# Performance Analysis of Identifier Locator Separating Protocols Based on a Distributed Hash Table in Traditional and Software Defined Networks

Bong-Jung Yoon, Seong-Mun Kim, and Sung-Gi Min

***Abstract*—The separation of host identifier (ID) and locator (LOC) is essential to support mobile environments in a permanent manner. Two up-to-date protocols, mobile oriented future internet (MOFI) and network-based host identifier locator separating protocol (NHILS), are ID/LOC separation architectures by using a distributed hash table. MOFI is a host-based mobility protocol and operates over traditional network environments, whereas NHILS is a network-based protocol and operates in software defined networks (SDN). In this paper, we present the cost model of each MOFI and NHILS, and conduct performance analysis for comparison. From numerical results, impact factors are confirmed in terms of signaling and data delivery, and the advantages and disadvantages of each protocol are produced. In addition, we explain the effect of adopting SDN on cost.**

***Index Terms*—Identifier locator separation, MOFI, NHILS, performance analysis, software defined networks.**

## I. Introduction

As mobile devices become popular, the mobility support is an essential part of the future Internet. The overloaded meanings of IP address as both host ID and LOC are a huge obstacle that has to be surmounted. Some researches about a protocol were conducted to address this problem in terms of mobility management and separation of ID and LOC. Mobile IPv6 (MIPv6) [1] which belongs to the former is a temporal measure to support mobility over existing IP stacks. The Host Identity Protocol (HIP) [2] and the Locator/Identifier Separation Protocol (LISP) [3] are affiliated with the latter. Although they separate ID and LOC in the network layer, mapping information is maintained by a centralized manner such as a Rendezvous Sever or a Map Server. Centralization cannot guarantee continuous service due to a single point failure problem. Mobile-Oriented Future Internet (MOFI) [4] and Network-based Host Identifier Locator Separating Protocol (NHILS) [5] solve this problem by adopting the mapping system based on a Distributed Hash Table (DHT).

MOFI is a state-of-art architecture designed with three key features, Global ID and Local LOC (GILL), Query-First Data Delivery (QFDD), and Distributed ID-LOC Mapping System (DMS). Each host has a globally unique ID for end-to-end communication and a local IP address used for packet delivery. To forward packets to a direct route, the LOC query is performed first before data packet is sent. And ID-LOC mapping information is maintained by caches in each access router (AR). But, the MOFI protocol stack has to be installed on a host and encapsulation is required to deliver packets.

NHILS operates over Software Defined Networks (SDN) [6] which makes network environments more flexible by separating control plane from data plane. In NHILS, a host identity tag (HIT) that is non-routable in a normal IP domain is routed in a Host Identity (HI) domain by a HIT controller (HC) which is adopting the content-addressable network (CAN) [7] configuration, and end node intervention in signaling process is clearly removed. It reduces overhead for delivering data packets by using header replacement instead of tunnelling.

In this paper, we evaluate performance of two DHT-based ID/LOC separation protocols, MOFI and NHILS. And from the numerical results, impact factors in term of signaling and data delivery are discovered. In addition, we ascertain the strengths and weaknesses of SDN in the perspective of ID/LOC separation.

The rest of this paper proceeds as follows. Section II describes the operation of two protocols in detail. Section III shows a network model for cost analysis and Section IV establishes cost models. Section V presents comprehensive numerical results base on the cost models. Finally, Section VI concludes the paper.

## II. Protocol Operation

### A. MOFI

The communication between nodes is accomplished by the support of access routers (AR) which own a Local Mapping Controller (LMC) maintaining a distributed hash table (DHT) and an HID-LOC Register (HLR). Each AR manages two caches for packet delivery. One is a Local Binding Cache (LBC) in which the list of mapping information between a Host ID (HID) and a Locator used within an access network (A-LOC) of attached hosts is contained. The other is a Data Forwarding Cache (DFC) which includes the mapping list (HID, Locator) used within backbone network (B-LOC) of remote hosts. For making description of signaling operation more understandable, let $LMC_{AR\text{-}X}$ and $LMC_{HL\text{-}X}$ represent the LMC that is located in the AR to which a node X is attached and the LMC that maintains the HLR of the node X, respectively. Fig. 1 shows the process that binding and data delivery is performed.

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When a correspondent node (CN) detects network attachment, it sends an HID Binding Request (HBR) to the AR to which the CN is attached ($AR_{CN}$). Upon receiving the HBR, the $LMC_{AR\text{-}CN}$ updates the CN's mapping information of the LBC in the $AR_{CN}$. After that, the $LMC_{AR\text{-}CN}$ forwards the HBR to the $LMC_{HL\text{-}CN}$ which is determined by DHT lookup. The $LMC_{HL\text{-}CN}$ now updates its HLR with a pair (an HID of the CN and an IP address of the $LMC_{AR\text{-}CN}$) and responds with an HID Binding ACK (HBA) to the $LMC_{AR\text{-}CN}$, and finally the HBA is delivered to the CN.

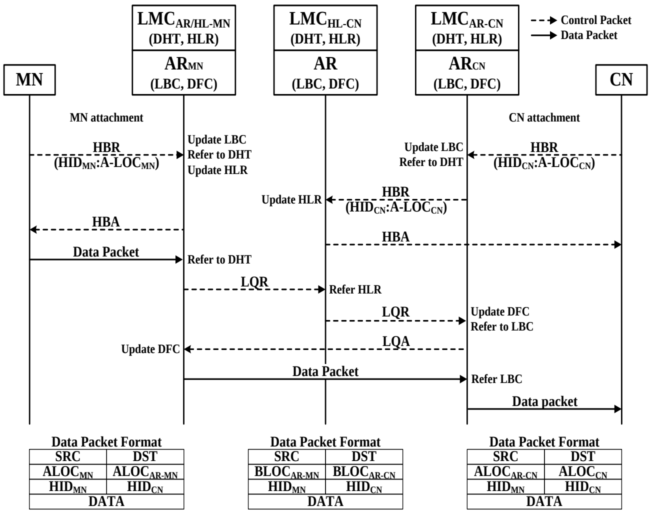

Fig. 1. Binding and data delivery in MOFI.

Data packets are delivered from a mobile node (MN) to the $AR_{MN}$ by referring to an A-LOC, whereas data delivery between ARs is performed by using a B-LOC. To obtain the B-LOC of the CN, the $LMC_{AR\text{-}MN}$ sends an LOC Query Request (LQR) to the $LMC_{HL\text{-}CN}$ chosen by DHT lookup. Then, the $LMC_{HL\text{-}CN}$ forwards the LQR to the $LMC_{AR\text{-}CN}$ which is founded by HLR lookup. The $LMC_{AR\text{-}CN}$ updates its DFC with the B-LOC of the MN and responds with an LOC Query ACK (LQA) including the B-LOC of the CN to the $LMC_{AR\text{-}MN}$. The $LMC_{AR\text{-}MN}$ that receives the LQA updates its DFC with the B-LOC of the CN. Now, the $LMC_{AR\text{-}MN}$ can send data directly to the $LMC_{AR\text{-}CN}$ by referring to its DFC, and the $LMC_{AR\text{-}CN}$ sends data packets to the CN through LBC lookup.

Data packets are encapsulated with an A-LOC at the MN and forwarded to the $LMC_{AR\text{-}MN}$. And then, the $LMC_{AR\text{-}MN}$ translates the header of encapsulated packet from the A-LOC into a B-LOC and sends it to the $LMC_{AR\text{-}CN}$. Finally, the $LMC_{AR\text{-}CN}$ replaces the B-LOC in the header of encapsulated packet with an A-LOC. It is noted that the $LMC_{AR\text{-}MN}$ has to wait until it receives the LQA before it forwards data packets. This QFDD feature could cause delay of data delivery if the LOC query operation is delayed.

### B. *NHILS*

The network consists of a Host Identity (HI) domain and an IP domain. An OpenFlow-capable switch (OFS) delivers packets by referring to flow tables which are managed by a designated host identifier tag (HIT) controller in the HI domain, and packets are delivered by normal IP routing in the IP domain. Communication between an OFS and an HIT controller (HC) is established by using OpenFlow messages [8] such as a Packet-in (PIN), a Packet-out (POUT) and a Flow modification (FMOD). HCs are categorized according to the role of which they are in charge. When an HC manages an OFS connected to an end node, it acts as a serving controller of the node (sHC). A home controller (hHC) maintains mapping information of nodes which are assigned by the CAN network configuration. An intermediate controller (iHC) is located in the middle of a sender and a receiver. It is only responsible for making flow table entries to forward packets to the next OFS which is closest to a destination among neighbor OFSs. The registration process of a CN is depicted in Fig. 2.

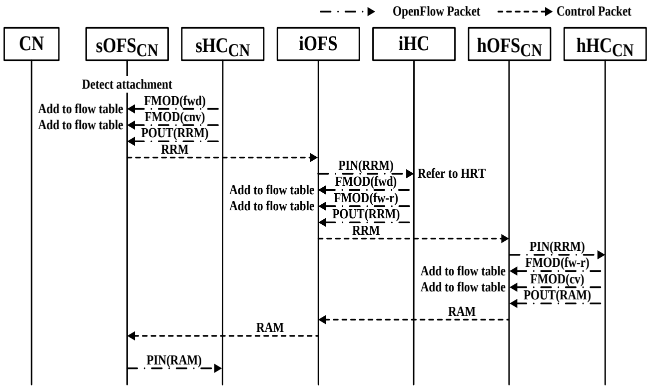

Fig. 2. Registration process in NHILS.

When a sHC of the CN ($sHC_{CN}$) detects CN's attachment, it makes two flow table entries. One is for forwarding a registration request message (RRM) to a next hop, the other is converting the LOC of the CN ($LOC_{CN}$) into the HIT of the CN ($HIT_{CN}$) for incoming packets. And it sends the RRM destined for the hHC of the CN ($hHC_{CN}$) to the OFS controlled by the $sHC_{CN}$ ($sOFS_{CN}$). Upon receiving the RRM, the $sOFS_{CN}$ forwards it to a next intermediate OFS (iOFS). The iOFS sends a PIN containing the RRM to the iHC which is controlling it. And then, the iHC determines a next OFS by referring to an HIT routing table (HRT) and adds two flow table entries for the forward and the reverse path. When the RRM arrives at the home OFS of the CN ($hOFS_{CN}$), it finally delivers the RRM to the $hHC_{CN}$. The $hHC_{CN}$ makes two flow table entries for the reverse path and conversion from the $HIT_{CN}$ into the $LOC_{CN}$. Then, $hHC_{CN}$ responds to the sender with a registration acknowledgement message (RAM). Because the flow table entries for the reverse path have been created while the RRM is delivered, the RAM is delivered directly to the $sHC_{CN}$, not via iHCs.

The process of route optimization (RO) and delivery of the first data packet (FDP) is depicted in Fig. 3. Data packets can be delivered through a direct/indirect path according to RO. After RO completion, all data packets are exchanged along the direct path. Unlike MOFI, a route optimization query (ROQ) is sent right after the FDP is sent. In other words, data packet delivery is performed immediately not to wait RO completion. Suppose that the MN is sender and the CN is a receiver. When the FDP is arrived at the serving HC of the MN ($sHC_{MN}$), it adds a flow table entry for delivery of the FDP and makes the serving OFS of the MN ($sOFS_{MN}$) send it to the next iOFS. Shortly afterward, the $sHC_{MN}$ generates an ROQ destined for the $hHC_{CN}$ and sends it. Similarly to registration process, flow table entries for the $HIT_{CN}$ are created while the FDP is delivered. So the ROQ which is following the FDP is delivered to the $hOFS_{CN}$ without the support of iHCs. When the FDP arrives at $hOFS_{CN}$, the destination address of the FDP is converted from the $HIT_{CN}$ into the $LOC_{CN}$, and then the FDP is forwarded to the $sOFS_{CN}$ through an IP domain. Finally, the FDP is delivered to the CN after the $LOC_{CN}$ is converted into the $HIT_{CN}$ at the $sOFS_{CN}$.

Upon receiving the ROQ, the $hOFS_{CN}$ forwards it to the $hHC_{CN}$ by referring to a TCP port number and flow tables although destination address of the ROQ is identical with that of FDP. Control messages are distinguished from data packets by a TCP port number and flow tables containing HITs of nodes whose HID-LOC mapping information is maintained by the $hHC_{CN}$. The HIT information is pre-configured by the CAN network configuration.

The $hHC_{CN}$ generates a route optimization reply (ROR) in response to the ROQ and send it to the $sHC_{MN}$. Flow tables needed to forward the ROR to the $sHC_{MN}$ are created at each OFS while the ROR is delivered. With receiving the ROR, the $sHC_{MN}$ adds a flow table entry for converting the $HIT_{CN}$ into the $LOC_{CN}$. Data packets following FDP before RO completion are routed by referring to flow table entries which are created during the FDP transmission. After RO, however, the destination address of the data packets heading for the CN is changed from the $HIT_{CN}$ into the $LOC_{CN}$ at the $sHC_{MN}$, so the data packets are delivered directly to the $sOFS_{CN}$ through the IP domain. Then, the destination address of data packets is converted from the $LOC_{CN}$ to the $HIT_{CN}$ at the $sOFS_{CN}$ and data packets are delivered to the CN.

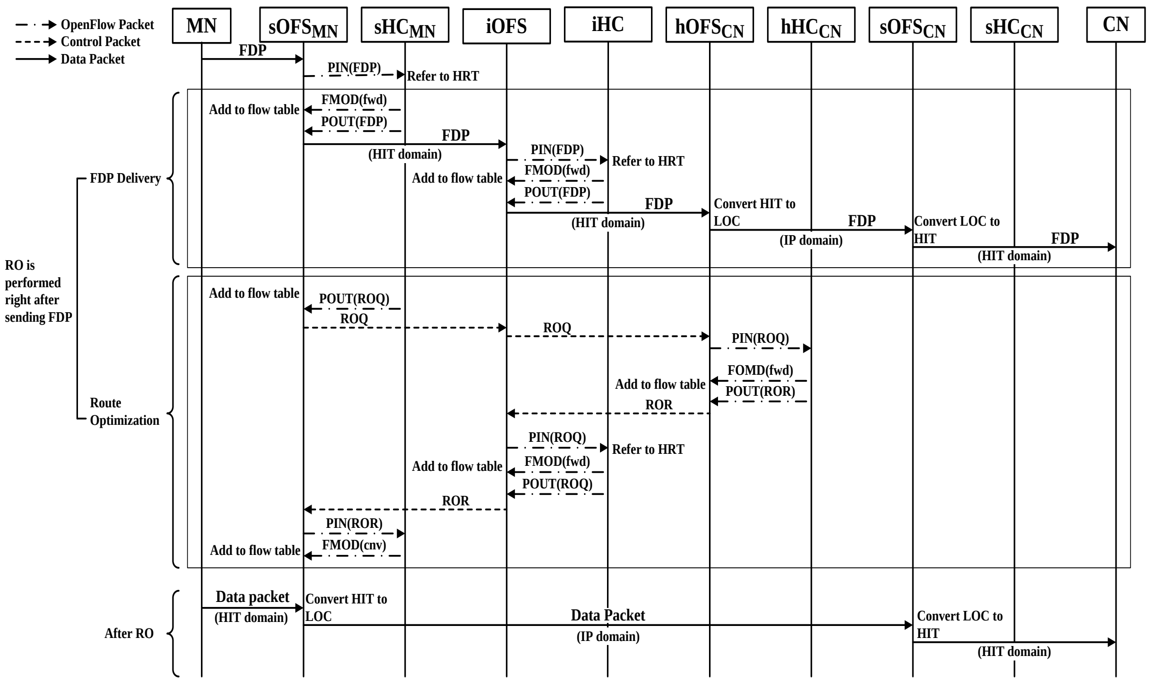


Fig. 3. RO and delivery of the FDP.

## III. Network Topology and Assumptions

To perform cost analysis, we develop intra-domain network topology based on [9]. This network model consists of four access routers (ARs), four host controllers (HCs), an MN, and an CN. All the ARs are connected to each other, building meshed network, and each AR has a wireless access point used for making a connection to the MN or the CN. And it is connected to an HC.

Because MOFI and NHILSP require different network entities, it is assumed that some entities change their function depending on the protocols. While communication between the MN and the CN is established based on MOFI, it is supposed that an LMC with a hash table and an HLR is located in each AR. And the HCs don't participate in the packet delivery in MOFI. On the other hand, it is assumed that each AR has all the qualities of an OpenFlow switch while NHILSP is operating. Suppose that $h_{X\text{-}Y}$ indicates average number of hops between X and Y [10]. Then, the list of average hop counts presented in Fig. 4 is as follows.

- $h_{A\text{-}A}$: between the AR and the AR.
- $h_{A\text{-}H}$: between the AR and the HC.
- $h_{A\text{-}N}$: between the AR and the nodes.

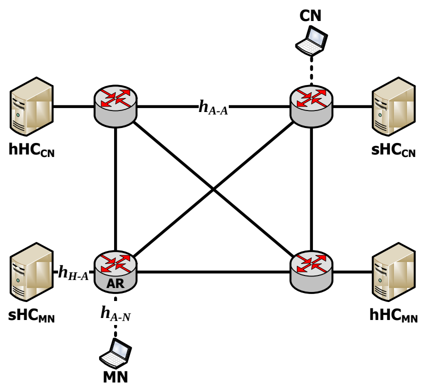


Fig. 4. Intra-domain network topology.

## IV. Cost Model

For performing cost analysis and comparison, we formulate the cost of signaling and data packet delivery. The signaling cost $C_{SG}^{(\cdot)}$ is the overhead caused by exchanging signaling messages among network entities before sending data packets. And the data packet delivery cost $C_{PD}^{(\cdot)}$ is the delay in conveying data packets from the MN to the CN. Each $C_{SG}^{(\cdot)}$ and $C_{PD}^{(\cdot)}$ can be represented as the message sizes in Bytes multiplied by the lengths of the path in hop count through which the packets are routed. And the total communication cost $C_{T}^{(\cdot)}$ is expressed as follows $C_{T}^{(\cdot)} = C_{SG}^{(\cdot)} + C_{PD}^{(\cdot)}$.

### A. MOFI

1) *Signaling Cost*: In MOFI, the operation for the HID-LOC binding and the LOC query should be conducted before exchanging data packets. Thus, the signaling cost of MOFI $C_{SG}^{(MO)}$ is expressed as

$$C_{SG}^{(MO)} = C_{BI}^{(MO)} + C_{QU}^{(MO)}, \tag{1}$$

where $C_{BI}^{(MO)}$ and $C_{QU}^{(MO)}$ indicate the cost of the HID-LOC binding and the LOC query, respectively. On detection of network attachment, the MN sends an HBR control message to the AR to which it is attached. After that, the $LMC_{AR\text{-}MN}$ forwards the HBR to the $LMC_{HL\text{-}MN}$. After the HBR is processed, this $LMC_{HL\text{-}MN}$ sends an HBA to the MN initiating the HID-LOC binding process. Because the HID-LOC binding cost of the MN and the CN can be regarded as same, $C_{BI}^{(MO)}$ is expressed as

$$C_{BI}^{(MO)} = 2(L_{HBR} + L_{HBA})(\beta h_{A-N} + \alpha h_{A-A}), \tag{2}$$

where $\alpha$ and $\beta$ signify the weighting factor for a wired link and a wireless link respectively, and $L_X$ is the message size of $X$ in Bytes. When the $LMC_{AR\text{-}MN}$ receives the first data packet from the MN, it begins the LOC query operation. To obtain the LOC information of the CN, an LQR message is delivered to the $LMC_{AR\text{-}CN}$ via the $LMC_{HL\text{-}CN}$, whereas an LQA message is forwarded from the $LMC_{AR\text{-}CN}$ to the $LMC_{AR\text{-}MN}$ directly. Thus, $C_{QU}^{(MO)}$ is represented as

$$C_{QU}^{(MO)} = (L_{LQR}\alpha 2h_{A-A}) + (L_{LQA}\alpha h_{A-A}). \tag{3}$$

2) *Data Packet Delivery Cost*: Data packets are routed along the direct path because delivery of data packets follows the LOC query operation. And an additional header containing the LOC information is required for data packet delivery. An A-LOC is used for delivering data packets from the MN to the $LMC_{AR\text{-}MN}$ and from the $LMC_{AR\text{-}CN}$ to the CN. The transmission of data packets from the $LMC_{AR\text{-}MN}$ to $LMC_{AR\text{-}CN}$ is facilitated by a B-LOC. Because the both headers have same values [11], the data packet delivery cost of MOFI $C_{PD}^{(MO)}$ is expressed as

$$C_{PD}^{(MO)} = N(p)(L_{DP} + \varpi)(\beta 2h_{A-N} + \alpha h_{A-A}), \tag{4}$$

where $N(p)$ and $L_{DP}$ indicate the number of data packets and the size of data packets in Bytes, respectively. And $\varpi$ is the header size for the LOC information in Bytes.

### B. NHILS

1) *Signaling Cost*: Upon detecting network attachment of the MN, the $sHC_{MN}$ sends a RRM to the home HC of the MN ($hHC_{MN}$) on behalf of the MN. And the $sHC_{MN}$ can send a query message to the $hHC_{CN}$ for route optimization. It is assume that the average registration cost of the MN and the CN is same. Thus, the signaling cost of NHILSP, $C_{SG}^{(NH)}$, is expressed as

$$C_{SG}^{(NH)} = 2(C_{RG}^{(NH)} + C_{RO}^{(NH)}), \tag{5}$$

where $C_{RG}^{(NH)}$ and $C_{RO}^{(NH)}$ represent the MN's cost of registration and route optimization (RO), respectively. $C_{RG}^{(NH)}$ can be divided into the registration request cost $C_{RR}^{(NH)}$ and the registration acknowledgement cost $C_{RA}^{(NH)}$.

$$C_{RG}^{(NH)} = C_{RR}^{(NH)} + C_{RA}^{(NH)}. \tag{6}$$

$C_{RR}^{(NH)}$ includes the cost of delivering the RRM $C_{DRR}^{(NH)}$ and using OpenFlow $C_{ORR}^{(NH)}$. Then, $C_{RR}^{(NH)}$ can be represented as

$$C_{RR}^{(NH)} = C_{DRR}^{(NH)} + C_{ORR}^{(NH)}. \tag{7}$$

The RRM is delivered from the $sHC_{MN}$ to the $hHC_{MN}$. Then, $C_{DRR}^{(NH)}$ is expressed as

$$C_{DRR}^{(NH)} = L_{RR}\alpha h_{A-A}, \tag{8}$$

where $L_{RR}$ means the size of the RRM in Bytes. $C_{ORR}^{(NH)}$ is classified according to the role of HCs, that is to say sHC, iHC, and hHC. Let $C_{sRR}^{(NH)}$, $C_{iRR}^{(NH)}$, and $C_{hRR}^{(NH)}$ be the OpenFlow cost generated by the $sHC_{MN}$, the iHCs, and the $hHC_{MN}$ for processing the RRM, respectively. Thus, $C_{ORR}^{(NH)}$ can be expressed as

$$C_{ORR}^{(NH)} = C_{sRR}^{(NH)} + C_{iRR}^{(NH)} + C_{hRR}^{(NH)}. \tag{9}$$

The $sHC_{MN}$ creates two flow table entries in the $sOFS_{MN}$ by sending two FMODs with an add-action. One is for forwarding the RRM to a next hop and the other is for converting the $LOC_{MN}$ into the $HIT_{MN}$. Thus, $C_{sRR}^{(NH)}$ can be expressed as

$$C_{sRR}^{(NH)} = (2L_{FM} + L_{rPO})\alpha h_{H-A}, \tag{10}$$

where $L_{FM}$ and $L_{rPO}$ represent the size of a FMOD and a Packet-out message (POUT) containing the RRM in Bytes.

An iHC receives a Packet-in message (PIN) from an iOFS and responds with a FMOD to add a flow table entry for delivering the RRM to a next hop. In addition to that, the iHC sends one more FMOD for reverse path in order to prepare delivery of a registration acknowledgement message (RAM). Therefore, $C_{iRR}^{(NH)}$ is expressed as

$$C_{iRR}^{(NH)} = (h_{A-A} - 1)(L_{rPI} + 2L_{FM} + L_{rPO})\alpha h_{H-A}, \quad (11)$$

where $L_{rPI}$ indicates the size of a PIN containing the RRM in Bytes. The $hHC_{MN}$ receives the PIN including the RRM from the home OFS of the MN ($hOFS_{MN}$) and replies with two FMODs. One is for converting the $HIT_{MN}$ into the $LOC_{MN}$ and the other is for forwarding the RAM. Thus, $C_{hRR}^{(NH)}$ is expressed as

$$C_{hRR}^{(NH)} = (2L_{FM} + L_{rPI})\alpha h_{H-A}. \quad (12)$$

Similarly to $C_{RR}^{(NH)}$, $C_{RA}^{(NH)}$ can be expressed as

$$C_{RA}^{(NH)} = C_{DRA}^{(NH)} + C_{ORA}^{(NH)}, \quad (13)$$

where $C_{DRA}^{(NH)}$ and $C_{ORA}^{(NH)}$ indicate the cost of delivering the RAM and using OpenFlow, respectively. Then, $C_{DRA}^{(NH)}$ can be represented as

$$C_{DRA}^{(NH)} = L_{RA}\alpha h_{A-A}, \quad (14)$$

where $L_{RA}$ means the size of the RAM in Bytes. As explained before, flow table entries for forwarding packets from the $hHC_{MN}$ to the $sHC_{MN}$ and converting the $LOC_{MN}$ into the $HIT_{MN}$ have been already inserted in the $sOFS_{MN}$. Therefore, $C_{ORA}^{(NH)}$ is expressed as

$$C_{ORA}^{(NH)} = (L_{aPO} + L_{aPI})\alpha h_{H-A}, \quad (15)$$

where $L_{aPI}$ and $L_{aPO}$ indicate the size of a PIN and a POUT containing the RAM in Bytes, respectively. $C_{RO}^{(NH)}$ can be divided into the RO query (ROQ) cost $C_{ROQ}^{(NH)}$ and the RO reply (ROR) cost $C_{ROR}^{(NH)}$.

$$C_{RO}^{(NH)} = C_{ROQ}^{(NH)} + C_{ROR}^{(NH)}. \quad (16)$$

And $C_{ROQ}^{(NH)}$ is expressed as

$$C_{ROQ}^{(NH)} = C_{DROQ}^{(NH)} + C_{OROQ}^{(NH)}, \quad (17)$$

where $C_{DROQ}^{(NH)}$ and $C_{OROQ}^{(NH)}$ indicate the cost of delivering the ROQ and using OpenFlow, respectively.

The ROQ is carried from the $sHC_{MN}$ to the $hHC_{CN}$. Thus, $C_{DROQ}^{(NH)}$ can be expressed as

$$C_{DROQ}^{(NH)} = L_{ROQ}\alpha h_{A-A}, \quad (18)$$

where $L_{ROQ}$ is the size of the ROQ in Bytes. It is noted that flow tables for forwarding the ROQ from the $sHC_{MN}$ to the $hOFS_{CN}$ have been created while the FDP is delivered. Thus, the OpenFlow cost for forwarding the ROQ is not driven and only a POUT and a PIN containing the ROQ is used at the $sHC_{MN}$ and the $hHC_{CN}$, respectively. Thus, $C_{OROQ}^{(NH)}$ is expressed as

$$C_{OROQ}^{(NH)} = (L_{qPO} + L_{qPI})\alpha\alpha_{H-A}, \quad (19)$$

where $L_{qPI}$ and $L_{qPO}$ indicate the size of a PIN and a POUT containing the ROQ in Bytes, respectively. $C_{ROR}^{(NH)}$ consists of the cost of delivering the ROR $C_{DROR}^{(NH)}$ and using OpenFlow $C_{OROR}^{(NH)}$. $C_{DROR}^{(NH)}$ is expressed as

$$C_{DROR}^{(NH)} = L_{ROR}\alpha h_{A-A}. \quad (20)$$

To deliver the ROR from the $hHC_{CN}$ to the $sHC_{MN}$, each HC should make flow table entries. When the ROR is arrived at the $sHC_{MN}$, it creates a flow table entry for converting the $HIT_{CN}$ to the $LOC_{CN}$. Let $C_{hROR}^{(NH)}$, $C_{iROR}^{(NH)}$, and $C_{sROR}^{(NH)}$ be the OpenFlow cost generated by the $hHC_{CN}$, the iHCs, and the $sHC_{MN}$ for processing the ROR, respectively. Then, $C_{OROR}^{(NH)}$ is expressed as

$$C_{OROR}^{(NH)} = C_{hROR}^{(NH)} + C_{iROR}^{(NH)} + C_{sROR}^{(NH)}. \quad (21)$$

Each cost is expressed as

$$\begin{aligned} C_{hROR}^{(NH)} &= (L_{FM} + L_{oPO})\alpha\alpha_{H-A} \\ C_{iROR}^{(NH)} &= (h_{A-A} - 1)(L_{oPI} + L_{FM} + L_{oPO})\alpha\alpha_{H-A}, \\ C_{sROR}^{(NH)} &= (L_{oPI} + L_{FM})\alpha\alpha_{H-A} \end{aligned} \quad (22)$$

where $L_{oPO}$ and $L_{oPI}$ indicate the size of a PIN and a POUT containing the ROR in Bytes, respectively.

2) *Data Packet Delivery Cost*: The data packet delivery cost of NHILP $C_{PD}^{(NH)}$ can be divided into two phases, the cost of delivering data packets $C_{DDP}^{(NH)}$ and using OpenFlow $C_{ODP}^{(NH)}$. Data delivery paths are contingent upon timing of RO. That is to say, data packets are delivered through an indirect path before RO is completed, and all data packets after RO are routed along a direct path. Thus, $C_{DDP}^{(NH)}$ is calculated as

$$\begin{aligned} C_{DDP}^{(NH)} = &(\omega N(p)L_{DP}(\beta 2h_{A-N} + \alpha 2h_{A-A})) \\ &+ ((1-\omega)N(p)L_{DP}(\beta 2h_{A-N} + \alpha h_{A-A})) \end{aligned}, \quad (23)$$

where $\omega$ is the ratio of data packets delivered along indirect path. It is noted that flow table entries for the path from the MN to the $hOFS_{CN}$ are set up while the FDP is delivered. And the cost generated by $hHC_{CN}$ is none as the FDP is forwarded to the IP domain immediately when it arrived at the $hOFS_{CN}$. $C_{ODP}^{(NH)}$ is represented as

$$C_{ODP}^{(NH)} = C_{sODP}^{(NH)} + C_{iODP}^{(NH)}, \quad (24)$$

where $C_{sODP}^{(NH)}$ and $C_{iODP}^{(NH)}$ are the OpenFlow cost generated by the sHC$_{MN}$ and the iHCs for processing the FDP, respectively. When the FDP is delivered, flow table entries for reverse path are not created. Thus, $C_{sODP}^{(NH)}$ and $C_{iODP}^{(NH)}$ are expressed respectively as

$$\begin{aligned} C_{sODP}^{(NH)} &= (L_{fPI} + L_{FM} + L_{fPO})\alpha\alpha_{H-A} \\ C_{iODP}^{(NH)} &= (h_{A-A} - 1)(L_{fPI} + L_{FM} + L_{fPO})\alpha\alpha_{H-A} \end{aligned} , \qquad (25)$$

where $L_{fPI}$ and $L_{fPO}$ indicate the size of a PIN and a POUT containing the FDP in Bytes, respectively. From (24) and (25), $C_{ODP}^{(NH)}$ is calculated as

$$C_{ODP}^{(NH)} = h_{A-A}(L_{fPI} + L_{FM} + L_{fPO})\alpha\alpha_{H-A}. \qquad (26)$$

## V. Numerical Results

In this section, a comparison of numerical results of MOFI and NHILS is performed and major impact factors are discovered from the results. Packet sizes in Bytes for cost analysis are represented in Table I based on [4], [5], [8] and [12]. All message sizes cover the upper layers of the network layer in the IP stack. In addition, the TCP Ack size, 60 Bytes, is included in these values because an OpenFlow message is delivered by TCP. Other system parameters are defined as follows: $h_{A-H}$ =1, $h_{A-N}$ =1, $\alpha$ =1, $\beta$ = 1.5, and $\omega$ = 0.1.

TABLE I: Packet Sizes (Bytes)

| Notation | Size | Notation | Size |
|---|---|---|---|
| $L_{DP}$ | 128 | $\varpi$ | 40 |
| $L_{HBR}$ | 88 | $L_{HBA}$ | 88 |
| $L_{RR}$ | 88 | $L_{RA}$ | 88 |
| $L_{ROQ}$ | 88 | $L_{ROR}$ | 88 |
| $L_{rPI}$ | 254 | $L_{rPO}$ | 246 |
| $L_{aPI}$ | 254 | $L_{aPO}$ | 246 |
| $L_{qPI}$ | 254 | $L_{qPO}$ | 246 |
| $L_{oPI}$ | 254 | $L_{oPO}$ | 246 |
| $L_{fPI}$ | 342 | $L_{fPO}$ | 334 |
| $L_{FM}$ | 116 | | |

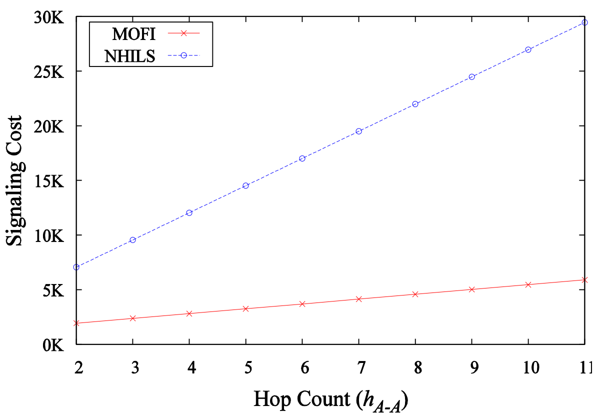

Fig. 5. Signaling cost.

### A. Signaling Cost

The signaling cost of each protocol is presented in Fig. 5 when $h_{A-A}$ is changed from 2 to 11 hops. The signaling cost of both protocols is directly proportion to $h_{A-A}$, and the signaling cost of NHILS is always higher than that of MOFI. That is because the OpenFlow messages for routing control messages in the HIT domain are exchanged between OFSs and HCs in NHILS, whereas normal IP routing is conducted in MOFI. Moreover, the communication cost between an LMC and an AR is ignored as the LCM is located in the AR.

### B. Data Packet Delivery Cost

The data packet delivery cost is shown in Fig. 6. We set $h_{A-A}$ as 4 and change a session length from 1.28 to 12.8 KBytes. The session length can be calculated as $L_{DP}$ multiplied by $N(p)$. Contrary to the signaling cost, the cost of MOFI is greater than that of NHILS and the gap is ever-widening as the session length increases. MOFI encapsulates a data packet in the LOC information for packet delivery so an additional header is attached to the packet. On the other hand, NHILS simply replaces a HIT of data packets with a LOC after RO completion and then forwards them into the IP domain. As a result, the encapsulation causes performance degradation in terms of the data packet delivery.

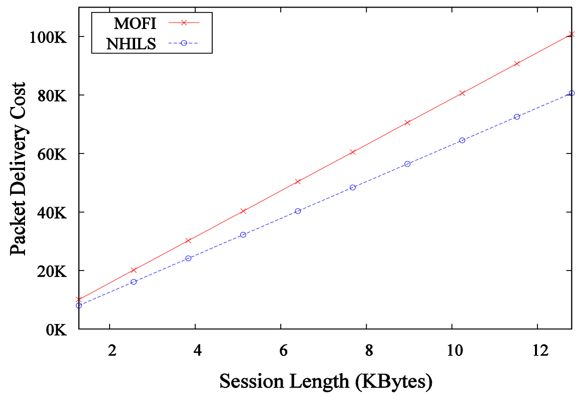

Fig. 6. Data packet delivery cost.

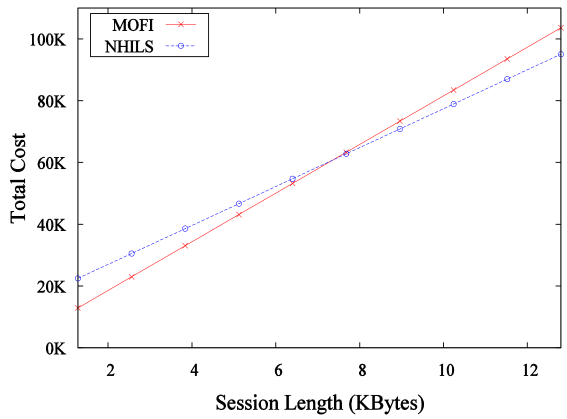

Fig. 7. Total cost.

### C. Total Cost

Fig. 7 represents the total cost of MOFI and NHILS, where system parameters are set as same as those in the data packet delivery cost. In the lower value of the session length, MOFI outperforms NHILS but the table is turned in the higher value of the session length. The signaling cost is not influenced by the session length so it is constant, whereas the session length is a primary impact factor in the data packet delivery cost. As the session length is increasing, the extra overhead of encapsulation for data packets is accumulated in MOFI. Considering the above signaling cost results, if $h_{A-A}$ increases to a greater value than 4, the intersection point will move toward the right. But given the increasing session size in the real world [13], we come to a conclusion that NHILS is more proper to support mobility in the intra-domain network environments.

## VI. Conclusions

In this paper, the performance analysis of two DHT-based ID/LOC separation protocols is conducted in terms of the signaling, packet delivery, and total cost. MOFI is operated in traditional network environments, whereas NHILS functions in SDN. From numerical results, NHILS has high signaling cost due to the OpenFlow cost. On the other hand, MOFI consumes much cost in data packet delivery as it generates extra overhead for encapsulating data packets. The total cost is influenced by $h_{A\text{-}A}$ and the session length. Hop counts are relatively small in the intra-domain network and traffic is exponentially increasing in the real world. Thus, NHILS is more efficient in the total cost because it outperforms MOFI in the respect of the data packet delivery. In addition, the results also show the potential possibility that SDN can be utilized effectively for ID/LOC separation.

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