An Adaptive Channel Utilization Method with Traffic Balancing for Multi-hop Multi-channel Wireless Backbone Network

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Abstract. This chapter presents an effective channel utilization method for a multi-hop wireless backbone network (WBN) constructed with multiple channels. In the previous work, we proposed a novel OpenFlow based management framework for the WBN, which enables access points to handle the unlimited number of channels simultaneously. Since the framework also enables us to easily and programmably use channels for packet forwarding, the utilization of multiple channels can be potentially optimized, thereby maximizing the network capacity of the WBN. However, since the previous work focused on the framework, the effective use of multiple channels was not completely addressed. Therefore, in this chapter, we propose a channel utilization method that balances the amount of traffic among multiple channels to maximize the network capacity. Through the performance evaluation in a real testbed, the proposed method can effectively use all channels in a 3-hop WBN.

Keywords: Effective channel utilization · Multiple channels · Wireless backbone network · Multi-hop communication · OpenFlow · WLAN

1 Introduction

Wireless mesh network (WMN) consists of two sorts of APs: gateway AP (IGW: Internet gateway) providing the Internet reachability to other APs and other APs constructing multi-hop wireless backbone network (WBN) to reach the Internet. Since a WMN can extend its coverage because of the ease of WBN extension, WMNs have been already deployed in wide area (e.g., shopping mall).

The WMN again attracts much attention as the promising large-scale wireless access network for emerging applications such as smart-grid communication, machine-to-machine communication, and mobile data offloading. The amount of traffic in such kind of communication is going to grow drastically along with the penetration of the devices. It is expected that more than 50 billion wireless devices including sensors, smart meters, and smartphones will connect to the

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Internet [1] and CISCO forecasts that the amount of mobile data traffic from such devices is increased by about 11 times between 2013 and 2018 [2]. However, existing WMN always suffers a limited network capacity due to the nature of multi-hop network. Therefore, the network capacity of WBN has to be increased especially on a single route toward the Internet (IGW).

Since the capacity of a single channel is physically limited, the effective use of multiple channels on WBN is absolutely necessary to expand the network capacity. To date, a routing protocol and channel assignment with multiple channels are mainly studied [3–6] but have the limitations on the number of channels APs simultaneously use and on the effective use of multiple channels. The previous work [7] proposed a new WBN, which handles the unlimited number of channels simultaneously. Also, a multi-channel management framework by exploiting OpenFlow was presented. However, since the previous work focused on the framework, the effective use of all available channels is not addressed.

In this chapter, we propose a channel utilization method that dynamically controls traffic on multi-channel WBN. Since our WBN has multiple wireless links with different channels between neighboring APs, the proposed method controls all traffic on WBN to balance traffic volume between all channels at each hop. Finally, the performance of the method is evaluated in a real testbed.

2 Related Work

The way to increase the network capacity is mainly studied by a multi-channel routing protocol with channel assignment [3–6]. Although the use of multiple channels is effective to increase the network capacity, many studies assume an AP with few interfaces (IFs) [6] due to hardware equipment, thereby limiting the increase of the network capacity. Since we actually observed that there are more than three vacant channels in 5 GHz band), the number of channels each AP simultaneously uses should be flexibly increased in accordance with the number of vacant channels.

The studies on the routing basically switch paths (with different channels) based on the routing table. However, these protocols cannot simultaneously use multiple links between two neighboring APs because the routing table contains only a single path (channel) to reach a destination IP address. To effectively utilize multiple channels, packets should be transmitted on different channels even if all packets have a same destination IP address. Thus, a traffic management framework that dynamically changes paths is essential.

IEEE standards of 802.11n/ac can increase the capacity by the channel bonding. The technology mandatory requires that consecutive channels (2, 4, or 8 channels) are vacant. In a real environment, it is difficult to monopolize the use of such channels because there are sometimes multiple but not consecutive vacant channels. Thus, the flexible way of integrating multiple channels is crucial.

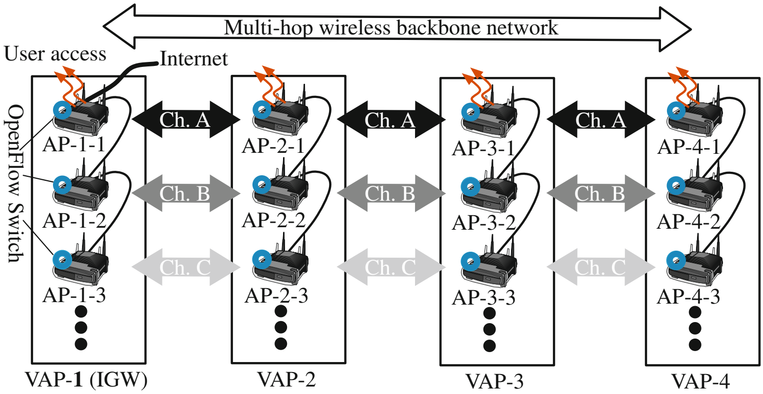


Fig. 1. VAP and WBN with multiple channels.

3 OpenFlow Based Management Framework

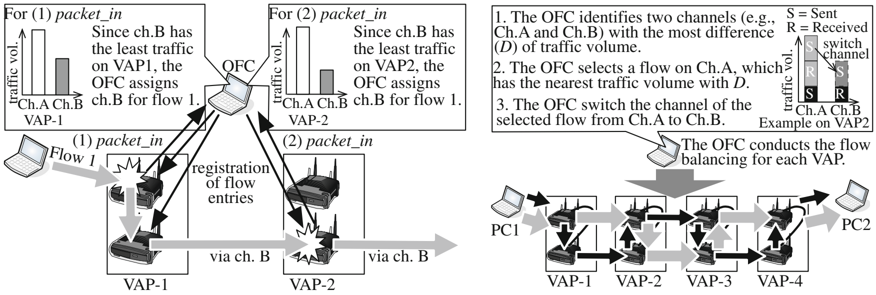
This section introduces our OpenFlow based management framework proposed in the previous work [7]. To handle the unlimited number of channels, we first employ a virtual AP (VAP) shown in Fig. 1. A set of APs (sub-APs), each of which uses a single but different channel for the WBN, is connected by Ethernet and then constructs a VAP handling multiple channels. From this architecture, the number of channels can be flexibly increased by adding sub-APs for VAP.

Since an existing technology cannot exhaustively utilize multiple channels, we next employ the OpenFlow technology to programmably control the channel utilization based on *flow* management. A flow is defined by various identifications between layer 1 and 4. In this study, we use 4-tuple (source/destination IP address and port number) as the flow identification.

OpenFlow consists of a controller (OFC) and switches (OFS). An OFC determines control rules of flows called *flow entries* (a pair of flow identification and action) and registers them to OFSs. An OFS controls each flow by following the registered rules. The registration is conducted when the OFS initially connects with an OFC and/or when the OFS receives unknown packets (i.e., the packet does not match any flow entries) and reports it to the OFC (called *packet_in*). We assume that an OFS is installed in all APs in this study. Also, an OFC is connected to all OFSs directly by Ethernet to avoid the effect on the control traffic. Note that, since our focus is to increase the network capacity on a single route to an IGW, we assume a WBN with a chain topology such as Fig. 1.

4 Adaptive Channel Utilization Method

Although the framework enables us to programmably guide packets through multiple channels, the way of maximizing the network capacity is still necessary. In the previous work [8], we implemented two channel utilization methods



(a) Channel assignment at flow arrival. (b) Periodic traffic balancing.

Fig. 2. The behavior of the proposed method.

that multiplex conventional WBNs. In both methods, the OFC allocates either channel in the arrival order of *packet_in*. The methods are different in multi-hop relay manners: each flow is transmitted on a persistent channel (BCA-PC), while being transmitted on a different channel for each hop (BCA-DC). However, the capacity of all channels cannot be fully consumed when a data rate of each flow is different. That is, because a channel is selected for each flow in the fixed order, a channel allocated for a flow with large data rate may be congested but will be allocated for a new flow even if the other channels are still underutilized.

To solve the problem, we propose a method that adaptably balances the traffic amount of all channels. Since the OFC guides each flows depending on its traffic volume from the aspect of traffic balancing on all channels, the whole capacity can be exhaustively consumed, thereby maximizing the network capacity. The procedures of our proposed method are described in following sections.

4.1 Arrival of a New Flow

All OFSs initially have no flow entries and thus must report *packet_in* at every arrival of new flow. Also, an OFC periodically collects the total amount of transmitted/received byte (traffic) for each channels of individual VAP based on a PortStats request/reply exchange at certain interval (*MonInt*). Since the PortStats indicates the cumulative traffic volume, we use the difference between two consecutive results of the PortStats transmitted for short interval (*StatsInt*).

When a new flow arrives at a VAP (Fig. 2(a)), the VAP sends *packet_in* to the OFC. The OFC determines the identification of the flow based on 4-tuple and selects a channel with the least amount of traffic. After the OFC registers the corresponding flow entries to the OFS(s) in the VAP, the VAP starts to forward packets of the flow through the selected channel. The next hop VAP also sends *packet_in* to the OFC when receiving a packet of the flow and then the OFC selects a channel in the same manner. In this way, the OFC guides packets of the flow through the channel with the least traffic volume at each hop. Note that, if the traffic volume on all channels is same (or there are no flows), the OFC selects a channel used by the first sub-AP.

Table 1. Throughput (Mbps).

	Maximum	Median	Minimum	Average
Conventional WBN (1ch)	9.54	9.48	9.40	9.48
BCA-PC (2ch)	11.47	11.35	11.28	11.36
BCA-DC (2ch)	15.82	15.76	15.65	15.74
Proposed method (2ch)	19.00	18.87	18.75	18.88

4.2 Periodic Traffic Balancing

To keep balancing the traffic volume on all channels, the OFC periodically checks the difference of traffic volume on all channels for each VAP (Fig. 2(b)). This check is periodically performed at the interval of *MonInt* as well as the periodic PortStats.

At the check for each VAP, the OFC identifies two channels (OFSs) whose difference of the traffic volume is the largest (this difference is referred as D). Then, the OFC collects the traffic volume of every flow on the OFS treating more traffic by exploiting a FlowStats request/reply exchange. Since the FlowStats provides the cumulative number, we use the difference of two consecutive results of the FlowStats transmitted for *MonInt* as a traffic volume of flow. The OFC next selects a flow that has the nearest traffic volume with $\frac{D}{2}$ and switches channels of the selected flow to the channel carrying the minimum traffic volume. In the same way, the OFC periodically balances traffic volume on multiple channels on all VAP, thereby utilizing the network capacity efficiently.

5 Performance Evaluation

5.1 Experimental Setup

We implement the proposed method on the OFC (Trema) and then conduct its performance evaluation. In the implementation, *MonInt* is configured to 1 s and *StatsInt* is 500 ms. We employ Buffalo WZR-HP-AG300H as a sub-AP and install OpenWrt firmware with Open vSwitch (version 2.1.0) to it. The OFC connects to OFSs by Ethernet. We also use the same topology (3-hop and 2 channels WBN) with Fig. 2(b) and place sub-APs to 0.7 m apart from each other. They operate IEEE802.11a with two channels of 40 and 48. Two PCs (PC1 and PC2) are connected to VAP1 and VAP4 directly by Ethernet.

5.2 Evaluation Result

In this experiment, PC1 transmits multiple flows to PC2 but their data rate is imbalanced each other. That is, PC1 transmits a flow of 1 Mbps UDP and a flow of 0.1 Mbps UDP at 5 s interval for 18 times (e.g., 1 Mbps, 0.1 Mbps, 1 Mbps, 0.1 Mbps ... totally, 19.8 Mbps), alternately. We then measure the network capacity by the total throughput received at PC2. The throughput is averaged for 30 s after 5 s since the transmission of all flows is started.

We here compare the proposed method with three comparative methods: a conventional WBN and our previous proposals (BCA-PC and BCA-DC) [8]. The conventional WBN uses a single channel but other methods use 2 channels simultaneously. The experiment is conducted for 9 times and the summary of the results is shown in Table 1. From Table 1, the conventional WBN can carry around 9.5 Mbps traffic, which is considered as the maximum capacity with 3-hop WBN with a single channel. Although BCA-PC/DC can use 2 channels simultaneously, the throughput is not double of the conventional WBN. Because both BCA-PC/DC allocate a channel in order of *packet_in* arrival, all 1-Mbps flows (totally, 18 Mbps) are concentrated on one specific channel so that the network capacity is inherently overloaded. As a result, the total throughput is saturated. BCA-DC switches channels at each hop to avoid the congestion but its improvement is limited. The proposed method brings almost the double of the conventional WBN. Therefore, the traffic balancing brought by our proposed scheme is effective to utilize the network capacity of all channels.

6 Conclusions

In this chapter, we proposed an OpenFlow based channel utilization method that adaptably allocates a channel for each flow to balance the amount of traffic transmitted on each channel. We implemented the method and evaluated its performance in a real testbed. Through the comparison with other methods, we can conclude that the proposed method can bring the largest network capacity even if the data rate of each flow is imbalance. For the next study, we will extend the method to control the dynamic traffic like TCP.

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