

Figures 11 and 12 illustrate the results in terms of handover cost and latency. Enlarging the domain size increases the handover metrics in all scenarios, except for the single domain. As shown in Figures 11(a) and 12(a), local handover with I-PMIP, iMAG, and the combination of PMIPv6+MIPv6 produce the same cost and latency as they all use original PMIPv6 protocol in local scale. However, the main difference is in global metrics (Figures 11(b) and 12(b)), in which the I-PMIP and iMAG show the best results in terms of signaling cost and latency, respectively. On the other end, GPMIP creates the highest cost and latency, which is the result of its specific design in duplicating control and data planes. The comparison of overall results (Figures 11(c) and 12(c)) proves that the enlargement of domain size has two simultaneous effects on handover performance. Larger domains indicate higher handover cost and latency, but this condition also means more local handovers in the domain and thus less global handovers. The combined effect causes slower grow rate in overall metrics.

5.2. **Radio effect.** Network-based mobility schemes try to avoid unreliable wireless links. However, part of the signals (e.g., address reconfiguration) should still go through the air. Another group of experiments are set to investigate this effect. The graph in Figure 13(a)

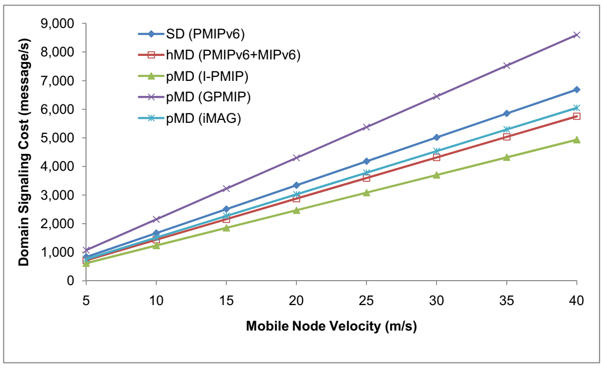


(a) Signaling cost versus wireless link cost (β)

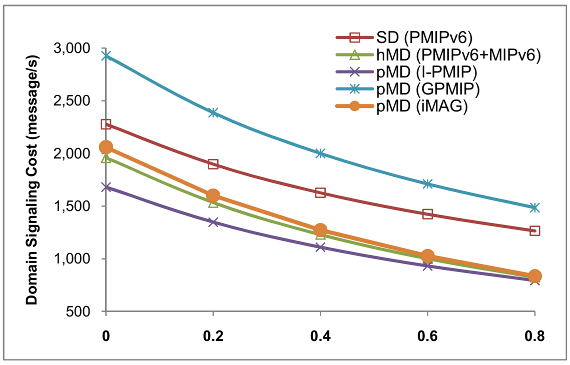


(b) Handover latency versus wireless link failure probability

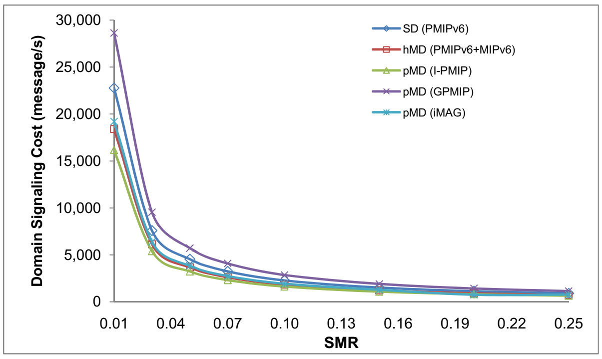
FIGURE 13. The effect of wireless link declines over IP mobility performance



(a) Effect of node's velocity



(b) Effect of node's stationary (φ)



(c) Effect of session-to-mobility ratio

FIGURE 14. Handover signaling cost of each domain per unit of time (R = 1)

shows that the handover cost in all schemes increases linearly by assuming higher relative cost (β) for wireless links. Similarly, Figure 13(b) shows how an unreliable wireless link increases the handover latency, exponentially. The error-prone radio transmission causes more signal retransmissions between mobile node and its access point. The results in Figure 13 also confirm higher performance of peer multi domain scenario with I-PMIP and iMAG among all schemes, at least in terms of the latency and cost of IP level handovers.

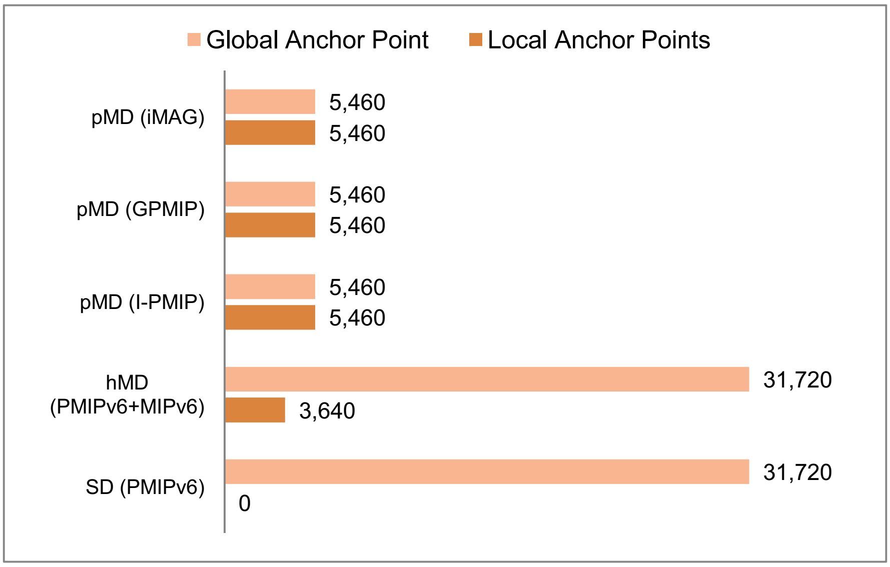


FIGURE 15. Number of binding records in each mobility anchor point (R = 1)

5.3. **Mobility and traffic effect.** Total signaling costs of a domain have been shown in Figure 14. The results show the effect of node and traffic dynamics, including velocity, tendency to stop, and SMR, on handover performance. According to Figure 14(a), fast moving users increase signaling cost as a result of higher number of handovers. Figure 14(b) shows that domains with uninterrupted movements ($\varphi = 0$) produce higher cost. One example of such dynamic domains exists in urban area with higher density of freeways. The plot in Figure 14(c) alternatively proves the same results. Higher SMR signifies that each mobile node experiences fewer handovers during an IP session, mainly because of MS's longer residence in the subnet.

5.4. **Scalability issue.** Having an estimation of the number of binding records in each anchor point is important as it indicates the processing load. A good practice in designing scalable IP mobility protocols is to avoid overloading the anchor points. The number of binding records have been shown in Figure 15, considering that each mobile node has at least one binding record in its local, as well as global anchor points and also assuming that the nodes are uniformly distributed throughout the network (default density is $\rho = 200$ nodes per km^2). The global anchor points in single domain and hierarchical multi-domain scenarios suffer from a high number of binding records. Inter-domain schemes (I-PMIP, GPMIP and iMAG) reduce this number by distributing the binding records among local anchor points. However, this condition increases the load of local anchors (from 3640 to 5460) in inter-domain schemes as they have to continue serving the mobile nodes after they have left the domain.

5.5. **Router serving time effect.** In a non-congested network, handover latency is a function of topological distance of mobility entities from each other (Figure 12). However, as shown by the graph in Figure 16, latency can critically increase once the network becomes congested. The results are determined by increasing the average queuing delay in each router, which is an indicator of the congestion. However, low latency mobility schemes, such as iMAG and I-PMIP, show less sensitivity to congestions.

5.6. **The effect of data packets.** Handover can influence quality of data services, particularly in delay sensitive streaming applications (e.g., VoIP, IPTV). Plots in Figure

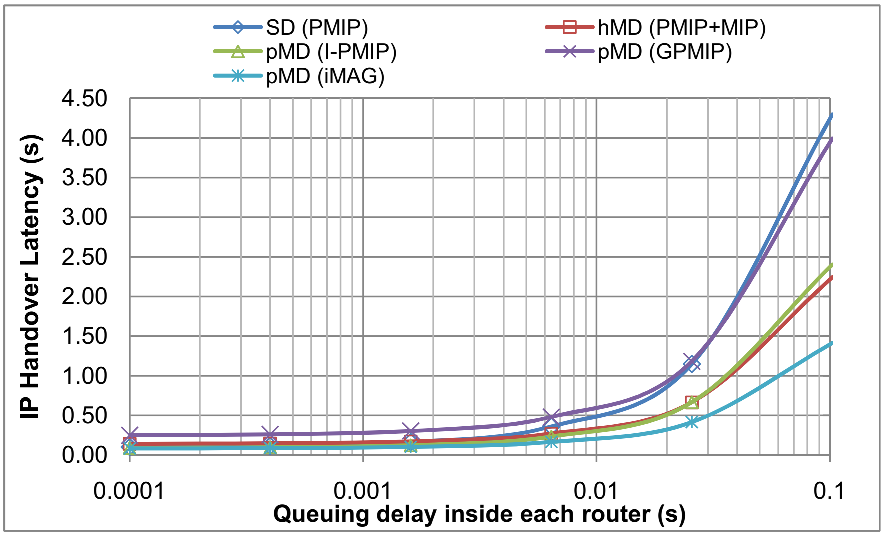
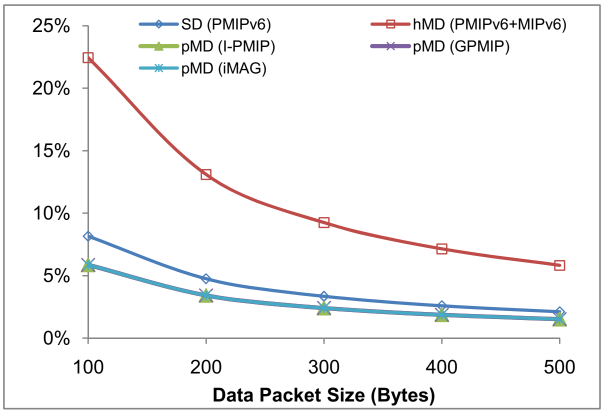


FIGURE 16. IP handover latency versus queuing delay inside each router (T_q)

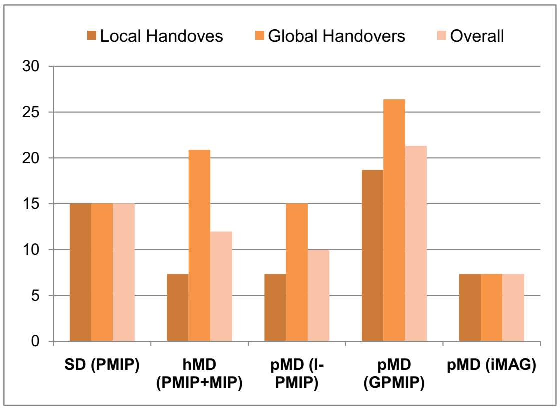
17 demonstrate this effect in terms of packet delivery overhead, number of lost packets (during handover), and goodput. The interconnection of PMIPv6 and MIPv6 produces the highest overhead (Figure 17(a)) caused by the nested mobility tunneling of MIPv6 and PMIPv6. The results in Figures 17(a) and 17(c) prove that the overhead of mobility tunneling is higher in data traffic with smaller packet size.

5.7. **The effect of main handover functions.** Any possible improvement in network-based IP mobility schemes requires a deep understanding of performance elements. According to the charts in Figure 18(a), the address configuration is the main element of local handover cost, with share equal to 47%, the other major contributors are BU with 24% and policy inquiry with 22%. The role of BU in producing signaling cost in global handovers (Figure 18(b)) increased up to 37%, equal to address configuration. The most important element with 74% contribution to handover latency, in both local and global handovers is BU (Figure 18(d)). As a result, any improvement in this function can improve significantly the entire handover process. Policy inquiry in local handover scenarios also has a noticeable contribution to latency (40%), as a result of PMIPv6 obligation to request the home prefix of the mobile node even in local handovers.

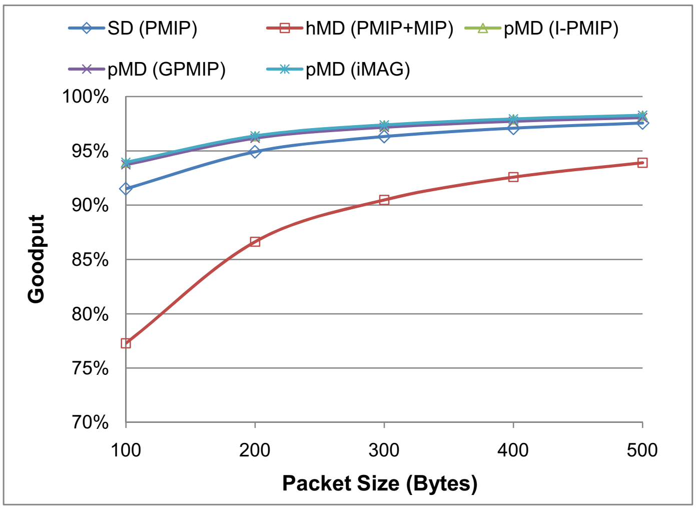
5.8. **Summary of the findings.** Based on the results and discussions in this section, the peer multi-domain scenario with proper schemes, such as I-PMIP and iMAG, are evidently more desirable options, at least in terms of handover performance. I-PMIP with minimum changes in IETF PMIPv6 [5] standard is apparently a promising option. However, the latency of this scheme in global handovers is still long enough to disturb the user's services. Global handovers in iMAG is as fast as local handovers, but this scheme produces higher signaling cost and involves difficulties to implement common MAG between domains. The present analysis also indicates that address configuration is the main contributor to the cost of handover, particularly inside the domains. However, BU still has the prominent role in handover between domains. Considering that address configuration is part of main IPv6 protocol stack, any possible enhancement in performance should be concentrated over improvement in BU and policy inquiry procedures.



(a) Packet delivery overhead versus packet size (P_{size})



(b) Number of lost packet during each handover



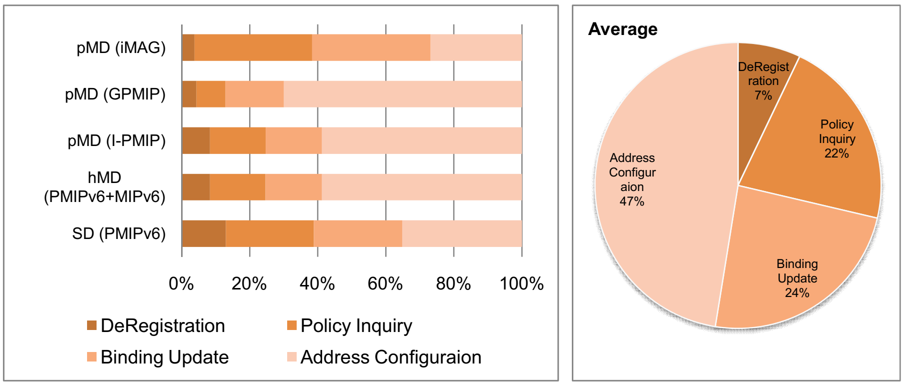
(c) Goodput versus packet size (P_{size})

FIGURE 17. The data traffic loss caused by the handovers

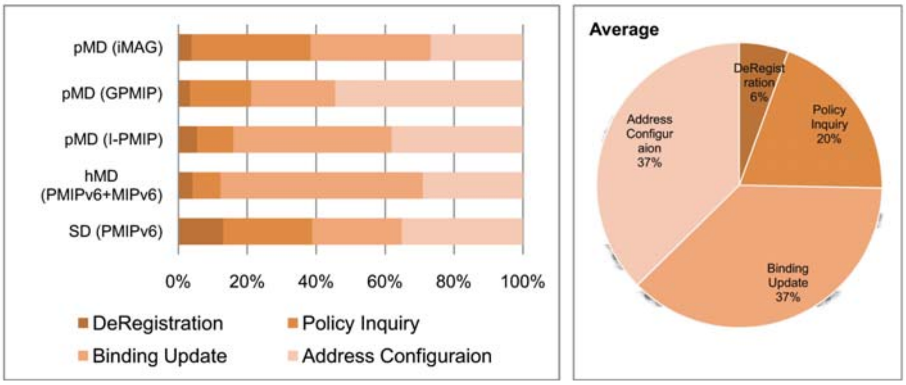
6. **A Design Example.** The proposed evaluation framework can be utilized to examine the design parameters of an extended network-based IP mobility scheme. In this section, a new scheme for IP level handover control in metropolitan area networks is outlined, and its performance metrics are analyzed to determine the proper trade-off between its complexity and effectiveness.

Majority of the mobile users in urban areas are the passengers of public and private transport systems. Consequently, their movement patterns follow the vehicular movement that has two important features, i.e., the movements are typically fast and relatively predictable. From the viewpoint of IP mobility, the former feature means more handovers, whereas the latter suggests a higher chance of predicting handover target. Figure 19 illustrates a city section, which is under the coverage of 15 mobility domains. Two automobiles (A and B) on the road are currently served by domains 1 and 2, respectively. Based on their current location and direction as well as the street map, the next possible domain for A could be one of domains 2, 6, or 12, but for B, the target will clearly be domain number 3.

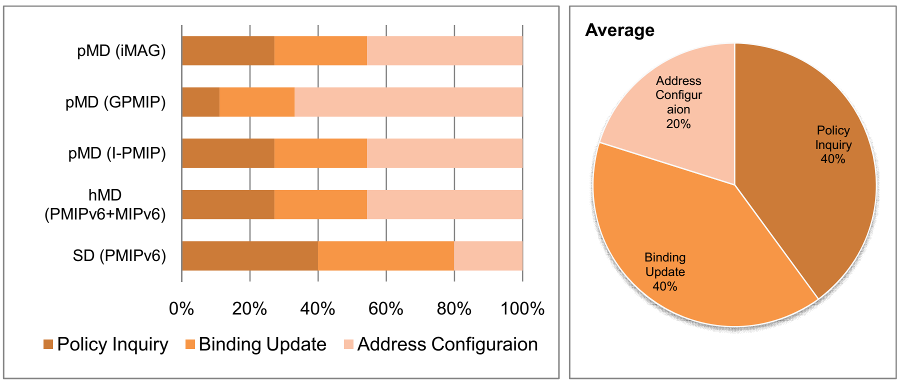
Taking advantage of this predictable mobility, the Prediction-assisted Proactive Mobility Session (PPMS) is proposed. Similar to I-PMIP and iMAG, PPMS is a globally



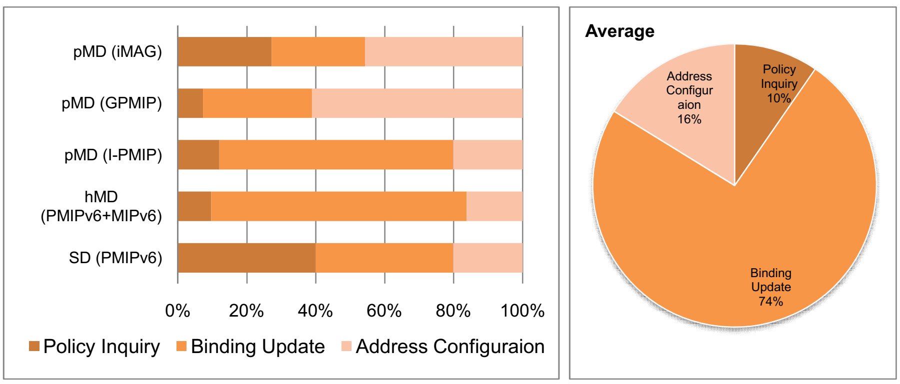
(a) Local handover cost



(b) Global handover cost



(c) Local handover latency



(d) Global handover latency

FIGURE 18. Contribution of main functions in performance metrics

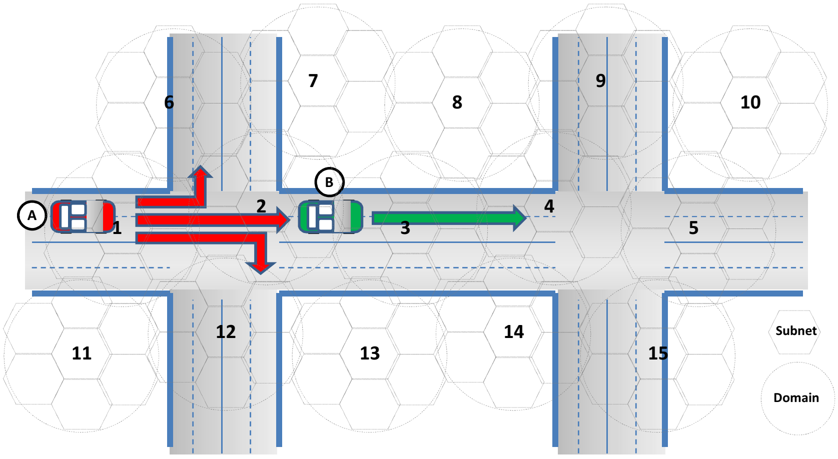
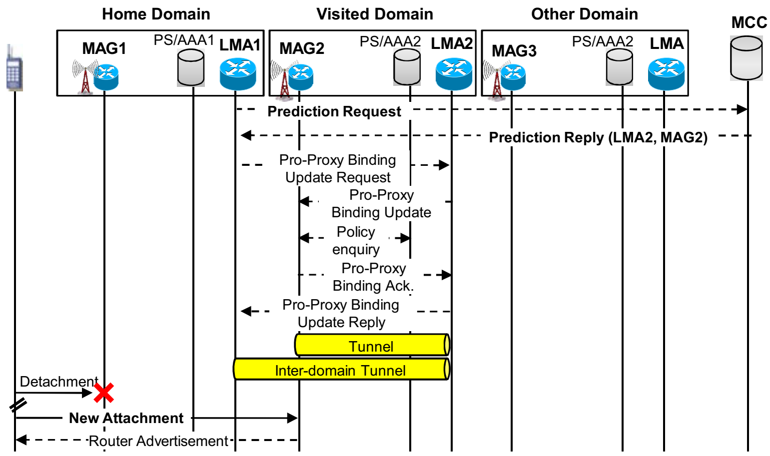
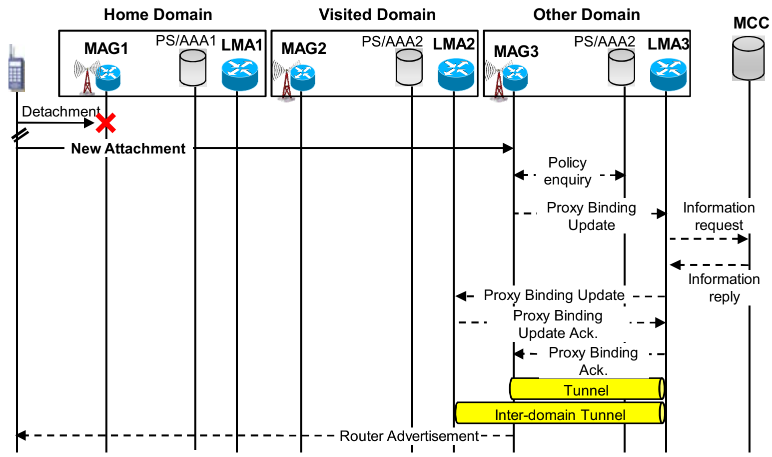


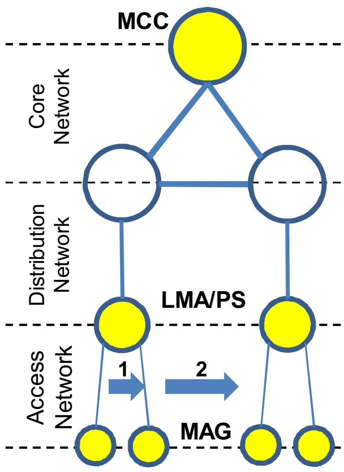
FIGURE 19. Movement prediction in a city section



(a) Correct prediction



(b) Wrong prediction (extra operations)



(c)

FIGURE 20. Inter-domain handover operation in PPMS scheme

extended version of PMIPv6 [5] equipped with a proactive handover procedure. The message flow map of PPMS is shown in Figure 20(a). During the prediction process, the local mobility anchor point (LMA1) of the serving domain consults the mobility control centre

TABLE 4. PPMS operational formula

Intra-domain (Local) Handover Procedure	Inter-domain (Global) Handover Procedure	
	Correct Prediction	Wrong Prediction
1.DeReg(MAG1 $\rightarrow$ LMA1) 2.PoInq(MAG1 $\leftrightarrow$ PS1) 3.PBU(MAG1 $\leftrightarrow$ LMA1) 4.AddConf(MN $\leftrightarrow$ MAG1)	1.Prediction(LMA1 $\leftrightarrow$ MCC) 2.GBU(LMA1 $\leftrightarrow$ LMA2) 3.PoInq(MAG2 $\leftrightarrow$ PS2) 4.PBU(MAG2 $\leftrightarrow$ LMA2) 5.DeReg(MAG1 $\rightarrow$ LMA1) 6.AddConf(MN $\leftrightarrow$ MAG2)	Steps 1,2,3,4,5 6.PoInq(MAG3 $\leftrightarrow$ PS3) 7.PBU(MAG3 $\leftrightarrow$ LMA3) 8.PoInq(LMA3 $\leftrightarrow$ MCC) 9.GBU(LMA3 $\leftrightarrow$ LMA1) 10.AddConf(MN $\leftrightarrow$ MAG3)

(MCC) that has global awareness of mobility domains and movement profiles of mobile nodes inside them. MCC replies to LMA1 with a possible target (including the IP addresses of LMA2 and MAG2). With this knowledge, the LMA1 requests the target domain to be prepared for incoming mobile node by creating a mobility session using proactive proxy binding update messages. The process is accomplished while the MN is still in its serving domain. However, if the prediction is wrong and the mobile node appears in a different domain (MAG3 in Figure 20(b)), the handover procedure has to be repeated in the reactive mode by creating a mobility session in this new domain. Considering the critical effect of latency and packet loss on the quality of VoIP services, the design needs to provide the accuracy at a proper level to reduce PPMS inter-domain handover latency to less than 100 ms, which is the unnoticeable threshold of interruption. Assuming the average VoIP packet rate, which is equal to 50, this latency causes only 5 packets to be dropped. The operational formulas of PPMS are listed in Table 4. Subsequently, the handover cost and latency of PPMS can be expressed according to the following equation:

$$\begin{aligned} C_g^{ppms} = (P_m)[C_l^{ppms} + (2\alpha H_{lma_2-mcc} + PC_{mcc}) + (2\alpha H_{lma_2-lma_1} + PC_{lma_1})] \\ + (1-P_m)[2C_l^{ppms} - 2(\alpha H_{ap-mag} + \beta) + (2\alpha H_{lma_2-mcc} + PC_{mcc}) \\ + (2\alpha H_{lma_2-lma_1} + PC_{lma_1}) + (2\alpha H_{lma_3-mcc} + PC_{mcc}) \\ + (2\alpha H_{lma_3-lma_1} + PC_{lma_1})] \end{aligned} \tag{40}$$

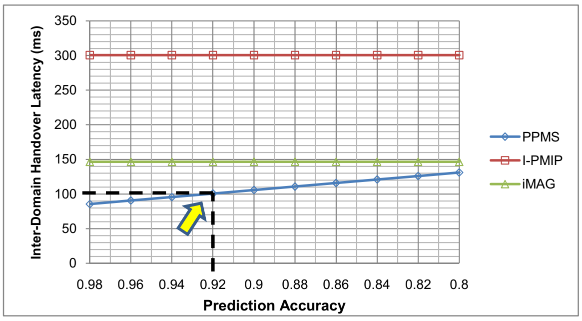
$$D_g^{ppms} = P_m[2 \times T_{mn-mag}] + (1-P_m)\left[D_l^{ppms} + 2 \times (T_{lma_3-mcc} + T_{lma_3-lma_1})\right] \tag{41}$$

where P_m is probability of correct prediction.

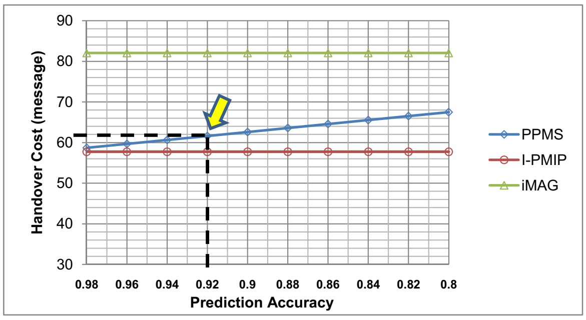
The performance metrics of the PPMS scheme as a function of its prediction accuracy are shown in Figure 21. The results of I-PMIP and iMAG are also included for comparison. Figure 21(a) proves that PPMS is faster than other schemes, however to reach the desired design goal, ($D_g^{ppms} \leq 100ms$), a prediction algorithm with 92% accuracy is necessary. Figure 21(b) shows that PPMS imposes an extra signaling cost (10% higher than I-PMIP, with 92% accuracy), though, it is still lesser than iMAG.

7. **Conclusion.** Network-based IP mobility has been suggested as a solution to the handover performance issue in mobile wireless network. In this paper majority of proposed schemes in this group has been identified and classified according to their adoption method in wireless networks. A comprehensive evaluation of their performance metrics is provided. Based on the findings, the peer multi-domain adoption scenario has better potential to improve handover performance.

The main contribution of the present study is a performance evaluation framework that is developed to accelerate the process of designing future solutions in network-based IP mobility area. The framework can be used to prioritize design parameters and make a trade-off between user satisfaction and network utilization. A new IP mobility scheme,



(a) Latency



(b) Signaling cost

Figure 21. Performance of PPMS versus prediction accuracy

PPMS has been proposed, and its design parameters have been analyzed as an example of the applications of the proposed framework.

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