Seamless Handoff and Performance Anomaly Reduction Schemes based on OpenFlow Access Points

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***Abstract*—The enterprise WLANs that are composed of multiple access points (APs) and AP controller, provide wireless backbone networks in the building and campus. In this paper, we propose the OpenFlow AP system that is a software-defined enterprise WLAN system based on the OpenFlow-based AP and the OpenFlow controller. Also, we propose the seamless handoff and performance anomaly reduction schemes based on the OpenFlow AP system in order to improve total throughput of the networks while user experience is guaranteed. We deployed the OpenFlow AP system in the lab building and performed several experiments to evaluate the efficiency of the proposed system and applications. When the proposed system is compared with the existing WLANs, it performs handoff seamlessly without re-association and increases total throughput of the network by 26.7% when client is located in overlapped service area.**

Keywords- Enterprise WLAN; SDN; OpenFlow; Handoff

I. Introduction

The researches in the field of enterprise WLAN are mainly focusing on the handoff, interference, and QoS (Quality of Service). Most of these researches require the communication protocol between the central controller and APs. The CAPWAP, which is one of the protocol between the controller and APs, has been published, but most vendors are employing their own protocols [1,2,3]. In this environment, actual users cannot deploy and use preferred APs; and applying of the latest technology is limited, and the network is hard to manage resiliently.

Software defined networking (SDN) is a new paradigm for programmable network, and it is adopted extensively on the enterprise network and data center [4]. It divides the control plane and data plane of the network. Thus, data plane process such as packet forwarding is performed by switch, and the network control is conducted by SDN controller that has total network view. The most popular protocol is OpenFlow, which defines the rules for communication between controller and switches [5]. When SDN is used, the network operator can apply routing protocols and network applications to the network easily and flexibly. Thus, in this paper, the OpenFlow AP system that is a software-defined enterprise WLAN system based on OpenFlow is proposed. We extend the OpenFlow protocol in order to apply it to WLAN control, and propose the OpenFlow-based AP (OFAP) architecture that is controlled through the extended OpenFlow protocol. And then, several features of this system are presented to support applications such as the seamless handoff scheme and the performance anomaly reduction (PAR) scheme [6]. The PAR scheme alleviates the performance anomaly effects based on various information collected from each OFAP. Lastly, all of these features are evaluated through the experiments.

The research contributions of this paper for enterprise WLANs are as follows.

- The seamless handoff mechanism as one of applications of the OpenFlow AP system that uses OpenFlow protocol and OFAP is proposed.
- The PAR scheme is introduced to reduce the effects of performance anomaly, so the system can improve the whole network throughput while user experience is guaranteed.

The remainder of this paper is organized as follows. Section 2 presents related works, and Section 3 presents the OpenFlow AP architecture. In Section 4, the detailed process of proposed system and the PAR scheme are explained, and in Section 5 the experimental results are analyzed. Finally, we conclude this paper in Section 6.

II. Related Work

Many researches about enterprise WLANs architecture are actively progressing [7,8,9,10]. The main goal of these researches is to enhance performance of enterprise WLANs by adopting centralized schemes such as channel allocation, transmit power control, association control, and handoff. All APs in the enterprise WLAN environment are controlled by centralized network controller. One of these studies is the DenseAP system that improves the performance of enterprise WLANs using a dense deployment of APs [7]. It controls association of clients by handling probe frames received from APs using hidden service set identifier (SSID). Also, it performs AP load balancing and client handoff using available capacity that considers data rate and wireless medium utilization nearby clients and APs. However, it needs to exchange of the management frames for client handoff such as the re-authentication and re-association frames, and it assumes that performance anomaly problem rarely happens. Similarly, N. Ahmed et al. [8] proposed SMARTA. It is a self-managing AP architecture based on

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centralized controller and enhances the performance of enterprise WLANs using channel allocation. However, it does not consider the client handoff issue.

R. Murty et al. [9] proposed Dyson, the software architecture for customizable WLANs. It provides easy way to change the network policy using various application programming interfaces. However, real deployment of this architecture is difficult because it requires heavy modification of clients. Similarly, L. Suresh et al. [10] proposed programmable enterprise WLAN framework, called Odin. Odin does not require any modification of client and uses LVAP abstraction that provides a virtual AP with unique basic service set identification (BSSID) to each client by virtualizing physical AP. All physical APs are controlled by OpenFlow controller using OpenFlow protocol. To perform client handoff, OpenFlow controller just moves LVAP to new physical AP. As this mechanism is transparent to the client, the client handoff does not need re-authentication and re-association. However, there is a scalability issue as the number of clients increases at a physical AP, because the physical AP should handle each client as a virtual AP, thus it occurs overheads in the MAC layer of the physical AP. In addition, it only considers the received signal strength indicator (RSSI) for the client handoff decision.

Handoff strategy based on RSSI is easy to implement. However, it does not guarantee the client performance but also the entire network throughput. Y. Fukuda et al. [11] proposed the maximizing local throughput (MLT) scheme considering both RSSI and channel interference for AP selection. K. Tsukamoto et al. [12] proposed the handover decision method between multi-rate WLANs (HDMW) that decides handoff point and handoff target AP based on data rate and frame retransmission rate. As the main goal is to select a best AP for each client in these client-driven AP selection schemes, they do not consider performance anomaly. Also, as these schemes need client modification, it is not suitable for applying to real-world solution.

X. Chen et al. [13] presented the smart AP (SAP) solution to solve the performance anomaly problem. This solution performs association control by estimating channel occupancy time through data rate and current traffic load of client. The AP devices of this solution use multiple interfaces, and each interface within one device is operated on a different channel and cooperated closely with each other. Also, the client handoff between each interface is performed using channel switch announcement message. In addition, to reduce performance anomaly effects, SAP moves client, which has long channel occupancy time due to low data rate, to the dedicated interface operated on the different channel. However, SAP only considers client handoff among the different interface within one AP, and it does not consider cooperation of inter-AP and enterprise WLAN environment.

In this paper, we propose the OpenFlow AP system, which is the software-defined enterprise WLAN solution based on the OpenFlow protocol. We also propose the seamless handoff and performance anomaly reduction schemes on this system. The system improves the entire network throughput by alleviating the performance anomaly problem using the collected and calculated information such as channel load of AP, current traffic load of each client, and expected data rate based on RSSI. Also, it does not need to modify the client to support the seamless handoff and the PAR schemes.

III. OpenFlow AP Architecture

The OFAP that composes the OpenFlow AP system provides the network-initiated handoff, and this handoff scheme does not require any client side modification. To support handoff without client modification, all OFAPs use the same BSSID and SSID. The client in the WLAN, which is covered by OFAPs, perceives that there is only one AP in the network wide, while the WLAN coverage is comprised of multiple physical OFAPs. With this mechanism, the network controller can control network-initiated applications such as association control and handoff, and therefore, the efficiency of SDN will be maximized.

Fig 1 shows the OFAP architecture. The OFAP performs client management, wireless channel monitoring, and AP hardware control according to the control messages from the controller. Unlike OF switch, OFAP with single interface has single port (If OFAP provides wireless service through multiple interfaces, it may have multiple ports.) However, multiple clients are connected with single interface within the OFAP. So, the network control is based on clients, not on ports. In addition, OFAP does not perform a complex routing based on multiple ports, so the controller executes association control, client handoff, and differential distribution of wireless resource for each client without resorting to routing control.

In addition, OFAP reports not only information of clients associated with but also signal information of clients which is not associated through the overhearing. This collected information for each client is the statistics related to the wireless communication. The controller can configure the reporting data type and the reporting period of OFAP, and OFAP should collect as much information as possible to support the various WLAN applications.

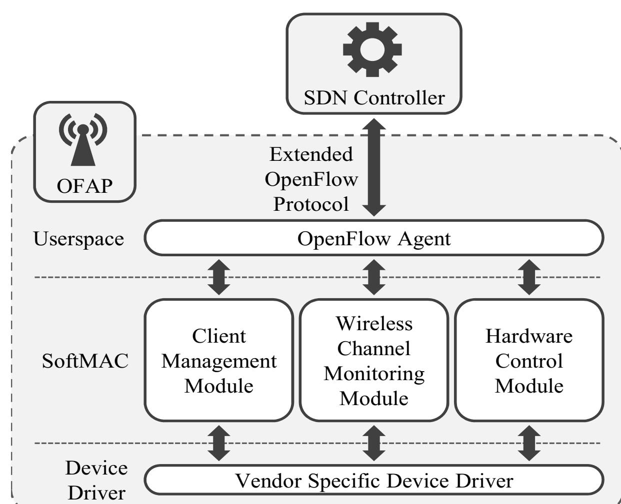

Figure 1. OpenFlow-based AP architecture

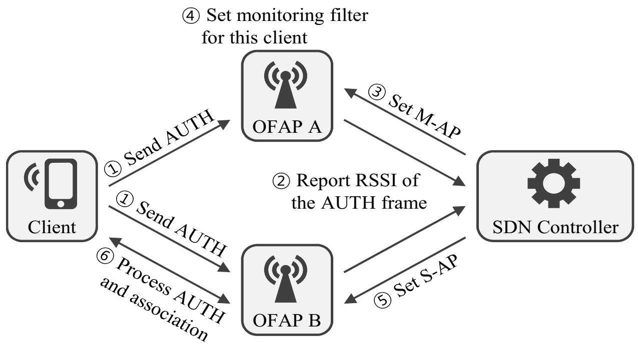

Figure 2. Association Process with OFAP

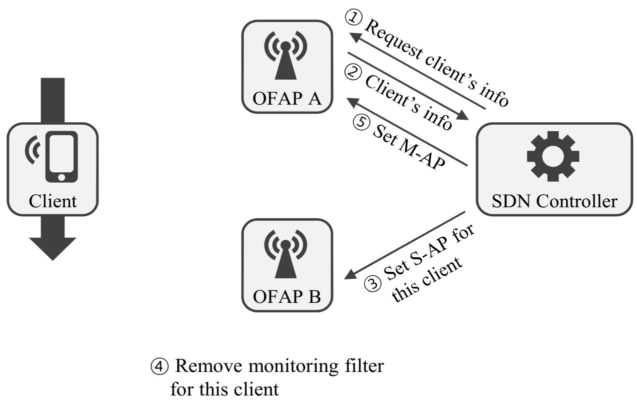

Figure 3. Seamless handoff with OFAP

IV. OpenFlow AP Applications

A. Association and Handoff Process

The initial association process is shown in Fig 2. The beacon frames that include the same BSSID and SSID are sent periodically from all OFAPs. As mentioned earlier, the client in this environment recognizes only one AP in the WLAN and transmits the authentication frame using that BSSID in order to join the WLAN. At this time, the probe request frame is not considered because the client may perform only passive scanning. All OFAPs that received the authentication frame report the RSSI of the frame to the controller. The controller collects the RSSIs of the authentication frames, which are transmitted by the client, from the multiple OFAPs during a certain period and decides the service AP (S-AP) that reports the highest RSSI. Other OFAPs are set as monitor APs (M-APs). After the setting of S & M-APs, the controller delivers the command to let all M-APs monitor the RSSIs of the frames transmitted by the corresponding client, and the controller also sends the command to the S-AP in order to service the client. The monitoring filters of all M-APs are set to collect RSSIs of frames transmitted by the client and drop these frames. The S-AP also collects frame information such as RSSI, communication usage, and data rate while providing wireless service for clients.

In Fig 3, the handoff process is presented when the client near OFAP A moves toward OFAP B. When the level of RSSI reported from each OFAP is changed according to the movement of the client, the controller determines the client handoff. If the controller decides that the client handoff is needed, it requests the current S-AP to send the information of the corresponding client; and the S-AP responds with the client information. The exchanged client information is the same as the information created as a result of the association process. The controller received the client information delivers it to the target OFAP and commands to remove that client from the monitoring filter. Then, the target OFAP adds the received client information and removes the client from the monitoring filter. When the setting of the target OFAP has been done, the controller sends the command to the current S-AP to add the client to the monitoring filter, and then, the current S-AP removes its own client information and starts monitoring for that client.

The main feature of the handoff process in the proposed system is that client never participates in this process. In other words, the handoff process is seamlessly conducted because all OFAPs use the same BSSID. In addition, the controller can control not only OFAPs but also OF switches, the handoff among OFAPs that are connected to different switches can be performed flexibly.

B. Performance Anomaly Reduction (PAR) Scheme

In this paper, we propose the PAR scheme to reduce the performance anomaly, which is a well-known phenomenon in WLAN, when the controller decides the target OFAP for handoff.

All OFAPs are operated on the same channel. And OFAPs should be installed so that the service area is overlapped. In this environment, the effect of channel occupancy of a client in the overlapped service area and performance anomaly due to the client will affect the adjacent OFAPs. Also, most of the traffic from WLAN participants takes a downlink form, and the traffic is transmitted using the data rate determined by the rate control algorithm of AP. Therefore, the PAR scheme focuses on the client which is located in the overlapped service area of two or more APs and generates heavy downlink traffic.

1) Empirical Estimation of Expected Data Rate: The PAR scheme estimates the expected data rate of client using collected RSSIs from multiple OFAPs. The factors that affect the performance anomaly phenomena are data rate and current traffic load. However, RSSI reported from an OFAP just means signal strength of frame transmitted by a client, so the RSSI value is not closely related with the data rate that is chosen by the OFAP to communicate with the client. The data rate is rather affected by the features of client hardware such as antenna receiving sensitivity. However, if the data rate distribution for a certain client is accumulatively recorded, the expected data rate can be estimated depending on the RSSI level of that client. The controller requests the data rate distribution according to RSSI change for each client to all OFAPs periodically.

Fig 4 and Fig 5 show the data rate that is collected for a certain period according to the RSSI change of client used in the experiment. Fig 4 presents the average value of data rate over RSSI, and Fig 5 indicates the distribution of data rate over RSSI. These data vary with client, so the controller keeps recent distribution or most frequently used value of

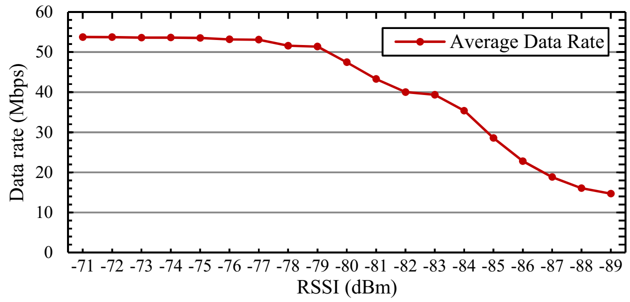

Figure 4. Average data rate over RSSI

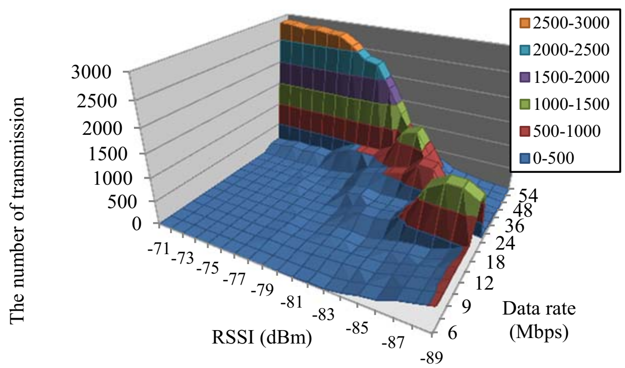

Figure 5. Distribution of data rate over RSSI

data rate for each client. Later, when the controller decides client handoff, it selects the best OFAP as handoff target by calculating the effect of performance anomaly using the expected data rate empirically obtained.

2) Association Control using Expected Data Rate: Now, the controller can estimate data rate based on the RSSI of client before handoff. However, the expected data rate cannot be trusted completely, so the appropriate action is required from the controller. In addition, some hysteresis schemes are required to avoid oscillation because the variation of RSSI is significantly large.

In this paper, the PAR scheme as shown in Fig 6 is proposed in order to conduct association control that reflects these considerations. This scheme has the following features. First, the RSSI range is divided into three sections on the basis of the expected data rate based on the collected RSSI. The sections are as follows; high quality (HQ) section that maintains the maximum data rate, moderate quality (MQ) section that maintains a relatively high data rate, and low quality (LQ) section that shows low data rate with high probability. As mentioned earlier, the client in the LQ section causes performance anomaly to multiple BSSs. Detailed configurations may vary depending on the network policies. The controller performs handoff according to the section that includes the RSSI collected from an S-AP. If the RSSI from an M-AP that has a maximum RSSI within the M-AP set is greater than the RSSI threshold of the S-AP, handoff will be performed to the M-AP as the target. Also, the RSSI threshold is different in each section. The threshold is set as higher value in the HQ section and lower value in the LQ section.

Another main feature is the handoff policy for client that

PAR Scheme Algorithm

$s \leftarrow$ S-AP, $s_s \leftarrow$ RSSI of s
$M \leftarrow$ M-AP set,
$m \leftarrow max\_rssi(M)$, $m_s \leftarrow$ RSSI of m
$b_{ab,bc} \leftarrow$ Boundary between Section A and B, B and C
$th_{a,b,c} \leftarrow$ RSSI threshold within Section A, B, C, respectively
if $(s_s \geq b_{ab}$ and $m_s > s_s + th_a)$ $handoff(m)$
elseif $(b_{ab} > s_s \geq b_{bc}$ and $m_s > s_s + th_b)$ $handoff(m)$
elseif $(b_{bc} > s_s)$
  if $(m_s > s_s + th_c)$ $handoff(m)$
  else
    m^{max} = **argmax**($crowded\_ap(m')$) **where** $|m'_s - s_s| \leq th_c$, $m' \in M$
    $handoff(m^{max})$
  endif
endif

Figure 6. PAR scheme with expected data rate and RSSI

may be connected with AP with low data rate. When the RSSI obtained from an S-AP is in the LQ section, the controller will perform handoff by two ways. Firstly, as mentioned above, handoff will be performed if RSSI from an M-AP is greater than the RSSI threshold of the S-AP. Secondly, when the RSSI from the M-AP that has reported the maximum RSSI does not exceed the RSSI threshold from the S-AP, the extra operation will be conducted. If the difference between the RSSI of the certain M-AP and the RSSI of the S-AP is within threshold, the extra operation is performed with those M-APs. In the latter case, if the difference between two RSSIs is small, the expected data rate may be similar. Even if the clients are connected to any AP, they will cause performance anomaly. Therefore, the controller decides the target OFAP in order to reduce the channel occupancy time of these clients. In other words, reducing the channel occupancy of clients that may be connected with low data rate increases the whole network throughput by limiting the effect of performance anomaly. In addition, this scheme does not mess up the service bandwidth for the clients with low data rate, because they are going to communicate using low data rate anyway.

In order to reduce the channel occupancy of the handoff target client with low data rate, the controller decides the most crowded AP as the handoff target AP. When the low data rate client is connected with the crowded AP that has many associated clients and heavy loads, the client has low opportunity to occupy the channel. Therefore, using the crowded AP to provide service for the low data rate client can help alleviate the performance anomaly effect.

When a client moves to the handoff target AP, the crowded level of the AP will be considered as a metric to determine the channel occupancy of the client. If the crowded level considers only the generated traffic size, the handoff target client may occupy the channel for a long time if there are only a small number of competing clients. Also, if only the number of associated clients is considered, the channel occupancy time of the handoff target client may vary depending on the generated traffic size. Therefore, the crowded level of the AP must consider both the channel load [17] and the number of associated clients which are generating downlink traffic. It can be defined as (1).

$$L_{crowded} = Channel\ Load\ \times N_{associated\ clients} \quad (1)$$

In (1), $L_{crowded}$ means the crowded level of AP, and $N_{associated\ clients}$ means the number of associated clients which are generating downlink traffic. The $crowded\_ap$ module in line 9 of Fig 6 calculates and returns $L_{crowded}$. Using this metric, the PAR scheme selects the M-AP that has the maximum value of $L_{crowded}$ as a handoff target AP.

V. Experimental Results

A. Experiment Setup

We performed experiments to evaluate the performance of the OpenFlow AP system. Two OFAPs are deployed on the same floor and the client moves along the corridor for handoff experiment. When an OFAP is turned on, it establishes an OpenFlow connection with the controller and exchanges the OpenFlow version, the hardware specification & capabilities, and etc. Then the controller sets the OFAP according to the network policy. All OFAP periodically report information to the controller according to the interval set by the controller. All OFAP, controller, data server, and clients are on the same subnet. The client is provided a static IP in order to exclude the delay due to the IP allocation from the DHCP server.

The experiments use Kulcloud MuL as the controller, and the OpenFlow Switching Reference System supporting OpenFlow 1.0 specification as the OpenFlow agent of OFAPs [14,15]. All OFAPs are implemented using OpenWrt embedded Linux package and equipped the wireless network card using Atheros AR9220 chipset [16]. And a laptop operated on Windows 7 is used as a client and its network driver is not modified at all. All OFAPs are operated on the same channel defined in the IEEE 802.11a.

We performed two kinds of experiments to evaluate the performance of the OpenFlow AP system. The first is that delay and throughput are measured over time in the absence of any other clients to evaluate the efficiency of the seamless handoff scheme. It is compared with a legacy 802.11 handoff scheme. The other one is that the whole network throughput is measured in the case of coexistence of multiple clients in the network to evaluate the efficiency of the PAR scheme. In these experiments, the PAR scheme is compared with the handoff based on RSSI and the handoff based on AP load. In the experiments, we set the parameters b_{ab} to -70, b_{bc} to -80, th_a to 10, th_b to 7, and th_c to 5.

B. Seamless Handoff Efficiency

For this experiment, the laptop is moved along the corridor, where two OFAPs are installed, with constant speed. In the experiment the data server sends TCP traffic to the laptop using iperf [18]. Fig 7 shows the result of legacy handoff. As shown in Fig 7 and Fig 9, the throughput is decreased and the delay is increased from 15 second. The

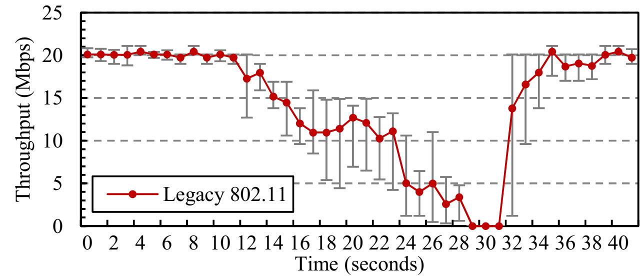

Figure 7. Throughput of moving client over time with legacy 802.11 handoff

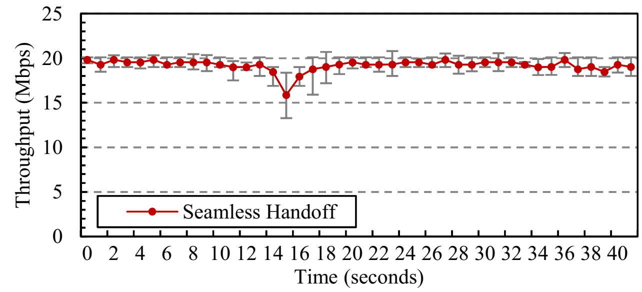

Figure 8. Throughput of moving client with the seamless handoff scheme of the OpenFlow AP system

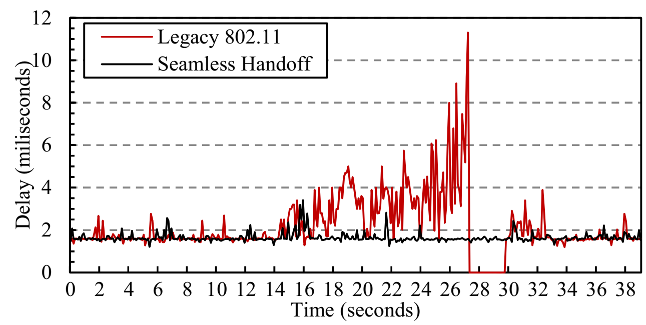

Figure 9. The packet delay during handoff

laptop lost current connection to initial AP at 30 second and recovers the connection by associating the other AP at 33 second. Because the handoff is not supported with independent APs, the client maintains existing connection although other AP's RSSI is greater than current AP's. Fig 8 shows the result of experiment when the seamless handoff scheme of the OpenFlow AP system is applied. The throughput is decreased and the delay is increased from 15 second. However, as the controller switches S-AP properly, we can observe that the throughput and delay are recovered to previous levels without any disconnection. The controller can switch S-AP for the laptop according to the RSSI of the laptop without re-authentication and re-association. As a result, the performance degradation due to handoff rarely happens.

C. Performance of the PAR Scheme

To evaluate the efficiency of the OpenFlow AP system which applies the PAR scheme, 2 OFAPs are deployed in the corridor and the laptop moves from source OFAP to target OFAP with constant speed. Source OFAP has no associated clients and target OFAP has three associated clients. All

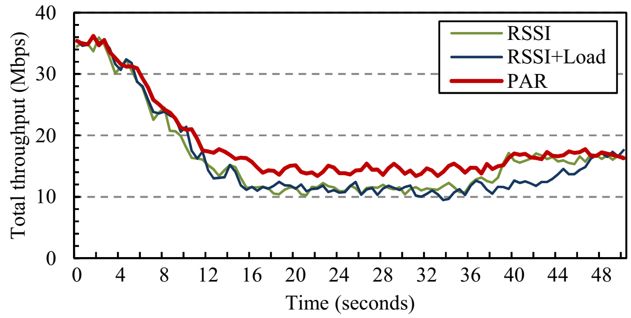

Figure 10. Total network throughput over time with various handoff metrics

clients in the network generate the downlink traffic, and the laptop moves with constant speed. Unlike the experiment for handoff, OFAPs are deployed so that the collected RSSI from the laptop, which is located in the overlapped service area, is continuously shown as the low value. All experiments are performed based on seamless handoff.

Fig 10 presents total throughput of network when the laptop moves from current OFAP to other OFAP, and in this experiment, the controller chooses the handoff target OFAP based on the RSSI, AP load, and the PAR scheme. At the beginning, as the laptop is far away from OFAP A, total throughput is decreased. And the laptop passes through the overlapped service area. If laptop is connected to OFAP A in the overlapped area, the channel occupation time of the laptop is increased, thus, total throughput is more decreased due to performance anomaly.

In the case of using the RSSI based handoff, the controller does not change the S-AP until RSSI of OFAP B is higher than RSSI of OFAP A. As mentioned earlier, total throughput is more decreased when the laptop is connected to OFAP A rather than OFAP B. In the AP load based handoff, the controller selects lightly loaded OFAP if RSSI of OFAPs is above the certain threshold. Therefore, the connection between OFAP A and the laptop is kept longer than the RSSI based handoff scheme. As a result, the network is affected by performance anomaly for a long time. In the PAR scheme, if the RSSI of the laptop is lower than the predefined threshold, the controller predicts that the laptop will cause performance anomaly and selects OFAP B, the crowded AP, as S-AP for the laptop. As a result, the PAR scheme can improve total throughput of the network by alleviating performance anomaly. In the experiment results, the PAR scheme increases total throughput of network compared to the RSSI based selection and the AP load based selection by 26.7% and 28.5% respectively, when client is moving in the overlapped service area.

VI. Conclusion and Future Work

In this paper, we proposed the OpenFlow AP system, which applies the SDN framework based on OpenFlow to enterprise WLANs, in order to enhance the applicability and scalability of the network. We also proposed the components of the OpenFlow AP system, such as the extended OpenFlow protocol to control WLANs and the controllable OFAP architecture. Then, we presented the seamless handoff scheme without client modification and the PAR scheme to reduce performance anomaly based on the seamless handoff scheme. Seamless handoff and the PAR scheme are evaluated through various experiments. The client handoff was performed seamlessly without any disruption and the PAR scheme improves the total throughput by 26.7% compared to the RSSI based handoff.

One of the future directions we want to study is the optimization of the PAR scheme, especially about the relationship between RSSI and data rate. We will also study the scheme for reducing the overhead of using OpenFlow protocol in the OpenFlow AP system and more categorized definition of OpenFlow protocol for various applications of the OpenFlow AP system.

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