Leveraging Software-Defined Wireless Network (SDWN) by Locator/Identifier Split Scheme for Mobility Management

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Abstract —To provide the improved Mobility Management (MM) of Software-Defined Mobile Networks (SDWN), the double separation approach is applied to SDWN. A Locator/Identifier split scheme is embedded in the Software-Defined Wireless Network (SDWN), which decouples the control plane and the data plane, while a Locator/Identifier split scheme splits the locator from the identifier (e.g., Location/ID Separation Protocol (LISP)). The major contribution of the research is that 1) the LISP functions of the Ingress/Egress Tunneling Router (xTR) do not require modification at all when xTRs are deployed in SDWN in order to enhance the SDWN as the LISP-SDWN and 2) the interoperability with other standard LISP sites are supported for routing scalability. The existing SDWN is based on the current IP address scheme requiring an extra overhead of location management that causes performance degradation. In order to improve the overhead of location management, the LISP-SDWN Controller is introduced as a centralized LISP management system dealing with the dynamic movement of MNs. The performance evaluation is carried out with the MIPv6, LISP, LISP Controller and LISP-SDWN in terms of the operational cost, and it shows that the proposed LISP-SDWN is the feasible and efficient solution for the SDWN providers.

Index Terms—SDWN, LISP, Mobility Management, SDN, wireless mobile network and locator/identifier split

I. Introduction

To satisfy the requirements of 2020 mobile networks [1], the telecommunication sector is undergoing a major revolution that will require fast deployment of new services and solutions against an explosion in the number of users and amount of traffic [2], [3]. In order to face these challenges, flexibility in management and configuration as well as vendor-independence are demanded in a Software-Defined Wireless Network (SDWN) [4]-[14]. However, the maturity of SWDN has not proven yet to be a feasible solution in career-grade networks requiring 50ms of minimum required recovery time for VoIP, fast-failover, reliability and scalability according to the size and complexity of the network. One cause of performance degradation is the current IP address scheme.

To tackle the limitations of the current IP address scheme, the Location/ID Separation Protocol (LISP) has been proposed because such separation would seamlessly provide mobility to the Internet. Actually, separating identity from routing location is an important design principle of inter-domain networks, known even before the Internet was created, but unfortunately the current architecture does not implement it. LISP uses two different types of addresses: Endpoint Identifiers (EIDs) and Routing Locators (RLOCs). Many ID/LOC split schemes can be found in [15]-[24].

In section II, as related works, the control plane and data plane separation (e.g., SDWN) is described, the two address schemes (e.g., Mobile IP-based scheme and Locator/Identifier split scheme) are addressed, and the Locator/Identifier split-based Software-Defined Networking (SDN) solutions are surveyed. In section III, the background information of LISP and the draft network architecture of LISP-deployed SDWN are described. In section IV, the LISP-SDWN is proposed. In Section V, the mathematical models of MIPv6, LISP, LISP Controller and LISP-SDWN are suggested and in Section VI the performance analysis is depicted and the test results are given. In Section VII and VIII, discussion is addressed and conclusions are made respectively.

II. Related Works

The proposed LISP-embedded Software-Defined Wireless Network (LISP-SDWN) is derived not only from Software-Defined Networking (SDN) perspectives for fast deployment of new services and solutions, but also from the Locator/Identifier split protocol for improved routing scalability and mobility management. In this section, control plane and data plane separation and location/identifier separation are described. As recent research, the Locator/Identifier split-based SDN solutions are also described in this section.

A. Control Plane and Data Plane Separation

In order to build the reference network architecture for LISP-SDWN, the SDN-based mobile network architecture in [8] is considered because it reflects the

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heterogeneous feature of future mobile networks. It consists of various wireless technologies (e.g., cellular networks, Wi-Fi and sensors) and multiple coverage layers (e.g., macro- and small cell-layers), and it is depicted in Fig. 1. Across the heterogeneous mobile edge networks and the core network, seamless mobility is required and is a goal of our research.

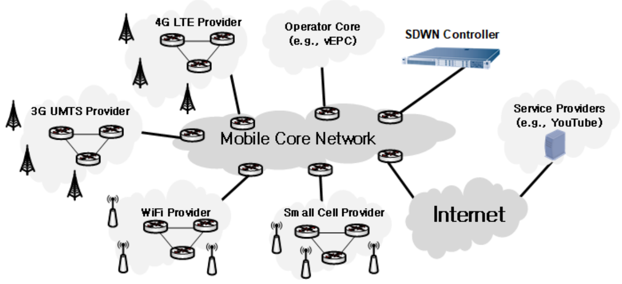

Fig. 1. Reference network architecture for SDWN

With the SDN-based solution, the key benefits are easier deployment of new services, reduced management cost of heterogeneous technologies, efficient operation of multi-vendor infrastructures, increased accountability and service differentiation, and the continuous and transparent enhancement of network operations [8].

B. Mobile IP-based and Locator/Identifier Split Scheme

In order to support the location management system in current IP network, a Mobile IP-based schemes use two locators: Home of Address (HoA) for identification purposes and Care of Address (CoA) for location purposes because the IP address scheme itself does not separate the location and identification information (i.e., MIPv6 [25], PMIP [27], DMM [28] and 3GPP mobility).

1) Mobile IPv6 (MIPv6): A host-based mobility protocol enables a Mobile Node (MN) to register its new physical address with Home Agent (HA) in a home network when it changes its network, a so-called foreign network, during handover. Then a bi-directional tunnel between the MN in the foreign network and the HA in the home network is established for forwarding packets sent by Corresponding Node (CN) to the new location of MN in the foreign network.

2) Proxy mobile IPv6(PMIPv6): It is the network based mobility protocol and it enables a Mobile Access Gateway (MAG) to register the new physical address of a Mobile Node (MN) with a Local Mobility Anchor (LMA) on behalf of a MN. Consequently, any control packets between the MN and the LMA are not required, so PMIPv6 is called a network based mobility protocol. MAG may be implemented in an access router. When the MN moves into a new network, the MAG of the new network detects the MN and sends the control message to the LMA to update the location of the MN. Then the bidirectional tunnel between the LMA and the new MAG is established to forward the packets destined for the MN. Note that the tunnel terminates at MAG, unlike the host-based mobility protocol where a tunnel is established to MN. Compared to the host-based mobility protocols, such as MIPv6, PMIPv6 provides better performance in terms of handover latency and control cost. However, PMIPv6 doesn't support inter-domain handoff, and due to this limitation the PMIPv6 is not chosen to compare with our proposed protocol in the evaluation stage.

3) GPRS tunnelling: It is implemented in the mobile core network. LTE networks require traffic to be sent to the Packet data network gateway(P-GW), which burdens P-GW with the traffic bottleneck and overhead of GPRS tunneling. Many different wireless technologies have been invented; however, a seamless roaming is not supported yet.

As for the Locator/Identifier split scheme, the current IP addressing is initially assigned in a hierarchical manner, and for the inter-domain routing address aggregation is required. However, currently aggregation is becoming more and more difficult due to dynamic internet growth. Consequently, today's Internet routing and addressing architecture is challenging the serious scaling and mobility problem. Identifier/Locator (ID/LOC) split protocols have been discussed under the Routing Research Group (RRG). LISP [15], HAIR [33], APT [34] and TRRP [35] are based on tunneling, which uses encapsulation where the source and the destination locators are included in a new header, and ILNP [22], Six/One Router [21], RANGI [29], GLI-Split [30], IRON [31] and Name Based Socket [32] are based on addressing rewriting, which replaces the existing source and the destination addresses with the locators.

1) The Location/ID Separation Protocol(LISP): It was proposed to provide an incrementally deployable solution, such as separation in the Internet, and it has two separate name spaces: Endpoint Identifiers (EIDs), used within sites, and Routing Locators (RLOCs), used by the transit networks that make up the Internet infrastructure. A host obtains its EID via existing mechanisms used to set a host's local IP address and its EID must be globally unique. An EID is allocated to a host from an EID-Prefix block associated with the site where the host is located, and its EID can be used by the host to refer to other hosts. EIDs must not be used as LISP RLOCs. Endpoint Identifiers (EIDs) and Routing Locators (RLOCs) are addressed for the tunneling of data transmission. EIDs identifying hosts are assigned independently of the network topology, while RLOCs identifying network attachment points are used for routing purpose. EIDs remain unchanged even if mobile hosts are roaming [15].

2) LISP Mobile Node (LISP-MN): It is a particular case of LISP which specifies mobility. The functions of ITR and ETR are implemented in the LISP mobile node itself, which makes a single mobile node look like a LISP site. Unlike standard ITR behavior of LISP [1], the LISP-MN encapsulates all non-local, non-LISP sites destined outgoing packets to a Proxy Egress Tunnel Router (PETR), which is an infrastructure element used to decapsulate packets sent from mobile nodes to non-LISP sites. A LISP-MN receives a new RLOC when it moves or roams onto a new network because it has ETR function for its EID-prefix. And its new RLOC set of existing ones and newly obtained ones will be registered in MS. New sessions can be established as soon as the registration process completes. During roaming, sessions encapsulating data to RLOCs are not changed [17].

3) Routing Architecture for Next Generation Internet (RANGI): It is similar to the Host Identity Protocol (HIP) [20] architecture, RANGI also introduces a host identifier (ID) layer between the IPv6 network layer and the transport layer and hence the transport-layer associations (e.g., TCP connections) are no longer bound to IP addresses, but to the host IDs. It has a hierarchical DHT-based mapping system [29].

4) Shim6: It is a site-multihoming solution because a communication can continue when a site faces an outage on a subset of these connections or further upstream if a site has multiple connections to the Internet. However, Shim6 processing is performed in individual hosts rather than through site-wide mechanisms [19].

5) Host Identity Protocol (HIP): It separates the end-point identifier and locator roles of IP addresses. The Internet has two main name spaces, IP addresses and the Domain Name System. HIP introduces a Host Identity (HI) name space, which fills an important gap between the IP and DNS namespaces and consists of Host Identifiers (HIs). The Host Identity Protocol provides secure methods for IP multihoming and mobile computing. All occurrences of IP addresses in applications are eliminated and replaced with cryptographic host identifiers. The effect of eliminating IP addresses in the application and transport layers is a decoupling of the transport layer from the internetworking layer [20].

6) Six/One Router: The scalability of the Internet routing system suffers from an increasing demand for provider-independent, non-aggregatable IP addresses in networks at the Internet edge. New routing architectures have been proposed that mitigate this problem through indirection between provider-independent addresses at the edge and aggregatable, provider-allocated addresses in the core of the Internet. A major challenge in these architectures is backwards compatibility. Address indirection requires support at the sender and the receiver, so without appropriate backwards compatibility support communication is defeated between the upgraded and the legacy Internet. This paper proposes an address-indirection-based solution that is backwards compatible. The solution is shown to offer the benefits of provider-independent addressing in a scalable and backwards compatible manner, and to provide the incentives necessary to foster its early deployment [21].

7) Global Locator Local Locator and Identifier Split (GLI-Split): It is a locator-identifier addressing and routing protocol and its address scheme consists of a global locator, local locator and an identifier. The GLI-gateway assisted by the mapping system is able to rewrite the local locator to a global locator [30].

C. Locator/Identifier Split-based Software-Defined Networking (SDN)

As Software-Defined Networking (SDN) has become a promising solution to the current IP network, it is also being applied to wireless mobile networks. LISP Controller [36], CIN [37] and a network-based host identifier locator separating protocol [39] achieved the centralized Locator/Identifier split management system replacing Mapping System (MS), however those have no compatibility with LISP and no interoperability with a standard LISP sites. And OpenISMA [39] and IDOpenFlow [40] enable the identifier to be routable on the basis of OpenFlow technology in LISP sites. In our research, the LISP Controller [36] is chosen for evaluation because it has the same features as the proposed scheme: 1) the centralized LISP management system and 2) the LISP-based solution. However, the target network is different; the LISP Controller is for ISP and the LISP-SDWN is for SDWN. And the most distinguishable difference is that LISP-SDWN supports the interoperability with other standard LISP sites and does not require the extra control packet, unlike the LISP Controller.

The LISP Controller was proposed as a centralized LISP management system for ISP [36]. The contribution of the LISP Controller provides the ISP with centralized control and management in order to lower latency between LISP Controller and xTRs. To implement the LISP Controller, extra Update and Update-Request are required. Those messages are used for push-based update in order to lower latency instead of the existing pull-based update. With Update message, the LISP Controller can directly access and modify map entries of xTRs, and an Update-Request message is proposed to notify of an update to the Map database from xTRs to the LISP Controller. Consequently, a faster mapping information convergence is achieved while the standard LISP uses the Solicit Mapping Request (SMR) for mapping information updates among MS and xTR.

III. BACKGROUND OF SDWN AND LISP

The architecture of LISP-SDWN is based on a Software-Defined Wireless Network (SDWN) with the LISP address scheme. We explain the main features of LISP, such as the LISP address scheme, tunneling and the mapping system in this section. Furthermore, the draft network architecture of LISP-deployed SDWN is proposed.

A. LISP Address Scheme

As for the LISP address scheme, LISP has two separate name spaces, Endpoint Identifiers (EIDs) and Routing Locators (RLOCs), for the tunneling of data transmission. EIDs are globally unique and independent of network topology, while RLOCs are associated with network attachment points and used for routing purposes. EIDs remain unchanged even if mobile hosts are roaming.

Packets are encapsulated and transmitted by the outer header with RLOCs through the Ingress/Egress Tunneling Router (xTR) and the inner header with EIDs. Tunneling between two xTRs, xTR-A with its RLOC (a0) and xTR-X with its RLOC (x0), is setup for a mobile host with its EID (M), which communicates with a host with its EID (X) in Fig. 2.

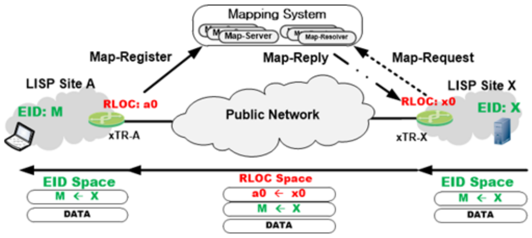

Fig. 2. LISP Operation and data transmission

B. *Mapping System (MS)*

A Mapping System (MS) is specified in LISP Alternate Topology [16], LISP Mobile Node [17] and Locator/ID Separation Protocol Map-Server Interface [18], and it is associated with EID-to-RLOC Map database, which is the key network infrastructure for internetworking among LISP sites. Each potential xTR typically contains a small piece of the EID-to-RLOC Map database: the EID-to-RLOC mappings for the EID-Prefixes "behind" the xTR. These map to one of the its own globally visible IP addresses. The EID-to-RLOC Map entries must be configured on all xTRs for a given LISP site. EID-to-RLOC Map database is distributed in several Mapping Servers of Mapping System in Fig. 2 and it maps EIDs to RLOCs as a location management system.

C. *LISP Tunnelling*

xTR is a general name of both the Ingress Tunneling Router (ITR) and Egress the Tunneling Router (ETR), which are functionally named, and xTR has both functions of ITR and ETR. During data transmission by LISP tunneling in Fig. 2, xTR-X performs the ITR function, which accepts an IP packet with a single IP header having no LISP header. Indeed, xTR-X prepends an "outer" IP header (x0 → a0), where RLOC (x0) is the globally routable RLOC in the source address field and RLOC (a0) is the result of the mapping lookup for the destination address field. Note that this destination RLOC may be an intermediate, proxy device that has better knowledge of the EID-to-RLOC mapping closer to the destination EID. xTR-A performs the ETR function, which receives LISP-encapsulated IP packets from the Internet on one side and sends the decapsulated IP packets to site end-systems on the other side.

D. *Draft Network Architecture of LISP-Deployed SDWN*

SDWN is referred to as a reference architecture for the proposed LISP-SDWN, and it consists of multiple wireless technologies, such as 2G, 3G, LTE, Wi-Fi, Small Cell and sensor networks, which reflect the future Wireless Mobile Network (WMN). In multiple heterogeneous Radio Access Networks (RAN), vertical handoff and mobility management are the biggest challenges, and the current Mobile IP-based solutions will be surpassed.

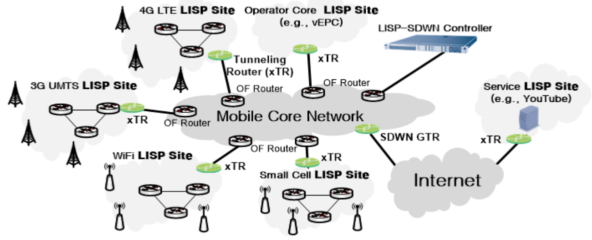

Fig. 3. LISP-deployed Software-Defined Wireless Network (LISP-SDWN)

The possible way to apply the Locator/Identifier Separation Protocol (LISP) into SDWN is depicted in Fig. 3. Each RAN technology may have different service providers, such as 2G providers, 3G UMTS providers, 4G LTE providers, Wi-Fi providers and Small Cell providers. We predict SDWN will consist of multiple LISP sites operated by different RAN technologies in Fig. 3. In this perspective, the proposed LISP-SDWN Controller needs to control and manage the multiple LISP sites residing in SDWN.

IV. LISP-Embedded Software-Defined Wireless Network (LISP-SDWN)

The architecture and components of the proposed LISP-SDWN is described in this section. In order to satisfy the requirements of the SDWN provider, the LISP-SDWN achieves a centralized LISP management entity in the SDWN Controller in Fig. 1 and also secures the routing scalability by realizing the interoperability with external LISP sites. Finally, the LISP-SDWN enables the SDWN provider to deploy LISP-enabled service and facilities (e.g., xTR) in its own SDWN Controller as the software system without any LISP function changes of LISP infrastructure (e.g., xTR, LISP-enabled host, etc.) residing in SDWN. The LISP-SDWN Controller in Fig. 3 is powered up not only with the flow information of data traffic, but also with the information of the EID-to-RLOC Map database.

A. *Design Principle and Components*

The design principle of LISP-SDWN is the centralized LISP management system and the routing scalability for the SDWN provider. In order to satisfy two contrary requirements, the SDWN Mapping System (SMS) and the SDWN Control System (SCS) are designed and implemented in the SDWN Controller [5] and it is referred to as the LISP-SDWN Controller in our research. The LISP-SDWN Controller controls and manages the LISP functions of xTRs residing in SDWN in Fig. 3. Note that each radio access technology is operated by its own xTRs and it is configured as one LIPS site.

B. Main Componenets

1) LISP-SDWN controller: It is an SDWN controller and it performs LISP functions, which are management of the SDWN EID-to-RLOC Map database and the control of xTRs. In this sense, the LISP-SDWN Controller is more powered by the EID-to-RLOC Map database and the OpenFlow Table I [11]. The SDWN Mapping System (SMS) and SDWN Control System (SCS) are introduced and embedded in the LISP-SDWN Controller in Fig. 4.

TABLE I: NOTATION TABLE

MS	Mapping System
HA	Home Agent
FA	Foreign Agent
CN	Corresponding Node
MAP	Mobility Anchor Point
ITR	Ingress Tunneling Router
ETR	Egress Tunneling Router
GTR	Gateway Tunneling Router of SDWN

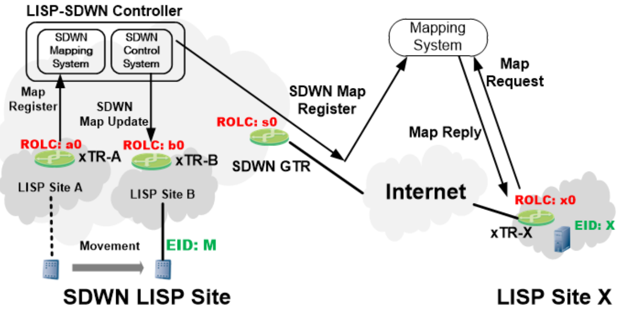

Fig. 4. System architecture overview of LISP-SDWN

2) SDWN Mapping System (SMS): It manages the SDWN EID-to-RLOC Map database composed of a small piece of the EID-to-RLOC Map database of xTRs and LISP Mobile Nodes (LISP-MNs) [17], and the SDWN EID-to-RLOC Map database is a locally accessible central database only in the SDWN while a standard EID-to-RLOC Map database in MS is a publicly accessible distributed database. SMS can generate and manage the SDWN EID-to-RLOC Map database without changing the LISP functions of xTRs residing in SDWN. Due to the OpenFlow control system of LISP-SDWN, xTRs don't need to change their LISP functions, but are able to communicate with external LISP sites via a standard MS.

3) SDWN Control System (SCS): It is a centralized control entity to bring consistency between the SDWN EID-to-RLOC Map database in the LISP-SDWN Controller and the small pieces of the EID-to-RLOC Map database in xTRs. When a change in the EID-to-RLOC Map database of xTRs occurs, it shall be updated in the SDWN EID-to-RLOC Map database of LISP-SDWN Controller as well; and if the SDWN EID-to-RLOC Map database of LISP-SDWN Controller is updated then corresponding EID-to-RLOC entries of xTRs are required to be updated as well.

4) xTRs: It is a general name for Ingress Tunnel Routers and Egress Tunnel Routers (xTR) and it is not dependent on the details of the mapping system database. The detailed description is in the LISP tunneling section.

5) OF vRouter: It operates with the basis of OpenFlow [11] to add, update and remove the flow entry, for additional functions, which attracts a Map-register destined to MS.

C. Central Management

In SDWN, each of the wireless technologies is configured as one LISP site and may be operated by different providers. Note that when MN handovers occur from one site to another site, it may also cause the vertical handover among the heterogeneous wireless technology networks. The SDWN EID-to-RLOC Map database is designed for seamless mobility. According to the LISP standard [15], the EID-to-RLOC Map database is located and managed in MS by control packets.

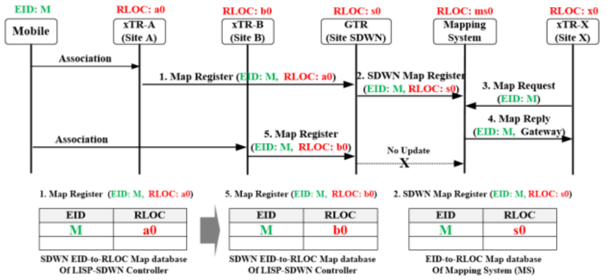

Fig. 5 EID-to-RLOC Map entry update in SDWN and Mapping System (MS)

In Fig. 5, when a MN with EID M moves into a new visited LISP site A, its new xTR-A directly sends Map-Resister to MS in order to register the newly obtained RLOC a0. In the proposed LISP-SDWN, a Gateway Tunneling Router (GTR) intercepts a Map-Register destined to MS and it reports the intercepted Map-Register to the LISP-SDWN Controller according to an OpenFlow table, which specifies that the packets destined for MS are forwarded to the LISP-SDWN Controller. Furthermore, the LISP-SDWN Controller adds the EID-to-RLOC Map entry <M, a0> to its own SDWN EID-to-RLOC Map database and also updates EID-to-RLCO Map database of GTR.

After the SDWN EID-to-RLOC Map database is updated with the Map entry <M, a0>, GTR performs the SDWN Map Register containing the Map entry <M, s0>, which attracts packets destined to EID M to GTR itself via MS (see Fig. 5). In this sense, any additional operation procedures for xTRs are not required. Finally, without any change of the LISP functions of xTR, SDWN EID-to-RLOC Map database is configured and managed in the LISP-SDWN Controller. Without informing MS of the handover of roaming MNs in SDWN, the LISP-SDWN Controller can provide seamless mobility with less LISP operation cost and less handover latency as well.

D. Routing Scalability

The bigger challenge is how to support routing scalability to LISP-SDWN. In LISP-SDWN, all MN RLOCs are stored in the SDWN EID-to-RLOC Map database, and if those are also stored in MS it causes another problem (e.g., consistency between controller and MS). Without registration of MN RLOCs in MS, MNs is not able to communicate outside of SDWN because there is no way to find the RLOCs assigned by SDWN, and it is isolated like other solutions [36]-[38], which achieve only a centralized LISP management system.

In our study, we achieve the routing scalability by the connection between the SDWN EID-to-RLOC Map database of the LISP-SDWN Controller and the EID-to-RLOC Map database of the MS. All RLOCs assigned in LISP-SDWN are mapped to global GTR RLOC(s) of the LISP-SDWN and several GTR RLOCs can be deployed for multihoming. GTR RLOC is then registered instead of MN RLOC in MS, which attracts packets destined to all RLOCs assigned in SDWN to GTR. In this sense, GTR RLOC is a like a global locator in GLI-Split [30], however GTR does not translate addresses like GLI-gateway or Network Address Translator. Finally, the LISP-SDWN Controller is able to make its SDWN function as a LISP site to communicate with other LISP sites operated by other providers without requesting any changes of xTRs.

E. Implementation of LISP-SDWN

The LISP-SDWN is being implemented rapidly on the Open Daylight, Open Overlay Router (OOR), Open Virtual Switch (OVS) and MiniNet. In order to deploy a scale network for LISP-SDWN, 1) MiniNet is used to create the network based on the OVS, 2) xTR is being implemented in OOR, and 3) the SDWN Mapping System and the SDWN Control System is being implemented in Open Daylight having LISP services. When we implement LISP-SDWN, then we can provide the real data for the performance evaluation, and we also expect a practical solution for a SDWN provider.

V. Mathematical Modeling

The operational cost to manage each location management system of MIPv6, LISP, LISP Controller and LISP-SDWN is mathematically modeled in this section. The simulation test bed is presented in Fig. 6.

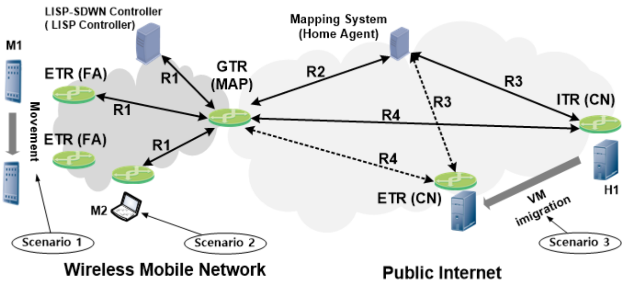

Fig. 6. Control paths of MN roaming inside/outside of SDWN

A. Operation Cost of LISP

The location management system, Mapping System (MS), requires the control packets such as Map-Register, Map-Notify, Map-Request, Map-Reply and Solicit-Map-Request (SMR) according to the LISP operation procedure. In order to perform the LISP operation procedure, the Egress Tunnel Router (ETR) cooperates with both the MS and the Ingress Tunnel Router (ITR). MS is registered with new MN RLOC and ITR is informed of the change of MN RLOC. We define C_{MS}^{MRG} which presents the control packet delivery cost for the Map registration between ETR and MS, C_{MS}^{MDC} which represents the control packet delivery cost for the Map discovery between ITR and MS, and C_{ITR}^{SRM} which represents the control packet delivery cost for the Map Solicitation between ETR and ITR to inform of the RLOC change of MN.

Notation for the operational cost evaluation and Simulation parameters are shown in Table II.

TABLE II: NOTATION FOR OPERATION COST AND SIMULATION PARAMETERS.

Notation		Simulation Parameters
C_{target}^{f}	**C**ost to perform **f** (function) toward **target** system	
MRG	Function of **M**ap **R**e**G**istration	
MDC	Function of **M**ap **D**is**C**overy	
SMR	Function of **S**olicit **M**ap **R**equest	
SC	**S**DWN **C**ontroller	
LC	**L**ISP **C**ontroller	
MN	**M**obile **N**ode	
FN	Number of **F**lows one MN keeps	1 to 12
TN	Number of Tunneling Router in SDWN	10
MG	Size of **M**ap Re**G**ister Packet	96 bytes
MT	Size of **M**ap No**T**ify Packet	96 bytes
MQ	Size of **M**ap Re**Q**uest Packet	80 bytes
MP	Size of **M**ap Re**P**ly Packet	80 bytes
SR	Size of **S**olicit Map **R**equest Packet	80 bytes
UR	Size of **U**pdate-**R**equest Packet	80 bytes
UP	Size of **UP**date Packet	80 bytes
BU	Size of **B**inding **U**pdate Packet	42 bytes
BA	Size of **B**inding **A**cknowledgment Packet	11 bytes
DC_{target}^{f}	**D**istance of **C**ontrol packets for function (e.g., R1, R2, R3, R1+R2, etc. of target)	
R1	Distance bet. ETR (FA) and GTR (MAP)	5 hopes
R2	Distance bet. GTR (MAP) and MS (HA)	5 hopes
R3	Distance bet. MS (HA) and (CN)	5 hopes
R4	Distance bet. GTR (MAP) and ITR (CN)	7 hopes

In IP networks, a packet delivery cost is the sum of the transmission cost and the processing cost. The transmission cost is related to the distance from the source to the destination node and the packet size, while the processing cost is from routing table lookup, route calculation, etc. In our evaluation, operational control packets are relatively much smaller than data packets, therefore the processing cost does not account for the total cost. The operational cost is approximated by the control packet transmission cost. For the total control cost of LISP, we set as below:

$$C_{LISP} = C_{MS}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR}, \text{ where } C_{MS}^{MRG} = DC_{MS}^{MRG} \times (MG + MT),\ C_{MS}^{MDC} = DC_{MS}^{MDC} \times (MQ + MP),\ C_{ITR}^{SMR} = DC_{ITR}^{SMR} \times SR.$$

B. Operation Cost of LISP Controller

The location management system, the LISP Controller, requires the control packets such as Update-Request, Update and Map-Notify in SDWN. For evaluating the operational cost, we define C_{LC}^{MRG} which represents the control packet delivery cost between ETR and the LISP Controller for registering the newly obtained RLOC of MN in the EID-to-RLOC Map database of the LISP Controller, and C_{LC}^{MDC}, which represents the control packet delivery cost between ITR and the LISP Controller for updating the newly obtained RLOC of MN in the EID-to-RLOC Map caches of all ITRs. The LISP Controller transmits Update control packets TN times, where TN is the number of xTRs in SDWN. Thus, we set as below:

$$C_{LC} = C_{LC}^{MRG} + C_{LC}^{MDC}, \text{where } C_{LC}^{MRG} = DC_{LC}^{MRG} \times (UR + MT) \text{ and } C_{LC}^{MDC} = DC_{LC}^{MDC} \times UP \times TN.$$

C. Operation Cost of LISP-SDWN

The location management systems, the SDWN Controller and the Mapping System, require control packets such as Map-Register, Map-Request, Map-Reply and Solicit-Map-Request (SMR) in LISP-SDWN. To evaluate the operational cost, we define C_{SDC}^{MRG} which represents the control packet delivery cost for the Map registration when the LISP-SDWN Controller is the anchor point between the Egress Tunneling Router (ETR) and the Mapping System (MS), C_{MS}^{MDC} which represents the control packet delivery cost for Map Discovery between the Egress Tunneling Router (ITR) and MS, and C_{CN}^{SMR} which represents the control packet delivery cost for Map Solicitation between MS and ITR. Thus, we set as below:

$$C_{SC} = C_{SC}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR}, \text{where } C_{SC}^{MRG} = DC_{SC}^{MRG} \times (MG + MT \times TN), C_{MS}^{MDC} = DC_{MS}^{MDC} \times (MQ+MP), C_{ITR}^{SMR} = DC_{ITR}^{SMR} \times SR.$$

where FN is 0 in the case of Intra-SDWN mobility and TN is the number of xTR in SDWN.

D. Operation Cost of MIPv6

MIPv6 has two systems to inform of its newly obtained routable address, which are Home Agent (HA) and Corresponding Node (CN), and MIPv6 requires Binding Update (BU) and Binding Acknowledgment (BA) to HA and the Binding Update (BU) and Binding Acknowledgment (BA) to CN for every handover

$$C_{MIPv6} = C_{HA}^{Binding} + C_{CN}^{Binding}, \text{where } C_{HA}^{Binding} = DC_{HA}^{Binding} \times (BU+BA) \text{ and } C_{CN}^{Binding} = DC_{CN}^{Binding} \times (BU + BA).$$

VI. Analytical Performance Evaluation Comparison

In this section, we demonstrate the feasibility of the LISP-embedded Software-Defined Wireless Network as a potential approach for future Mobile Networks. As pioneering solutions and the latest solutions, MIPv6, LIPS and the LISP Controller have been chosen for the performance evaluation against the proposed LISP-SDWN. Mathematical models of MIPv6, LISP, the LISP Controller and LISP-SDWN are specified in terms of the operational cost in section V. The performance evaluation is carried out with those mathematical models. In Fig. 6, three test scenarios are considered for the performance evaluation. Our research aims are related to SDWN, so that test scenarios include various mobility cases.

A. Intra-SDWN Mobility: Scenario 1

The purpose of the first test scenario is to show the difference between the domain-level centralized location management system and the globally distributed location management system during Intra-SDWN mobility. MIPv6 and LISP have a globally distributed location management system (e.g., HA for MIPv6 and MS for LISP) and the LISP-SDWN has a centralized management system (e.g., LISP-SDWN Controller for LISP-SDWN) in the scope of SDWN.

Scenario 1 differentiates the domain-level centralized location management system from the globally distributed location management system by showing the lowest overhead to maintain the location management system. The handover of MN M1 means inter-LISP mobility for LISP, however it means intra-SDWN mobility for LISP-SDWN. In Intra-SDWN mobility, LISP-SDWN performs only the function of Map registration to the LISP-SDWN Controller, which updates its SDWN EID-to-RLOC database and updates EID-to-RLOC Map cache of all xTR.

In Fig. 6, when MN M1 moves from one site to another site: 1) MIPv6 performs the Binding Update (BU) and Binding Acknowledgement (BA) with HA and CN respectively, 2) LISP performs the Map-Register, Solicit-Map-Request, Map-Request and Map-reply with MS, and 3) LISP-SDWN performs only Map-register between ETR and LISP-SDWN Controller. The total operational costs of MIPv6, LISP and LISP-SDWN are specified below.

$$C_{MIPv6} = C_{HA}^{Binding} + C_{CN}^{Binding} \times FN, \text{where } DC_{HA}^{Binding} = R1 + R2, DC_{CN}^{Binding} = R1 + R4.$$

$$C_{LISP} = C_{MS}^{MRG} + (C_{MS}^{MDC} + C_{ITR}^{SMR}) \times FN, \text{where } DC_{MS}^{MRG} = R1 + R2, DC_{MS}^{MDC} = R3, DC_{ITR}^{SMR} = R1 + R4.$$

$$C_{SC} = C_{SC}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR}, \text{where } DC_{SC}^{MRG} = R1, DC_{MS}^{MDC} = 0 \text{ and } DC_{ITR}^{SMR} = 0.$$

The operation control cost of LISP-SDWN shows the steadiest and the lowest; moreover, LISP-SDWN is not affected by the number of flows in Fig. 7.

The highest operation control cost is shown in LISP and the difference between LISP and MIPv6 is caused by: 1) the function of Map Discovery and 2) the bigger size of the control packet of LISP compared with the size of control packet in MIPv6 in Table II. If CN is close to MN in the case of MIPv6, the operational cost of MIPv6 shows as better even against LISP-SDWN because the LISP itself requires more control cost to maintain MS in Fig. 8. However, the data packet delivery cost may be much better in the case of the LISP-based solution because the MIP-based solution has a route optimization problem for data packet delivery.

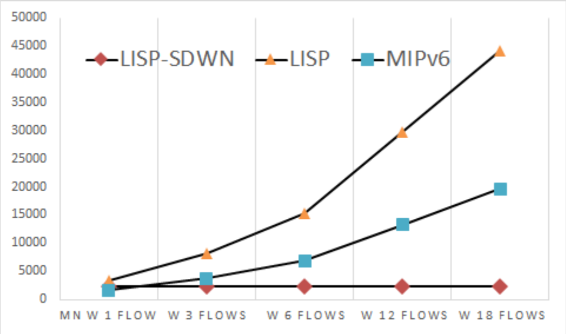

Fig. 7. Operational costs of LISP-SDWN, LISP and MIPv6 where R4 is bigger than R3 (It means the distance between MN and CN is long).

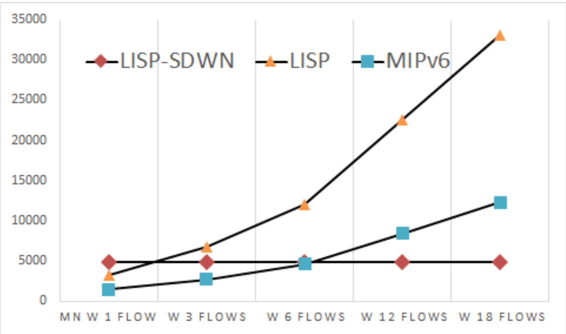

Fig. 8. Operational costs of LISP-SDWN, LISP and MIPv6 where R4 is smaller than R3 (It means the distance between MN and CN is relatively short)

B. *Intra-SDWN Mobility between Among MNs in SDWN: Scenario 2*

The purpose of this scenario is to show the capability of fast handover required by SDWN with MIPv6, LISP, the LISP Controller and LISP-SDWN. In SDWN, the major traffic comes from MNs and the handover of MNs may cause a huge burden to the network, when you consider the future network which will accommodate at least 1000 base stations in one domain. Moreover, each base station will serve at least 1000 MNs respectively, and each of one million MNs need multiple flows for its running application on powerful devices. In this sense the control overhead for the location management system, which needs to handle at least 10 million flows in SDWN, must be minimized and we will observe the operational cost among MIPv6, LISP, LISP Controller and LISP-SDWN. In Fig. 6, MN M1 is communicating with another MN M2 during the movement and it is a one-to-one connection. We consider one-to-many connections such as M0 with M1, M2, M3 and Mn and n means the number of hosts communicating MN M0. The total operational cost of MIPv6, LISP, LISP Controller and LISP-SDWN are:

$$C_{MIPv6} = C_{HA}^{Binding} + C_{CN}^{Binding} \times FN, \text{ where } DC_{HA} = R1 + R2 \text{ and } DC_{CN} = R1.$$

$$C_{LISP} = C_{MS}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR} \times FN, \text{ where } DC_{MS}^{MRG} = R1 + R2,\ DC_{MS}^{MDC} = R1 + R2,\ DC_{ITR}^{SMR} = R1.$$

$$C_{LC} = C_{LC}^{MRG} + C_{LC}^{MDC}, \text{ where } DC_{LC}^{MRG} = R1, DC_{LC}^{MDC} = R1.$$

$$C_{SC} = C_{SC}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR}, \text{ where } DC_{SC}^{MRG} = R1, DC_{MS}^{MDC} = 0 \text{ and } DC_{ITR}^{SMR} = 0.$$

All of domain-level centralized solutions (LISP Controller and LISP-SDWN) show that the overhead of control packets is low and the number of flow doesn't affect the performance and the lowest overhead is shown by the LISP Controller in Fig. 9.

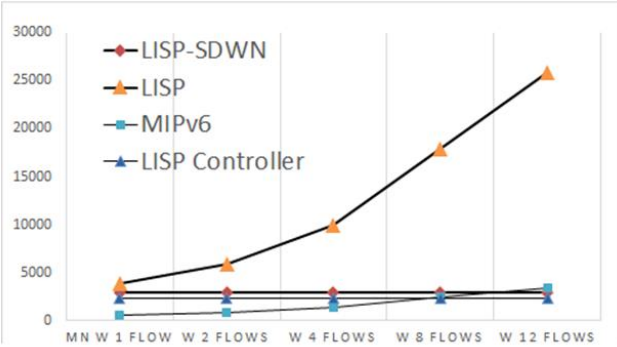

Fig. 9. Intra-SDWN mobility between among MNs in SDWN

It worth noting that the LISP Controller is operating only in the domain level and it doesn't provide the Inter-connection between the LISP Controller and external LISP sites. It depends on a Proxy Tunneling Router (PTR) for external communication. In this sense, the LISP Controller doesn't need to pay an extra operation cost for that and can show better performance against LISP-SDWN.

C. *CN Movement Outside Domain: Scenario 3*

The purpose of this scenario is to test the ability of how to share the changed address of remote CN among MIPv6, LISP, LISP Controller and LISP-SDWN. Let's assume that Virtual Machine (VM) services the stream video and that VM needs to migrate to another cloud platform with new RLOC or new routable address, and the CN is not supported by any domain centralized solutions, such as LISP Controller and LISP-SDWN. In order to increase the overhead to each solution, scenario 3 considers that multiple CNs are changing their routable addresses simultaneously during the movement. In this sense, the total operation cost to propagate the changed address of CN to other MNs communicating with the CN in the SDWN are:

$$C_{MIPv6} = (C_{HA}^{Binding} + C_{CN}^{Binding}) \times FN, \text{ where } DC_{HA}^{Binding} = R3 \text{ and } DC_{CN}^{Binding} = R1 + R4.$$

$$C_{LISP} = (C_{MS}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR}) \times FN, \text{ where } DC_{MS}^{MRG} = R3, DC_{MS}^{MDC} = R1 + R2, DC_{ITR}^{SMR} = R1 + R4.$$

$$C_{LC} = (C_{LC}^{MRG} + C_{LC}^{MDC}) \times FN, \text{ where } DC_{LC}^{MRG} = R1 + R4 \text{ and } DC_{LC}^{MDC} = R1.$$

$$C_{SC} = (C_{SC}^{MRG} + C_{MS}^{MDC} + C_{ITR}^{SMR}) \times FN, \text{ where } DC_{SC}^{MRG} = R3, DC_{MS}^{MDC} = R2 \text{ and } DC_{ITR}^{SMR} = R4.$$

Mobile-based solutions show better performance compared with the LISP-based solutions in terms of the operational cost, and the domain-level centralized management system shows slightly better performance due to their domain controller, which can inform of the changed addresses of other ITRs in Fig. 10. Otherwise, every ITR needs to perform the map discovery for itself.

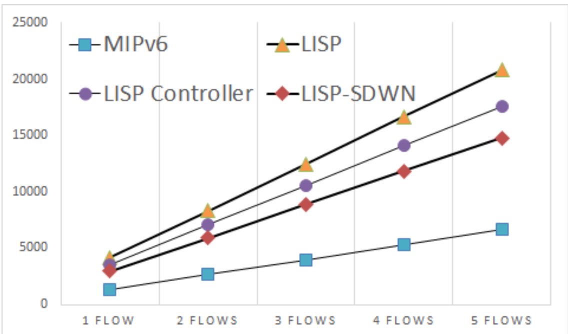

Fig. 10. Operational costs for CN movement

VII. Discussion

In this paper, the only metric for the performance evaluation is the operational cost among MIPv6, LISP, the LISP Controller and LISP-SDWN. Though it is enough to compare the proposed LISP-SDWN with LISP and the LISP Controller, however it doesn't explain the difference between LISP-SDWN and MIPv6 in regard to the operation control cost because MIPv6 has the lowest cost. The data packet delivery cost is also required because the route optimization is one of the factors to evaluate system performance as a future work.

VIII. Conclusion

The LISP-SDWN is proposed and the feasibility of the proposed LISP-SDWN is shown through our research. Compared with LISP, the operational cost of LISP-SDWN decreases up to 15% in the case of scenario 2 with 12 flows in order to operate a location management system. Moreover, our contribution is that: 1) the draft network architecture of the LISP-deployed SDWN is designed, 2) the mathematical comparison model among MIPv6, LISP, the LISP Controller and LISP-SDWN is designed, 3) the advantage of SDWN deployed with the LISP is addressed, and 4) the feasibility of the LISP-SDWN Controller is shown. In future works, 1) the data packet delivery cost and handover latency will be included, 2) the LISP-SDWN Controller will be implemented on the Open Daylight, and 3) Testbed will be deployed with Open Daylight, Open virtual Router (OVS) and Open Overlay Router (OOR).

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