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The Scalable LISP-Deployed Software-Defined Wireless Network (LISP-SDWN) for a Next Generation Wireless Network

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ABSTRACT In order to improve the network and mobility management in wireless mobile networks, decoupled control and data planes have been designed, which is called the software-defined wireless network (SDWN). In this paper, we choose the locator/identifier separation protocol (LISP) to foster mobility management in an SDWN due to its address scheme. However, LISP adopts a distributed system to manage the location and identifier information of mobile nodes, which does not fit the SDWN requirement of a centralized management entity. Accordingly, recent LISP-related works have focused on how to build a LISP-centralized management entity, which does not guarantee routing scalability due to the lack of connectivity with the standard LISP sites outside of an SDWN. We present an OpenFlow-based centralized LISP management system where the routing coverage is scalable by the OpenFlow technology, which enables a transparent connectivity between the LISP-SDWN controller and mapping system without any changes to the LISP procedure. Another aim of our study is reducing the deployment cost from the perspective of the SDWN provider. The benefits of the OpenFlow technology include the fact that LISP-SDWN does not require extra control messages or LISP specification modification, while previous LISP-enabled solutions required extra control messages and procedure changes. Therefore, the deployment cost will be minimized as compared to other LISP-centralized management systems. We evaluate the location management and total operation costs of LISP-SDWN, LISP, LISP controller, HMIP, and MIP. The proposed LISP-SDWN shows the lowest management cost in different scale communications such as intra-domain communication, inter-domain communication, and inter-domain with a remote moving node.

INDEX TERMS Computer network management, next generation networking, software-defined networking.

I. INTRODUCTION

The wireless mobile network industry is undergoing a major revolution which requires the fast deployment of new services and solutions to meet the exponential growths in both the number of users and amount of traffic [1]. In order to resolve this major requirement, not only are flexibility and scalability required in terms of management and configuration, but vendor independence is demanded as well. Consequently, the Software-Defined Wireless Network (SDWN) was designed and proposed to enable the current mobile wireless networks to serve as operator-definable networks for new solutions and mobile applications [2]–[7].

SDWN effectively shows the heterogeneous wireless mobile network as an example of a next generation mobile network. It consists of various wireless mobile technologies (e.g., LTE, Wi-Fi, etc) and multiple coverage layers (e.g., macro- and small cell-layers) across heterogeneous mobile edge networks as well as the core network. The SDWN

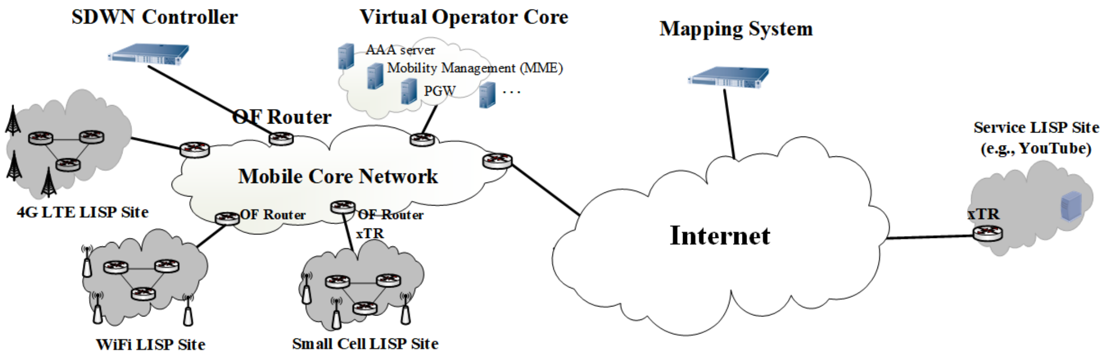


FIGURE 1. Network architecture of software-defined wireless network with mapping system.

architecture provides service providers and/or operators with APIs to manage, control, and orchestrate SDWN networks, as shown in Fig. 1.

Service providers/operators can configure an SDWN and control the network operation by accessing the SDWN controller through APIs. The SDWN controller provides service providers with the benefits of easier deployment of new services, reduced management cost of heterogeneous technologies, efficient operation of multi-vendor infrastructures, increased accountability, service differentiation, continuous network operation, and transparent enhancement of network operation [8].

SDWN is based on the Mobile IP-based protocol, whose location and identification information are stored in a single field of the IP header. Controlling and maintaining the location management systems of mobile IP-based protocols leads to inefficient traffic management costs and extra overhead (i.e., HMIP [9], MIP [10], PMIP [11], and 3GPP mobility).

In our work, in order to improve the network and mobility management of SDWN, we deployed the Locator/Identification Separate Protocol (LISP), a distributed management system, into the SDWN requiring a centralized management system. Recent LISP related works, such as routing in the centralized identifier network [12], the network-based host identifier locator separating protocol [13], and the LISP Controller [14], have successfully achieved a centralized LISP management system. However, the LISP operations and procedures in those target networks were modified and extra control messages were required as well. Even the most important requirement, routing scalability, was either limited or not considered. In this sense, routing scalability became the most important research challenge in our work.

As the design principle of deploying LISP-SDWN, we specify the technical requirements of an SDWN service provider: centralized LISP management, routing scalability, seamless vertical handover, and traffic-aware management. Moreover, we design a method for deploying LISP in an SDWN according to the standard LISP specification.

From the perspective of an SDWN service provider, another important requirement involves the deployment cost. Any LISP function modification or other control packets should be avoided because of their extra costs in terms of labor per month and working days. Considering the above factors, we propose a LISP-SDWN system architecture based on a seamless and novel approach, where not only does LISP-SDWN not require extra messages and procedures, but it also only cooperates with the OpenFlow service, which the SDWN Controller already has as one of its supporting services.

A. SUMMARY OF CONTRIBUTIONS

a) The major achievement of our study is that the LISP-SDWN accomplished two contrasting features: centralized control and scalability with a low location management cost. This achievement can be highlighted when it is known that the major traffic comes from MN handovers. In this sense, the traffic burden will become substantial in the future because an SDWN domain will eventually be expected to handle at least one million flows, which is a huge amount of traffic that the current wireless mobile networks cannot handle. b) We integrate LISP with the OpenFlow technology in the LISP-SDWN Controller so that the OpenFlow technology can control LISP messages without modifying the LISP procedure or specification. Moreover, from the perspective of an SDWN provider, this deployment method achieves minimum cost. c) By utilizing the Endpoint Identifier (EID) of LISP, the LISP-SDWN Controller enables EID-based traffic management to offload traffic for better bandwidth utilization in wireless mobile networks [16]. d) Another distinguished benefit of LISP-SDWN is seamless vertical MM in heterogeneous Radio Access Networks (RANs).

The rest of the paper is organized as follows. In Section II, background information on the LISP procedure and the Mapping System (MS) is given. In Section III, the modeling of the scalable LISP-SDWN is discussed. In Section IV, the mathematical model of LISP-SDWN is suggested. In Section V, the results of the performance analysis and testing are given.

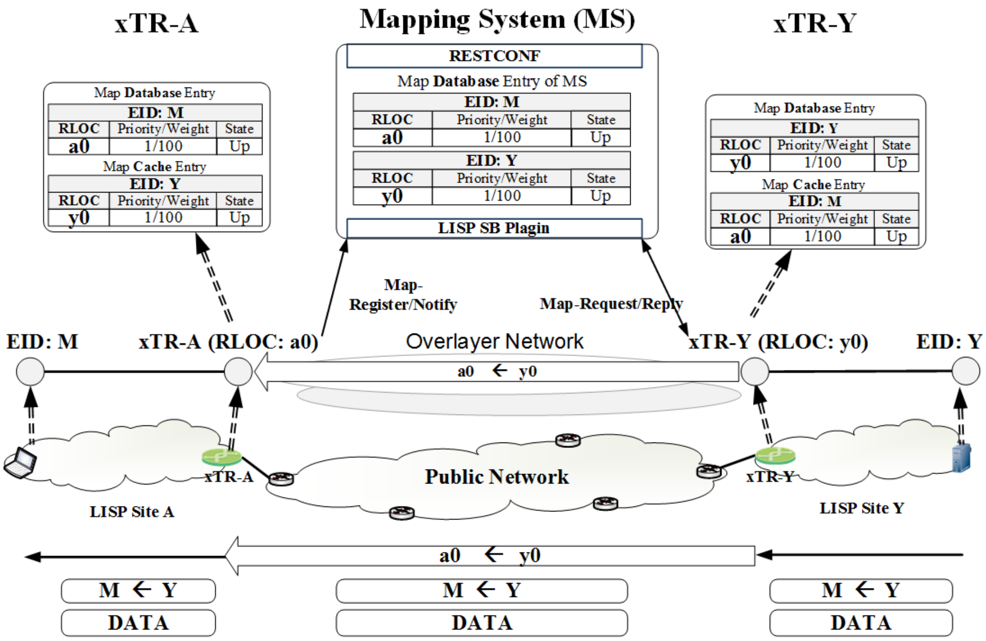


FIGURE 2. LISP operation procedure and data transmission.

Finally, the conclusion and future plan are discussed in Section VI.

II. BACKGROUND AND RELATED WORKS

The proposed scalable LISP-deployed Software-Defined Wireless Network (LISP-SDWN) is derived not only from the perspective of SDWN for the fast deployment of new services and solutions, but also from the perspective of the ID/LOC split protocol for improved mobility management. LISP, a standard protocol specification [9], is one of the ID/LOC split protocols and our proposed model is based on LISP. In this section, the operation and procedure of LISP are addressed and the functions of the Mapping System (MS) are also described in order to provide increased understanding of the LISP-SDWN Controller as shown in Fig. 2. Related works and their limitations are introduced; moreover, the difference between the method of deploying LISP-SDWN and the method of deploying the LISP Controller, as described by one of the related works, was discussed and is illustrated in Fig. 3 in terms of network architecture.

To date, the Routing Research Group (RRG) has handled ID/LOC split protocols in the following ways: The tunneling-based ID/LOC split protocols, which are LISP [15], HAIR [18], APT [19] and TRRP [20], use encapsulation by a new extra header including the source and destination locator addresses. While address rewriting-based ID/LOC split protocols, which are ILNP [21], Six/One Router [22], RANGI [23], GLI-Split [24], IRON [25], and Name-Based Socket [26], replace the existing source and destination addresses with the locator addresses. Considerations of LISP network element deployment are addressed [17].

In the initial research stage, we discovered that SDWN Mobility Management (MM) could be improved by utilizing the ID/LOC split scheme, which would support seamless vertical mobility to the Internet [27]–[30]. This is because the current IP-based Internet suffers from the operation overhead of MM due to an excessively large number of mobile nodes and substantial amounts of traffic, which require an extra location management cost to map information between the locations and identities of Mobile Nodes (MNs). LISP could lessen the location management cost and provide seamless mobility management for an SDWN.

LISP is an ID/LOC split scheme that was proposed by CISCO as drafts from the Internet Engineering Task Force (IETF) and implementation on the OpenDaylight controller. LISP consists of Endpoint Identifiers (EIDs) and Routing Locators (RLOCs) as two divided name spaces for the tunneling of data transmission. RLOCs are assigned by network access points belonging to an RAN and are used for packet routing, while EIDs are not related to packet routing and are independent of the network topology; furthermore, EIDs remain unchanged even when mobile devices are roaming around an SDWN. The outer LISP header includes source and destination RLOCs and encapsulates the inner LISP header and data; moreover, the LISP encapsulated packets are transmitted between the Egress Tunneling Router (ETR), and Ingress Tunneling Router (ITR). The inner LISP header includes source and destination EIDs, and data packets are routed to the destination mobile device by the destination EID; moreover, the session connection between devices is built by EIDs. The two xTRs build tunneling between the source and destination devices by RLOCs, such as xTR-A

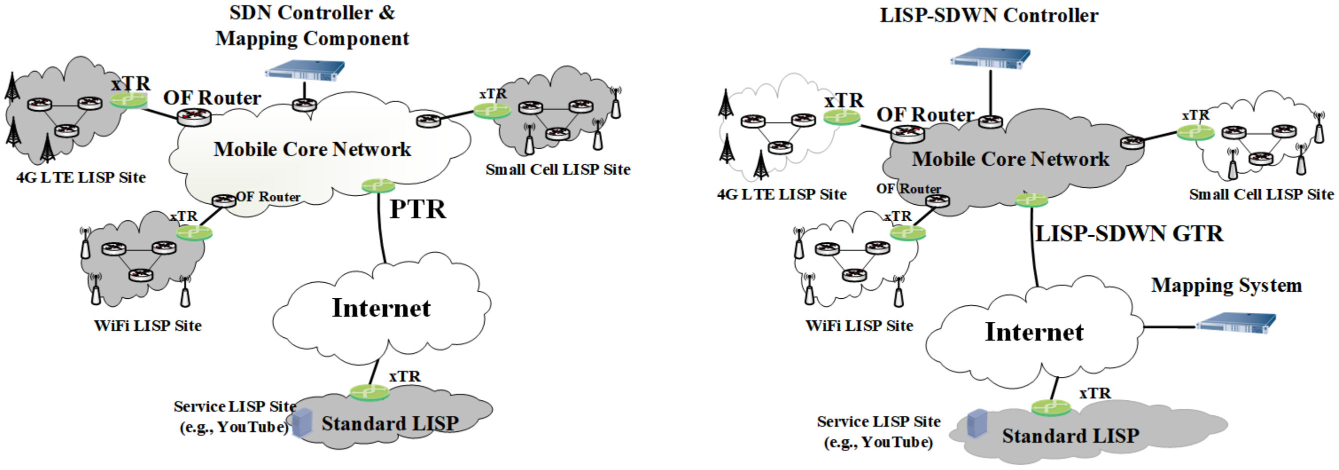


FIGURE 3. **Network architecture of lisp controller and LISP-SDWN.**

with its RLOC a0 and xTR-Y with its RLOC y0, as shown in Fig. 2.

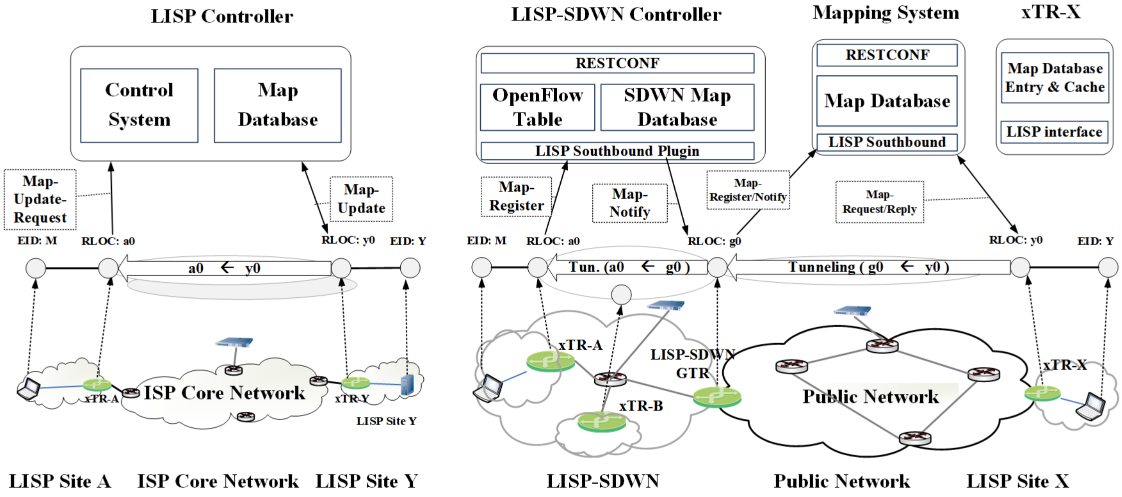
As shown in Fig. 2, when a mobile device with EID M moves into the LISP-site A, xTR-A creates a map entry $\langle M, a0\rangle$ in the map database when the mobile device transmits data. After creating a map entry, xTR-A performs map registration toward MS by a Map-Register containing $\langle M \rightarrow a0\rangle$ on behalf of the mobile device with EID M. Upon receiving a Map-Register message by xTR-A, MS creates a map entry $\langle M \rightarrow a0\rangle$ in its global map database and replies to xTR-A with a Map-Notify message; eventually, MS becomes ready to support a map discovery requested by other LISP-enabled devices. When a corresponding host with EID Y sends a packet to a mobile device with EID M, it transmits a packet containing just EIDs $\langle Y \rightarrow M\rangle$ with out RLOCs because a map discovery is carried out by xTR.

xTR-Y is an edge LISP router of LISP-site Y that eventually receives packets heading for a mobile device with EID M because EID M does not belong to LISP-site Y. When packets destined for EID M are transmitted to xTR-Y, xTR-Y looks up an EID-to-RLOC map cache (hereafter referred to as a map cache) with EID M, and notes that no map entry of EID M exists. In order to find a RLOC of EID M, the map discovery is carried out by xTR-Y by initiating a Map-Request containing EID M toward MS. When the Map-Request is received by MS, a Map-Reply containing the map entry $\langle M, a0\rangle$ is sent to xTR-Y by MS in reply. Upon receiving a Map-Reply, xTR-Y store mapping information (e.g., $\langle M, a0\rangle$) in the map cache; moreover, xTR-Y capsulates packets destined for EID M with RLOCs $\langle y0 \rightarrow a0\rangle$, as shown in Fig. 2.

The detail specifications of MS are described in the LISP Mobile Node [31] and the LISP Alternate Topology [32], as well as in the Locator/ID Separation Protocol Map-Server Interface [33]. MS controls and manages an EID-to-RLOC map database (hereafter referred to as a map database) for connecting multiple LISP-sites and is the key network infrastructure in LISP-enabled networks. A global map database in MS consists of a small piece of a map database created and managed by each potential xTR; furthermore, a global map database is distributed and federated by multiple mapping systems at the point of a mobile client's service provider unlike Mobile IP [11].

As SDN has become a feasible alternative to the current IP-based Internet, it is also an applicable solution to wireless mobile networks. The LISP Controller [14], the Centralized Identifier Network (CIN) [12], and a network-based host identifier locator separating protocol [13] comprised a centralized ID/LOC split management system and successfully replaced MS; however, its interoperability with a standard LISP site is not guaranteed and its routing scalability is limited as well. In addition, OpenISMA [34] and IDOpenFlow [35] enable identifiers of mobile nodes to be routable based on OpenFlow technology [36] in LISP-sites; however, the scalabilities of these identifiers are limited as well. The LISP Controller has features and a purpose similar to the proposed scalable LISP-SDWN: 1) the centralized LISP management system for mobile devices and 2) the LISP-based SDN solution. However, the target network differs between the two; the LISP Controller is used for an ISP and LISP-SDWN is used for an SDWN. The main difference between the LISP Controller and LISP-SDWN is routing scalability; moreover, most ID/LOC split-based SDN solutions, including the LISP Controller, do not support routing scalability while additionally requiring extra operation procedure and control messages.

The candidate architecture used to deploy LISP into an SDWN is illustrated in the right side of Fig. 3. Each RAN can be operated by a different service provider: a 3G UMTS provider, a 4G LTE provider, a Wi-Fi provider, etc. Through the use of SDWN technology, even a small service provider with a small amount of capital can own and operate an RAN and provide mobile users with various new services. Therefore, we predict SDWN will be composed of multiple LISP-sites operated by different RAN technologies, and the



(a)

(b)

FIGURE 4. Architectures of LISP-SDWN and LISP controller based on the tunneling structure.

proposed scalable LISP-SDWN Controller requires the management of multiple LISP-sites in an SDWN.

The LISP deployment method is illustrated in the left side of Fig. 3. MS is integrated with the SDN Controller in order to comprise a LISP centralized management system in [12]–[14]. The proposed LISP-SDWN is designed in Fig. 3B, where a dual mapping system is chosen to support routing scalability, so that Mobile Nodes (MNs) associated with the LISP-SDWN Controller are registered in the external standard Mapping System.

III. MODEL OF THE SCALABLE LISP SOFTWARE-DEFINED WIRELESS NETWORK (LISP-SDWN)

The related works focused on a centralized LISP Management system by integrating LISP and SDN as shown in Fig. 4A; however, routing scalability was not guaranteed in these works. The most distinguishable feature of the proposed LISP-SDWN as compared with the related works is the centralized LISP management system with routing scalability, which was described in [37]. This paper extends the previous work by adding the following features:

- With the benefits of OpenFlow, the LISP-SDWN Controller can control the LISP packets in an SDWN and also generate the SDWN Map Database (see Fig. 4B) connecting to the Mapping System (MS).
- The minimum deployment cost is accomplished through the lack of a need for LISP modification and extra control packets for the SDWN service provider.
- Seamless vertical Mobility Management (MM) among the heterogeneous RANs.
- Maximum bandwidth utilization in a cellular network is accomplished by offloading the specific traffic from the cellular network to other networks: WLAN, Small cell, etc (see Fig. 7).

TABLE 1. Basic notation for network infrastructure components.

Name	*Description*
MS	Mapping System
HA	Home Agent
FA	Foreign Agent
ETR	Egress Tunneling Router
MAP	Mobility Anchor Point
ITR	Ingress Tunneling Router
CN	Corresponding Node
GTR	Gateway Tunneling Router
RAN	Radio Access Network
xTR	Egress/Ingress Tunneling Router
Map Cache	EID-to-RLOC Map Cache
Map Database	EID-to-RLOC Map Database

A. CENTRALIZED LISP/OpenFlow MANAGEMENT SYSTEM WITH ROUTING SCALABILITY

LISP-SDWN enables an SDWN service provider to deploy LISP-enabled services and facilities (e.g., xTR in Table. 1) through its own LISP-SDWN Controller. An LISP-SDWN is powered not only with mapping information from a map database, but also with flow information from an OpenFlow table; moreover, the architecture of the LISP-SDWN Controller is illustrated in Fig. 4B, and the architecture of the LISP Controller is illustrated in Fig. 4A.

The LISP-SDWN Controller is our proposed centralized LISP/OpenFlow management system based on the SDWN Controller, which originally controls and manages the flow table of OpenFlow routers in an SDWN. We design and customize a standard map database to be an SDWN map database for an SDWN Controller, which becomes a LISP-SDWN Controller consisting of an SDWN map database and an OpenFlow table, as seen in Fig. 4B. The LISP-SDWN Controller adopts a dual Mapping System: an SDWN map database is designed for seamless vertical Mobility Management (MM) among heterogeneous RANs, and a map database

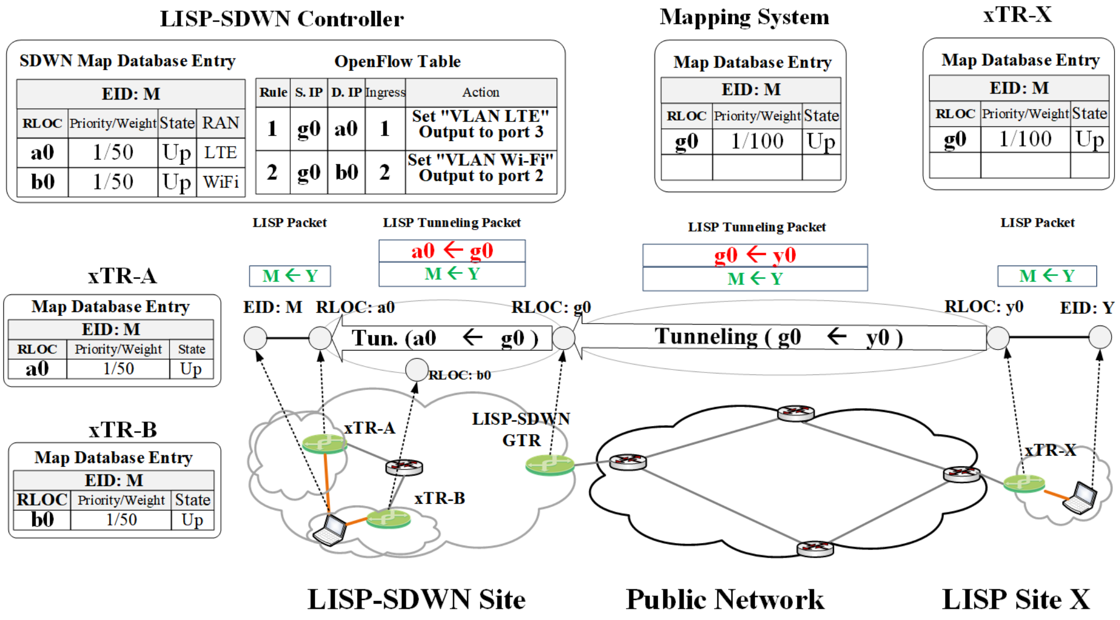


FIGURE 5. Map entry update in the LISP-SDWN controller and MS.

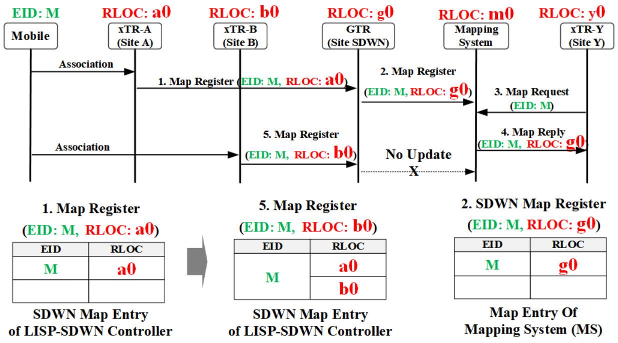


FIGURE 6. Flow diagram for map entry update of the LISP-SDWN controller and MS.

of external standard MS is used to connect between the inside SDWN domain and the outside standard LISP sites as shown in Fig. 4A.

The SDWN map database is composed of small pieces of a map database of xTRs and the LISP Mobile Nodes [31]. It is a central map database that is only locally accessible by an SDWN, while a standard map database of MS is a publicly accessible distributed database. An SDWN map database entry consists of the RLOC, priority, weight, state, and type of RAN; moreover, two RLOCs (a0 and b0) indicate two interfaces as shown in Fig. 5.

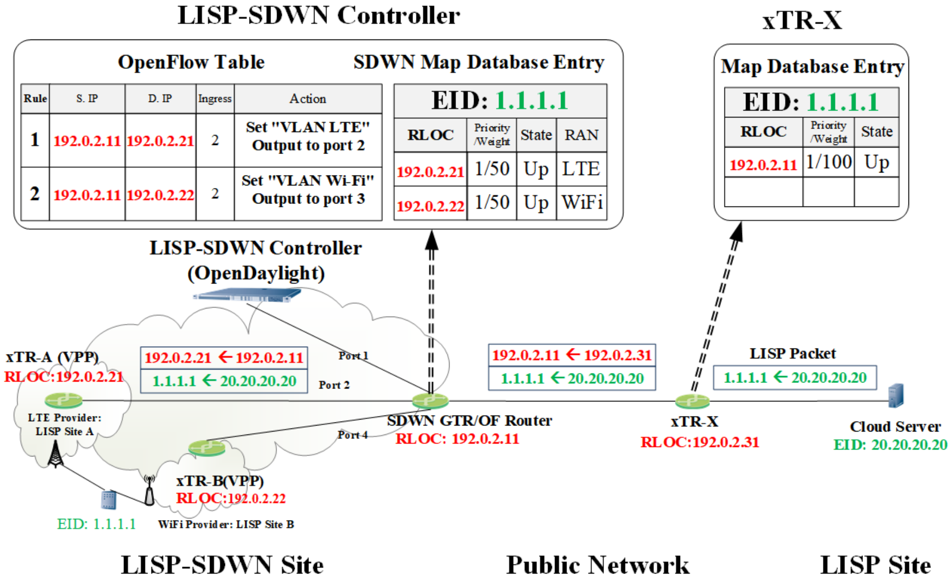
The connection between an SDWN map database and a standard map database is accomplished by registering the RLOC of the LISP-SDWN GTR into a map database of MS. The SDWN map database is located in the LISP-SDWN Controller, and the standard map database is located in a standard MS. In order to connect the two map databases, the GTR RLOC g0 is registered in the map database of MS, instead of $\langle M, a0\rangle$, and $\langle M, b0\rangle$ being stored in an SDWN map database, as shown in Fig. 6. When a mobile node moves to site B from site A, Map Register is performed and intercepted by the LISP-SDWN Controller. The new location information of a mobile node is registered in the SDWN map entry of the LISP-SDWN Controller, then a map register packet is discarded due to intra-SDWN mobility. During intra-SDWN mobility, Map Register is carried out not for MS but for the LISP-SDWN Controller; furthermore, the control messages occurring during intra-SDWN mobility are suppressed and traffic overhead is lessened in the public network.

Routing Scalability is secured by registering the GTR RLOC in a standard MS, e.g., the map entry $\langle M, g0\rangle$ in MS, will attract packets destined for EID M to GTR from the outside of an SDWN.

B. THE MINIMUM DEPLOYMENT COST FOR THE SDWN PROVIDER

One of the requirements for minimizing the deployment cost is that there are no modifications and no changes of LISP specification when LISP is deployed into an SDWN. If LISP deployment requires LISP modification in an SDWN, extra costs are needed to make up these changes, and at worst it can be impossible for an internetworking with external standard LISP systems.

In wireless mobile networks, the majority of traffic comes from MNs due to handover. The next generation network will accommodate more than 1000 base stations and each base station will serve more than 1000 MNs in a domain;



OpenFlow Table

Rule	S. IP	D. IP	Ingress	Action
1	192.0.2.11	192.0.2.21	2	Set "VLAN LTE" Output to port 2
2	192.0.2.11	192.0.2.22	2	Set "VLAN Wi-Fi" Output to port 3

SDWN Map Database Entry

EID: 1.1.1.1			
RLOC	Priority /Weight	State	RAN
192.0.2.21	1/50	Up	LTE
192.0.2.22	1/50	Up	WiFi

Map Database Entry

EID: 1.1.1.1		
RLOC	Priority /Weight	State
192.0.2.11	1/100	Up

FIGURE 7. Simulation scenario for traffic-aware management.

moreover, each MN will require at least 10 flows for its running applications. This means that more than 10 million flows will need to be handled with high location management costs.

When a mobile device with EID M moves into a newly visited LISP-site A, according to a standard map registration procedure, its new xTR-A directly sends a Map-Resister to MS in order to register the newly obtained RLOC a0, as shown in Fig. 5. If a Map-Register is directly sent from an xTR to an MS, there is no chance to update the SDWN map database in the LISP-SDWN Controller. The core technique of LISP-SDWN involves building the SDWN map database without interrupting the map registration process between xTR and MS. By controlling the flow entries in OpenFlow routers in an SDWN, the LISP-SDWN Controller is able to intercept the control messages (e.g., Map-Register and Map-Notify) destined for MS. Through the OpenFlow control function of the LISP-SDWN Controller, an SDWN map database is created and managed by the interactive work between the LISP-SDWN Controller and OpenFlow routers.

Finally, without any changes to the LISP procedure, an SDWN map database is configured; moreover, the LISP-SDWN Controller can provide seamless vertical handover without needing to inform MS of the newly obtained RLOC of roaming MNs in an SDWN. Therefore, the LISP-SDWN Controller is transparent to xTRs and MS; eventually, no additional operation procedures will be required, which will reduce the location management cost.

C. SEAMLESS VERTICAL MOBILITY MANAGEMENT AMONG HETEROGENEOUS RANs

The vertical handover process becomes critical and complex as users come to have multiple connections of different radio access technologies such as LTE, WiMax, WLAN, small cell, etc. However, with LISP, the vertical handover process can be simplified in terms of the location management cost because the session between source and destination remains connected even during handovers in different radio access networks. This means that no location management is required because EID remains the same from the perspective of the end-to-end connections between source and destination; furthermore, it is easy to manage multiple connections of a MN with different radio access networks.

According to the standard map registration procedure, the Map Register directly goes to MS; moreover, whenever the handover of a MN occurs, each Map-Register is transmitted to MS all the way through public networks. In LISP-SDWN, once a MN joins a new LISP site and a newly obtained RLOC of a MN is registered in an SDWN map database, a map registration is not required by MS for the next handover within an SDWN. For instance, after the LISP-SDWN Controller receives a Map-Registration, the LISP-SDWN adds a map entry $\langle M, a0 \rangle$ to its own SDWN map database; moreover, the LISP-SDWN Controller updates a map database entry (e.g., $\langle M, a0 \rangle$) of the LISP-SDWN GTR through OpenFlow control messages. The LISP-SDWN GTR performs a map registration containing the map entry $\langle M, g0 \rangle$ instead of $\langle M, a0 \rangle$, which attracts packets destined for EID M to GTR itself via MS (see Fig. 5).

All RLOCs (e.g., $a0$, $b0$, etc) in an SDWN are mapped to global GTR RLOC(s) (e.g., $g0$). A GTR RLOC (e.g., **g0** in Fig. 5) is then registered in MS instead of MN RLOC **a0**, which attracts packets destined to RLOCs assigned in the SDWN to GTR. In this sense, GTR with RLOC **g0** is similar to a global locator in GLI-Split [24]; however, GTR does not translate addresses, unlike a GLI-gateway.

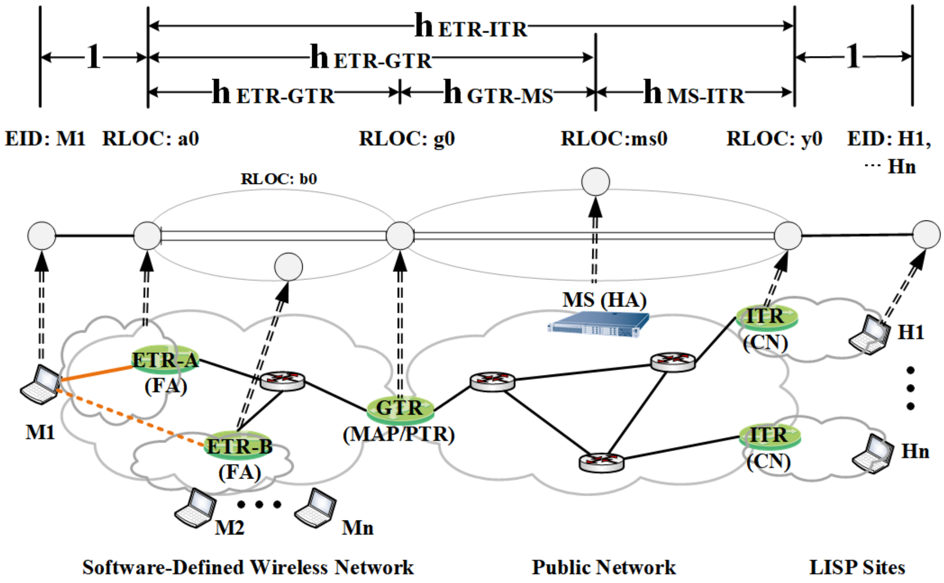


FIGURE 8. Control message paths for the LISP-SDWN operation cost.

TABLE 2. EID-based traffic-awareness.

Name of Traffic	*List of EID*
Cloud Service	20.20.20.20, 20.30.0.0
Multimedia Stream service	10.0.0.1, 10.0.0.2

The SDWN map database is one of the core components in LISP-SDWN; moreover, the traffic issued by a map registration is suppressed in the public networks and the map database updating time is shorter compared to a standard map registration.

D. EID-BASED TRAFFIC AWARE MANAGEMENT (ETAM) FOR THE MAXIMUM BANDWIDTH UTILIZATION

The aim of the SDWN service provider is to maximize the utilization of limited bandwidth in wireless mobile networks, in which it is necessary to offload certain traffic to other connections (e.g., Wi-Fi, Small Cell, etc) from a specific connection such as the expensive cellular connection or some other connection. One of the candidates for offloaded traffic is cloud service, and since the features of cloud service traffic is defined as bandwidth-hungry and delay-tolerant, it does not require an expensive cellular connection. In LISP-SDWN, we realize EID-based Traffic-Awareness Management (ETAM), which is a metric for offloading certain traffic from a cellular network to other networks. EID-based traffic-awareness is implemented by mapping EIDs to specific traffic types, as shown in Table. 2.

In the next generation network, the major traffic will be derived from cloud services; in particular, cloud data access and storage for mobile devices will occupy most of cloud service traffic. Cloud traffic detection and offload is demonstrated as an example of a feasible solution in this paper. A cloud server with EID 20,20,20,20 is already known to clients, and traffic with EID 20,20,20,20 is classified as cloud traffic (see Table. 2) and then offloaded to a Wi-Fi network as shown in Fig. 7. In this paper, we propose a method of classifying and offloading traffic, but one that does not involve identifying the type of traffic.

IV. MATHEMATICAL MODELING OF LISP-SDWN

We mathematically model the <u>C</u>ost of the <u>L</u>ocation update (C^L), the <u>C</u>ost of the Dis<u>C</u>overy (C^C) and the <u>C</u>ost of <u>D</u>ata packet delivery (C^D) of LISP-SDWN based on the network architecture shown in Fig. 8. The total operation cost, C^{Total}, is defined as the sum of C^L, C^C and C^D. In this paper, the mathematical model is described only for LISP-SDWN in order to concentrate on modeling LISP-SDWN. The mathematical models of the rest of the protocols were presented in [37].

In IP networks, the packet delivery cost is the sum of the transmission cost and the processing cost. The delivery cost is related to the distance from the source to the destination node and the packet size, while the processing cost is taken from the routing table lookup, route calculation, etc. In our paper, the packet delivery cost is approximated only by the transmission cost and without the processing cost.

A comparative evaluation of the five protocols is shown with the notations and simulation parameters described in Table. 3.

A. ANALYTIC MOBILITY MODEL

For the sake of simplicity, we assume that each ETR/FA is assigned a unique subnet address. In the fluid flow model, the direction of a MN movement in a subnet or an SDWN domain is uniformly distributed in $[0, 2\pi]$, where ω_c and ω_d

TABLE 3. Notation for cost and simulation parameters.

Not.	*Description*	*Parameter*
R_C	Radius of the Cell area	100
R_D	Radius of the Domain area	1000
ω_c	Cell crossing rate	
ω_d	Domain crossing rate	
ω_s	Cell crossing rate within the same domain	
E_{ω_c}	Average number of handovers for a cell crossing	
E_{ω_d}	Average number of handovers for inter-domain mobility	
E_{ω_s}	Average number of handovers for a MN, which is still in the same SDWN	
E_S	Average session length of packet	51 bytes
α	Weighting factor for the wireless Link	1.5
β	Weighting factor for the wired link	1
δ	Weighting factor	1.1
	for the tunneling overhead	1.1
λ_α	Session arrival rate for each MN	0.01-0.1
F_{flow}	Number of Flows one MN keeps	1 to 10
$D_{SDWN-size}$	Number of xTR in an SDWN	1 to 5

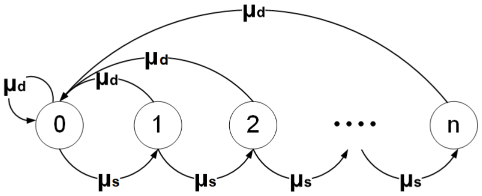


FIGURE 9. Markov chain model for mobility.

are the border crossing rates for a MN from a LISP subnet and an SDWN domain, respectively.

$$\omega_c = \frac{2V}{\pi R_C} \quad \text{and } \omega_d = \frac{2V}{\pi R_D} \tag{1}$$

where V is the average speed of MNs, and R_C and R_D (See Table. 3) are the radii of the circular areas of a LISP subnet and an SDWN domain, respectively.

ω_d is defined as the border crossing rate of the MN, which remains in the same SDWN domain, and can be calculated by subtracting from ω_c to ω_d as shown in below.

$$\omega_s = \omega_c - \omega_d \tag{2}$$

The state transition rate ω_c represents the number of handovers during roaming in an SDWN and ω_d represents the transition rate from an SDWN to another SDWN. In order to model the location update process of MN, the Markov chain model is used, as shown in Fig. 9.

Based on Eqs. (1) and (2), the average number of handovers is calculated during the inter-session arrival. The average number of handovers for a cell crossing is defined as E_{ω_c} and the average number of handovers for the domain crossing is defined as E_{ω_d} on Eqs. (3) and (4).

$$E_{\omega_c} = \frac{\omega_c}{\lambda_\alpha} \quad \text{and } E_{\omega_d} = \frac{\omega_d}{\lambda_\alpha} \tag{3}$$

TABLE 4. Notation for packet and packet size.

Notation	*Description*	*Parameter*
$P_{Map-Reg}$	Map-Register message size	124 bytes
$P_{Map-Noti}$	Map-Notify message size	128 bytes
$P_{Map-Req}$	Map-Request message size	116 bytes
$P_{Map-Rep}$	Map-Reply message size	120 bytes
$P_{Map-Sol}$	Solicit-Map-Request message	124 bytes

TABLE 5. Notation for path hop count shown in Fig. 8.

Notation	*Description*	*Parameter*
$h_{ETR-GTR}$	Average hop btw. ETR and GTR	5 hops
h_{ETR-MS}	Average hop btw. ETR and MS	13 hops
$h_{ETR-ITR}$	Average hop btw. ETR and ITR	21 hops
h_{GTR-MS}	Average hop btw. GTR and MS	8 hops
$h_{GTR-ITR}$	Average hop btw. GTR and ITR	16 hops
h_{ITR-MS}	Average hop btw. ITR and MS	8 hops

where λ_α is the session arrival rate based on a Poisson distribution. When an MN remains in the same SDWN during handovers, the average number of handovers will be as follows:

$$E_{\omega_s} = \frac{\omega_s}{\lambda_\alpha} \tag{4}$$

B. PACKET SIZE AND HOP COUNT

In LISP-SDWN shown in Fig. 8, ***the packet size*** is defined in Table. 4, and

the Path Hop Count according to the control paths as well as the number of hops between the two systems is defined in Table. 5.

C. COST MODELING OF LISP-SDWN (L-SDWN)

LISP-SDWN involves two location management systems: the LISP-SDWN Controller and MS. For the intra-SDWN handover, map registration and map discovery are performed by the LISP-SDWN Controller; however, for the inter-SDWN handover, map registration and map discovery both are performed by MS. The total operation cost of LISP-SDWN is as follows:

$$C^{Total}_{L-SDWN} = C^{L}_{L-SDWN} + C^{C}_{L-SDWN} + C^{D}_{L-SDWN} \tag{5}$$

where C^{L}_{L-SDWN} on Eq. (6) represents the cost of the location update, C^{C}_{L-SDWN} on Eq. (7) represents the cost of the map discovery, and C^{D}_{L-SDWN} on Eq. (8) represents the cost of the data delivery.

1) LOCATION UPDATE COST

In order to perform the map registration of the LISP-SDWN Controller, a Map-Request message and a Map-Notify message are required between the ITR and the LISP-SDWN Controller for an intra-SDWN handover, and the same are required between ITR and MS for an inter-SDWN handover. The location update cost of the LISP-SDWN is defined as follows:

$$\begin{aligned} C^{L}_{L-SDWN} &= E_{\omega_s}(P_{Map-Req} + P_{Map-Noti})\beta h_{ITR-L\_SDWN} \\ &\quad + E_{\omega_d}(P_{Map-Reg} + P_{Map-Noti})\beta h_{ITR-MS} \end{aligned} \tag{6}$$

where p_0 on Eq. (3) is the state probability of an inter-domain handover and p_i on Eq. (4) is the state probability of an intra-domain handoff, while an MN remains in the same SDWN domain, as shown in Fig. 9.

Regarding an intra-SDWN handover, map registration requires a Map-Register message and a Map-Notify message between ITR and the LISP-SDWN Controller. For a moving MN within an SDWN, the map registration cost is defined as follows: $E_{\omega_s}(P_{Map-Reg} + P_{Map-Noti})\beta h_{ITR-L\_SDWN}$.

In the case of an inter-SDWN handover, a Map-register message and a Map-Notify message are exchanged between ITR and MS through the LISP-SDWN Controller; moreover, the map database of a newly joined MN is created in the SDWN map database of the LISP-SDWN Controller, and the RLOC of the new LISP-SDWN Controller is registered in the map database of a standard MS. For a moving MN outside of an SDWN, the map registration cost is defined as $E_{\omega_d}(P_{Map-Reg} + P_{Map-Noti})\beta h_{ITR-MS}$, where $h_{ITR-MS} = h_{ITR-GTR} + h_{GTR-MS}$, as seen in Table. 5.

2) MAP DISCOVERY COST

A Map-Request message and a Map-Reply message are exchanged in order to discover the RLOC of an MN between ETR and MS.

With the benefits of the LISP-SDWN Controller, the Map Discovery does not require a Map-Request and a Map-Reply message when a host communicating with an MN inside an SDWN is located outside of an SDWN. Intra-SDWN mobility does not affect anywhere outside of the SDWN; therefore, LISP-SDWN is transparent to standard LISP systems. The map discovery is required only when two communicating nodes are located in the same SDWN as follows:

$$C^{C}_{L-SDWN} = (P_{Map-Req} + P_{Map-rep})\beta h_{ETR-L\_SDWN} \tag{7}$$

Data Delivery Cost is as follows:

$$C^{D}_{L-SDWN} = \lambda_\alpha E_S h_{H1-MN} \tag{8}$$

where λ_α is the average session arrival rate in a MN, E_S is the average session length of data packets, and h_{H1-MN} is the number of hop counts between H1 and MN (See Fig. 8) for the data packet path, and is defined by Eq. (9).

$$h_{H1-MN} = \alpha h_{H1-ETR} + \beta\delta h_{ETR-GTR} + \beta\delta h_{GTR-ITR} + \alpha h_{ITR-MN} \tag{9}$$

where δ is a weighting factor for the tunneling overhead of the data transmission, and α is a weighting factor for the wired link. The two paths between ETR and GTR and between GTR and ITR are set up by the tunneling connection, thus δ was used for the tunneling overhead of data transmission.

The total operation costs of LISP, LISP Controller, HMIP and MIP are computed in the same way as that of LISP-SDWN; moreover, those cost results are used for the performance comparison.

V. ANALYTIC PERFORMANCE EVALUATION

We compare the proposed LISP-SDWN with LISP and MIP as pioneering solutions, the LISP Controller as a LISP centralized management system in an ISP, and HMIP as a typical domain centralized system. In order to evaluate these solutions, mathematical cost modeling is carried out for the location management cost and the total operation cost based on the a reference network architecture illustrated in Fig. 8, and a real testbed is designed and configured as shown in Fig. 7 for EID-based Traffic-Awareness Management (ETAM). Finally, the performance of LISP-SDWN is steady and shows a lower operation cost than the other four protocols in the various communication domains in terms of scalability.

A. TEST SCENARIOS AND METRICS

Three communication scenarios are considered:

- ***Mobility Scenario 1:*** *Inter-domain Communication*
- ***Mobility Scenario 2:*** *Intra-domain Communication*
- ***Mobility Scenario 3:*** *Inter-domain Communication with a remote moving node*

In Fig. 8, mobility scenario 1 represents the case in which M1 moves from LISP-site A to LISP-site B while communicating with stationary hosts: H1, H2 . . . Hn, where n is the number of nodes; mobility scenario 2 represents the case in which M1 moves around while communicating with other stationary mobile nodes: M2, M3 . . . Hn within the same SDWN; and mobility scenario 3 represents the case in which M1 remains stationary in a LISP site of an SDWN domain, without handover, while communicating with a moving host: H1. In these three scenarios, we evaluate the following metrics:

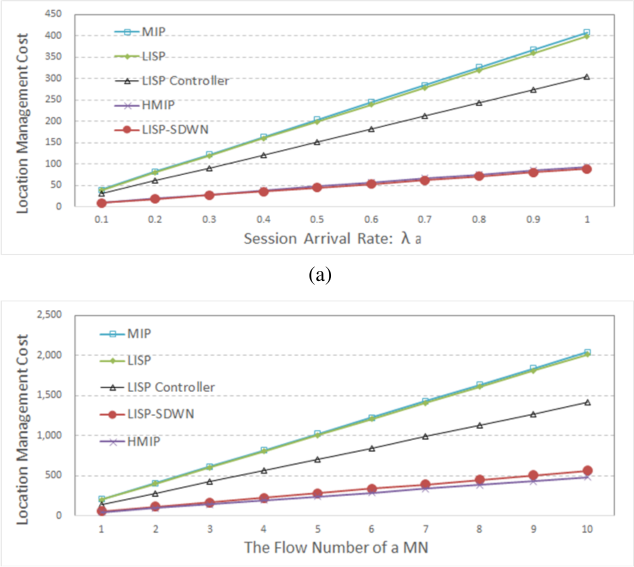
- ***Location management cost:*** sum of the location update cost and the discovery cost
- ***Total operation cost:*** sum of the location update cost, the discovery cost, and the data packet delivery cost
- ***EID-based Traffic-Awareness Management (ETAM):*** ability to offload a certain type of traffic from one RAN to another RAN

The location management cost and the total operation cost of LISP, LISP Controller, the LISP-SDWN, HMIP, and MIP are evaluated based on mathematical modeling.

1) MOBILITY SCENARIO 1

The location management cost is the traffic overhead obtained by issuing the control messages for Map Registration, Map Discovery, Map Solicitation, and Binding Updating to order to maintain the location management systems such as MS, the LISP Controller, the LISP-SDWN Controller, MAP, and HA. The location management costs of LISP, the LISP Controller, LISP-SDWN, HMIP, and MIP with the following metrics are evaluated in scenario 1, where M1 moves around, while communicating with remote hosts outside of an SDWN:

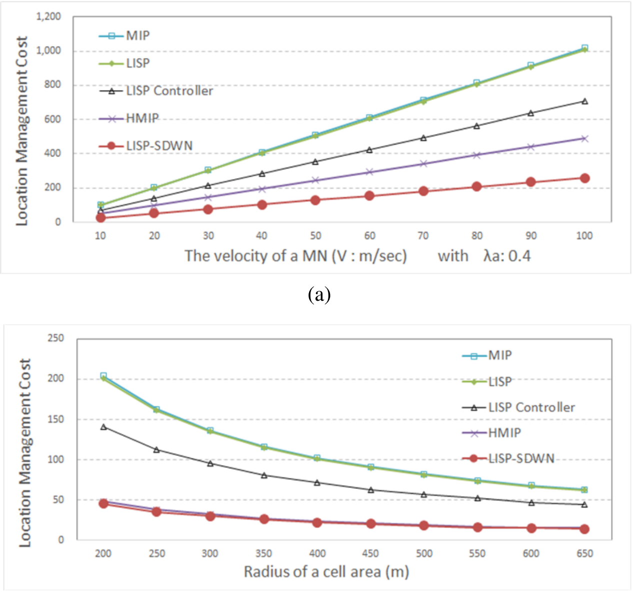
- With the session arrival rate, the location management costs of the five protocols are shown in Fig. 10A



(a)

(b)

FIGURE 10. Location management cost by session arrival rate and the number of flow.



(a)

(b)

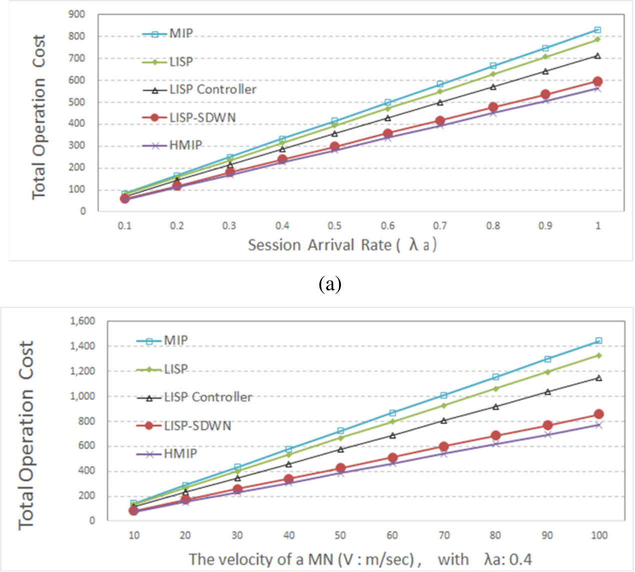
FIGURE 11. Location management cost by the velocity of a MN and the radius of a cell area.

- With the number of flows, the location management costs of the five protocols are shown in Fig. 10B
- With the velocity of a moving mobile node, the location management costs of the five protocols are shown in Fig. 11A
- With the radius of the cell area, the location management costs of the five protocols are shown in Fig. 11B

2) MOBILITY SCENARIO 2

The total operation cost is the total sum of the location update costs, the discovery costs, and the data packet delivery costs of LISP, the LISP Controller, LISP-SDWN, HMIP, and MIP; moreover, two total operation costs of the five protocols are evaluated in scenario 2, where M1 moves around, while communicating with other stationary mobile nodes inside of an SDWN as follows:

- With the session arrival rate, the total operation cost is shown in Fig. 12A
- With the velocity of a moving mobile node, the total operation cost is shown in Fig. 12B



(a)

(b)

FIGURE 12. The operational cost when two MNs communicate in the same SDWN.

3) MOBILITY SCENARIO 3

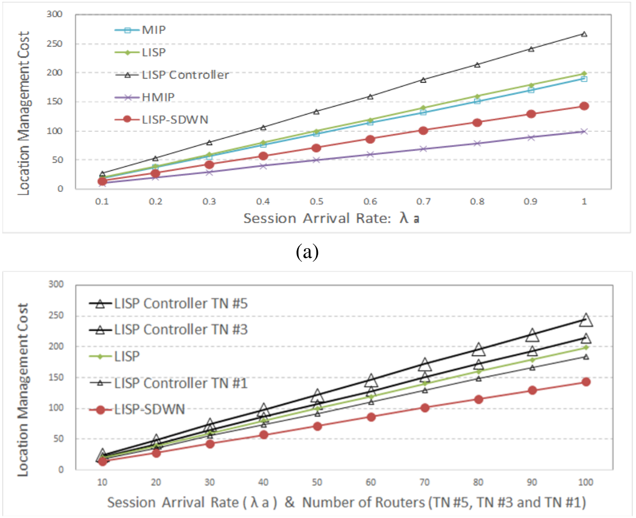
The location management cost of LISP, the LISP Controller, LISP-SDWN, HMIP, and MIP with the following two metrics are evaluated in scenario 3, where M1 remains stationary in a LISP site without handover, while communicating with a moving remote host outside of an SDWN:

- With the session arrival rate, the location management costs of the five protocols are shown in Fig. 13A
- With the velocity of the moving remote host, the location management costs of the five protocols are shown in Fig. 13B

4) SCALABILITY EVALUATION OF LISP-SDWN

The location management cost of LISP-SDWN is compared to those of LISP and the LISP Controller in three mobility scenarios: Inter-domain Communication, Intra-domain Communication,and Inter-domain Communication with a remote moving node.

- With the session arrival rate, the location management cost of LISP-SDWN is steady and lower than those of the others in all three mobility scenarios shown as solid lines in Fig. 14.



(a)

(b)

FIGURE 13. **The location management cost when CN moves.**

- With the velocity of a moving remote host, the location management cost of LISP-SDWN is steady and lower than those of the others shown as dotted lines in Fig. 14; furthermore, LISP-SDWN has a smaller effect in Inter-domain communication with a remote moving node.
- Scalability of LISP-SDWN is shown in all three mobility scenarios in terms of the location management cost compared to LISP and the LISP Controller.

EID-Based Traffic-Awareness Management (ETAM) is the ability to offload certain traffic from a RAN to another RAN for maximum bandwidth utilization in an SDWN. In this paper, we set up a testbed, as illustrated in Fig. 7. An SDWN is configured with a LISP-SDWN Controller, a LISP-SDWN GTR, and two xTRs.

The LISP-SDWN Controller is implemented in OpenDaylight and xTR is running on the Vector Packet Processing (VPP) platform, which provides the extended LISP-based map-assisted control plane to look up overlay-to-underlay address mappings provided by the OpenDaylight controller. The LISP-SDWN GTR is carried out with both as xTR and OF router; therefore, it has both an OpenFlow table and an SDWN Map database. The two xTRs serve a LISP-site A operated by an LTE provider and a LISP-site B operated by a Wi-Fi provider respectively. A remote LISP-site is configured with one xTR and one host, which is a cloud server.

The test scenario involves the LISP-SDWN GTR changing the path of the flows from an LTE RAN to a Wi-Fi RAN, when it notices that the source of the traffic is a cloud server (e.g., EID 20.20.20.20), as shown in Table. 2. In order to show the feasibility of ETAM, the latency of the location information update is tested and shown.

B. LOCATION MANAGEMENT COST IN SCENARIO 1

TABLE 6. **Simulation parameters in mobility scenario 1.**

Items	*Parameters*
Radius of the Cell area	200 to 650 meters
Number of cells in an SDWN	30
Session arrival rate for each MN	0.1 to 1
Number of flow which a MN handles	1 to 10
Average session length of packet	51 bytes
Weighting factor for the wireless Link	1.5
Weighting factor for the wired link	1
Weighting factor for the tunneling overhead	1.1
Velocity of a MN	10m/sec to 100m/sec
Number of xTR	5

One of our research concerns is minimizing the location management cost in an SDWN. Fig. 10A shows the location management cost by **session arrival rate**; moreover, the Y-axis represents the sum of the location update cost (C^L) and the discovery cost (C^C), and the X-axis represents the session arrival rate (λ_α). Further, Fig. 10B shows the location management cost by **the number of flows**, with the simulation parameters shown in Table. 6.

Fig. 11A shows the location management cost by **the velocity of an MN**, and Fig. 11B shows the location management cost by **the radius of a cell area**.

Fig. 10A shows the location management costs of LISP, the LISP Controller, LISP-SDWN, HMIP, and MIP in terms of the session arrival rate. LISP-SDWN and HMIP have lower location management costs than LISP, the LISP Controller and MIP. The major reason is that the control messages for location updating are suppressed outside of the SDWN domain during an intra-SDWN handover. By taking full advantage of the LISP-SDWN controller, LISP-SDWN can reduce the control packets as compared to LISP and MIP, and also shows a steadier and better performance.

The LISP Controller has a lower location management cost than LISP and MIP, which use a distributed management method, while LISP-SDWN, the LISP Controller, and HMIP use a domain centralized management method; however, the LISP Controller has a higher location management cost than LISP-SDWN and HMIP. Note that the LISP Controller has a higher location management cost than LISP-SDWN and HMIP due to the pushing method of updating a map entry whenever a map entry changes, while LISP-SDWN uses the pulling method of updating a map entry by default. The location management costs of LISP and MIP increase linearly as the session arrival rate increases, while the location management costs of domain centralized solutions (e.g., HMIP and LISP-SDWN) are steady and not dynamically affected by the number of flows.

Fig. 10B shows the location management costs of the five protocols in terms of the number of flows handled by an MN. The result between the session arrival rate and the number of flows does differ substantially, but the location management cost of HMIP is slightly lower than that of LISP-SDWN. It is worthwhile to evaluate the location management cost in terms of the number of flows, because a personal device will retain a high number of flows for many running applications; therefore, a candidate solution needs to be able to successfully

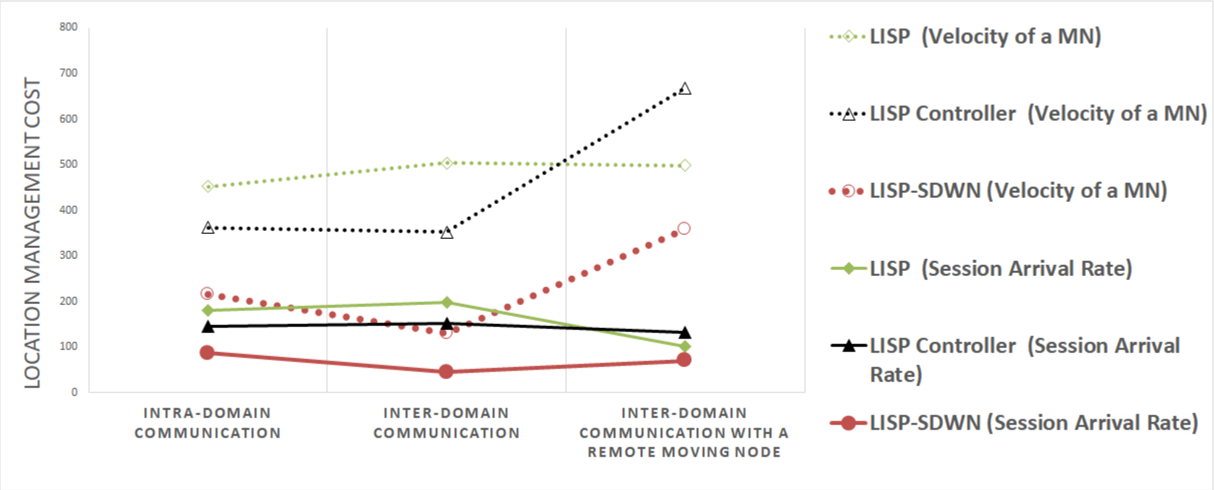


FIGURE 14. Scalability evaluation while the communication coverage varies from intra-domain to inter-domain.

handle a large number of flows. The location management cost of domain centralized solutions is affected by the way in which the map entry is updated to the xTR in an SDWN, such as a pull-based or push-based map entry update. In this simulation, a pull-based map entry update is adopted for both the LISP Controller and LISP-SDWN, so the location management costs of the LISP Controller and LISP-SDWN may increase with domain size.

Fig. 11A shows the location management costs of the five protocols in terms of the velocity of an MN. As the velocity of an MN increases, the number of map control packets issued increases in order to update a map database or binding information; consequently, the location management cost increases. LISP-SDWN remarkably shows the lowest location management cost as compared to the other four protocols. According to the results of the other protocols, HMIP has a cost similar to that of LISP-SDWN; however, LISP-SDWN had much better performance in terms of the velocity of a moving MN. This is because LISP-SDWN and HMIP have similar location management costs during intra-SDWN mobility; however, once an MN leaves the SDWN domain, HMIP has a higher location management cost because both HA and MAP are informed of binding information, while LISP-SDWN requires a location management cost for one MS. The number of location management systems changes its location management cost.

Fig. 11B shows the location management costs of the five protocols in terms of the radius of a cell area. As the radius of a cell area increases, the number of map control packets issued decreases for a map database or binding information; consequently, the location management cost decreases. The larger the radius of cell size, the smaller the overhead cost. From our observations, the location management costs of LISP-SDWN, the LISP Controller, and HMIP remain steady from a 500 meter radius, and there is not a big difference between the LISP Controller and LISP after 600 meters.

TABLE 7. Simulation parameters in mobility scenario 2.

Items	*Parameters*
Radius of the Cell area	200 meters
Number of cells in an SDWN	30
Session arrival rate for each MN	0.1 to 1
Average session length of packet	51 bytes
Velocity of a MN	10 to 100 m/sec
Number of xTR	5

C. TOTAL OPERATION COST IN MOBILITY SCENARIO 2

Fig. 12 shows the total operation costs of the five protocols: the sum of the location update cost, the discovery cost, and the data packet delivery cost in terms of the session arrival rate and the velocity of MN with the simulation parameters shown in Table. 7. The total operation cost is evaluated when M1 is moving around while communicating with another stationary mobile node, as seen in Fig. 8.

The five protocols evaluated in this paper are classified as either domain-centralized management systems or distributed-based management systems. Basically, the domain-centralized management systems, which are the LISP-Controller, LISP-SDWN, and HMIP, show better total operation costs than the distributed-based management systems of LISP and MIP. Fig. 12A shows the location management costs of the five protocols in terms of the session arrival rate. HMIP has the lowest location management cost compared to the other four protocols, as it is even lower than that of LISP-SDWN.

To the best of our knowledge, the path of the HMIP control messages is longer than that of LISP-SDWN control messages; moreover, for inter-SDWN mobility, HMIP has a higher location management cost because both HA and MAP are informed of binding information, while LISP-SDWN only needs to inform MS of a newly obtained RLOC. For intra-SDWN mobility, LISP-SDWN and HMIP have similar location management costs. Even though LISP-SDWN is an

TABLE 8. Simulation parameters in mobility scenario 3.

Items	*Parameters*
Radius of the Cell area	200 meters
Number of cells in an SDWN	30
Session arrival rate for each MN	0.1 to 1
Average session length of packet	51 bytes
Number of xTR: TN#1	One xTR
Number of xTR: TN#3	Three xTRs
Number of xTR: TN#5	Five xTRs

efficient method, HMIP is shown to have the best location management cost. The reason for this is that the control message size of HMIP is smaller than that of LISP-SDWN, e.g., a Map-Register message of LISP-SDWN is 124 bytes and a Binding Update(BU) of HMIP is 56 bytes; further, LISP has at heavier control management system due to the tunneling technology. LISP-SDWN and HMIP both have lower total operation costs than the LISP Controller; as expected, the pushing method requires a high control cost.

Fig. 12B shows the location management costs of the five protocols in terms of the velocity of an MN. LISP-SDWN and HMIP shows lower location management costs than to the other three protocols. According to the results of Fig. 12A and Fig. 12B, LISP-SDWN and HMIP show better operation costs in the velocity of an MN than in the session arrival rate; this means that the velocity of an MN causes more control messages than the session arrival rate. All of the domain-centralized solutions show that the overhead of control packets is steadier and lower. The reason for this is that intra-SDWN mobility does not propagate the map registration messages and binding message to the outside by domain controllers, MAP, the LISP Controller, and the LISP-SDWN Controller; therefore, those messages are suppressed. By taking full advantage of the LISP-SDWN controller, LISP-SDWN can reduce the control packets as compared to LISP and MIP, and also shows a steadier and better performance in all mobility scenarios.

D. LOCATION MANAGEMENT COST IN MOBILITY SCENARIO 3

Fig. 13 shows the location management costs of the five protocols with the simulation parameters listed in Table. 8, when M1 remains stationary within an SDWN without a handover, while communicating with moving remote hosts.

In this section, the location management cost is evaluated instead of the total operation cost, because the data packet delivery costs of the five protocols are similar or even identical to each other, which does not help to distinguish the costs more distinguishable. In this scenario, CN in the outside of an SDWN is a moving remote host, while an MN remains stationary and is under control of a centralized management system: HMIP, the LISP Controller, and LISP-SDWN. A handover of a remote host can compromise the benefits of the centralized management systems: the LISP Controller, the LISP-SDWN Controller, and MAP.

Fig. 13A shows the location management costs of the five protocols in terms of the session arrival rate. HMIP has the lowest location management cost of all of the protocols including LISP-SDWN; this means that HMIP has the least effect or has the least dependency on the location management system, which is MAP. In contrast, the LISP Controller and LISP-SDWN each have a high dependence on their location management systems: the LISP Controller and the LISP-SDWN Controller.

Unlike LISP-SDWN, the LISP Controller does not provide inter-connection between the LISP Controller and external LISP-sites and, for outside communication, it needs to rely on a Proxy Tunneling Router (PTR), which is one of the standard LISP Tunneling Routers. PTR performs a mapping database lookup as well as the LISP encapsulation function on behalf of non-LISP-capable sites. The remote moving host eliminates the benefits of the LISP Controller; therefore, the location management cost of the LISP Controller is even higher than those of LISP and MIP.

A similar situation occurs in LISP-SDWN because every handover of a remote moving host triggers a map registration and a map discovery so as to inform of a newly obtained RLOC; however, the LISP-SDWN GTR performs a map discovery on behalf of the M1, as seen in Fig. 8. Instead of the full path (e.g., between xTR-A and ITR) of a map discovery, the shorter path (e.g., between LISP-SDWN GTR and ITR) is performed; therefore LISP-SDWN has a lower location cost than the LISP Controller.

Fig. 13B shows the location management costs of LISP, the LISP Controller, and LISP-SDWN in terms of two metrics: the session arrival rate and the number of xTRs of an SDWN. This evaluation measures the location management cost as the number of xTRs increases. LISP-SDWN uses the pulling method; moreover, with the benefits of the LISP-SDWN GTR, LISP-SDWN is not fully compromised by a remote moving host. Consequently, LISP-SDWN shows the lowest location management cost among all of the LISP-related solutions. The LISP Controller employs the pushing method and shows an increasing location cost with the number of xTRs. The most predominant effects on location management cost for the LISP Controller are its dependence of PTR and its pushing method for updating a map database entry. Every handover of a remote host forces the LISP Controller to update a new RLOC of a remote host to all xTRs by Map-Update messages; further, as the number of xTRs grows bigger, the location management cost of the LISP Controller becomes more critical than those of LISP and MIP. In Fig. 13B, when the number of xTRs is larger than three, the location management cost of the LISP Controller is the largest among all of the protocols.

E. SCALABILITY EVALUATION OF LISP-SDWN

Fig. 14 shows the location management cost of LISP-SDWN compared to those of LISP and the LISP Controller in three mobility scenarios with simulation parameters, as shown in Table. 9.

TABLE 9. Simulation parameters for three mobility scenarios.

Items	*Parameters*
Radius of the Cell area	200 meters
Number of cells in an SDWN	30
Session arrival rate for each MN	0.5
Velocity of a MN	50 m/sec
Number of xTR	5
Average session length of packet	51 bytes
Weighting factor for the wireless Link	1.5
Weighting factor for the wired link	1
Weighting factor for the tunneling overhead	1.1

TABLE 10. Location management cost ratio of LISP-SDWN to LISP and the LISP controller.

By the Session Arrival rate, Ratio of LISP-SDWN to	LISP	LISP Controller
Inter-domain	0.22 : 1	0.30 : 1
Intra-domain	0.48 : 1	0.60 : 1
With a remote moving node	0.70 : 1	0.53 : 1
By the Velocity of MN, Ratio of LISP-SDWN to	LISP	LISP Controller
Inter-domain	0.26 : 1	0.26 : 1
Intra-domain	0.47 : 1	0.47 : 1
With a remote moving node	0.72 : 1	0.72 : 1

The result contains four findings: 1) LISP-SDWN shows the best performance compared to LISP and the LISP Controller in terms of the location management cost in all mobility scenarios: Inter-domain Communication, Intra-domain Communication, and Inter-domain Communication with a remote moving node, 2) the velocity of an MN has a bigger effect on the burden of location management than the session arrival rate, and 3) Inter-domain communication with a remote moving node compromises the domain centralized systems: the LISP Controller and the LISP-SDWN Controller, and 4) in the conditions of Inter-domain Communication with a remote moving node and velocity variation, the LISP Controller shows the biggest location management cost, even as compared to LISP, due to the map updating cost based on the pushing method.

In Fig. 14, the location management costs of LISP-SDWN are represented by the brown dotted and solid lines, where the brown dotted line with empty circles represents the location management cost caused by the velocity and the brown solid line with solid circles represents the location management cost caused by the session arrival rate. LISP shows the lowest location management cost compared to LISP and the LISP Controller in all mobility scenarios, as shown in Table. 10; moreover, the location management cost of LISP-SDWN ranges from 22 percent to 72 percent of the location management cost of LISP, and the location management cost of LISP-SDWN ranges from 26 percent to 72 percent of the location management cost of the LISP Controller.

With the three LISP-based solutions, the location management cost caused by the velocity is much higher than the location management cost caused by the session arrival rate shown in Fig. 14. All of the dotted lines have higher location management costs than the solid lines. This means that the velocity has a larger burden on the location management cost than the session arrival rate.

TABLE 11. Location management cost difference between the velocity and the session arrival rate.

Ratio of the Velocity to Session Arrival Rate by	LISP-SDWN	LISP Controller	LISP
Inter-domain	2.88 times	2.32 times	5.04 times
Intra-domain	2.47 times	2.47 times	5.03 times
With a remote moving node	2.53 times	2.5 times	4.94 times

In the case of communication with a remote moving host, the average difference of the location management cost caused by velocity and session arrival is around five times, while the average difference of the location management cost is around 2.5 times that of other mobility scenarios. As for LISP-SDWN, the location management cost is 2.88 times higher in Inter-domain communication; however, it is over five times higher in Inter-domain communication with a remote moving node, as shown in Table. 11. The remote moving node partially compromises the benefits of the LISP-SDWN Controller, while the benefits of the LISP Controller are completely compromised. However, if LISP-SDWN uses the pushing method for the map information update, it will have a higher location management cost than LISP. This is still considered an open issue in our study, and as such is beyond the scope of this paper.

F. EID-BASED TRAFFIC-AWARENESS MANAGEMENT (ETAM)

Cloud traffic is defined as being bandwidth-hungry and delay-tolerant, and it does not require an expensive cellular connection. We demonstrate that the cloud traffic shifts from a cellular network to a Wi-Fi network by the LISP-SDWN Controller in the network layer. In Fig. 7, the LISP-SDWN GTR has an SDWN map database and flow table. When the LISP-SDWN GTR receives the LISP packets with source EID 20.20.20.20 and destination EID 1.1.1.1 in Table. 2, it notes the following:

1) The Mobile Node with EID 1.1.1.1 has two interfaces, RLOC 192.0.2.21 from LTE connection and RLOC 192.0.2.22 from Wi-Fi connection through the SDWN map database.
2) The source host with EID 20.20.20.20 is a cloud server handling cloud traffic. We assume that EID of a cloud server is well known on the Internet.

Once the LISP-SDWN GTR decides to forward the packets classified as cloud traffic, it sets up tunneling between the LISP-SDWN GTR and xTR-B and capsulates the LISP packets with the source RLOC 192.0.2.11 and the destination RLOC 192.0.2.22. The capsulated packets are then forwarded to Wi-Fi RAN via port 4 of the OF Router controlled by the LISP-SDWN Controller. All OF Routers in an SDWN receive flow entries issued by the LISP-SDWN Controller. Table. 12 shows the transmission times of Map Request/Reply to be 1.4ms and of map update latency to be 3.4ms.

As a result, the map update latency by the LISP-SDWN Controller is small enough so as to not affect the minimum required latency for time critical mobile applications such

TABLE 12. Map database update latency based on Map-Request/Map-Reply.

Index	Map Request/reply	Map Update Latency
Time	1.4ms	3.4 ms

as VoIP [16]. This is one of the practical benefits of LISP-SDWN that may allow it to become a feasible solution from the perspective of an SDWN service provider; therefore, LISP-SDWN will handle dynamic mobile traffic.

G. DISCUSSION

LISP-SDWN shows the best performance in terms of the location management cost; however, this paper does not consider other performance metrics, such as end-to-end transmission latency, handover latency, etc. In order to evaluate those performance metrics, we planned to design the LISP-SDWN Controller on the OpenDaylight Controller (ODL). However, the implementation of the LISP-SDWN Controller on the ODL requires a substantial amount of work; therefore, we are considering a collaboration with other research groups in future studies. We were able to configure the LISP services of ODL to simulate the LISP service in a simple network architecture, so that only the map update latency was measured in our work.

It is not fair to evaluate the difference between LISP-based solutions and MIP-based solutions, due to difference in the network intrastate components, packet formats, and protocols. For this reason, we did not cover all details of control messages for AAA, association on the wireless links, etc; instead, we aim to evaluate the five protocols in terms of three metrics: the location update cost, the discovery cost, and the data packet delivery cost. We assume that the control management costs caused by AAA and association may be similar; consequently those control management costs do not need to be involved in our evaluation.

If the LISP-SDWN Controller uses the pushing method in order to update a map entry whenever a map entry changes like the LISP Controller, the LISP-SDWN Controller may not show better performance than the LISP. We plan to research the optimization method of location updating based on the benefits of the LISP-SDWN Controller having a global view of a database within an SDWN. The optimization solution may not be a fully pushing method, and it may need to handle a large amount of fast updating traffic in a dynamic mobile network circumstance.

VI. CONCLUSION

In this paper, we introduce a method of deploying LISP into a next generation network (e.g., SDWN) by satisfying the technical features and the minimum deployment cost required by an SDWN service provider from the perspective of an SDWN service provider. The proposed LISP-SDWN can provide a LISP and OpenFlow centralized management, routing scalability, seamless vertical handover, and traffic-aware management by reducing the location management cost by 28-78% compared to those of previous LISP and the LISP Controller. We successfully kept the deployment cost down and retained compatibility with the standard LISP without the need for extra control packets and procedures. LISP-SDWN also shows the lowest location management and operation costs, which are up to 22% of those of the previous LISP. We plan to implement a more sophisticated LISP-SDWN and final model of EID-based Traffic-Awareness Management (ETAM) in a future study.

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