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RESEARCH ARTICLE

A hash-based distributed mapping control scheme in mobile locator-identifier separation protocol networks

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Summary

In the locator-identifier separation protocol (LISP), the existing mapping control scheme is based on a centralized approach, in which a map server is used as a mobility anchor for mobile hosts. However, such a centralized scheme has some limitations that include traffic overhead at the central map server, service degradation by a single point of failure, and large data transmission delay. In this article, we propose a new hash-based distributed mapping control scheme of endpoint identifier (EID) and local locator in the LISP-based mobile networks. In the proposed scheme, each access router in the mobile network has a distributed local map server. For a mobile host, a distributed local map server is designated to manage the associated EID-local locator mapping by using a hash function. For roaming support, each gateway has a distributed global map server, which maintains visiting EID-locator register. From the numerical results, we see that the proposed scheme can reduce the amount of control traffic at the map server and total signaling delay compared to the existing mapping control schemes.

1 | INTRODUCTION

For most of today's business and private communications, the Internet has become the nervous system, and the rising connections of the systems and networks to the Internet has been rapidly increasing.[1–4] Many networks connected to several Internet service providers through multiple points of attachment for reliable interconnection. This needs IP addresses, which must be routable in the Internet in the default-free zone, and add additional entries in Boarder Gateway Protocol (BGP) routing tables. The growing size of these BGP routing tables will cause scalability problems.[5]

To solve this issue, several approaches have been proposed in Internet Engineering Task Force (IETF) and Internet Research Task Force (IRTF); most are based on the locator/identifier (LOC/ID) split.[6,7] It uses special identifier addresses (IDs) to denote end-hosts, which are not routable in the default-free zone. Instead, a locator is added to the packets to send them over the Internet. The locator for each ID is returned by a mapping system (map server) that stores an ID-LOC mapping for each ID.

The locator-identifier separation protocol (LISP) has recently been made in IETF,[8] which provides an incrementally deployable solution to such separation in the Internet. LISP splits the current IP address space into endpoint identifier (EID), which identifies hosts, and routing locator (RLOC), which identifies network attachement points. This allows the EID to remain unchanged even in the event of a handover to another network. LISP also introduces a mapping system,[9] which maps EIDs-RLOCs. For data delivery between 2 hosts, an ingress tunnel router (ITR) prepends a new LISP header to the data packet of a source host, and an egress tunnel router (ETR) strips the LISP header prior to final delivery to the destination host.

LISP provides 2 important features to the Internet. First, it splits the location from the identity, which provides native mobility and multihoming. Second, it provides a new level of indirection. DNS returns EIDs and a mapping system returns RLOCs.

Mobility management is one of the primary functions of wireless cellular systems.[10–12] Most of the current Internet mobility schemes are based on a centralized anchor, as shown in the home agent of mobile IP (MIP),[13] the mobility anchor point of hierarchical MIP,[14] and the local mobility anchor of proxy MIP.[15]

The basic LISP architecture does not support the mobility of mobile hosts. To address the LISP mobility control, the host-based scheme (LISP-MN) was proposed,[16] in which each mobile host implements the tunnel router (TR) functionality. Each mobile host acts as its own LISP gateway, and uses the globally routable address as RLOC. It is noted that LISP-MN depends on a global centralized MS, which may incur significant overhead of control messages at MS in the global scale. To deal with this problem, Menth et al[17] proposed an enhanced scheme for LISP-MN, which is denoted by LISP-MN-German-Lab (GLAB) in this article. The main idea is the same with LISP-MN. However, a local map server (LMS) is employed at the gateway of the mobile network to provide a localized mobility control. Therefore, LISP-MN-GLAB can be viewed as hierarchical approach. However, such a centralized scheme tends to induce traffic overhead at the central server, service degradation by a single point of failure, and large data transmission delay.

To overcome these problems, we propose a distributed mobility control of EID-local locator (LLOC) mappings in the LISP-based mobile networks. In the proposed scheme, a host is uniquely identified by a hierarchical 128-bit EID structure,[18] which contains the information of the home domain that the host was subscribed to. By this, the access router (AR) will check whether the EID belongs to its domain (nonroaming case) or not (roaming case). In the proposed scheme, each AR is equipped with a distributed LMS (D-LMS). For a mobile host, a D-LMS will be designated to control the EID-LLOC mappings by using a hash function. For roaming support, each gateway has a distributed global map server (D-GMS), which maintains visiting EID-locator register (vELR).

The rest of this article is organized as follows. In Section 2, 3, 4, 5, we review the existing schemes for EID-LLOC mapping control. In Section 3, we describe the proposed hash-based distributed mapping control scheme. Section 4 compares the current and proposed schemes in terms of control traffic overhead (CTO) and total signaling delay (TSD). Section 5 concludes this article.

2 | RELATED WORK

In this section, we describe the existing LISP mobility schemes; we consider a generalized network model for LISP mobility control, as shown in Figure 1. In the figure, it is assumed that both a correspondent node (CN) and a mobile node (MN) are located within the same mobile domain (ie, both are mobile hosts).

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).

In this article, we will focus on only the intradomain localized mobility control within a local mobile LISP domain, rather than the interdomain mobility control across different mobile domains because there are various possible scenarios for interdomain communication.

2.1 | LISP-MN

To support LISP mobility, the LISP-MN architecture[16] was proposed, in which MN implements a lightweight tunnel router (TR) functionality and thus it acts as an ITR/ETR in the mobile network. In this architecture, a central MS is used to process all control traffic 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 operations are illustrated in Figure 2.

In the figure, we assume that MN and CN were subscribed to the same mobile domain. When MN is connected to an AR in the mobile domain, it configures its RLOC. Then, MN will send a *Map Register* message to 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* message to MN (Step 2). For data delivery, 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 can forward 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.

2.2 | LISP-MN-GLAB

It is noted that LISP-MN depends on a centralized MS for mapping control operations, which may incur significant

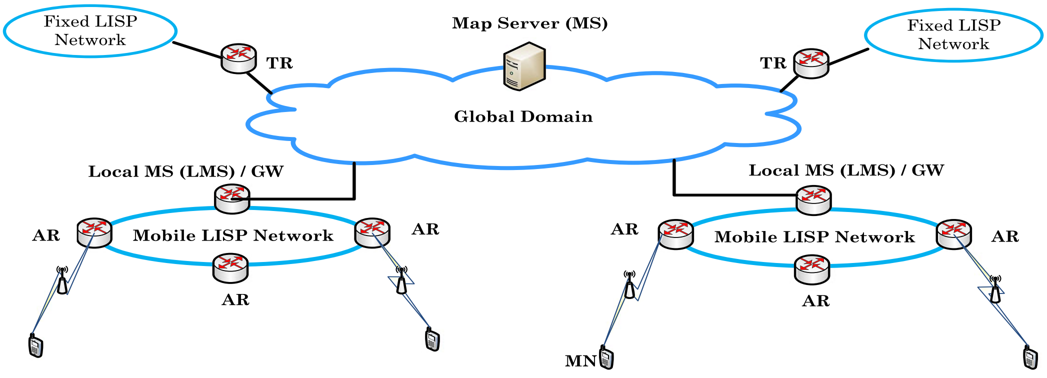

FIGURE 1 Generalized network model for LISP mobility control

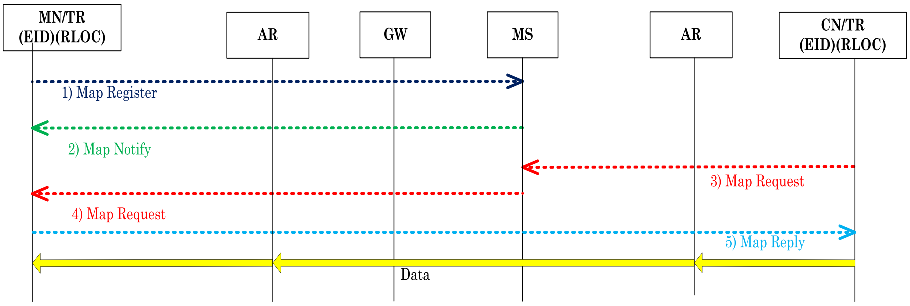

FIGURE 2 EID-RLOC mapping management in LISP-MN

overhead of control messages at MS. To deal with this problem, the work by Menth et al[17] proposed an enhanced scheme for LISP-MN, which is denoted by LISP-MN-GLAB in this article. The main idea of LISP-MN-GLAB is the same with that of LISP-MN. However, an LMS is employed at the gateway (GW) of the mobile network to provide localized mobility control. In terms of mapping server, LISP-MN-GLAB uses the 2 types of servers: LMS and MS. In this respect, LISP-MN-GLAB can be viewed as a hierarchical approach.

The mapping management operations of LISP-MN-GLAB are described in Figure 3. In the figure, a global MS is used for interdomain communication, and an LMS is employed to support intradomain communication. LMS may be located with the gateway of the mobile domain. A gateway has its RLOC, and each MN uses a local LOC (LLOC) that is configured with a dynamic IP address configuration scheme. This LLOC is used only in 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 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 the data delivery operation, CN sends a data packet to MN. CN will first send a *Map-Request* message to LMS (gateway) to find the LLOC of MN (Step 3). Then, LMS will find the LLOC of MN and will respond with *Map-Reply* message to CN (Step 4). Now, CN can send a data packet to MN.

The LMS performs Map Register/Notify operations for EID-RLOC mapping with MS and also performs Map-Request/Reply operations with global MS to find the RLOC of specific hosts.

It is noted that LISP-MN and LISP-MN-GLAB mostly used LISP alternate topology (LISP-ALT)[19] for global mapping systems. In LISP-ALT, Map-Request used BGP/GRE overlay from map resolver (MR) to map server (MS). Therefore, it takes a long time to find the ETR. Now, LISP-ALT is being replaced by LISP delegated database tree (LISP-DDT).[20] In LISP-DDT, the ITR sends a Map-Request to MR and the MR sends an iterative Map-Request to its statically configured root DDT-node. Then, the root DDT-node sends a map referral to MR informing the MR who is the next DDT-node. The MR repeats until it gets to the MS, which has the EID registered, and then the ETR sends a Map-Reply to the ITR. By this procedure, the Map-Request operation takes a long time to reach to the final ETR.

To overcome this problem, in the proposed scheme, a host is uniquely identified by a hierarchical 128-bit EID structure,[18] which contains the information of the home domain that the host was subscribed to. By this, the AR will check whether the EID belongs to its domain (nonroaming case) or not (roaming case). Note that an AR can determine this, based on the EID, because an EID contains the information of the home domain of MN. In the nonroaming case, the AR will use the hash-based function to find the D-LMS of the specific host. Because each AR is equipped with a D-LMS. In the roaming case, the AR will forward the request to the gateway of the domain. Because each gateway of the domain is equipped with distributed GMS (D-GMS) that maintains the vELR.

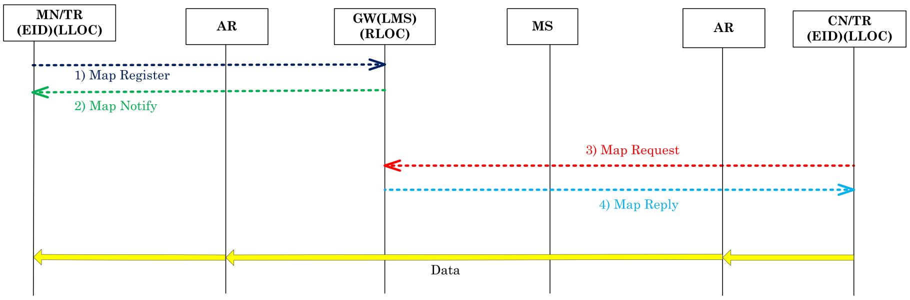

FIGURE 3 EID-LLOC mapping management in LISP-MN-GLAB

3 | PROPOSED HASH-BASED MAPPING CONTROL SCHEME BASED ON LISP NETWORK

In this section, we describe a hash-based distributed EID-LLOC mapping control scheme in the LISP-based mobile networks, denoted by LISP-MN-HD.

3.1 | Design consideration

We first discuss the design features of LISP-MN-HD with respect to the architecture. Table 1 compares the main features of LISP-MN-HD with those of the existing LISP-MN and LISP-MN-GLAB schemes.

3.2 | Architectural design

In the proposed scheme, a host is uniquely identified by a hierarchical 128-bit EID structure,[18] which contains the information of the home domain that the host was subscribed to. By this, the AR will check whether the EID belongs to its domain (nonroaming case) or not (roaming case). Note that an AR can determine this, based on the EID, because an EID contains the information of the home domain of MN. It is assumed that each AR in the mobile network has a D-LMS with a hash table and EID-LLOC register (ELR), as shown in Figure 4. For a given EID, the D-LMS is determined by the hash table. That is, the hash table is used to find the D-LMS that is responsible for the mapping control of a specific host. ELR maintains the list of EID-LLOC bindings for the associated hosts. In this way, the ELRs are distributed onto ARs in the LISP mobile network. Each ELR is updated in the Map Register and Notify operation and referred to in the Map-Request/Reply operation. For roaming support, each gateway has a D-GMS, which maintains the vELR, as shown in Table 2.

TABLE 1 Comparison of centralized and distributed mobility control schemes

Schemes	Mapping architecture	Mapping server
LISP-MN	Centralized	MS
LISP-MN-GLAB	Centralized	MS, LMS
LISP-MN-HD	Distributed	D-GMS, D-LMS

[a]LISP-MN is a host-based centralized approach, in which a central MS is used as an anchor point of mobile hosts for both intradomain and interdomain communications. LISP-MN-GLAB is also a host-based centralized approach that uses a 2-level hierarchy of map servers: LMS and MS. MS is used for interdomain communication, and LMS handles intradomain mappings. The proposed LISPMN-HD scheme is a host-based distributed approach, in which the gateway has a D-GMS, which is used for the interdomain mapping control, whereas each AR in the mobile network has a D-LMS for intradomain mapping control and the functionality of a central LMS is distributed onto the D-LMSs in the mobile domain.

As for locators, the access locator (ALOC) represents the private IP address of the MN. LLOC represents the IP address of AR and it is used as locator within a domain, whereas RLOC represents the IP address of D-GMS/gateway and it is used for interdomain communication.

In this article, we consider the mapping control within a single LISP mobile domain. The mapping control in different LISP domains is beyond the scope of this article.

Each D-LMS is used to manage the EID-LLOC mappings for some hosts. For a mobile host, a D-LMS is designated to manage the EID-LLOC mapping information by applying a simple hash function to the host ID, such as a *modulo* (%) operator. For example, if there are n D-LMSs in the mobile domain, the designated D-LMS for a host can be determined by "EID % n." A host will update its EID and LLOC with its designated D-LMS.

Figure 5 shows the Map-Request/Reply-first data delivery operation with mapping system. In the figure, the ALOC is used within the access network and LLOC is used in the backbone network. Each AR performs the LOC translation between the ALOC and LLOC.

TABLE 2 Visiting EID-locator register (vELR)

No.	EID	Locator (visited domain)	Home D-GMS
1	EID1	LLOC1	RLOC1
2	EID2	LLOC2	RLOC2

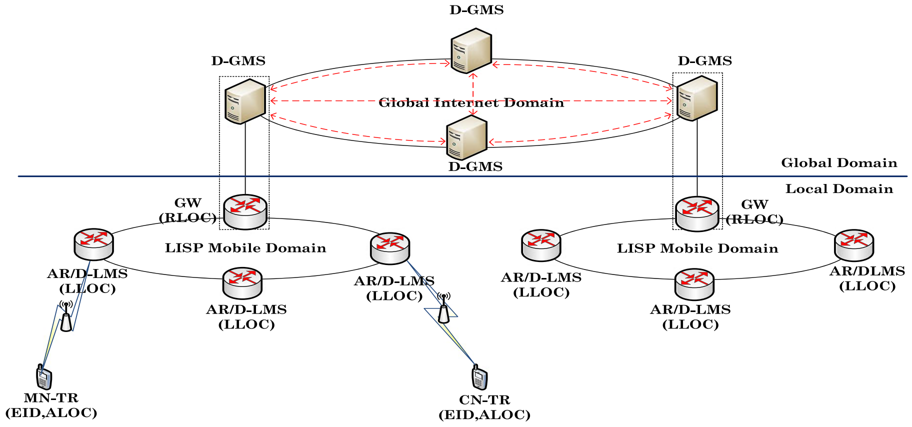

FIGURE 4 Network model for LISP-MN-HD

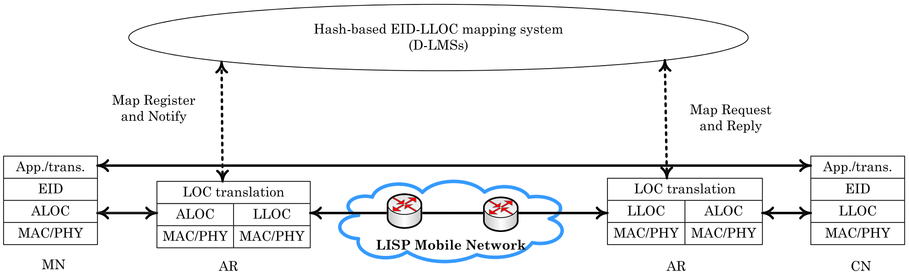

FIGURE 5 Map-Request/Reply-first data delivery with local mapping system (D-LMS)

3.3 | LISP-MN-HD NAT traversal

Figure 6 shows the NAT traversal of LISP-MN-HD. When MN moves to a non-LISP domain, the MN will obtain the private care-of-address. The MN will send a Map Register to the NAT gateway. The NAT gateway will forward the Map Register message to the home domain of the MN. Because the EID contains information on its home domain. The home D-GMS will store the IP address of the NAT gateway as a routing locator (RLOC).

3.4 | EID-LLOC mapping control operations

When an MN is connected to a new AR in the network, it sends a Map Register message to the AR for an EID-LLOC mapping update. Then, the AR will determine the designated D-LMS for the mobile host by using a hash function. As a result, the designated D-LMS will be on either the D-LMS/AR that the host is connected to or the other D-LMS. In the first case, no further action is required, whereas, in the second case, the Map Register message is forwarded to the designated D-LMS.

Now, let us consider that CN transmits data packets to MN. First, CN will send a Map-Request message to AR, and then AR performs the hash function to locate the designated D-LMS of MN. By applying the hash function, there are 3 possible cases:

- Case 1: the designated D-LMS of MN is on the AR that MN is connected to;
- Case 2: the designated D-LMS is on the AR that CN is connected to; or
- Case 3: the designated D-LMS is on another AR.

Figure 7 describes the control operations for Case 1, in which the designated D-LMS is on the AR that MN is connected to. When MN is connected to AR, the Map Register and Map Notify messages are exchanged for EID-LLOC mapping updates between MN and AR of MN. No further forwarding of Map Register message is done. For data transmission, CN sends a Map-Request message to the AR. Then, the AR of CN will determine the designated D-LMS of MN by using a hash function, and the Map-Request message is forwarded from the AR of CN to the D-LMS/AR of MN. Then, D-LMS/AR of MN will respond with a Map-Reply

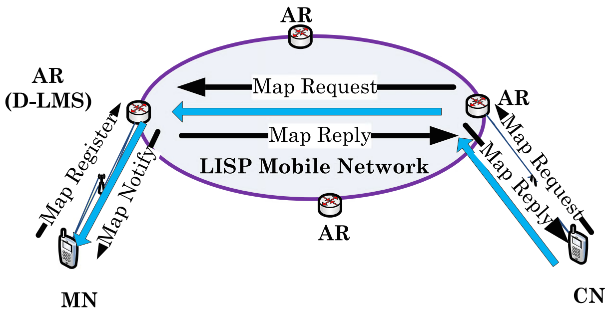

FIGURE 7 Case 1: Designated LMS is on the AR of MN

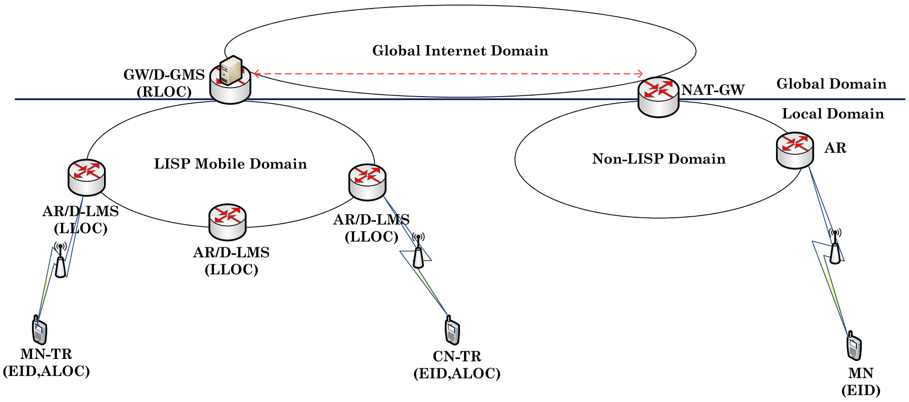

FIGURE 6 NAT traversal for LISP-MN-HD

message to AR of CN and further to CN. Now, CN can send the data packets to MN.

Figure 8 describes the control operations for Case 2, in which the designated D-LMS is on the AR of CN. The Map Register and Map Notify messages are exchanged for EID-LLOC mapping update between MN and AR of MN, and also between AR of MN and D-LMS/AR of CN. Then, D-LMS/AR of CN updates the EID-LLOC mapping information of MN. For data transmission, CN sends the Map-Request message to its AR. Then, D-LMS/AR of CN determines the location of MN by the lookup of its mapping table, and it responds with a Map-Reply message to CN.

Figure 9 describes the control operations for Case 3, in which the designated D-LMS is on another AR in the mobile network. Initially, the Map Register and Map Notify messages are exchanged between MN and AR of MN, and also between AR of MN and D-LMS/AR. Then, D-LMS/AR will update the EID-LLOC information of MN.CN will send a Map-Request message to AR. Then, AR of CN will determine the designated D-LMS of MN by using a hash function, and the Map-Request messages are forwarded from the AR of CN to D-LMS/AR of MN. Then, D-LMS/AR of MN will respond with the Map-Reply message to AR of CN, and further to CN. Now, CN can send the data packets to MN.

3.5 | Implementation aspects: System design perspective

3.5.1 | Host

The host will use a 6-to-4 tunneling scheme. For EID, the IPv6 address will be used, whereas the private IPv4 address will be used as ALOC. The 128-bit EID includes a 2-byte prefix for 6-to-4 tunneling. Figure 10 shows the protocol stack for possible implementation in the host, in which ALOC will be used for packet delivery between host and AR.

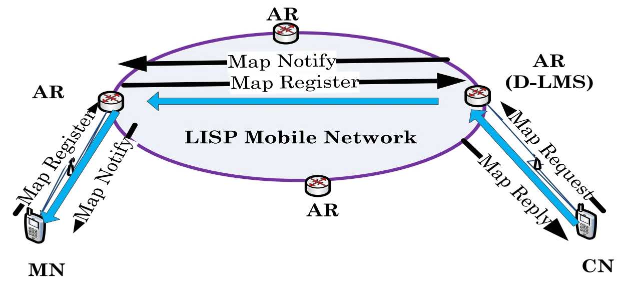

FIGURE 8 Case 2: Designated LMS is on the AR of CN

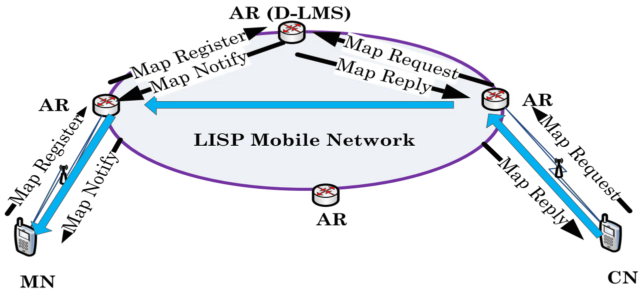

FIGURE 9 Case 3: Designated LMS is on the other AR

3.5.2 | Access router

For possible implementation of AR, we will use *netfilter* and *iptables,*[19] for the LOC translation from ALOC to LLOC for the data packets. Figure 11 shows the possible protocol stack for implementation using *netfilter* at the AR. It is noted that *iptables* will be used together with *netfilter*. It is noted that LLOC will be public IPv4 address.

Figure 12 describes the netfilter functions to support the LOC translation at the AR. In the figure, the modified function modules (netfilter hooking points) are indicated as shared boxes. In the figure, when a packet arrives from the host, the ip_rcv function is invoked to process the packet at the network layer. Then, the NF_IP_PRE_ROUTING function hooks the data packet. After that, the LOC is translated from the ALOC to the LLOC (or from the LLOC to the ALOC). When this LOC translation is complete, the NF_IP_POST_ROUTING function forwards the packet to the ip_finish_output2 function for data forwarding.

3.5.3 | D-LMS

For implementation of D-LMS, we will use a simple hash function using *modulo (%)* operator. That is, for a given EID, to determine the D-LMS that is responsible for the concerned host, we will calculate "*EID %*" (number of D-LMSs in the mobile LISP network).

For this purpose, we will number the D-LMS in sequence. Then, the D-LMS that will be responsible for a host will be selected as the D-LMS, which has an equal sequence number with the resulting value of the *modulo* hash

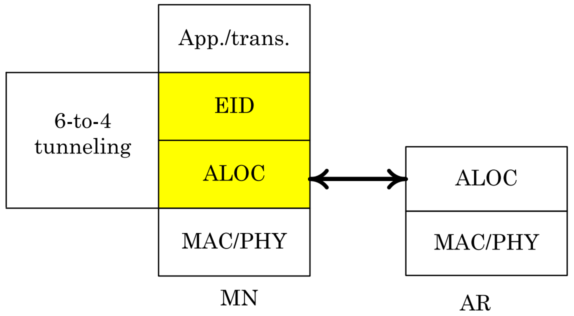

FIGURE 10 Implementation stack at host

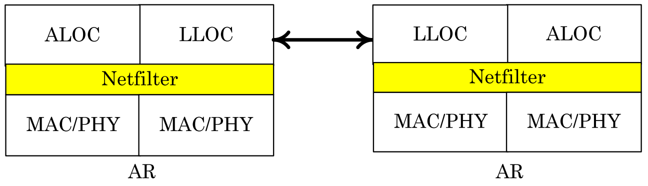

FIGURE 11 Implementation stack at AR

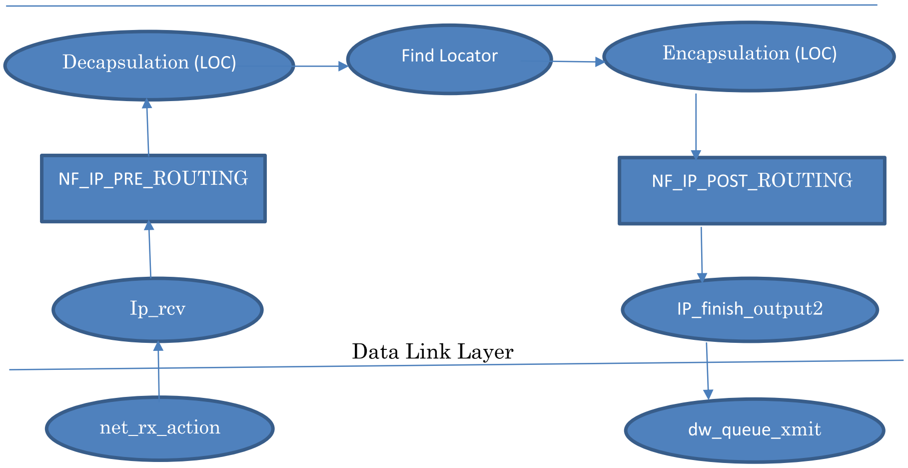

FIGURE 12 Netfilter modules used for AR implementation

function. Once the D-LMS is determined, the Map Register/Notify and Map-Request/Reply operation will be performed.

4 | PERFORMANCE ANALYSIS

To analyze the performance of the proposed mapping control scheme, we evaluate the CTO at map servers and the TSD for all candidate schemes. We consider the 2 existing schemes because these 2 schemes are well known in the research community.

4.1 | Analysis model

We consider a network model for analysis for all candidate schemes, as illustrated in Figure 13.

For analysis, we define the following parameters, as shown in Table 3.

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

TABLE 3 Parameters used for cost analysis

Parameters	Description
S_c	Size of control packets (bytes)
B_w	Wired bandwidth
B_{wl}	Wireless bandwidth
L_w	Wired link delay
L_{wl}	Wireless link delay
$\mathrm{H}_{\mathrm{a-b}}$	Hop count between node a and b in the network
N_{Host}	Number of hosts in the domain
N_{GW}	Number of gateways
N_{AR}	Number of ARs in the domain

Let $T_{x-y}(S, H_{x-y})$ denote the transmission delay of a message of 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, for control packets: $T_{x-y}(S_c, H_{x-y}) = H_{x-y} \times [(S_c/B_w) + L_w]$.

4.2 | Analysis of CTO

To analyze the scalability by mapping control operations, we evaluate the traffic overhead for mapping management at

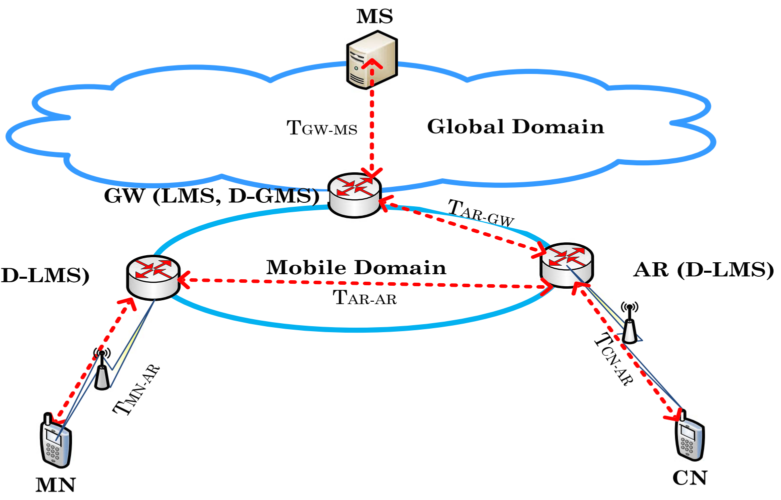

FIGURE 13 Network model for analysis

LMS or D-LMS. We will not consider the LISP-MN scheme because it uses the global MS for intradomain communication, which tends to induce much larger traffic overhead than LISP-MN-GLAB and LISP-MN-HD.

4.2.1 | LISP-MN-GLAB

In the LISP-MN-GLAB, as shown in Figure 3, we calculate the CTO by the number of mapping control messages to be processed by the gateway. It is assumed that mobile hosts are equally distributed in the network. For mapping updates, all hosts in the network will send the *Map Register* messages to the gateway. Thus, the *Map Register* messages of $S_c \times N_{\mathrm{Host}} \times N_{\mathrm{AR}}$ shall be processed by the gateway. For data transmission, each host sends *Map-Request* messages to the gateway. Thus, the *Map-Request* messages of $S_c \times N_{\mathrm{Host}} \times N_{\mathrm{AR}}$ shall be processed by the gateway. Accordingly, we obtain the CTO of LISP-MN-GLAB as follows:

$$\mathrm{CTO}_{\mathrm{LISP-MN-GLAB}} = 2 \times S_c \times N_{\mathrm{Host}} \times N_{\mathrm{AR}}$$

4.2.2 | LISP-MN-HD

In the proposed LISP-MN-HD scheme, as shown in Figure 5, when MN is connected to AR, it sends a Map Register message to its attached D-LMS/AR. With the assumption that the hosts are equally distributed in the mobile network, each D-LMS/AR will process the Map Register messages of $S_c \times (N_{\mathrm{Host}}/N_{\mathrm{AR}})$. After that, AR will perform the hash function to determine the designated D-LMS/AR for MN. If the hashed value of MN is equal to the AR itself (Case 1), no further operation is performed. For data delivery, each host sends *Map-Request* messages to AR. After that, AR performs the hash function to determine the designated D-LMS/AR of the MN. Then, AR forwards a *Map-Request* message to the designated D-LMS of MN. Thus, the *Map-Request* messages of $S_c \times (N_{\mathrm{Host}} - N_{\mathrm{Host}}/N_{\mathrm{AR}})$ shall be processed by D-LMS/AR. Let us assume that the probability for Case 1 is $1/N_{\mathrm{AR}}$. Accordingly, we obtain the CTO of LISP-MN-HD for Case 1 as follows:

$$\mathrm{CTO}_{\mathrm{LISP-MN-HD1}} = \left(\frac{1}{N_{\mathrm{AR}}}\right) \times \left\{ S_c \times \frac{N_{\mathrm{Host}}}{N_{\mathrm{AR}}} + S_c \times \left(N_{\mathrm{Host}} - \frac{N_{\mathrm{Host}}}{N_{\mathrm{AR}}} \right) \right\}$$

In Case 2, as shown in Figure 6, after receiving the *Map Register* message from MN, AR will perform the hash function to determine the designated D-LMS/AR for MN. If the hashed value of MN is the other D-LMS/AR, then AR will forward the *Map Register* message to the designated D-LMS/AR of MN. Thus, the *Map Register* message of $S_c \times (N_{\mathrm{Host}} - N_{\mathrm{Host}}/N_{\mathrm{AR}})$ shall be processed. For data delivery, each host sends *Map-Request* messages to AR. After that, AR will perform the hash function to determine the designated D-LMS/AR of the MN. If the hashed value is equal to itself, no further operation is performed. Thus, the *Map-Request* messages of $S_c \times N_{\mathrm{Host}}/N_{\mathrm{AR}}$ shall be processed by D-LMS/AR. Let us assume that the probability for Case 2 is $1/N_{\mathrm{AR}}$. Accordingly, we obtain the CTO of LISP-MN-HD for Case 2 as follows:

$$\mathrm{CTO}_{\mathrm{LISP-MN-HD2}} = \left(\frac{1}{N_{\mathrm{AR}}}\right) \times \left\{ S_c \times \frac{N_{\mathrm{Host}}}{N_{\mathrm{AR}}} + S_c \times \left(N_{\mathrm{Host}} - \frac{N_{\mathrm{Host}}}{N_{\mathrm{AR}}} \right) \right\}$$

In Case 3, as shown in Figure 7, after receiving the *Map Register* message from MN, AR will perform the hash function to determine the designated D-LMS/AR for MN. If the hashed value of MN is the other D-LMS/AR, then the AR will forward the *Map Register* message to the designated D-LMS/AR of MN. Thus, the *Map Register* message of $S_c \times (N_{\mathrm{Host}} - N_{\mathrm{Host}}/N_{\mathrm{AR}})$ shall be processed. For data delivery, each host sends *Map-Request* messages to AR. After that, AR will perform the hash function to determine the designated D-LMS/AR of MN. Then, AR will forward the *Map-Request* message to the designated D-LMS of MN. Thus, the *Map-Request* messages of $S_c \times (N_{\mathrm{Host}} - N_{\mathrm{Host}}/N_{\mathrm{AR}})$ shall be processed by D-LMS/AR. Let us assume that the probability for Case 3 is $(N_{\mathrm{AR}} - 2)/N_{\mathrm{AR}}$. Accordingly, we obtain the CTO of LISP-MN-HD for Case 3 as follows:

$$\begin{aligned}\mathrm{CTO}_{\mathrm{LISP-MN-HD3}} = \left(\frac{N_{\mathrm{AR}}-2}{N_{\mathrm{AR}}}\right) \times \Bigg\{ & S_c \times \left(N_{\mathrm{Host}} - \frac{N_{\mathrm{Host}}}{N_{\mathrm{AR}}} \right) \\ & + S_c \times \left(N_{\mathrm{Host}} - \frac{N_{\mathrm{Host}}}{N_{\mathrm{AR}}} \right) \Bigg\}\end{aligned}$$

Overall, we obtain the total CTO for the proposed LISP-MN-HD scheme as follows:

$$\begin{aligned}\mathrm{CTO}_{\mathrm{LISP-MN-HD}} = {} & \mathrm{CTO}_{\mathrm{LISP-MN-HD1}} + \mathrm{CTO}_{\mathrm{LISP-MN-HD2}} \\ & + \mathrm{CTO}_{\mathrm{LISP-MN-HD3}}\end{aligned}$$

4.3 | Analysis of TSD

The binding update delay and the binding query delay are denoted by BUD and BQD, respectively. Then, the TSD can be represented as TSD = BUD + BQD.

4.3.1 | LISP-MN

In LISP-MN, as shown in Figure 2, the binding update operations are performed as follows. When MN enters a new AR region, it configures its RLOC. After that, MN will perform the Map Register operation with MS by exchanging the *Map Register* and *Notify* messages, and MS updates the database. This operation takes $2 \times (T_{\text{MN-AR}}(S_c) + T_{\text{AR-GW}}(S_c, H_{\text{AR-GW}}) + T_{\text{GW-MS}}(S_c, H_{\text{GW-MS}}))$. Then, the BUD of LISP-MN is represented as follows:

$$\begin{aligned}\mathrm{BUD}_{\mathrm{LISP-MN}} = {} & 2\times(T_{\mathrm{MN-AR}}(S_c) + T_{\mathrm{AR-GW}}(S_c, H_{\mathrm{AR-GW}}) \\ & + T_{\mathrm{GW-MS}}(S_c\,, H_{\mathrm{GW-MS}}))\end{aligned}$$

In LISP-MN, the binding query cost from CN to MN can be calculated as follows. First, CN will send a *Map-Request* message to MS to find the RLOC of MN. Then, MS will look for the RLOC of MN in its database. Then, MS will forward *Map-Request* message to MN. After that, MN responds directly to CN with *Map-Reply* message. This takes $2T_{\text{CN-AR}}(S_c) + 2T_{\text{MN-AR}}(S_c) + T_{\text{AR-AR}}(S_c,H_{\text{AR-AR}}) + 2T_{\text{AR-GW}}(S_c,H_{\text{AR-GW}}) + 2T_{\text{GW-MS}}(S_c,H_{\text{GW-MS}})$. Thus, the BQD can be represented as follows:

$$\begin{aligned}\mathrm{BQD}_{\mathrm{LISP-MN}} = {} & 2\times T_{\mathrm{CN-AR}}(S_c) + 2\times T_{\mathrm{MN-AR}}(S_c) \\ & + T_{\mathrm{AR-AR}}(S_c\,, H_{\mathrm{AR-AR}}) \\ & + 2\times T_{\mathrm{AR-GW}}(S_c\,, H_{\mathrm{AR-GW}}) \\ & + 2\times T_{\mathrm{GW-MS}}(S_c\,, H_{\mathrm{GW-MS}})\end{aligned}$$

Therefore, we obtain the TSD of LISP-MN as

$$\mathrm{TSD}_{\mathrm{LISP-MN}} = \mathrm{BUD}_{\mathrm{LISP-MN}} + \mathrm{BQD}_{\mathrm{LISP-MN}}$$

4.3.2 | LISP-MN-GLAB

The binding update operations of LISP-MN-GLAB are done as shown in Figure 3. MN performs the *Map Register* operation with the gateway by exchanging *Map Register* and *Map Notify* messages, and the Gateway updates its database. This operation takes $2 \times (T_{\text{MN-AR}}(S_c) + T_{\text{AR-GW}}(S_c,H_{\text{AR-GW}}))$. Accordingly, the BUD of LISP-MN-GLAB is represented as

$$\mathrm{BUD}_{\mathrm{LISP-MN-GLAB}} = 2\times(T_{\mathrm{MN-AR}}(S_c) + T_{\mathrm{AR-GW}}(S_c, H_{\mathrm{AR-GW}}))$$

In LISP-MN-GLAB, the BQD from CN to MN can be calculated as follows. First, CN will send a *Map-Request* message to the gateway to finding the LLOC of MN. Then, the gateway will look for the LLOC of MN in its database. After that, the gateway responds with a *Map-Reply* message to CN. Therefore, the delay of control message transmission is equal to $2T_{\text{CN-AR}}(S_c) + 2T_{\text{AR-GW}}(S_c,H_{\text{AR-GW}})$. Then, the data packet will be forwarded directly from CN to MN. Thus, the BQD can be represented as follows:

$$\begin{aligned}\mathrm{BQD}_{\mathrm{LISP-MN-GLAB}} = {} & 2\times T_{\mathrm{CN-AR}}(S_c) \\ & + 2\times T_{\mathrm{AR-GW}}(S_c\,, H_{\mathrm{AR-GW}})\end{aligned}$$

Therefore, we obtain the TSD as

$$\begin{aligned}\mathrm{TSD}_{\mathrm{LISP-MN-GLAB}} = {} & \mathrm{BUD}_{\mathrm{LISP-MN-GLAB}} \\ & + \mathrm{BQD}_{\mathrm{LISP-MN-GLAB}}\end{aligned}$$

4.3.3 | LISP-MN-HD

In the proposed scheme, the binding update operations of LISP-MN-HD for Case 1 are done as shown in Figure 5. When MN enters a new AR region, it configures its LLOC. After that, MN performs the *Map Register* operation with D-LMS/AR by exchanging the *Map Register* and *Map Notify* messages, and D-LMS/AR updates its database. This operation takes $2 \times T_{\text{MN-AR}}(S_c)$. Thus, the BUD of LISP-MN-HD for Case 1 is represented as

$$\mathrm{BUD}_{\mathrm{LISP-MN-HD1}} = 2\times T_{\mathrm{MN-AR}}(S_c)$$

The BQD for Case 1 can be calculated as follows. First, CN sends a *Map-Request* message to AR. AR performs the hash function to determine the designated D-LMS/AR for MN. Then, AR forwards the Map-Request message to D-LMS/AR. After that, D-LMS/AR responds with a *Map-Reply* message to CN. Therefore, the delay of control message is $2T_{\text{CN-AR}}(S_c) + 2T_{\text{AR-AR}}(S_c,H_{\text{AR-AR}})$. Thus, we obtain the BQD as follows:

$$\begin{aligned}\mathrm{BQD}_{\mathrm{LISP-MN-HD1}} = {} & 2\times T_{\mathrm{CN-AR}}(S_c) \\ & + 2\times T_{\mathrm{AR-AR}}(S_c\,, H_{\mathrm{AR-AR}})\end{aligned}$$

The probability for Case 1 is $1/N_{\text{AR}}$. Therefore, we obtain the TSD as follows:

$$\begin{aligned}\mathrm{TSD}_{\mathrm{LISP-MN-HD1}} = {} & \left(\frac{1}{N_{\mathrm{AR}}}\right)\times\Big\{\mathrm{BUD}_{\mathrm{LISP-MN-HD1}} \\ & + \mathrm{BQD}_{\mathrm{LISP-MN-HD1}}\Big\}\end{aligned}$$

The binding update operations of LISP-MN-HD for Case 2 are done as shown in Figure 6. MN performs the *Map Register* operation with AR by exchanging *Map Register* and *Map Notify* messages, and then AR will also perform the *Map Register* operation with D-LMS/AR, and D-LMS/AR updates its database. This operation takes $2 \times T_{\text{MN-AR}}(S_c) + 2 \times T_{\text{AR-AR}}(S_c,H_{\text{AR-AR}})$. Thus, the BUD of LISP-MN-HD for Case 2 is represented as follows:

$$\begin{aligned}\mathrm{BUD}_{\mathrm{LISP-MN-HD2}} = {} & 2\times T_{\mathrm{MN-AR}}(S_c) \\ & + 2\times T_{\mathrm{AR-AR}}(S_c\,, H_{\mathrm{AR-AR}})\end{aligned}$$

The BQD for Case 2 can be calculated as follows. First, CN will send a *Map-Request* message to AR. AR will perform a hash function to determine the designated D-LMS/AR for MN. If the hashed value points to the AR itself, no further operation is performed. Therefore, the delay of control message transmission is equal to $2T_{\text{CN-AR}}(S_c)$. Thus, the BQD can be represented as follows:

$$\mathrm{BQD}_{\mathrm{LISP-MN-HD2}} = 2\times T_{\mathrm{CN-AR}}(S_c)$$

The probability for Case 2 is $1/N_{\text{AR}}$. Therefore, we obtain the TSD as follows:

$$\mathrm{TSD_{LISP-MN-HD2}} = \left(\frac{1}{N_{\mathrm{AR}}}\right) \times \{\mathrm{BUD_{LISP-MN-HD2}} + \mathrm{BQD_{LISP-MN-HD2}}\}.$$

The binding update operations of LISP-MN-HD for Case 3 are done as shown in Figure 7. MN configures an LLOC and performs the *Map Register* operation with AR by exchanging the *Map Register* and *Map Notify* messages. AR also exchanges the *Map Register* and *Notify* messages with D-LMS/AR, and D-LMS/AR updates the database. This operation takes $2 \times T_{\text{MN-AR}}(S_c) + 2 \times T_{\text{AR-AR}}(S_c, H_{\text{AR-AR}})$. Accordingly, the BUD of LISP-MN-HD for Case 3 can be represented as follows:

$$\begin{aligned}\mathrm{BUD_{LISP-MN-HD3}} &= 2\times T_{MN-AR}(S_c)\\ &+ 2\times T_{AR-AR}(S_c\ , H_{AR-AR})\end{aligned}$$

The BQD for Case 3 can be calculated as follows. First, CN sends a *Map-Request* message to AR. AR performs the hash function to determine the designated D-LMS/AR for MN. Then, AR forwards the Map-Request message to D-LMS/AR. After that, D-LMS/AR responds with a *Map-Reply* message to CN. Therefore, the delay of control message transmission is equal to $2T_{\text{CN-AR}}(S_c) + 2T_{\text{AR-AR}}(S_c, H_{\text{AR-AR}})$. Then, the data packet will be forwarded directly from CN to MN. Thus, we obtain the BQD as follows:

$$\begin{aligned}\mathrm{BQD_{LISP-MN-HD3}} &= 2\times T_{\mathrm{CN-AR}}(S_c)\\ &+ 2\times T_{\mathrm{AR-AR}}(S_c\ , H_{\mathrm{AR-AR}})\end{aligned}$$

The probability for Case 3 is $(N_{\text{AR}} - 2)/N_{\text{AR}}$. Therefore, we obtain the TSD as

$$\mathrm{TSD_{LISP-MN-HD3}} = \left(\frac{N_{\mathrm{AR}}-2}{N_{\mathrm{AR}}}\right) \times \{\mathrm{BUD_{LISP-MN-HD3}} + \mathrm{BQD_{LISP-MN-HD3}}\}$$

Overall, we obtain the TSD of LISP-MN-HD with 3 possible cases as follows:

$$\begin{aligned}\mathrm{TSD_{LISP-MN-HD}} &= \mathrm{TSD_{LISP-MN-HD1}} + \mathrm{TSD_{LISP-MN-HD2}}\\ &+ \mathrm{TSD_{LISP-MN-HD3}}\end{aligned}$$

4.4 | Numerical results

Based on the analytical equations given 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 4, by referring to Makaya and Pierre.[21]

4.4.1 | Control traffic overhead

Figure 14 compares the number of control messages to be processed by LMS or D-LMS for different N_{Host}. We can see that the proposed LISP-MN-HD scheme provides smaller CTO than the existing LISP-MN-GLAB scheme. This is because all mapping control messages shall be processed by LMS in the existing scheme, whereas in the proposed LISP-MN-HD scheme, the mapping control traffic is distributed onto the D-LMSs in the network. The gaps of performance between centralized and distributed schemes become larger as the number of hosts in the network increases.

TABLE 4 Default parameter values

Parameter	Default	Minimum	Maximum
L_{wl}	10	1	55
$H_{\text{AR-GW}}$	10	1	55
L_{w}	2	1	10
N_{Host}	100	1	1000
N_{AR}	30	10	100
$H_{\text{AR-AR}}$	$\sqrt{N_{\text{AR}}}$		
$H_{\text{GW-MS}}$	20		
$H_{\text{MN-AR}}$, $H_{\text{CN-AR}}$	1		
N_{GW}	50		
S_{c}	96 bytes		
B_{wl}	11 Mbps		
B_{w}	100 Mbps		

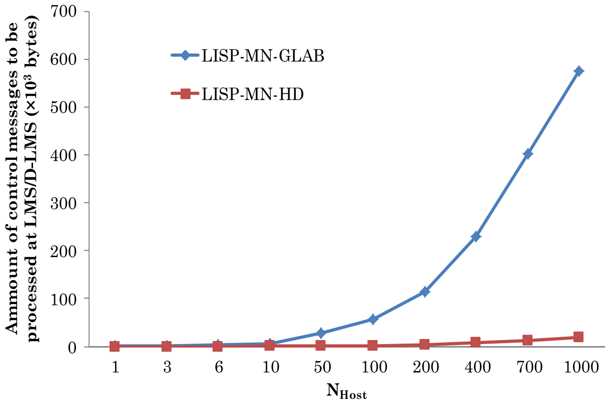

FIGURE 14 Effect of N_{Host} on control traffic overhead

Figure 15 compares the number of control messages to be processed by LMS or D-LMS for different N_{AR}. We can see that the proposed scheme is not affected by N_{AR}, differently from the existing scheme. This is because all mapping control messages shall be processed by the central LMS in the

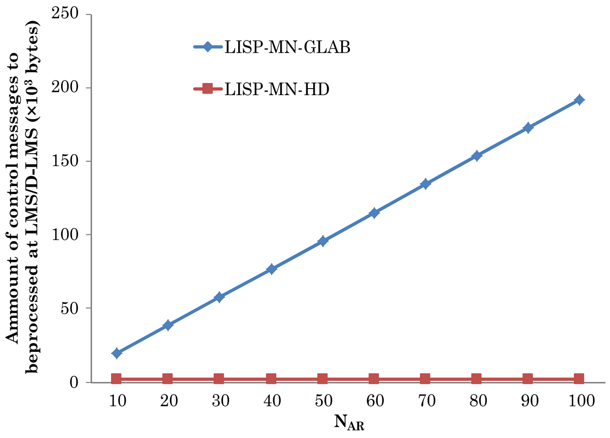

FIGURE 15 Effect of N_{AR} on control traffic overhead

existing scheme, whereas, in the proposed scheme, the mapping control traffics are processed by each D-LMS/AR in the network.

4.4.2 | Total signaling delay

Figure 16 shows the effect of wireless link delay (L_{wl}) on TSD. From the figure, we can see that the TSD linearly increases as L_{wl} becomes larger for all the candidate schemes. It is shown that the proposed LISP-MN-HD scheme provides better performance than the existing 2 schemes. LISP-MN-GLAB provides better performance than LISP-MN because LISP-MN-GLAB uses an LMS for binding query operations.

Figure 17 shows the effect of wired link delay (L_w) on TSD. It is shown that the proposed LISP-MN-HD scheme provides better performance than the existing LISP-MN and LISP-MN-GLAB schemes. This implies that the proposed scheme provides a performance gain over the existing schemes for wired links as well as for wireless links.

Figure 18 compares the TSD for different hop counts between AR and GW ($H_{AR\text{-}GW}$). In the figure, we can see that LISP-MN-GLAB provides better performance than LISP-MN-HD until the hop count reaches 2. However, if the hop count is greater than 2, the proposed LISP-MN-HD scheme provides smaller delays than the 2 existing schemes, and the performance gaps between candidate schemes become larger as $H_{AR\text{-}GW}$ increases.

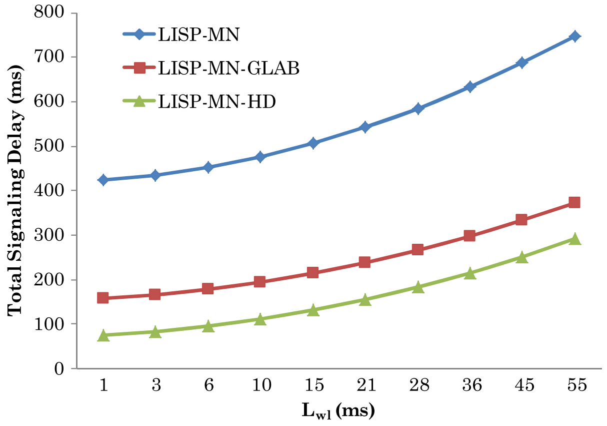

FIGURE 16 Effect of L_{wl} on TSD

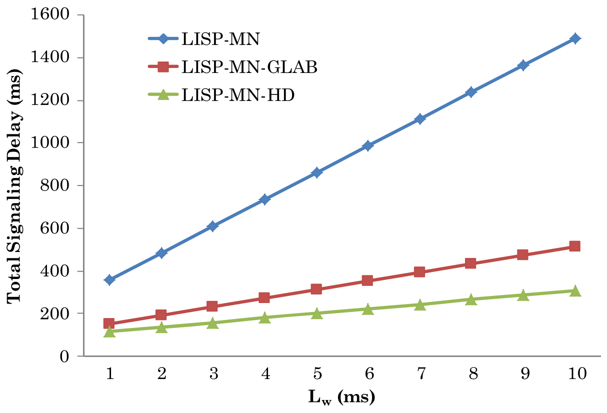

FIGURE 17 Effect of L_w on TSD

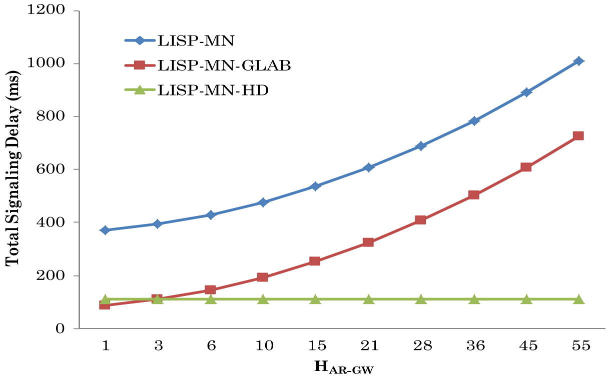

FIGURE 18 Effect of $H_{AR\text{-}GW}$ on TSD

Figure 19 shows the effect of the number of ARs (N_{AR}) on TSD. From the figure, the TSD slightly increases as N_{AR} becomes larger for the proposed schemes. This implies that the proposed hash-based distributed scheme is much preferred in the mobile network with a smaller number of AR. Overall, the proposed distributed scheme provides much smaller TSD than the existing schemes. This is because *Map-Request and Map Register* messages are processed by a nearby D-LMS/AR in the proposed distributed scheme, whereas the Map Register and Request is processed by the distant central LMS and/or MS in the existing scheme.

4.4.3 | Discussion

In addition to the numerical analysis and results until now, we discuss the qualitative comparison of centralized and distributed approaches. Table 5 summarizes the pros and cons of centralized and distributed approaches by functionality.

Centralized schemes maintain the data path between a central network entity and the host. A single data path is maintained per host. The tunnel management is easy to deploy and broadly used. However, those tunnels tend to induce data overhead due to encapsulations and data processing. Tunnels header compression may also add further

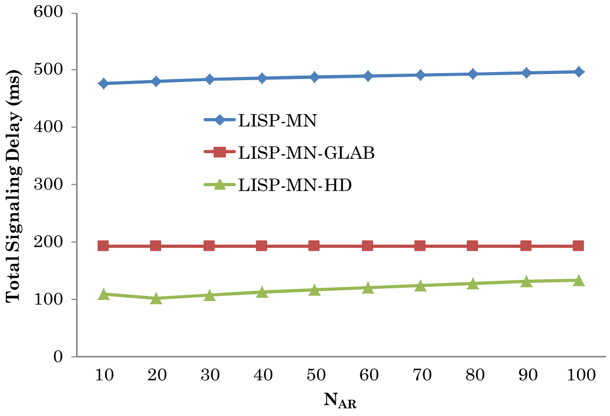

FIGURE 19 Effect of N_{AR} on TSD

TABLE 5 Qualitative analysis of centralized and distributed schemes

Functionality		Centralized	Distributed
Encapsulation	Pros	Single path per host	No tunnel is required when the active host is motionless Avoid unnecessary overhead
	Cons	Permanent tunnel per active host Overhead in processing	
Tunnel management	Pros	Easy to deploy	Temporary tunnel endpoints distributed at access node level Avoid single point of failures
	Cons	Huge aggregated traffic in network Bottlenecks/single point of failure	Multiple interaccess node tunnels per host situation
User context	Pros	Easy to administrate	Avoid scalability issues
	Cons	Dimensioning of central mobility agents, scalability	Contexts replication (eg, for a host with flows on different anchors)

processing. This induced overhead may affect core network links as well as access networks. In the centralized schemes, the central entities need to maintain per-user tunneling contexts, which may cause scalability issues. The aggregated traffic is huge, and a mobile data traffic explosion may occur. The data path centralization tends to induce a single point of failure and bottleneck issues.

On the other hand, in distributed schemes, only the necessary and temporary tunnels are used between access nodes. If a MN does not move, its data traffic can be simply routed without additional overhead. The tunnel endpoints are located at the access level, thus the rest of the network is not affected. This can reduce the processing overhead for encapsulation and decapsulation. However, each access node may need to be maintained in per-user context. An active host may have parallel data flows that are anchored at different access nodes. The user contexts and tunnel maintenance are distributed among access nodes, which is helpful to avoid the single point of failure and bottleneck issues. When the flows of a moving host are anchored on different access nodes, they require several parallel updates. Delays and packet loss may be affected by the distance between access nodes.

5 | CONCLUSION

In this article, we propose a hash-based distributed mapping control of identifiers and locators in the LISP-based mobile networks. In the proposed scheme, it is assumed that each AR in the mobile network has a D-LMS. For a mobile host, a D-LMS is designated to manage the associated EID-LLOC mapping by using a hash function. For roaming support, each gateway has a D-GMS that maintains the vELR. From the numerical results, we can see that the proposed scheme reduces the CTO at map servers and the TSD compared to the existing schemes.

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