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A Review on SDN Principles in Wireless Mesh Networks

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Abstract: Software Defined Network (SDN) is the next generation network paradigm came into existence by separating data and control plane, with a centralized network management and optimization using global network information. However, overheads incurred by SDN are quite high, so its potential benefits must be evaluated in each networking setting. Fortunately, the benefits of SDN appear to outweigh the overheads incurred by it in most of the Wireless environments so far. In this paper, we will discuss SDN principles proposed and applied till date to WMN. SDN provides an arbitrary path for data flow by using a centralized controller, thereby making it very useful in deploying fine-grained traffic engineering algorithms in WMNs. However, since in WMNs the network is highly prone to fragmentation and node isolation, a centralized control may do more harm than good.We discuss many of the proposed way of implementing the same including an approach of performing network virtualization, routing and traffic engineering in the SDN-based WMNs and also a wireless spectrum allocation process; more specifically various scheduling and spectrum allocation algorithms, namely NFB-NS, FB-NS, and NFB-S that organize both data traffic and control traffic.

Keywords: Software Defined Networks (SDN), Wireless Mesh Network, Router, Open-Flow.

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I. INTRODUCTION

Computer networks are typically built from a large number of network devices such as routers, switches and numerous types of middle boxes with many complex protocols implemented on them. Among which a Wireless

Mesh Network (WMN) is a modern communications network fabricated with radio nodes organized in a mesh topology. It is also a form of wireless ad hoc network. A mesh refers to rich interconnection between devices or nodes. However, there are various wireless routers available today, which allows us to configure multiple interfaces for making a steadfast infrastructure. Access Point (AP) and Station (STA) are the basic two types of router configuration of hub routers and spoke routers respectively in a network. Software Defined Networking and its Open-Flow implementation [1] have been recently proposed for application in Wireless Mesh Networks (WMNs). The work in [2] describes the definition and implementation of a solution for Open-Flow-based routing in WMNs and its applicability to the mobility management of mobile clients. The works in [3] and [4] provide an analysis of opportunities and research challenges arising from the application of SDN in wireless heterogeneous scenarios, including WMNs.

In practical terms, switching from current WMNs based on IP routers to WMNs based on Open-Flow switches require a software update only. Indeed, most WMN nodes are based on Linux OS (e.g. OpenWRT distribution) and Open-Flow tools like the Open-Flow Reference Implementation [13] or Open vSwitch [14] are available for Linux-based systems (including OpenWRT).

While implementing SDN to WMN environment the unpredictability of radio channels may delay the communication with the controller and also the absence of layer 2 routing mechanisms such as spanning tree or Auto learning hampers the communication between the switches and the controller. Thus, with the achievement of many pros we get these cons as a bonus, which must be dealt with for a better network establishment. A proposal for using OpenFlow switches to route data traffic, and utilize the OLSR routing protocol to: i) route OpenFlow control traffic; ii) route data traffic in the emergency case of controller unavailability.

The centralized management and global knowledge is the biggest achievements of SD-WMN approach, but to maintain these features there is a huge overhead of message exchange between the controller and the Mesh routers which degenerates the network transmission with congestion. Therefore, some traffic scheduling algorithms are proposed by allocating spectrum, namely Fixed-Bands Non-Sharing (FB-NS), Non-Fixed-Bands, Non- Sharing (NFB-NS), and Non-Fixed-Bands Sharing (NFB-S) algorithms, to utilize spatial and frequency multiplexing.

II. RELATED WORKS

The SD-WMN can be classified into two broad categories when differentiated on the basis of communication style between the controller and the node routers. They are: 1) in-band (where data traffic as well as the control traffic are induced in the same network. [8,9]) 2) out-of-band (where the control traffic has a separate exclusive network[7]). Dely *et al.* [7] proposed the application of service set identifiers (SSIDs) in the IEEE 802.11 standard for distinguishing the control network and data networks in the same physical network. Detti *et al.* [8] have shown the installation of an in-band-style with OLSR for both control and data packets. Yang *et al*. [9] have also implemented the in-band approach to set an Open-Flow-based WMN which is used to balance the Internet traffic load. Chung *et al.* [10] has exploited both in-band as well as out-of-band configurations. Moreover a cascade-connected topology between switches and controller to forward traffic was also proposed based on in-band control deployment. Without any traffic control mechanism the throughput and the resource utilization of the network is depleted hugely when the control and data traffic compete with each other to be transmitted via a common channel. Hence we will also discuss a proposal from [11] where 3 traffic orchestration algorithms are discussed which divide the available bandwidth for traffic management, namely, FB-NS, NFB-NS, and NFB-S.

III. WORKING OF OPEN-FLOW SWITCH

An Open-Flow based SDN may be described by a standardized programming interface, called the Open-Flow protocol, which separates the control and forwarding functionalities. As shown in Figure 1, an Open-Flow network is formed by switches that forward data packets and communicates with one or more controllers using the Open-Flow protocol.

All the packets are forwarded based on the rules set by the controller. These rules not only define the behavioral model of the switches' response, but also take care of routing within the network. The rules consist of two basic parts, one of which is a match and the other is action. The packets coming into the routers check with the flow table to find if there is any match available to the type of packet received, if yes then follow the action associated with it to deal with the packet. Otherwise, the packet itself is forwarded to the controller to apply its programmed set of rules or logic to assign an action needed to be taken to deal with that packet.

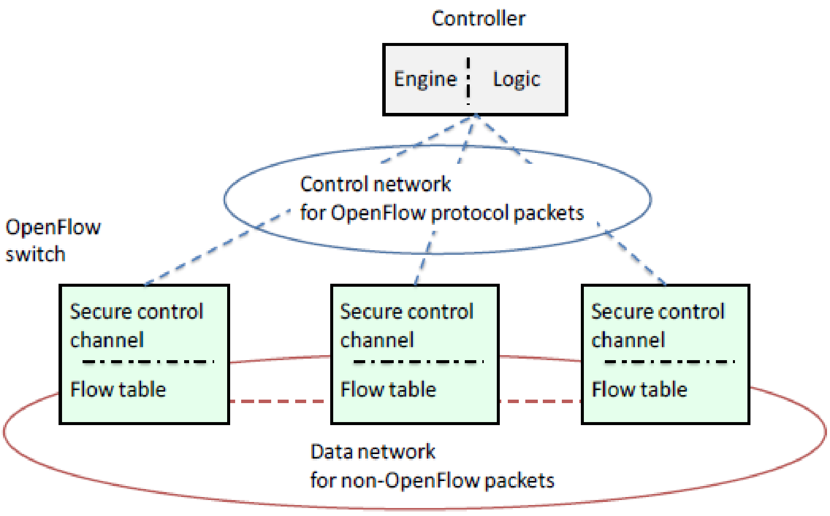

Figure 1: Open-Flow Network[5]

The rules are set in a proactive approach by the controller. In the time of forwarding a packet to the controller it is encapsulated in the open-flow control packet called packet-in.[9] The flow table replaces the routing table in a openflow switch, every packet flowing through the network follows the rules set in the flow table to move from a source to a destination via proper interface. Not only this the flow table is also responsible for rewriting the source and destination MAC addresses of the data packet at each router. We very well know the fact that in IP routing the next hop address is taken from the routing table and the conversion of IP address to MAC address can be done with ARP at the time of packet forwarding, but in case of Open-flow switch based routing the destination MAC address must be known when the rules are being set for packet forwarding. This marks of the biggest and basic difference between the IP based and Open-flow based routing. For implementing the Open flow mechanism one of the most important issues is the communication between the routers and the controller, which happens over TCP. Now this control may happen either "in-band" or "out-of-band" depending on the network setup, in other words, if the data and control traffic use the same network its call in-band whereas if it uses different networks then it is called out-of-band. There are some well known switching mechanisms like spanning tree algorithm or auto learning of MAC addresses which may be used to transfer data after a VLAN is set up to implement an out-of-band control, or an extra VLAN may be made specifically for transferring data traffic wherein the controller could handle the forwarding of data packets. But in case of in-band control implementation both the data traffic as well as the control traffic is managed by the Open-Flow controller. Similarly the incoming and outgoing packets to and from a controller are assigned actions based on locally constituted control rules or predefined (software defined) logics.

IV. WIRELESS MESH SOFTWARE DEFINED NETWORK

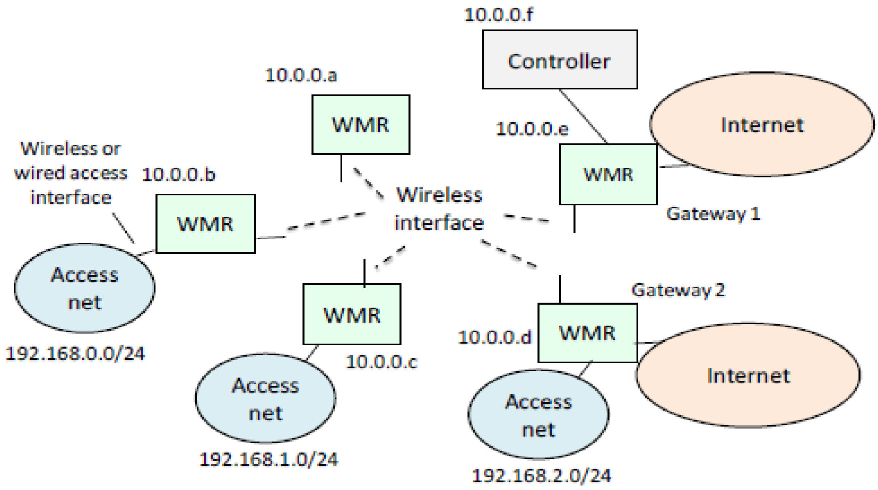

Figure 2: A WMN [6]

For implementing an Open-Flow based SDN in a WMN environment, we need to deal with some prerequisite issues , like setting up a robust network wherein the switches can communicate with the controller as well as also deal with a situation wherein the controller is unavailable due to any reason from link partitioning to device failure. A few proposals made to solve this issue one of which is included in [6] employs the use of different SSIDs to the network separately for data and control traffic. There is also a suggested strategy which takes care of controller failures by using the OLSR to set and assign control rules as well as routing information in a centralized controlled environment using only a single SSID.

For reference a network scenario shown in figure 2 is a WMN composed of WMRs providing connectivity to a set of Access Networks. This is the current status of a typical Wireless network. Whereas in SDN based approach a open-flow controller is connected to the WMRs through wired/wireless media. And the data traffic uses different subnets as control traffic.

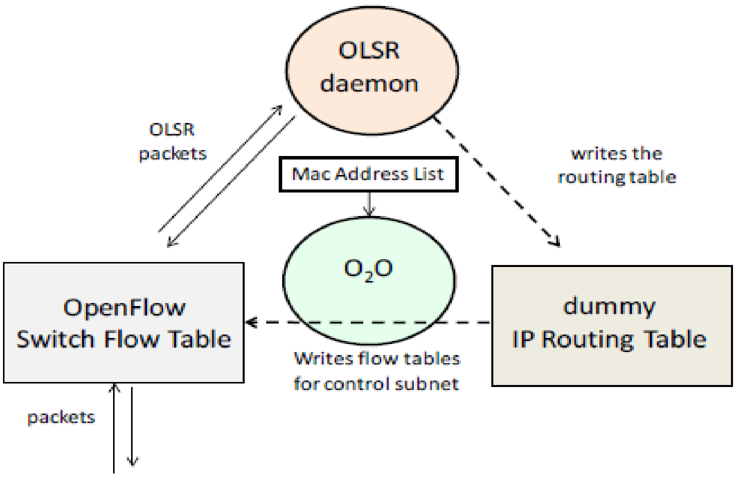

Figure 3: Open-Flow and OLSR interplay [6]

The controller and the WMR wireless interfaces get an address of the control subnet, while other interfaces of the network get an IP address belonging to different subnets, e.g. 192.168.x.0/24, each announced in OLSR as an HNA network. Figure 3 shows the main entities of a WMR involved in the interaction between OLSR and Open-Flow. The control-rules used by Open-Flow message are configured by the OLSR-to-Open-Flow (O2O) entity, by inspecting an IP routing table handled by the OLSR daemon.

The O2O sets a timeout (e.g. 60s) to the inserted control-rules for following any topology change and at the timeout expires the dummy IP table is dumped again on the Open-Flow Table. The OLSR operation as well as the Open-Flow traffic is supported by the control rules available in the flow table. These rules define the route of the incoming as well as outgoing packets to and from the OLSR daemon. Initially the packets received by the WMR search for any matching rules in the flow table which would define the upcoming action to be taken to forward the packet. If nothing is found, then the packets are embedded and transferred to the controller. The controller on receiving the packet applies the programmed routing logic to define the further course of action need to be taken for the packet. If in some case a controller fails due to any technical fault or natural disaster, all the rules in the flow table as well as the routing tables previously defined are flushed. Then the OLSR gains control of the routing and the Open-Flow mechanism is used for forwarding until the controller is back online. Once the controller is again reachable the emergency status is lifted and all the ongoing data flow is diverted to the controller, where it is decided how to re-route them.

V. USE-CASE: GATEWAY BALANCING

In this segment we discuss a proposal to balance traffic among the gateways of a WMN using Open-Flow switches. For a WMN using OLSR and IP forwarding the data fetch throughput is lower than Wm-SDN. Moreover a set of WMRs is used to connect the WMN to the internet, also known as gateways. Such an environment is exemplified in Figure 4 where the wireless mesh network is created by the combination of 6 Wireless Mesh Routers among which two routers act as Gateway to access internet services through an ADSL connection with uplink bandwidth 1MB/s. A controller and a server are also connected to this. For instance, in fig-4 the outgoing traffic takes either GW1 or GW2 to connect to the internet. By properly implementing a gate balancing algorithm we can distribute the load on each gate for better throughput and obtain high performance. One of the simplest proposed methods is to implement a round robin Gateway selection Algorithm (GSA) for the Open-Flow controller. The flow table of Wireless mesh routers receives the rules meant for routing a single data flow to a gateway, from the GSA. These rules use a couple of Source IP and Destination IP to identify the flow of the data by following two basic steps: i) First change the source MAC and destination MAC with MAC address on current WMR and MAC address of the next hop WMR respectively. ii) And secondly, forward the packet to the next WMR (i.e.; the WMR pointed by the destination MAC address field).[9]

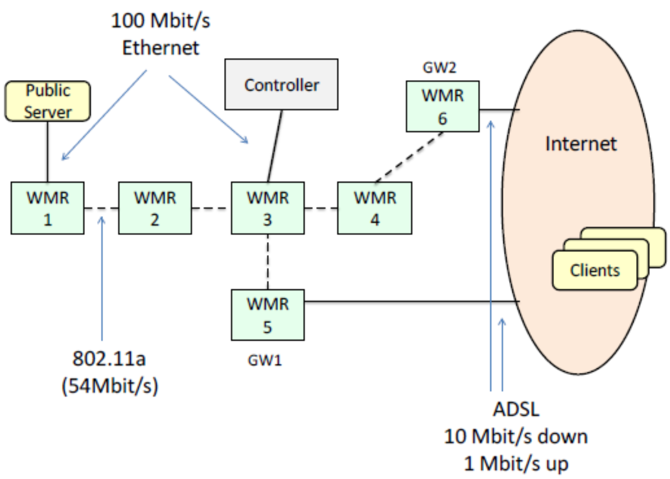

Figure 4: An example for gate-balancing implementation [9]

As for how to implement this GSA, we can simply select or assign the least recently used or assigned gateway to the flow in a round robin fashion. Although at the beginning of a new data flow the network itself is new to each node itself including the controller. The controller has no idea how to route these packets, however once the flow is calculated as mentioned above, the flow table is fed to the WMR by the controller. A weighted approach of the round robin fashion is useful for networks having different uplink bandwidth. In many cases the gateway failures may occur and once this is detected, all the existing rules are flushed forcefully by the controller and the outgoing data flow is restarted, taking into account the change in topology of the network.

For example in the scenario of Figure 4, we have two outgoing gateways namely GA1 and GA2, and if in case GA1 fails due to some technical or natural causes all the data flow is routed through the GA2 whileflushing and re-initiating any and all previous flow setup procedures [5].

VI. SPECTRUM ALLOCATION BASED WM-SDN

Radio spectrum is a canter source that should be powerfully utilized. For example, there are only 3 non-overlapping channels in the range of 2.4 to 2.483 GHz of IEEE 802.11b std. We can use these three channels to build a connection but the problem with that would be the interference of the signal while connecting more than 3 mesh routers. We also have an option of slicing the bandwidth and thereby reduce the interference while increasing the throughput. To say it in theory, it is as simple as a cup of tea, but the real life implementation is very sophisticated. Moreover, for the actualization of this idea we will initially require the global information about the topology of the network as well as the status of the links between the nodes of the network.[11]

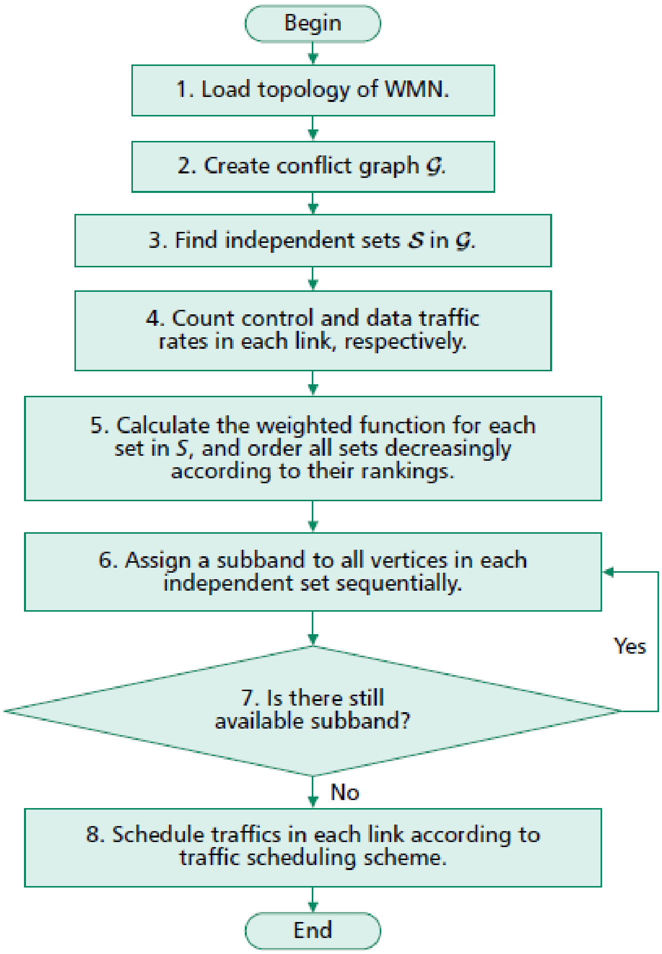

Figure 5: The framework of the FB-NS topology [11]

Fixed-Bands Non-Sharing Algorithm

One of the easiest and simplest algorithm proposed by Huang et.al [11], the FB-NS algorithm as shown in Fig 5. It simply allocates a fixed fraction of sub-bands to control traffic and data traffic separately. That is considering a total of S sub-bands, **a.S** sub-bands can be used to transmit control traffic and the rest **(1-a).S** sub-band for data traffic. As shown in Fig. 4, initially we need to know the WMN topology, after loading the topology to the algorithm, it creates a conflict graph G and an independent set of nodes S. The interference in radio networks can be described by conflict graphs [12], similarly in this graph G the vertices are connected via an edge if they conflict, i.e., the two can't be scheduled with the same sub-band simultaneously. In the forth step, the rates of control and data traffic are counted in each link available. After that the weighted function for each set is calculated and sorted in the decreasing order of their weighted throughput. In step-6, a sub -band is assigned to each independent set sequentially. Finally, if there is no sub-band available traffic is scheduled for each link according to the traffic scheduling scheme.

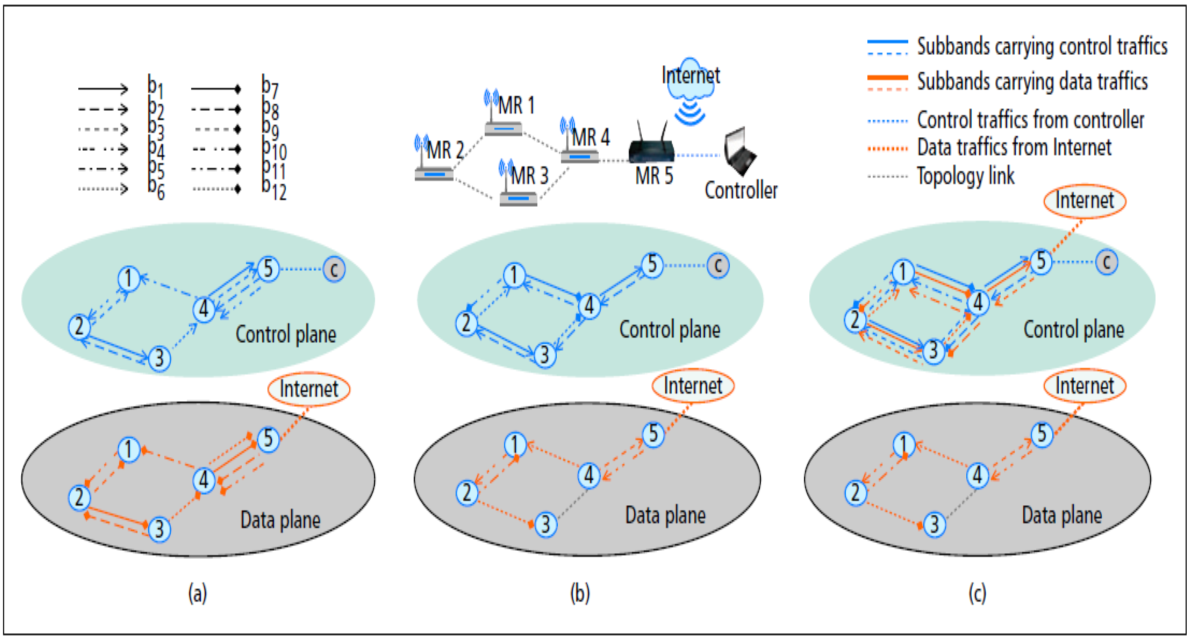

Figure 5: The illustration of three algorithms: a) traffic scheduling in the FB-NS algorithm; b) traffic scheduling in the NFB-NS algorithm; c) traffic scheduling in the NFB-S algorithm [11].

Non-Fixed-Band Non-Sharing Algorithm

There is a huge drawback to the FB-NS algorithm, although it is very simple and easy at implementation. The basic problem is that the fixed spectrum allocation is not capable of handling the real life scenario of traffic distribution which is by nature uneven over the entire network. This leads to low resource utilization and lesser throughput. Let's consider a real life scenario, where generally the control traffic is heavy near the controller and data traffic near the gateway. Thus, for avoiding congestion as much as possible, we may set the fixed allocation strategy. And thus a new algorithm was proposed NFB-NS which has no specific spectrum partitioning compared to the FB-NS algorithm.

Here the sub-bands are freely assigned to control and data traffic with control traffic having higher preference. For example, in the link (4, 1), sub-band set *b*5 is scheduled first for the control plane; the other available sub-band set, *b*6, is then selected to carry data traffic in the data plane. However, the same sub-band can't be shared by the control and data traffic flows, in other words they are transmitted in separated networks.[11] For example, in link (5, 4), b2 can be exploited to transmit control traffic only but not data traffic even though it has remaining capacity.

Non-Fixed-Band Sharing Algorithm

The NFB-NS algorithm doesn't allow the control and data traffic to share a sub-band, thereby reducing the forwarding capability, as the traffic rate is less than sub-band capacity. Hence a third algorithm was proposed to share a sub-band and improve spectrum utilization with similar motivation as NFB-NS of spectrum allocation. Here the data and control traffic shares the same sub-band, i.e.; once the need for control traffic is sufficed if there is any available bandwidth left it is used to transmit data traffic [11].

VII. OBSERVATIONS

After the detailed study of all the fore mentioned approaches in applying SDN to WMN, the observations and comparisons are listed in table1, while the pros and cons are listed in table2.

Table 1: Comparison of available principles of SDN which are implemented in WMN.

Literature and algorithms	Fashion	Approaches to building a control channel	Spectrum Spatial reuse	Guaranteed Control traffic	Multiple interfaces Required
Open-flow for WMN[7]	Out-of-band	Service set identifiers (SSIDs)	No	No	Yes
	In-band	Handled by Open-flow mechanism and locally configured control-rules	No	No	Yes

Wireless Mesh Software Defined Networks (WMSDN)[8]	Out-of-band	A substitutive wired network	No	No	Yes
	In-band	Legacy mesh communication	No	No	Yes
Open-flow Based Load Balancing for WMN[9]	In-band	OLSR routing protocol	No	No	Yes
Open-Flow based Gateway balancing[5]	In-band	Forwarding packets on a flow-basis and to route different flows on different gateways.	No	No	Yes
FB-NS[11]	Out-of-band	Spectrum division to allocate a fixed fraction of sub-bands to control traffic	Medium	Yes	No
NFB-NS[11]	Out-of-band	Spectrum division with no fixed band range restriction	Medium	Yes	No
NFB-S[11]	In-band	Based on NFB-NS, control and data traffic can share each sub-band capacity	Strong	Yes	No

Table 2: Pros and Cons of Traffic orchestration algorithms.

Algorithms	Pros.	Cons.
FB-NS[11]	Simplest of traffic control algorithms which divides and allocates the spectrum into fixed sub-bands to control and data traffic separately	The fixed spectrum allocation, easily leads to low resource utilization due to uneven flow of traffic in SD-WMN.
NFB-NS[11]	Control and data traffic are assigned bandwidth from available sub-band spectrum with no specific spectrum partitioning	Doesn't allow the control and data traffic to share a sub-band, thereby reducing the forwarding capability, as the traffic rate is less than the sub-band capacity
NFB-S[11]	The control and data traffic can share each sub-band capacity	It is really very hard to design such sophisticated traffic control algorithm

Summarizing all the above observation, we can easily deduce that: Aside from the traffic orchestration algorithms the Gate-balancing approach better exploits the uplink capacity provided by all the mesh gateways which improves the network throughput considerably, whereas on the other hand, although the implementation is quite sophisticated but the best performance with limited resources can only be achieved with the NFB-S algorithm with the developments so far.

VIII. CONCLUSION

The WMN itself is not so much flexible in real life implementation. The currently available resources, infrastructure and topologies of the WMN are too stiff at its core, bringing in the concept of SDN to define a WMN is a very new and broader way to exploit how much flexible the WMN can become. The simplicity to manage data and control flow once separated into two different planes is a special feature of the SDN. Also the SDN follows a central server architecture which, when implemented in WMN the wireless resources can be easily optimized and the system throughput is hugely benefited. The study above review mostly all available principles implemented in WMN till date, the Open-Flow based architecture showed how to increase network throughput by better managing the data and control flow through the gates connecting to servers and the internet. And the spectrum division techniques provided better traffic scheduling compared to OLSR based routing techniques.

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