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Extended-LLF: A Least Loaded First (LLF)-Based Handover Association Control for Software-Defined Wireless Network

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ABSTRACT

Association control is a mechanism that regulates the association between stations and access points in the network. Two mechanisms that can be emulated in Mininet-WiFi as the emulator for SDN in wireless environment are Strongest Signal First (SSF) and Least-loaded First (LLF). In this study, we propose Extended-LLF, which is a refinement of existing mechanism that is able to overcome the weaknesses in LLF. A parameter of maximum RSSI difference is added as a requirement in association decision.

Based on the tests conducted on the mobility scenario with 3 access points and 10 stations, Extended LLF mechanism provides better RSSI reception than LLF as the existing load balancing mechanism. In terms of performance, Extended LLF provides an increase over LLF on jitter, packet loss, and throughput by 6.69, 0.38, and 0.04 percent, respectively. However, there is a degradation of performance in terms of delay by 0.85 percent. Compared to SSF, Extended LLF results in better performance in terms of delay, jitter, and throughput by 18.58, 13.46, and 0.05 percent, but with performance degradation of packet loss by 5.86 percent.

Keywords: *Association Control, Handover, Software-defined Wireless Network, Mininet Wi-Fi.*

1. INTRODUCTION

Over the years, mobile devices has become one of the major access methods in communication. The number of users continue to grow, yet users' expectations to experience the best network performance becomes even higher. Association control, which is a mechanism in wireless environment that governs how mobile stations associate to access points (APs), can be leveraged to help coping with the requirement to deliver high aggregate network performance.

Software Defined Networking (SDN) is an emerging paradigm which separates control plane and data plane in the network. This approach is said to be essential for network deployment in the future [1]. However, association control in SDN-based wireless environment has not been studied extensively until very recently.

Mininet-WiFi [2], a fork of Mininet [3] which is a widely-used tool to emulate SDN environment, adds the capability of wireless functionality to the platform. For association control, there are currently two available options in Mininet-WiFi, namely Strongest-Signal-First (SSF) and Least-Loaded-First (LLF). However, each mechanism possesses its own weakness that will not be beneficial to the network. Improvement in this field is still required to enhance the network performance.

In this research, we propose an association control mechanism entitled Extended-LLF, a load balancing algorithm for access point selections developed from the existing LLF mechanism in Mininet-WiFi. The aim of this mechanism is to improve the RSSI value received by stations and gain better performance in SDN-based wireless environment by taking the value of Received Signal Strength Indication (RSSI) into account in the association decision. The proposed mechanism is examined in mobility scenario, i.e. handover scheme, to observe its association and its performance. The results are then compared to SSF and LLF as the existing mechanism.

This paper is organized as follows: Section II describes related works, the theory that underlies association control, and our contributions; Section III outlines the design in the proposed scheme; Section IV elaborates the emulation scenario and interprets the result of experiment; and Section V concludes the paper.

2. LITERATURE REVIEW

2.1 Related Works

There are considerable amount of papers that discuss association control on Wi-Fi networks, as presented in the taxonomy on *Fig. 1*. Most of them propose some kind of load balancing to improve the original mechanism used in 802.11, which is similar to SSF. In [4], a load balancing entitled Predictive Association Algorithm (PAA) takes into account not only Received Signal Strength Indication (RSSI) and load in general, but also interference and AP loadings as factors for station association to the available AP. The experiment is performed on the physical environment by comparing PAA performance with LLF and SSF. The result obtained is the PAA algorithm increases the average system attainable data rate by 50 percent.

In [5], load balancing is done by adjusting the size of access point (AP) range as required. This principle has been known previously in cellular network as Cell Breathing. Mathematic and pseudo-algorithmic principles are explained for various scenarios along with strategies that can be done to minimize the deficiencies in the proposed mechanisms. Based on the simulation, better performance than SSF and LLF is obtained.

In [6], associations are determined by channel utilization of each station, which is defined as the ratio of bandwidth requirements and bandwidth availability estimation. Bandwidth calculation methods as well as problems that may arise from the method used is elaborated, along with the solutions to the problems. Simulation performed on Qualnet results in an average throughput increase per station by 38.4% compared to SSF and 29.1% compared to LLF.

For SDN-based networks, there is quite only a few discussion related to association control. This is because SDN is still fairly new although the concept has existed since the emergence of the term passive networking in the 70s [7]. In addition, the initial goal of SDN that was intended for wired networks also causes the SDN research direction in terms of wireless is not well-developed yet. Only after the development of simulation and emulation tools such as Mininet-WiFi does the studies begin to emerge and focus on various aspects that occur specifically in wireless conditions, such as mobility.

One of the research focusing on association control in SDN-based wireless network is found in [8]. An adaptive load balancing scheme to address the unfairness in bandwidth allocation is proposed. The mechanism is run in the controller. For each new station connected to the network, AP will inform the controller through the mechanism of event detection. AP will also provide traffic load information, to be later used by the controller to determine the load balancing mechanism that suits the current network conditions best. The simulation result on NS3 shows that the proposed mechanism provides a minimum throughput increase of 16% against SSF, 76% against LLF, and 23% against Cell Breathing method.

Other research related to association control on SDN environment is found in a working paper on [9]. The proposed load balancing mechanism determines when to perform change of association based on estimated highest throughput that can be obtained by station in each AP. which in principle is quite similar to the method in [4], but for SDN-based wireless network. Throughput calculations and decision making is elaborated analytically, but experiments conducted and the analysis is not yet explained in depth as the research is not yet finished.

In [10], the study focuses on comparing the result of association and its performance in existing version of LLF and SSF supported in Mininet-WiFi. It aims to observe how UEs associate to AP and also to measure the performance in terms of transfer, jitter, and packet loss. The experiment is of mobility scenario, i.e. handover, with two APs and 10 stations in the network. From the measurement and discussion, it is concluded that LLF performs better than SSF, but with the disadvantage of several stations suffer from the lowest level of RSSI even when there is a neighboring AP available to give higher RSSI value.

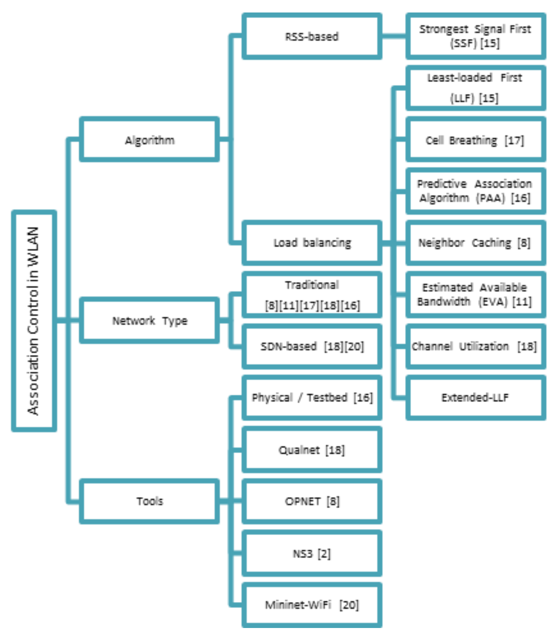

Fig. 1. Research on association control in WLAN

To the best of our knowledge, only three papers studies specifically about association control in SDN-based network, all of which has been discussed in the previous paragraphs. Of the three, only one leverages Mininet-WiFi as the tool. This indicates that there are still many research opportunities in wireless networks based on SDN.

As for this research, we continue the work done in [10].

The strength and weakness of existing LLF and SSF mechanism in Mininet-WiFi that is elaborated in [10] is included as the consideration in designing the association control mechanism. Extended-LLF, as our proposed scheme, is a load balancing algorithm that can overcome the weakness of Least-loaded First (LLF) algorithm in Mininet-WiFi. Our contributions are in the enhancement of RSSI level received by stations, resulting in higher performance in some metrics than the two existing algorithms.

2.2 Handover and Wi-Fi Association

Handover is the mechanism of changing an association of a mobile station from one access point to another in a wireless network [11]. Handover procedures consists of three phases [8]: discovery, authentication, and association. In the third phase, a mechanism termed *association control* manages how stations associate to access points in the network.

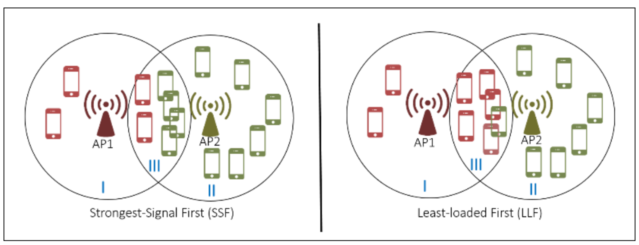

Fig. 2. Illustration of Existing Association Control Mechanisms

Two mechanisms currently supported in Mininet-WiFi are Strongest-Signal-First (SSF) and Least-Loaded-First (LLF). Using SSF, stations would connect to the AP that provides the highest RSSI value. As illustrated in *Fig. 2*, SSF yields association as follows: 4 stations associate to AP1 while 10 other stations associate to AP2. LLF would result in, for example, 7 stations connected to AP1 and 7 other stations connected to AP2. Load, here defined as number of stations connected to APs, is distributed more evenly among the APs.

3. PROPOSED SCHEME

The current association control mechanisms, as stated in [10], possess certain advantages and disadvantages. SSF ensures each station in the network receives the highest RSSI value, which is one of the factors to obtain higher performance metrics, e.g. throughput and jitter. Nevertheless, load distribution is not taken into account, resulting in a situation of imbalanced load between the APs. On the other hand, LLF maintains a more distributed AP load, but with the drawback of not considering the signal strength received by the station which can also result in lower performance metric, e.g. obtained bit rate. Each of these characteristics may decrease the overall network performance.

Several considerations in designing the proposed algorithm are as follows:

1) *Future technology trends*: In the future, the use of wireless devices is forecasted to grow very rapidly [12]. For the year of 2020 alone, 5G standard, with the requirement of 1 ms maximum latency and minimum throughput of 1 Gbps is planned to be released. With the multitude use of machine-to-machine (M2M) communication and the utilization of internet of things (IoT), the circumstances will progressively shift towards denser network.
2) *Utilization:* Utilization of network devices is essential to be maintained in large network. As stated in [5], it is undesirable to have devices in the conditions of imbalanced utilization. The algorithm developed should be able to accommodate this issue.
3) *Performance:* The proposed algorithm shall be able to provide better performance than the existing mechanism. The performance metrics are tailored to the requirement in the network.

Based on these considerations, the design of proposed association control mechanism that is most suitable for use can be concluded. It is known that the network will move towards the dense network for the future. Furthermore, a balanced utilization between network devices will also be important because of the density of the network to gain better performance. In this circumstances, SDN paradigm is beneficial because of its ability to perceive the global view of the network. This characteristic can be leveraged to monitor the condition of the network elements, which is the requirement for load balancing algorithm.

SSF-based mechanism alone is irrelevant to be used in future network condition. Although the network will be denser over time, users or stations will not likely be distributed evenly within the network. Rather, they are congested sporadically in certain popular spaces [13]. Using this approach, several APs will be too loaded while others may be under-utilized, which is not suitable for the implementation. However, the value of RSSI remains one of the factors considered important for obtaining high data rates [4]. It is known that the existing load balance algorithm in Mininet-WiFi has not considered this factor. As observed in [10], the existing LLF algorithm prevents some stations to reassociate to other AP in the network, even when the received RSSI from the current associated AP is the lowest. This is a gap that can be utilized for enhancement.

```
for all APs:
    for all stas:
        if sta is connected to AP then
            record sta to associated stas
            map sta to AP
        endif
    endfor
    if ∑(associated stas  in connected AP – associated stas in neighboring AP) > 2 then
            if RSSI to neighboring AP - RSSI to connected AP > 0.1 then
                    change association of sta
            endif
    endif
endfor
```

Fig. 3. Extended-LLF Algorithm

The objective of this research is to modify the LLF mechanism by adding the RSSI parameter which is implemented in the SSF. As shown in *Fig. 3*, RSSI threshold is added as a condition to perform reassociation. This will affect the RSSI received by each station, where the value will be higher than that in LLF, but still has load balancing capability that does not exist in SSF.

Extended-LLF, in principle, holds similar characteristics of LLF. The difference lies in the inspection of RSSI value difference between neighboring AP and connected AP before deciding to change station's association. If the RSSI difference is more than the determined threshold, the station will execute handover to gain better RSSI while still preserving load balancing in the network. Load in this research, as used in the existing LLF mechanism in Mininet-WiFi, is defined as the number of stations connected to the access points. It should be noted that in the implementation, both RSS-based and load-based mechanisms may vary depending on the requirement and configuration.

4. PERFORMANCE EVALUATION

4.1 Experiment Setup

In order to evaluate Extended-LLF mechanism in handover scheme, an experiment as shown in *Fig. 4* is emulated in Mininet-WiFi. Three APs in mode g are arranged horizontally, with 10 stations simultaneously moving from the transmission range of AP1 through the transmission range of AP3. During the stations' mobility process, two main assessments are examined for Extended-LLF, LLF, and SSF: station's association to the APs in mobility scenario is observed, and its performance is measured.

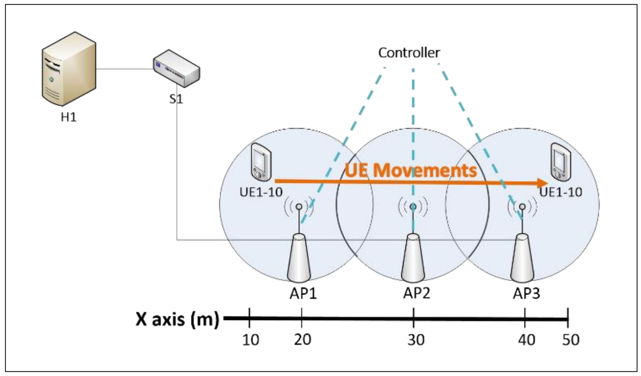

Fig. 4. Experiment scenario

Observation of association is performed by logging each station's position in integer form and its corresponding acquired RSSI value during mobility. The values are then analyzed and interpreted as graphs as shown in the next section. For SSF, all stations will produce similar association results while for load balancing mechanism, i.e. Extended-LLF and LLF, several stations will acquire similar association result while the others are not, producing several types of association. In this experiment, stations' mobility is done statically using *setPosition* method.

Four performance metrics to be measured in this experiment are throughput, delay, jitter, and packet loss. In order to measure the performance, the scenario is as follows: one station communicates to the host, H1, while others communicate with each other in pairs. The one that communicates with the host is measured, while the others serve as the background traffic.

In the experiment, APs are connected to the controller, OpenDayLight Beryllium, via out-of-band connection. The controller installs the required flow for APs to communicate properly. In this experiment, the controller is used to provide basic connectivity in the network, but does not serve in mobility controls, which is handled by Mininet-WiFi in this experiment. Adding flow entry from controller to forwarding device is implemented in reactive fashion. The reason for this approach is that unlike in fixed networks, the nodes in wireless network commonly undergo frequent reassociation due to its mobile characteristic. In addition, connection method in wireless network is different from that in wired network, in which the station is not connected specifically to a certain physical port. Installing flow in proactive fashion is burdensome and inefficient as the port of AP, in which station attaches to, changes dynamically according to the stations' mobility.

4.2 Association Result

In the experiment, all 10 stations start moving from the leftmost side, at x=10 m, to the right, at x=50 m as shown in the emulation scenario on *Fig. 4*. In *Fig. 5*, there consists two elements: experiment scheme containing the positions of APs and stations, and RSSI graph containing its corresponding RSSI values. This figure depicts acquired RSSI value in the stations if connected to each AP, for every position. Highest RSSI value is acquired at the center of each AP while lower level of RSSI is received when stations move farther to other points.

At the start of the experiment, stations would all connect to AP1 because it is the only in-range AP for them. Stations would first experience relatively low signal in AP1, then gradually receive higher RSSI as they move closer to the center of AP during mobility. As expected, when stations consequently move away from the center of current AP, the signal value decreases.

In all three mechanism, all stations would attach to AP1 at the initial condition and would eventually connect to AP3 in their final condition. The difference of each mechanism lies in the position and RSSI value in which handover is performed.

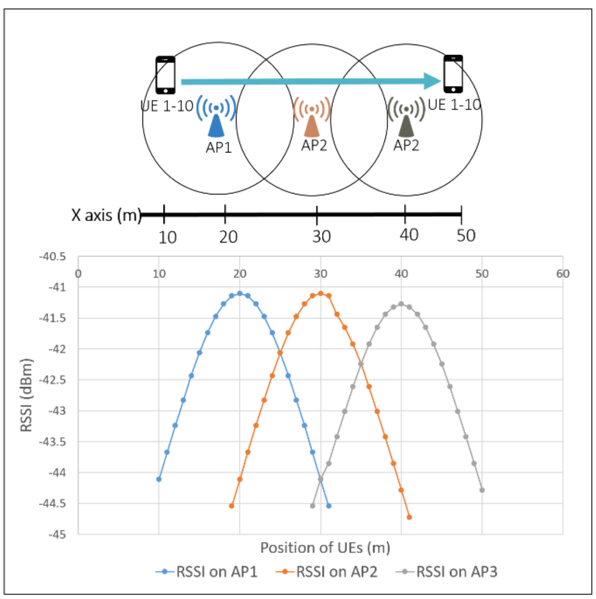

Fig. 5. RSSI received by UEs in each AP

Handover, or change of AP association in stations, may occur when there is more than one AP in the station's range, represented in the graph by more than one RSSI value at certain positions, i.e. at 19-41 m in *Fig. 5*. In all these points, stations may experience 3 different states in succession: in range of both AP1 and AP2 only; then in all three APs' range; and subsequently in range of both AP2 and AP3 only. Stations may execute handover anywhere between these points, which will result in various types of association. Thus, the difference in the association types between Extended-LLF and the existing mechanism can be observed in this area.

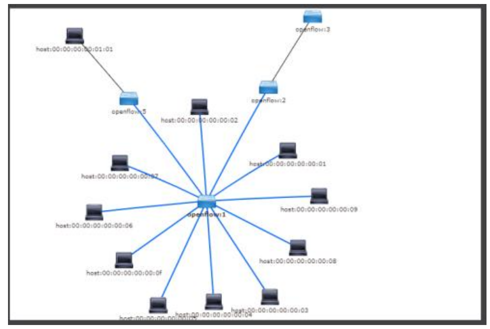

Fig. 6. Stations' association in initial condition

Association can also be observed in the controller using YangUI, a web-based GUI for OpenDayLight controller. *Fig. 6* depicts the stations' association at the start of experiment. All stations are connected to AP1, which is shown in the figure as *openflow:1*. At the end of the mobility scenario, controller shows the result of association as in *Fig. 7*. All stations are associated to AP3, shown as *openflow:3*. It can be observed in the latter figure that there is a second link connecting the stations with AP1. Rather, old flows that are pushed by OpenDayLight may still be available and not expired [10].

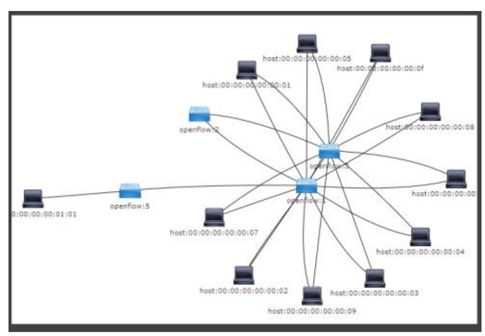

Fig. 7. Stations' association in final condition

Based on the observation for 3 APs and 10 stations, the association for each mechanism can be classified into several types based on the acquired RSSI graph as follows:

1) SSF: one type of association as shown in *Fig. 8*;
2) LLF: 5 types of association; and
3) Extended-LLF: 4 types of association.

Identical RSSI graph of the stations indicates that those stations associate to the same AP and also perform handover at the same time. Fewer association types indicate that the load is concentrated in the same AP. This condition will be minimized in mechanisms that utilize load balancing principle.

Discussion of association types in the later section will focus on the comparison of Extended-LLF with LLF as they share the same general principle of load balancing. SSF is discussed separately to avoid redundancy of explanation in each station, as SSF only has one type of association.

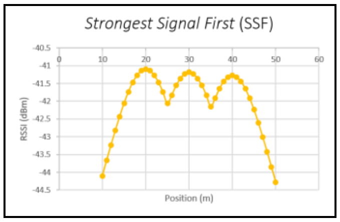

Fig. 8. RSSI received in all stations in SSF mode

In SSF, the association result for every station (also termed as user equipment or UE) is presented in *Fig. 8*. By comparing it with the possible acquired RSSI value depicted in *Fig. 5*, it can be concluded intuitively that in SSF, every stations associate to the AP that gives the highest level of signal strength. As soon as the neighboring AP yields higher RSSI by at least 0.1 dB, stations change associations from the current AP to the neighboring AP. For this scenario, handovers occur at two points, x=26 m and x=36 m.

In both LLF and Extended-LLF, more than one type of association is present in the network. Several stations share the same type of association while others follow other types of association. This is due to the load balancing mechanism that exists in the network.

In general, improvement in terms of RSSI value is accomplished in most stations. Several other stations experience similar RSSI level as LLF, with the exception of lower level of RSSI in a few positions.

For ease of analysis, association or RSSI graph in LLF and Extended-LLF is compared per UE. Therefore, there should be 10 pairs of stations to be analyzed. However, only three pairs are presented in this paper, i.e. UE1, UE2, and UE3, due to limited space.

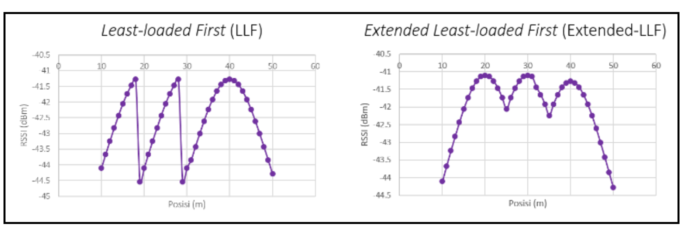

Fig. 9. RSSI graph of LLF and Extended-LLF in UE1

RSSI graph of UE1 for LLF and Extended-LLF is presented in *Fig. 9*. In LLF, RSSI value received by UE is not considered, shown by the handovers that occurs at x=19 m and x=29 m, which is in the condition where the current associated AP still gives higher RSSI value than neighboring AP. On the other hand, Extended-LLF averts handover when RSSI difference between APs is below certain threshold. This result in higher RSSI value received in the station. For this station, RSSI graph of Extended-LLF resembles that in SSF mechanism, giving it the highest level of RSSI among others.

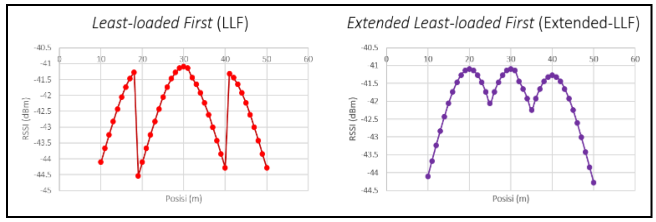

Fig. 10. RSSI graph of LLF and Extended-LLF in UE2

Similar result is also acquired for UE2, as shown in *Fig. 10*. In LLF, first handover occurs when current associated AP yields higher signal strength, resulting in lower RSSI level in the station after handover. For the second handover, station change its association to gain higher RSSI value. However, those acquired signal strength is still below the ones acquired in Extended-LLF, which UE2's RSSI graph is still the same as UE1's, giving the highest level of RSSI that can be acquired in the network.

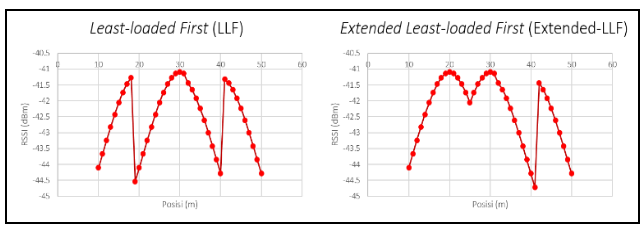

Fig. 11. RSSI graph of LLF and Extended-LLF in UE3

The RSSI graph of UE3 is depicted in *Fig. 11*. For LLF, UE3's type of association is the same as UE2's. In Extended-LLF, first handover at x=26 m is executed to gain higher level of RSSI by associating to neighboring AP, resulting in higher RSSI than that in LLF. However, in the second handover at x=41 m, it is found that the signal strength in Extended-LLF is slightly lower than those experienced in LLF. That is because at one point before that, which is at x=40 m, UE3 in LLF has already changed its association to AP3, gaining better RSSI.

At this point in the Extended-LLF experiment, there are 6 stations in AP2 and 4 stations already connected to AP3. The first condition in Extended-LLF algorithm as shown in *Fig. 3* (difference of number of stations is more than 2) is not met. This causes the second condition (the difference of RSSI is more than 0.1 dB) is also not checked, restraining stations to change association to neighboring AP. This situation, even if it is not considered to be very beneficial to the station, is required to maintain balanced load in the network. Nevertheless, the overall RSSI value in the station is still higher in Extended-LLF than in LLF.

4.3 Performance Comparison

In addition to observing the association and RSSI value acquired in each stations, performance measurement is also conducted to support the proof of concept of Extended-LLF. Measurements are made in one of the stations, streaming VoIP traffic to the H1 host. Distributed Internet Traffic Generator (D-ITG) program is used as the traffic generator while other stations act as background traffic by using Iperf.
In this study, UE3 is the station to be compared between the three mechanisms. This is because UE3 possess the most distinct type of association which is occurred in none of SSF nor LLF as the existing mechanisms. In other words, measurements are made on the station whose trait is specific to Extended-LLF.
Based on the tests performed, Extended-LLF mechanism yields better performance compared to LLF as its parent in terms of jitter, throughput, and packet loss by 6.69, 0.04, and 0.38% respectively. This improvement can be attributed to the higher RSSI value obtained by stations while still maintaining the principle of load balancing. However, there is a decrease in performance in terms of delay by 0.85%. This is due to the additional process that needs to be done to calculate the RSSI value in the network system.
Compared to SSF, Extended-LLF mechanism yields improved performance in terms of delay, jitter, and throughput. This is due to the principle of load balancing performed on Extended-LLF. However, there is a decrease of performance in terms of packet loss by 5.86%. The test results are summarized in *Table 1*.

Table 1: Performance of Extended-LLF compared to LLF and SSF

Metrics	Result of Measurement			Improvement of Extended-LLF	
	Extended-LLF	LLF	SSF	over LLF	Over SSF
Delay (ms)	0.834	0.827	0.989	-0.85%	18.58%
Jitter (ms)	0.36	0.38	0.41	6.69%	13.46%
Throughput (Kbps)	44.10	44.08	44.07	0.04%	0.05%
Packet loss (%)	2.40	2.41	2.26	0.38%	-5.86%

5. CONCLUSION

Extended-LLF is a proposed algorithm that aims to improve the existing association control currently supported in SDN wireless network emulator, Mininet-WiFi, namely SSF (Strongest Signal First) and LLF (Least-loaded First). The idea of Extended-LLF is to add RSSI as one of the considerations to perform change of association in load balancing mechanism. Hence, higher RSSI value can be obtained by stations while keep balancing the load between APs.
In terms of association, Extended-LLF in the emulation scenario yields higher RSSI value in most stations than LLF. In terms of performance, Extended LLF in the experiment provides an increase over LLF on jitter, packet loss, and throughput by 6.69, 0.38, and 0.04 percent, respectively. However, declined performance is found in terms of delay by 0.85 percent. Compared to SSF, Extended LLF results in better performance in terms of delay, jitter, and throughput by 18.58, 13.46, and 0.05 percent, but with performance decrease of packet loss by 5.86 percent.

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