A new SDN-based load balancing algorithm for IoT devices

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Article Info	ABSTRACT
	Nowadays, the emergence of the Internet of things devices has wholly revolutionized the customer's communication habits. The information can be collected at any time and anywhere. However, the mobility of communication devices in a dense network results in several problems, such as unbalanced network load and increased bandwidth demands, which decrease the network performance. To deal with these issues, this paper proposes a new load balancing algorithm based on the software-defined Network to enhance the performance of mobile devices communication over a Wi-Fi network. The use of the software-defined network automatizes the configuration of the network through a centralized controller; it provides programmability and an overall view of the network, along with optimizing resource allocation based on real-time network information, which facilitates the implementation of our algorithm. The proposed algorithm is implemented and evaluated through simulation using mininet-WiFi. The results indicate that our proposed method provides an efficient network load balancing and improves performancdevices' performance.

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1. INTRODUCTION

Internet of Things (IoT) [1], or in a broader sense, Internet of Everything (IoE), is a relatively recent concept. It is considered a significant technological and economic innovation in new information and communication technology. IoT is defined as an expansion of today's internet to all devices that can directly or indirectly communicate with electronic devices that are connected to the internet. Many heterogeneous devices (telephone, computer, watch, refrigerator) are now widely used in everyday life. Figure 1 shows that the most commonly used IoT architecture comprises three layers: the perception layer, the network layer, and the application layer.

With the exponential development of these connected devices with heterogeneous characteristics, future networks must evolve towards new architectures to adapt to the increase in traffic load, ensure security, and improve service quality, especially in mobile devices. The standardized communication protocols used for IoT, such as 802.11 standards [2], do not offer native mobility management or load balancing mechanisms. In a traditional Wi-Fi network, the re-association process between APs and nodes is based on the RSSI (Received Signal Strength Indication) [3]. This can lead to an unbalanced load of the different access points, especially when moving within the network, the mobile node may connect to an overloaded access point. Besides, the authentication process between the node and the AP during the re-association is a time-limited phase. If this delay is exceeded, a loss of network connection occurs. These limitations may result in degradation and reduction of applications running on IoT device's performances.

In this context, developing efficient solutions for load balancing is an excellent necessity for better performance. In [4], the authors propose a new algorithm based on the subgradient method, called Congestion-Optimal Wi-Fi Offloading (COWO), to achieve the ideal offloading ratio for the different access point to ensure maximized throughput and minimizes the traffic congestion. In [5], a new architecture is presented for a seamless handover and a better load balancing using SDN. The authors provide a solution to minimize data propagation delay through the earlier publication of the OpenFlow table. Using a theoretical model, the authors in [6] introduce a new inter-BSS handoff scheme for the Wi-Fi network where the mobile nodes switch from one AP to another in an overlapping area, especially when detecting a performance degradation. An interleaved scanning mechanism is conceived to identify the alternative APs in the proximity of a mobile node. Authors in [7] propose a cell breathing technique for load balancing in WLAN, especially the Wi-Fi network, to prevent network traffic congestion and APs saturation. Two algorithms are used to minimize the load of the loaded AP(s) in the network, and the second generates an optimal load-balanced solution. In [8], LABERIO is presented to solve the load imbalance issue caused by the loading failure in the middle of traffics' transmission. To evaluate the packet transmission path and adjust the ways to achieve load balance dynamically, authors in [9] use the Fuzzy Synthetic Evaluation Mechanism. Authors in [10] propose to distribute the load by implementing an algorithm based on a round-robin. The simulation results show that the proposed method's response time gives better results than the random load balance. The authors in [11] implement a load targeted handover (LTH) scheme to enhance mobility management by offering a seamless handover and balance the load by a targeted association with less loaded APs. In [12], the authors used a method based on the server response time; the server with the most stable response time is selected to ensure network load balancing. Authors in [13] propose a two-tier dynamic load balancing solution for the SDN-enabled Wi-Fi network is presented; this method allowed the controller to estimate the load balancing degree among the different APs and determine until which load level the APs can accept association requests without consulting the controller. In comparison, in our paper, we can ensure good mobility management using the SDN controller and balance the network load using our load balancing algorithm.

In recent years, the introduction of Software-Defined Networks (SDNs) has introduced new technics for enhancing network and communications management [14]. SDN is considered a significant innovation for more efficient management of connected devices and can meet the IoT's current needs for heterogeneity and flexibility. The SDN enables the separation between the control plane and the data plane and provides centralized control to facilitate the optimization and configuration efficiently and automated. It also accelerates the deployment of new services by responding dynamically to policy changes [15]. The use of SDN as a centralized architecture enforces SLAs by establishing a unified network that allows users to have an equitable experience regardless of their access methods; it also ensures interoperability between heterogeneous devices, which make it very suitable for IoT networks. All the cited enhancements enable us to provide better results by improving network quality for the IoT.
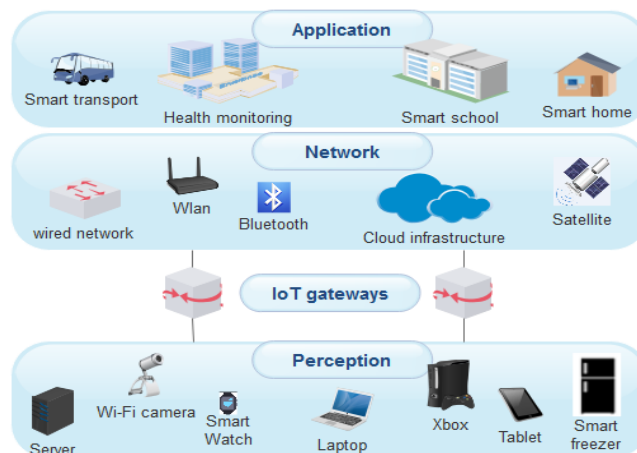

Figure 1. IoT architecture

In this paper, we propose a load balancing algorithm based on SDN for enhancing the performance of mobile IoT devices communication over a Wi-Fi network. Our objective is to highlight the contribution of deploying SDN for managing the high traffic load generated in an IoT architecture and improving network

performances by enhancing the throughput of the different APs, reducing the packet loss and the communication delay. We propose an extensive simulation using the Mininet Wi-Fi emulator to evaluate and compare the proposed approach's performance with the traditional network architecture using standard AP (Access Point). The rest of the paper is structured as follows. Section 2 introduces the proposed approach. Section 3 describes the simulation setup. Section 4 provides the simulation results and discussion, while Section 5 concludes the paper and offers suggestions on future researches.

2. PROPOSED ALGORITHM

Several technologies can be deployed for connecting IoT devices at the physical level [2, 16-19]. The new 802.11ax standard [20] is considered the most suitable standard for IoT, allowing high throughput and reducing the connected devices' energy consumption. One of the significant challenges in implementing the Wi-Fi network is mobility. Most mobile devices need to be connected to the services they want at all times while moving; the interruption of these services can occur when they move from one access point to another. In a traditional Wi-Fi network, the association process between APs and nodes is based on the RSSI; this can lead to an unbalanced load of the different access points. The mobile node may connect to an overloaded access point, especially when moving within the network. This process has a significant impact on the performance of the entire Wi-Fi network.

In this article, we integrate SDN technology to improve both mobility management and network load. Through the separation of the control plane from the data plane, the SDN makes the network's automatic configuration via the controller and allows efficient management of scalability and mobility of the equipment, as we demonstrated in our previous work [21]. The centralized controller also provides programmability, a global view of the network, and optimizes resource allocation based on real-time network information that helps implement rules and algorithms to optimize Wi-Fi network performance.

In the proposed algorithm, the controller collects information such as AP capacity, current load of APs, the distance separating different APs, and the lists of devices associated with each AP. This information helps the controller to calculate and deduce the best AP for the new associations. When a device enters an overlapped area, it broadcasts probe request messages; the targeted AP collects the connected devices' information within this message and sends it to the controller. The controller can refuse or accept the association's request of the connected devices to the specific AP based on the collected information. The controller will redirect the device to another AP if the targeted AP is overloaded. The OpenFlow switches reside in the access points; they are responsible for the mobility management of the tools and the exchange of OpenFlow messages with the controller via the OpenFlow protocol [22].

As shown in Figure 2, when a mobile device is entering an overlapping area, it will be associated with an AP based on the RSSI. The controller will compare the load of this AP to a threshold. If it detects that this access point is overloaded, it checks the possibility of transferring the connected device to a neighboring AP (the less loaded AP). In this regard, we are working on the same process evoked by [23] by adding a significant step, adjusting each AP's transmission power according to their load. The controller sends a message (beacon frame) to the first AP to disconnect the device and adjusts the power of the other APs so that the less loaded AP's strength is higher than the power of other APs in the overlapping area. The disconnected device does not need a handshake message to connect to a new AP because its MAC address is already stored in the controller database. For no-mobile devices located in an overlapped area, the AP's association is also based on the strongest RSSI. The controller will accept the association requests if this AP is less loaded. Otherwise, the device will be redirected to another AP. This process is both fast and straightforward and will improve the network load and its throughput.
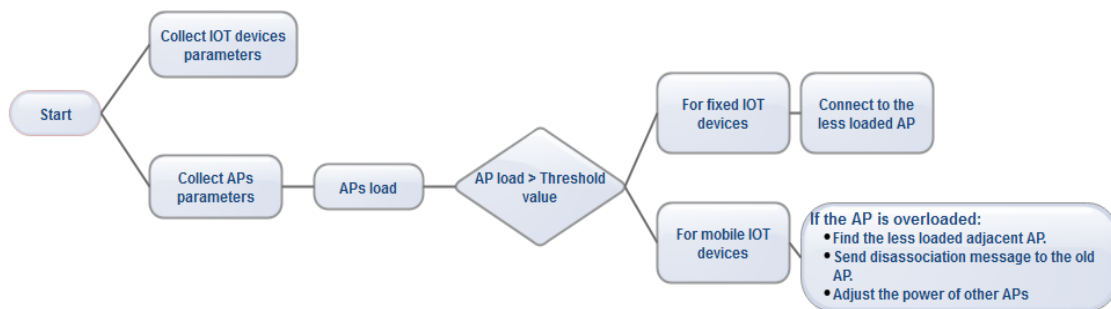

Figure 2. Description of the SDN-based load balancing algorithm

Figure 3 describes the association control message flow between mobile devices, OpenFlow enabled-APs, and the SDN controller. The APs are connected to the SDN controller via a secure channel. We suppose that the mobile device is located in an overlapping area covered by the three access points (AP1, AP2, AP3), and based on RSSI, it is connected to one of the three APs (for example, AP1).

a)   Step 1. When a device enters the overlapping area, it receives a beacon frame from the three APs and broadcasts probe request messages.

b)   Step 2. The APs reply with the probe response messages and report via the Packet-In message to the controller: their load value, association event, also the device information contained in the probe request.

c)   Step 3. The controller updates the APs' information periodically, checks the AP load and association events and runs the load balancing algorithm if necessary (AP load>threshold).

d)   Step 4. If the (AP1 load > threshold), the controller sends beacon-config messages (SetConfig message) to the AP1 to disassociate the device and adjusts the power of the less loaded AP in such a way to be higher than the other APs in the overlapping area.

e)   Step 5. The AP1 sends a disassociation notification to the device.

f)   Step 6. The same as step 1.

g)   Step 7. The device sends an association request to the AP with the high RSSI; once the device receives the AP's association response, the connection is established.

Setting the signal power values of the different APs according to their load (step 4) is crucial since it improves the association time between devices and access points, especially in mobile devices located in an area covered by more than 2 APs. Our algorithm is developed to allow the controller to configure the least loaded access points with the highest signal strength. In this case, the device will directly re-associates with the appropriate AP, and it will not waste time trying to connect to an overloaded access point and switch to another. This will optimize the association time, and thus the number of requests exchanged.
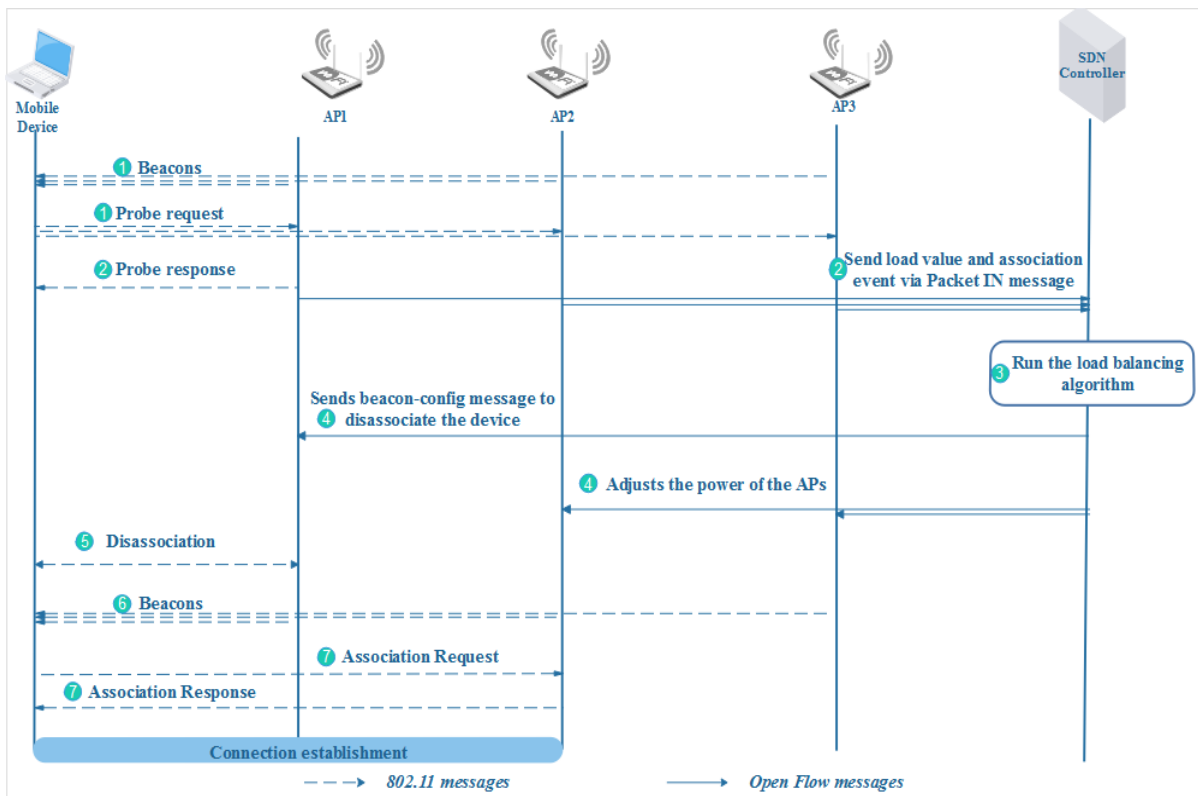

Figure 3. Message Flow for association using load balancing algorithm based SDN

3.   SIMULATION SETUP

The SDN architecture is a distributed design in which a centralized global controller is used to monitor other equipment's within the network. The application resides on the top of the SDN controller, as

illustrated in Figure 4, and it uses different interfaces to implement network services. Mobile stations are accessing services through OpenFlow-enabled APS, which are controlled by the SDN controller.
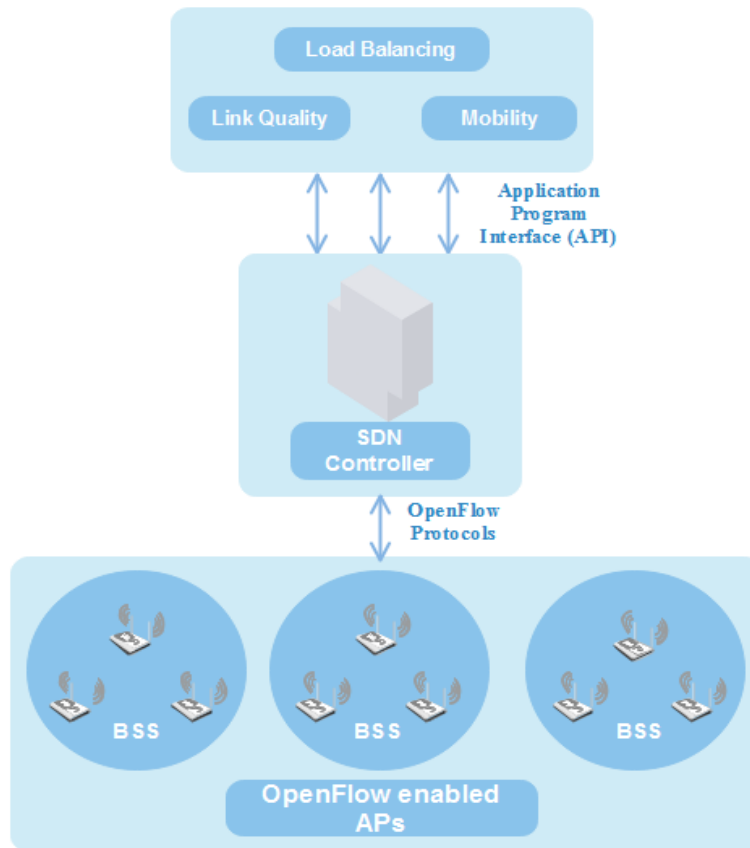

Figure 4. SDN-based

To simulate the wireless network scenario with SDN and to demonstrate the performance of our proposed method, we used: mininet Wi-Fi version 2.2.2 [24] running on Ubuntu 16.04, VMware software tool to run the virtual network, and Iperf [25] to generate TCP, and UDP traffic flows between the different devices [26]. The detailed simulation parameters are given in the Table 1:

Table 1. Simulation setup setting

Controller	RYU v4.27
Operating system	Ubuntu 16.04
Type of traffic	TCP, UDP
Packet size range	Min 1 Mb
	Max 50 Mb
APs	802.11 ax {AP1, AP2, AP3}
Tx power	{20 dbm, 20 dbm, 20 dbm}
SSID	{new-ssid1, new-ssid2, new-ssid3}
Mobility speed	1 m/s

As shown in the Figure 5, the three APs are set so that their coverage overlaps. Mobile and fixed stations represent the smart devices; each station is given a unique IP and Mac address. The whole topology is under the control of the RYU, an open-source controller, licensed by Apache 2.0, entirely written in Python, supported and deployed by Nippon Telegraph and Telephone's cloud data centers [27].
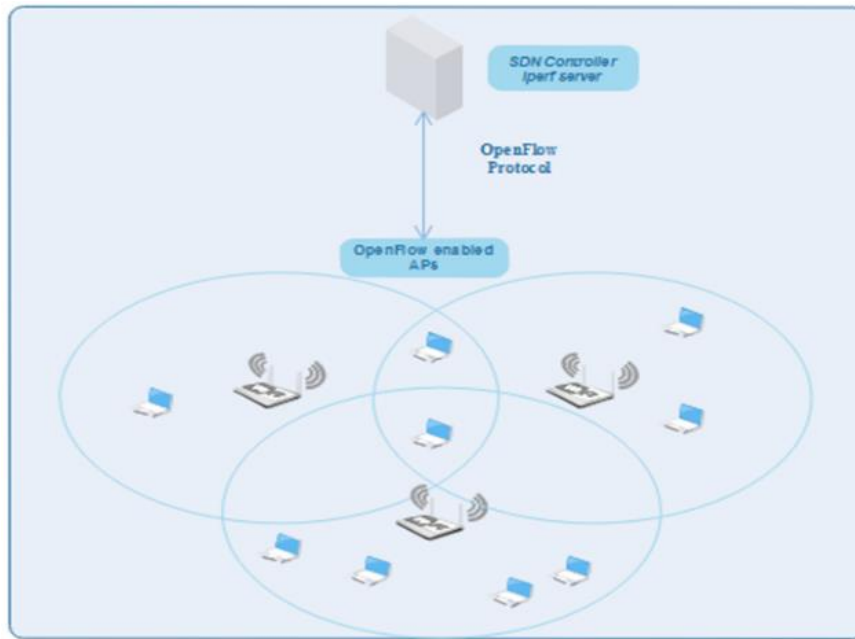
Figure 5. Simulated scenario

4. SIMULATION RESULTS AND DISCUSSION

Our first scenario includes 30 stations associated with three access points based on the RSSI value (traditional method), six stations are associated with AP1, 14 with AP2, and 10 with AP3. These stations exchange TCP traffic. Figure 6(a) presents the result of the first scenario and shows that the network load is unbalanced: the station connected to AP2 receives a lower throughput (51 Mbps on average) compared with AP1 (56 Mbps) and AP3 (63 Mbps). In the second scenario, we use the same topology, but with the implementation of our load balancing algorithm based on SDN, the results show that the network load is balanced and that the number of stations is equally distributed among the three APs, which improves the throughput in each AP as shown in Figure 6(b).
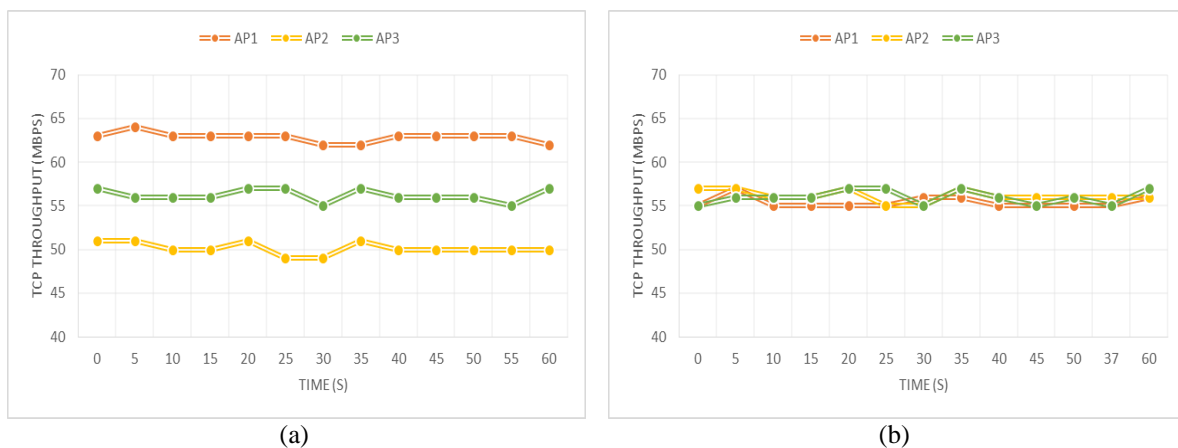

(a)	(b)

Figure 6. TCP traffic in traditional Wi-Fi network and when using the
load balancing algorithm based on SDN

To better evaluate the proposed approach, we decided to exchange UDP traffic and perform the same experiment with the same parameters. As shown in Figure 7(a), the stations connected to AP2 receives a low throughput compared with AP1 and AP3. After deploying our load balancing algorithm, the load is balanced between the three APs as shown in Figure 7(b).
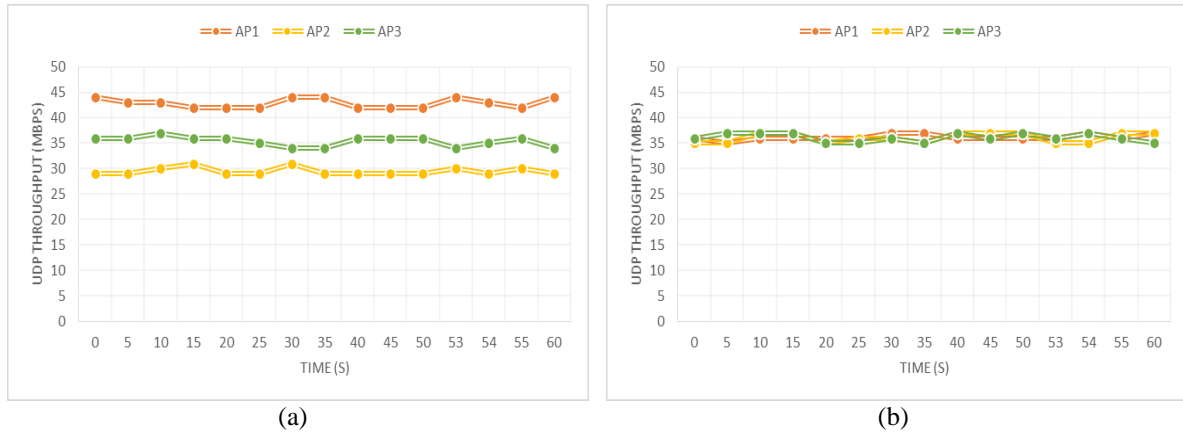
(a)　　　　　　　　　　　　　　　　　(b)

Figure 7. UDP traffic in traditional Wi-Fi network and when using the
load balancing algorithm based on SDN

Figure 8(a) presents the jitters variation in traditional and using our load balancing algorithm based on SDN. In a traditional network, the average jitter value during the UDP transmission for stations associated with AP1 is 0,64 ms, the stations related to AP2 and AP3 receive 2,14ms and 1,62 ms, respectively. When using our load balancing algorithm based on SDN, the jitter values of the three APs (AP1, AP2, and AP3) are 1,50 ms, 1,59 ms, and 1,54 ms. An enhancement of the jitter values is observed in Figure 8(b) in comparison to the traditional network.
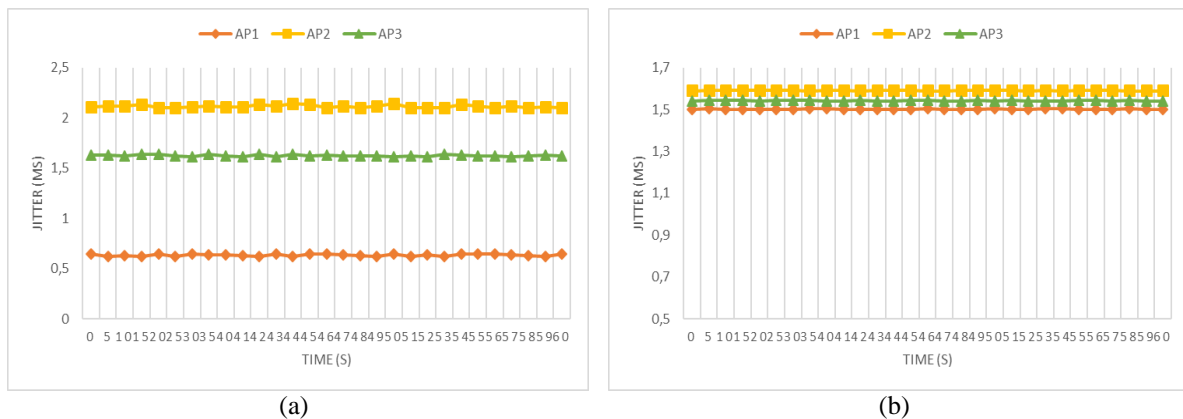

(a)　　　　　　　　　　　　　　　　　(b)

Figure 8. Jitter values in traditional Wi-Fi network and when using the
load balancing algorithm based on SDN

5. CONCLUSION

In this paper, we proposed a load balancing algorithm based on SDN for enhancing the performance of mobile IoT devices communication over Wi-Fi networks. We built a simulation environment using mininet to implement and analyze the performance of the developed concept. The results have shown that the proposed scheme significantly balances the entire network's load and enhances the throughput of the devices compared with the traditional architecture where no load balancing mechanism is applied. We aim to consider other constraints and metrics in developing and evaluating the current algorithm in the future.

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