

Proactive Forwarding of High Data Rate in Smart Virtualization Networks for High-Speed Trains

Fouad Ali Yaseen , *Student Member, IEEE*, Hamed Al-Raweshidy , *(Senior Member, IEEE)*

Abstract—The Internet and mobile services provided by High-Speed Train (HST) communication networks are affected by high occurrences of interruptions due to high speed movement. Rapid connection and disconnection with the Access Points (APs) impacts the performance of quality of service to indoor train communication. To ensure a high data rate delivery and highly reliable connection to the Internet for end-users, we propose a novel method of handling packet flows in HST communication networks based on Software Defined Networking (SDN) and Network Functions Virtualization (NFV). Our proposed combination of technologies is called Smart Virtualization (SV). The approach in this paper is based on making decisions to change the paths of packet flows between the APs, depending on the use of a triggering signal to initiate layer 2 handover. This packet path switching is controlled by an SDN controller. Our proposed approach operates by sending train information via a train head triggering signal for proactive registration in advance when the train enters an overlap area of AP signals. The suggested SDN network has been emulated and performed by using the Mininet simulator, and MATLAB platform. After extensive testing, the obtained results that were supported by the triggering signal has an efficient reduction in delay and packet loss than the obtained results without using triggering signal. The average control delay time was reduced by nearly 45% and the retrieved data were roughly 90% of packet loss when adopting the triggering signal system.

I. INTRODUCTION

ALWAYS being available and connected at any time, anywhere on the Internet by mobile or fixed devices is a feature of present-day existence. Increasingly, the development of application services is leading to need deliver large amounts of data without delay or interruption through online connection during user movement. To achieve this, an efficient network is required to handle the transferred data. When associating moving targets to a network, this is more difficult than for stationary, because their changing position and location for both geographic and topology of accessing attachment points of that network. Since packets forwarding amongst network devices depends on IP addresses, several protocols have been proposed to tackle packet loss and long handover latency through rapid acquiring the IP address of a mobile node. Such protocols include the Mobile IPv6 (MIPv6) [1], Fast Mobile IPv6 (FMIPv6) [2], Hierarchical Mobile IPv6 (HMIPv6) [3], Proxy Mobile IPv6 (PMIPv6) [4], and Fast Proxy Mobile IPv6 (FPMIPv6) [5]. Despite these protocols having been developed and provided significant advances in mobility management, they suffer from many obstacles such as long handover delay time, signaling overhead, and a high rate of packet loss [6]. These protocols serve as mobility management ones with the ability to handle such management through the IP layer.

Moreover, they have provided significant features for mobility management at low and medium speed of moving targets [7]. However, the mobility management issue for high-speed moving targets is too difficult for the existing protocols and needs creative solutions to tackle this context. As a High-Speed Train (HST) moves from one AP to another, it requires disconnecting from the current AP (AP_c) and connecting to the next AP (AP_n) to sustain its session connectivity to the Internet, a process known as handover. The handover delay time is known as the timespan that is required by network devices to complete handover handling. Within the handover process, the HST is separated from the network for a while. Hence, transmitted data packets addressed to HST according to its IP address, may be dropped if the handover processing time is too long. HSTs suffer from the weak achievement of wireless connection services as trains run at high speed. Hence, this poor performance is reflected in the provided Internet services to the passengers in the compartments of those trains. The HSTs have witnessed a fast evolution in traveling at high speed up to 98 m/s and greater [8]. The provided Internet services to HSTs are far from adequate due to too much repeated handover during their rapid movement. This frequent handover means the Internet services and connectivity have become critical. A new mechanism for routing and delivering data must be implemented to ensure high data rates and continuous Internet connectivity for end-users [9].

Emerging virtualization of networking technologies, such as Software Defined Networking (SDN) and Network Functions Virtualization (NFV) have been helping to make mobile and Internet networks more flexible and agile. A network architecture based on SDN technology depends on the separation of the data layer (also known as the Data Plane), which is the bottom plane and consists of network devices such as switches, routers, APs whether they are real or virtual devices are separated from the control layer (known as the Control Plane), that administers the control functionalities of the SDN network. The data layer involves physical or virtual switches with high performance to deliver the data to their destination. While, the control layer is represented by the SDN controller (SDNc), which is centralized in the logical software substance [10]. On the other hand, NFV runs network functions like load balancing, cipher/decipher, firewall, etc. By using SDN and NFV together, the network infrastructure can be reduced by more than 30% for a new installation of physical infrastructure [11], [12]. The OpenFlow is a well-known protocol that links the SDNc and forwarding devices. ONF standardized the OpenFlow protocol to be the significant southbound API which it could be an open standard or user

proprietary. Switches and routers should support the OpenFlow protocol in the transfer of controlling information with SDNc. The southbound APIs can be customized by the user to achieve an appropriate task and approach [12]–[14].

Our contribution concerns the fixed or wired part of wireless network systems (i.e., neglecting RF or wireless matter). In other words, we are interested in the access points and the stationary infrastructure devices of the wireless network (routers and switches). We consider our proposal for designing a virtualized domain as a part of a wireless network, a domain that consists of SDN controllers, enabled OpenFlow switches and wireless access points. The main contributions in this paper are as follows:

- 1) Using an SDN technique to administer the handling of packet flows during HST mobility. In SDN networks, the most important feature is to relieve the overhead control messages or signals that direct the flows of packets.
- 2) Drawing on the excellent feature of the SDN of its capability of dealing with per packet or per flow independently from the IP address to destine data packets, we put forward a technique for picking specific fields from the IP address fields to be fragmented and consolidated with other fields by utilizing SDNc to steer packet flows.
- 3) Utilizing a triggering signal to direct packet streams proactively. The SDNc uses the information that is included in the triggering signal to initiate redirection processing to change the packet flow paths from APc to APn. This proactive processing leads to reduced packet loss and decreased handling delay time, whilst keeping the continuity of connection during HST mobility.

This paper is structured as follows. Section. II provides a brief overview of the wireless technologies that can deliver a high data rate, which are proposed to be in employed in this research for network systems, with related works being presented at the end of this section. Section. III illustrates the structure of the proposed system, whilst Section. IV explicates the distance estimation that has been used in our work. The obtained numerical measurements from the experiments have been analyzed in details in Section V. Section. VI explains the setup of the testbed and its implementation with Mininet simulation. Finally, the conclusions are drawn in Section. VII.

II. PRELIMINARIES

In this Section, a brief outline of some technologies that can be used in the proposed network to facilitate the understanding of the main idea, including object speed calculations, millimeter wave AP, massive MIMO antennae, wireless Gigabit AP, identifiers of network and host as well as IP address and mobility. In addition, a review of important related studies is provided.

A. Technologies May Be Used

1) *Target Speed And Wireless Registration*: High-speed moving targets (trains or cars) suffer from interrupted wireless services when they cross from the attached access point (AP) to a new one. That is, this happens due to breaking of the connection from APc and connecting to the next AP, i.e.,

the wireless re-registration process. Suppose that the speed of a moving target is 350 km/h, the delay time of the layer 2 wireless registration Control Plane (CP) is 50-250 msec [15] and the separation distance between any two adjacent APs is 200-1000 m.

With a simple calculation via Equation 1, we can estimate the delay time that is required by a moving target to move from one AP to another as flows, such that:

$$t = d/\nu \quad (1)$$

where, t is the time required to cross the distance d with target speed ν .

- Separation distance between APs is 200 m:
350 km/h = 97.222 m/s
So, 200 m / 97.222 m/s = 2.057 sec.
- Separation distance between APs is 1000 m:
350 km/h = 97.222 m/s
So, 1000 m / 97.222 m/s = 10.286 sec

It is clear that layer 2 wireless registration time delay of CP is much smaller than that required by a moving target to move between the adjacent APs. Consequently, there is enough time to complete RF registration when the moving target travels between any pair of adjacent APs. In other words, there is enough time to handle data packets between any pair of adjacent APs.

2) *Millimeter Wave Access Point* : The most important feature of a millimeter wave (mmW) is its frequency bands ability to carry multigigabit throughput data rates at a range from one meter to a few thousand meters. [16], [17]. The frequency bands (30-300) GHz of mmW can give more than 200 folds than the usage of current wireless bandwidth. This wide bandwidth has encouraged the wireless industry to utilize mmW APs for use in outdoor and indoor small cells ranging from a few meters to a few kilometers [18], [19]. By using mmW, a multi-Gbps rate can be delivered to the users by the beamforming technique which overcoming short and loss of channel propagation of the mmW [20], [21].

3) *Massive MIMO Antennae*: Massive Multiple Input Multiple Output (MIMO) antennae schemes can be employed to enhance the data rate, improve fidelity, boost radiated energy-efficiency, reduce of latency on the wireless interface, and simplify the multiple- access of the Media Access Control (MAC) layer. Massive MIMO impacts the performance of wireless communication systems when the sender and recipient support utilizing many antennae to receive and transmit multiple streams of data concurrently [22], [23]. By using physical layer characteristics, the massive MIMO technology can directly be combined with that of mmW to provide the throughput of Gbps traffic for wireless APs. Moreover, massive MIMO with mmW can improve link reliability [24].

4) *Wireless Gigabit Attachment Point*: One of the most important characteristics of the 5G network is its ability to perform high data rate ranging (1 to 7 Gbps). This means that the last distribution point of a wireless LAN (WLAN) should be able to provide a capacity of data rate of more than one Gbps to users. Wireless Gigabit (WiGig) is the standard of IEEE 802.11ad works as indoor mmW AP at 60 GHz [25],

being able to achieve the multigigabit transmission rate. The beamforming technique has been found to overcome the issues of non-line-of-sight, whilst improve energy efficiency [26]. WiGig access points are suitable for being used inside the compartments of the HST.

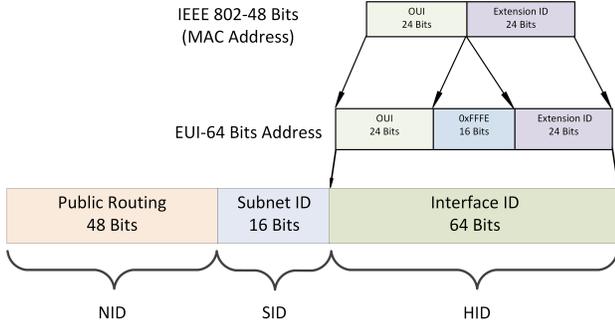


Fig. 1: IPv6 Structure

5) *IP Address and Mobility*: We have focused on IPv6, because of its capability to provide a vast number of IP addresses. Moreover, it has the significant attribute IP address auto-configuration. Also, the IPv6 address is a combination of physical ID and logical ID, which represent host and network interface IDs respectively. Fig. 1 illustrates the IPv6 structure, which shows how the device can identify itself through its IPv6 address. In other words, IPv6 is not utilized by the communication networks for routing purposes only, for it can also be worked as an indicator of the location of a mobile device in the network. Fig. 1 shows the three parts of the identifier elements of the IPv6. [27], [28]:

- Network Identifier(NID), which represents the public topology (public routing) and consists of 48 bits. Moreover, it can be considered as the parent of the SID;
- Subnetwork Identifier(SID), which pertains to the site topology (local routing) and consists of 16 bits. As above alluded to, the SID is viewed as the child of the NID which can involve a vast number of SIDs. The NID and SID together represent the global routing prefix of an IPv6. Also, they can be used as an indicator of the location;
- Host Identifier (HID), which represents the interface attachment port of a device that can connect to a network through it, being 64 bits long. The combination of the NID, SID, and HID create a single IPv6 address that is used by a device to be an End-to-End identifier for it. Furthermore, HID can work as an indicator of the mobile device's position.

The network operator who provides services to a mobile device should have information about geographic locations of all the subnetworks that belong to his/her network. That position of a mobile device can be determined by its IP address, due to the previous location knowledge of the subnet that serves the device [29].

B. Related Works

The world has witnessed a significant development in the maximum moving speed of HSTs. With this development,

several issues have faced HSTs like a train running safety, high rate of handover repetition, and maintaining continuous Internet services. Our study concerns handling and routing packets in an SDN network. Specially, managing and controlling of data packets that have been proactively destined by an SDNc through pre-exchange controlling messages are the objectives.

The authors in [30] explored the evolution of wireless Heterogeneous Networks towards mobile 5G networks for high-speed moving vehicles. They used narrowband RF channels for the control data, while for the user traffic wideband high-frequency wireless channels were deployed. However, the drawback of this research was the utilization of different RF technologies, because forwarding of packets would need more processing, thus resulting in long handover latency. In reference [31], the authors presented various scenarios for high-density transportation moving targets at high or low speed over heterogeneous networks and dense cells. They aimed to estimate the performance of a proposed vehicular networks architecture based on a multi-access router. The shortcoming of this study is dependence on the multi-access router, consisting of several antennae that could physically connect many types of wireless network technologies. Hence, a long handover process problem remained. Based on the logical design for network slicing and mobility management amongst many kinds of access points, a study was presented by [32]. This work was founded on separation of the logical network into various layers based on an edge cloud and core cloud. [33] presented a study of the causes of random delay of control services of high-speed railways and their influence on speed profile and the path of HST. These authors formulated the movement of trains as a part of the Markov approach to analyses fading channels for HSTs.

Several protocols have been proposed and implemented to resolve the handover latency and data loss dilemmas. Some them have used a reactive approach, whilst others have adopted a proactive one in relation to handling data packets. MIPv6, PMIPv6, and Hierarchical MIPv6 (HMIPv6) were designed as reactive protocols to address mobility management problems during handover within sub-networks [4], [34], [35]. These protocols have been used by communication networks to optimize the handover procedure, decrease overhead signaling, and realize layer 3 handover. Whilst, enhancements have been made in handover procedures, they still suffer from high rates of packet loss and long delay times [36]. Those protocols did not use layer 2 information to predict the direction of a moving target. As expansion and improved versions of the MIPv6 and PMIPv6 are Fast MIPv6 (FMIPv6) and Fast PMIPv6 (FPMIPv6) respectively [6]. A proactive scheme was used by these protocols, which were created principally to cope with the handover delay time and data packet loss problems. By employing a predictive scheme, the network starts layer 2 handover over using the Received Signal Strength (RSS) of the moving target [36]. All of these protocols still have considerable problems in terms of long handover latency and high rates of data loss. Moreover, They were designed to manage the mobility of low speed moving targets up to a maximum 70 km/hr [36]. Designing of 5G-Crosshaul based on SDN and NFV have been presented by [37], with this study

considering the principal parameters of application elements and their interactions with the control layer. In addition, the mmWave communication network and HST scenarios were investigated by the authors. The authors in [38] put an expectation maximization algorithm depending on the historical information basis, as well they provided estimator of a blind channel model for the uplink of an RF transmission scheme on HST.

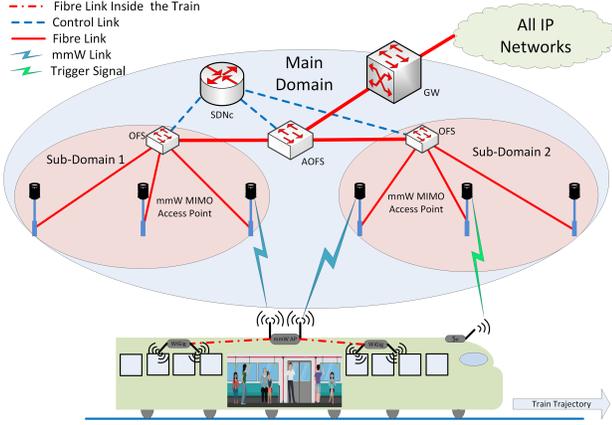


Fig. 2: System Architecture

III. PROPOSED SYSTEM DESCRIPTION

The structure of the proposed system as shown in Fig. 2 consists of three principal parts. The first represents the main domain (operator network), the second is the sub-domains (subnetworks or subnets), and part three pertains to the train (its AP and triggering signal). The following subsections explain these parts.

A. Main Domain

The main domain comprises the Software-Defined Networking controller (SDNc), Gateway (GW), Aggregator OpenFlow Switch (AOFS) and other OpenFlow Switches (OFSs) in each domain. The SDNc regulates and supervises the AOFS and other OFSs. Based on the saved information in the SDNc lookup table about the links that connect all devices associated with the system. The SDNc dictates the AOFS and OFSs to govern traffic flow from/to the main domain and sub-domains. According to this information, the SDNc creates and maintains its lookup table and makes the rules and actions, which are sent to the AOFS and other OFSs as flow tables. The SDNc is considered as the brain of the main domain due to it determining the packet routes. It sends the decisions and actions regarding these to the AOFS and OFSs to forward the data to a specific interface that links the AP to deliver the data to the destination target. That is, the decisions are taken based on the lookup tables and saved in SDNc. The lookup table of the SDNc consists of the main domain prefix (network operator prefix NID), sub-domain identifier (SID), virtual local area networks (VLANs) which serve as APs, and the train identifier which is equivalent to HID. Table I illustrates the entries of the lookup table and the field entries that should

TABLE I: The SDNc Entries Lookup Table.

Main Domain Prefix (NID)	Sub-domain (SID)	VLAN	Train ID (HID)
2001:0DB8:ACAD/48	:0001/16	AP1	$T_{11}, T_{12}, \dots, T_{1n}$
		AP2	$T_{21}, T_{22}, \dots, T_{2n}$
		AP3	$T_{31}, T_{32}, \dots, T_{3n}$
	:0002/16	AP4	$T_{41}, T_{42}, \dots, T_{4n}$
		AP5	$T_{51}, T_{52}, \dots, T_{5n}$
		AP6	$T_{61}, T_{62}, \dots, T_{6n}$

be processed to make decisions and rules. In our proposal, the VLAN ID represents the local network topology of an AP that serves trains under its coverage area.

The AOFS receives the data from the GW to forward that data to its destination based on the SDNc rules and actions. The AOFS's responsibility is that of directing packet flow among the sub-domains as the train traverses from one sub-domain to another. That is, when the train moves from one domain to another, the AOFS changes the path of packet flow from the previous domain to the new one. However, when the train moves from one AP to another within one sub-domain, the AOFS keeps the path of packet flow unchanged. Fig. 3 illustrates the entries of the flow table and the fields that the packets have to subject to it. The GW represents the gate to all IP networks that are installed outside the main domain. This is a tradition device that connects the main domain (operator network) to the Internet backbone and other IP networks. It works according to rules and policies that are applied to the traditional network devices, which means that, the GW is not subject to the rules and actions of the SDNc.

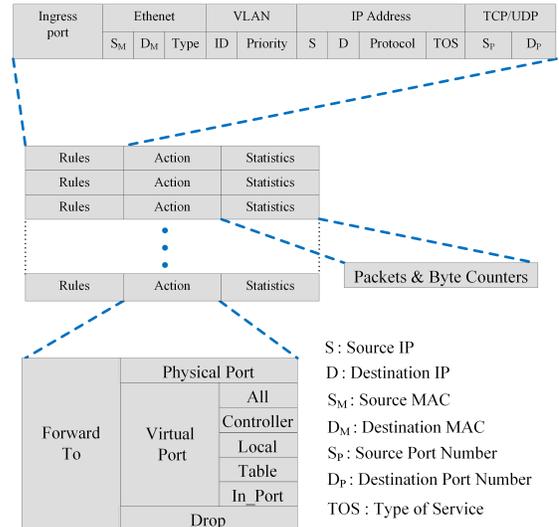


Fig. 3: Generated SDN OpenFlow Table

B. Sub-Domains

Every sub-domain consists of at least one OFS and several APs. For simple understanding, we provided a single OFS in each sub-domain as shown in Fig. 2. The OFS and AOFS communicate with each other through the forwarding layer (data plane) to send and receive the data. The OFS forwards

the received packets according to rules and actions that have been made by the SDNc. However, these are not the same as those that the SDNc has made for the AOFS. The OFS steers packet flow between APs as the train moves from the current AP (AP_c) to the next AP (AP_n) during its passing on the trajectory. The NID is still the same for the main domain even when the train moves among the sub-domains, whereas the SID is changed by the SDNc when the train does so. APs work as VLANs, which means each AP can provide an independent virtual network that can afford many virtual IP addresses based on one real IP address. To put it simply, a single SID can provide many virtual networks, each being able to provide several IP addresses. As we mentioned above, the train AP represents HID and hence, the stateless auto-configure of the train's IPv6 address involves NID, SID, and HID. This IPv6 address indeed is used as the train identifier in a specific network. Furthermore, it can be used by the network operator as a pointer to the location of the train.

C. Trigger Signal and Train AP

We proposed an innovative mechanism to manage the forwarding of packets according to an independent triggering signal that is sent by the train. This signal is received by the AP_n which in turn sends the triggering signal to inform the SDNc about the train location. We called this signal the handover triggering signal (S_H). The S_H is sent by an antenna positioned at the front of the train. The S_H is sent by the train in one direction to be received by the AP_n before the train reaches the AP_n so as to prepare the flows path switching of packets by the SDNc. S_H involves information such as HID, which pertains to the AP ID of the train, the destination of the train, the current AP attached to the train, and the train speed T_s . The AP_n forwards this information to the SDNc to switch the flow direction of the OFS only or the OFSs and the AOFS, if the train moves from one AP to another within one sub-domain or from one sub-domain to another respectively. The primary purpose of S_H is that of notifying the SDNc to dictate to the OFSs and AOFS to change the flow direction. When the SDNc receives the triggering signal, it starts to modify the flow path direction from the AP_c to the AP_n. The modifications are sent to AOFS and OFSs to achieve packet flow handover to the appropriate AP. Fig. 4 shows the hierarchical architecture of the proposed scheme for forwarding packets inside the main domain. Also, Fig. 4 points to the NID (red), SID (green), and HID (blue) parts of the IPv6 address for the train. Receiving S_H urges the AP_n to start layer 2 handover by notifying the SDNc to make decisions and actions to direct the flow session of the train between the APs seamlessly. This proactive procedure enables the AP_n to be ready to host the connection with the train while it is still associated with the current AP. The handover begins based on changing the quality parameters of the links. We rely on the received signal strength indicator (RSSI) parameter in our proposal, which can be used by the AP to predict the distance between it and the train. So the handover procedure is started by the AP to deliver the data to the train.

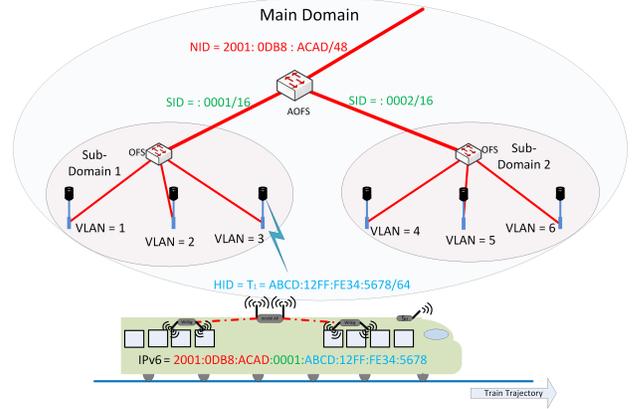


Fig. 4: Proposed SDN IPv6 Hierarchy Structure

D. Packet Flow Forwarding Scenario

When a mobile device changes its attachment point from one AP to another, it is required to register to the new AP at the layer 2 level. This means this registration can be made without changing the prefix (64 bits) of the IPv6 address. This process decreases the handover latency and helps to keep ongoing connection without any lapse as the train moves between APs. This scenario has proposed as the train traverses between APs within one sub-domain. Fig. 5 represents forwarding of packet flow between the train and the AP_c, which is controlled by the OFS flow table created by the SDNc. This means that the AOFS flow table entries are not modified when the train transits between the APs of one sub-domain. Fig. 6 shows the

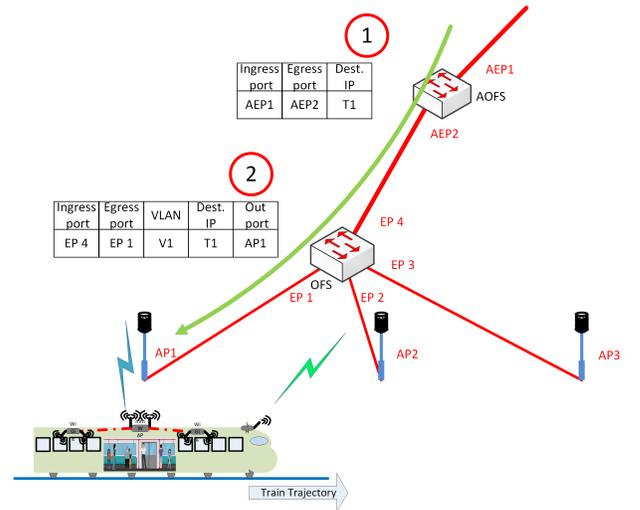


Fig. 5: Packet Forwarding Based on the Flow Table Within One Sub-domain

path switching of the packet flow when the train moves from the AP_c to the AP_n in the same sub-domain. We can recognize from Figs. 5 and 6 that the responsibility of OFS is to manage this flow within one sub-domain, according to its flow table made by the SDNc. At the same time, S_H is received by the AP_n to provide information to commence a layer 2 handover between it and the train's AP.

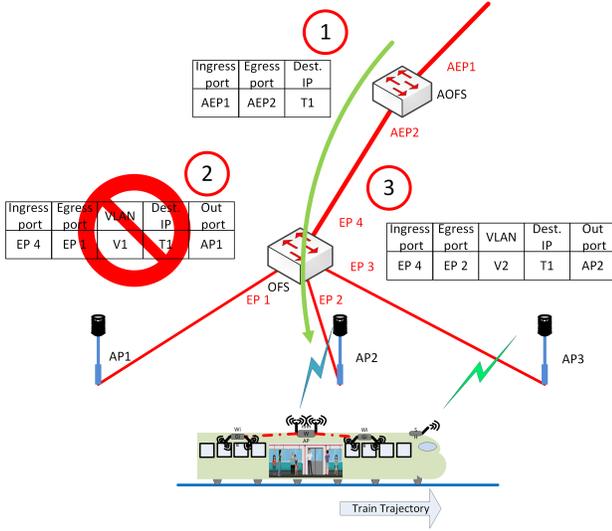


Fig. 6: Packet Forwarding Based on the Modified Flow Table Within One Sub-domain

Fig. 7 shows the last AP of a sub-domain that is providing services to the train as the AP_n of another sub-domain receives the S_H . In the meantime, the flow table entries of the OFS and AOFS have not changed until the SDNc decides the right time to send modifications to the AOFS and the OFSs of the new sub-domain. Fig. 8 explains the events of packets

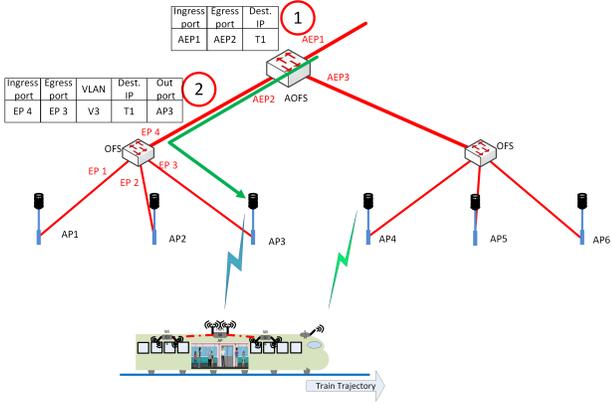


Fig. 7: Packet Forwarding Based on the Flow Table Between Adjacent Sub-domains

handover between adjacent sub-domains. After the SDNc finishes processing the incoming information from the AP_n as a result of the train's movement, the SDNc sends amended flow tables to the AOFS and OFS to handle the packet flow.

IV. DISTANCE ESTIMATION AND RSSI

The SDNc has a holistic view of the SDN network topology and knows about the global positioning system (GPS) coordinates of the APs, the train speed and the train destination, HID and QoS provision of all the SDN network's APs. The SDNc can estimate the suitable time to be associated with the coverage range of the AP_n through measurements that are executed by the SDNc. These measurements are based on the

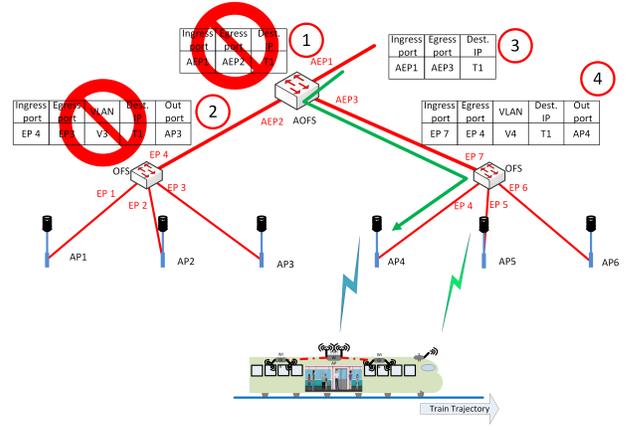


Fig. 8: Packet Forwarding Based on the Modified Flow Table Between Adjacent Sub-domains

information that is sent by S_H as well as. that programmed and saved in the applications layer and the control layer of the SDN network.

Fig. 9 illustrates the essential time sequence of the proposed procedure. The begins when the AP_n receives S_H and then forwards this information to the OFS which forwards to the SDNc to change the path of that session based on modifying the OFS flow table. This procedure occurs when the train moves between two APs within one sub-domain. While, when the train crosses from one sub-domain to another, the SDNc dictates its rules and actions to the AOFS and OFS to alter the session flow path based on the modified flow tables on the AOFS and OFS.

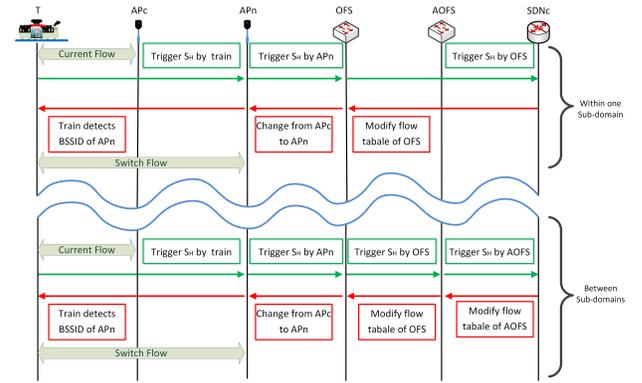


Fig. 9: Association with the AP_n: With and Without the Support of S_H

The SDNc measures the distance between the train and the AP_n by using the GPS coordinates of the two. The two-dimensional space distance separating two positions can be calculated by the famous Pythagoras theorem and can be expressed by Equation 2.

$$D_{T_i}^{AP_n} = \sqrt{(x_1 - x_{T_i})^2 + (y_1 - y_{T_i})^2} \quad (2)$$

where, $D_{T_i}^{AP_n}$ is the distance between the train i and the AP_n, x_1 and y_1 are the coordinates of the AP_n, whilst x_{T_i} and y_{T_i} are the GPS coordinates of the train i .

Measuring the RSSI does not refer directly to determining the position of the train. However, it can be used to form an equation in terms of changing the distance between the train and the APn. Suppose the train sent S_H with power $P_{Re_{D_{T_i}^{APn}}}$ at the distance $D_{T_i}^{APn}$, $P_{Re_{D_0}}$ is the received signal strength at a specific known distance D_0 , and the wireless wave propagation in free path loss γ equals 2 [39]. We can get Equation 3 as follows.

$$P_{Re_{D_{T_i}^{APn}}} = P_{Re_{D_0}} - 10 \times \gamma \times \log\left(\frac{D_{T_i}^{APn}}{D_0}\right) \quad (3)$$

The conversion from the (mW) to the (dBm), or from (dBm) to (mW) can be done by Equations 4 or 5 respectively,

$$P_{Re_{D_{T_i}^{APn}}} (dBm) = 10 \times \log[P_{Re_{D_{T_i}^{APn}}} (mW)] \quad (4)$$

$$P_{Re_{D_{T_i}^{APn}}} (mW) = 10^{\frac{P_{Re_{D_{T_i}^{APn}}} (dBm)}{10}} \quad (5)$$

Equation 3 can be written as follows, when γ equals 2.

$$\frac{P_{Re_{D_{T_i}^{APn}}}}{P_{Re_{D_0}}} = \left(\frac{D_{T_i}^{APn}}{D_0}\right)^2 \quad (6)$$

Thus, the distance between the train and the APn can be found by the RSS (S_H) at the distance $D_{T_i}^{APn}$ and the RSS ($S_{H_{D_0}}$) at the reference distance D_0 ,

$$D_{T_i}^{APn} = D_0 \times \sqrt{\frac{S_H}{S_{H_{D_0}}}} \quad (7)$$

Equation 7 can be used to determine the distance between the train and the APn ($D_{T_i}^{APn}$). Also, it is utilized to discover the position of the train for making the handover decision. The $D_{T_i}^{APn}$ calculated by Equation 7 is based on the geographic points of the X as well as Y axes, and the RSS of the S_H received by the APn with the help of GPS. All the locations of APs are known and at fixed positions in advance, being saved by the SDNc which can use this information to steer packet flows in the SDN network.

From the predicted $D_{T_i}^{APn}$ and the known T_s , the SDNc can decide the appropriate time to change the packet flow between APs. Fig. 10 shows the impact of utilizing S_H on link switching when the train enters a signals overlap area (it is 40 m where the lowest transmitted signals of APs can be received by the HST) of APc and APn. By using the S_H , the link switch starts at an earlier time than when not deploying it. In other words, the start of the link switch is prepared and executed by the SDNc as the APn receives S_H even though the signal strength of APc is larger than APn. Using S_H improves the seamless handover due to the proactive preparation of layer 2 handover in SDN network. Consequently, regarding packet loss, throughput data rate, session interruption, and handover delay all these terms are enhanced.

Also, Fig. 10 shows the impact of using S_H on receiving data from the APn when the HST enters the overlap area. By utilizing it, the HST can receive data at almost -80 dBm, which represents the minimum value of the Transmitted Signal

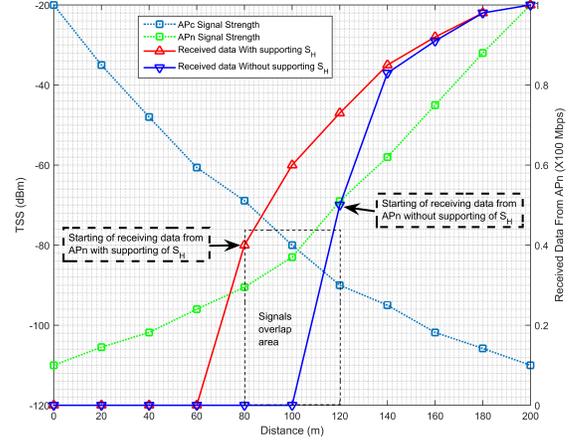


Fig. 10: Association with the APn: with and Without the Support of S_H .

Strength (TSS), i.e., the transmitted power by the APn to be obtained the data from the APn by the HST. This TSS value can practically be detected and the data extracted by the HST. Also, from the figure, we can observe that the support of S_H enables the HST to receive data from APn at distance of 20 meters before the crossing point of the APc and APn signals at mid-distance between them. The amount of data the HST has obtained is almost 40 Mb of the overall data of 40.8 Mb that has been injected by the simulated scenario along the overlap area. Whilst, the HST could not obtain any data from the APn when not supported by S_H until the TSS of APn hit the value of -70 dBm. This improvement in receiving the data has been achieved through proactive triggering of the SDNc to change packet flow direction from APc to the APn. Without using S_H the link switch (switch from APc to APn) only happens when the train was in the area where the TSS of APn is larger than that of APc. In this case, the SDNc receives delayed information about the train's position in preparation for changing the path of the packet flow from APc to APn.

V. NUMERICAL MEASUREMENT

To determine the amount of data that exists within one meter for a specific throughput with respect to a specific T_s , Equation 8 can be used,

$$M_d (Mb/m) = \frac{Thr (Mb/s)}{T_s (m/s)} \quad (8)$$

where, M_d is the amount of data per meter regarding a certain throughput Thr of a particular bandwidth. This is with supposing the APs signals overlap area is 40 m and RF registration is 50 ms as a minimum value of layer 2 RF registration delay time. The maximum probability of packet loss within the overlap space (40 m) can be calculated by the following equation.

$$P_{loss} = \frac{DM_{overlap} \times RF_{50ms}}{1518 \times 8} \times \frac{1}{DR_{overlap}} \quad (9)$$

where, $DM_{overlap}$ is the amount data that can be transmitted by APs at a certain T_s and bandwidth, RF_{50ms} is the time delay of RF registration and $DR_{overlap}$ is the average received data when the train is within the signals overlap area. Table II shows the calculated numbers based on our proposal. The

TABLE II: The Results of Measurement Calculations

T_s	Bandwidth			Data amount within 40 m overlap area	Distance crossed within 50 ms	Data amount within RF registration delay 50
	100 Mbps	1 Gbps	10 Gbps			
98 m/s	1.02 Mb/m	10.2 Mb/m	102 Mb/m	40.8 Mb for (100 Mbps)	4.9 m	4.998 Mb for (100 Mbps)
				408 Mb for (1 Gbps)		49.98 Mb for (1 Gbps)
				4080 Mb for (10 Gbps)		499.8 Mb for (10 Gbps)
56 m/s	1.786 Mb/m	17.86 Mb/m	178.6 Mb/m	71.44 Mb for (100 Mbps)	2.8 m	5.0008 Mb for (100 Mbps)
				714.4 Mb for (1 Gbps)		50.008 Mb for (1 Gbps)
				7144 Mb for (10 Gbps)		500.08 Mb for (10 Gbps)
28 m/s	3.571 Mb/m	35.71 Mb/m	357.1 Mb/m	142.84 Mb for (100 Mbps)	1.4 m	4.9994 Mb for (100 Mbps)
				1428.4 Mb for (1 Gbps)		49.994 Mb for (1 Gbps)
				14284 Mb for (10 Gbps)		499.94 Mb for (10 Gbps)

amount of data per meter that should be transmitted by APc or by APn within the overlap area has been estimated by Equation 9, according to different bandwidths and different train speeds (as shown in Table II). These calculations have been used to predict the packet loss and the average of received data.

Fig. 11 illustrates the percentage of the probable number of lost packets within the overlap distance. The figure shows that the rate of the lost packets increases due to a rise in the capacity of the channel bandwidth and with increasing the speed of the train. The increase in the percentage of lost packets is as a result of the increasing in the data amount (Mb) that existed in the distance unit (m). This means the APc or APn transmit data rate per time unit per meter (Mb/s/m) depends on channel bandwidth capacity, hence, every meter crossed by the HST is being not connected to APc either APn will increase the number of packet loss. As well as, the packet loss increases with an increase in the HST's speed, i.e., the traversed meters by the HST for one second will be higher when it moves a quickly than it runs slowly. That is, the HST crosses relatively long distance without it is neither associated with APc nor APn. By way of explanation, the number of lost packets depends on the layer 2 RF registration time that the train needs to connect with APn. That is, a long RF registration time leads to a large number of packets being lost. Furthermore, when the train moves fast, it will move a longer distance than when it slower, but the same amount of time is required to complete the RF registration (50 ms to associate with APn).

Fig. 12 shows the data amount per meter regarding different values of a channel throughput versus different train speeds that related to 50 ms. The data amount per meter increases exponentially with increasing channel throughput. In other words, the number of bits in each meter jumps to a high value due to the capacity of the transmission channel (100 Mbps, 1 Gbps, and 10 Gbps). On the other hand, an increase in the T_s (as proposed 28, 56, and 98) m/s leads to an increase in the number of meters that are traversed by the HST within 50 ms.

Fig. 13 shows the received data against T_s during the HST traverses between the APc and the APn within the proposed SDN network. Supposing the throughput of the channel capacity is 100 Mbps as the throughput data rate. Then, the obtained results show that the received data with supporting S_H are

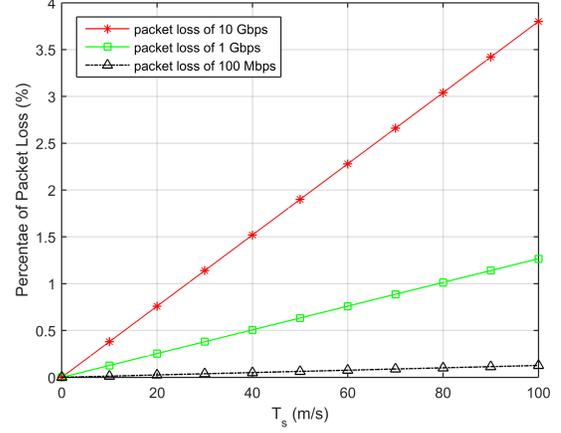


Fig. 11: Lost Packets for Different Throughput vs. T_s .

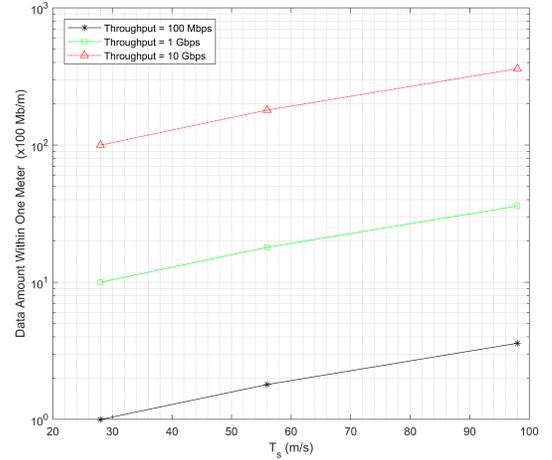


Fig. 12: Data Amount per Meter Against Different Values of T_s .

higher than those reported without it as a proactive signal to start path modification by the SDNc. We considered an overlap distance of 40 m (between 80 m and 120 m) for collecting the data. The line graph above represents the average data received by the HST from APc and APn together. It can be seen that the proactive scheme of layer 2 RF registration improved the SDN network performance in handling the packet flow between the APs. This improved performance appeared in the received data at the signals overlap area. The HST received 93%, 90% and 89% of the data that existed in the 40 m of overlap distance at different values of T_s of 28 m/s, 56 m/s, and 98 m/s, respectively. In contrast, the received data percentages were 61%, 52%, and 40% before using S_H . This degradation in received data percentages is as a result of the reactive system of the SDNc to direct the packet flow between the APs without the support of S_H .

To build and manage a dynamic network in an SDN environment. The SDNc should exchange control messages (packets) with the other devices (OFS)s to handle the data flow within the network. We have considered the delay (transmission,

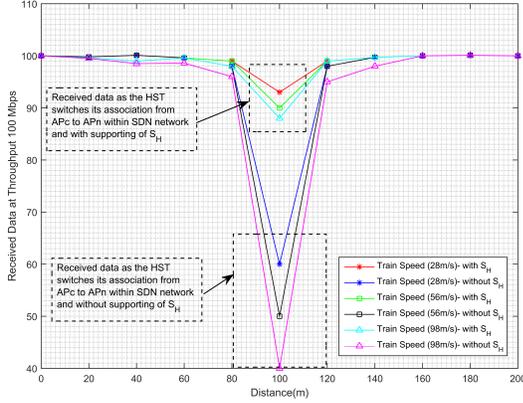


Fig. 13: Average Received Data During HST Crosses Signals Overlap Area.

process, and queue) in successive devices along the whole path instead of a delay in each device belonging to that path. By pinging the SDNc from any AP (host), we can notice the overall delay time of packets within the round trip time required to finish its journey. This constitutes three delay times making up the total (t_{tot}), namely: the RTT between the SDNc and the OSF (t_{OFS}), the RTT between the SDNc and the AOSF (t_{AOFS}), and the link delay (t_{link}). We represented the delay time by the following equation:

$$t_{tot} = t_{link} + t_{OFS} + t_{AOFS} + Cal \quad (10)$$

where, Cal represents the SDNc calibration with variable value and corresponds to the constraints of the SDNc. Fig. 14 shows that the estimated delay values grow with an increase in the number of hops. The measured values are obtained from the hop number multiplied by the offset value of the SDNc [40]. Moreover, we can see from Fig. 14 that the path delay is linear with increasing the number of the switches that are linked serially in the SDN network.

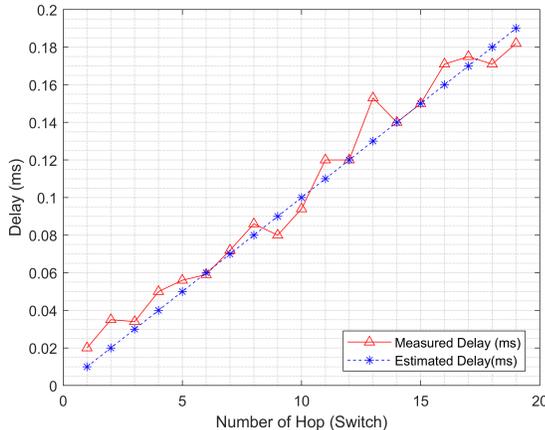


Fig. 14: Path Delay of the Control Packets Corresponding to the Number of Switches

TABLE III: The Hardware and Software Used in the Testbed

Item	PC1	PC2
Type	hp	hp
CPU Vendor	Intel(R)	Intel(R)
CPU Type	Core i7-4790 @ 3.60 GHz	Core i7-4790 @ 3.60 GHz
RAM	16 GB	16GB
Host Operating System	Windows 10	Ubuntu 14.4
Host Software	MATLAB R2017b	Python 3.7.0, Mininet 2.2.1

VI. TESTBED SETUP AND IMPLEMENTATION

A Mininet simulator, Python network programming, and MATLAB software have been used for the virtual realization and implementation of the proposed SDN network with supporting physical AP devices.

- 1) Mininet Simulator: This is a network emulator that can design and imitate a complete OpenFlow network locally on a desktop or laptop computer. It builds virtual network devices such as hosts, links, switches, and controllers. The hosts run on the Linux system software. The switches support OpenFlow for very flexible manner routing and subject to be controlled by the internal or external SDN controller. Mininet supports research, learning, development, prototyping a network, testing and performing a complete experimental network on a desktop or laptop. It affords a suitable and reasonable for network testbed, allows for complex topology testing without wiring up any physical devices, supports random system topologies and provides an extensible Python API for experimental network production.
- 2) Python Network Programming: This is a comprehensive object-oriented programming method, which includes a standard library that covers everything demanded for quickly creating effectual network applications. Moreover, Python has a diverse of third-party libraries and combinations that expand Python to all field of network programming and topologies creation.
- 3) MATLAB Platform: This has been employed to assess the performance of the proposed SDN network. In addition, it has been used to interface and control the physical AP devices.

To simulate the connection change between the train and APs (handover), we utilized two APs, represented as (APc and APn). Specially, we regulated the TSS of both simultaneously, such that of APc decreased, whilst that of APn increased by same value. This process represents and mimics the assumed movement of the HST that should move from the APc to the APn. The crossing point of the curves in Fig. 10 represents the threshold point of TSS of the APs and at this point, the train can receive data packets from APc and APn. This process has been simulated and coded by the MATLAB platform. 400 packets have been injected by the programming code to the APs during the handover procedure. Handling the packets? path direction (switching from APc to APn) is based on the Mininet VM, which includes the SDNc, AOFs, and OFSs. We neglected the wireless registration procedure, i.e. the RF registration (Authentication, Authorisation and Accounting).

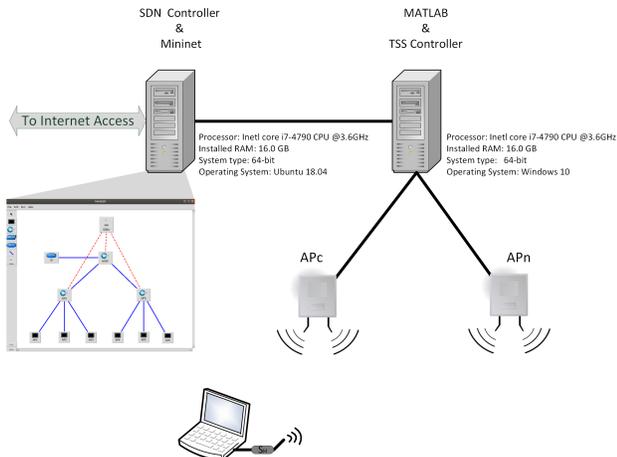


Fig. 15: Testbed Setup Block Diagram.

Fig. 15 illustrates the testbed setup of the proposed network implemented to emulate the SDN network. The Mininet network has been configured using the Python programming language. The experiment topology consists of 3 switches (2 OFSs and 1 AOFS) linked by the SDNc, and 6 hosts represent the APs connected by the OFSs. For simplicity, we connected 2 physical APs that are controlled and interfaced by Python and MATLAB coding.

In the first experiment scenario, we performed the measurements to see the control delay when the injected data changes its path from APc to APn without the support of S_H . The second experiment scenario was carried out in the same way, but this time S_H was utilized.

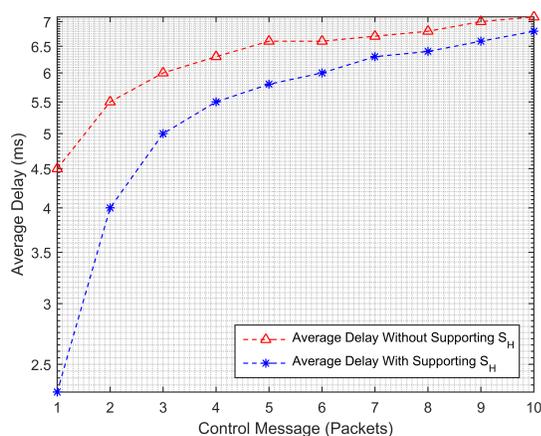


Fig. 16: Impact of S_H on the Average Delay of Control Packets

The comparison of the effect of using S_H on the average delay values is presented in Fig. 16. From the results displayed in the figure, we find that the average delay values of experimenting values without using the proactive signal are higher than when S_H is deployed. In fact, the average delay almost is halved when using it. The SDN network can be enhanced by using a creative idea to improve the performance of the SDN network through reducing the delay of both the

control plane and data plane. Fig. 17 shows the measured delay and estimated delay for the experiment scenarios, with the parameters for these being listed in Table IV. The performance of the proposed SDN network is improved by using the proactive scheme versus the reactive scheme for both the measured and estimated controlling delay. The overall test period was 100 seconds. We configured and programmed the network based on the HST sending its S_H , which is received by the APc and at that instant APc pings the SDNc to make the flow decision. this process is configured to happen after 20 seconds of beginning the test. To mimic the transferring of HST from APc to APn, we controlled the TSS of APc by attenuating its TSS, at the same time, the TSS of APn increases according to the time increasing. By so doing, the handover between the APs has been mimicked. The injected data start at TSS equals -80 dBm to represent the proposed data that should be in the signals overlap area. The amount of data in this area is expressed as the throughput rate of proposed channel capacities (40.8 Mb to 14284 Mb for 100 Mbps and 10 Gbps respectively). The experiment setup was constructed by using two *hp* computers as workstations for this work, which have the specifications provided in Table III.

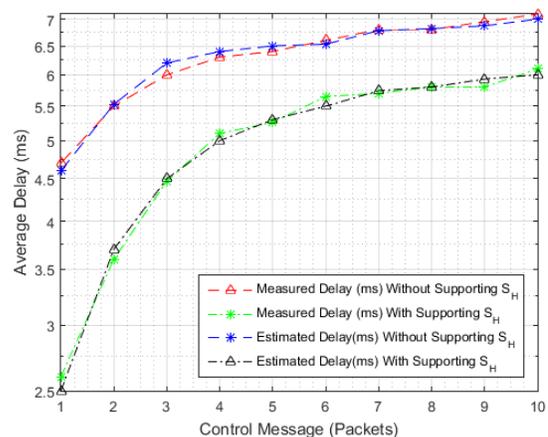


Fig. 17: Measured and Estimated Delay Comparison for Control Packets

In Fig. 17, a comparison between the measured and estimated delay values with the support of S_H and without S_H for both cases is depicted. The figure shows that the practical and predicted results scored higher delays when S_H was not utilized as a triggering signal than when it, with the corresponding estimation deviation varying from 0.02 ms to 0.27 ms. Also, from Fig. 17, it can be observed that for both cases of estimated and measured results, the proactive scheme of directing the flow of packets is developed by using S_H in the SDN network. The control delay has experienced a noticeable reduction in measured values by utilizing S_H . This reduction in the delay can be observed at the launch of making the decision by the SDNc to switch the packet flow path. This decrease in the delay is due to the proactive processing of control messages that are exchanged by the SDNc, AOFS, and the OFSs to switch the packets stream from APc to APn. The same observation of control delay can be seen with the

TABLE IV: The Testbed Setup Parameters.

Parameters	Value
T_s	28, 56, 98 m/sec
Packet Size	1522 Byte
Control Messages	10 message
Overlap Distance	40 m
Delay Per Link	0.001 msec
Processing Delay	0.005 msec
OFS Modifying Delay	0.005 msec
AOFS Modifying Delay	0.005 msec
SDN Modifying Delay	0.010 msec
Layer 2 RF Registration	50 msec
Test Duration	100 sec
Test Repetition	10 Times

predicted values. That is, this decreases at the beginning of taking the decision to change the packet flow path between the APs.

VII. CONCLUSION

Virtualization has added exceptional features to communication networks such as cloud computing, SDN, NFV, etc, which have led to improvements in performance. Despite these techniques having been applied, communication networks still need new creative ideas to meet the demands of the vital matters, such as reducing delay, dealing with high data rate throughput, enhancing reliability, guaranteeing session continuity, etc. Our proposal for an SDN network environment serving HSTs and provides results in a low controlling delay and high data rate delivery. We obtained the advantages of our proactive scheme through the reduction of controlling delay messages between the SDNc and the underlying OpenFlow switches. Moreover, our technique results in a decrease in the number of lost packets during the handover procedure in both the cases of increasing the channel bandwidth capacity and the train speed. Given the achieved results, we conclude that the obtained results indicate that, there is a need to find innovative ideas to enhance and support the virtualization techniques, for forwarding and directing flows of packets and reducing packets loss which greatly influenced by the speed of HSTs and the capacity of the data transmission link.

REFERENCES

- [1] D. Johnson, C. Perkins, and J. Arkko, "Mobility support in ipv6. ietf, request for comments: 3775, june 2004," 2004.
- [2] R. Koodli, "Fast handovers for mobile ipv6," 2005.
- [3] H. Soliman, C. Castelluccia, K. El Malki, and L. Bellier, "Hierarchical mobile ipv6 mobility management (hmip6)," Tech. Rep., 2005.
- [4] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy mobile ipv6," Tech. Rep., 2008.
- [5] H. Yokota, K. Chowdhury, R. Koodli, B. Patil, and F. Xia, "Fast handovers for proxy mobile ipv6," Tech. Rep., 2010.
- [6] J.-H. Lee, J.-M. Bonnin, I. You, and T.-M. Chung, "Comparative handover performance analysis of ipv6 mobility management protocols," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 3, pp. 1077–1088, 2013.
- [7] H. Modares, A. Moravejsharieh, J. Lloret, and R. B. Salleh, "A survey on proxy mobile ipv6 handover," *IEEE Systems Journal*, vol. 10, no. 1, pp. 208–217, 2016.
- [8] W. Luo, X. Fang, M. Cheng, and Y. Zhao, "Efficient multiple-group multiple-antenna (mgma) scheme for high-speed railway viaducts," *IEEE Transactions on Vehicular Technology*, vol. 62, no. 6, pp. 2558–2569, 2013.

- [9] J. Kim, H.-S. Chung, I. G. Kim, H. Lee, and M. S. Lee, "A study on millimeter-wave beamforming for high-speed train communication," in *Information and Communication Technology Convergence (ICTC), 2015 International Conference on*. IEEE, 2015, pp. 1190–1193.
- [10] M. Karakus and A. Durresi, "Quality of service (qos) in software defined networking (sdn): A survey," *Journal of Network and Computer Applications*, vol. 80, pp. 200–218, 2017.
- [11] G. Faraci and G. Schembra, "An analytical model to design and manage a green sdn/nfv cpe node," *IEEE Transactions on Network and Service Management*, vol. 12, no. 3, pp. 435–450, 2015.
- [12] J. Doherty, *SDN and NFV simplified: a visual guide to understanding software defined networks and network function virtualization*. Addison-Wesley Professional, 2016.
- [13] P. A. Morreale and J. M. Anderson, *Software defined networking: Design and deployment*. CRC Press, 2014.
- [14] J. Costa-Requena, J. L. Santos, V. F. Guasch, K. Ahokas, G. Premsankar, S. Luukkainen, O. L. Pérez, M. U. Itzazelaia, I. Ahmad, M. Liyanage *et al.*, "Sdn and nfv integration in generalized mobile network architecture," in *Networks and Communications (EuCNC), 2015 European Conference on*. IEEE, 2015, pp. 154–158.
- [15] F. Anwar, M. H. Masud, S. Bari, and S. A. Latif, "Enhanced handoff latency reduction mechanism in layer 2 and layer 3 of mobile ipv6 (mip6) network," *Australian Journal of Basic and Applied Sciences*, vol. 7, no. 6, pp. 658–671, 2013.
- [16] A. I. Sulyman, A. T. Nassar, M. K. Samimi, G. R. MacCartney, T. S. Rappaport, and A. Alsanie, "Radio propagation path loss models for 5g cellular networks in the 28 ghz and 38 ghz millimeter-wave bands," *IEEE Communications Magazine*, vol. 52, no. 9, pp. 78–86, 2014.
- [17] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N. Wong, J. K. Schulz, M. Samimi, and F. Gutierrez, "Millimeter wave mobile communications for 5g cellular: It will work!" *IEEE access*, vol. 1, pp. 335–349, 2013.
- [18] T. S. Rappaport, J. N. Murdock, and F. Gutierrez, "State of the art in 60-ghz integrated circuits and systems for wireless communications," *Proceedings of the IEEE*, vol. 99, no. 8, pp. 1390–1436, 2011.
- [19] S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter-wave cellular wireless networks: Potentials and challenges," *Proceedings of the IEEE*, vol. 102, no. 3, pp. 366–385, 2014.
- [20] K. Sakaguchi, E. M. Mohamed, H. Kusano, M. Mizukami, S. Miyamoto, R. E. Rezagah, K. Takinami, K. Takahashi, N. Shirakata, H. Peng *et al.*, "Millimeter-wave wireless lan and its extension toward 5g heterogeneous networks," *IEICE Transactions on Communications*, vol. 98, no. 10, pp. 1932–1948, 2015.
- [21] S. Hur, T. Kim, D. J. Love, J. V. Krogmeier, T. A. Thomas, and A. Ghosh, "Millimeter wave beamforming for wireless backhaul and access in small cell networks," *IEEE Transactions on Communications*, vol. 61, no. 10, pp. 4391–4403, 2013.
- [22] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive mimo for next generation wireless systems," *IEEE communications magazine*, vol. 52, no. 2, pp. 186–195, 2014.
- [23] T.-T. Tran, Y. Shin, and O.-S. Shin, "Overview of enabling technologies for 3gpp lte-advanced," *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, no. 1, p. 54, 2012.
- [24] Z. Gao, L. Dai, D. Mi, Z. Wang, M. A. Imran, and M. Z. Shaker, "Mmwave massive-mimo-based wireless backhaul for the 5g ultra-dense network," *IEEE Wireless Communications*, vol. 22, no. 5, pp. 13–21, 2015.
- [25] D. Wang and C. H. Chan, "Multiband antenna for wifi and wigo communications," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 309–312, 2016.
- [26] S. Wyne, K. Haneda, S. Ranvier, F. Tufvesson, and A. F. Molisch, "Beamforming effects on measured mm-wave channel characteristics," *IEEE Transactions on Wireless Communications*, vol. 10, no. 11, pp. 3553–3559, 2011.
- [27] T. Reshmi and K. Murugan, "Light weight cryptographic address generation (lw-cga) using system state entropy gathering for ipv6 based manets," *China Communications*, vol. 14, no. 9, pp. 114–126, 2017.
- [28] S. Hagen, *IPv6 essentials*. O'Reilly Media, Inc., 2006.
- [29] J. Davies, *Understanding ipv6*. Pearson Education, 2012.
- [30] S. Banerjee, M. Hempel, and H. Sharif, "Decoupled u/c plane architecture for hetnets and high speed mobility: research directions & challenges," in *2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC)*. IEEE, 2017, pp. 1–6.
- [31] P. Dong, T. Zheng, S. Yu, H. Zhang, and X. Yan, "Enhancing vehicular communication using 5g-enabled smart collaborative networking," *IEEE Wireless Communications*, vol. 24, no. 6, pp. 72–79, 2017.

- [32] H. Zhang, N. Liu, X. Chu, K. Long, A.-H. Aghvami, and V. C. Leung, "Network slicing based 5g and future mobile networks: mobility, resource management, and challenges," *IEEE Communications Magazine*, vol. 55, no. 8, pp. 138–145, 2017.
- [33] L. Lei, J. Lu, Y. Jiang, X. S. Shen, Y. Li, Z. Zhong, and C. Lin, "Stochastic delay analysis for train control services in next-generation high-speed railway communications system," *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, no. 1, pp. 48–64, 2016.
- [34] K. Banerjee, S. M. R. Islam, Z. I. Tahasin, and R. Uddin, "An efficient handover scheme for pmipv6 in ieee 802.16/wimax network," *International Journal of Electrical & Computer Sciences IJECS-IJENS*, vol. 11, no. 05, pp. 8–16, 2011.
- [35] C. Makaya and S. Pierre, "An analytical framework for performance evaluation of ipv6-based mobility management protocols," *IEEE Transactions on wireless communications*, vol. 7, no. 3, pp. 972–983, 2008.
- [36] M.-S. Chiang, C.-M. Huang, D.-T. Dao, and B.-C. Pham, "The backward fast media independent handover for proxy mobile ipv6 control scheme (bfmih-pmipv6) over heterogeneous wireless mobile networks." *J. Inf. Sci. Eng.*, vol. 34, no. 3, pp. 765–780, 2018.
- [37] X. Li, R. Ferdous, C. F. Chiasserini, C. E. Casetti, F. Moscatelli, G. Landi, R. Casellas, K. Sakaguchi, S. B. Chundrigar, R. Vilalta *et al.*, "Novel resource and energy management for 5g integrated backhaul/fronthaul (5g-crosshaul)," in *Communications Workshops (ICC Workshops), 2017 IEEE International Conference on*. IEEE, 2017, pp. 778–784.
- [38] X. Wang, G. Wang, R. Fan, and B. Ai, "Channel estimation with expectation maximization and historical information based basis expansion model for wireless communication systems on high speed railways," *IEEE Access*, vol. 6, pp. 72–80, 2018.
- [39] X. Yin and X. Cheng, *Propagation channel characterization, parameter estimation, and modeling for wireless communications*. John Wiley & Sons, 2016.
- [40] K. Phemius and M. Bouet, "Monitoring latency with openflow," in *Network and Service Management (CNSM), 2013 9th International Conference on*. IEEE, 2013, pp. 122–125.



Fouad Ali Yaseen received the BSc degree from the University of Technology, Baghdad, Iraq, in 1994. He received the MSc degrees from University of Baghdad, Baghdad, Iraq, in 2010, both in electronic and communications engineering. He is currently doing his PhD at Brunel University London since 2016. His research interests include wireless communication networks and mobile communication systems. He is a student member of the IEEE.



HAMED S. AL-RAWESHIDY received the B.Eng. and M.Sc. degrees from the University of Technology, Baghdad, Iraq, in 1977 and 1980, respectively, the Post Graduate Diploma degree from Glasgow University, Glasgow, U.K., in 1987, and the Ph.D. degree from the University of Strathclyde, Glasgow, in 1991. He was with the Space and Astronomy Research Centre, Baghdad, PerkinElmer, Waltham, MA, USA, British Telecom, London, U.K., Oxford University, Oxford, U.K., Manchester Metropolitan University, Manchester, U.K., and Kent University, Canterbury, U.K. He is currently the Director of the Wireless Network Communications Centre, Brunel University London.