Effective Handover Process for Reliable Video Streaming Over Software-Defined Wireless Networking

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Abstract. Handover process plays a crucial role in a Wireless Local Area Network (WLAN) with multiple Access Points (APs). To meet Quality of Service (QoS) or Quality of Experience (QoE) requirements for end-users, especially during video transmissions, such as real-time multimedia streaming or VoIP, the time required for handovers from one AP to another AP should be highly efficient; otherwise, end users may likely experience packet losses or longer delay, which leads to loss of significant information and degraded QoS/QoE. This paper discusses handover mechanisms using Software Defined Networking (SDN) for AP selection in a WLAN. The proposed approach enhances the existing handover process by considering both the received signal strength and load balancing of APs in order to provide better QoS/QoE during video transmissions over a Software-defined WLAN with multiple APs. A number of experiments have been performed using the Mininet-WiFi environment and the Ryu SDN controller. The results show that the proposed method improves QoS/QoE with lower delay, higher transmitted bytes, and visually higher quality video images.

Keywords: Software-Defined Networking (SDN) · Wireless Local Area Network (WLAN) · Handover · Video streaming · Received Signal Strength Indicator (RSSI)

1 Introduction

Cisco has predicted that 82% percent of the Internet traffic would be IP video transmissions by 2021 in a recent survey [1], especially mobile devices such as smartphones would become most end-user devices or host stations for the Internet video traffic. Although 5G, 4G and 3G wireless technologies are in trend for mobile radio communications, Wi-Fi is still highly popular. Wi-Fi is standard IEEE 802.11x media access protocol that is widely used in Wireless Local Area Network (WLAN), especially in schools, universities, buildings, apartments, public transport stations and places where people gather.

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Wi-Fi is more preferable for indoor communications compared to 3G or 4G technologies because of its download and upload speed, bandwidth usage and cost-effectiveness.

In a large WLAN environment where multiple Access Points (APs) exist, handovers of mobile terminals (MTs) from one AP to another AP are common for user mobility. A handoff is a process where a mobile terminal (MT) disassociates from currently connected AP and then associates to another AP whenever the MT moves away from the current AP or when the current AP highly congested. It is a standard and well-established technique that in normal conditions may require a few seconds to complete. For simple applications, such as web browsing and email, it works smoothly and as expected. However, for delay-sensitive applications, especially real-time video streaming and Voice over IP (VoIP), a few seconds may compromise Quality of Service (QoS) and/or Quality of Experience (QoE) by introducing undesirable delay, jitter and packet losses which is unreliable for the communication [2].

The AP from where the MT gets disassociated is known as Source Access Point (SAP) and the one with which it gets associated after handover is known as Target Access Point (TAP). The standard handover mechanism of IEEE 802.11x introduces handover delay of 2 to 6 s which is undesirable for video streaming applications [3]. Moreover, as a new MT is connected to an AP which is already to a number of MTs, throughput for each MT becomes even lower. Hence, it is important to distribute load among other APs, if possible, in order to achieve high throughput for each MT, especially for video transmissions [4].

The connection of MTs to a nearby AP typically is based on the Received Signal Strength Indicator (RSSI) value in Wi-Fi networks. However, as the number of MTs connected to AP increases, the may AP become overloaded and balancing of data throughput to each MT becomes difficult. One mitigation to this issue is that AP shares load with neighbor APs within the network through the handover process. The handover also happens when an MT exits one AP's radio range and enters the region of other's radio range. The crucial point in the handover process is how fast the handover process can occur so that mobile users or MTs can have low delay, i.e., in *msec*, particularly for Multimedia transmission, so that it can achieve reliable communications by providing high throughput, low delay, low contention on each AP. Moreover, it provides the opportunity to select multiple communication paths for data transmission.

Video streaming is one of the main services which could be affected by the handover transition and MTs encounter increased freeze time for the video which eventually distress the QoS/QoE [5]. The main challenge is to load balance among MTs by maintaining higher RSSI values, and less freeze time and delay.

The proposed method in the paper uses Software-defined Networking (SDN) solution. Since the SDN controller has full information for the entire network topology, it can control the flow of data through network switches based on the network configuration and traffic conditions. In the case of WLAN, SDN can assist and control the connection of MTs connected to APs during handover. The paper presents:

- An enhanced handover process by considering both RSSI and the load balancing of APs for handover decision with the SDN controller in order to improve QoS/QoE during video steaming for WLANs.
- A performance comparison using various algorithms, including IEEE 802.11 b.

We have conducted a number of experiments using Mininet-WiFi, Ryu SDN controller [24], and other related tools. The results show that our proposed handover mechanism reduces delay, increases the number of transmitted bytes, and higher visual quality.

The rest of the paper is organized as follows. Section 2 highlights the background information and related work. Section 3 presents the design and implementation of the proposed approach. Section 4 presents some experimental results using the SDN environment. Section 5 describes the conclusion and future directions.

2 Background and Related Work

2.1 Handovers in WLAN

Substantial research has been conducted to improve QoS and shorten low latency during the handover process in the field of wireless. However, some major challenge still exists for handover delay for live video streaming. Since the demand on live video streaming is increasing rapidly, handovers and load balancing among APs for WLAN becomes challenging to provide uninterrupted video streaming services to the end users. Specifically, there is a requirement to provide low handover delay and to perform load balancing among APs in order to provide better QoS/QoE to the end users.

Most of the current solutions to handover process improvement either lead to major change in the standardized wireless protocol during adaptation or focus on standalone changeover such as only in scanning, IP configuration, Authentication related to Association. (See Sect. 2.2 for a description on those tasks.) In order to reduce the scanning delay, various papers proposed algorithms to scan certain channels and avoid the entire set of channels to scan for selecting a best channel for the wireless connection hence scanning latency can be reduced [7–9]. In [7], the author proposed a method to inform the stations about the neighboring APs to scan before the handover process starts. The author in [8] proposed an adaptive algorithm in the scanning phase based on the use-case requirements. In [9], the author proposed a method to reduce the scanning time based on IEEE 802.11 standards by utilizing White-Fi channel space.

The above-mentioned methods lack concentrating on the other factors during handover, such as load balancing and distribution of stations. The authors in [10] explained a handover method to load balance among APs by utilizing SDN. However, the approach does not pinpoint the delay during scanning and authentication during the handover process.

The authors in [11] discussed multi-connectivity design with one or more APs in order to reduce handover cost because of network densification. However, the approach does not address challenges faced and latency introduced in handovers.

In [12], the authors discussed about optimizing the handover performance in 5G heterogeneous networks by utilizing cloud server to calculate the Congestion Window (CWND) values which is collected from wireless access networks. Chi et al. [13] presented a technique for fast handover which concentrates on the mobility of inter-area where MTs visit another domain which is monitored by its associated radius server. The researchers in [14] discussed about 5G wireless networks that co-exist with 4G networks by deploying small cells in large amount of ultra-dense networks. Due to the increased number of handovers, mobility management becomes difficult and the proposed approach mitigates the degradation of handover performance based on the fuzzy self-optimization algorithm for the enhancement of the handover control parameters.

The aforementioned approaches cover certain aspects of the handover process, but some parameters or the metrics are not in the consideration. Some methods are difficult to achieve in the real world, some are inconvenient for deployments and certain implementations are not open source. In order to cover wholesome from the AP selection to handover transition latency and complete load balancing of the adjacency APs, this paper proposes to implement a non-proprietary, non-vendor specific, standalone handover method which lessens the latency and improves the overall handover process in order to enhance the experience of high-speed video transmission.

2.2 IEEE 802.11 Wi-Fi and Handover Process

IEEE 802.11 protocols work under MAC and PHY. It was first released in 1997, but a number of subsequent amends have been released since then [15, 16]. Some have still been introduced recently, which reveals its popularity in practice. For instance, the following highlight some recent developments and key features:

- IEEE 802.11u (2011): support pre-association discovery of service
- IEEE 802.11v (2011): include additional wireless network management features
- IEEE 802.11aa (2012): support audio and video high-speed streaming
- IEEE 802.11ac (2013): contain multi-user MIMO (multiple input multiple output)
- IEEE 802.11ad (2012): include very high throughput, up to 7 Gbits/sec for short-range communications
- IEEE 802.11af (2014), also known as Super-WiFi/White-Fi: cover TV spectrum and supports up to 568.9 Mbits/sec.

In a multi-AP WLAN environment, when an MT reconnects from one AP to another AP due to mobility or another reason, the Source AP (SAP) must transfer the station active connectivity to Target AP (TAP) by following a series of four handoff procedures [3]:

- **Discovery:** SAP starts by scanning the suitable APs which are in the range to connect. There are two methods of scanning, active scanning and passive scanning. Active scanning is preferred over passive scanning since passive scanning station has to wait and listen for beacon frames from all the channels to get control and timing information of the TAP. For instance, new IEEE 802.11 standards have multiple channels, e.g., 11 channels.

  For active scanning, an MT sends a probe request and starts probe timer, it waits for probe response till *minChannelTime* then it moves onto the next channel. If it receives probe response within that time, it keeps on receiving it until *maxChannelTime* then it moves onto the next channel and repeats the procedure. Scanning time for each channel takes 8 ms [19]. However, further reduction is required to reduce the latency during video streaming to improve QoS/QoE.

- **Authentication:** Only legitimate users are allowed to establish a connection with the TAP. Latency in this phase depends on the security standards defined in IEEE 802.11 protocols. IEEE 802.11r introduced fast handover transition [22] which has lower authentication latency, but still the authentication latency is 30–60 ms [13].
- **Key exchange:** TAP and MT undergo several key exchange mechanisms using a four-way handshake and generate the cryptographic keys which are exchanged and placed on connecting TAP and station. Further, SAP and TAP exchange Inter Access Point Protocol (IAPP) security information block related to the station [21].
- **Association:** Association phase reconnects the MT to TAP based on the configured associate factors such as RSSI, etc. When the MT trying to associate with the TAP which sends a reassociation request to the SAP. SAP then initiates an IAPP-Move Request frame to TAP [20].

2.3 Software-Defined Networking and OpenFlow Protocol

SDN has been developed as the predominant programmable network architecture. SDN decouples the software control plane from the forwarding hardware nodes such as routers and switches and runs the control software either in a local server or using cloud which controls several devices [4]. SDN allows network administrators to manage their network equipment in a flexible and efficient manner using external server software as a controller to communicate with and manage network switches [6] using standard OpenFlow protocol.

OpenFlow allows the SDN controller to program all the configuration and flows to the devices [17]. OpenFlow supports network administrators to partition forwarding traffic and control flows according to their requirements which ultimately allow better performance of the system. SDN allows traffic based on the flow entry configuration on the switch and it can be modified by the controller. Figure 1 shows the key modifiable parameters.

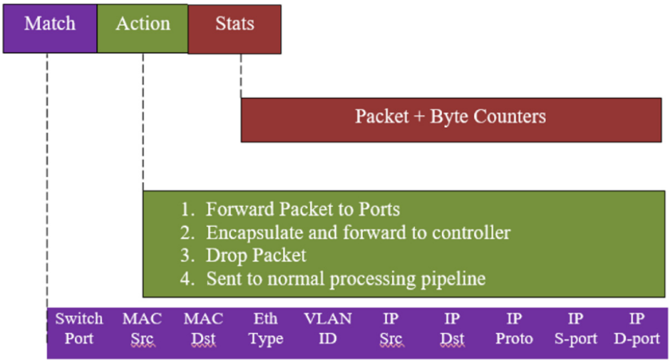

Fig. 1. OpenFlow protocol flow table entry [17]

Packets are forwarded by switches based on the entries in the flow table. The entries in the flow tables can be added, deleted and updated by the controller using OpenFlow messages [17]. OpenFlow switches keep a simple flow table than the ordinary switches. The OpenFlow switch flow table would consist of various flow entries and every flow entry includes six parameters. The Match fields include packet headers and ingress port that are used to match incoming packets to allow data. Priority in the Stats field is used for matching the preference of the flow entry. Counters in the Stats filed is used to count the matching packets. Instructions in the Stat filed provide a way to modify the action set and pipeline processing. The Stat Timeouts field sets the total time or idle time to live before the switch expires. The controller uses cookies to filter the flow statistics, change the flow and delete the flow [18]. The Match field supports 12 header fields and some of them are shown in Fig. 1. In this paper, programming the controller and APs has done based on the above parameters.

SDN can also be used to improve handover and load balancing in wireless networks [4, 10, 25]. It can retrieve workload information from APs and then make handover decisions based on the workload in the case of AP load balance-based handover. Accessing workload information inside APs would be difficult without SDN. Hence, it is considered as one of the main benefits of SDN in the handover process.

Hence, our proposed approach makes use of SDN and OpenFlow to program the controller and APs based on the RSSI information, traffic flow information and workload of APs for handover decision making with an aim to reduce the handover time.

3 Design and Implementation

This section describes the system design and experimental implementation. AP selection is a key step in handover. We have considered four different algorithms for AP selection based on RSSI, workload, and a pre-configured threshold value (see description in Sect. 3.1). Further, active scanning is adopted based on total interference factor [23] and IEEE802.11r for fast roaming is also adopted. The pre-authentication feature introduced in IEEE 802.11r together with the SDN controller are integrated for our proposed solution.

3.1 Proposed Design for AP Selection

Handover consists of four main phases: Discovery, Authentication, Key exchange and Association, as described in Sect. 2.2. Singh and Pandey [3] presented techniques in reducing the delay for the Discovery phase and the Authentication phase. The scanning feature used in the Discovery phase can impose high delay and is considered a performance bottleneck [7, 19]. The authors in [3] proposed to shorten the scanning delay by checking the scan cache associated with appropriate TAP, instead of scanning all the channels (14 channels for 2.4 GHz band and 40 channels for 5 GHz band). As a result, the number of channels needs to be scanned is reduced and hence the time it takes is reduced as well. The Authentication Latency can be reduced to eliminate re-authentication at the neighboring APs with the support of SDN controller [3].

This paper focuses on reduction of the Association latency and load balancing among APs to improve video streaming experience during mobility. Two main factors are considered in the design: RSSI and workload of APs. We investigated four algorithms for the Association mechanism for AP selection during the handover process [4, 10]:

- Algorithm 1: Strongest Signal First (SSF)
- Algorithm 2: Least Load First (LLF)
- Algorithm 3: Combination of LLF and SSF (LLF_SSF)
- Algorithm 4: LLF-SSF with a pre-configured workload threshold (LLF-SSF-T)

Algorithm 1 SST: RSSI is the most commonly used criterion for handover, which is also adopted in IEEE 802.11 standards. For this paper, SSF is still designed and implemented with SDN controller. The stronger RSSI value is, typically the higher the data rate is, if an AP is not overloaded. When an MT moves to overlapping coverage area of two or more APs, SSF considers all the APs that the MT can detect and chooses the one with the highest RSSI value. The method is conceptually simple, as shown in Fig. 2, since it is only related to the physical distance between an MT and an AP. Specifically, for our SSF, the Association phase occurs if a neighboring AP provides higher RSSI than the SAP by 0.1 dBm which is configurable value.

However, considering SSF only may cause congestion or unbalanced workload on some APs if many MTs are connected to those overloaded APs, which may still have neighboring APs that have low MTs connected. In other words, congestion may happen on some APs, but some neighboring APs may still be lightly loaded.

Algorithm 2 LLF: In SSF, an MT can get high-speed data rate by connecting to a nearby AP provided the AP is not overloaded. However, load distribution among APs in WLAN is also an important factor for the Association decision, as it may lead to data congestion and result in poor QoS/QoE if many MTs try to associate to the same AP which provides high RSSI value.

LLF considers only load balance situation, i.e., LLF emphases only on one association control parameter, that is the load of the APs, which is in the coverage area of a moving MT in AP selection decision. The AP load in this paper is defined as the number of MTs associated with an AP. More sophisticated calculation of workload can also be considered, e.g., CPU utilization and available bandwidth.

Since all APs are connected to the SDN controller. The controller makes the decision based on each AP's data path ID (DPID) table which is maintained in the control plane. The AP DPID tables in the controller provide the number of MTs connected to each AP. By looking at all the APs' DPID tables which are in the coverage area of requested re-association mobile station, the controller chooses a TAP that has the least load and changes the flow table in that AP for the requested MT and initiates re-association with the MT.

The flowchart for the proposed LLF algorithm is shown in the Fig. 3. As described in the flowchart, the SDN controller keeps track of the number of stations associated with each AP and identify the least loaded neighbor AP for handover decision making. If the SAP has higher number of connected MTs than the identified neighboring AP, then it dissociates a station from itself and the MT starts the association phase with the neighboring AP with a smaller number of associated MTs to achieve load balancing and ultimately avoid overloaded APs as much as possible.

Algorithm 3 LLF-SSF: LLF tries to achieve load balancing with the possible expense of weaker RSSI which affects the data rate and eventually maybe QoS/QoE for some

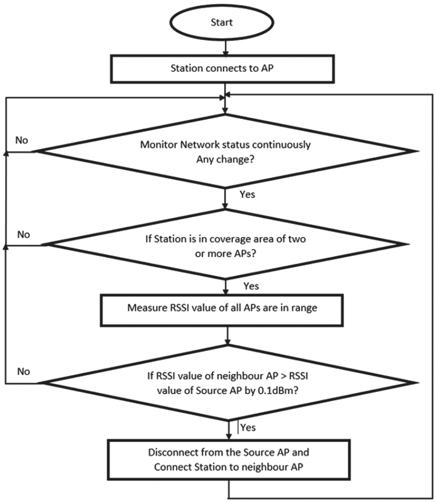

Fig. 2. SSF algorithm

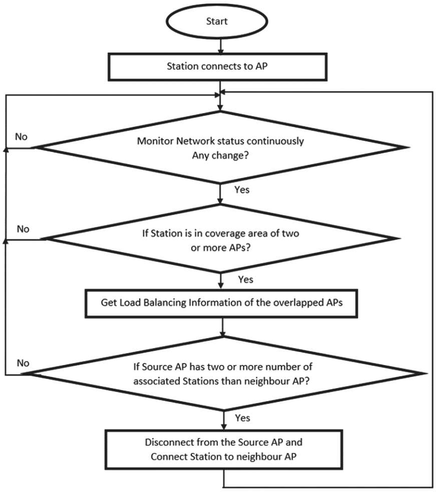

Fig. 3. LLF algorithm

MTs. LLF-SSF integrates SSF and LLF by making the association decision based on both parameters: RSSI value with the moving MT and the load of each AP in the coverage range. This leads to higher RSSI values and higher date rate, while maintaining load distribution among APs.

The flowchart for this algorithm is depicted in Fig. 4. When an MT moves at a random direction, its behavior is observed at every *msec*. The controller selects the best AP according to the proposed algorithm when an MT moves to overlapping region of APs. The controller then updates the flow table of the selected TAP.

Algorithm 4 LLF-SSF-T: This algorithm extends LLF-SSF by adding a third parameter – a threshold indicating the maximum number of MTs that can be associated with an AP. The threshold is introduced to put a limit on the number of MTs to associate with certain APs by configuration. The motivation is to improve load balancing and higher RSSI values and QoS/QoE for MTs. The threshold value used in the experiment is only for feasibility study. In practice, the value needs to be supported by careful network monitoring and planning. The threshold value is examined after checking the load balance condition, but before testing the RSSI condition as to ensure the association decision based on load first. Such a design of choice can make the RSSI values of some MTs higher than those values that have been obtained with LLF-SSF. Figure 5 shows the flowchart of the proposed algorithm.

3.2 Implementation

The proposed framework was implemented using Mininet-Wifi which is an advancement of Mininet emulator software tool for wireless network environment. Ryu controller [24] is used as a remote SDN controller in the control plane to allow traffic based on the applied

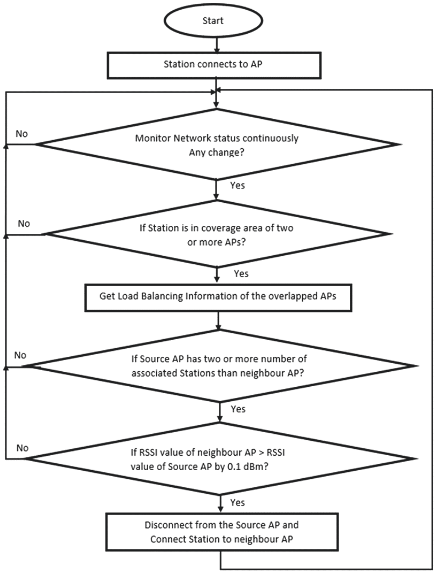

Fig. 4. LLF-SSF algorithm

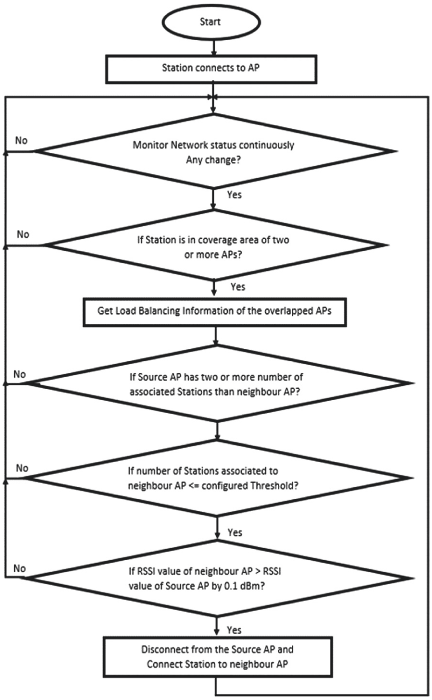

Fig. 5. LLF-SSF-T algorithm

configuration rules on flows and to manage network topology. OpenFlow protocol is used between the control plane and the data plane. Figure 6 represents the high-level block diagram of implemented architecture. SDN mainly has three components, Data Plane at the bottom level, Control Plane at the middle level and Application Plane at the top level.

During the handover process, selection of AP is one of the critical decisions because if the stations are mobile and streaming live data (such as video), and if a poor-suited AP is chosen, for example weak signal strength, less bandwidth and low coverage area, then MTs experience poor QoS and congestion during roaming. Hence, AP Selection is one of the main design criteria.

Data Plane: All the configuration and flow control can be applied to the APs which is present in the forwarding plane so that APs allows MTs connectivity accordingly. MTs can move at random direction, hence the algorithm should be independent of the mobility.

Control Plane: The control plan contains the centralized SDN controller which monitors and retrieves the states of the network continuously such as MTs' positions, load status of each AP, radio-signal related data, i.e., RSSI of all MTs and then use such information to decide whether an MT needs to associate to another AP based on RSSI or load status.

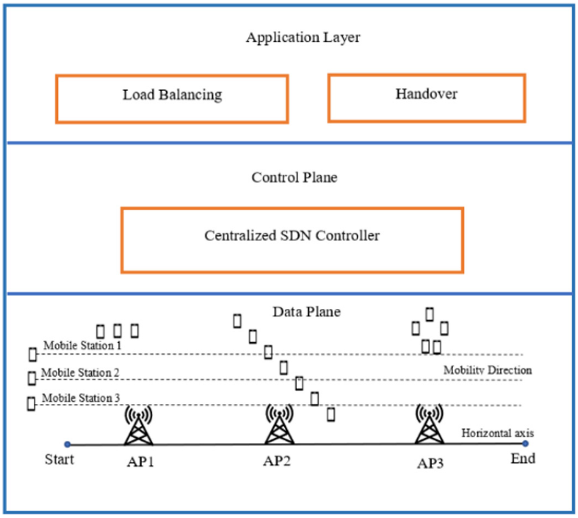

Fig. 6. High level block diagram of implemented architecture

Application Layer: The application layer contains load balancing and handoff services running above the SDN controller configured accordingly for the authentication server, neighbor list manager, topology service manager and IP mobility manager.

Experiments for handover mobility scenarios have been set up, which is described as follows:

- Figure 7 presents the emulated network topology where x and y axes indicate the distance in meters. There are three horizontally aligned APs with coverage areas: AP1 = 40, AP2 = 50 and AP3 = 90. These three APs are placed in such a way that their coverage areas overlap with a neighboring AP to observe handover as the MTs move through the ranges of the APs at the same speed.
- Eighteen stations are used, in which AP1 contains five stations that are stationary, fixed in one place. Seven stationary stations are associated to AP2 and five stations interact with AP3 which are stationary as well. Stations are distributed unequally to three APs to get more accurate results in wide range of load balancing scenarios which affects video streaming as well.
- All three APs are connected to a switch. A host in Mininet-WiFi is configured as the video server that is connected to the switch. The switch and the video server are not shown in Fig. 7.
- The remaining three stations S1, S2, and S3 are MTs which move simultaneously along the x-axis at the same speed starting at x = 0 m and ending at x = 290 m in order to compare four handover algorithms.
- Also, S1, S2 and S3 are data receivers from the video server across APs. APs send special notifications to the controller to associate and disassociate with those MTs.

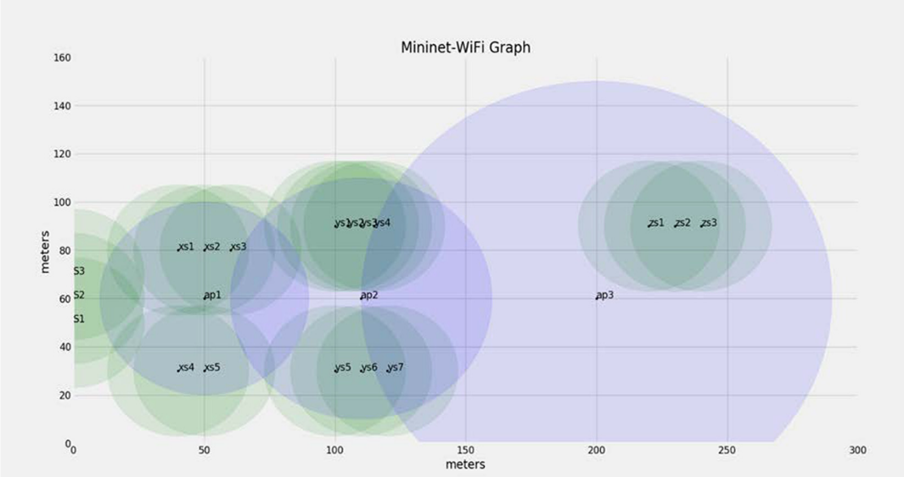

Fig. 7. Network topology used for experiments

IEEE 802.11ax was adopted for better results. Path loss was set to 5, the default value configured in Mininet-WiFi. Channels 36, 40 and 44 have chosen for different APs, i.e., a different channel has been selected for each AP to avoid interference between APs. Other important parameters used for experiments are listed in Table 1.

Table 1. Configuration parameters used in Mininet-WiFi

Access point	OVSKernelAP/UserAP
Mode	IEEE 802.11ax
Channel	1–6, 36–255 (varies for each mode)
Propagation Model	Logdistance/friis/twoRayGround logNormalShadowing/ITU
ac_method	ssl/llf
Authentication parameters Encrypt, passwd	WPA/WPA2
bgscanning parameters bgscan_threshold, s_inverval, l_interval	Threshold in dBm, interval in seconds

In addition, *bgscan* module and 802.11r are used to reduce scan and Authentication latency in Mininet-WiFi. IEEE 802.11r provides an equal amount of handover delay provided by LTE (i.e. 50 ms handover duration). Background scanning using *bgscan* module was utilized to roam within ESS in which all APs have the same SSID. *Bgscanning* is enabled for three moving stations in which *bgscan_threshold* represents whenever station reaches −60 dBm RSSI value AP starts scanning for the reassociation. *s_interval* indicates short time interval which was set to 5 s and *l_interval* indicates long time interval set to 10 s.

To reduce scanning latency, available channels are selected for data transmissions without scanning all the channels in every AP which is implemented in the code. To reduce authentication latency, WPA2 with 4-way handshake and IEEE 802.11r with background scanning is enabled. This was implemented during the handover process.

4 Experimental Results

Live video has been streamed using VLC media from the video server to moving stations or MTs which were emulated as data receiver just like smartphones/client using VLC media server by providing IP address and port of the video server. When the MTs start moving from AP1 to AP3, they receive live video continuously until the video transmission completes. During this time, handovers occur from AP1 to AP2 and AP2 to AP3 as expected. However, at which point handover happens depends on the proposed algorithms.

We have evaluated four aforementioned four algorithms for the Association phase for AP selection. The techniques used for the other three phases were identical for all experiments. Three performance metrics were used for evaluation:

- Signal Strength: The signal strength for the moving stations were measured.
- Delay: Delay is measured for the handovers. Higher the delay, lower the QoS/QoE.
- Transmitted bytes: Total transmitted bytes are captured. The values indicate the amount of data received at stations. This metric is highly related to packet delivery rate (PDR) that is often used for performance evaluation. The higher the number, the less packets have been discarded, which has direct impact on QoS/QoE.

As stated, three stations, S1, S2, and S3 were configured as MTs for evaluating handovers. Each experiment was repeated three times for each of the four algorithms. The average values obtained from the three runs were calculated for the final results. In addition, data have been collected for each of those three stations for video streaming from the server. Figure 8 depicts the results for signal strength for moving station S1 for all four algorithms, Fig. 9 shows the results for S2, and Fig. 10 presents the results for S3, respectively.

As shown in those figures, there are three peaks in each result, which indicates the RSSI value as a station moves along APs. RSSI increases when an MT is moving closer to another AP. As depicted in those figures, RSSI values are mostly higher for SSF for all three stations, S1, S2, and S3 compared to other three algorithms. In comparison of SSF and LLF, the average RSSI values are either similar between these two algorithms or higher for SSF, as RSSI is the sole consideration for SSF for handover decision. SSF mostly is used in IEEE 802.11 standards.

Unlike SSR, in LLF, handover happens when a station enters the overlapping region of two APs and chooses the least loaded AP for association. In the setup, AP1 has 5 stations, AP2 has 7 stations and AP3 has 3 stations. When these three mobile stations (S1, S2 and S3) move closer to the neighboring AP, e.g., in AP1–AP2 overlapping region, 3 stations are associated to AP1 as much as possible, because AP1 is less loaded compared to AP2. As a result, handovers from AP1 to AP2 occurred later for LLF. When MTs continue moving, they associate to AP3 as soon as they enter the AP2–AP3 overlapping region, since AP3 only has 3 stations. Hence, we can see in the figures that generally there is not steady increment and decrement of signal strength apart from AP1 due to immediate change in APs handover, as LLF is designed to equally distribute load among APs.

LLF-SSF is similar to LLF, since the load of APs has higher precedence over RSSI in the method. There is generally a smoother curve for LLF-SSF in the graphs after the first handover in comparison to that of LLF.

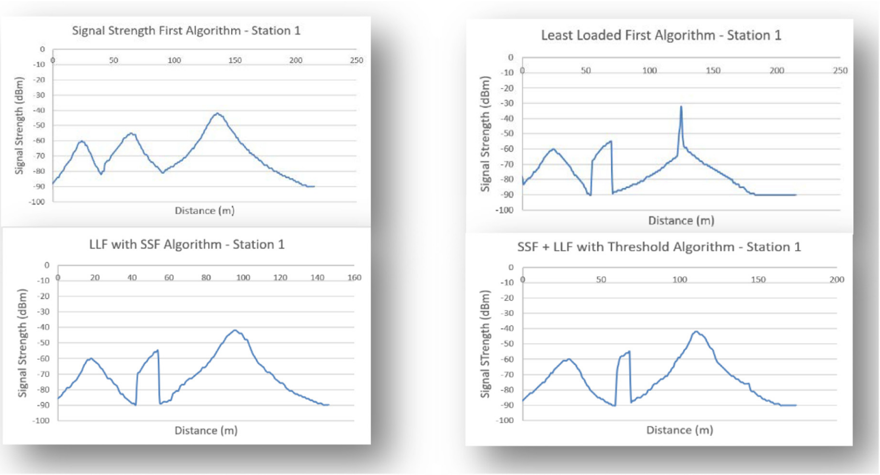

Fig. 8. Signal strength results for S1 for four algorithms

The result from LLF-SSF-T is similar to that of LLF-SSF. However, since a threshold is introduced on the allowable number of connected stations to AP, mobile stations when moving away from AP1 generally are associated with AP2 slower in time. Also, the effective coverage area of AP2 becomes smaller due to the fact that the handover from AP2 to AP3 happened earlier even though RSSI was considered because of the threshold condition. Hence the load in both APs becomes more balanced. From this method, video streaming quality would be better when there is a high number of video streaming stations, as it tries to maintain good signal strength and available bandwidth.

Moreover, we also evaluated the delay impact for the proposed LLF-SSF-T method and IEEE 802.11b that does not use the SDN controller. As stated earlier, the SSF presented in this paper is very similar to IEEE 802.11 standards, except SSF was still implemented with the SDN environment. Wireshark was used to capture data traffic. Figure 11 shows that there is lower latency (50–60 ms handover delay observed for the proposed LLF-SSF-T handover method compare to IEEE 802.11b experiment which has nearly 4–7 s handover delay, e.g., from ~43 s to 50 s for the handover process.

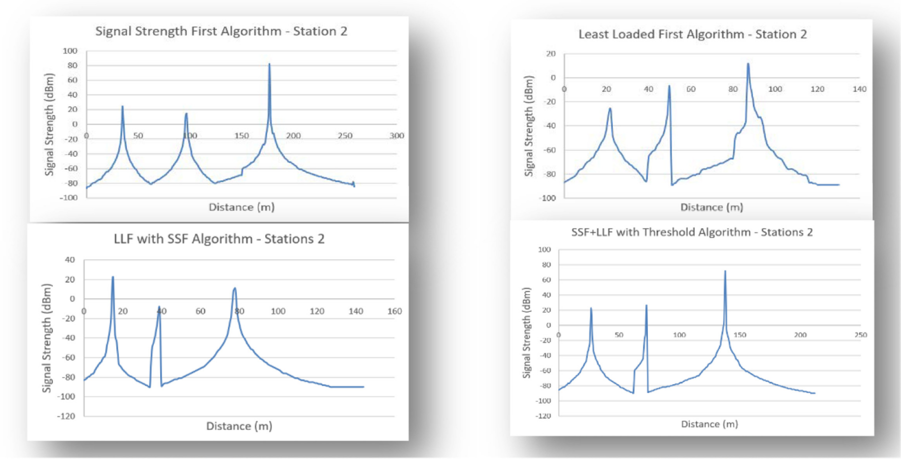

Fig. 9. Signal strength results for S2 for four algorithms

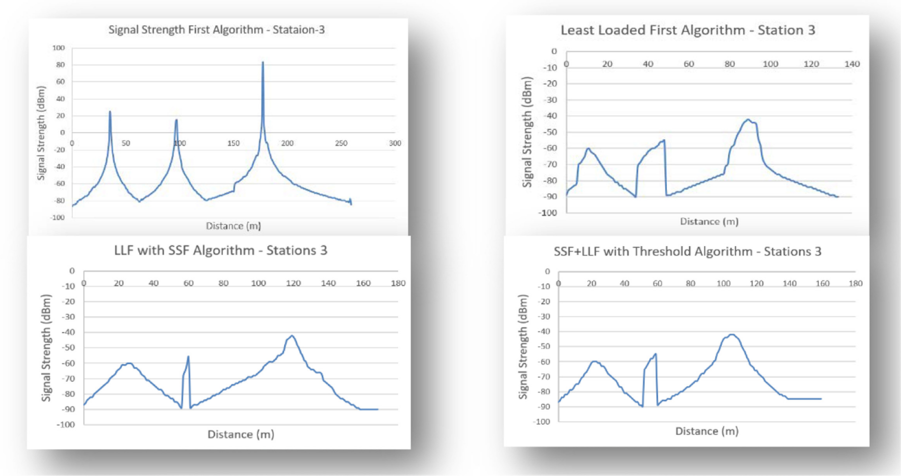

Fig. 10. Signal strength results for S3 for four algorithms

The number of transmitted bytes (y-axis) which is closely related to commonly used PDR, is much higher for LLF-SSF-T method than that of IEEE 802.11b for the entire experiment period. The higher delay for the handover periods is highly related to the result.

In addition, video quality has been observed and compared visually for both IEEE 802.11b and the proposed LLF-SSF-T. Fig. 12 illustrates three examples of results from two methods. The left column shows for results obtained from IEEE 802.11b and the right column shows images for the proposed LLF-SSF-T. As we can see visually, there is improved quality observed in the proposed method compared to that of IEEE 802.11b.

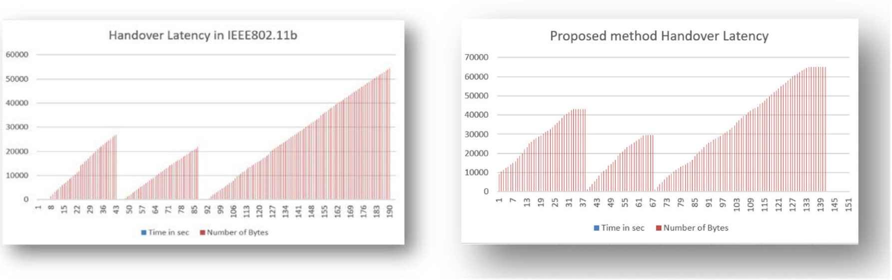

Fig. 11. Comparison of delay and transmitted bytes for IEEE 802.11b (left) and the proposed LLF-SSF-T (right) method.

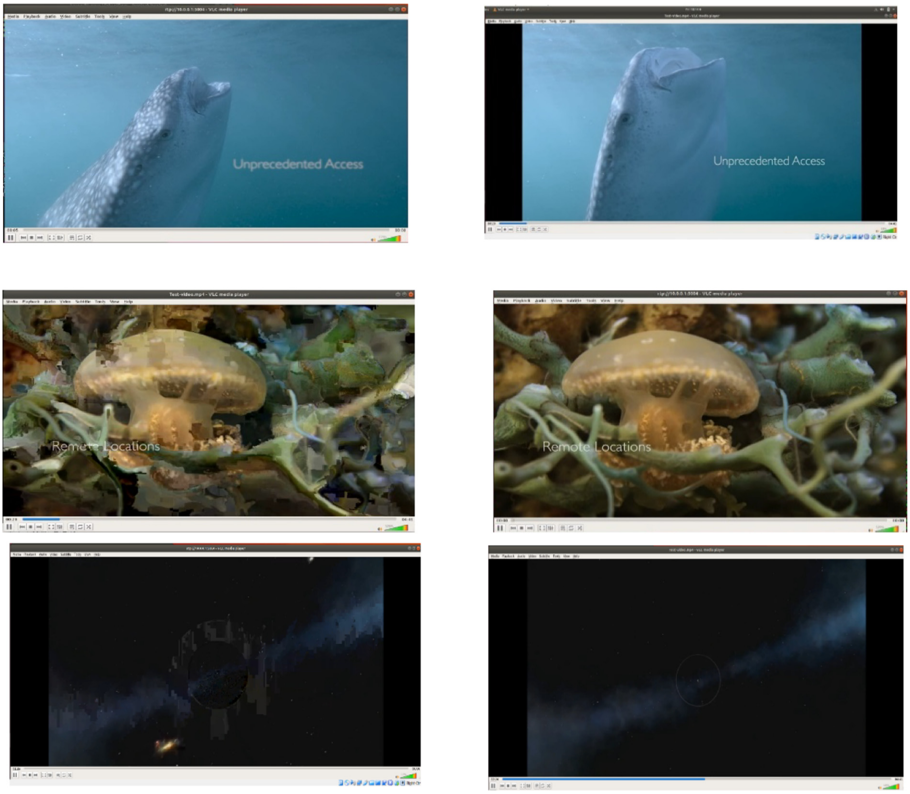

Fig. 12. Visual comparison of video quality for IEEE 802.11b (left) and the proposed LLF-SSF-T (right): an illustration.

5 Conclusions and Future Research

The paper presented SDN-based handover process for video streaming over SDN-based WiFi. The simulation was built with Mininet-WiFi, OpenFlow protocol, and the Ryu

SDN controller. The emphasis of the simulation evaluation was on the Association phase for handovers. We evaluated four SDN-based algorithms that could be used to improve QoS/QoE or the overall system performance. Further, all the algorithms are compared in terms of performance and quality of video streaming using VLC.

The results obtained from a number of experiments demonstrated that the proposed handover methods in WLAN with the use of SDN improves the performance of video streaming by reducing handover latency compared to standardized wireless protocol handover latency. This solution is also independent on external network elements such as modifying in APs or at the end MTs. SDN locally handles the changes which effect on mobility of the MTs to improve seamless video transmission.

Several research directions can be further investigated. Some areas include: (i) increase the number of stations, MTs and APs for performance evaluation; (ii) vary the speeds of MTs and switching rates for handovers; and (iii) consider network caching for the experiments and QoS/QoE evaluation.

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