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# Inter-Domain Mobility Management Based on the Proxy Mobile IP in Mobile Networks

Moneeb Gohar* and Seok-Joo Koh**

**Abstract**

System Architecture Evolution (SAE) with Long Term Evolution (LTE) has been used as the key technology for the next generation mobile networks. To support mobility in the LTE/SAE-based mobile networks, the Proxy Mobile IPv6 (PMIP), in which the Mobile Access Gateway (MAG) of the PMIP is deployed at the Serving Gateway (S-GW) of LTE/SAE and the Local Mobility Anchor (LMA) of PMIP is employed at the PDN Gateway (P-GW) of LTE/SAE, is being considered. In the meantime, the Host Identity Protocol (HIP) and the Locator Identifier Separation Protocol (LISP) have recently been proposed with the identifier-locator separation principle, and they can be used for mobility management over the global-scale networks. In this paper, we discuss how to provide the inter-domain mobility management over PMIP-based LTE/SAE networks by investigating three possible scenarios: mobile IP with PMIP (denoted by MIP-PMIP-LTE/SAE), HIP with PMIP (denoted by HIP-PMIP-LTE/SAE), and LISP with PMIP (denoted by LISP-PMIP-LTE/SAE). For performance analysis of the candidate inter-domain mobility management schemes, we analyzed the traffic overhead at a central agent and the total transmission delay required for control and data packet delivery. From the numerical results, we can see that HIP-PMIP-LTE/SAE and LISP-PMIP-LTE/SAE are preferred to MIP-PMIP-LTE/SAE in terms of traffic overhead; whereas, LISP-PMIP-LTE/SAE is preferred to HIP-PMIP-LTE/SAE and MIP-PMIP-LTE/SAE in the viewpoint of total transmission delay.

**Keywords**

Comparison, HIP, LTE, LISP, MIP, Mobility Management, PMIP, SAE

## 1. Introduction

System Architecture Evolution (SAE) with Long Term Evolution (LTE) has been used as the key technology for the next generation mobile networks [1-4]. SAE is the core network architecture of the 3GPP. The main components of SAE architecture are the Evolved Packet Core (EPC) and Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). EPC networks are composed of different entities such as the Serving Gateways (S-GW), Mobility Management Entity (MME), Packet Data Network Gateway (P-GW), Home Subscriber Server (HSS), and Policy and Charging Rules Function (PCRF). S-GW works as a mobility anchor for intra-3GPP handover. MME handles the mobility management, authentication, and bearer management. P-GW performs IP address allocation. HSS is a central database that contains subscription-related information and user authentication. PCRF is the com-


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ponent that determines the policies for policy management such as quality of services and charging rules. The evolved Node B (eNB) constitutes the E-UTRAN [5].

There are several network layer mobility protocols that could be used to support mobility in LTE/SAE [6,7]. In particular, the Proxy Mobile IPv6 (PMIPv6) has been considered to support IP mobility in the LTE/SAE architecture [8,9]. In our study, to support the PMIPv6 in the LTE/SAE architecture, the P-GW is used for the Local Mobility Anchor (LMA) of the PMIPv6, and the S-GW is used as the Mobile Access Gateway of the PMIPv6. There are several schemes for PMIP-based inter-domain mobility management [10,11]. However, these schemes are designed for general IP networks, rather than for LTE/SAE-based mobile networks [10,11].

In this paper, we discuss how to provide the inter-domain mobility management over PMIP-based LTE/SAE networks. For this purpose we will investigate the following three possible scenarios: 1) Mobile IP with PMIP (denoted by MIP-PMIP-LTE/SAE), 2) HIP with PMIP (denoted by HIP-PMIP-LTE/SAE), and 3) LISP with PMIP (denoted by LISP-PMIP-LTE/SAE).

In MIP-PMIP-LTE/SAE, the Home Agent (HA) of MIP [12] is used for mobility management among different domains, while the mobility management within a domain is governed by the PMIP. The home agent will maintain the binding information between the Home Address (HoA) of the mobile node and the regional Care-of-Address (RCoA) of the P-GW/LMA at the HA.

In HIP-PMIP-LTE/SAE, the rendezvous server (RVS) of the HIP [13] is used to perform the mobility management among different domains, whereas the local mobility management is handled by the PMIP in which P-GW/LMA acts as a 'HIP-proxy' functionality to perform the HIP-based signaling. The HIP-proxy of P-GW will process all HIP messages on behalf of mobile nodes in the domain. The global RVS needs to keep the mapping between the home address of the mobile nodes and the global locator of the P-GW. The P-GW also needs to keep the mapping between the home address of the mobile node and the proxy Care of Address (pCoA) of MAG.

In LISP-PMIP-LTE/SAE, the Map Server (MS) of LISP [14,15] is used for mobility management among different domains, whereas, the local mobility management is managed by the Tunnel Router (TR) of LISP over the P-GW/LMA of the mobile domain. The map server needs to keep the updated information of mapping between the home address of the mobile node and the routing locator of the tunnel router. The tunnel router also needs to keep the mapping between the home address of MN and the pCoA of the MAG.

The rest of this paper is organized as follows: in Section 2, we review the candidate schemes for inter-domain mobility management architectures in the PMIP-based LTE/SAE networks. Section 3 analyzes the performance of the candidate schemes in terms of the total transmission delays and the traffic overhead. In Section 4 we discuss the comparison of candidate architectures with numerical results. Section 5 concludes this paper.

## 2. Candidate Mobility Management Architectures

### 2.1 Overview

To describe the candidate mobility management schemes, we will first consider a generalized network model for a PMIP-based LTE/SAE network, as shown in Fig. 1. In Fig. 1, we assume that a Mobile Node

(MN) is located in the PMIP-based LTE/SAE network domain, whereas, a Correspondent Node (CN) is in the fixed network domain.

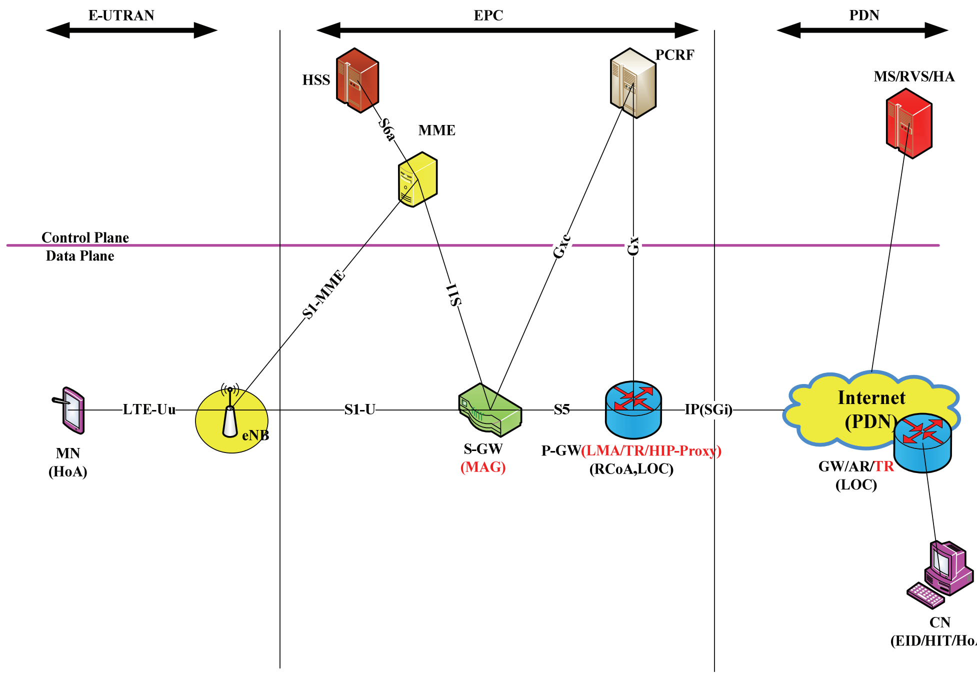


**Fig. 1.** Generalized network model.

In the Fig. 1, S-GW works as a MAG of the PMIP, and P-GW functions as a LMA of the PMIP. In addition, P-GW is used to provide inter-domain mobility management, which depends on the associated protocol such as Mobile IP (MIP), Host Identity Protocol (HIP), and Locator-Identifier Separation Protocol (LISP). That is, P-GW will function as a TR for integration of LISP with the PMIP, whereas, P-GW will perform the HIP-proxy function for integration of HIP with PMIP. In the public Internet, the MS, RVS, and HA will be used for global mobility management.

Before going into the detailed description, we compared the candidate mobility management schemes in the architectural perspective, as described in Table 1.

**Table 1.** Comparison of Inter-domain mobility management architectures

| Architectures | MIP-PMIP-LTE/SAE | HIP-PMIP-LTE/SAE | LISP-PMIP-LTE/SAE |
|---|---|---|---|
| Approach | Host + Network | Host + Network | Network + Network |
| Mapping agents | HA/LMA | RVS/LMA/HIP-proxy | MS/LMA/TR |
| Data delivery model | Data-first | Query-first | Query-first |

In MIP-PMIP-LTE/SAE, MIP is a host-based approach, whereas, proxy MIP (PMIP) is a network-based approach. The HA of MIP is used for global (inter-domain) mobility management, and LMA of the PMIP is used for local (intra-domain) mobility management. In data delivery, the data packets of CN will be first delivered to HA/LMA, and then HA/LMA will forward these data packets to MN.

In HIP-PMIP-LTE/SAE, HIP is host-based, whereas, the PMIP is network-based. The RVS is used to keep the mapping management globally, whereas, the PGW acts as a HIP-proxy for HIP-based call signaling, and LMA is used for local mapping management. For data delivery, CN first performs the location query operation by using the HIP *I1* signaling message, before data transmission to MN.

In LISP-PMIP-LTE/SAE, LISP and PMIP are both network-based approaches. The MS of LISP is used for global mapping management, and the TR of LISP is located at the P-GW of LTE/SAE, and the LMA of the PMIP is used for local mapping management. For data delivery, CN first performs the location query operation by using the LISP Map Request signaling message, before data transmission.

## 2.2 MIP-PMIP-LTE/SAE

To describe the MIP-PMIP-LTE/SAE mobility management scheme, we will first consider a network model, as shown in Fig. 2. In the figure, we assume that a MN is subscribed to the PMIP-based mobile network, whereas, a CN is in the fixed network domain.

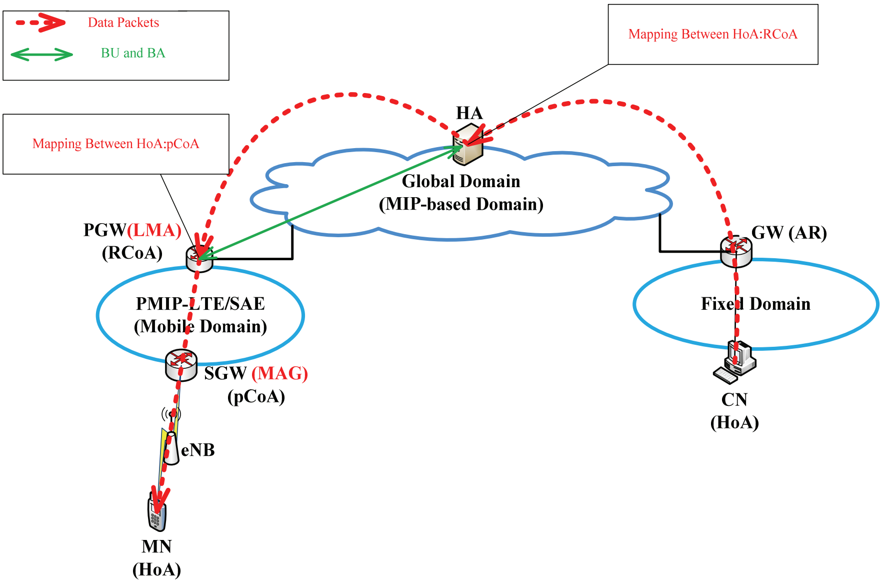


**Fig. 2.** Network model of MIP-PMIP-LTE/SAE architecture.

In the Fig. 2, LMA is employed on the gateway (P-GW) of the domain, while S-GW acts as the MAG. LMA will keep track of the binding between the HoA of MN and pCoA of the MAG, whereas, HA maintains the binding between the HoA and the regional CoA (RCoA) of LMA. The P-GW will perform the binding update operation with HA. CN will first send the data packets to HA, and these data packets are further delivered to PGW/LMA and MN.

The binding update and data delivery operations of MIP-PMIP-LTE/SAE are illustrated in Fig. 3. When MN establishes a radio link with eNB, it sends an *Attach Request* to the MME. Then, the security-related procedures are performed between the MN and MME (Steps 1, 2, 3). The MME sends the *Update Location Request* to the associated Home Subscriber Server (HSS). Then, the HSS will respond with the *Update Location Acknowledgement* to the MME (Steps 4, 5).

To establish a transmission path, the MME sends a *Create Session Request* to S-GW. When S-GW receives the request from the MME, it will send a *Proxy Binding Update (PBU)* message of the PMIP to the P-GW. Then, P-GW will allocate an IP address for the MN. The PGW will also send a *Binding Update (BU)* message of the MIP to the HA for binding the HoA and RCoA. HA will respond with a *Binding Ack (BA)* message of the MIP to the PGW. The P-GW responds with a *Proxy Binding ACK (PBA)* message of the PMIP to the S-GW. Then, the S-GW will respond with a *Create Session Response* to the MME (Steps 6–11). Now, the MME sends the information received from the S-GW to the eNB within the *Initial Context Setup Request* message. This signaling message also contains the *Attach Accept Notification*, which is the response of *Attach Request* in Step 2 (Steps 12, 13). Then, the eNB responds with an *Initial Context Setup Response* to the MME. Then, the MN sends the *Attach Complete* message to the MME (Steps 14, 15). Then, the MME sends the *Modify Bearer Request* message to the S-GW, and the S-GW will respond with the *Modify Bearer Response* to the MME (Steps 16, 17).

For data delivery, the CN will send a data packet to the HA. Then, the HA finds the location of the MN from its database, and it will forward the data packet to the P-GW and further onto the MN.

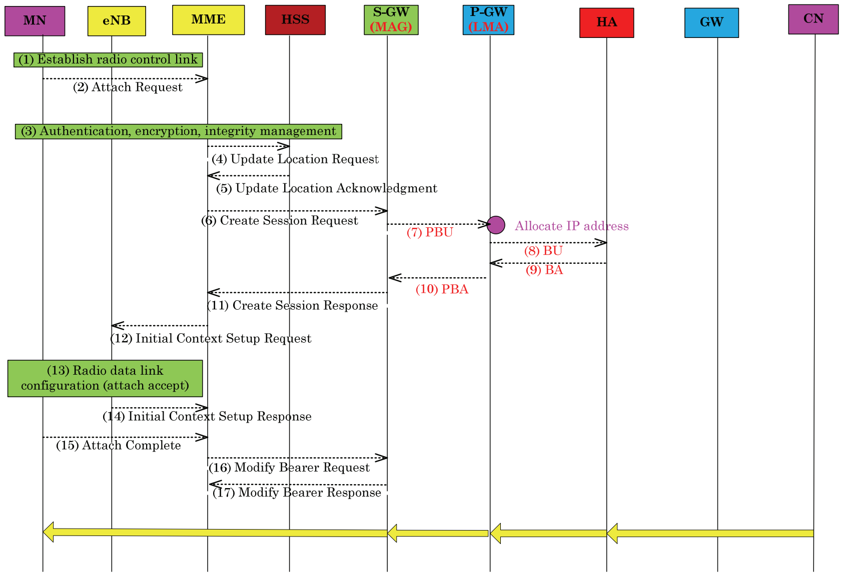


**Fig. 3.** Binding update and data delivery in MIP-PMIP-LTE/SAE.

## 2.3 HIP-PMIP-LTE/SAE

To describe the HIP-PMIP-LTE/SAE scheme, we used the network model shown in Fig. 4. In HIP-PMIP-LTE/SAE, the P-GW acts as the LMA of the PMIP and also as the HIP-proxy to support the HIP-based signaling operations, while the S-GW acts as a MAG. The LMA will keep track of the bindings between the HoA and pCoA, while the RVS will maintain the binding between the HoA and Locator (LOC). The P-GW will perform the binding update operation with the RVS.

The binding update and data delivery operations of HIP-PMIP-LTE/SAE are shown in Fig. 5. The initial procedures of HIP-PMIP-LTE/SAE (Step 1–17) are the same as those of MIP-PMIP-LTE/SAE. However, the P-GW will exchange *HIP Update and Ack* messages with the RVS (Steps 8, 9).

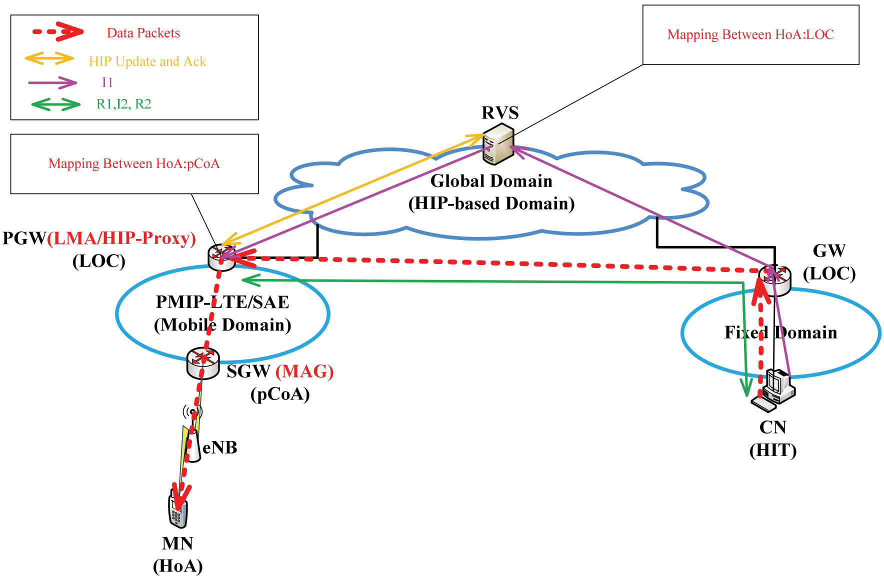


**Fig. 4**. Network model of HIP-PMIP-LTE/SAE architecture.

In the data delivery operation, CN will send the *I1* message to the gateway (GW) to find the location of the MN. The GW will forward the *I1* message to the global RVS. Then, the RVS will also forward the *I1* message to the P-GW (with HIP-proxy). Since then, the subsequent *I2, R1, R2* messages are exchanged between the PGW and CN (Step 18–23). Now, the CN sends the data packet directly to the MN by way of the GW and P-GW.

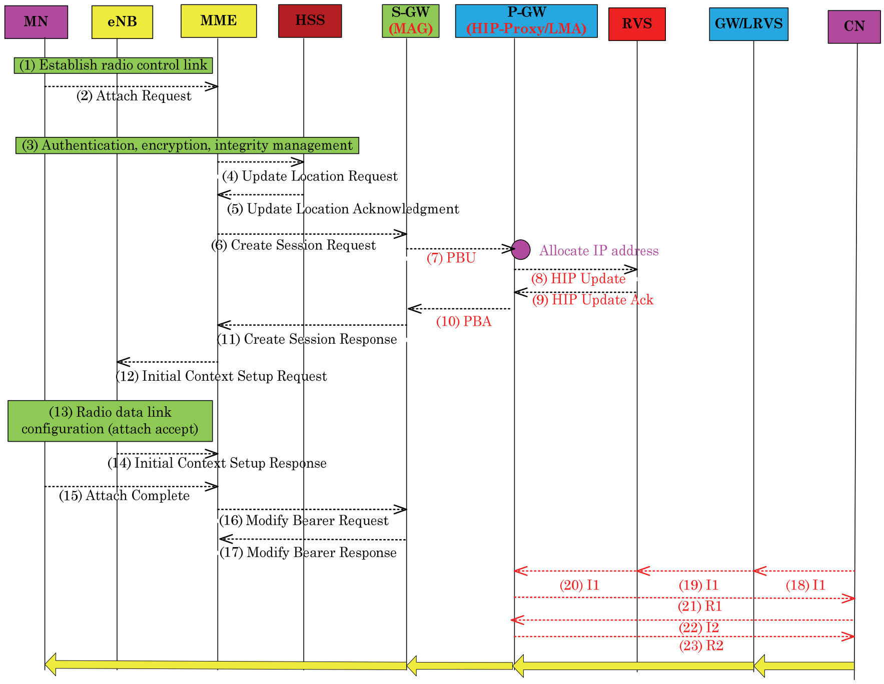


**Fig. 5.** Binding update and data delivery in HIP-PMIP-LTE/SAE.

## 2.4 LISP-PMIP-LTE/SAE

The network model for LISP-PMIP-LTE/SAE is shown in Fig. 6. In LISP-PMIP-LTE/SAE, the P-GW acts as a TR, as well as the LMA of the PMIP, while the S-GW acts as a MAG of the PMIP. The TR will keep track of the bindings between the HoA and pCoA, while the MS of LISP will maintain the bindings between the HoA and routing Locator (RLOC). The P-GW will perform the LISP Map Register operation with the map server. The CN will send data packets to the GW, and the GW performs the query operation with the map server so as to find the location of the MN.

The binding update and data delivery operations of LISP-PMIP-LTE/SAE are shown in Fig. 7. The initial procedures of LISP-PMIP-LTE/SAE (Steps 1–17) are the same as those of MIP-PMIP-LTE/SAE. However, the P-GW will exchange the *Map Register and Map Notify* messages with the map server (Steps 8, 9).

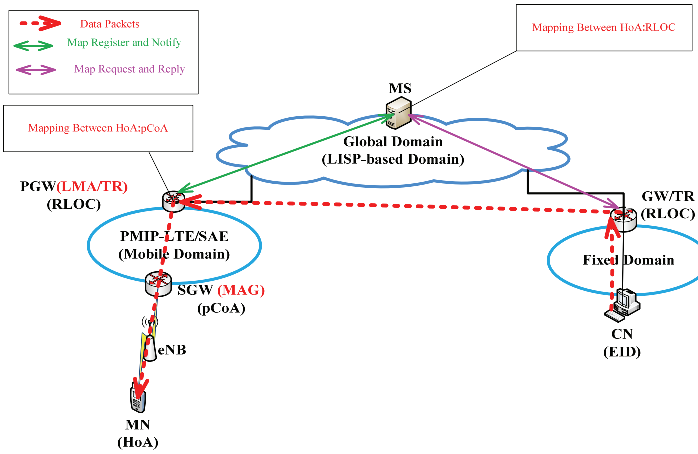


**Fig. 6.** Network model of LISP-PMIP-LTE/SAE architecture.

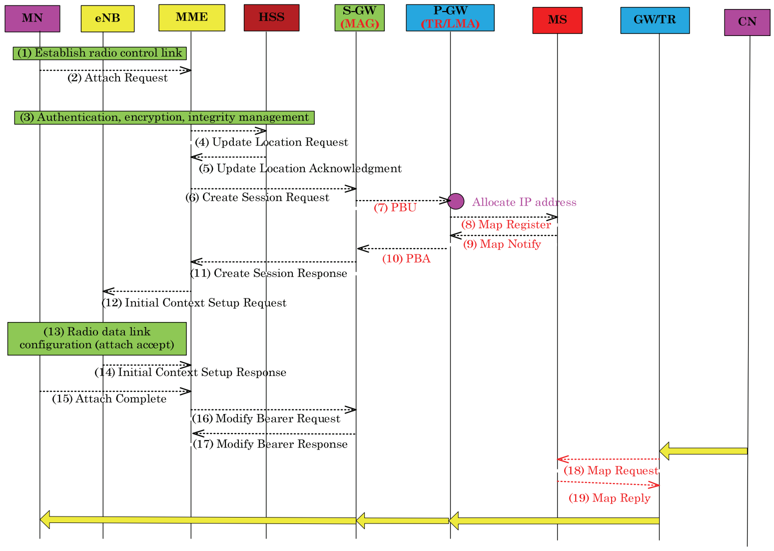


**Fig. 7.** Binding update and data delivery in LISP-PMIP-LTE/SAE.

In the data delivery operation, the CN sends a data packet to the TR/GW. Then, the TR will send the *Map Request* message to the map server to find the location of the MN. The map server responds with a *Map Reply* message to the TR of the CN (Steps 18, 19). Then, the CN sends the data packet directly to the MN by way of the GW and P-GW.

# 3. Performance Analysis

In this section, we analyze the Traffic Overhead (TO) at the central mapping agent and the Total Transmission Delay (TTD) required for the binding update, binding query, and data delivery operations.

## 3.1 Analysis Model

We used a network model for performance analysis, as illustrated in Fig. 8.

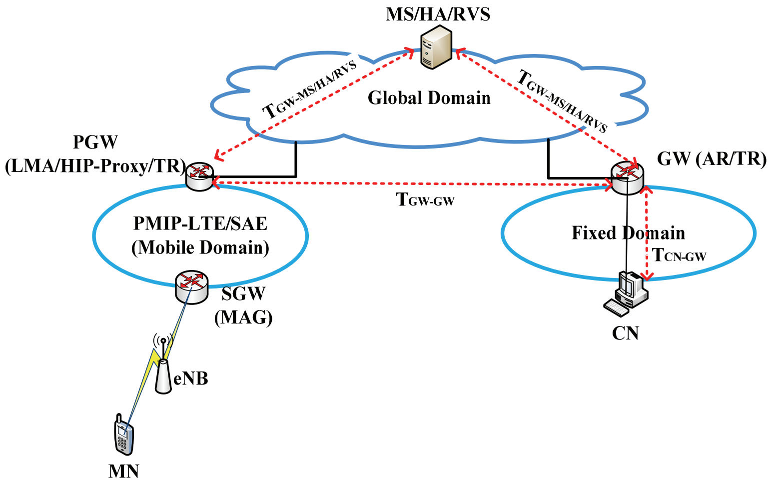


**Fig. 8.** Network model for performance analysis.

For numerical analysis, we used the following notations, as shown in Table 2.

**Table 2.** Parameters used for numerical analysis

| Parameters | Description |
|---|---|
| $S_c$ | Size of control packets (bytes) |
| $S_d$ | Size of data packets (bytes) |
| $B_w$ | Wired bandwidth (Mbps) |
| $L_w$ | Wired link delay (ms) |
| $H_{a-b}$ | Hop count between node a and b in the network |
| $T_q$ | Average queuing delay at each node (ms) |
| $N_{Host}$ | Number of host in the domain |
| $N_{GW}$ | Number of gateways |

In the Table 2, we denote $T_{x\text{-}y}(S,H_{x\text{-}y})$ by the transmission delay of a message with size *S* sent from *x* to *y* via the *wired* link, where $H_{x\text{-}y}$ represents the number of wired hops between node *x* and node *y*. Then, $T_{x\text{-}y}(S,H_{x\text{-}y})$ is expressed as $T_{x\text{-}y}(S, H_{x\text{-}y}) = H_{x\text{-}y}\times [(S/B_w)+L_w+T_q]$.

In the analysis, we will focus on the inter-domain (global) mobility scenario, rather than the intra-domain (local) mobility scenario, since the PMIP is commonly used for intra-domain mobility management. In the analysis, the TTD consists of the Binding Update Delay (BUD), the Binding Query Delay (BQD), and the Data Delivery Delay (DDD). That is, TTD = BUD + BQD + DDD.

## 3.2 Analysis of Traffic Overhead

To analyze the performance of the candidate mobility management schemes, we evaluated the traffic overhead for control and data traffics at the central agents such as MS, RVS, and HA.

### 3.2.1 MIP-PMIP-LTE/SAE

First, we calculated the TO by the number of control and data messages to be processed by the HA. It is assumed that the hosts are equally distributed in the mobile domain. For mapping update, the P-GW will send the *BU* messages to the HA. Thus, the *BU* message of $S_c\times N_{Host}\times N_{GW}$ is processed by the HA. For data transmission, each host sends a data packet directly to the HA, and the HA will forward the data packet to the P-GW. Thus, the data packets of $S_d\times N_{Host}\times N_{GW}$ are processed by HA.

Accordingly, we get the TO of MIP-PMIP-LTE/SAE as follows:

$$TO_{MIP-PMIP-LTE/SAE} = S_C \times N_{Host} \times N_{GW} + S_d \times N_{Host} \times N_{GW} \quad (1)$$

### 3.2.2 HIP-PMIP-LTE/SAE

In HIP-PMIP-LTE/SAE, we calculated the TO by the number of control messages to be processed by the RVS of the HIP. For mapping update, the P-GW will send the *HIP Update* messages to the RVS. Thus, the *HIP Update* messages of $S_c\times N_{Host}\times N_{GW}$ shall be processed by the RVS. For data transmission, the CN sends *I1* messages to the RVS. Thus, the *I1* messages of $S_c\times N_{Host}\times N_{GW}$ are processed by the RVS.

Accordingly, we obtain the TO of HIP-PMIP-LTE/SAE as follows:

$$TO_{HIP-PMIP-LTE/SAE} = 2 \times S_C \times N_{Host} \times N_{GW} \quad (2)$$

### 3.2.3 LISP-PMIP-LTE/SAE

In LISP-PMIP-LTE/SAE, we calculated the TO by the number of mapping control messages to be processed by the MS. For mapping update, the LISP TR over the P-GW will send the *Map Register* messages to the MS. Thus, the MS shall process the *Map Register* messages of $S_c\times N_{Host}\times N_{GW}$. For data transmission, the gateway of the CN will sends a *Map Request* message to the MS. Thus, the *Map Request* messages of $S_c\times N_{Host}\times N_{GW}$ are processed by the MS. Accordingly, we get the TO of the LISP-PMIP-LTE/SAE as follows:

$$TO_{LISP-PMIP-LTE/SAE} = 2 \times S_C \times N_{Host} \times N_{GW} \quad (3)$$

## 3.3 Analysis of Total Transmission Delay

In this paper, TTD is defined by the sum of the BUD, BQD, and DDD. That is, TTD = BUD + BQD + DDD.

### 3.3.1 MIP-PMIP-LTE/SAE

In MIP-PMIP-LTE/SAE, the binding update operations are performed as follows. When a mobile node enters a new S-GW, it configures its pCoA. After that, the S-GW will perform the proxy binding operation with the P-GW. Then, the P-GW performs the binding operation with the HA by exchanging the *BU* and *BA* messages with the HA. This operation takes $2 \times T_{GW\text{-}HA}(S_c,H_{GW\text{-}HA})$.

Accordingly, the binding update delay of MIP-PMIP-LTE/SAE is represented as follows:

$$BUD_{MIP-PMIP-LTE/SAE} = 2 \times T_{GW-HA}(S_C, H_{GW-HA}) \quad (4)$$

In MIP-PMIP-LTE/SAE, the binding query delay is 0.

$$BQD_{MIP-PMIP-LTE/SAE} = 0 \quad (5)$$

In data delivery, the data packet is first delivered to the HA, and the HA will forward the data packet to the concerned host. So, the data delivery delay is represented as follows:

$$DDD_{MIP-PMIP-LTE/SAE} = 2 \times T_{GW-HA}(S_d, H_{GW-HA}) \quad (6)$$

So, we obtained the total transmission delay of MIP-PMIP-LTE/SAE as $TTD_{MIP\text{-}PMIP\text{-}LTE/SAE} = BUD_{MIP\text{-}PMIP\text{-}LTE/SAE} + BQD_{MIP\text{-}PMIP\text{-}LTE/SAE} + DDD_{MIP\text{-}PMIP\text{-}LTE/SAE}$.

### 3.3.2 HIP-PMIP-LTE/SAE

The binding update operations of HIP-PMIP-LTE/SAE are done as follows. The S-GW performs the proxy binding operation with the P-GW. After that, the P-GW performs the update operation with the RVS by exchanging the *HIP Update* and *HIP Update Ack* messages. This operation takes $2 \times T_{GW\text{-}RVS}(S_c,H_{GW\text{-}RVS})$.

Accordingly, the binding update delay of HIP-PMIP-LTE/SAE is represented as follows:

$$BUD_{HIP-PMIP-LTE/SAE} = 2 \times T_{GW-RVS}(S_C, H_{GW-RVS}) \quad (7)$$

In HIP-PMIP-LTE/SAE, the binding query delay from a CN to the P-GW can be calculated as follows. First, the CN will send an *I1* message to the RVS to find the LOC of the MN. Then, the RVS looks up the LOC of the MN in its database. Then, the RVS will forward the *I1* message to the P-GW of the MN. After that, the CN and P-GW exchange the subsequent *R1, I2,* and *R2* messages. This operations take $4T_{CN\text{-}GW}(S_c,H_{CN\text{-}GW}) + 2T_{GW\text{-}RVS}(S_c,H_{GW\text{-}RVS}) + 3T_{GW\text{-}GW}(S_c,H_{GW\text{-}GW})$.

Thus, the binding query delay can be represented as follows:

$$BQD_{HIP-PMIP-LTE/SAE} = 4 \times T_{CN-GW}(S_c, H_{CN-GW}) + 3 \times T_{GW-GW}(S_c, H_{GW-GW}) + 2 \times T_{GW-RVS}(S_c, H_{GW-RVS}) \quad (8)$$

In data delivery, the data packet is first delivered to the GW, and the GW will forward the data packet to the P-GW of the MN, and the P-GW will forward it to the concerned host. So, the data delivery delay of HIP-PMIP-LTE/SAE is obtained as follows:

$$DDD_{HIP-PMIP-LTE/SAE} = T_{CN-GW}(S_d, H_{CN-GW}) + T_{GW-GW}(S_d, H_{GW-GW}) \quad (9)$$

So, we obtained the total transmission delay of HIP-PMIP-LTE/SAE as $TTD_{HIP\text{-}PMIP\text{-}LTE/SAE} = BUD_{HIP\text{-}PMIP\text{-}LTE/SAE} + BQD_{HIP\text{-}PMIP\text{-}LTE/SAE} + DDD_{HIP\text{-}PMIP\text{-}LTE/SAE}$.

### 3.3.3 LISP-PMIP-LTE/SAE

In LISP-PMIP-LTE/SAE, the S-GW will perform the proxy binding operation with the P-GW. After that, the P-GW will perform the LISP Map Register operation with the MS by exchanging the *Map Register* and *Map Notify* messages, and MS will update its database. This operation takes $2 \times T_{GW\text{-}MS}(S_c,H_{GW\text{-}MS})$. Accordingly, the binding update delay of LISP-PMIP-LTE/SAE can be represented as follows:

$$BUD_{LISP-PMIP-LTE/SAE} = 2 \times T_{GW-MS}(S_c, H_{GW-MS}) \quad (10)$$

In LISP-PMIP-LTE/SAE, the binding query delay from the CN to the MN can be calculated as follows. First, the CN will send a data packet directly to its GW with the LISP TR. The GW/TR will send the *Map Request* to the MS. The MS will look for the routing locator of the MN from its database. Then, the MS will respond with a *Map Reply* message to the GW of the CN. Thus, the binding query delay can be represented as follows:

$$BQD_{LISP-PMIP-LTE/SAE} = 2 \times T_{GW-MS}(S_c, H_{GW-MS}) \quad (11)$$

In data delivery, the data packet is first delivered to the GW, and the GW will forward the data packet to the P-GW of the MN, and the P-GW will forward to the concerned host. So, the data delivery delay of LISP-PMIP-LTE/SAE is calculated as follows:

$$DDD_{LISP-PMIP-LTE/SAE} = T_{CN-GW}(S_d, H_{CN-GW}) + T_{GW-GW}(S_d, H_{GW-GW}) \quad (12)$$

So, we obtained the total transmission delay of LISP-PMIP-LTE/SAE as $TTD_{LISP\text{-}PMIP\text{-}LTE/SAE} = BUD_{LISP\text{-}PMIP\text{-}LTE/SAE} + BQD_{LISP\text{-}PMIP\text{-}LTE/SAE} + DDD_{LISP\text{-}PMIP\text{-}LTE/SAE}$.

# 4. Comparison with Numerical Results

Based on the analytical equations for traffic overhead and total transmission delay given so far, we will now compare the performance of the candidate schemes. For numerical analysis, we configured the default parameter values, as described in Table 3, by referring to [16].

**Table 3.** Default parameters values

| Parameter | Default | Minimum | Maximum |
|---|---|---|---|
| $H_{GW-HA/RVS/MS}$ | 20 | 1 | 55 |
| $T_q$ | 5 | 1 | 10 |
| $N_{GW}$ | 100 | 10 | 300 |
| $N_{Host}$ | 500 | 1 | 1000 |
| $N_{AR}$ | 30 | 1 | 100 |
| $S_c$ | 50 | 10 | 100 |
| $S_d$ | 1024 | 100 | 1500 |
| $L_w$ | 2 | 1 | 10 |
| $B_w$ | 100 Mbps | | |
| $H_{GW-GW}$ | $\sqrt{N_{GW}}$ | | |
| $H_{CN-GW}$ | 1 | | |

## 4.1 Traffic Overhead

Figs. 9 and 10 compare the number of control/data messages to be processed by MS/RVS/HA for a different number of hosts and gateways. It has been noted that the performances of the LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE are almost the same, since both schemes perform the similar binding update and query operations with the MS of LISP or the RVS of HIP. In Figs. 9 and 10, we can see that LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE provide smaller traffic overhead than MIP-PMIP-LTE/SAE. This is because in MIP-PMIP-LTE/SAE all control and data messages shall be processed by the HA, whereas, only the control traffics are processed by the MS or the RVS in LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE. The gaps of performances between MIP-PMIP-LTE/SAE and LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE schemes get larger, as the number of hosts and gateways increases.

Figs. 11 and 12 show the impacts of the control/data messages ($S_c/S_d$) to be processed by MS/RVS/HA. We can see in Fig. 11 that the traffic overhead linearly increases as $S_c$ gets larger. It is shown that the LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE schemes give better performance than MIP-PMIP-LTE/SAE. This is because in MIP-PMIP-LTE/SAE all the control and data packets are processed by the HA. In Fig. 12, we can see that the two schemes (LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE) are not affected by $S_d$ because the RVS and MS will process only the control packets for the binding update and query operations. In the meantime, MIP-PMIP-LTE/SAE is significantly affected by $S_d$ because the HA processes all the control and data packets.

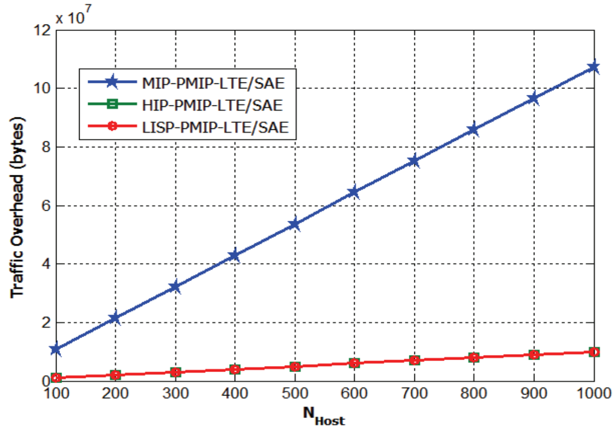


**Fig. 9.** Impact of $N_{Host}$ on traffic overhead.

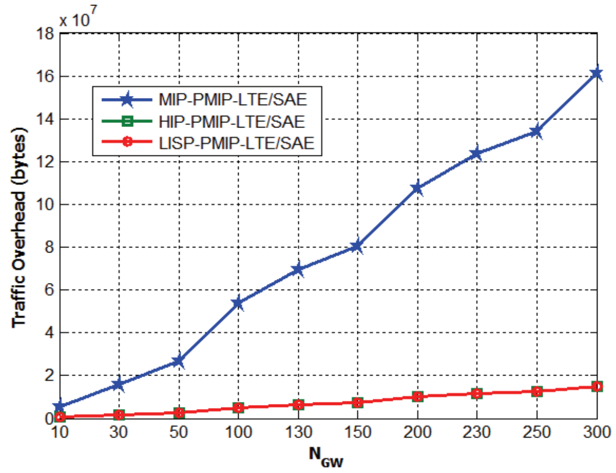


**Fig. 10.** Impact of $N_{GW}$ on traffic overhead.

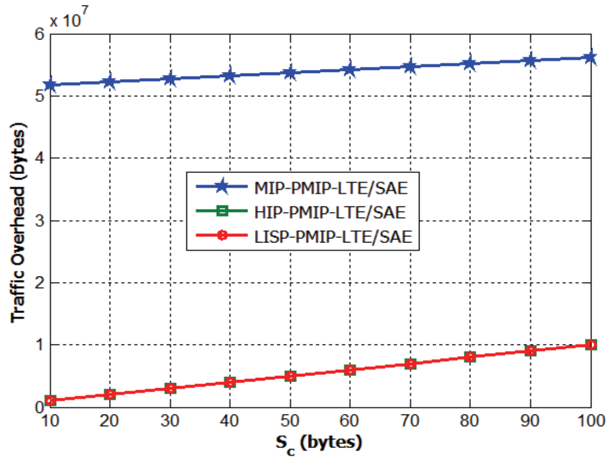


**Fig. 11.** Impact of $S_c$ on traffic overhead.

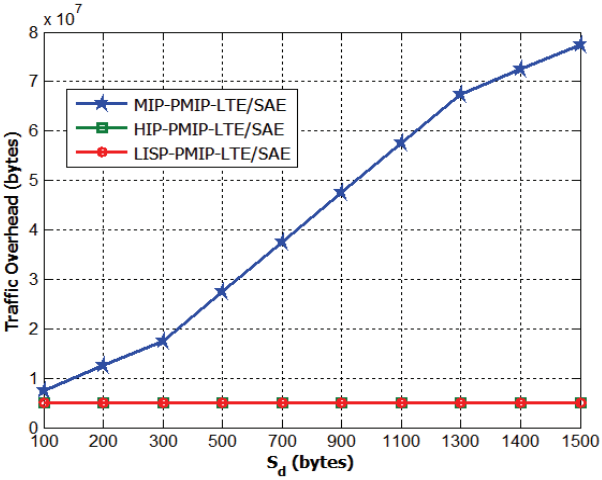


**Fig. 12.** Impact of $S_d$ on traffic overhead.

## 4.2 Total Transmission Delay

Fig. 13 shows the impact of hop counts between the gateway and HA/RVS/MS ($H_{GW\text{-}HA/RVS/MS}$) on total transmission delay. From Fig. 13, we can see that TTD linearly increases as $H_{GW\text{-}HA/RVS/MS}$ gets larger for all the candidate schemes. It is shown that the LISP-PMIP-LTE/SAE scheme provides better performance than MIP-PMIP-LTE/SAE. This is because the binding and query operations are performed between the gateway and MS/RVS, whereas, the data delivery is done through the optimized route. MIP-PMIP-LTE/SAE gives the worst performance, because the hop counts between the gateway and HA is used for both the control and data packets. LISP-PMIP-LTE/SAE provides better performance than HIP-PMIP-LTE/SAE, because in HIP-PMIP-LTE/SAE the *I1* message is forwarded by the RVS to the gateway of the MN, whereas, in LISP-PMIP-LTE/SAE the map request operation is performed between the MS and the GW of the CN.

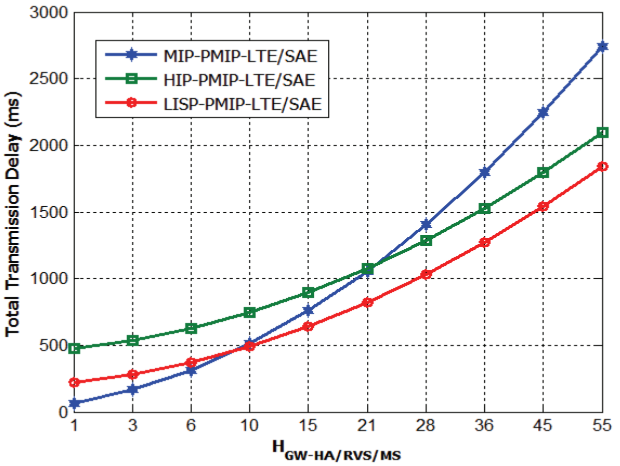


**Fig. 13.** Impact of $H_{GW\text{-}HA/RVS/MS}$ on total transmission delay.

Figs. 14 and 15 compare the TTDs for different average queuing delays ($T_q$) at each node and the wired link delay ($L_w$). It is shown in Figs. 14 and 15 that the TTD linearly increases as $T_q$ and $L_w$ get larger at each node for all candidate schemes. But, HIP-PMIP-LTE/SAE gives the worst performance. This is because HIP-PMIP-LTE/SAE performs the 4-way handshaking operations before data delivery. On the other hand, it is shown in Figs. 14 and 15 that LISP-PMIP-LTE/SAE performs better when $T_q$ and $L_w$ increases.

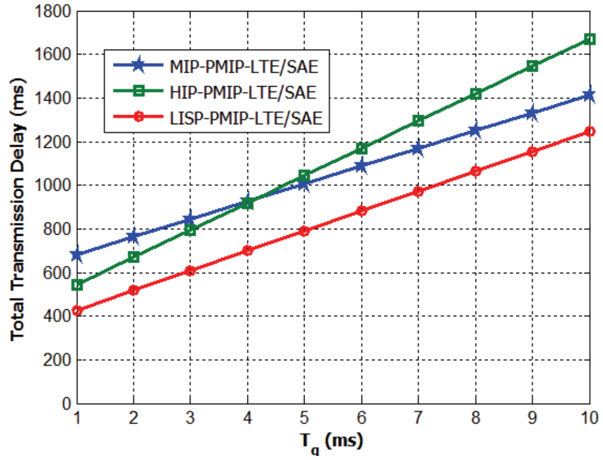


**Fig. 14.** Impact of $T_q$ on total transmission delay.

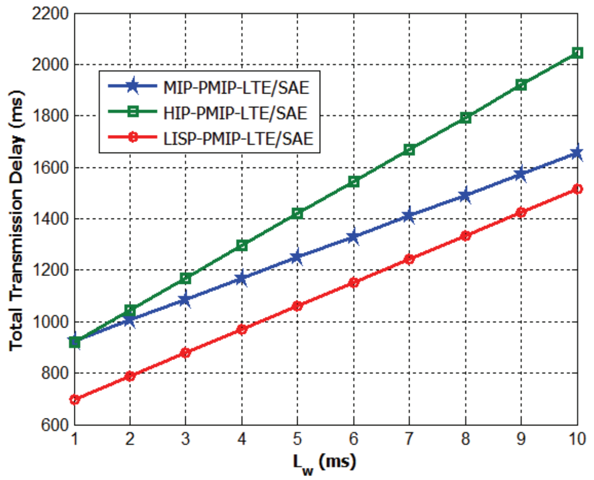


**Fig. 15.** Impact of $L_w$ on total transmission delay.

Fig. 16 shows the impact of the number of GWs on TTD. From Fig. 16, we can see that there is a significant impact of $N_{GW}$ on the total transmission delay of LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE. This is because both schemes use the optimal routes for data delivery. On the other hand, LISP-PMIP-LTE/SAE gives the best performance among the candidate schemes. HIP-PMIP-LTE/SAE performs the worst. This is because the HIP 4-way handshaking operations for a session setup tend to require a large binding query delay.

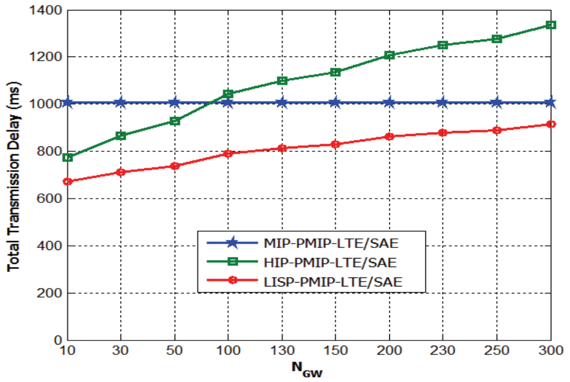


**Fig. 16.** Impact of $N_{GW}$ on total transmission delay.

Figs. 17 and 18 compare the TTDs for different size of control and data packets ($S_c$ and $S_d$). It is shown in Fig. 17 that the TTD linearly increases, as $S_c$ gets larger for all candidate schemes. But, HIP-PMIP-LTE/SAE gives the worst performance. On the other hand, the LISP-PMIP-LTE/SAE scheme performs the best. In Fig. 18, the TTD linearly increases as $S_d$ gets larger for all candidate schemes, whereas, MIP-PMIP-LTE/SAE performs the worst. This is because the data delivery of MIP-PMIP-LTE/SAE is done by way of the HA, whereas, LISP-PMIP-LTE/SAE and HIP-LTE/SAE use the optimal path for data delivery.

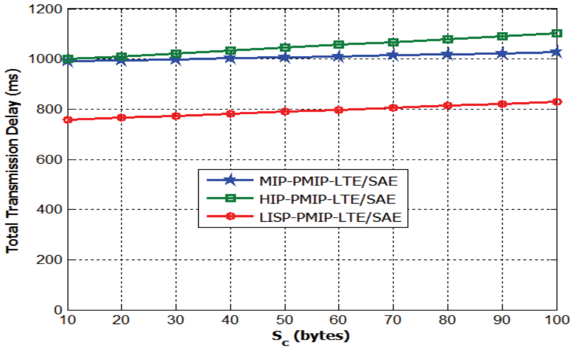


**Fig. 17.** Impact of $S_c$ on total transmission delay.

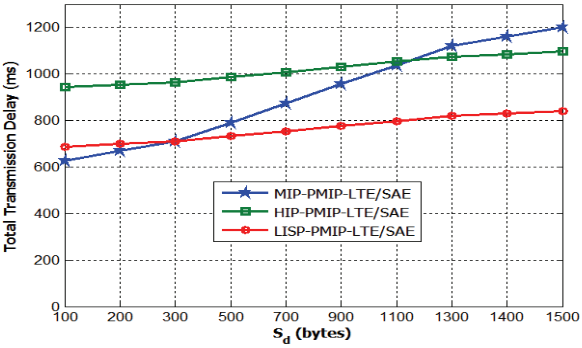


**Fig. 18.** Impact of $S_d$ on total transmission delay.

## 5. Conclusions

In this paper, we have discussed how to provide inter-domain mobility management in PMIP-based LTE/SAE mobile networks. For this purpose, in this paper, we investigated and compared the three candidate schemes for PMIP-based inter-domain mobility management: MIP-PMIP-LTE/SAE, HIP-PMIP-LTE/SAE and LISP-PMIP-LTE/SAE. By performance analysis, the three candidate schemes are compared in terms of TTD and TO. From numerical results, we can see that LISP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE can provide better performance than MIP-PMIP-LTE/SAE in the viewpoint of traffic overhead. However, from the perspective of TTD, LISP-PMIP-LTE/SAE is preferred to MIP-PMIP-LTE/SAE and HIP-PMIP-LTE/SAE.

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