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SDN-based Hybrid Distributed Mobility Management

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Abstract

Distributed mobility management (DMM) does not use a centralized device. Its mobility functions are distributed among routers; therefore, the mobility services are not limited to the performance and reliability of specific mobility management equipment. The DMM scheme has been studied as a partially distributed architecture, which distributes only a packet delivery domain in combination with the software defined network (SDN) technology that separates the packet delivery and control areas. Particularly, a separated control area is advantageous in introducing a new service, thereby optimizing the network by recognizing the entire network situation and taking an optimal decision. The SDN-based mobility management scheme is studied as a method to optimize the packet delivery path whenever a mobile node moves; however, it results in excessive signaling processing cost. To reduce the high signaling cost, we propose a hybrid distributed mobility management method and analyze its performance mathematically.

Index Terms: Hybrid distributed mobility management, Performance analysis, Software defined network

I. INTRODUCTION

The rapidly growing mobile traffic in recent years is expected to reach 77.5 EB per month by 2022 and account for 71% of total internet traffic. The growth in mobile traffic is accelerating owing to the advent of smartphones and expansion of video services [1]. There are several strategies to deal with this soaring mobile traffic. 5G technology has been introduced to increase the transmission capability of wireless networks, and the structural improvement of wired networks is being studied. Distributed mobility management (DMM) schemes to enhance network structure by dispersing mobility functions have been researched. Although the centralized mobility management (CMM) method is dependent on a home agent (HA) or a local mobility agent (LMA), all the routers can serve as mobile anchors in the DMM scheme. The DMM scheme can prevent the problem of excessive traffic concentration on some specific devices (e.g., HA and LMA) and improve reliability of the network by solving the problem of service interruptions in the case of device failure. Additionally, by moving the mobile anchor closer to the user, the packet delivery path can be optimized and effective interworking can be ensured with a content delivery network.

A major recent trend in network technology is a software defined network (SDN). An SDN separates packet processing and the control areas of a network device and virtualizes the network functions and services; hence, it can operate with a general-purpose server instead of using special hardware. By introducing the SDN technology, it is possible to reduce the time and cost of introducing new services. Particularly, the separation of the data transfer and control parts of a network device through SDN can be successfully integrated with DMM technology in accordance with the method of distributing mobility functions in DMM. In this study, we propose a hybrid interworking method to improve signaling

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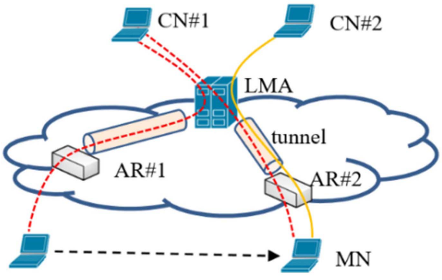
processing performance in SDN and DMM interworking systems and analyze its performance. Section II describes the related studies; Section III presents the proposed scheme; Section IV discusses the performance analysis; Section V presents the performance evaluation; and Section VI concludes the study.

II. RELATED STUDIES

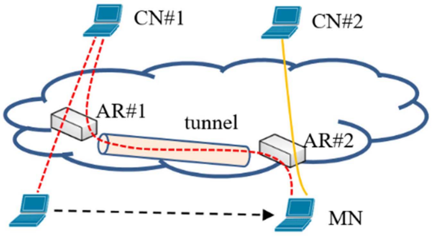
Fig. 1 shows the difference between CMM and DMM scheme when a mobile node (MN) is moved to AR #2 after AR #1 is connected. MN starts a session with CN #1 before handover and maintains the session after the handover. It starts a new session with CN #2 after the handover. In the CMM scheme, because the LMA acts as a mobile anchor, it exchanges data packets by creating a tunnel between itself and the AR to which the MN is connected. However, in the DMM scheme, the AR connected at the start of the session performs the function of a mobile anchor and creates a tunnel with a new AR after handover. For a new session, the currently connected AR acts as a gateway to perform simple packet forwarding without mobility management. DMM does not require centralized devices such as HA or LMA, and all the routers can perform the mobility functions provided in HA or LMA entities. Consequently, the role of a mobile anchor is distributed between multiple routers; hence, reliability is improved by solving the single point of failure problem. Additionally, unlike the CMM scheme, where an HA or LMA is used, it is possible to transmit data packets efficiently and reduce network burden because DMM uses more shortened packet delivery paths [2]. According to performance evaluation [3, 4] of the DMM scheme, although it is advantageous in terms of packet delivery cost, it is disadvantageous in terms of signaling performance. To overcome this disadvantage, hybrid DMM methods have been proposed for specific sessions [5, 6]. A hybrid DMM scheme distributes the packet delivery area in a manner similar to that of the DMM scheme. However, the disadvantage of the DMM scheme is largely overcome by reducing the burden of signaling processing by designating a specific router as a centralized mobile anchor for some sessions.

SDN abstracts network devices to separate control and data transfer functions and defines SDN controllers to centrally control and manage network devices. It uses a virtualization technology that can be flexibly operated in a general-purpose server by separating network functions and services from network-dedicated equipment. Fig. 2 illustrates the virtualized network structure using the SDN technology [7]. The software-based SDN controller is a centralized device with the entire network structure and all status information and assumes that OpenFlow switches (OFS) are controlled through the OpenFlow interface. OFSs in the infrastructure layer no longer need to be implemented for several protocols and all operations are performed by the SDN controller. As a result, network operators can organize and operate networks in a flexible and diverse manner similar to software programs. Adopting the SDN technology can reduce capital expenditure and operating expense, provide new network services quickly, and flexibly satisfy different requirements for each user.

Several researchers are considering the introduction of the SDN concept into a wireless communication system similar to that of Bernardos et al. [8]. Particularly, the technical concept of the DMM method is based on separating the data processing and control layer. Moreover, evaluations show that it is easy to combine this method with the SDN technology, i.e., the SDN controller operates as a controller of the



(a) CMM



(b) DMM

Fig. 1. Mobility management operation based PMIPv6.

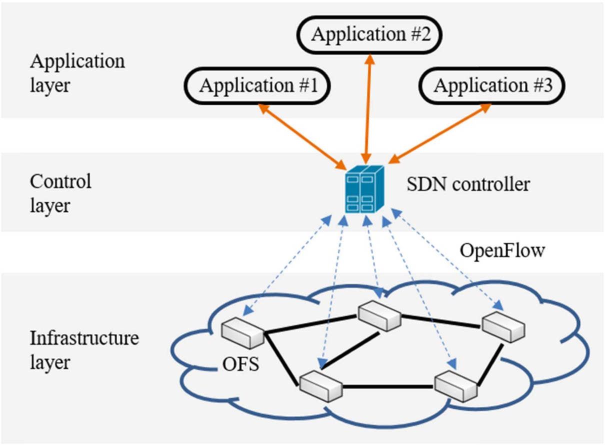


Fig. 2. SDN architecture.

DMM and the switches of the infrastructure layer operate as data processing devices. Jeon et al. [9] summarized the design options that can be selected in designing the DMM system by comparing the characteristics of various DMM methods. They described the qualitative performance by summarizing the method of changing the mobile anchor by combination with the SDN technology. This method is classified into fixed anchoring and dynamic anchoring or re-anchoring methods according to whether an anchor is fixed. In the fixed anchor method, the mobile anchor is fixed per session and held until the session is released. The fixed anchoring scheme has a disadvantage that the packet delivery path becomes inefficient when the MN moves farther. On the contrary, the dynamic anchoring scheme adjusts the position of the anchor to optimize the packet delivery path each time. In this study, we also assume that the DMM scheme with the SDN technology optimizes the delivery path through dynamic anchoring. Guist et al. [10] presented the DMM technology in 5G networks. They studied the DMM technology based on PMIPv6, SDN, or routing protocols. Performance measurement of the WLAN-based test bed confirmed that the SDN-based DMM method shows satisfactory performance similar to the PMIPv6-based DMM method. Condeixa and Sargento [11] proposed a method of optimizing the routing path by introducing a dynamic anchoring method according to the situation of the MN and network. However, the MN instead of the SDN method must select an anchor; therefore, the possibility of implementation of such a method is very low. Cominardi et al. [12] proposed an SDN-based DMM solution and their test bed showed satisfactory results. However, there is a problem with the scalability of this solution because the testing method involves optimization of the packet delivery path using a preconfigured VLAN. Yang and Kim [13] also showed that it is possible to improve performance by eliminating tunnels between routers and optimizing the routing path by using the SDN technology. Nguyen et al. [14] proposed two operation options: tunnel mode and optimization mode. In the tunnel mode, the packet delivery path is inefficient and the cost owing to the tunnel overhead increases; however, the signaling procedure is simple. On the contrary, in the optimization mode, the packet delivery path is minimized through dynamic anchoring between the correspondent nodes (CN) and MN. However, in this work, the DMM operation scenario with two modes is not suggested and varieties of session characteristics are not analyzed mathematically.

III. PROPOSED SCHEME

We propose a hybrid DMM scheme based on the SDN technology; therefore, the OFS performs the packet forwarding function in the data area. The OFS operating as a wireless access router is also equipped with a wireless communication technology such as wireless LAN or LTE. In the control area, the SDN controller grasps the entire network situation and adjusts the operation of the OFS. The OFS plays the role of a general router, and it can update the flow table according to the command of the SDN controller. It maintains an IP address pool that can be allocated to the MN. Our proposed SDN-based hybrid DMM (S-hDMM) application runs on the SDN controller. The interface between the SDN controller and OFS is assumed as the OpenFlow interface, and the interface between the controller and application is not considered in this study, assuming that the SDN controller and DMM application operate with the same equipment.

As shown in Fig. 3, when the MN initially attaches, the OFS starts by receiving a router solicitation (RS) message transmitted by the MN. The OFS sends a PacketIn message that contains the RS message received from the MN to the SDN controller. The S-hDMM application operating in the upper layer of the SDN controller allocates an IP address from the address group managed by the OFS. As a response to the initial registration procedure, a router advertisement (RA) message is constructed and delivered to the MN through the PacketOut message. Subsequently, the MN obtains the prefix information and configures its IP address. When the session starts after the initial registration procedure is completed and the actual data packet is generated, the first packet is transmitted to the SDN controller through the PacketIn message. The S-hDMM application at the upper level of the SDN controller analyzes the received packet, creates the internal binding cache entry (BCE) to manage the MN's mobility, and updates the OFS's flow table using the FlowMod message to perform packet processing.

In the S-hDMM scheme, the OFS that is connected for the first time after the MN is powered on is used as a special mobile anchor, which is termed as a soft anchor. For sessions using soft anchors as mobile anchors, dynamic anchoring is not performed to suppress the excessive signaling processing cost. However, for other sessions, the packet delivery path is optimized through dynamic anchors and the packet delivery cost is reduced. For some sessions using soft anchors, triangular delivery paths via soft anchors without optimizing the data delivery path are used. In other words, they reduce the signaling load in exchange for the inefficiency of packet delivery. Therefore, there are two choices for the mobile anchor selection in the S-hDMM scheme when a new session starts. Either the current serving OFS or a soft anchor can be designated as a mobile anchor. In the S-hDMM scheme, an anchor can be selected based on its sensitivity to packet loss. For a loss-sensitive session, packet loss during handover is minimized by selecting a soft anchor as a mobile anchor, whereas choosing a serving OFS as a mobile anchor for loss-insensitive sessions optimizes the packet delivery

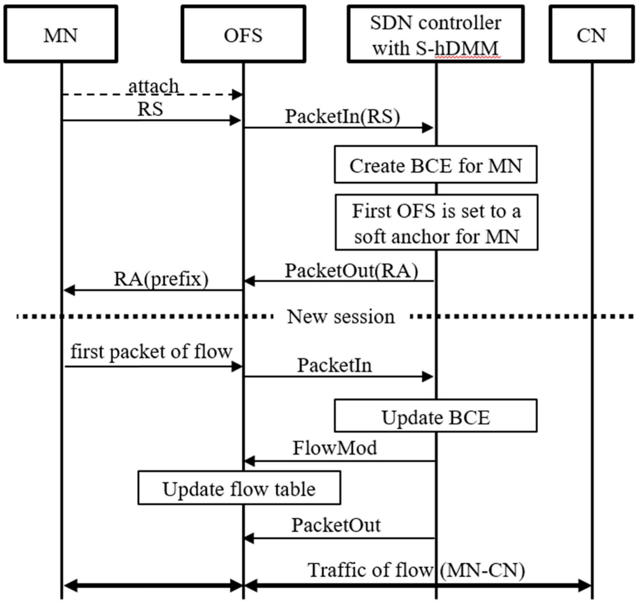


Fig. 3. Initial registration procedure.

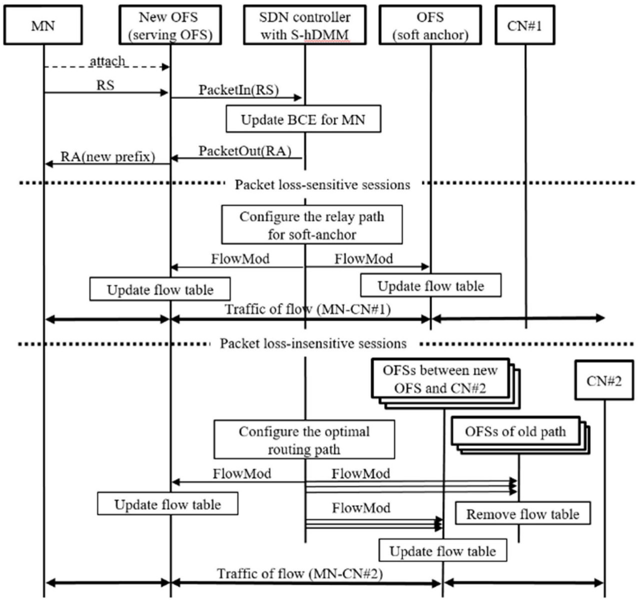


Fig. 4. Handover procedure.

path through dynamic anchoring at handover. In dynamic anchoring, the packet delivery path is optimized; however, a large number of signaling messages are generated and the processing time for the messages increases, thereby increasing packet loss.

Different OFSs act as soft anchors for each MN; therefore, not only is the processing load distributed but also is the damage when failure of a soft anchor occurs. There are several suggestions for choosing a soft anchor. A method of designating a router as a mobile anchor near a CN is presented in [15], and a method of designation using the number of available anchors or the MN's speed is presented in [11]. In this study, the method of designating a soft anchor is not considered and the OFS that the MN first connects to is simply designated as the soft anchor.

Fig. 4 shows the handover procedure of the S-hDMM scheme. If the MN hands over to a new serving OFS area, a new IP address is allocated through an RS/RA message similar to the initial registration procedure. To maintain the existing session, the packet delivery path must be reconfigured. The reconfiguration method depends on the sensitivity of packet loss in our S-hDMM scheme. For loss-sensitive sessions using the soft anchor, the SDN controller establishes a relay path between the soft anchor and the new serving OFS. In the existing DMM method, a tunnel is used; however, in the S-hDMM method in which the SDN technology is combined, the relay path can be configured by IP address translation. Therefore, IP rewriting and restoring operations should be performed in both soft anchor and serving OFS. For this relay path configuration, the S-hDMM application in the SDN controller changes the flow table of the soft anchor and the serving OFS. It does not constitute an optimal delivery path; however, it has the advantage that the signaling processing cost is low and there is no tunnel overhead. For packet loss-insensitive sessions, the SDN controller performs the optimization of the packet delivery path. During the path optimization procedure, new OFSs may be included and existing ones may be excluded.

The implementation methods for specifying a soft anchor or a serving AR as a mobile anchor according to session characteristics are not described here because it is beyond the scope of this study. However, related ideas can be introduced for further study. First, an access network discovery and a selection function (ANDSF) client of the MN and the ANDSF server of the network exchange session information, and the mobile anchor can be selected according to the session characteristics with ANDSF functions. Second, the SDN technology is extended to the MN as in [9], and the MN operates as a device of the infrastructure layer. It is possible to classify the session according to the rules given by the SDN controller and select the mobile anchor.

IV. PERFORMANCE ANALYSIS

For performance analysis, the protocol cost of a mobility management method is divided into signaling cost and packet delivery cost. Signaling cost is the cost of exchanging the RS/RA message and updating the OFS's flow table using the FlowMod message when a handover occurs. Packet delivery cost is calculated by multiplying the length of the packet by the hop distance. The cost of processing data packets or messages in OFS or SDN controllers is also considered.

A. System Model

The moving speed of an MN is defined as ν, and the handover rate (ν_s) is calculated by the following equation as the relation between the size (A) of the AR area and the moving speed of the MN.

$$\mu_s = 2v/\sqrt{\pi A}\ . \tag{1}$$

The parameter values assumed are defined in Table 1. Some parameters from those mentioned in [6] and [12] are reused as the system values. The hop distance (d_{oo}) of the relay path is assumed to be the root value ($\sqrt{d_{co}}$) of the hop distance between the CN and the OFS, and the number of hops between the SDN controller and the OFS is assumed to be the same as d_{oo}.

To analyze various sessions with different characteristics, we use the session model proposed in [6]. We assume that the session arrival process follows a Poisson process and a session's duration has an exponential distribution and the two are independent of each other. Different characteristics of sessions can be modeled by differently defining arrival rate, duration, packet generation rate, and packet length. In this study, we define G session groups. Session group refers to a set of sessions with the same characteristics. Average arrival rate of session group i is defined as λ_i and the average duration is defined as $1/\mu_i$. Among all the G session groups, $g(1 \le g < G)$ session groups are sensitive to packet loss, whereas the remaining sessions are insensitive.

B. Performance Analysis

The message flow according to the handover in Fig. 4 can be divided into three stages. First is the registration and IP allocation procedure. The signaling cost is as follows:

$$\begin{aligned} C_{sig}^{reg} &= w_2\left[d_{om}\left(L_{RS}+L_{RA}\right)\right] \\ &\quad + w_1\left[d_{so}\left(L_{PI(RS)}+L_{PO(RA)}\right)\right] + U_{OFS} + P_{OFS}\ . \end{aligned} \tag{2}$$

Second is the signaling cost to update the relay path between the soft anchor and the serving OFS for loss-sensitive sessions.

$$C_{sig}^{relay} = w_1\left(2d_{so}L_{FlowMod}\right) + 2U_{OFS} + P_{SDN}\ . \tag{3}$$

Third is the signaling cost to establish an optimized path between the serving OFS and the CN for loss-insensitive sessions. There are OFSs to add a flow table while reconfiguring an optimized path, and OFSs to delete a flow table. The number of OFSs located in the optimized path depends on the network configuration and topology. It is difficult to model these accurately; therefore, it is assumed that the flow table is updated for OFSs by the number of hops between the CN and the serving OFS.

$$C_{sig}^{opt} = w_1\left(d_{so}d_{co}L_{FlowMod}\right) + d_{co}U_{OFS} + P_{SDN}\ . \tag{4}$$

If the number of sessions in group i is defined as M_i, the signaling cost can be summarized as follows:

$$C_{sig} = \mu_s\left[C_{sig}^{reg} + C_{sig}^{relay} + \sum_{i=g+1}^{G} C_{sig}^{opt}E\left(M_i\right)\right]. \tag{5}$$

Intuitively, the value of $E(M_i)$ is equal to the average number (λ_i/μ_i) of customers in a queue ($M/M/\infty$) with a customer arrival rate (λ_i) and a service rate (μ_i). To solve this, we assume that OFS_0 is the current serving OFS and OFS_j indicates an OFS that has passed through j times before the MN moves to OFS_0. The value of $E(M_{ij})$ indicates the average number of sessions of group i generated in OFS_j and maintained in OFS_0. To obtain this value, we can use the conditional average value as follows:

$$\begin{aligned} E\left(M_i\right) &= \sum_{j=1}^{\infty} E\left(M_{ij}\right) \\ &= \sum_{j=1}^{\infty}\sum_{n_{ij}=0}^{\infty} E\left(M_{ij}\middle|N_{ij}=n_{ij}\right)\Pr\left(N_{ij}=n_{ij}\right), \end{aligned} \tag{6}$$

where the variable N_{ij} indicates the number of sessions of group i generated in OFS_j. The probability that one session of group i generated in OFS_j remains in OFS_0 is obtained using the property of exponential distribution as follows:

$$p_{ij} = \left(\frac{\mu_s}{\mu_i+\mu_s}\right)^j . \tag{7}$$

Table 1. Parameters used for performance analysis.

Notation	Description
w_1, w_2	weighting factor in wired and wireless, 1 and 1.5, respectively
L_{RS}	size of RS message, 48 bytes
L_{RA}	size of RA message, 76 bytes
$L_{PI(RS)}$	size of PacketIn(RS) messages, 178 bytes
$L_{PO(RA)}$	size of PacketOut(RA) messages, 218 bytes
$L_{FlowMod}$	size of FlowMod message, 264 bytes
U_{OFS}	updating cost in OFS's flow table, 20
P_{OFS}	packet processing cost in OFS, 8
P_{SDN}	processing cost in SDN controller, 24
d_{co}	hop distance of CN-OFS, 10 hops
d_{so}	hop distance of SDN controller-OFS, 3 hops
d_{oo}	hop distance of OFS-OFS, 3 hops
d_{om}	hop distance of OFS-MN, 1 hop

Probability that the sessions remain alive, when the number of sessions of group i generated in the OFS$_j$ is n_{ij}, is a binomial distribution with a success probability p_{ij} in n_{ij} number of attempts. Using the formula for obtaining the mean value of a binomial distribution, we summarize the following:

$$\begin{aligned} E(M_i) &= \sum_{j=1}^{\infty}\sum_{n_{ij}=0}^{\infty} E\left(M_{ij}\middle|N_{ij}=n_{ij}\right)\Pr\left(N_{ij}=n_{ij}\right) \\ &= \sum_{j=1}^{\infty}\sum_{n_{ij}=0}^{\infty} n_{ij}p_{ij}\Pr\left(N_{ij}=n_{ij}\right) \\ &= \sum_{j=1}^{\infty}\left[\sum_{n_{ij}=0}^{\infty} n_{ij}\Pr\left(N_{ij}=n_{ij}\right)\right]p_{ij} \\ &= \sum_{j=1}^{\infty}\frac{\lambda_i}{\mu_s}\left(\frac{\mu_s}{\mu_i+\mu_s}\right)^j. \end{aligned} \tag{8}$$

Using the method of calculating the convergence value of an infinite series, Eq. (8) is summarized as follows:

$$\begin{aligned} E(M_i) &= \sum_{j=1}^{\infty}\frac{\lambda_i}{\mu_s}\left(\frac{\mu_s}{\mu_i+\mu_s}\right)^j \\ &= \frac{\lambda_i}{\mu_s}\left[\left(\frac{1}{1-\mu_s/(\mu_i+\mu_s)}\right)-1\right] \\ &= \frac{\lambda_i}{\mu_i}. \end{aligned} \tag{9}$$

Mobile anchors are selected differently depending on their sensitivity to packet loss; therefore, the packet delivery cost is also different. In the case of a session using a soft anchor, data packets are transmitted through a relay path between a soft anchor and a serving OFS, and the packet delivery cost is summarized as follows:

$$\begin{aligned} C_{PD,i}^{relay} &= w_2\left(S_iL_i\right)d_{om} + w_1\left(S_iL_i\right)\left(d_{co}+d_{oo}\right) \\ &\quad + \left(d_{co}+d_{oo}\right)P_{OFS}. \end{aligned} \tag{10}$$

In the case of a session that is insensitive to packet loss, where the packet is delivered through the optimized path, the packet delivery cost is summarized as follows:

$$C_{PD,i}^{opt} = w_2\left(S_iL_i\right)d_{om} + w_1\left(S_iL_i\right)d_{co} + d_{co}P_{OFS}. \tag{11}$$

Then, including the session groups, the total packet delivery cost can be summarized as follows:

$$C_{PD} = \sum_{i=0}^{g}\lambda_i C_{PD,i}^{relay} + \sum_{i=g+1}^{G}\lambda_i C_{PD,i}^{opt}. \tag{12}$$

V. PERFORMANCE EVALUATION

For simplicity, we consider that the session groups are categorized into two groups: group 1 is defined as a loss-sensitive session group using soft anchor and group 2 is defined as a loss-insensitive session group. Characteristics such as the number of packets per session, average length or duration of packets may be different for each session group. However, in this study, to compare the characteristics of the S-hDMM scheme, we assume that the two groups have the same characteristics. Unless otherwise noted, the following parameter values are assumed.

- $A=\pi(100)^2 \approx 31{,}415\text{m}^2$; the area of a cell with a radius of 100 m
- $v=1$; MN's moving speed (m/s)
- $S_1=S_2=100$; average number of packets per session
- $L_1=L_2=500$; average length of packets (bytes)
- $\lambda_s=\lambda_1+\lambda_2=0.02$; total arrival rate
- $\alpha=\lambda_1/\lambda_s=0.5$; proportion of loss-sensitive session
- $1/\mu_1=1/\mu_2=1000$; session duration (s)

Fig. 5 shows the signaling cost according to the total arrival rate. As the total arrival rate increases, the signaling cost also increases. It can be seen that the difference of the signaling cost is according to the proportion of loss-sensitive sessions (α). If the value of α is 0, then all sessions are loss-insensitive and the SDN controller performs path optimization whenever handover occurs as shown in Fig. 4. Because we assume that two session groups have the same traffic characteristics, the total session model is maintained regardless of the value of α. Thus, if the value of α is 0, then the operation mechanism is the same as that of a dynamic anchoring DMM strategy and the signaling cost is increased by performing path optimization for all sessions. On the contrary, the larger the value of α, the greater is the proportion of sessions using soft anchors. The value of α increases in the same environment; therefore, the signaling cost is reduced by soft anchors. If the value of α is 1, it indicates that all sessions use a centralized device such as a soft

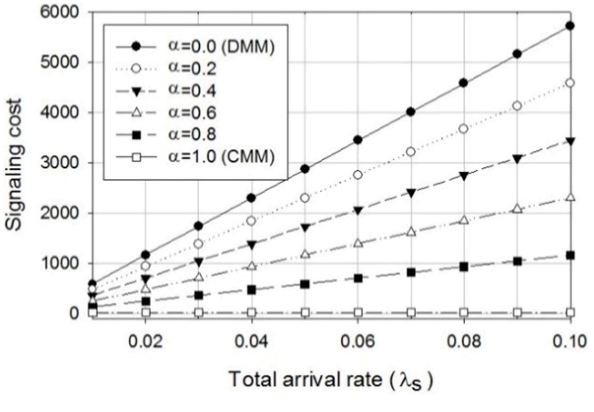


Fig. 5. Signaling cost according to the total arrival rate.

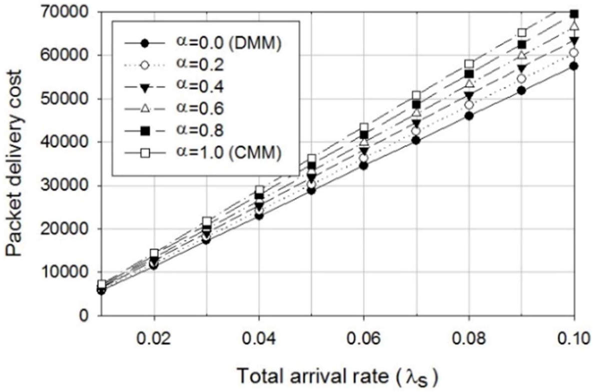


Fig. 6. Packet delivery cost according to the total arrival rate.

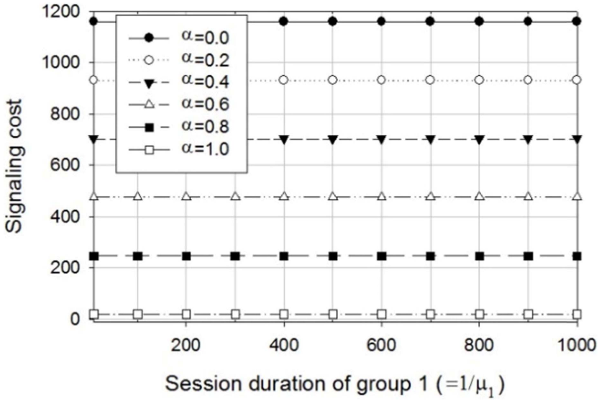


Fig. 8. Signaling cost according to the session duration of group 1.

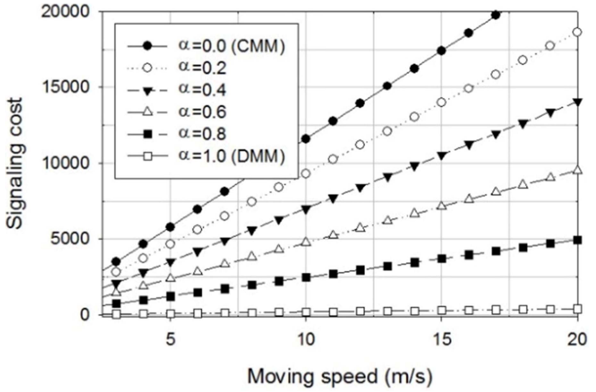


Fig. 7. Signaling cost according to MN's moving speed.

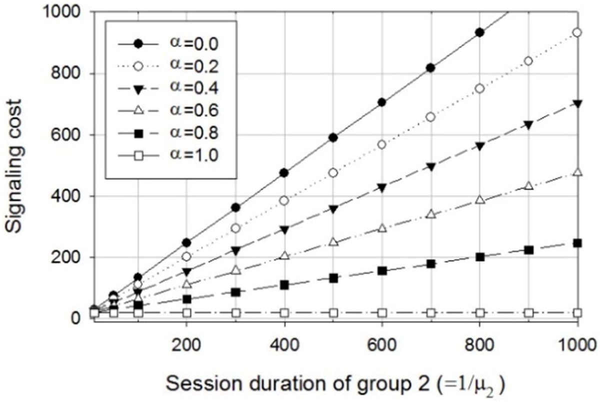


Fig. 9. Signaling cost according to the session duration of group 2.

anchor to provide the same operation mechanism and the same performance as the CMM scheme. Therefore, we define α as the proportion of the packet loss-sensitive sessions; however, because we assume that the session groups have the same characteristics, the value of α can also indicate the degree of hybrid operation. It should be noted that when the value of α is 0 or 1, the performance values of the DMM scheme or the CMM scheme are displayed.

Fig. 6 shows the packet delivery cost according to the total arrival rate. The packet forwarding route is optimized for a session that is insensitive to packet loss; therefore, the smaller the value of α, the lower is the packet delivery cost.

Fig. 7 shows the signaling cost according to the MN's moving speed. As the MN moves fast, the handover occurs frequently and the signaling cost increases because related messages must be exchanged between the SDN controller and the OFSs. Particularly, it can be seen that the signaling cost increases when the proportion of loss-sensitive sessions is low.

Fig. 8 shows the signaling cost according to the session duration of group 1. As the session duration increases, the average number of sessions also increases. This causes an increase in the signaling cost. However, in the S-hDMM scheme, group 1 uses a soft anchor; therefore, the signaling cost is not related to the number of sessions, and the handover processing cost is kept constant even though the number of sessions of group 1 increases. Therefore, it can be seen that the signaling cost remains constant although the session duration increases.

Similarly, Fig. 9 shows the signaling cost according to the session duration of group 2. It can be seen that the result in Fig. 9 differs from that in Fig. 8. Session group 2 requires path optimization for each session, thereby increasing the number of sessions, and further causing an increase in the signaling cost.

VI. CONCLUSION

The DMM method becomes more realistic when the SDN technology is combined with it. Studies have shown that the SDN controller manages the entire network and optimizes the packet delivery path each time the MN performs a handover. Optimizing the packet delivery path has the advantage of reducing the packet processing burden of the network equipment and decreasing the packet delivery delay. However, the signaling cost for optimizing the delivery path increases and the possibility of packet loss increases until the optimizing procedure is completed. As a solution to this problem, we proposed a hybrid method. According to the sensitivity to packet loss, some sessions optimize the packet delivery path at the time of handover, whereas others set the relay path via the soft anchor. Soft anchors can be selected in a variety of ways and regarded as a distributed system for the whole system because they are distributed to each MN. Additionally, depending on the session characteristics, the use of a soft anchor is determined; however, this can be done manually according to the intention of the operator. Therefore, the hybrid operation can be performed in a flexible manner according to the load condition of the network system.

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