SWITCH: SDN-WLAN Integrated Handover Scheme for QoS-Guaranteed Mobile Service

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Abstract

The handover procedure of IEEE 802.11 wireless local area networks (WLANs) introduces significant delay, which can degrade the quality of service (QoS) especially for delay-sensitive applications. Although studies have been conducted to support handover in SDN-based WLAN, there is no research to reduce the channel scanning procedure that takes up the most delay time in the handover process. The channel scanning procedure is essential to determine the appropriate access point (AP). To mitigate this problem, this paper proposes a SWITCH: SDN-WLAN integrated handover scheme for QoS-Guaranteed mobile service. In SWITCH, each AP periodically broadcasts beacon frames through different channels in a predetermined order that includes the operating channel information of the AP. This allows mobile stations (MSs) to receive the beacon frames of nearby APs, and therefore they can determine the appropriate APs for handover without the channel scanning procedure. By reporting the information of the newly moved AP to the SDN controller, a flow rule is installed in advance to provide fast handover, and packet loss is reduced by buffering data destined for MS. In addition, the proposed scheme can adaptively operate SWITCH to consider the user location and QoS requirement of flow to save radio resource overhead. Performance evaluation results demonstrate that SWITCH can reduce the handover delays, flow table utilization ratio and radio resource overhead while improving the network throughput.

Keywords: Channel scanning, handover, SDN, IEEE 802.11, QoS, WLAN.

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1. Introduction

As mobile communication network technology develops, various mobile devices such as smart phones have been diversified and spread widely over the world, promoting a greater variety of mobile multimedia services [1, 2]. In parallel with this trend, as a short-distance wireless communication system, the applications of IEEE 802.11 wireless local area networks (WLANs) have been focused a lot with its unique advantages of broadband communication capability at a reasonable cost. In addition, WLANs using multiple access points (APs) are being built at airports, campuses and shopping malls so that provide mobile multimedia services at anytime and anywhere.

WLAN was originally intended to provide wireless communication services within a limited area and did not consider the mobility of mobile stations (MSs) between APs [3]. When a MS moves between APs, the connection with the previous AP is terminated and MS needs to connect to a new AP (i.e., handover). MS can experience the long handover delay, which results in the quality of service (QoS) degradation especially for delay-sensitive applications. The handover delay is caused by three procedures: channel scanning, authentication, and re-association [4]. Among them, the channel scanning procedure for scanning all of the available channels to collect adjacent APs' information accounts for the largest portion [4, 5], and therefore MS needs to reduce the time to improve the service continuity. That is, the reason of the long handover delay is the lack of information on the neighboring APs (NAPs).

As software-defined networking (SDN) begins to be widely used, researchers have studied to realize the advanced features of SDN in WLANs. SDN simplifies network management tasks by separating control planes and data planes, provides programmability to wireless networks, and introduces new network functions and applications. In addition, thanks to the centralized control method, SDN enables global network state awareness and flow-level QoS control. Recently, several integrations of SDN and WLAN systems have been proposed [6-10]. In [6], Kyung et al. present flow classification and propose QoS-Aware flexible handover management. DeRy [7] is another proposal for reducing handover delay, which determines handover at AP controller on behalf of MS. In SDWLAN [8], the SDN controller consults with AP and MS to determine the association for MS. In [9], the AP controller sends a channel switching announcement message to MS considering the load information of the AP and distributes the load to the other APs. The above studies can reduce packet loss by reducing authentication/reassociation delay in the handover process or by pre-setting a new routing path, but still have not come up with a way to reduce the channel scanning procedure to find a new AP for MS.

There have been several prior studies which improve the channel scanning procedure to reduce the handover delay [11-14]. In a neighbor list proactive (NLP) based-handover scheme [11], MS receives NAPs list from the controller at each handover. The scanning delay time can be reduced by checking the corresponding list and scanning only the operating channels of the NAPs. However, this scheme still requires not only the scanning procedure, but also a new delay and overhead to receive the neighbor list from the controller at every handover. A seamless passive scan (SPS) scheme [12] used dual network interfaces (NIs), the primary one for data communication with MSs and secondary one dedicated to transmit beacon frames using channels of NAPs. Through this, instead of channel scanning, MSs can receive beacons sent by secondary NIs of NAPs using the operating channels of MSs to obtain information from NAPs. Although the handover delay can be greatly reduced by omitting the channel scanning procedure, using two NIs is quite price inefficient. Two NIs have an opportunity cost to more than double the system throughput, which will be described in Section 3. Y. Kim et al. [13] introduced neighbor beacon transmission scheme. APs send beacons to channels of NAPs as well as their own channels. To prevent these beacons from collisions, the APs are synchronized with each other and coordinate beacons transmission according to a predetermined order. This helps a MS which is adjacent to multiple APs receive beacon frames from them and make an appropriate handover decision, which can eliminate the channel scanning procedure. However, even if APs' beacon frames transmission time is synchronized, the timing of beacon frames transmission can be delayed depending on the status of each channel of APs. Moreover, beacon collisions can prevent MS from collecting the information of NAPs. In addition, it is overhead that the AP must always transmit multiple beacon frames even when MSs are not in a handover situation.

We propose a complete integration of SDN and WLAN architecture for MS to provide a seamless handover scheme without packet loss. The proposed method is called SDN-WLAN InTegrated handover sCHeme (SWITCH), which combines SDN's proactive flow rule cache (PRC) method with NAP navigation using WLAN's neighbor beacon. The PRC method in SDN-based access network minimizes packet loss by installing a flow rule before MS moves to new AP and allows the new AP to deliver data quickly without sending packet-in messages to the controller [10, 15]. Since it is necessary to predict the new target AP for MS, depending on the accuracy of the prediction, there is a possibility that the flow rule will be wasted or obsolete, and there is still a handover latency by the channel scanning procedure. To complement PRC method on the above issues, each AP periodically broadcasts beacon frames containing the operating channel information of the AP over the channel of the NAP at the command of the controller. MS receives beacon frames of NAPs in every beacon period, allowing accurate handover prediction and no channel scanning procedure by comparing RSSI of currently connected APs with that of NAPs.

The remainder of this paper is organized as follows. The proposed scheme is presented in Section 2. Then, performance evaluation is described in Section 3. Section 4 concludes this paper.

2. Proposed Scheme

This paper proposes SWITCH for seamless and packet-loss-free mobile service. In SWITCH, each AP periodically broadcasts beacon frames through the channels of NAPs in a predetermined order which contains the operating channel information of the AP. This enables that MSs can receive the beacon frames of NAPs. Consequently, they can decide the suitable AP for handover without the channel scanning procedure. Using this information, the SDN controller establishes a flow rule in advance, and the new AP buffers data destined for MS, allowing it to transmit immediately after the attachment.

2.1 Network Architecture of SWITCH

Fig. 1 shows the access network architectures of SDN-based WLANs in which the APs and SDN switch are deployed in the forwarding plane and the SDN controller is in the control plane. AP communicates with MS as an AP in a wireless network, and at the same time, it acts as an SDN switch in a wired network managed by an SDN controller using a specific interface (e.g., OpenFlow). APs in the domain of interest are time-synchronized with an SDN controller, which coordinates the wireless channels used by APs and manages beacon frames transmission time of APs. The SDN controller is responsible for authentication and association on initial access to MS, and does not require additional authentication and re-association procedures for handover between APs. This paper considers hexagonal cell deployment where all APs have six NAPs which can be tactically assumed in the enterprise network [16]. In this cell arrangement, it is possible to prevent channels from overlapping with NAPs using only three channels.

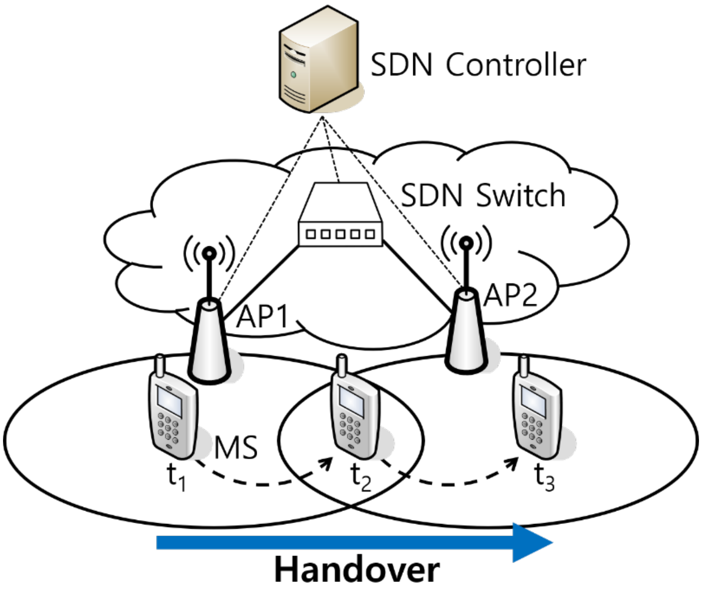

Fig. 1. Simplified network architecture of SWITCH

2.2 Proposed Operation of SWITCH

In SWITCH, each AP communicates with MSs on a single operating channel, but transmits additional beacon frames during the beacon frame transmission duration through different channels. First of them is delivered in the AP's operating channel (i.e., basic beacon frame (BBF), and the next frame (i.e., neighbor-beacon frames (NBFs) is transmitted using operating channels of NAPs. The order and timing in which the AP sends one BBF and two NBFs are managed and determined by the SDN controller. The beacon frame contains the operating channel information of the transmitting AP. MS can receive these beacon frames, which came from serving AP and NAPs, and use them to know the optimal AP for handover without channel scanning. When MS forwards the handover trigger (i.e., L2 trigger) to the AP, the AP reports it to the AP controller. Based on the reports, the controller installs the flow rule in the path in advance and commands the new AP to buffer packets destined to MS.

Fig. 2 shows the sequence diagram of SWITCH. MS performs a handover from AP1 to AP2 while moving as shown in **Fig. 1**. At t_1, MS connects to AP1 using channel A and only hears the BBF from AP1. This is because MS is within the service area of AP1 and not close to AP2. In this case, since there is no NAP with stronger RSSI than AP1, data communication is performed through AP1. When MS moves to AP2 and reaches at time t_2, it receives the BBF of AP1 and the NBF of AP2. MS can receive two beacon frames at every beacon period and compare RSSIs between them. After that, MS can send a L2 trigger for handover if the RSSI of AP2 is continuously greater than that of AP1. In other words, MS can compare the received signal strength indication (RSSI) of AP1 and AP2 to determine when and what AP it tries to perform handover [17-20]. AP1 reports MS handover triggering to the controller through statistics report message. The SDN controller recognizes the handover of MS, calculates the path, and updates the flow rule with a Flow Mod message.

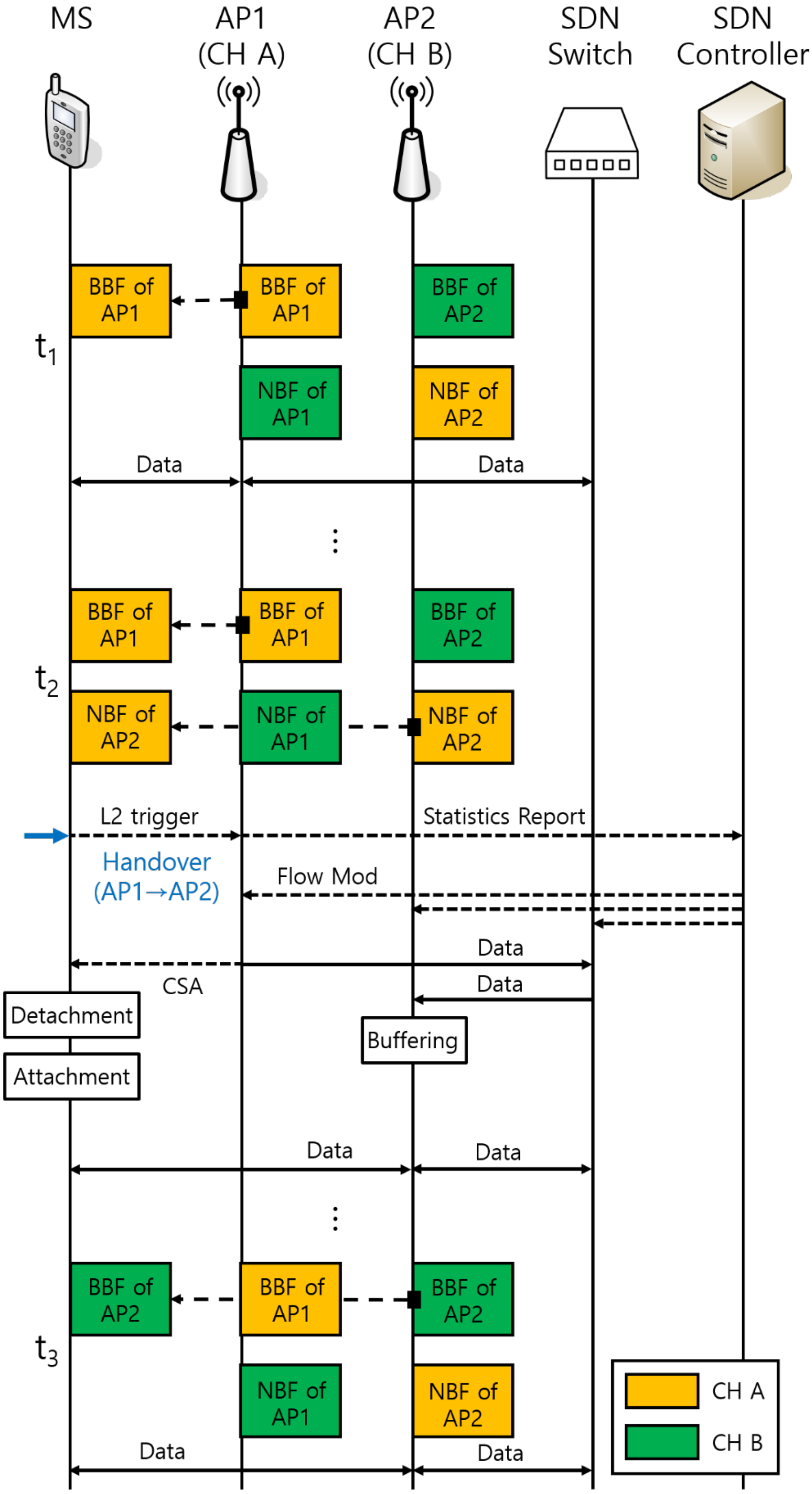

Fig. 2. Sequence diagram of SWITCH

AP1 forwards data destined for MS to AP2 and sends a channel switching announcement message to MS to change MS's channel to CH B. MS changes channels to CH B for AP2, which has already received information about MS from the controller and transmits buffered data directed to MS, and the data is then transferred directly to MS through the AP2. After the time t_3, MS receives the BBF of the AP2 transmitted through CH B.

Based on the above procedure, it is possible to perform a fast and packet-loss-free handover by finding an accurate target AP without the channel scanning procedure. In addition, the problem of mobility prediction of PRC can also be solved to save resources in flow tables that can be wasted.

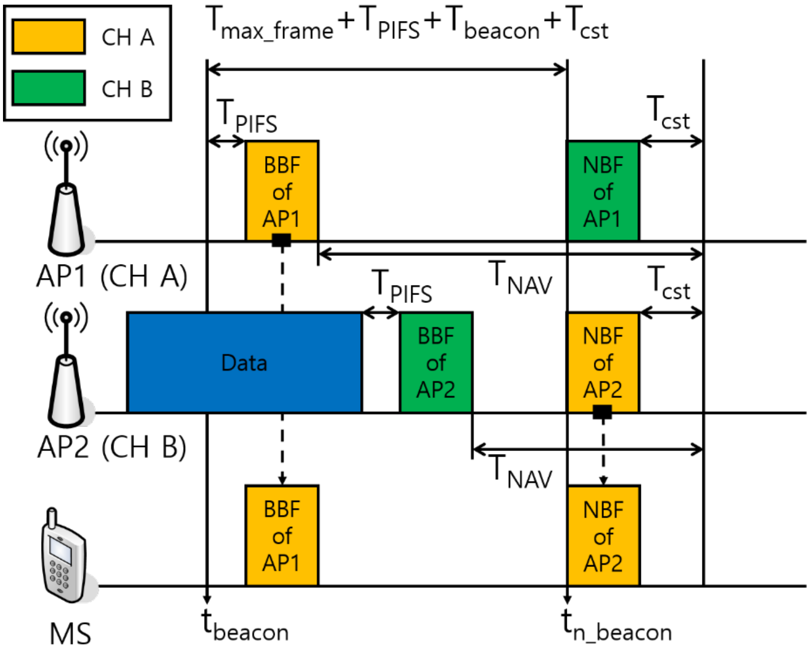

Fig. 3. NBF transmission timing diagram to prevent beacon collision

2.3 Synchronizing BBF and NBF transmission timing

Time synchronization to prevent collision of beacon frames in SWITCH is an important issue. For time synchronization, the AP controller notifies the APs of transmission times of the BBF (i.e., t_{beacon}) and the NBF (i.e., t_{n_beacon}). However, even though the AP controller manages the timing of beacon frame transmission for APs, since the wireless medium access of the WLAN is a competitive approach, the beacon frames may not be transmitted at t_{beacon} and t_{n_beacon} depending on the channel status. Therefore, NBF which can cause collisions with neighbor MS or NAPs should be sent at time t_{n_beacon}, accurately. **Fig. 3** shows the NBF transmission timing diagram to solve this problem. When the time of the AP reaches t_{beacon}, the AP waits by T_{PIFS} and then broadcasts the BBF. The reason for waiting as much as T_{PIFS} is to occupy the wireless medium with higher priority than other MSs. The AP occupies wireless medium using network allocation vector (NAV) in the duration field of BBF for NAV value (T_{NAV}) to ensure NBF transmissions in time. For this, t_{beacon} has the following relationship with t_{n_beacon}

$$t_{beacon} = t_{n\_beacon} - (T_{max\_frame} + T_{PIFS} + T_{beacon} + T_{cst}) \tag{1}$$

where T_{max_frame} and T_{beacon} are the transmission times of maximum frame and beacon frame, respectively. And T_{cst} is channel switching time. Since there is as much free time as (T_{max_frame} + T_{PIFS} + T_{beacon} + T_{cst}) between t_{beacon} and t_{n_beacon}, no matter what size of data the AP receives from a MS at time t_{beacon}, BBF can be sent before t_{n_beacon}. If the AP has data that can be sent within the time occupied by NAV so as not to interfere with the beacon frame, the data can be sent. As shown in AP2 of **Fig. 3**, if the medium is busy at t_{beacon}, the AP waits until the medium is idle, waits again by T_{PIFS}, and sends the BBF. T_{NAV} is set up to (t_{n_baecon}+T_{beacon}+T_{cst}). A beacon frame collision can be prevented by occupying a radio medium with the NAV with a sufficient margin between the BBF and the NBF. However, there can be a problem that the resource overhead for transmitting the beacon frame increases.

2.4 Mobility and QoS-Aware Adaptive SWITCH

SWITCH makes it possible to know real-time NAP channel information to MS through periodic NBF transmission. Although this can give a lot of benefits in the handover process, transmitting the NBF periodically even when there is no MS close to the handover does not efficiently utilize radio resources. In this paper, radio resource overhead is defined as the time required for handover preparation such as beacon transmission or channel scanning procedure. In case of SWITCH, the radio resource overhead O is defined as the total time taken for beacon frame transmission T_{total_beacon} over the beacon interval T_{beacon_period}. It can be expressed as

$$O = T_{total\_beacon} / T_{beacon\_period} \tag{2}$$

In addition, max (T_{total_beacon}) can be calculated as follows

$$\max(T_{total\_beacon}) = (t_{n\_beacon} - t_{beacon}) + 2 \times (T_{beacon} + T_{cst}) \tag{3}$$

where T_{beacon} is the time taken for beacon frame transmission [21] which can be denoted by [12]

$$T_{beacon} = T_{PHY} + (L_{beacon} / R_{basic}) \tag{4}$$

Consequently, the maximum overhead can be expressed as

$$\max(O) = \max(T_{total\_beacon}) / T_{beacon\_period} \tag{5}$$

Considering **Table 1** [21], the maximum overhead can be approximately calculated as 2.0 %. It can be larger depending on the T_{cst}. For example, when T_{cst} is considered as 2ms, the overhead increases to 4.5 %. Note that it is not appropriate that overhead occurs continuously even when handover does not occur.

To address this problem, SWITCH can be adaptively operated only when there is at least one delay-sensitive MS that needs to prepare handover. Delay-sensitive MS means MS using delay-sensitive mobile service. As shown in **Fig. 4**, APs monitor the RSSI from MSs in their service areas in order to identify which MS moves away. When an AP finds MS whose RSSI drops below th_{HP}, it sends a statistics report to the SDN controller to prepare handover of MS. The SDN controller checks the flow of the corresponding MS. If there is a delay-sensitive flow, the controller then transmits a control message (i.e., SWITCH initiation request) to AP1 and AP2 which are the candidate APs of MS for handover. Meanwhile, when the AP finds that RSSI of MS increases above the th_{HP}, the AP sends a statistics report to the SDN controller to inform that MS is no longer in handover preparation area. Consequently, the SDN controller stops APs from transmitting NBFs. In other words, only when there is any delay-sensitive MS for handover, the SWITCH is initiated. Therefore, adaptive SWITCH can reduce the radio resource overhead.

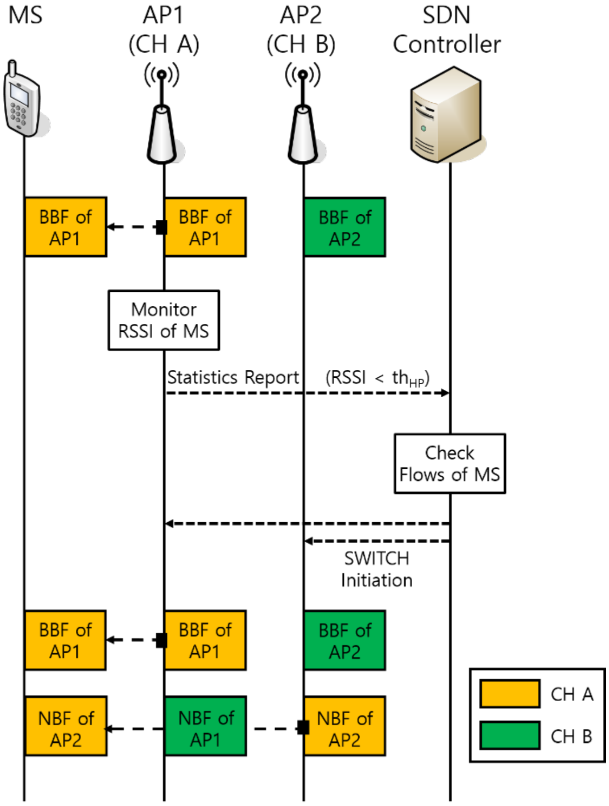

Fig. 4. Signaling procedure for adaptive SWITCH

3. Performance Evaluation

In this chapter, we evaluate the performance of the proposed SWITCH in terms of flow table utilization compared with basic reactive flow rule cache method and MobiFlow [15] which uses the proactive flow rule cache method. Afterwards, the neighbor list proactive (NLP) based-handover scheme [11] and SPS scheme [12], which are handover techniques of WLAN, are compared with the proposed SWITCH in terms of handover delay, radio resource overhead, and network throughput. In this simulation, it is assumed that 7 APs are placed in hexagonal cell deployment. In addition, the distance between APs is set to 40m. Moreover, this paper assumes the random way point mobility model [22] whose range of velocity and direction are between 0m/s to 8m/s and between 0 to 360 degrees, respectively. Furthermore, packets are generated based on the Poisson distribution with the mean arrival rate λ. Important parameters used in the performance evaluation are included in **Table 1**.

Table 1. Simulation Parameters

Parameter	Value
Processing capacity of the controller (C)	5,000 messages/second
Flow rule capacity	20,000 [10]
Bandwidth of the control channel	100 Mbps
Ratio of delay-sensitive flows	50 %
PHY specification	IEEE 802.11n
Propagation loss model	Logarithm distance
Propagation delay model	Constant speed
Transmission time of the preamble and header of the physical layer, T_{PHY}	20 µs
Beacon frame size, L_{beacon}	200 bytes
The transmission times of the maximum size frame, T_{max_frame}	2.7 ms [23]
Basic transmission rate, R_{basic}	6 Mbps
Channel switching time, T_{cst}	0.2 ms [24]
Beacon Period, T_{beacon_period}	200 ms
Max channel time	20 ms [10]
Slottime	9 µs
Short inter-frame space, SIFS	16 µs
Point coordination function (PCF) inter-frame space, T_{PIFS}	25 µs
Distributed inter-frame space, DIFS	34 µs
Packet arrival rate, λ	30

Fig. 5 shows the flow table utilization ratio of the AP according to the flow arrival rate of each MS. Since the reactive flow rule cache method installs a flow rule through a packet-in message only when necessary after handover, it has a minimum flow table utilization ratio without unnecessary flow rules. In case of delay-sensitive MS, SWITCH uses the proactive flow rule cache method. Since it can find the correct handover target AP, it has the minimum flow table utilization ratio without unnecessary flow rule installation like the reactive method. Since MobiFlow uses the proactive flow rule cache method according to mobility prediction, resulting in unnecessary flow rules, which increases the handover delay as the flow arrival rate increases. For example, if the flow arrival rate is 500, SWITCH can save the flow table utilization ratio up to 18 percent of the flow table space compared with MobiFlow.

Fig. 6 shows the average handover delay according to the number of NAPs. Since the NLP selectively performs active scanning only for the channels of the NAPs, the channel scanning delay increases in proportion to the number of NAPs. Accordingly, the overall handover delay also increases. SWITCH and SPS are not affected by the number of NAPs by removing channel scanning delays. Handover delay of the above two methods consist of T_{cst}, authentication and re-association delay. In the case of SWITCH, since the SDN controller is responsible for authentication and association, MS could receive data after attachment from the new AP without re-authentication during handover. Handover delays of SPS and SWITCH are 2.23ms and 4.65ms at 6 NAPs, respectively. The difference of the handover delay between SPS and SWITCH is caused by authentication and re-association delay. As shown in **Fig. 6**, SWITCH and SPS have significantly lower handover delay than that of NLP.

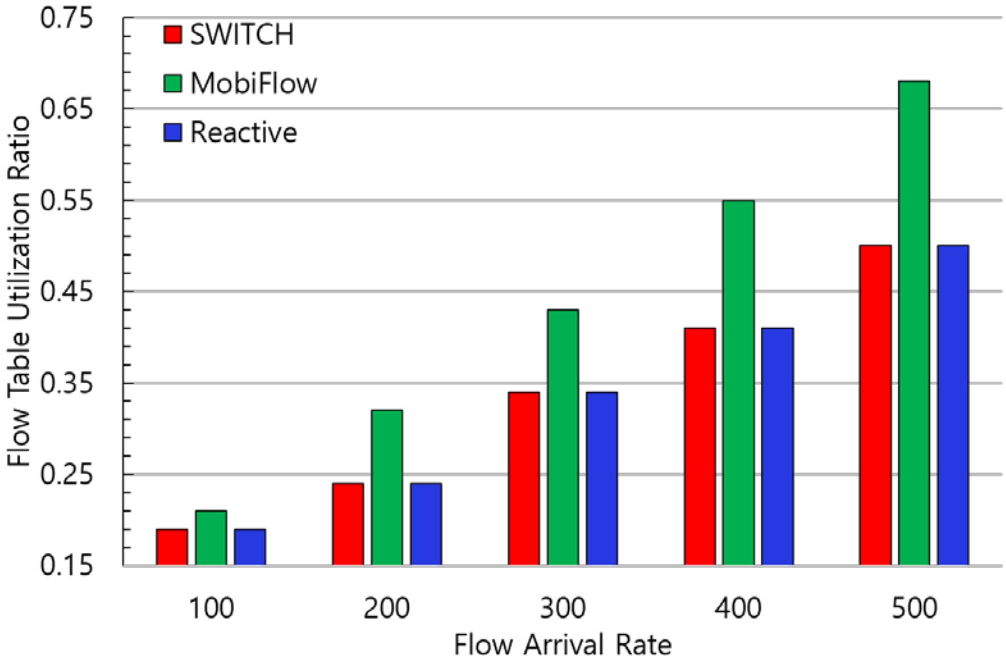

Fig. 5. Flow table utilization ratio according to the flow arrival rate of each mobile user

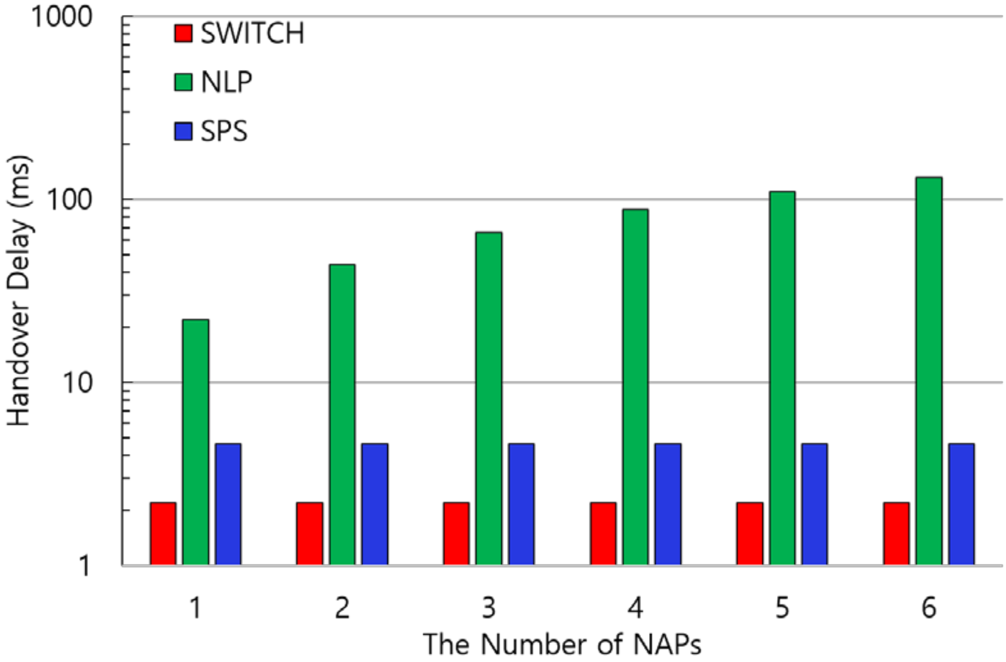

Fig. 6. Handover delay with the number of NAPs

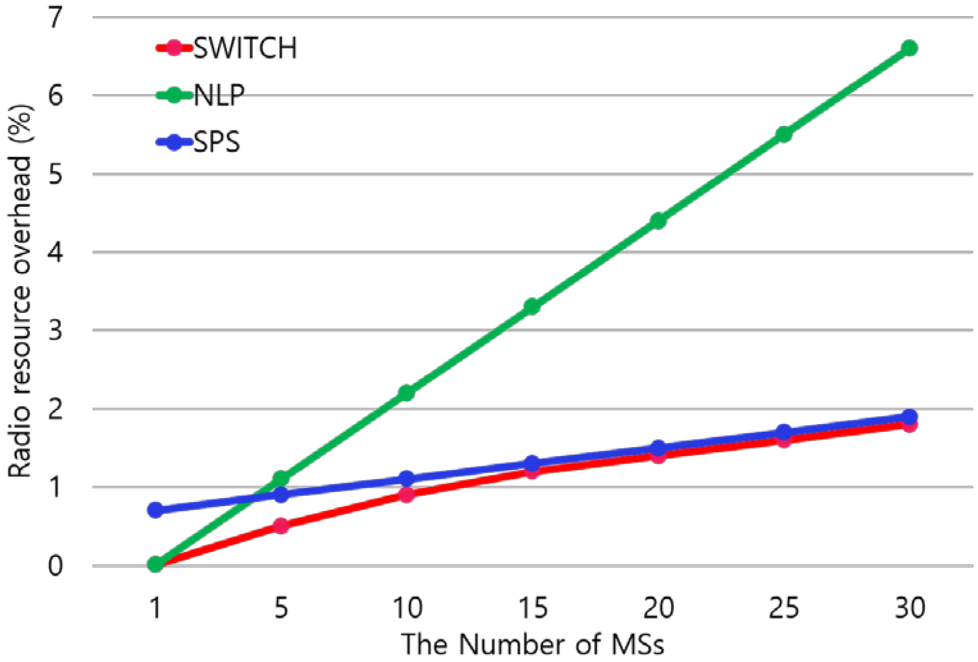

Fig. 7. Radio resource overhead according to the number of MSs

Fig. 7 shows the average radio resource overhead according to the number of MSs. NLP has neighbor list request/response and probe request/response overhead in the active scanning procedure. Consequently, in the case of NLP, the number of handovers and overhead also increase in proportion to the number of MSs. Since NLP generates the overhead at every handover. The overhead of SPS also increases in proportion to the number of MSs, but the slope is less than that of NLP. Since the SPS transmits a beacon frame without guaranteeing protection of collision, as the number of MSs increases, the collision probability increases, and thus overhead increases according to beacon retransmission. SWITCH has the lowest overhead in all ranges. Although the overhead increases as the number of MS increases because the SWITCH activation duration increases, it can be seen that if the number of MSs exceeds 25, it converges to 2 %.

Fig. 8 demonstrates the average network throughput according to the number of MSs. Note that two NIs are used in SPS. Specifically, one of them is an additional NI only for the channel scanning assistance. Consequently, for the fair comparison, it is assumed that other schemes also use two NIs indicated as '(2NI)' in **Fig. 8**. When two NIs are used, the number of MSs per NI is reduced compared to when the AP uses one NI, so the retransmission and back off times due to beacon collision are reduced and the network throughput increases [25]. The advantage of using two NIs for data communication could be clearly seen in SWITCH and NLP except for SPS. In SWITCH, the maximum throughput is more than twice as large as that of SPS. In addition, while the throughput of SPS becomes maximized when the number of MSs is 10, and then gradually decreases, that of SWITCH has maximum value when there are 20 number of MSs, and then also decreases. In other words, it can be found that the number of affordable MSs of SWITCH is nearly twice than that of SPS. Moreover, the graph shows that SPS has smaller network throughput compared to others even though it uses two NIs. This means that using one NI only for the channel scanning pays a large opportunity cost. In the case of SWITCH (2NI), network throughput is the highest.

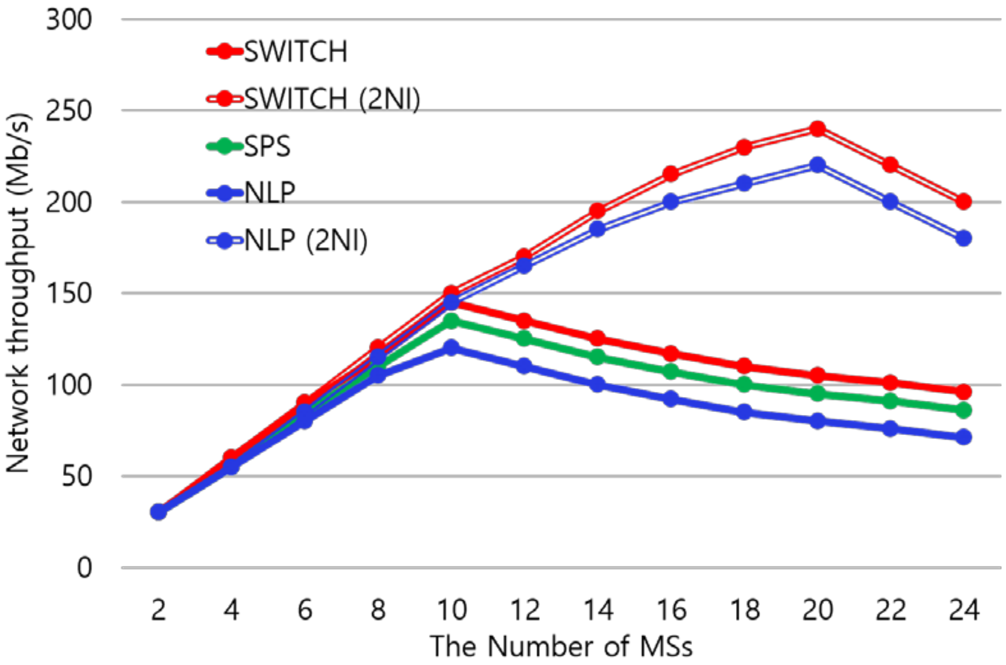

Fig. 8. Network throughput with the number of MSs

3. Conclusion

This paper proposed SWITCH in SDN-WLAN integrated access network. Since SWITCH allows MSs to receive the beacon frames of NAPs, they could determine the appropriate APs for handover without the channel scanning procedure. By reporting the information of the newly moved AP to the SDN controller, a flow rule is installed in advance to provide fast handover, and packet loss is reduced by buffering data destined for MS. In addition, proposed scheme could adaptively operate SWITCH to save the radio resource overhead. Through the performance evaluation, it was found that the proposed schemes could provide a seamless handover while maintaining low overhead as well as high network throughput. In our future work, we will consider the power consumption aspect which can be affected by the periodic switching and further explore the optimal SWITCH utilization policy considering the power consumption based on the deep reinforcement learning.

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