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A distributed mobility control scheme in LISP networks

Moneeb Gohar · Seok-Joo Koh

Abstract The locator identifier separation protocol (LISP) has been made as an identifier-locator separation scheme for scalable Internet routing. However, the LISP was originally designed for fixed network environment, rather than for mobile network environment. In particular, the existing LISP mobility control schemes use a centralized map server to process all the control traffics, and thus they are intrinsically subject to some limitations in mobile environment, such as large overhead of mapping control traffics at central map server and degradation of handover performance. To overcome these problems, we propose a distributed mobility control scheme in LISP networks. In the proposed scheme, we assume that a mobile host has a hierarchical endpoint identifier which contains the information of its home network domain. Each domain has a distributed map server (DMS) for distributed mapping management of Endpoint Identifiers (EIDs) and Locators (LOCs). For roaming support, each DMS maintains a home EID register and a visiting EID register which are used to keep the EID-LOC mappings for mobile hosts in the distributed manner. For performance analysis, we compare the control traffic overhead (CTO) at map servers, the signaling delay required for EID-LOC mapping management, and the handover delay for the existing and proposed schemes. From numerical results, it is shown that the proposed distributed scheme can give better performance than the existing centralized schemes in terms of CTO, total signaling delay for EID-LOC mapping management, and handover delay.

Keywords LISP · Mobile networks · Mobility · Distributed control · Mapping management · Handover

1 Introduction

With a wide popularity of smart phones, the number of mobile Internet users has been rapidly increasing [1–3]. Mobility management is one of the primary functions in wireless cellular systems [4]. Most of the current Internet mobility schemes are based on a centralized anchor, as shown in the Home Agent of Mobile IP (MIP) [5], the Mobility Anchor Point of Hierarchical MIP [6], and the Local Mobility Anchor of Proxy MIP [7].

The locator identifier separation protocol (LISP) has been proposed to address the routing scalability problem in IETF [8–10], which splits the current IP address space into endpoint identifier (EID) and routing locator (RLOC). The Ingress/Egress Tunnel Routers (ITRs/ETRs) maintain the EID-RLOC mappings.

To address the LISP mobility control issue, host-based schemes were proposed [11–13], in which a mobile node implements the LISP-Tunnel Router (LISP-TR) functionality to maintain EID-RLOC mapping. In addition, the work in [14] has proposed a network-based scheme, in which a border router of domain implements the LISP-TR functionality. We note that all of the existing LISP mobility schemes are based on a central map server (MS) to process all control traffics for EID-RLOC mapping management and handover control. Accordingly, such a centralized scheme tends to induce large control traffic overhead (CTO) at a central MS as well as large handover delay,

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since all control messages shall be processed by a central MS.

In this paper, we propose a distributed mobility control scheme in mobile LISP networks. In the proposed scheme, we assume that a mobile node has a globally unique and hierarchical EID which contains the information of its home network domain. Each network domain has a distributed map server (DMS) for distributed mapping management of EIDs and LOCs. For roaming support, each DMS maintains its own home EID register and visiting EID register which are used to keep the EID-LOC mappings for mobile nodes in the distributed manner. The proposed scheme can be used to effectively support the mobility in mobile LISP networks, compared to the existing centralized schemes.

The rest of this paper is organized as follows. In Sect. 2, we review the existing centralized schemes for LISP mobility control. In Sect. 3, we describe the proposed distributed mobility control scheme. Section 4 analyzes and compares the existing and proposed schemes in terms of CTO, signaling delay for EID-LOC mapping management, and handover delay. Section 5 concludes this paper.

2 Related works

To describe the existing LISP mobility schemes, we consider a generalized network model for LISP mobility control, as shown in Fig. 1. In the figure, LISP networks are divided into a global Internet domain and many mobile domains. A central map server (MS) is employed in the global domain, and each mobile domain is connected to the global domain through a gateway (GW). For description, we assume that a correspondent node (CN) is connected to an access router (AR) in the mobile domain, and a mobile node (MN) is initially attached to an AR (denoted by ARold in Fig. 1) in another mobile domain. By handover, MN will move into another AR (denoted by new access router (ARnew) in Fig. 1).

2.1 LISP-MN

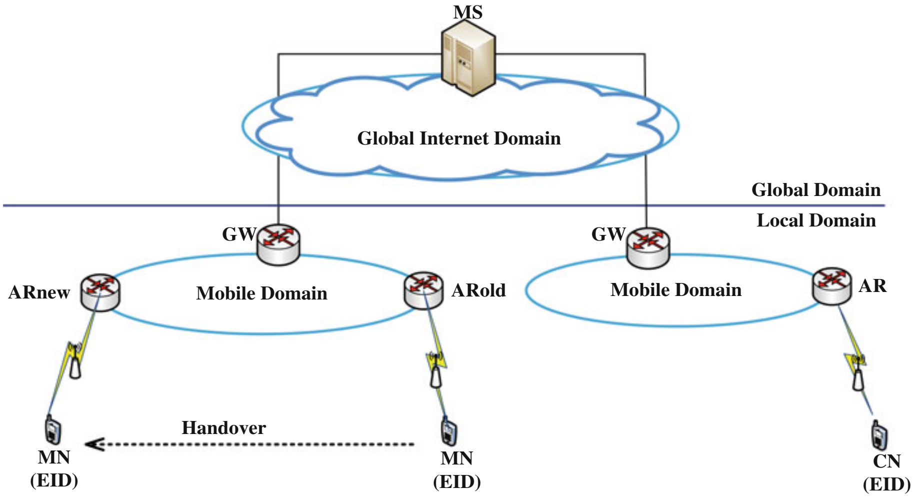
To support LISP mobility, the LISP-MN architecture [11, 12] was proposed, in which MN implements a lightweight Tunnel Router (TR) functionality and thus it acts as an ingress/egress TR in mobile network. In this architecture, a central MS is used to process all control traffics for mobility control, and MN will maintain the EID-LOC map caches and directly communicate with MS.

In LISP-MN, the EID-LOC mapping management and handover operations are illustrated in Fig. 2. In the figure we assume that MN and CN were originally subscribed to the same mobile domain, and MN is now in another mobile domain by roaming and further moves to a ARnew region by handover.

When MN is connected to an AR in a new mobile domain, it configures its RLOC. Then, MN will send a *Map Register* message to the MS for EID-RLOC binding update (Step 1). This MS will register the EID-RLOC mapping cache for MN and respond with a *Map Notify* [15] message to MN (Step 2).

For data delivery, a CN sends a data packet to MN. CN will first send a *Map Request* to MS (Step 3). By referring to the EID-RLOC database, MS forwards the *Map Request* to MN (Step 4). MN then responds with a *Map Reply* message directly to CN (Step 5). Now, CN can send the data packets directly to MN. For data packet delivery, CN and MN will encapsulate an original data packet destined to their EIDs with an outer IP header destined to their RLOCs, since the LISP-TR functionality is implemented within the host in the LISP-MN architecture. On reception of an encapsulated data packet, CN and MN will

Fig. 1 Network model for centralized mobility control in LISP networks



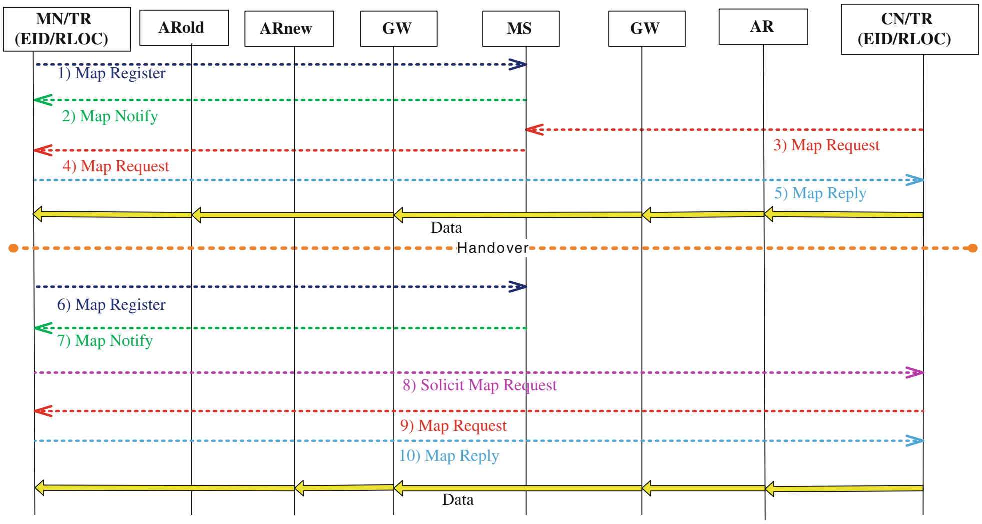


Fig. 2 EID-LOC mapping management and handover operations in LISP-MN

de-capsulate the encapsulated data packet so as to get the original data packet.

Now, we consider a handover event in which MN moves from ARold to ARnew during data transmission with CN. By handover, MN shall configure its new RLOC using an IP address configuration scheme. Then, *Map Register* and *Map Notify* messages are exchanged between MN and MS for EID-RLOC binding update (Step 6 and 7). After that, MN sends a *Solicit Map Request* message to CN so as to update the mapping information (Step 8). After receiving the *Solicit Map Request* message, CN sends a *Map Request* message to MN so as to get the updated mapping information (Step 9). Then, MN responds with a *Map Reply* message to CN (Step 10). Finally, the data packet can be exchanged between CN and MN.

2.2 LISP-MN-GLAB

It is noted that LISP-MN depends on a central MS for mapping control operations, which may incur significant overhead of control messages at MS. To deal with this problem, the work in [13] proposed an enhanced scheme of LISP-MN, which is denoted by LISP-MN-GLAB in this paper. The main idea of LISP-MN-GLAB is the use of Local Map Server (LMS) at the gateway of mobile network so as to provide a localized mobility control.

The mapping management and handover operations of LISP-MN-GLAB are described in Fig. 3. In the figure, a global MS is used for inter-domain communication, and LMS is employed to support intra-domain communication. LMS may possibly be located with the gateway (GW) of

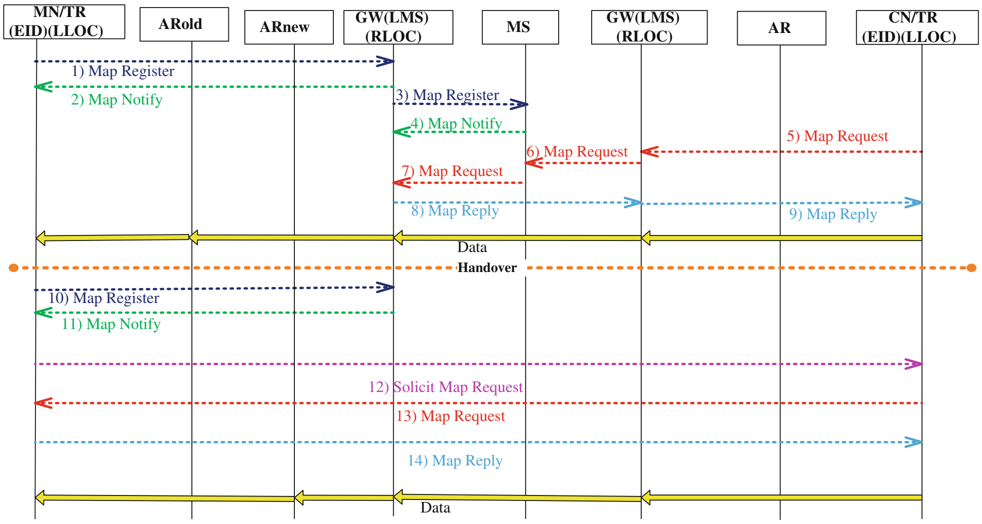


Fig. 3 EID-LOC mapping management and handover operations in LISP-MN-GLAB

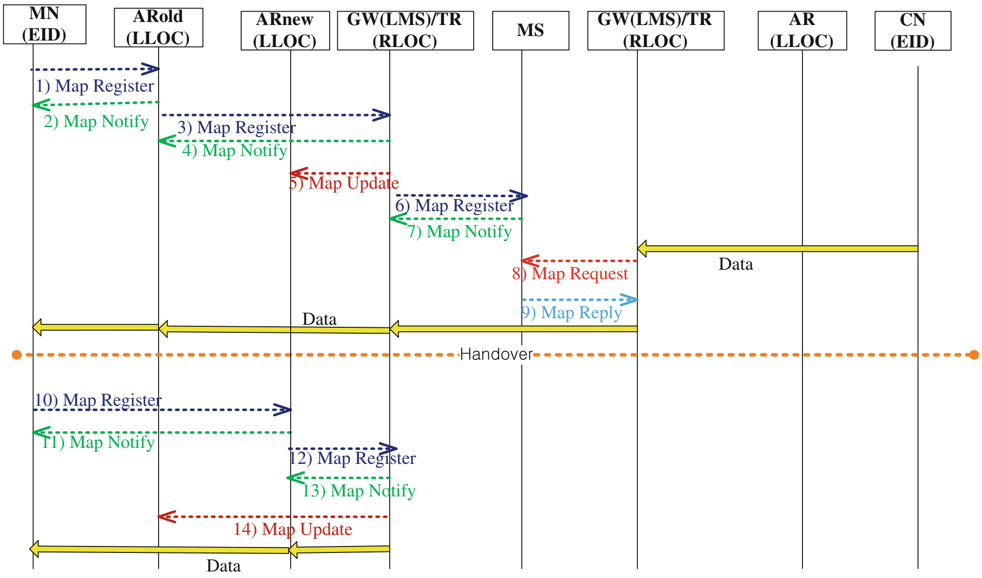
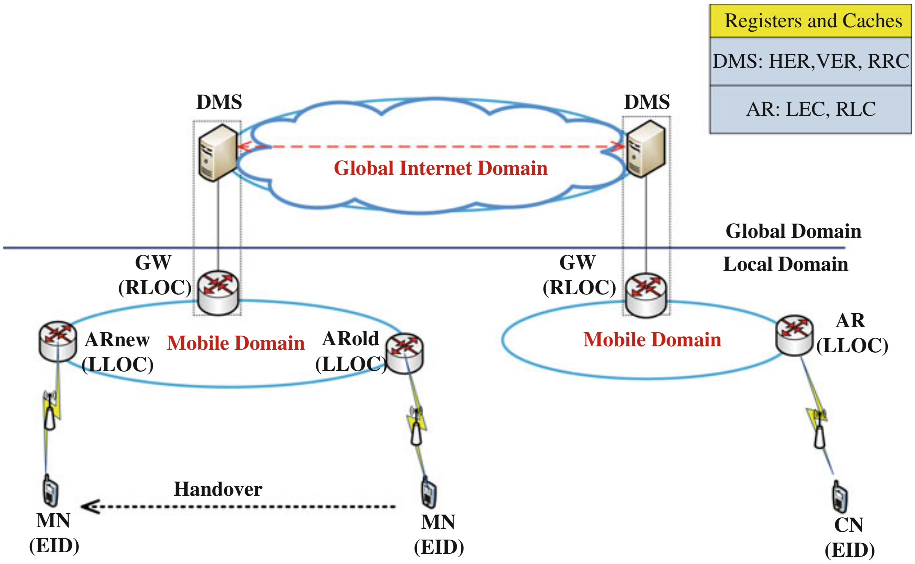


Fig. 4 EID-LOC mapping management and handover operations in LISP-SMOS

Fig. 5 Network model for LISP-DMC



the mobile domain. A gateway has its own RLOC and each MN uses its Local LOC (LLOC) which will be configured with a dynamic IP address configuration scheme. This LLOC is used only within the local domain.

In the figure, when MN is connected to an AR, it configures its LLOC. Then, MN will send a *Map Register* message to LMS for EID-LLOC binding update (Step 1). Then, LMS will register the EID-LLOC mapping for MN and respond with a *Map Notify* message to MN (Step 2). In addition, LMS also exchanges the *Map Register* and *Map Notify* messages with the global MS, so as to register the mapping between EID of MN and RLOC of LMS (Step 3 and 4).

In the data delivery operations, CN sends a data packet to MN. CN will first send a *Map Request* message to LMS/GW so as to find the LLOC of MN (Step 5). If there is no information, LMS sends a *Map Request* message to the global MS to find the RLOC of MN (Step 6). MS now forwards the *Map Request* message to LMS of MN (Step 7). Then, LMS of MN will directly respond to LMS of CN with a *Map Reply* message after looking up its database (Step 8). In turn, LMS will respond to CN with a Map Reply message (Step 9). Now, CN can send the data packet directly to MN. In the data delivery process, the EID-LLOC encapsulation and decapsulation operations are done at MN and CN, whereas the

Table 1 Comparison of the centralized and distributed mobility control schemes

Schemes	Approach	Mapping architecture	Mapping server
LISP-MN	Host-based	Centralized	MS
LISP-MN-GLAB	Host-based	Centralized	LMS, MS
LISP-SMOS	Network-based	Centralized	LMS, MS
LISP-DMC	Network-based	Distributed	DMS

EID-RLOC encapsulation and decapsulation operations will be done at LMS/GW.

For handover of MN from ARold to ARnew, MN shall configure its new LLOC address. Then, *Map Register* and *Map Notify* messages are exchanged between MN and LMS for binding update (Step 10 and 11). After that, MN sends a *Solicit Map Request* message to CN (Step 12). After receiving the *Solicit Map Request* message, CN will send a *Map Request* message to MN so as to get the updated binding information (Step 13). Then, MN will send a *Map Reply* message to CN with the updated mapping information (Step 14). Finally, the data packet is forwarded from CN to MN.

2.3 LISP-SMOS

On the other hand, the work in [14] proposed the seamless mobility support (SMOS) scheme in LISP networks, which is denoted by LISP-SMOS in this paper. The main feature of LISP-SMOS is that the EID of MN represents a 128-bit identifier such as host identity protocol [16]. Each host uses an IP address of AR as its Local LOC (LLOC) for network-based mobility control. The border router (BR) of a domain implements the LISP-TR functionality and has LMS to maintain the EID-LLOC mapping information for MNs in the domain.

The EID-LOC mapping management and handover operations of LISP-SMOS are shown in Fig. 4. When MN is connected to a ARnew, it sends a *Map Register* message to the AR (Step 1). Then, the AR responds with a *Map Notify* message with LLOC (e.g., IP address of AR) to MN (Step 2). In turn, the AR sends a *Map Register* message with the EID-LLOC mapping of MN to the gateway (Step 3). Gateway will respond to the AR with a *Map Notify* message (Step 4). Gateway will update the mapping of EID-LLOC for MN in its LMS. After that, the gateway announces the new mapping information of MN by broadcasting a newly defined *Map Update* message to all ARs in the domain (Step 5). In addition, the gateway sends a *Map Register* message to MS, and then MS responds to the gateway with a *Map Notify* message (Step 6, 7).

For data delivery, CN sends a data packet, and the data packet will be delivered to the gateway. Then, the gateway finds the LLOC of MN by looking up its LMS. If MN is not located in the same domain, then the gateway sends a *Map Request* message to MS so as to find the RLOC of MN (Step 8). After that, MS will respond with a *Map Reply* message to the gateway (Step 9). Then, the gateway will forward the data packet to the gateway of MN, and finally the data packet is forwarded to MN. In the data delivery process, the original data packets will be encapsulated and de-capsulated at the LMS/GW in LISP-SMOS.

When MN moves from ARold to ARnew by handover, the *Map Register* and *Map Notify* messages are exchanged between MN and ARnew (Step 10 and 11) and also between ARnew and the gateway so as to update the modified LLOC information (Step 12 and 13). After that, the gateway will broadcast the *Map Update* message to all ARs in the domain (Step 14). Now, CN can deliver the data packets to MN through the gateway.

3 Proposed distributed mobility control scheme

In this section, we describe the proposed distributed mobility control scheme, named LISP-DMC.

3.1 Overview

The proposed LISP-DMC model is shown in Fig. 5. In the figure, we assume that MN is in the visiting domain by roaming, and it moves to a ARnew by handover.

In the LISP-DMC scheme, it is assumed that a host is uniquely identified by a hierarchical 128-bit EID structure which contains the information of the home domain that the host was subscribed to. In particular, an EID is required to contain the information of domain, such as 2-byte Autonomous System (AS) number. Note that this hierarchical EID format has also been discussed in [17].

Fig. 6 EID-LOC binding operations in LISP-DMC

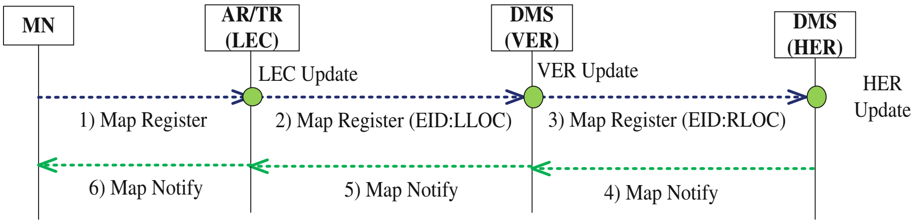


Table 2 Local EID Cache (LEC)

No.	EID	Link information	Type
1	EID1	…	Home
2	EID2	…	Visiting
3	EID3	…	…

Table 3 Visiting EID Register (VER)

No.	EID	LLOC (in visited domain)	Home DMS
1	EID1	LLOC1	RLOC1 (DMS of EID1)
2	EID2	LLOC2	RLOC2 (DMS of EID2)
3	…	…	

Table 4 Home EID register (HER)

No.	EID	LOC	Domain
1	EID1	IP address of AR (LLOC)	Home
2	EID2	IP address of DMS (RLOC)	Visiting
3	…	…	…

As for locators, the location of MN is identified by local LOC (LLOC) and global RLOC. LLOC represents the IP address of AR and it is used as locator within a domain, whereas RLOC represents the IP address of DMS/gateway and it is used for inter-domain communication. Note that MN does not maintain its LLOC or RLOC information, since the EID-LOC mapping information for MN is managed by AR (for EID-LLOC) and DMS/gateway (for EID-RLOC).

In the figure, each AR implements the tunnel router (TR) functionality and maintains a Local EID Cache (LEC) which contains the list of EIDs for the locally attached hosts. Each AR shall also maintain a Remote LLOC Cache (RLC), which contains the mappings of EID-LLOC for the remote hosts. Each gateway (GW) of the domain has a DMS which keeps Home EID Register (HER) and Visiting EID Register (VER). HER keeps track of the EID-LOC mapping information for the hosts, and VER maintains the list of EID-LLOC mapping information for the visited hosts. Each DMS shall also maintain its Remote RLOC Cache (RRC), which contains the mapping of EID-RLOC for the remote hosts.

Before going into further description of the proposed LISP-DMC scheme, let us compare the proposed and existing schemes in the architectural perspective, as described in Table 1.

In the viewpoint of mobility control approach, LISP-MN and LISP-MN-GLAB are host-based schemes, in which MN configures its LLOC and performs the mobility control operations. LISP-SMOS and LISP-DMC are network-based schemes, in which the IP address of AR (not MN) is used as LLOC and the mobility control operations are performed by the ARs and the gateway.

In the mapping architecture, all of the existing schemes can be regarded as a centralized approach, in which all control traffics are processed by a global MS. The proposed LISP-DMC is a distributed approach, in which the control traffics are processed at a distributed DMS, not at a global MS.

In terms of mapping server, LISP-MN-GLAB and LISP-SMOS uses the two types of servers: LMS and MS. In this respect, these two schemes can be viewed as hierarchical approach. On the other hand, LISP-MN and LISP-DMC use only the DMS.

3.2 Mapping management procedures

3.2.1 EID-LOC binding

In the proposed scheme, the EID-LOC binding operations are performed, as shown in Fig. 6.

In the figure, MN sends a *Map Register* message to the connected AR (Step 1). Then, the AR updates its local EID Cache (LEC) which contains the list of EIDs for all of the attached hosts. An example format of LEC is given in Table 2. In the table, the 'Link Information' field may include the link-layer information. In addition, the 'Type'

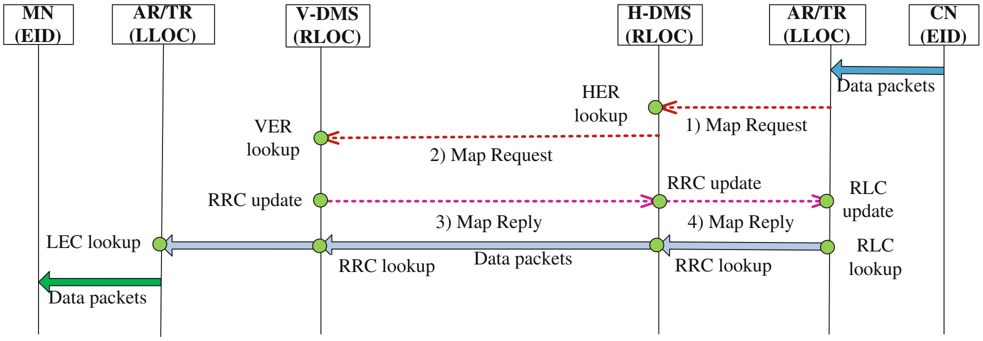


Fig. 7 Map request and data delivery operations in LISP-DMC

field indicates whether MN is now in the *home* or *visiting* domain. The local EID cache information will be referred to by the AR to deliver the data packets to the local hosts in the data delivery operation.

Next, the AR will check whether the EID belongs to its domain (non-roaming case) or not (roaming case). Note that an AR can determine this, based on the EID, since an EID contains the information of the home domain of MN. Then, the AR will send a *Map Register* message to the *visited* DMS in the domain (Step 2). On reception of this message, the *visited* DMS will update its visiting EID register (VER) which maintains the list of EID-LLOC mappings for the visited hosts in the domain. An example format of VER is given in Table 3.

In the roaming case, the *visited* DMS sends a *Map Register* message to the *home* DMS that is located in the home domain of the roaming host (Step 3). The *home* DMS will update its home EID register which maintains the list of EID-RLOC mappings for the visited hosts, as shown in Table 4. The home EID register keeps track of EID-LOC mapping information for hosts. When a host remains in its home domain, the LOC in the table represents the IP address of AR (LLOC) in the home domain. Otherwise, if the host is roaming in the other domain, the LOC indicates the host is roaming in the other domain, and the LOC represents the IP address of DMS (RLOC) that the host is staying at present.

After the home EID register update, the *home* DMS responds with a *Map Notify* message to the *visited* DMS, which will further be delivered to the roaming host (Step 4, 5, 6).

3.2.2 Map request and data delivery

Figure 7 shows the map request and the data delivery operations in the proposed scheme. CN first sends a data packet to its AR. The AR will send a *Map Request* to its *home* DMS (Step 1). By referring to its home EID register, then the home DMS (H-DMS) will forward the *Map Request* to the *visited* DMS (V-DMS) where MN stays at that time (Step 2). Then, V-DMS will respond with a *Map Reply* message to the AR of CN (Step 3, 4). Now, the AR of CN can deliver the data packet to MN via V-DMS. In data packet delivery, the encapsulation/de-capsulation between EID and LLOC will be done by AR, whereas the EID-RLOC encapsulation/de-capsulation is done at DMS/gateway.

After the map request operation, each AR shall maintain its Remote LLOC Cache (RLC), which is shown in Table 5. The RLC contains the mapping of EID-LLOC for the remote hosts that are in active communication with a certain local host.

In the map request operation, each DMS shall maintain its Remote RLOC Cache (RRC), which is shown in Table 6. The RRC contains the mapping of EID-RLOC for the remote hosts that are in active communication with a certain local host, which is referred to by DMS for data forwarding.

Table 5 Remote LLOC Cache (RLC)

No.	EID	LLOC
1	EID1	LLOC1
2	EID2	LLOC2
3	…	…

3.3 Handover control procedures

To support handover, we assume that the proposed scheme uses the link-layer information, which is defined in the IEEE 802.21 [18]. With the help of link-layer triggers, such as Link-Detected (LD) and Link-Up (LU) of the new link, a mobile node can realize that it is moved to a new network while it is staying in the old network. Figure 8 shows the handover operations of LISP-DMC.

By handover, MN sends a *Map Register* message to the ARnew, and ARnew will update its local EID cache for MN (Step 1). Then, ARnew sends a *Map Register* message to the *visited* DMS (step 2). On reception of this message, the *visited* DMS will update its visiting EID register and respond with a *Map Notify* message to ARnew, which will further be delivered to the host (Step 3, 4). The visiting EID register maintains the list of EID-LLOC mapping information for the visited hosts in the domain. Now, V-DMS can deliver the data packet to MN via ARnew.

In the handover process, the data path will be optimized between MN and CN, as also shown in the MIPv6 route optimization [5]. It is also noted that the concepts of 'home DMS' and 'visited DMS' are based on the well-known GSM system [3].

4 Performance analysis

In order to evaluate the performance of the proposed LISP-DMC scheme, we analyze the CTO, the signaling delay for mapping control, and the handover delay for all candidate schemes.

Table 6 Remote RLOC Cache (RRC)

No.	EID	RLOC
1	EID1	RLOC1
2	EID2	RLOC2
3	…	…

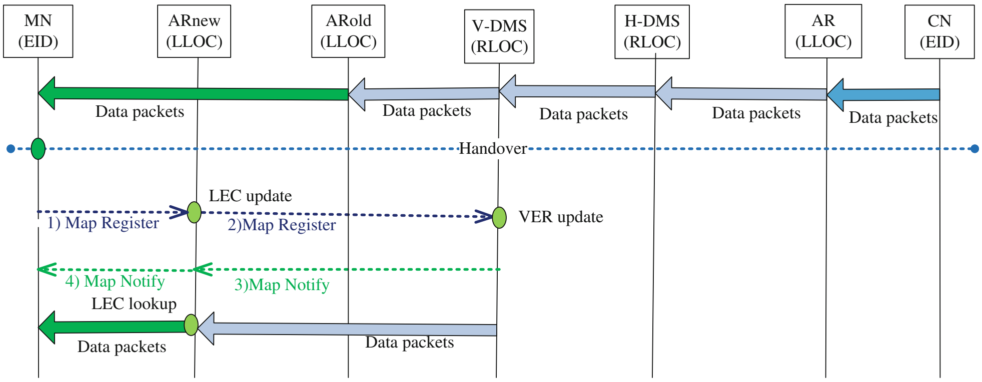
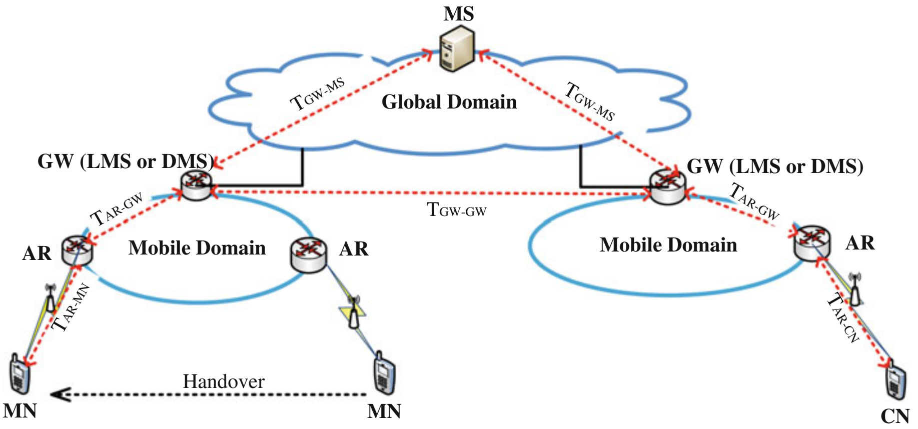


Fig. 8 Handover operations in LISP-DMC

Fig. 9 Network model for analysis



4.1 Analysis model

We consider a network model for analysis, as illustrated in Fig. 9.

For analysis, we use the following notations, as shown in Table 7.

Let $T_{x-y}(S)$ denote the transmission delay of a message with size S sent from 'x' to 'y' via the 'wireless' link. Then, $T_{x-y}(S)$ can be expressed as follows: $T_{x-y}(S_c) = [(S_c/B_{wl}) + L_{wl}]$ for control packets, and $T_{x-y}(S_d) = [(S_d/B_{wl}) + L_{wl}]$ for data packets.

Let $T_{x-y}(S,H_{x-y})$ denote the transmission delay of a message with size S sent from 'x' to 'y' via 'wired' link. H_{x-y} denotes the number of wired hops between node x and node y. Then, $T_{x-y}(S,H_{x-y})$ is expressed as follows: $T_{x-y}(S_c,H_{x-y}) = H_{x-y} \times [(S_c/B_w) + L_w]$ for control packets, and $T_{x-y}(S_d,H_{x-y}) = H_{x-y} \times [(S_d/B_w) + L_w]$ for data packets.

4.2 Analysis of control traffic overhead

To analyze the performance of the candidate schemes, we evaluate the CTO required for mapping management at gateways or map servers.

4.2.1 *LISP-MN*

We define the CTO by the number of mapping control messages to be processed at map server (MS). It is assumed that the hosts are equally distributed in the mobile domain. For mapping update, all hosts in the network will send *Map Register* messages to MS. Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR} \times N_{GW}$ shall be processed by MS. For data transmission, each host sends *Map Request* messages to MS. Thus, the *Map Request* messages of $Sc \times N_{Host/AR} \times N_{AR} \times N_{GW}$ shall be processed by MS.

Accordingly, we get the CTO of LISP-MN as follows.

$$CTO_{LISP-MN} = Sc \times N_{Host/AR} \times N_{AR} \times N_{GW} + Sc \\ \times N_{Host/AR} \times N_{AR} \times N_{GW}.$$

4.2.2 *LISP-MN-GLAB*

In LISP-MN-GLAB, we calculate CTO as the number of mapping control messages to be processed by a gateway and MS. For mapping update, all hosts in the network send *Map Register* messages to a gateway. Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR}$ shall be processed by a gateway. Then, the gateway will also send *Map*

Table 7 Parameters used for cost analysis

Parameters	Description
S_c	Size of control packets (bytes)
S_d	Size of data packets (bytes)
B_w	Wired link bandwidth (Mbps)
B_{wl}	Wireless bandwidth (Mbps)
L_w	Wired link delay (ms)
L_{wl}	Wireless link delay (ms)
$H_{a\text{-}b}$	Hop count between node a and b in the network
T_{AC}	Address configuration delay (ms)
T_{MD}	Movement detection delay (ms)
T_{L2}	Link switching delay (ms)
$N_{Host/AR}$	Number of hosts attached to an AR
N_{AR}	Number of ARs in the domain
N_{GW}	Number of gateways in the domain

Register messages to MS. Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR} \times N_{GW}$ shall be processed by MS. For data transmission, each host sends *Map Request* messages to a gateway. Thus, the *Map Request* messages of $Sc \times N_{Host/AR} \times N_{AR}$ shall be processed by a gateway. If there is no information, then the gateway will send *Map Request* message to MS. Thus, MS will process *Map Request* message of $Sc \times N_{Host/AR} \times N_{AR} \times N_{GW}$. Then, MS will forward the *Map Request* message to the gateway of MN, which will require the *Map Request* message of $Sc \times N_{Host/AR} \times N_{AR}$.

Accordingly, we get the CTO of LISP-MN-GLAB as follows.

$$\begin{aligned} CTO_{LISP-MN-GLAB} &= Sc \times N_{Host/AR} \times N_{AR} + Sc \times N_{Host/AR} \times N_{AR} \\ &\quad \times N_{GW} + Sc \times N_{Host/AR} \times N_{AR} + Sc \times N_{Host/AR} \\ &\quad \times N_{AR} \times N_{GW} + Sc \times N_{Host/AR} \times N_{AR} \end{aligned}$$

4.2.3 LISP-SMOS

In LISP-SMOS, for mapping update, all hosts in the network will send the *Map Register* messages to a gateway. Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR}$ shall be processed by a gateway. Then, the gateway will forward the *Map Register* messages to MS. Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR} \times N_{GW}$ shall be processed by MS. For data transmission, the gateway of CN will send *Map Request* messages to MS, if there is no information of LLOC on gateway. Thus, the *Map Request* message of $Sc \times N_{Host/AR} \times N_{AR} \times N_{GW}$ shall be processed by MS.

Accordingly, we get the CTO of LISP-SMOS as follows.

$$\begin{aligned} CTO_{LISP-SMOS} &= Sc \times N_{Host/AR} \times N_{AR} + Sc \times N_{Host/AR} \\ &\quad \times N_{AR} \times N_{GW} + Sc \times N_{Host/AR} \times N_{AR} \\ &\quad \times N_{GW}. \end{aligned}$$

4.2.4 LISP-DMC

In the proposed LISP-DMC scheme, for mapping update, all hosts in the network will send the *Map Register* messages to an AR and then the AR will send *Map Register* message to a gateway (V-DMS). Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR}$ shall be processed by a gateway (V-DMS). Then, V-DMS will send the *Map Register* message to H-DMS. Thus, the *Map Register* messages of $Sc \times N_{Host/AR} \times N_{AR}$ shall be processed by the gateway of H-DMS. For data transmission, an AR sends *Map Request* messages to gateway (H-DMS). If MN is in roaming, H-DMS will send the *Map Request* message to V-DMS. Thus, the *Map Request* messages of $Sc \times N_{Host/AR} \times N_{AR}$ shall be processed by H-DMS and V-DMS.

Accordingly, we get the CTO of LISP-DMC as follows.

$$\begin{aligned} CTO_{LISP-DMC} &= 2 \times Sc \times N_{Host/AR} \times N_{AR} + 2 \times Sc \\ &\quad \times N_{Host/AR} \times N_{AR}. \end{aligned}$$

4.3 Analysis of signaling delay

The binding update and query delays are denoted by *BUD* and *BQD*, respectively. Then, the total signaling delay (TSD) required for mapping management can be represented as TSD = BUD + BQD.

4.3.1 LISP-MN

In LISP-MN, the binding update operations are performed as follows. When MN enters a new access router region, it configures its RLOC, which takes T_{AC}. After that, MN performs the map register operation with MS by exchanging the *Map Register* and *Notify* messages. This operation takes $2 \times (T_{MN\text{-}AR}(S_c) + T_{AR\text{-}GW}(S_c, H_{AR\text{-}GW}) + T_{GW\text{-}MS}(S_c, H_{GW\text{-}MS}))$.

Accordingly, the binding update delay of LISP-MN can be represented as follows.

$$\begin{aligned}\mathrm{BUD}_{\mathrm{LISP-MN}} &\\ &= \mathrm{T}_{\mathrm{AC}} + 2 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S_c}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{AR-GW}})\\ &\quad + \mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-MS}})).\end{aligned}$$

In LISP-MN, the binding query delay from CN to MN can be calculated as follows. First, CN sends a *Map Request* message to MS so as to find the RLOC of MN. Then, MS forwards the *Map Request* message to MN. After that, MN responds directly to CN with a *Map Reply* message. This takes $2\mathrm{T}_{\mathrm{CN\text{-}AR}}(\mathrm{S_c}) + 2\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{MN\text{-}AR}}) + \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{GW\text{-}GW}}) + 4\mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + 2\mathrm{T}_{\mathrm{GW\text{-}MS}}(\mathrm{S_c},\mathrm{H}_{\mathrm{GW\text{-}MS}})$.

Thus, the binding query delay of LISP-MN can be represented as follows.

$$\begin{aligned}\mathrm{BQD}_{\mathrm{LISP-MN}} &\\ &= 2\mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S_c}) + 2\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{MN-AR}})\\ &\quad + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-GW}}) + 4\mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{AR-GW}})\\ &\quad + 2\mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-MS}}).\end{aligned}$$

So, we obtain the TSD of LISP-MN as $\mathrm{TSD}_{\mathrm{LISP\text{-}MN}} = \mathrm{BUD}_{\mathrm{LISP\text{-}MN}} + \mathrm{BQD}_{\mathrm{LISP\text{-}MN}}$.

4.3.2 LISP-MN-GLAB

The binding update operations of LISP-MN-GLAB are done as follows. When MN is connected to a new access router, it configures an LLOC, which takes roughly T_{AC}. After that, MN performs the map register operation with the gateway by exchanging the *Map Register* and *Map Notify* messages. After that, the gateway performs the map register operation with MS by exchanging the *Map Register* and *Map Notify* messages. This operation takes $2 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S_c}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}MS}}(\mathrm{S_c},\mathrm{H}_{\mathrm{GW\text{-}MS}}))$.

Accordingly, the binding update delay of LISP-MN-GLAB can be represented as follows.

$$\begin{aligned}\mathrm{BUD}_{\mathrm{LISP-MN-GLAB}} &\\ &= \mathrm{T}_{\mathrm{AC}} + 2 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S_c}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{AR-GW}})\\ &\quad + \mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-MS}}))\end{aligned}$$

The binding query delay from CN to MN can be calculated as follows. First, CN sends a *Map Request* message to the gateway to find the LLOC of MN. Then, the gateway will look for the LLOC of MN in its database. If there is no information, then the gateway will forward the *Map Request* message to MS. Then, MS will forward the *Map Request* message to the gateway of MN. After that, the gateway of MN will respond with *Map Reply* message to CN via the gateway of CN and AR. So, the transmission delay of control message is equal to $2\mathrm{T}_{\mathrm{CN\text{-}AR}}(\mathrm{S_c}) + 2\mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + 2\mathrm{T}_{\mathrm{GW\text{-}MS}}(\mathrm{S_c},\mathrm{H}_{\mathrm{GW\text{-}MS}}) + \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{GW\text{-}GW}})$. Then, the data packet will be forwarded directly from CN to MN.

Thus, the binding query delay of LISP-MN-GLAB can be represented as follows.

$$\begin{aligned}\mathrm{BQD}_{\mathrm{LISP-MN-GLAB}} &= 2\mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S_c})\\ &\quad + 2\mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{AR-GW}})\\ &\quad + 2\mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-MS}})\\ &\quad + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-GW}}).\end{aligned}$$

So, we obtain the signaling delay as $\mathrm{TSD}_{\mathrm{LISP\text{-}MN\text{-}GLAB}} = \mathrm{BUD}_{\mathrm{LISP\text{-}MN\text{-}GLAB}} + \mathrm{BQD}_{\mathrm{LISP\text{-}MN\text{-}GLAB}}$.

4.3.3 LISP-SMOS

For binding update, MN sends a *Map Register* message to an AR. Then, the AR responds with a *Map Notify* message to MN. The AR performs the map register operation with the gateway by exchanging the *Map Register* and *Map Notify* messages. After that, the *Map Update* message is broadcast to all ARs in the domain. After that, the gateway performs the map register operation with MS by exchanging the *Map Register* and *Map Notify* messages. This operation takes $2 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S_c}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}MS}}(\mathrm{S_c},\mathrm{H}_{\mathrm{GW\text{-}MS}})) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S_c},\mathrm{H}_{\mathrm{AR\text{-}GW}}) \times \mathrm{N}_{\mathrm{AR}}$.

Accordingly, the binding update delay of LISP-SMOS can be represented as follows.

$$\begin{aligned}\mathrm{BUD}_{\mathrm{LISP-SMOS}} &\\ &= 2 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S_c}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{AR-GW}})\\ &\quad + \mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-MS}})) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{AR-GW}}) \times \mathrm{N}_{\mathrm{AR}}\end{aligned}$$

In LISP-SMOS, the binding query delay can be calculated as follows. First, CN sends a data packet to the gateway. Then, the gateway will look for the LLOC of mobile node in its database. If there is no information, then the gateway will send the *Map Request* to MS. Then, MS responds with a *Map Reply* message to the gateway of CN.

Thus, the binding query delay of LISP-SMOS can be represented as follows.

$$\mathrm{BQD}_{\mathrm{LISP-SMOS}} = 2\mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S_c}, \mathrm{H}_{\mathrm{GW-MS}}).$$

So, we obtain the TSD of LISP-SMOS as $\mathrm{TSD}_{\mathrm{LISP\text{-}SMOS}} = \mathrm{BUD}_{\mathrm{LISP\text{-}SMOS}} + \mathrm{BQD}_{\mathrm{LISP\text{-}SMOS}}$

4.3.4 LISP-DMC

The binding update operation is performed as follows. When a host is attached to the network, the map register operation will be performed by exchanging the *Map Register* and *Map Notify* messages. After that, the AR will also exchange the *Map Register* and *Map Notify* messages with the *visited* DMS. This operation takes

$2 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}))$. The *visited* DMS will also exchange the *Map Register* and *Map Notify* messages with the *home* DMS. This operation takes $2 \times \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{GW\text{-}GW}})$.

Accordingly, the binding update delay of LISP-DMC can be represented as follows.

$$\mathrm{BUD}_{\mathrm{LISP-DMC}} = 2 \times \Big(\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-GW}})\Big)$$

For binding query, a data packet of CN is delivered to AR of CN. Then, AR of CN sends a *Map Request* to H-DMS to find the LLOC of MN. After that, H-DMS of CN forwards the *Map Request* to V-DMS of MN. After that, V-DMS responds to AR of CN via H-DMS with a *Map Reply* message.

Thus, the binding query delay of LISP-DMC can be represented as follows

$$\mathrm{BQD}_{\mathrm{LISP-DMC}} = 2\mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) + 2\mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-GW}}).$$

So, we obtain the TSD of LISP-DMC as $\mathrm{TSD}_{\mathrm{LISP\text{-}DMC}} = \mathrm{BUD}_{\mathrm{LISP\text{-}DMC}} + \mathrm{BQD}_{\mathrm{LISP\text{-}DMC}}$

4.4 Analysis of handover delay

In this section, we analyze the handover delay (HOD) for the existing and proposed schemes.

4.4.1 LISP-MN

In LISP-MN, the link switching and movement detection operations are performed, which take T_{L2} and T_{MD}. After that, MN configures its new RLOC, which takes T_{AC}. Then, MN exchanges the *Map Register* and *Map Notify* messages with MS, which takes $2 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}MS}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{GW\text{-}MS}}))$. After that, MN exchanges the *Solicit Map Request*, *Map Request* and *Map Reply* messages with CN, which takes $3 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{GW\text{-}GW}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{CN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}))$. Then, CN delivers the data packets to MN, which takes $\mathrm{T}_{\mathrm{CN\text{-}AR}}(\mathrm{S}_{\mathrm{d}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{d}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S}_{\mathrm{d}},\mathrm{H}_{\mathrm{GW\text{-}GW}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{d}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{AR\text{-}MN}}(\mathrm{S}_{\mathrm{d}})$.

Then, we can derive the handover delay of LISP-MN as follows.

$$\begin{aligned}
\mathrm{HOD}_{\mathrm{LISP-MN}} = {} & \mathrm{T}_{\mathrm{L2}} + \mathrm{T}_{\mathrm{MD}} + \mathrm{T}_{\mathrm{AC}} + 2 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) \\
& + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) + \mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-MS}})) \\
& + 3 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) + \mathrm{T}_{\mathrm{GW-GW}} \\
& (\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-GW}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{c}})) \\
& + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{d}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{GW-GW}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{AR-MN}}(\mathrm{S}_{\mathrm{d}}) = \mathrm{T}_{\mathrm{L2}} + \mathrm{T}_{\mathrm{MD}} + \mathrm{T}_{\mathrm{AC}} + 2 \\
& \times \big(\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{GW-MS}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-MS}})) + 3 \times \big(\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) \\
& + 2\mathrm{T}_{\mathrm{AR-GW}}\big(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}\big) + \mathrm{T}_{\mathrm{GW-GW}}\big(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-GW}}\big) \\
& + \mathrm{T}_{\mathrm{CN-AR}}\big(\mathrm{S}_{\mathrm{c}}\big)) + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{d}}) \\
& + 2\mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{AR-GW}}) + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{GW-GW}}) \\
& + \mathrm{T}_{\mathrm{AR-MN}}(\mathrm{S}_{\mathrm{d}}).
\end{aligned}$$

4.4.2 LISP-MN-GLAB

In LISP-MN-GLAB, the link switching and movement detection operations are performed, which takes T_{L2} and T_{MD}. After that, MN configures its new LLOC, which takes T_{AC}. Then, MN will exchange the *Map Register* and *Map Notify* messages with LMS, which takes $2 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}))$. After that, MN exchanges the *Solicit Map Request*, *Map Request* and *Map Reply* messages with CN, which takes $3 \times (\mathrm{T}_{\mathrm{MN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{GW\text{-}GW}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{c}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{CN\text{-}AR}}(\mathrm{S}_{\mathrm{c}}))$. Then, CN delivers the data packet to MN, which takes $\mathrm{T}_{\mathrm{CN\text{-}AR}}(\mathrm{S}_{\mathrm{d}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{d}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{GW\text{-}GW}}(\mathrm{S}_{\mathrm{d}},\mathrm{H}_{\mathrm{GW\text{-}GW}}) + \mathrm{T}_{\mathrm{AR\text{-}GW}}(\mathrm{S}_{\mathrm{d}},\mathrm{H}_{\mathrm{AR\text{-}GW}}) + \mathrm{T}_{\mathrm{AR\text{-}MN}}(\mathrm{S}_{\mathrm{d}})$.

Then, we can derive the handover delay of LISP-MN-GLAB as follows.

$$\begin{aligned}
\mathrm{HOD}_{\mathrm{LISP-MN-GLAB}} = {} & \mathrm{T}_{\mathrm{L2}} + \mathrm{T}_{\mathrm{MD}} + \mathrm{T}_{\mathrm{AC}} \\
& + 2 \times \big(\mathrm{T}_{\mathrm{MN-AR}}\big(\mathrm{S}_{\mathrm{c}}\big) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}})\big) \\
& + 3 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-GW}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{c}})) + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{d}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{GW-GW}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{AR-MN}}(\mathrm{S}_{\mathrm{d}}) = \mathrm{T}_{\mathrm{L2}} + \mathrm{T}_{\mathrm{MD}} + \mathrm{T}_{\mathrm{AC}} \\
& + 2 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) + \mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}})) \\
& + 3 \times (\mathrm{T}_{\mathrm{MN-AR}}(\mathrm{S}_{\mathrm{c}}) + 2\mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{c}}, \mathrm{H}_{\mathrm{GW-GW}}) + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{c}})) \\
& + \mathrm{T}_{\mathrm{CN-AR}}(\mathrm{S}_{\mathrm{d}}) + 2\mathrm{T}_{\mathrm{AR-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{AR-GW}}) \\
& + \mathrm{T}_{\mathrm{GW-GW}}(\mathrm{S}_{\mathrm{d}}, \mathrm{H}_{\mathrm{GW-GW}}) + \mathrm{T}_{\mathrm{AR-MN}}(\mathrm{S}_{\mathrm{d}}).
\end{aligned}$$

4.4.3 LISP-SMOS

The handover operations of LISP-SMOS are performed as follows. First, the link switching and movement detection operations are performed, which takes T_{L2} and T_{MD}. Then, MN will exchange the *Map Register* and *Map Notify* messages with the ARnew, which takes $2T_{MN\text{-}AR}(S_c)$. After that, the ARnew sends *Map Register* message to the gateway, and the gateway will respond with a *Map Notify* message to the AR. These operations take $2T_{AR\text{-}GW}(S_c,H_{AR\text{-}GW})$. Then, the gateway will broadcast the *Map Update* message in the domain, which takes $T_{AR\text{-}GW}(S_c,H_{AR\text{-}GW}) \times N_{AR}$. Then, CN delivers the data packets to MN via the gateway and the new access router, which takes $T_{AR\text{-}GW}(S_d,H_{AR\text{-}GW}) + T_{AR\text{-}MN}(S_d)$.

Accordingly, we can derive the handover delay of LISP-SMOS as follows.

$$\begin{aligned}\mathrm{HOD}_{\mathrm{LISP-SMOS}} &= T_{L2} + T_{MD} + 2T_{MN-AR}(S_c) + 2T_{AR-GW}(S_c, H_{AR-GW}) \\ &\quad + T_{AR-GW}(S_c, H_{AR-GW}) \times N_{AR} + T_{AR-GW}(S_d, H_{AR-GW}) \\ &\quad + T_{AR-MN}(S_d).\end{aligned}$$

4.4.4 LISP-DMC

In the proposed LISP-DMC scheme, the link switching and movement detection operations are performed, which take T_{L2} and T_{MD}. Then, MN will exchange the *Map Register* and *Map Notify* messages with the AR, which takes $2 \times (T_{MN\text{-}AR}(S_c))$. After that, the AR exchanges *Map Register* and *Map Notify* messages with the gateway of V-DMS, which takes $2 \times (T_{AR\text{-}GW}(S_c,H_{AR\text{-}GW}))$. Finally, V-DMS will send data packets to the new access router, and then the new access router will deliver data packets to MN. These operations take $T_{AR\text{-}GW}(S_d,H_{AR\text{-}GW}) + T_{AR\text{-}MN}(S_d)$.

Then, we can derive the handover delay of LISP-DMC as follows.

$$\begin{aligned}\mathrm{HOD}_{\mathrm{LISP-DMC}} &= T_{L2} + T_{MD} + 2 \times (T_{MN-AR}(S_c)) \\ &\quad + 2 \times (T_{AR-GW}(S_c, H_{AR-GW})) \\ &\quad + T_{AR-GW}(S_d, H_{AR-GW}) + T_{AR-MN}(S_d).\end{aligned}$$

4.5 Numerical results

Based on the analytical equations described so far, we compare the performance of the existing and proposed schemes. For numerical analysis, we configure the default parameter values, as described in Table 8, by referring to [19].

Table 8 Default parameter values

Parameter	Default	Minimum	Maximum
L_{wl} (ms)	10	1	55
T_{AC} (ms)	50	10	400
$H_{AR\text{-}GW}$	2	1	55
$N_{Host/AR}$	100	1	1,000
N_{AR}	30	1	100
N_{GW}	50		
$H_{GW\text{-}GW}$, $H_{GW\text{-}MS}$	6		
L_w	2 ms		
S_c	96 bytes		
S_d	200 bytes		
B_{wl}	11 Mbps		
B_w	100 Mbps		
T_{MD}	10 ms		
T_{L2}	50 ms		

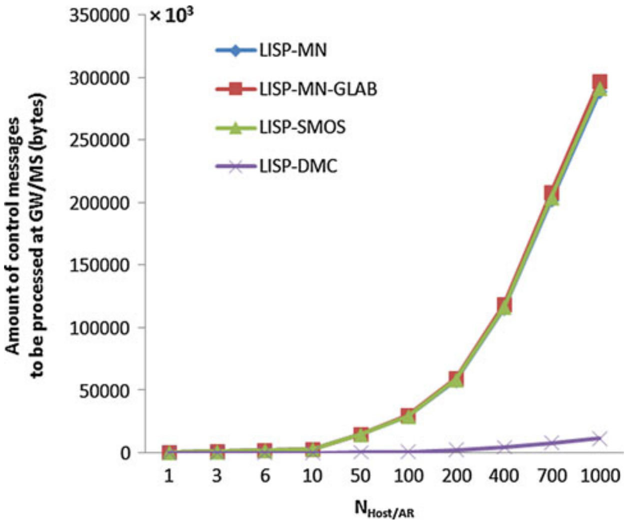


Fig. 10 Impact of $N_{Hosts/AR}$ on CTO

4.5.1 Control traffic overhead

Figure 10 and 11 compare the number of control messages to be processed by gateway or MS for different $N_{Host/AR}$ and N_{AR}. We can see that the proposed scheme provides smaller CTO than the existing schemes. This is because all mapping control messages shall be processed by a gateway and MS in the existing centralized schemes, whereas in the distributed scheme the mapping control traffics are distributed on to each DMS in the network. The gaps of performance between centralized and distributed schemes get larger, as the number of hosts or ARs in the network increases.

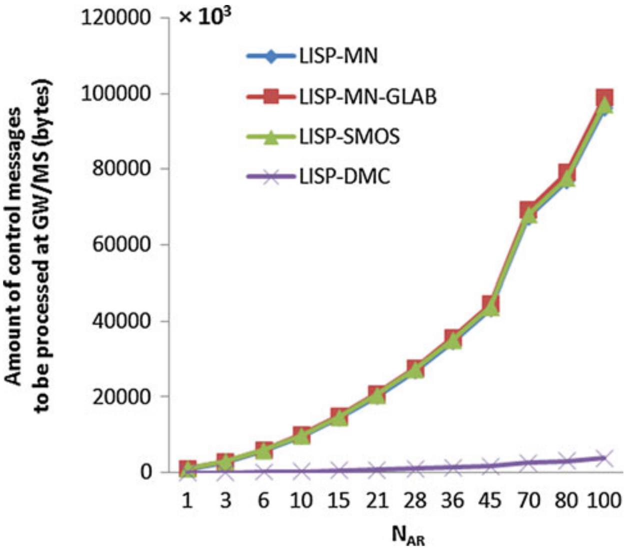


Fig. 11 Impact of N_{AR} on CTO

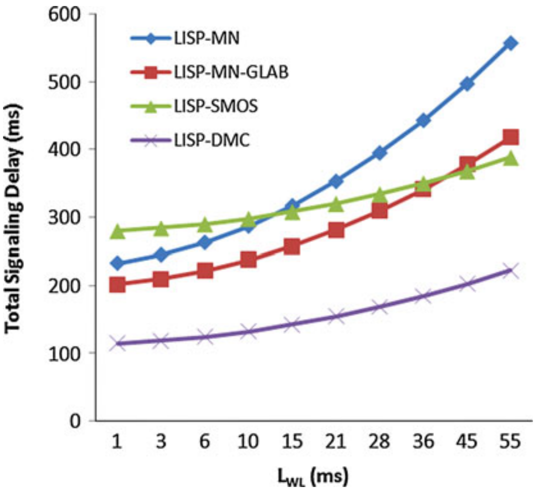


Fig. 12 Impact of L_{wl} on TSD

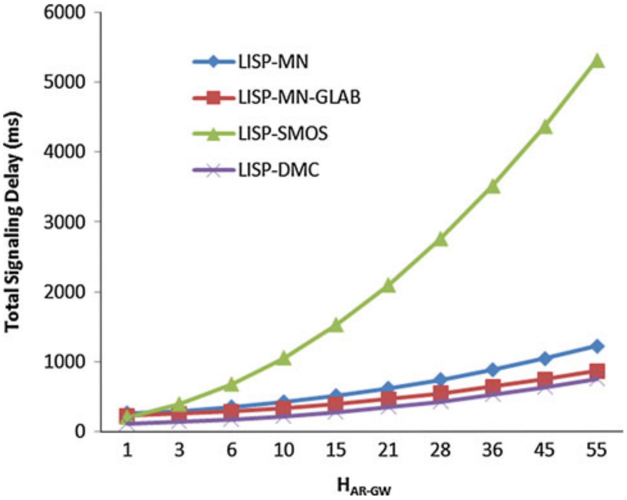


Fig. 13 Impact of $H_{AR\text{-}GW}$ on TSD

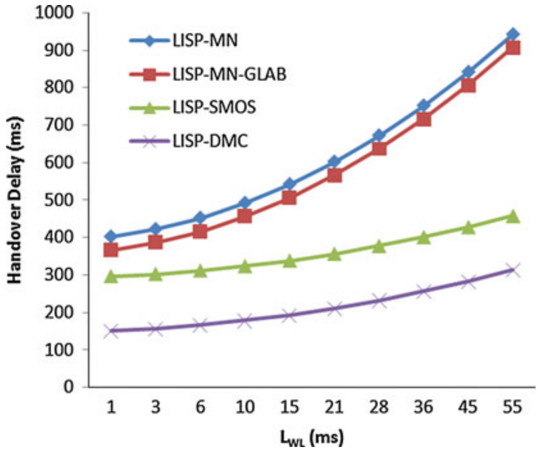


Fig. 14 Impact of L_{wl} on handover delay

4.5.2 Signaling delay for mapping management

Figure 12 shows the impact of wireless link delay (L_{wl}) on TSD. From the figure, we can see that the TSD linearly increases, as L_{wl} gets larger, for all candidate schemes. It is shown that the proposed LISP-DMC scheme gives better performance than the existing centralized schemes. It is also noted that LISP-MN-GLAB gives better performance than LISP-MN. This is because LISP-MN-GLAB uses a local MS for binding query operations. In the meantime, LISP-SMOS gives the worst performance, since the map update message is broadcast in the domain.

In Fig. 13, we can see the impact of hop counts between AR and gateway ($H_{AR\text{-}GW}$). From the figure, we can see that the signaling delay linearly increases for all candidate schemes. Among the existing schemes, LISP-SMOS gives the worst performance. This is because the map update message is broadcast in the domain. Among candidate schemes, the proposed LISP-DMC scheme provides the best performance.

4.5.3 Handover delay

Figure 14 compares the handover delays of candidate schemes for different wireless link delays (L_{wl}). It is shown in the figure that the handover delay increases for all the schemes, as the wireless link delay gets larger. The proposed LISP-DMC scheme gives better performance than the other candidate schemes.

In Fig. 15, we can see the impact of hop counts between AR and gateway ($H_{AR\text{-}GW}$). From the figure, we can see that the handover delay linearly increases for all the candidate schemes. In the existing schemes, LISP-SMOS gives the worst performance, because the map update message is broadcast in the domain. Among the candidate schemes, the LISP-DMC scheme provides the best performance.

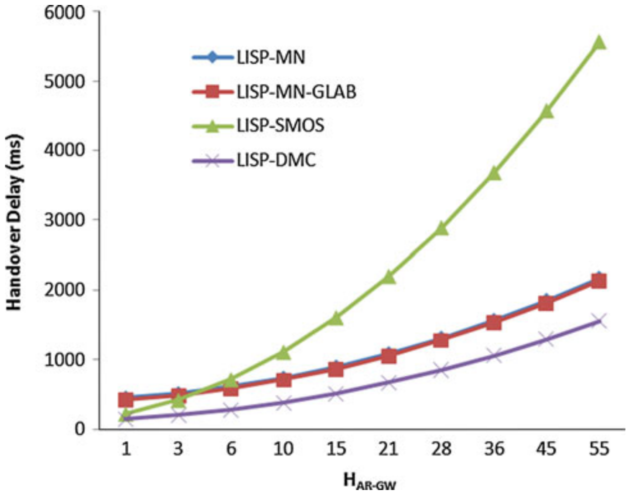


Fig. 15 Impact of $H_{AR\text{-}GW}$ on handover delay

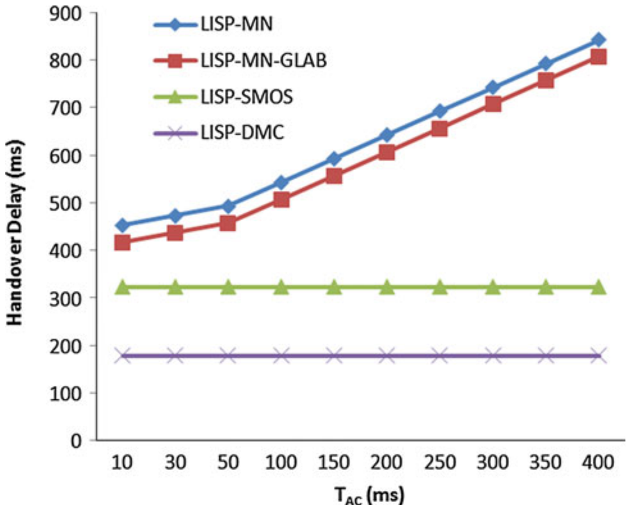


Fig. 16 Impact of T_{AC} on handover delay

Figure 16 compares the handover delays for different T_{AC}. In the figure, we see that the two schemes (LISP-SMOS and LISP-DMC) are not affected by T_{AC}, because mobile node uses the IP address of AR and does not need the LOC configuration, while the other two existing schemes (LISP-MN and LISP-MN-GLAB) shall configure a new LOC when mobile node moves to another location. From the figure, we can see that LISP-DMC scheme gives the best performance among all the candidate schemes.

5 Conclusions

In this paper, we proposed a distributed mobility control scheme in mobile LISP network. In the proposed scheme, we assume that a mobile host has a hierarchical endpoint identifier which contains the information of its home domain. Each domain has a DMS for distributed mapping management of endpoint identifiers and locators.

By numerical analysis, we can see that the proposed scheme can give better performance than the existing schemes in terms of CTO, TSD for mapping management and handover delay.

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