Prototyping a Small-Scaled Resilient Software-Defined Wireless Mesh Network with Dual-band Data and Out-of-band Control Planes

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***Abstract*—The proposed design in this paper aims to improve the resiliency of Software-Defined Wireless Mesh Network (SD-WMN), by separating control and data planes, for the real-time video streaming applications. In this design prototype of SDWMN, dual-band (2.4GHz and 5GHz) wireless interfaces are adopted for the data plane while the out-of-band wired network is used for the control plane. The resiliency evaluation with the interface down scenario shows that the SDN-coordinated rerouting can effectively replace broken interconnections between selected wireless mesh nodes.**

***Keywords*—Software Defined Wireless Mesh Network, Ryu Controller, Open vSwitch**

I. Introduction

Wireless Mesh Network (WMN) [1] is the multi-hop adhoc network consisting of wireless mesh nodes and wireless mesh gateways. WMN are cost effective to apply widely due to its extendable ad-hoc behaviors. IEEE802.11 wifi standard [6] is used for wireless connectivity for the WMN. There are traditional routing protocols used in WMN , namely, proactive protocol, reactive protocol, and hybrid protocol [7]. However, routing behaviors of distributed mesh routing protocols used in WMNs are difficult to be modified and managed. Therefore, Software defined Networking (SDN) [2] with the help of OpenFlow protocol is used to eliminate the limitation of traditional WMN by separating the control plane and data plane of the network. There are data plane, control plane and application plane in SDN. The forwarding functions are done at the forwarding plane of the SDN. However, the forwarding decisions are accomplished by the instructions from the control plane of SDN which is the brain of the network. Any applications , for instance, routing and load balancing applications are written in the application plane of the SDN. The feature of network programmability provided by SDN lets the network administrator modify the routing behavior easily by using high-programming languages. The combination of WMN and SDN becomes Software Defined Wireless Mesh Network (SDWMN) [8] for the easier management of WMN. Open vSwitch (OVS) [3] is installed in all wireless nodes and works together with the SDN controller in the SDWMN. RYU [4] application is installed in Intel ® NUC for the features of the SDN controller. There are two ways to set up the control plane for the SDN. They are out-of-band and in-band modes. Out-of-band uses the dedicated control plane and in-band uses the shared control plane [5]. For the out-of-band strategy, since the control plane uses another dedicated network, it needs the additional networks such as 3G/4G connections, LoRaWAN [9], Zigbee [10] and WiMAX, and direct cabling between the SDN switches and the SDN controller.

In this paper, to achieve the control plane reliability, out-of-band mode is used, whereas dual-band is used for the resilient data plane. If an interface of one wireless mesh node is down, the Ryu controller application must have the ability to instruct that wireless node to switch the interface, change the routing and send the traffic to the destination nodes according to the flow rules that are predefined. This mechanism can provide the resilience for the data plane. The resiliency evaluation with the interface down scenario shows that the SDN-coordinated rerouting can effectively replace broken interconnections between selected wireless mesh nodes. In this paper, switching the interfaces according to the written flow rules are presented. This interface switching ability is essential for future steps to build the reliable resilient data and control planes.

II. Proposed Design and Implementation

The proposed design and implementation of the small-scaled resilient SDWMN are described in this section.

A. Proposed Design of SDWMN

This proposed design aims to improve the resiliency of Software-Defined Wireless Mesh Network (SDWMN), by separating control and data planes, for the real-time video streaming applications. In this design prototype of SDWMN, dual-band (2.4GHz and 5GHz) wireless interfaces are adopted for the data plane while the out-of-band wired network is used for the control plane. The control plane of the proposed SDWMN is implemented via the wired connection from each wireless mesh node and wireless gateway node to Intel NUC, where Ryu application is installed. The reason to choose out-of-band control plane in this proposed design is for the control plane reliability [5]. The data plane of the proposed SDWMN is implemented via the wireless connection from each wireless mesh node to wireless gateway provided by 2.4GHz and 5GHz bands. The primary route and the alternative route for the data plane are implemented by assigning the forwarding rules from the Ryu controller. Fig 1 shows the equipment setting of SDWMN by using 6 Raspberry Pi's and an Intel NUC. The data plane is divided into the primary route and the alternative route. The primary route is built by a 2.4 GHz band, and the alternative route is built by a 5 GHz band. The IP configuration and design of proposed SDWMN is shown in Fig 2.

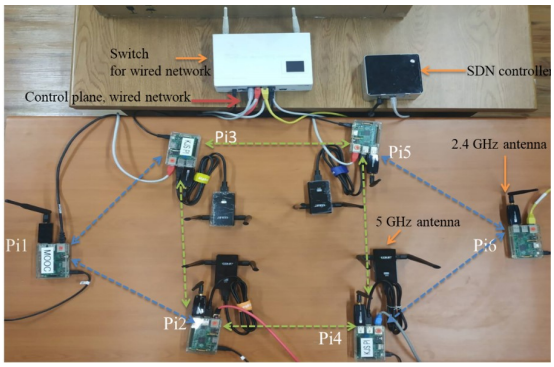

Fig. 1: Proposed SDWMN Network.

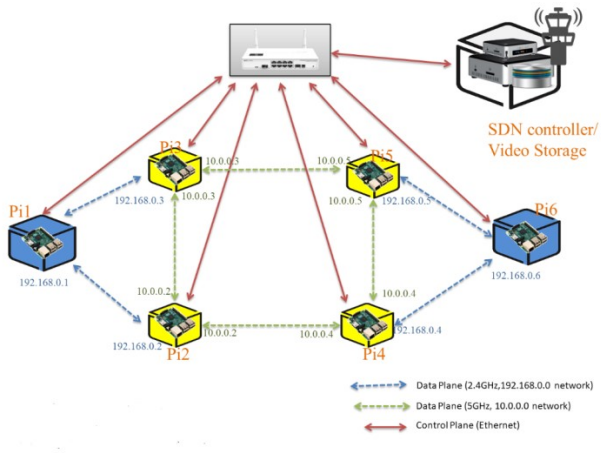

Fig. 2: Proposed SDWMN network with IP configuration.

B. Implementation of the Proposed Design

For the physical implementation of proposed SDWMN, the devices listed in Table I are used. The software needed for installation are listed in Table II. Four EDUP wireless Usb 3.0 dual band 2T2R dongles are equipped in Pi2, Pi3, Pi4 and Pi5 and are used as for the 5GHz band alternative data route. Six wtxup atheros ar9271 802.11n 300mbps wireless usb wifi adapters are adopted in all wireless mesh nodes to set up the 2.4GHz band primary data route. 192.168.0.0 network is used to set up the primary data routes and 10.0.0.0 network is used for the alternative data routes. In current setting, every wireless mesh nodes are reachable to each other. For example, Pi1 is reachable to Pi6 firstly via the primary data route. If Pi1 doesn't want to use primary route to reach to pi6, the alternative data routes are used. The Ryu application from the Ryu controller assigns the flow rules to the wireless mesh nodes so that wireless mesh nodes can be reachable to each other via the desired data routes.

TABLE I: Hardware list of indoor SDWMN in-band testbed.

Device	Functionality	Quantity
Intel ® NUC: 16GB, Intel ® Core™ i5-5300U CPU @ 2.30GHz x 4 [12]	As Ryu Controller	1
Raspberry Pi 2 Model B 2014 ver 1.1 [11]	As wireless mesh node	6
EDUP wireless USB 3.0 dual band 2T2R dongle	For the network reachability	4
Wtxup Atheros ar9271 802.11n 300Mbps wireless USB WiFi adapter	For the network reachability	6
Mikrotik Cloud Router Switch CRS109-8G-1S-2HnD-In [15]	To set up LAN connection among the Ryu controller and wireless mesh nodes	1

TABLE II: Software list of SDWMN in-band testbed.

Software	Function	Installed node
Ubuntu (16.04 LTS 64 bits) [14]	Linux operating system	Intel ® NUC
Ubuntu Mate (16.04.2 32 bits) [13]	Linux operating system	All Raspberry Pi's
Open Vswitch (version 2.5.5)	Virtual OpenFlow switch	All Raspberry Pi's
RYU	SDN controller	Intel ® NUC

III. Results and Discussions

To check whether the primary route and alternative route work correctly, ping program is used. Fig 3 shows the ping results from Pi3 to its neighboring wireless nodes. Ping result from Pi3 to Pi6 is shown in Fig 4. According to the results of Fig 3 and Fig 4, the primary route and the alternative route of SDWMN work properly. In order to check the connection status between the Ryu controller and the wireless nodes, the command described in Fig 5 is used. Fig 5 also shows the configuration of patch ports under OVS bridges. Patch ports are used to communicate between two OVS bridges. They are very important for interface switching mechanisms. According to Fig 5, the connection between Ryu controller and Pi3 is established correctly.

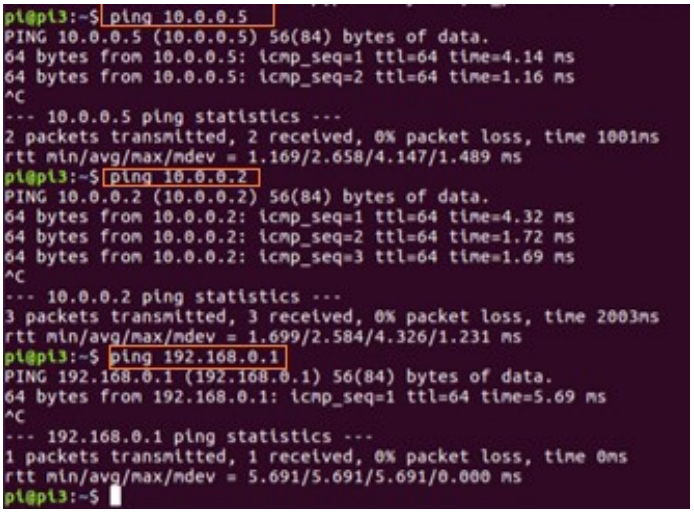

Fig. 3: Ping results from Pi3 to its neighboring nodes.

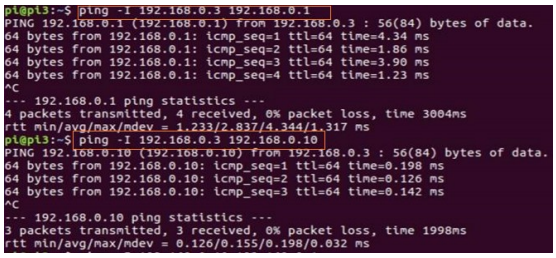

Fig. 4: Ping Results from Pi3 to Pi6.

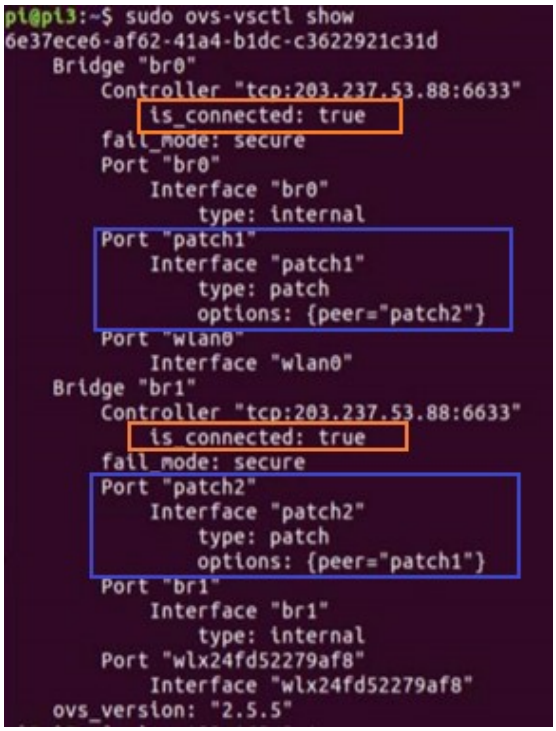

Fig. 5: Controller connection status and patch port configuration at Pi3.

IV. Conclusion

The prototype small-scaled resilient dual-band based SD-WMN testbed is implemented. The failure scenario of the wireless mesh node's single wireless interface and interface switching mechanisms are tested in the developed real testbed. With Ryu application implemented to install the necessary pre-planned forwarding rules for the primary route and the data plane, our test has confirmed the functionality of proposed SDWMN.

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