New mobility Scheme based on SDN in Wi-Fi network

Hind Sounni [a], Najib El Kamoun [b] andFatima Lakrami[c]
[a] Laboratory of Sciences and Technologies of Information and Communication, Physics Department, Faculty of Sciences, Chouaïb Doukkali University, El Jadida, Morocco

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Abstract: The massive use of wireless device and the increasing of traffic volume lead to find solutions to extend the coverage and increase wireless LANs' capacity. Given the distributed nature of 802.11-based WLANs, the existing solutions can become inefficient. Mobility is one of the main challenges when implementing a Wi-Fi network. Most mobile devices require a permanent connection to the desired services. An interruption of these services can occur during handover, i.e., when the access point is changed. This paper proposes a new mobility scheme based on an emerging technology called Software-Defined Networking (SDN). This technology allows centralized management, dynamic, automated configuration, and planning of the wireless network. A network simulation using Mininet Wi-Fi is done to analyze and compare the proposed mobility scheme's performance to the existing mobility protocol (PMIPv6). The results are very promising and prove the efficiency of our mobility system

Keywords: Wi-Fi, Software-Defined Network, PMIPv6, Mobility, Scalability, Performance evaluation

1. Introduction

The recent wireless communication technologies (Wi-Fi) and mobile devices' emergence provide access to the network anywhere and anytime. Users are allowed to move freely while staying connected to their network services. The growing need for wide coverage, a better quality of service with seamless mobility lead to the emergence of new Wi-Fi standards. The IEEE 802.11n standard, for example, can achieve high data rates through the use of MIMO (multiple-input multiple-output) technology on each of the usable frequency bands (Karmakar et al., 2017).

Mobility and scalability are among the issues that impact the performance of Wi-Fi networks. Mobility is a device's ability to switch between access points (APs) while keeping an active connection to the network. Network scalability can increase the network's size by adding new nodes and connecting more applications without affecting its quality of service. In this context, several studies were performed to analyze and enhance mobility in Wi-Fi networks. Martinez et al. (Martinez et al., 2018) proposed a new platform to facilitate trusted communications for robot mobility through SDN orchestration and intelligent function splitting of Wi-Fi network elements. Wu et al. (Wu et al., 2018) presented UbiFlow, a software-defined IoT scheme providing a combination of ubiquitous control of flow and mobility management in heterogeneous urban networks. UbiFlow uses several controllers to split the urban-scale SDN into various geographic divisions. In (Raza et al., 2020), Raza et al. proposed the OF-PMIPv6 protocol that uses PMIPv6 and SDN. OpenFlow allows information to be sent for three purposes: for MN authentication, tunnelling configuration on the nOMAG (nextOpenFlow Mobile Access Gateway) side, and informing the controller of the transfer event. In (Raza et al., 2020), SDN controllers activated PMIPv6 domains to provide inter-domain mobility through distributed communication. A new scheme allows domains to retrieve prefixes once the mobile node releases them.

This paper's main objective is to propose a new mobility scheme to enhance the Wi-Fi network's performance using the emerging technology Software-Defined Networking (SDN) (Zhang et al., 2018). The aim is to determine the changes introduced by the SDN technology during mobility and evaluate its effect on the Wi-Fi network's performance. The introduction of SDN architecture in wireless networks, especially Wi-Fi, has become one of the most active research areas (Bera et al., 2017, Restuccia et al., 2018, Tsai et al., 2018). This technology allows centralized management, dynamic, automated configuration, and wireless network planning. SDN decouples control from the data plane and centralizes all network intelligence in the SDN controller. A performance evaluation of the Wi-Fi network based on the SDN is done under two constraints: mobility speed and scalability. The results are compared to the existing mobility protocol PMIPv6. The network performance evaluation refers to a quantitative calculation of networks, nodes, or transported applications parameters.

The rest of the paper is presented as follows. Section II provides a mobility scheme in a Wi-Fi network. Section III present the proposed method. Section IV provides simulation results and discusses the proposed mobility scheme's performance study, while section IV concludes the paper.

2. Mobility scheme in Wi-Fi network

Mobility, handover, or roaming in Wi-Fi represents a station's ability to change access point (AP) without losing its network connectivity. There are several levels of mobility that refer to the OSI model. This article introduces level 2 mobility and level 3 mobility, which are also called micro-mobility and macro mobility.

2.1. Level 2 mobility

In a Wi-Fi network, the access points (Aps) are bridges that carry traffic between mobile stations and the Internet. Before a station can send traffic through an ESS (Extended Service Set), it must be associated with an AP. When a mobile station enters an overlapped area (area covered by multiple APs) and detects that the AP's transmission power is associated with low or encounters transmission problems, the handover process is initiated. As shown in Figure 1, when the STA detects the appropriate AP on the basis of the RSSI (Received Signal Strength Indication), the re-association process is triggered; this process is similar to the association process. Once the station is re-associated with the new AP, the old AP transmits the mobile station's data to the new AP through the Distributed System (DS).

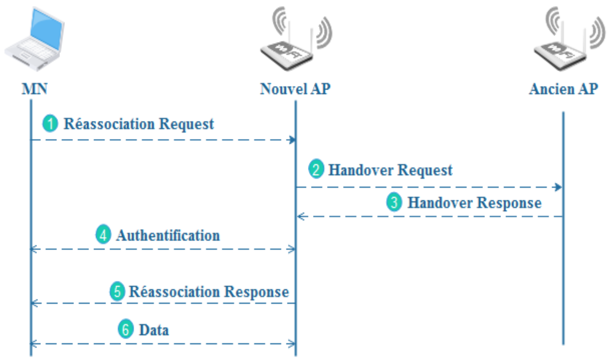

Figure 1. Handover Process (Re-association)

2.2. Level 3 mobility

The mobile IP protocol was published in 2002 by the IETF (RFC 4004, 2002). This protocol aims to maintain current communications between a mobile node and its correspondents, even while the latter is moving. To meet all these requirements, the IETF has defined two specific mobility standards: Mobile IPv4 and Mobile IPv6 (Al-Ani et al., 2018).

Since mobile IP can experience high latency during handover, the IETF has developed various extension-based solutions for mobile IP, like FMIPv6 (Fast Mobile IPv6) (Berguiga et al., 2018), which introduces communication between the access routers of the old and new networks. HMIPv6 (Hierarchical Mobile IPv6) (Kresna et al., 2019) is designed around a hierarchical architecture that prevents signalling and enhances delay and scalability. Although FMIPv6 and HMIPv6 have enhanced handover delay, they are host-based protocols where the mobile must change its protocol stack to deal with mobility signalling, resulting in a lack of flexibility.

Therefore, the IETF developed a network-based localized mobility management system (NetLMM). Network entities are responsible for exchanging mobility signals on behalf of the mobile node. Mobility is performed without the need for node-specific configuring or software installation. The IETF developed PMIPv6 (Proxy Mobile IPv6), a network-based localized mobility management solution that employs IP tunnelling with no mobile protocol stack modification. It was defined in RFC 5213 and adopted by the 3GPP.

2.2.1. Proxy Mobile IP version 6 (PMIPv6)

PMIPv6 adopts the concept of network-based localized mobility management (Gundavelli et al., 2008). In PMIPv6, the MN no longer needs to report to the connected mobility topology when it moves to another network location; This is an advantage over the above protocol. There is no need to implement the complex process of configuring and authenticating host mobility for signal exchange and routing updates. Therefore, the concept eliminates the need to install a mobility stack on the MN.

With PMIPv6, the mobility functions are supported by the mobility protocol network entity. When the MN joins the PMIPv6 domain, the Mobile Access Gateway (MAG) sends a Proxy Binding Update (PBU) message to the Local Mobility Anchor (LMA) containing the MN information. When the message is received, the LMA assigns a prefix to the MN and sends an acknowledgement message which includes the prefixes inserted into the MAG.

At the same time, a two-way tunnel is created between the MAG and the LMA. Next, the MAG sends a Router Advertisement (RA) message to the MN for address configuration. The bi-directional tunnel created between the LMA and the MAG is a gateway for the MN's data traffic (Figure 2). Traffic addressed to or from the MN is transmitted through the LMA and MAG; after decapsulation, the traffic is routed directly to the appropriate correspondent node. PMIPv6 uses the unique MN prefix address compared to other protocols that implement the shared MN prefix approach. As a result, an improvement in forwarding protocol performance is seen since duplicate address detection (DAD) is not applied.

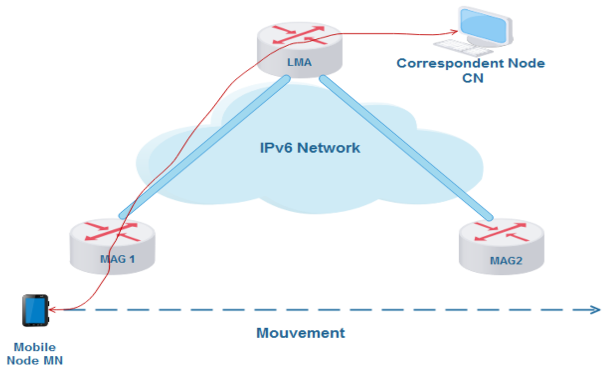

Figure 2. PMIPv6 protocol network

2.3. Mobile IP limitations

Mobile IP's weakness lies in detecting movement between two APs in the same domain or micro-mobility. The protocol is not able to determine the new location of the user in real-time. Consequently, a session break and a loss of data occur. Other protocol limitations are listed in the following table:

Table 1. MIP limitations

Security	There is no standardized key management or distribution protocol
Delay	The delay depends on the distance between the home agent (HA) and the foreign agent (FA).
Triangular routing	The correspondent node (CN) has to send packets to the mobile node (MN) via the HA, while the MN sends packets directly to the CN, resulting in low efficiency, especially when the MN is far from the HA and the CN is close to the MN.
Handover	The HA sends the MN's IP packets to the originating foreign network over the tunnel because it is not aware of the MN's last address of record (CoA). Therefore, these IP packets affect the MN and the CN's communication, especially when the MN is far away from the HA.

Although MIPv6 is a fully developed protocol for supporting IP mobility and solves many problems encountered in MIPv4 (triangular routing, security, and limited IP address space), it still suffers from some issues such as handover latency packet loss and overhead signalling. Also, the handover latency related to MIPv4/v6 does not provide quality service (QoS) requirements for real-time applications.

3. Proposed mobility scheme using SDN

The existing mobile IP protocols can be used in a mobile Wi-Fi network based on SDN; However, those mobility protocols operation is not linked to the SDN components; it is done individually. Therefore, to realize an SDN-based Wi-Fi network, two ways are possible. The first is to modify the mobility protocol to cooperate with SDN signallisation. The second is to develop a new approach using SDN signalling without existing IP mobility protocols. In this paper, we adopt the second way; This allows for a simple real-world implementation compared to existing protocols.

In an SDN-based Wi-Fi network, the OpenFlow switch is located at the AP, allowing the data plane to be directly installed on the AP. The OpenFlow protocol provides interoperability among controllers and APs, enabling control and data plans to be managed. The use of SDN technology provides centralized network control and facilitates its optimization; it also solves several problems of overload, transfer delay and reduces packet loss compared to a traditional Wi-Fi network. Two elements are essential in an SDN-based Wi-Fi network: The SDN controller and the OpenFlow enabled AP. The controller makes all decisions about packet processing (deleting or adding an entry to the Aps flow table).

To further explain a mobile station's handover procedure in an SDN-based Wi-Fi network, Figure 3 presents the exchanges (steps) involved in the mobility process when the SDN controller is present. It can be defined in two phases: registration and handover of the mobile station (MN). These two procedures are established by transmitting OpenFlow messages to report MN's activities and routing path updates. In Figure 3, we suppose that the mobile station is associated with the AP1, and AP2 is the one to which the mobile station is re-associated later.

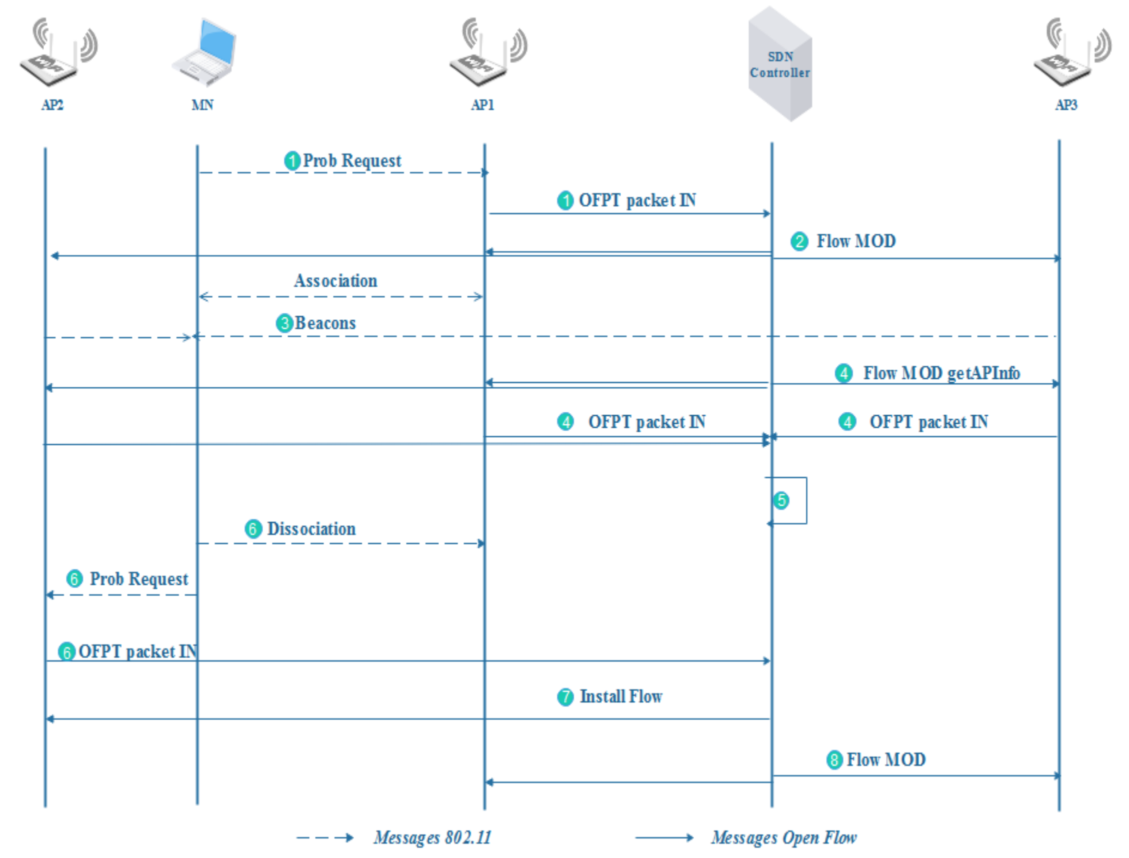

Figure 3. The exchange messages between the controller, APs, and mobile station during the handover

When the AP detects an association request from a mobile station (Probrequest), the information contained in this message is forwarded to the controller (OFPT PACKET IN). The controller processes and approves the association request; if this station does not exist in the rejection list, the FLOW MOD message is sent to all other APs to add the routing flow to the mobile station. The station captures all the beacon frames broadcasted continuously by the access points through the passive scan. It compares the RSSI values of the different access points to check and see if there is a possibility to switch to a better AP in that area. The controller periodically requests traffic information from each AP (FLOW MOD getApInfo). Using OFPT PACKET IN messages, the Aps send the responses to the controller. All information is collected to obtain an idea about the network load.

A dissociation is done by both the access point based on the controller's request and the mobile station to detect the RSSI quality deterioration. Once the station is disassociated, it sends a Probe request message for re-association with the new AP having the highest RSSI. The information in this message is forwarded to the controller (OFPT PACKET IN), the re-association request is accepted if the station is not on the reject list. The controller sends to the new AP the message (InstallFlow) containing all station information and its communication status. Thus, the appropriate flow for the mobile station is already installed on it. The FLOW MOD messages are sent to all access points to update the routing flow to the MN (add/remove).

4. Implementation and performance evaluation of the mobility scheme using SDN

4.1. Scenarios and simulation parameters

The mobility scheme based on SDN implementation is done using MininetWi-Fi version 2.2.2 running on Ubuntu is used as a simulation tool. Mininet Wi-Fi is a simple, robust system and network tool for developing and testing OpenFlow-based applications.

The experimental network is used to evaluate and compare the performance of mobility schemes using SDN and PMIPv6. Figure 4 presents the component used in PMIPv6 and SDN scenarios. We use the same scenarios to test PMIPv6 and mobility using SDN. Those scenarios have been proposed to analyze the performance using the UDP transport protocol. These scenarios are realized to determine the impact of introducing SDN in the Wi-Fi network and defining which architecture responds more efficiently and quickly when the network load and mobility speed during a handover increases.

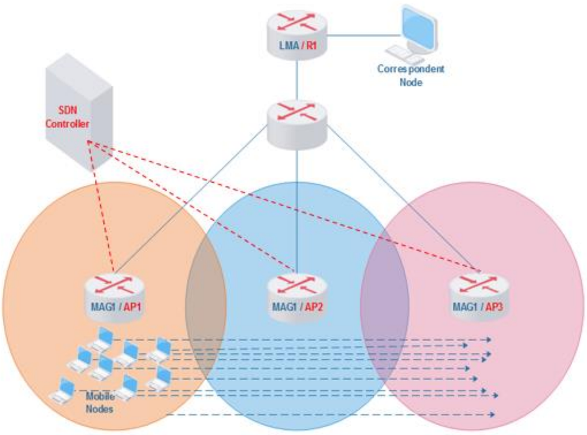

Figure 4. The used topology

For the PMIPv6 scenario, the UMIP mobility patch is installed with a kernel compilation (Shultz, 2019), the RYU controller (Islam et al., 2020) is used for the SDN-based Wi-Fi network. The Iperf tool (iPerf) generates UDP traffic and collects the performance measurement. The UDP packet size is set to generate multimedia traffic which is very sensitive to temporal constraints. Indeed, any disruption of a few milliseconds impacts the transmission and the quality of the traffic negatively.

A straight line with different speeds defines the mobility scheme. The architecture used is a client/server architecture; the two entities exchange UDP traffic. The other emulation parameters are mentioned in Table 2.

Table 2. Simulation parameters

Parameters	**Configuration**	
	PMIPv6	**SDN**
Emulation platform	**Mininet-Wifi**	
Mobility Program	**PMIPv6-v0.4.1**	**-**
SDN Controller	**-**	**RYU**
OpenFlow Messages	**-**	**v1.3.0**
Traffic generator	**IPerf v2.0.5**	
Type of traffic	**UDP**	
Packet size	**1450 octets**	
Mobility model	**Straight line: (net.startmobility and net.mobility methods)**	
Mobility speeds	**1, 5 and 10m/s**	
Access point	**802.11n, 100Mbit/s**	

4.2. Scenarios and simulation parameters

UDP traffic was generated from MN to CN during the simulation time; the results are reported using the iperf tool. The PMIPv6 and SDN-based Wi-Fi evaluation results can be illustrated in Figures 5 -7. The performance metrics used are throughput, UDP delay, and packet loss. The result shows that the throughput of SDN-based Wi-

Fi is higher than PMIPv6 by approximately 0.8 Mbps, caused by the tunnelling overhead of PMIPv6. This overhead also impacts the delay of PMIPv6, as shown in Figure 6. Both methods' delay increased, and the throughput decreased significantly when the MN changed the attachment point to the other access point. Then, a re-establishment of these metrics is observed when the MN attaches again to the access point. For SDN-based Wi-Fi, the throughput started to increase at the second 20.5 and a second 21.5 for PMIPv6. This time difference is due to the handover delay of about 1.0 seconds for SDN-based Wi-Fi and about 2.0 seconds for PMIPv6. As shown in Figure 7, the packet loss percentage is 3.49% for the PMIPv6 network and 1.76% for the SDN-based Wi-Fi network. The result of PMIPv6 is approximately two times higher than SDN-based Wi-Fi network.

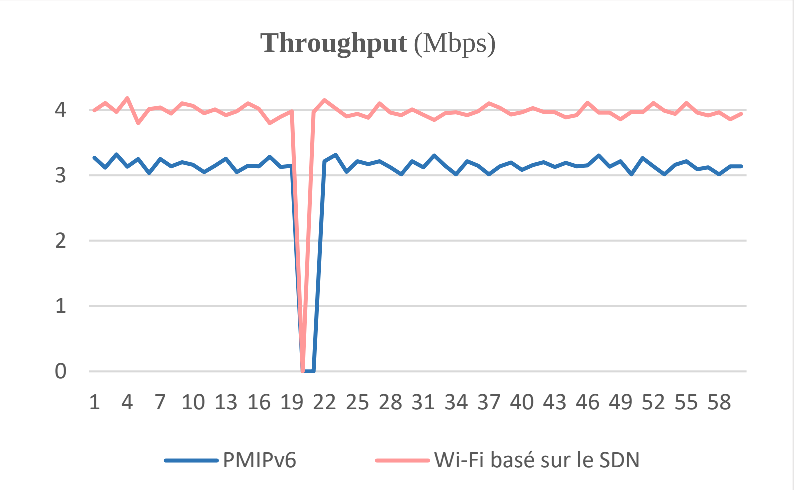

Figure 5. UDP throughput: PMIPv6 vs SDN

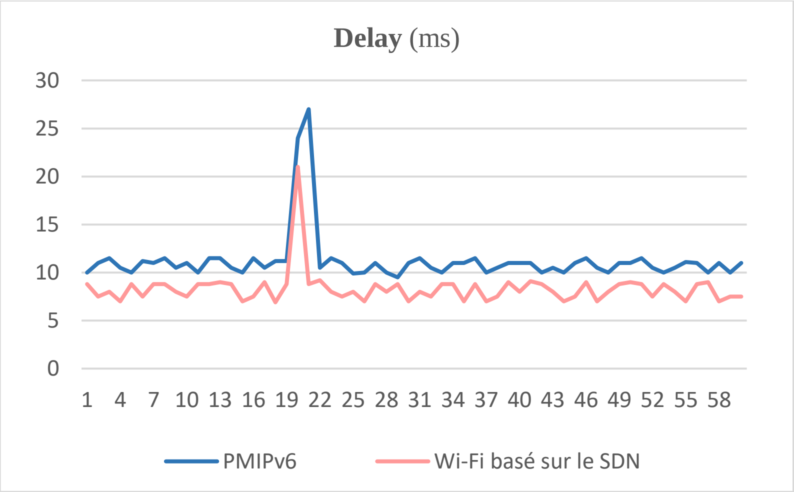

Figure 6. UDP delay: PMIPv6 vs SDN

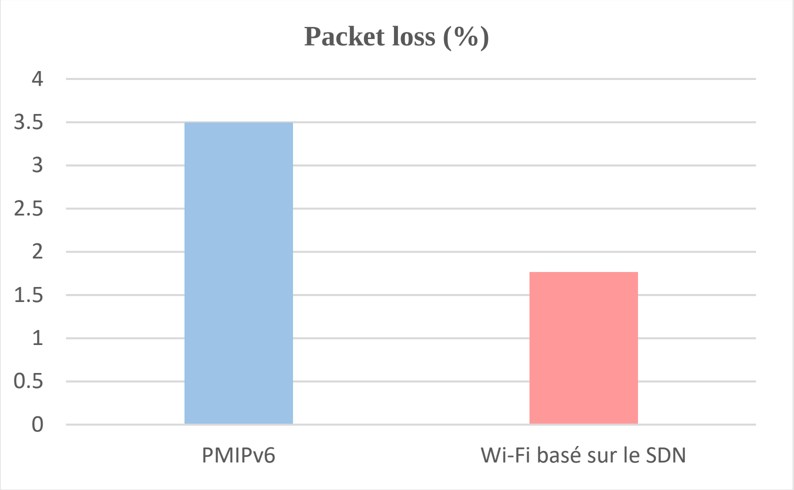

Figure 7. Packet loss: PMIPv6 vs SDN

- **Mobility speed and scalability analysis**

Several scenarios have been simulated to study the impact of mobility speed and scalability on Wi-Fi network performance. We varied the mobility speed of the MN from 0 to 10m/s and the number of stations from 1 to 50. The graphs containing the simulation results are plotted against the mobile station speed. Figures 3.15-3.20 show the results of the performed evaluations. Performance degradation when using PMIPv6 is observed; this degradation is due to the tunnelling overhead; on the other hand, we notice that the SDN improves the Wi-Fi network's performance for all scenarios.

We varied the mobility speed of the MN from 0 to 10m/s and the number of stations from 1 to 50. The graphs containing the simulation results are plotted against the mobile station speed. Figures 8-13 shows the results of the performed evaluations. Performance degradation when using PMIPv6 is observed; this degradation is due to the tunnelling overhead; however, we notice that the SDN improves the Wi-Fi network's performance for all scenarios.

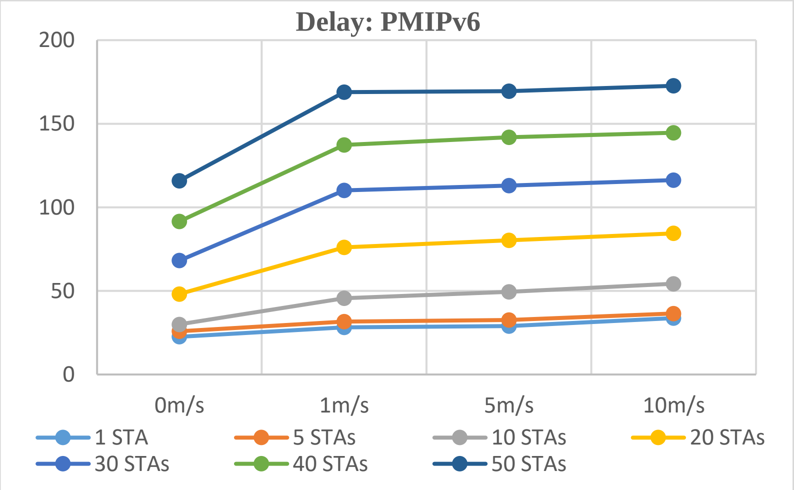

Figure 8. Wi-Fi network delay using PMIPv6

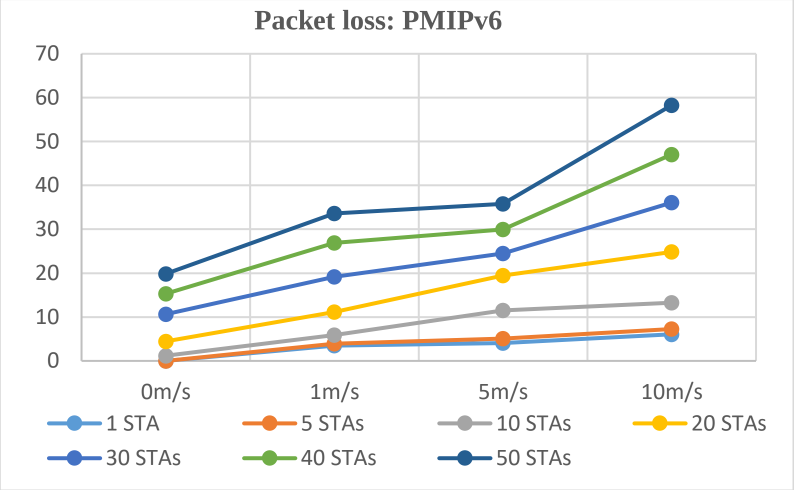

Figure 9. Wi-Fi network packet loss using PMIPv6

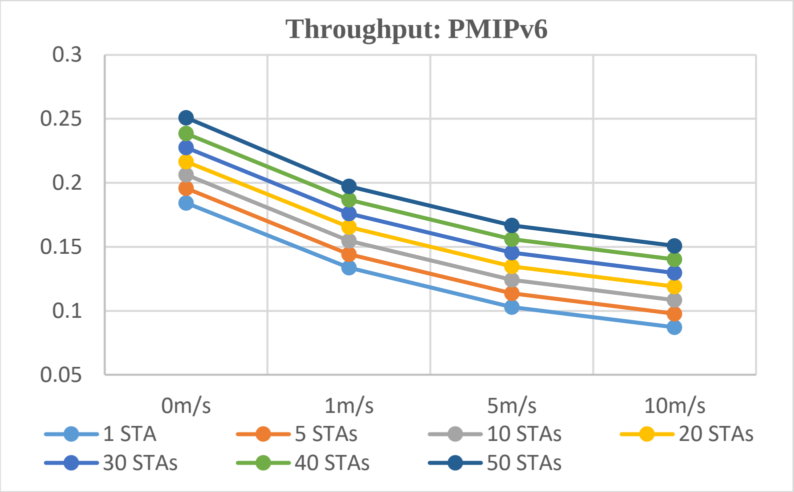

Figure 10. Wi-Fi network throughput using PMIPv6

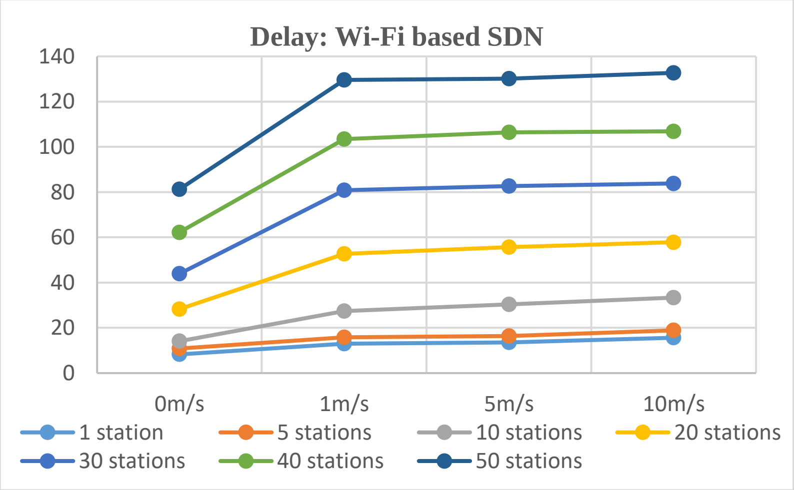

Figure 11. Wi-Fi network delay using SDN

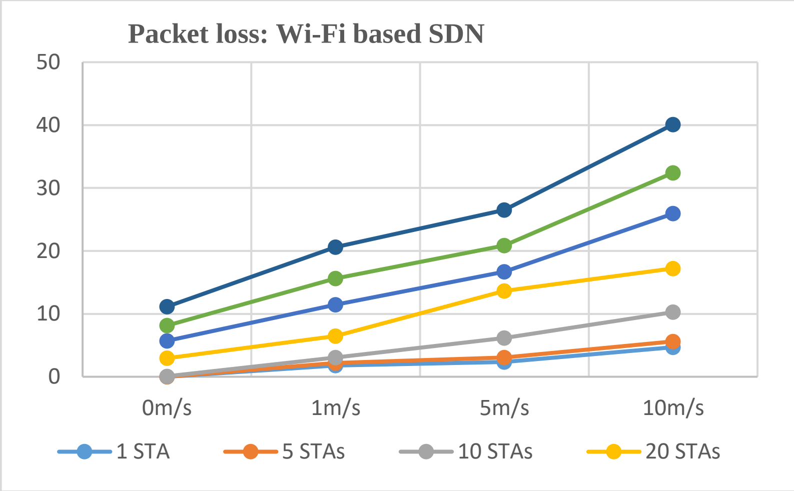

Figure 12. Wi-Fi network packet loss using SDN

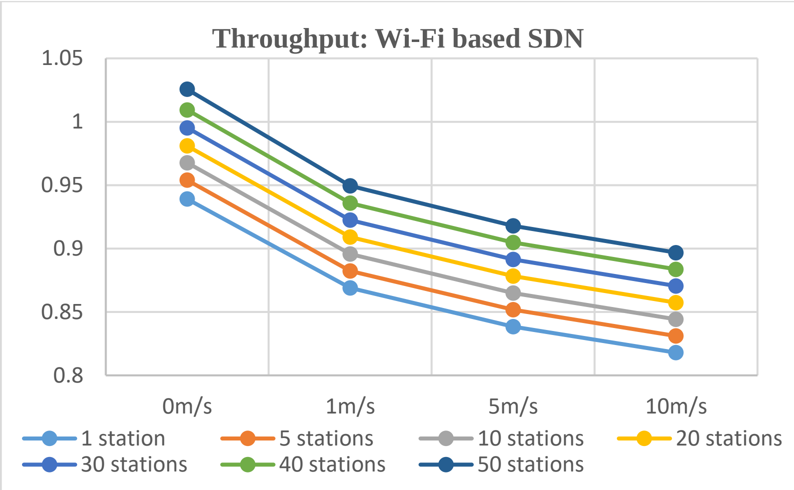

Figure 13. Wi-Fi network throughput using SDN

Conclusion

Mobility using SDN is a network-based mobility approach that does not require MN signaling, and is suitable for implementing a localized mobility network. Similar to PMIPv6, when using SDN, an auto configuration is performed to obtain an IP address. The PMIPv6 messages are used to set up an IP-in-IP tunnel allowing communication from MN to CN, whereas in the case of SDN mobility, the OpenFlow messages are used to immediately update the routing path to avoid IP in IP tunnelling; As a result, an enhancement in the performance of the Wi-Fi network is observed even when several constraints are present. The packet loss during MN handover still a problem to solve. In future work, we aim to implement an approach to improve packet loss in the Wi-Fi network using SDN..

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