Implementing Endpoint Identifier Local Locator Mapping Tables for Reducing Packet Switching Time Delays

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Abstract

The Internet Engineering Task Force proposed the Locator Identifier Separation Protocol. This has the objectives of separating the endpoint identifier (EID) and routing locator (RLOC), which was originally used as the identifier and locator of nodes, to save and manage the EID-RLOC mapping tables by using the map server, and to perform route processing according to the EID-RLOC mapping relationship.

The current study proposes an LISP-EID-local locator mapping table (LISP-ELMT) transmission scheme. In contrast to map caching, the ELMT scheme proposed an extension of the map cache table storing source and destination EID-RLOC instead of only destination EID-RLOC. When movements occur, the new positions of RLOCs in the ELMT are compared to notify the original and destination RLOCs, therefore reducing the complexity of mapping database protocols between RLOCs and the map server. The results indicated that the ELMT provided more information for map caching and consequently resulted in a time delay reduction of approximately 35%-50% during the packet switching of mobile nodes. Compared with LISP-mobile node, LISP-proxy mobile IP, and LISP-distributed handover control (LISP-DHC) methods, the LISP-ELMT scheme registered a more effective reduction in the influence of time delay in wired connections.

Keywords: Handover control, Locator Identifier Separation Protocol (LISP), Mapping tables

1 Introduction

In current network operation, because of Internet protocol (IP) technologies, the following conditions are observed when devices undergo Layer 3 switching: (1) After a device is moved, a new network segment IP address is registered in the destination router and a new gateway location is provided to conform to traditional network operation schemes. However, because this interrupts the original data connection, the received packets must be retransmitted. (2) When a device is moved to new areas without changing the IP address, a tunnel relationship must be established between the source and destination routers to redirect the traffic from the default gateway via the established tunnel to the new corresponding area of extension. In this method, area extension is achieved and the transmission of the initially received packets is continued without the necessity of establishing new connections. However, this technique results in additional traffic and increased time delays during packet transmission [1].

The Internet Engineering Task Force (IETF) proposed a new routing protocol named Locator Identifier Separation Protocol (LISP) [2-4]. The objectives of this protocol are to separate the endpoint identifier (EID) and routing locator (RLOC) from the source IP address used for identifying and locating nodes, to save and manage the EID-RLOC mapping tables by using the map server (MS), and to perform route processing according to the EID-RLOC mapping relationship. An EID-RLOC mapping table is generated in the MS when RLOCs register EIDs on the map server (MS). When a source and destination first establish a transmission, the source RLOC transmits a map request to the MS. After the destination EIDs and corresponding RLOCs are identified, an EID-RLOC mapping table is generated and stored in the RLOC map cache table. The EID-RLOC mapping relationship is stored in the map cache table for 24 hours. In addition, TRs can be categorized as ingress TR (ITR) and egress TR (ETR). The ITR encapsulates source data in the LISP headers, and ETR decapsulates and delivers source data to destination node.

Regarding the development of the LISP, the deployment of an effective LISP network environment was investigated in [5], and the LISP was argued to be applicable to IPv6 environments in the future [6-7]. The performance of LISP applications can be enhanced by separating the EIDs and local locators (RLOCs) in LISP networks [8-9].

Numerous studies have discussed the application and improvement of the LISP [10-13]. Scholars have

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proposed various schemes, and such schemes include LISP-MS [14], LISP alternative topology [15], LISP not-so-novel EID-to-RLOC database [16], LISP distributed hash table (LISP-DHT) [17, 25], and the content distribution overlay network service for LISP [18]. A similarity among these schemes is that the EIDs are expected to be successfully aggregated within the edge network. However, when a mobile device switches networks with its EID, the aggregation process becomes difficult. Therefore, several improvements were suggested in [19].

To solve the aggregation problem encountered in RLOCs when EIDs move to other networks, host-based schemes have been successively proposed in [20-22]; in these schemes, mobile devices were combined with ITR/ETR to reduce the aggregation difficulty. Moreover, network-based schemes were subsequently developed in [22]. Specifically, the tunnel router (TR) and border router (BR) were integrated to overcome the extremely high demand of host-based schemes on hardware performance.

Gohar and his colleagues adopted a distributed architecture to relieve the burden of MS and unnecessary network traffic [23-24]. The distributed architecture can substantially reduce the handover latency during the movement of mobile devices [23-25].

The current study proposes an LISP-EID-local locator mapping table (LISP-ELMT) transmission scheme. In this scheme, the EID-RLOC cache table required in the transmission process is sent to the corresponding RLOCs of the source and destination as soon as the source and destination establish data transmission. This method enables rapidly transmitting destination data to the corresponding new RLOC when mobile devices switch to new locations, reducing counts of map request and map replay between RLOCs and map server. Moreover, in this study, various schemes involving LISP-ELMT, LISP-DHC, LISP mobile node (LISP-MN), and LISP-proxy mobile IP (LISP-PMIP) were compared; these comparisons were performed to understand how to effectively improve the overall transmission performance in situations involving various moving distances for mobile devices and how to enhance the LISP performance. This study verified that the proposed LISP-ELMT scheme can satisfy for current mobile network demands. Section 2 presents the centralized and distributed architectures. The proposed LISP-ELMT scheme is explained in Section 3. Section 4 presents the analysis and comparison data, and Section 5 presents the conclusion.

2 Literature Review

2.1 Scheme Overview

The current LISP-based handover mechanisms for mobile devices are divided into host-based and network-based schemes [23]. For example, LISP-MN, which was proposed by Farinacci et al. [3], is a host-based scheme that entails using an MN as the ITR/ETR equipment to simulate the functionality of TRs. The MN can obtain the IP address of the destination host from an MS by temporarily storing the map cache information. This thus ensures the possibility of direct data transmission between hosts. However, the LISP-MN scheme is not practical because numerous procedures are involved.

Choi et al. [22] proposed the LISP-PMIP scheme, which includes a global mobility anchor tunnel point (GMATP) and local mobility anchor tunnel point (LMATP). GMATPs can replace the function of traditional TRs and can manage the EIDs of local hosts and connections to outside hosts. LMATPs act as traditional access routers (ARs) for detecting the movement of hosts.

Gohar and Koh proposed the LISP-DHC scheme [24] in which a distributed scheme is adopted. The routers in the network are divided into various groups, and the ARs in the same domain serve as TRs. Thus, unnecessary network traffic can be reduced.

The terms used in this paper are defined as follows:

(1) Tunnel router (TR): A border routing device that encapsulates and decapsulates LISP packets.

(2) Ingress tunnel router (ITR): A device that encapsulates packets with LISP headers and sends the packets to the endpoints.

(3) Egress tunnel router (ETR): A device that decapsulates the LISP-encapsulated packets.

(4) Service area (SA): An area formed by a set of ITR and ETR.

(5) Destination node (DN): The node of the destination.

(6) Mobile node (MN): The node of the mobile device.

(7) Access router (AR): AR refers to the node of the access point within SA. One SA may involve one or numerous ARs.

Figure 1 illustrates the operating procedure of the LISP network. When mobile devices switch from ARold to ARnew router locations, ARnew proceeds to the map register in the MS (local MS; LMS), during which the MS simultaneously updates the EID-RLOC table. Via the AR, the destination router sends map search requests to the MS and obtains the EID and RLOC where the mobile devices are located. The DN and MN then reestablish data connection.

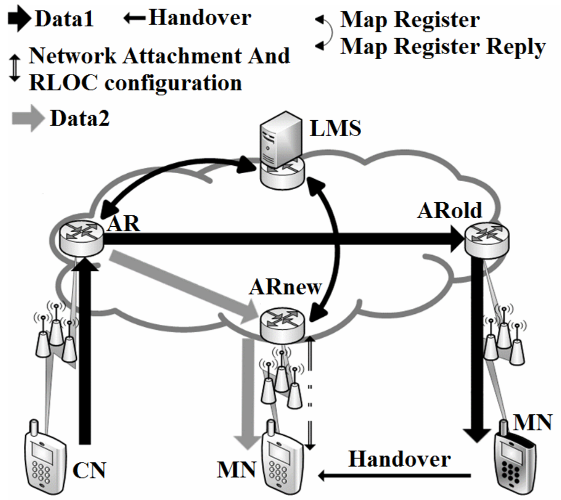


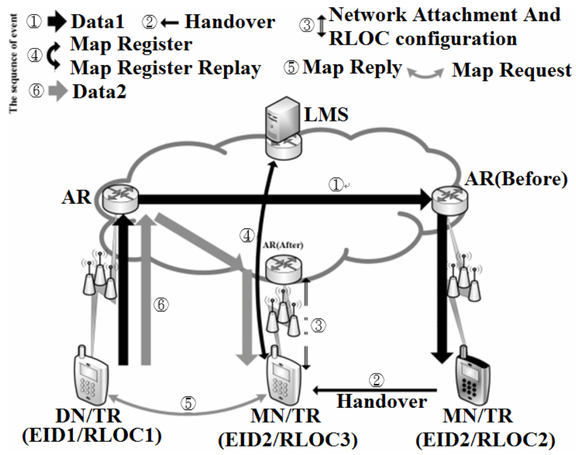
Figure 1. LISP scheme network switching process

The mobile device handover procedures in the LISP-MN, LISP-PMIP, and LISP-DHC schemes are elucidated as follows: Figure 2(a) illustrates the handover process in the LISP-MN scheme.

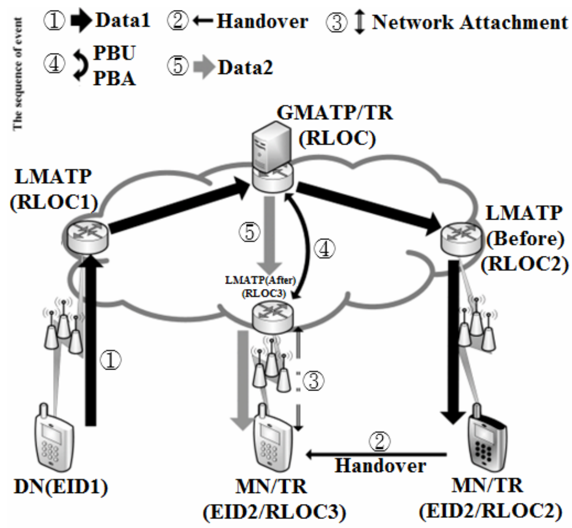
When data transmission is established (Step 1), MN/TR (EID2/RLOC2) obtains a DN/TR map cache through LMSs and receives data from DN/TR(EID1/RLOC1). When a mobile device (i.e., MN/TR) is moved from the EID2/RLOC2 location to EID2/RLOC3 (Step 2), EID2/RLOC3 registers with AR(After) and acquires a new IP address (Step 3). Subsequently, MN/TR sends a map register message to the LMS (Step 4), and MN/TR (EID2/RLOC3) notifies DN/TR (EID1/RLOC1) of an MN's new location (Step 5). Therefore, DN/TR (EID1/RLOC1) can appropriately send data to the MN's new location MN/TR (EID2/RLOC3) (Step 6).

Figure 2(b) illustrates the handover procedures of LISP-PMIP scheme. Step 1 involves the assumption that the data transmission has been initiated. When an MN device is moved from the LMATP (Before) network to that of LMATP (After) (Step 2), it is only required to notify LMATP (After) of its new location (Step 3). In Step 4, LMATP (After) delivers Proxy Binding Update (PBU) packets to GMATP/TR (RLOC), which manages the entire domain, to update the MN's new location. After the Proxy Binding Acknowledgement (PBA) packets are sent back to the LMATP (After), data transmission can be continued as shown in Step 5.

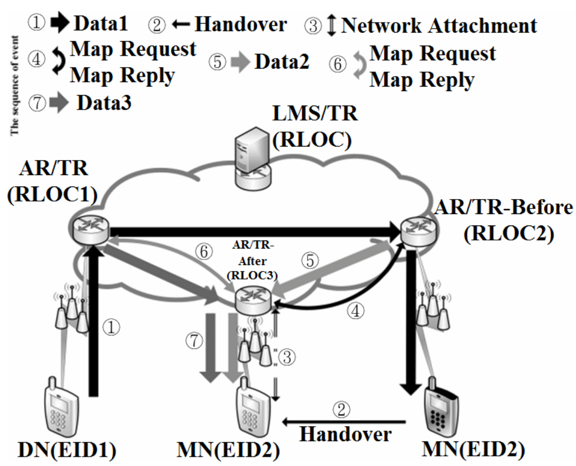
Figure 2(c) depicts the LISP-DHC handover process. Step 1 involves the assumption that the data transmission has been initiated. When an MN moves from the AR/TR (Before) network to that of AR/TR (After) (Step 2), it sends a notification message to AR/TR (After) regarding its new location (Step 3). In Step 4, AR/TR (After) sends a map request to AR/TR (Before) to update the new location of the MN and then receives a map reply. Subsequently, data transmission can be reinitiated as shown in Step 5. In Step 6, AR/TR (After) sends a map request to AR (RLOC1) to update the new location of the MN (EID2) and waits for the map reply from AR (RLOC1). Finally, AR/TR (After) receives data from AR (RLOC1) to complete the whole handover and convergence process (Step 7).



(a) A handover of the LISP-MN scheme



(b) A handover simulation of the LISP-PMIP scheme



(c) A handover simulation of the LISP-DHC scheme

Figure 2.

3 LISP-ELMT Scheme

When Layer 3 switching occurs during data transmission in mobile devices, in current routing schemes, the transmission process is interrupted because a new IP address must be registered at the new gateway location after the movement. When this occurs during data transmission, the previously transmitted data becomes completely invalid because of the newly acquired IP address during the Layer 3 switching, thus necessitating a new transmission.

The subsequent section describes the operating methods of the LISP-MS and map cache and the proposed LISP-ELMT scheme.

3.1 LISP-MS and Map Cache Operation

When a connection is established, the map cache content information (Table 1) can be observed on the SR/TR (RLOC1). This information is primarily comprised of the mapping relationships of the destination RLOC (i.e., 10.22.0.2) and EID (i.e., 112.1.1.102/32). When mobile devices move from 10.22.0.2 (RLOC2) to 10.33.0.2 (RLOC3), RLOC2 and RLOC3 update the map register after the movement (Table 2). Subsequently, RLOC1 sends a map request to MS and waits for a map replay from MS to obtain the updated RLOC location. RLOC1 updates its own map cache content of destination RLOC location from 10.22.0.2 (RLOC2) to 10.33.0.2 (RLOC3) (Table 3).

Table 1. Contents of the map cache table (before movement) in RLOC1

destination EID	uptime	expires	vis	complete
112.1.1.102/32	00:13:54	23:46:05	Map-reply	complete
destination RLOC		uptime	state	Pri/Wgt
10.22.0.2		00:13:54	Up, self	10/50

Table 2. Information stored in the Ms

	Site Name	Last Register	up	Who Last Register	EID Prefix
	RLOC1	00:00:50	yes	10.11.0.2	111.1.1.1/32
	RLOC2	never	no	--	113.1.1.0/24
Before movement	RLOC2	00:00:33	yes	10.22.0.2	112.1.1.102/32
After movement	RLOC3	00:00:33	yes	10.33.0.2	112.1.1.102/32

Table 3. Contents of the map cache table (after movement) in RLOC1

DST EID	uptime	expires	vis	complete
112.1.1.102/32	00:17:30	23:59:05	Map-reply	complete
DST RLOC		uptime	state	Pri/Wgt
10.33.0.2		00:00:54	Up, self	10/50

LISP-MS involves storing only destination EID-RLOC mapping tables, but LISP-MS needs to wait a period of time to get the updated EID and RLOC locations from MS. In this study, the ELMT proposed an extension of the map cache table by storing source and destination EID-RLOCs. When movements occur, RLOCs in the ELMT are compared before the movements and to expedite the transmission process during the mobile device packet switching. This method can be used to enhance the entire process and speed of Layer 3 switching. Section 3.2 describes the operating method and execution steps of the LISP-ELMT in detail.

3.2 LISP-ELMT Operation

In the ELMT Table, 4 B are used for the entry of the current data transmission number to enable correct update, and 64 B are separately reserved for storing the IPs of the source and destination RLOCs and EIDs. During the first communication, the corresponding extension of the map table is generated by MS in which the mobile devices are located. The remaining 2 B are reserved for the flag (1 b) and the cache table live time (15 b). The flag indicates whether the source or destination EID devices within the data entry belong to the RLOC. A flag number of 0 indicates that neither EID devices are in this RLOC or that movement has occurred. Consequently, data cannot be transmitted at this point in time. A flag number of 1 denotes that either or both the source and destination EID devices exist in RLOCs. When one of RLOCs identifies missing EID device, the flag number is switched from 1 to 0, which triggers the live-time countdown. If the MS updates cannot be received before the live-time countdown is completed, the source or destination EID devices are then considered missing, and RLOC must thus notify the MS that the number connection is missing. When RLOC identifies EID devices movements, the information provided by the ELMT table is compared. If the information contains the EID, the flag would be switched from 0 to 1 and correct data would be updated for the number in the MS (Table 4). Update or invalidity notifications and live-time reset for neighboring RLOCs can be initiated only from RLOCs that switched flags. When devices move to a new RLOC that does not contain the corresponding EID information, the ELMT table can be actively obtained by the new RLOC from the premovement RLOC. When the transmission of the current entry of connection data is completed, an invalidity notification for the corresponding ELMT number is transmitted from the RLOC to the MS, which then notifies the other RLOCs of cache invalidity, thus completing the process. The method that entails integrating map cache with ELMT can be applied in mobile devices or server machine movements. However, additional storage space is necessary.

Table 4. Contents of the ELMT in the source RLOC

ELMT number	Source EID IP	Source RLOC IP	Destination EID IP	Destination RLOC IP	Flag	Live Time
1	112.1.1.102	10.22.0.2	111.1.1.1	10.11.0.2	0	107s
2	112.1.1.102	10.22.0.2	111.1.1.1	10.22.0.2	0	107s
3	112.1.1.90	10.22.0.2	201.25.31.26	170.16.100.30	1	300s
4	112.1.1.117	10.22.0.2	100.101.1.123	50.50.50.254	1	300s

3.3 LISP-ELMT Switch Scheme

The example illustrated in Figure 3 indicates that the DN (EID1) and MN (EID2) IP addresses 111.1.1.1 and 112.1.1.102 are in a state of connection (Step 1). Thus, when this data transmission entry is established, the MS transmits the required ELMT information (Table 4) to other RLOCs such as RLOC1 and RLOC3 to generate the contents shown in Table 5. At this time, MN (EID2) has not switched to other neighboring networks. Subsequently, MN (EID2) moves from RLOC2 to RLOC3 (see Step 2). MN (EID2) connects with RLOC3. RLOC3 notifies RLOC2 to transfer the transmission packets to RLOC3; this notification is conducted through the gateway address in resolution protocol table of MN (EID2). Simultaneously, RLOC2 transmits an event trigger message to RLOC1 to notify that MN (EID2) has disconnected from its subnetwork. Consequently, the flag in the ELMT of RLOC1 is switched from 1 to 0 and any ongoing data transfers are paused. Furthermore, the update request of RLOC3 corresponding to MN (EID2) is queued (Step 3). The RLOC3 then faces one of two situations. 1. If the map cache in RLOC3 does not contain the corresponding DN (111.1.1.1) and RLOC1 (10.11.0.2) mapping information to signify that the connection from RLOC3 to RLOC1 is new, the ELMT table (Table 5) can add the corresponding information into the map cache. 2. If the map cache contains the corresponding DN(111.1.1.1) and RLOC1(10.11.0.2) information to mean that RLOC3 to RLOC1 have connected before, the corresponding information connects RLOC1 and RLOC3 by using the EID (111.1.1.1) and RLOC1 (10.11.0.2) mapping information (destination EID IP and RLOC IP) in the ELMT (Table 5). Data are continually transmitted in Steps 4 and 5 according to the routes after the update. Finally, route update is performed by RLOC3 to the MS according to Step 6.

During the handover process, the various moving directions of mobile devices may lead to changes in network latency. A device may be subject to three movement situations. In the first situation (approaching), the device is moved from a tunnel point far from the destination host to a point close to the host. In the second situation (away), the device is moved from a tunnel point near the destination host to a distant point. In the third situation (equidistance), the distance remains unchanged.

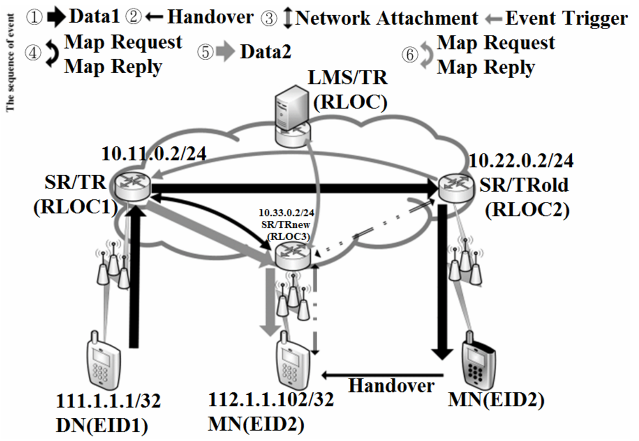


Figure 3. A network switching simulation diagram in the LISP-ELMT scheme

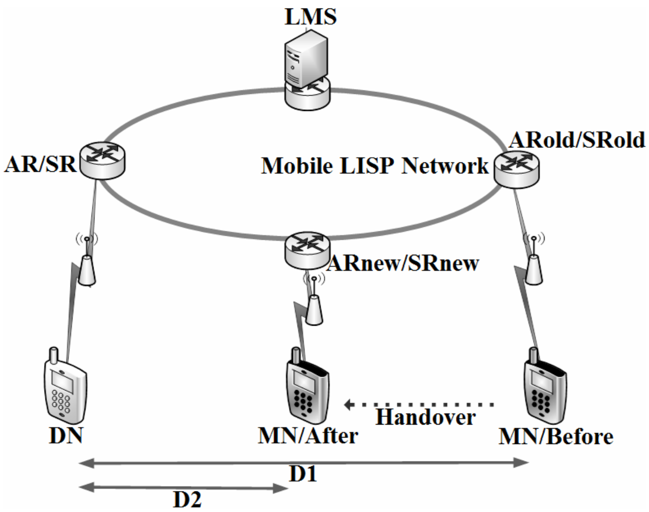
Table 5. Contents of the ELMT in the RLOC2

ELMT number	Source EID IP	Source RLOC IP	Destination EID IP	Destination RLOC IP	Flag	Live Time
1 (before movement)	112.1.1.102	10.22.0.2	1111.1.1.1	10.11.02	1	300s
1 (during movement)	112.1.1.102	10.22.0.2	1111.1.1.1	10.11.02	0	107s
1 (after movement)	112.1.1.102	10.33.0.2	1111.1.1.1	10.11.02	1	300s
2 (before movement)	112.1.1.102	10.22.0.2	101.1.1.1	10.11.02	1	300s
2 (during movement)	112.1.1.102	10.22.0.2	101.1.1.1	10.11.02	0	107s
2 (after movement)	112.1.1.102	10.33.0.2	101.1.1.1	10.11.02	1	300s
3	112.1.1.90	10.22.0.2	201.25.31.26	170.16.100.30	1	300s
4	112.1.1.117	10.22.0.2	100.101.1.123	50.50.50.254	1	300s

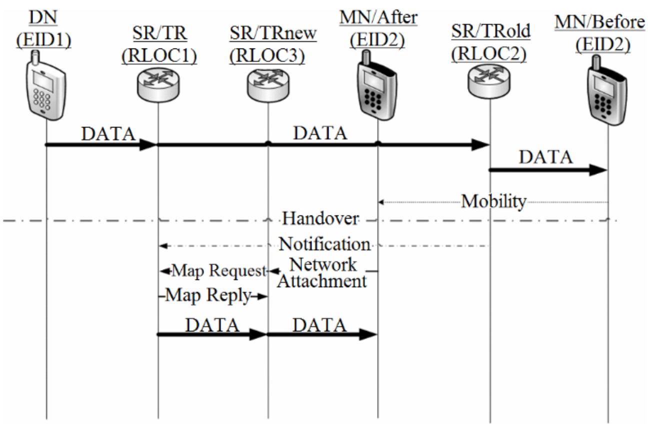
3.4 Three Situations in the LISP-ELMT Scheme

The relative distance between the source and destination EID devices after the movement of the mobile device may be one of the following situations: (1) the distance between the two devices reduces, (2) distance between the two devices increases, and (3) distance between the two devices remains unchanged. These situations are analyzed as follows:

Situation 1 (Approaching). The approaching situation was defined as a mobile device approaching its destination (Figure 4). As illustrated in Figure 4(a), MN/Before denotes the location of the mobile device when it just began receiving data from the destination (i.e., the DN) before moving. MN/After indicates the location of the device after its movement. D1 represents the distance between MN/Before and the DN, and D2 indicates the distance between MN/After and the DN. In the situation of approaching, D2 was shorter than D1, indicating that the distance between the device and the DN decreased. Figure 4(b) depicts the entire handover process. The route of data transmission from the DN to MN/Before was longer than that from DN to MN/After. Thus, the overall network latency may be reduced because of the decreased distance.



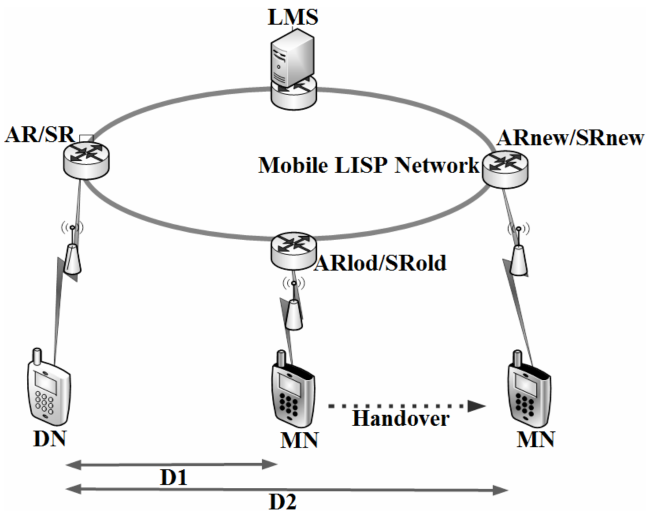
(a) Handover simulation (approaching) in the LISP-ELMT scheme



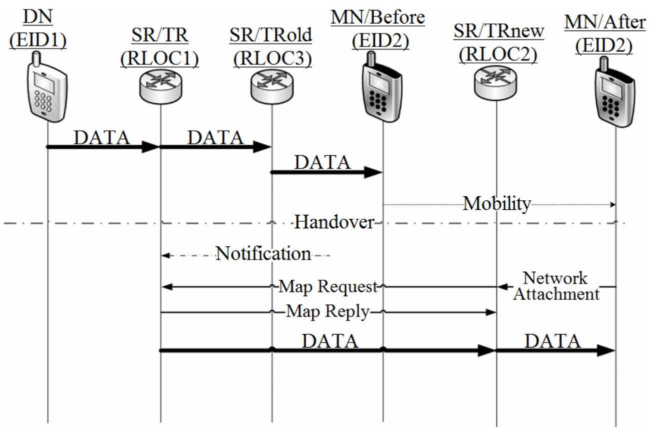
(b) Handover process (approaching) in the LISP-ELMT scheme

Figure 4.

Situation 2 (Away). The away situation was defined as a mobile device moving away from its destination (Figure 5). As shown in Figure 5(a), MN/Before represents the location of the mobile device when it just started receiving data from the DN before moving. MN/After denotes the location of the device after it moved. D1 represents the distance between MN/Before and the DN, and D2 indicates the distance between MN/After and the DN. In away situations, D2 was longer than D1; that is, the distance between the device and the DN increased. Figure 5(b) illustrates the entire handover process. The route of data transmission from DN to MN/Before was shorter than that from DN to MN/After. Thus, the overall network latency may be increased because of increased distance.



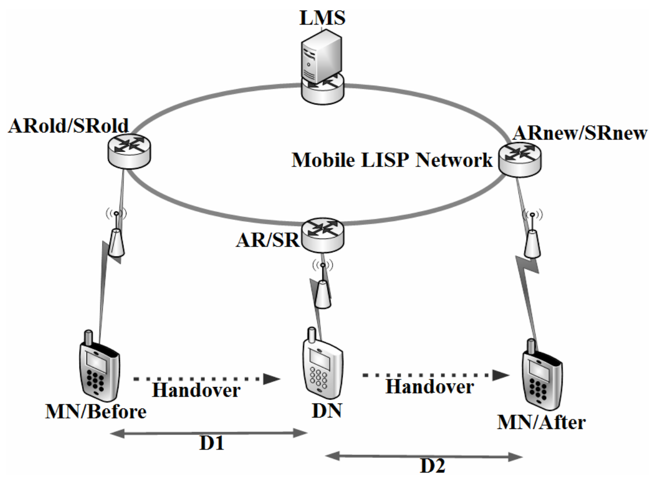
(a) Handover simulation (away) in the LISP-ELMT scheme



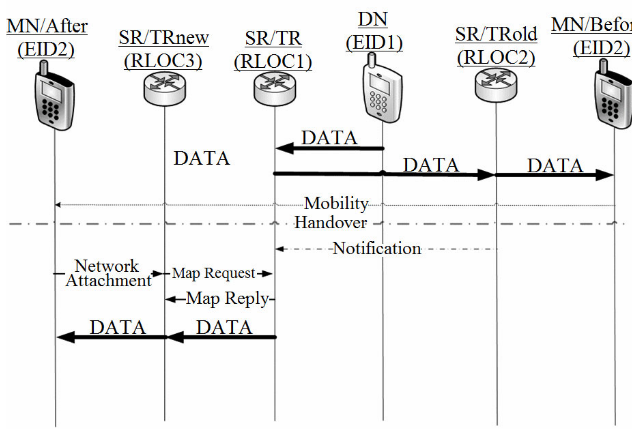
(b) Handover process (away) in the LISP-ELMT scheme

Figure 5.

Situation 3 (Equidistance). The equidistance situation was defined as the distance between a mobile device and its destination remained unchanged after the device was moved (Figure 6). As depicted in Figure 6(a), MN/Before represents the location of the mobile device when it just started receiving data from the DN before moving. MN/After denotes the location of the device after it moved. D1 represents the distance between MN/Before and the DN, and D2 indicates the distance between MN/After and the DN. In the equidistance situation, D1 was equal to D2, indicating that the distance between the device and the DN remained the same after the device moved. Figure 6(b) shows the entire handover process. The data transmission route from the DN to MN/Before was similar than that from the DN to MN/After. Thus, the overall network latency may remain constant because of the movement of the device.



(a) Handover simulation (equidistance) in the LISP-ELMT scheme



(b) Handover simulation (equidistance) in the LISP-ELMT scheme

Figure 6.

4 Performance Analysis

In this study, equipment such as AR/RLOC1 (10.11.0.2/24), ARnew/RLOC2 (10.22.0.2), ARold/RLOC3 (10.33.0.2), and MSs were implemented in the OpenLISP open-source program to simulate the LISP network encapsulation and decapsulation environments. Furthermore, ELMT was implemented in AR/RLOC1, ARnew/RLOC2, and ARold/RLOC3. The OpenLISP control plan was mounted in a FreeBSD operating system environment. Figure 7 (the first red box) illustrates the cache connection established for data transmission between AR/RLOC1 and ARold/RLOC3; 1 min and 57 s after AR/RLOC1 received a notification, the mobile devices were switched to ARnew/RLOC2. The second and third red boxes depicted in Figure 7 indicate the cache connection for data transmission established between AR/RLOC1 and ARnew/RLOC2. The simulation results indicated that the proposed ELMT can reduce packet switching delay during mobile device movements.

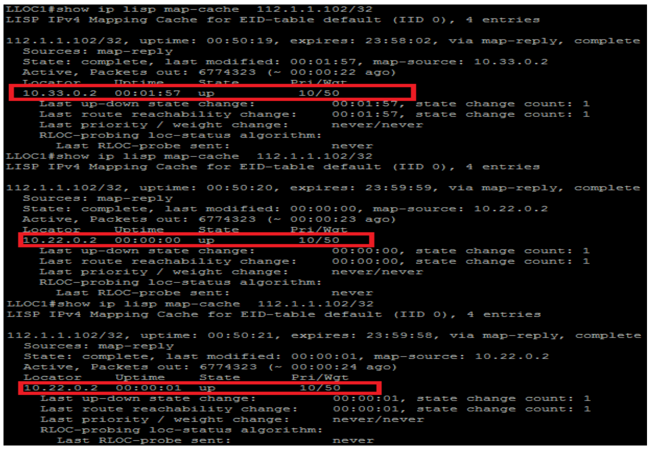


Figure 7. Handover cache record of RLOC1 from RLOC3 to RLOC2

4.1 Three Situations in the LISP-ELMT Scheme

In this study, the analysis approach proposed by Gohar and Koh [24] was adopted and mobile device handover was simulated in a single domain by using the network environment simulation diagram (Figure 8). In such a domain, BR/GMATP/LMS was used to serve the entire network, and AR/SR/LMATPs were used to serve the subnetworks.

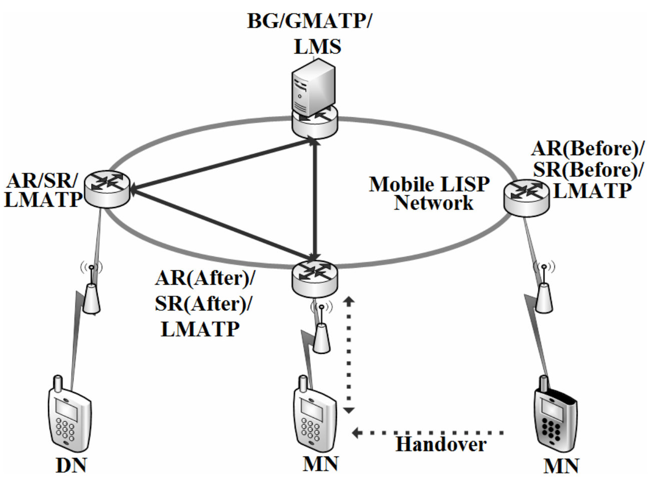


Figure 8. Handover simulation diagram

As shown in Figure 8, the MNs were connected to AR/SR/LMATPs by a wireless network, whereas BG/GMATP/LMS was connected to AR/SR/LMATPs by a wired network.

The transmission latency during data transmission through the wireless network was denoted as t(s) and defined (Table 6) using the following equations:
When control packets were transmitted,

$$t(s) = [(L_C / B_{wi}) + D_{wi}] \quad \textbf{(1)}$$

When data packets were transmitted,

$$t(s) = [(L_d / B_{wi}) + D_{wi}] \quad \textbf{(2)}$$

Table 6. Parameters used in the analysis

Parameters	Description
L_C	The size of control packets
L_d	The size of data packets
B_w	Wired network bankwidth
B_{wi}	Wireless network bankwidth
D_w	Wired connection latency
D_{wi}	Wireless connection latency
C_{a-b}	Number of routers between node a and node b
D_{RP}	Lookup latency and treatment latency of routers
D_M	Detection latency during the movement of nodes
D_S	Handover latency

The transmission latency during the data transmission through the wired network was denoted as t(s, $C_{x\text{-}y}$) and defined as follows:
When control packets were transmitted,

$$t(s, C_{x-y}) = C_{x-y} \times [(L_c / B_w) + D_{wi}] + (C_{x-y} + 1) \times D_{RP} \quad (3)$$

When data packets were transmitted,

$$t(s, C_{x-y}) = C_{x-y} \times [(L_d / B_w) + D_{wi}] + (C_{x-y} + 1) \times D_{RP} \quad (4)$$

4.2 Data Analysis

The LISP-DHC and LISP-ELMT schemes were compared using convergence latency (CL) analysis.

LISP-DHC. The CL of LISP-DHC was calculated using equation (5):

$$CL_{LISP-DHC} = D_S + D_M + 2 \times T_{AR_b - AR_a}(L_C) + T_{AR_b - AR_a}(L_d) + T_{AR_a - MN}(L_d) + 2 \times T_{AR_b - AR}(L_c) + T_{AR_a - MN}(L_d) \quad (5)$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, and $2 \times T_{AR_b - AR_a}(L_c)$ is the map requests and replies delivered between the AR(Before) and AR(After). The data transmission latency between AR(Before) and AR(After) is $T_{AR_b - AR_a}(L_d)$, and that between AR(After) and MN is $T_{AR_a - MN}(L_d)$. The map request and reply as well as the data transmission latency between AR(After) and AR are signified as $2 \times T_{AR_a - AR}(L_c)$ and $T_{AR_a - AR}(L_d)$, respectively.

Subsequently, equation (6) was obtain by substituting equation (3) and equation (4) into equation (5).

$$\begin{aligned} CL_{LISP-DHC} = {} & D_S + D_M + 2 \times [C_{AR_b - AR_a} \times \\ & ((L_C / B_w) + D_w) + (C_{AR_b - AR_a} + 1 \times D_{RP}] + \\ & [C_{AR_b - AR_a} \times ((L_C / B_w) + D_w) + \\ & (C_{AR_b - AR_a} + 1 \times D_{RP}] \times ((L_d / B_w) + \\ & D_{wl}) + 2 \times [C_{AR_b - AR_a} \times ((L_C / B_w) + D_w) + \\ & (C_{AR_b - AR} + 1 \times D_{RP}] \times [C_{AR_b - AR} \times \\ & ((L_d / B_w) + D_w) + (C_{AR_a - AR} + 1 \times D_{RP}] \end{aligned} \quad (6)$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, $C_{AR_b - AR_a}$ is the number routers between the AR(Before) and AR(After), L_C is the size of control packets, B_w is the bandwidth of wired network, D_w is the latency of wired network, D_{RP} is the lookup latency of routers, B_{wi} is the bandwidth of wireless network, D_{wi} is the latency of wireless network, L_d is the size of data packets, $C_{AR_b - AR}$ is the number routers between the AR(After) and AR.

LISP-ELMT. The *CL* of LISP-ELMT was calculated using equation (7):

$$CL_{LISP-ELMT} = D_S + D_M + 2 \times T_{SR_a - SR} + (L_c) + T_{SR_a - SR}(L_d) + T_{SR_a - MN}(L_d) \quad (7)$$

where D_S is the handover latency in the wireless networks, D_M is detection latency after the mobile device starts moving, and $2 \times T_{SR_a - SR}(L_c)$ is the map requests and replies delivered between SR(After) and SR. The data transmission latency between SR(After) and SR is $T_{SR_a - SR}(L_d)$ and that between SR(After) and MN is $T_{SR_a - SR}(L_d)$.

Equation (3) and equation (4) were then substituted into equation (7) to derive equation (8).

$$\begin{aligned} CL_{LISP-ELMT} = {} & D_S + D_M + 2 \times [C_{SR_a - SR} \times \\ & ((L_c / B_w) + D_w) + (C_{SR_a - SR} + 1 \times D_{RP}] + \\ & [C_{SR_a - SR} \times ((L_C / B_w) + D_w) + \\ & (C_{SR_a - SR} + 1 \times D_{RP}] \times ((L_d / B_{wl}) + D_{wl}) \end{aligned} \quad (8)$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, $C_{SR_a - SR}$ is the number routers between the SR(After) and SR, L_c is the size of control packets, B_w is the bandwidth of wired network, D_w is the latency of wired network, D_{RP} is the lookup latency of routers, B_{wi} is the bandwidth of wireless network, D_{wi} is the latency of wireless network, L_d is the size of data packets.

LISP-MN. The *CL* of LISP-MN was calculated using equation (9):

$$CL_{LISP-MN} = D_S + D_M + D_{AC} + 2\times T_{MN-LMS}(L_c) + 2\times T_{MN-DN}(L_c) + T_{DN-AR}(L_d) + T_{AR-AR_a}(L_d) + T_{AR_a-MN}(L_d) \quad \textbf{(9)}$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, D_{AC} is the address configuration delay, $2\times T_{MN-LMS}(L_c)$ is the map requests and replies delivered between MN and LMS, $2\times T_{MN-DN}(L_c)$ is the map requests and replies delivered between MN and DN, $T_{DN-AR}(L_d)$ is the data transmission latency between DN and AR, $T_{AR-AR_a}(L_d)$ is the data transmission latency between AR and AR(After), and $T_{AR_a-MN}(L_d)$ is the data transmission latency between AR(After) and MN.

$$T_{MN-LMS}(L_c) = ((L_c/B_{wl}) + D_{wl}) + [C_{AR-LMS}\times ((L_c/B_w) + D_w) + [C_{AR-LMS} + 1\times D_{RP}] \quad \textbf{(10)}$$

where L_c is the size of control packets, B_{wl} is the bandwidth of wireless network, D_{wl} is the latency of wireless network, C_{AR-LMS} is the number routers between the AR and LMS, B_w is the bandwidth of wired network, D_w is the latency of wired network, D_{RP} is the lookup latency of routers.

$$T_{MN-LMS}(L_c) = ((L_c/B_{wl}) + D_{wl}) + [C_{AR-AR_b}\times ((L_c/B_w) + D_w) + C_{AR-AR_b} + 1\times D_{RP}] + ((L_c/B_{wl}) + D_{wl}) \quad \textbf{(11)}$$

where L_c is the size of control packets, B_{wl} is the bandwidth of wireless network, D_{wl} is the latency of wireless network, C_{AR-AR_b} is the number routers between the AR and AR(Before), B_w is the bandwidth of wired network, D_w is the latency of wired network, D_{RP} is the lookup latency of routers.

Equation (3), equation (4), equation (10), and equation (11) were then substituted into equation (9) to derive equation (12).

$$CL_{LISP-MN} = D_S + D_M + D_{AC} + 2\times[((L_c/B_{wl}) + D_{wl}) + [C_{AR-LMS}\times((L_c/B_w) + D_w) + (C_{AR-LMS}+1)\times D_{RP}]] + 2\times[((L_c/B_{wl}) + D_{wl}) + [C_{AR-AR_b}\times((L_c/B_w) + D_{wl})] + (C_{AR-AR_b}+1)\times D_{RP}] + ((L_C/B_{wl}) + D_{wl})] + ((L_d/B_{wl}) + D_{wl}) + [C_{AR-AR_a}\times((L_d/B_{wl}) + D_w) + (C_{AR-AR_a}+1)\times D_{RP}] + ((L_d/B_{wl}) + D_{wl})] \quad \textbf{(12)}$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, D_{AC} is the address configuration delay, L_c is the size of control packets, B_{wl} is the bandwidth of wireless network, D_{wl} is the latency of wireless network, C_{AR-LMS} is the number routers between the AR and LMS, B_w is the bandwidth of wired network, D_w is the latency of wired network, D_{RP} is the lookup latency of routers, C_{AR-AR_b} is the number routers between the AR and AR(Before), L_d is the size of data packets, and C_{AR-AR_a} is the number routers between the AR and AR(After).

LISP-PMIP. The *CL* of LISP-PMIP was calculated using equation (13):

$$CL_{LISP-PMIP} = D_S + D_M + 2\times T_{LMATP-GMATP}(L_c) + T_{LMATP-GMATP}(L_d) + T_{LMATP-MN}(L_d) \quad \textbf{(13)}$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, $2\times T_{LMATP-GMATP}(L_c)$ is the PBU and PBA between LMATP(After) and GMATP, $2\times T_{LMATP-GMATP}(L_d)$ is the data transmission latency between LMATP(After) and GMATP, and $2\times T_{LMATP-MN}(L_d)$ is the data transmission latency between LMATP(After) and MN.

Equation (3) and equation (4) were then substituted into equation (13) to derive equation (14).

$$CL_{LISP-PMIP} = D_S + D_M + 2\times[C_{LMTP-GMATP}\times ((L_c/B_w) + D_w) + (C_{LMTP-GMATP} + 1\times D_{RP}] + [C_{LMTP-GMATP}\times((L_d/B_w) + D_w) + (C_{LMTP-GMATP}+1)\times D_{RP}] + ((L_d/B_{wl}) + D_{wl}) \quad \textbf{(14)}$$

where D_S is the handover latency in the wireless networks, D_M is the detection latency after the mobile device starts moving, $C_{LMTP-GMATP}$ is the number routers between the LMTP and GMATP, L_c is the size of control packets, B_w is the bandwidth of wired network, D_w is the latency of wired network, B_{wl} is the bandwidth of wireless network, D_{wl} is the latency of wireless network, D_{RP} is the lookup latency of routers, and L_d is the size of data packets.

According to the presented *CL* equations, data analysis diagrams were produced using the parameters proposed by Makaya and Pierre [26] (Table 7).

Table 7. Initial default parameter valuesw

Parameters	Values
L_C	50 bytes
L_d	1,024 bytes
B_w	100 Mbps
B_{wi}	54 Mbps
D_w	3 ms
D_{wi}	10 ms
C_{a-b}	$\sqrt{R}$
D_{RP}	0.1 ms
D_M	10 ms
D_S	50 ms
$R_{SR/AR-LMS}$	10 ms
R	30 units
d_{AC}	150 ms
$C_{SR/AR-LMATP-BR/GMATP/LMS}$	20 ms

4.3 Experimental Data

This section presents the analysis of the three possible situations of mobile device movement described in Section 3; the analysis was performed using the handover simulation diagram and equations presented in the previous sections.

Equidistance situation (3 ms). When the total latency time increased, additional convergence time was required in the four schemes (Figure 9). Specifically, the *CL* and total latency time required in the LISP-ELMT scheme were 10%-15% shorter than those required in the LISP-DHC scheme. Therefore, the LISP-ELMT scheme exhibited a superior performance to the LISP-DHC scheme.

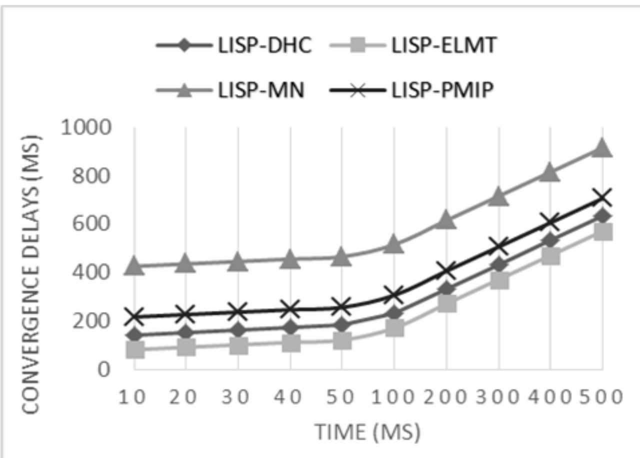


Figure 9. The relationship between CL and total latency in the equidistance situation (3 ms)

The four schemes demonstrated an increase in the convergence time when the wireless connection latency increased (Figure 10). The *CL* and wireless connection latency in the LISP-ELMT scheme were 20% shorter than those of the LISP-DHC scheme. Therefore, the proposed LISP-ELMT scheme exhibited optimal performance.

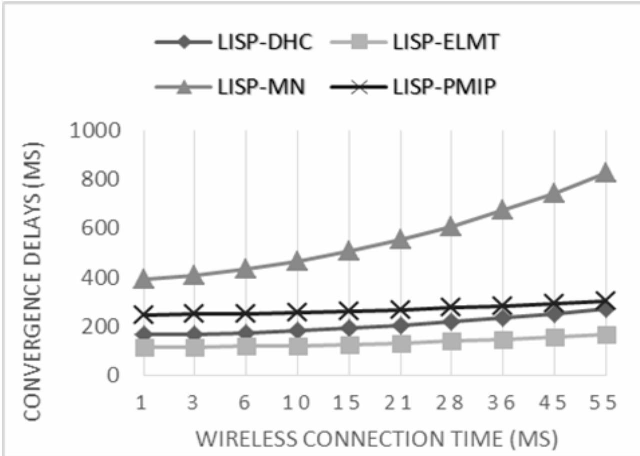


Figure 10. The relationship between CL and wireless connection latency in the equidistance situation (3 ms)

The convergence time required in the four schemes increased with the node moving time (Figure 11). The *CL* and node moving time in the LISP-ELMT scheme were 10%-15% shorter than those of the LISP-DHC scheme, indicating that the proposed LISP-ELMT scheme demonstrated a more efficient performance than the LISP-DHC did.

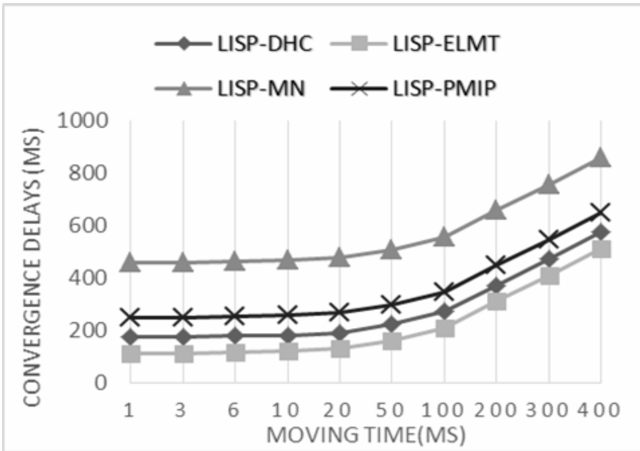


Figure 11. The relationship between CL and node moving time in the equidistance situation (3 ms)

Away situation (5 ms). When the total latency time increased, additional convergence time was required in the four schemes (Figure 12). Specifically, the convergence time required in the LISP-ELMT scheme was 10%-15% shorter than that required in the LISP-DHC scheme, indicating that the LISP-ELMT scheme demonstrated superior performance to the LISP-DHC scheme.

The four schemes exhibited an increase in convergence time as the wireless connection latency increased (Figure 13). However, the effect of the wireless connection latency on *CL* in the LISP-ELMT scheme was stable. In addition, the *CL* in the LISP-ELMT scheme was 20% shorter than that in the LISP-DHC scheme. Therefore, the proposed LISP-ELMT scheme exhibited optimal performance.

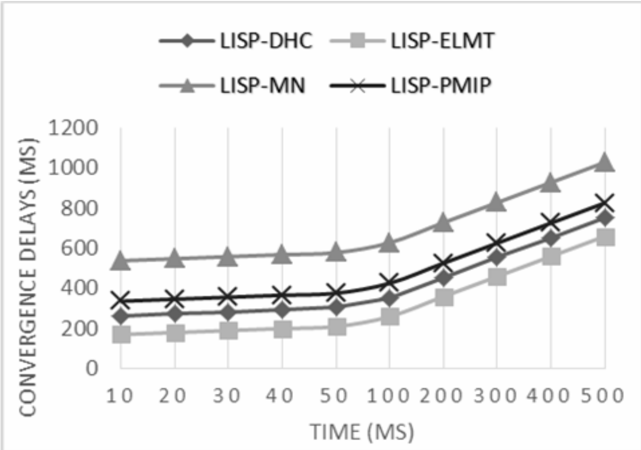


Figure 12. The relationship between CL and total latency in the away situation (5 ms)

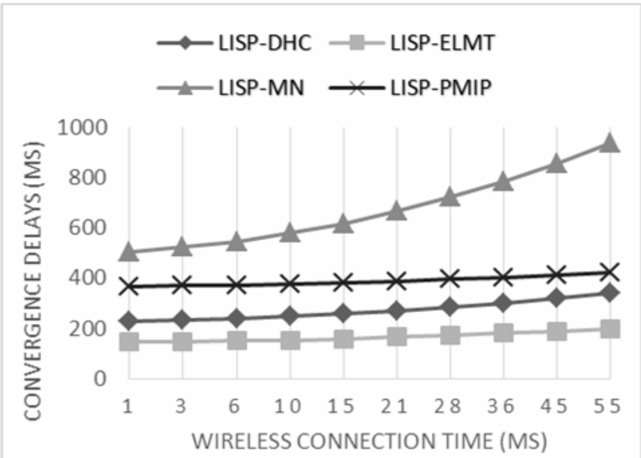


Figure 13. The relationship between CL and wireless connection latency in the away situation (5 ms)

The convergence time required in the four schemes increased as the node moving time increased (Figure 14). The LISP-ELMT scheme required 10%-15% shorter *CL* than the LISP-DHC scheme did.

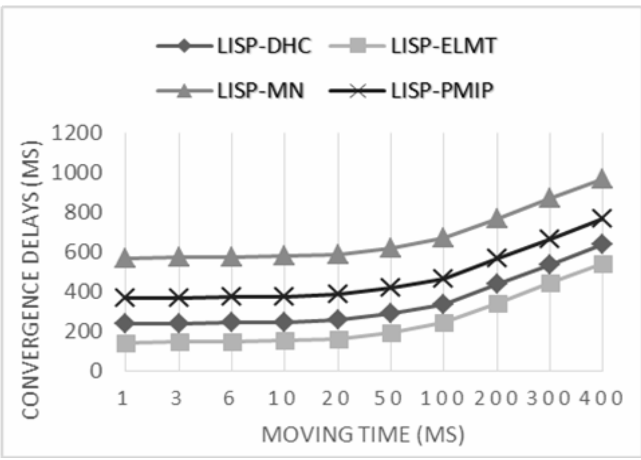


Figure 14. The relationship between CL and node moving time in the away situation (5 ms)

Approaching situation (1 ms). When the total latency increased, additional convergence time was required in the four schemes (Figure 15). The convergence time required in the LISP-ELMT scheme was 5%-10% shorter than that required in the LISP-DHC scheme, indicating the optimal performance of the LISP-ELMT scheme.

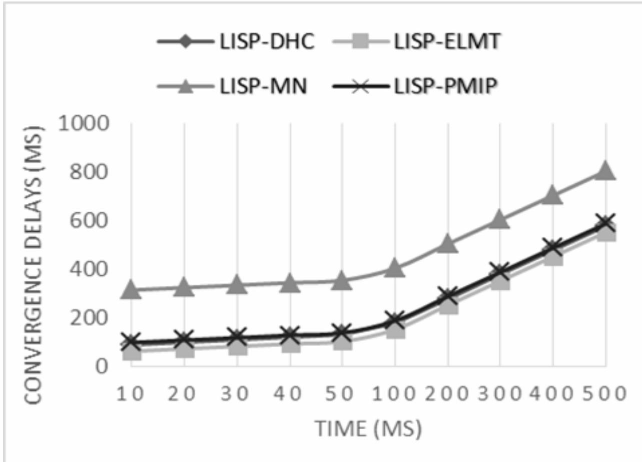


Figure 15. The relationship between CL and total latency in the approaching situation (1 ms)

The four schemes demonstrated an increase in convergence time as the wireless connection latency increased (Figure 16). However, the effect of wireless connection latency on *CL* in the LISP-ELMT scheme was stable. In addition, the *CL* required in the LISP-ELMT scheme was 20% shorter than that required in the LISP-DHC scheme. Therefore, the proposed LISP-ELMT scheme exhibited superior performance to the LISP-DHC scheme.

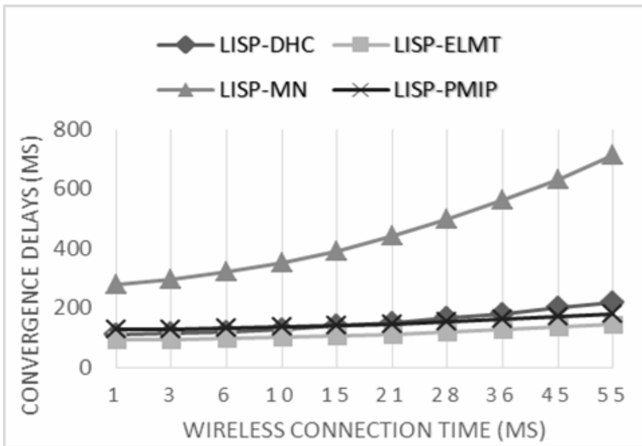


Figure 16. The relationship between CL and wireless connection latency in the approaching situation (1 ms)

The convergence time required in the four schemes increased as the node moving time increased (Figure 17). The LISP-ELMT scheme required 5%-10% shorter *CL* than the LISP-DHC scheme did, indicating the optimal performance of the LISP-ELMT scheme.

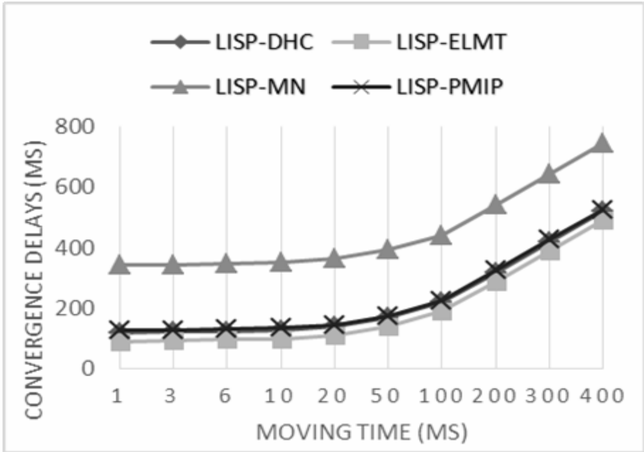


Figure 17. The relationship between CL and node moving time in the approaching situation (1 ms)

When the wired connection latency increased, additional convergence time was required in the four schemes (Figure 18). However, compared with other schemes, the influence of wired connection latency on the LISP-ELMT scheme was relatively moderate, and the degree of influence diminished as the wired connection latency increased. The *CL* in the LISP-ELMT scheme was 40%-50% shorter than that in LISP-DHC scheme, indicating that the proposed LISP-ELMT scheme demonstrated optimal performance.

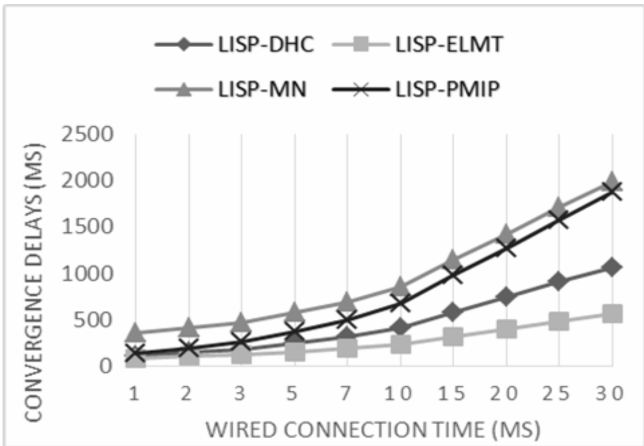


Figure 18. The relationship between CL and wired connection latency

5 Conclusion

The LISP-ELMT scheme proposed in this study is a distributed scheme in which a map cache is integrated with the proposed ELMT scheme to avoid the complexity of the mapping database protocols. In this method, the number of queued searches for EID-RLOC in the MS during network switching of mobile devices and the convergence time required for this switching process were reduced. The results indicated that simplified network switching processes accelerated convergence time by approximately 35%-50%. However, this required an approximate 25% increase in storage space.

In this study, mobile device locations before and after the movement of the device were analyzed; three movement situations were analyzed: (1) the mobile device (i.e., the source) approached the destination; (2) the source moved away from the destination; and (3) the distance between the source and the destination remained the same after movement. The simulation results indicated that the direction of movement influences network latency. According to the analysis of the experimental data, the LISP-ELMT scheme required 10%-25% shorter convergence time than those of the other schemes. Therefore, the LISP-ELMT scheme can be effectively applied to network environments in the future.

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