A Channel Utilization Method for Flow Admission Control with Maximum Network Capacity toward Loss-free Software Defined WMNs

Masaki Tagawa
Graduate School of Information Science
Nara Institute of Science and Technology
Nara, Japan
e-mail: tagawa.masaki.td4@is.naist.jp

Yuzo Taenaka
Information Technology Center
The University of Tokyo
Tokyo, Japan
e-mail: taenaka@nc.u-tokyo.ac.jp

Kazuya Tsukamoto
Department of Computer Science and Electronics
Kyushu Institute of Technology
Fukuoka, Japan
e-mail: tsukamoto@cse.kyutech.ac.jp

Suguru Yamaguchi
Graduate School of Information Science
Nara Institute of Science and Technology
Nara, Japan
e-mail: suguru@is.naist.jp

***Abstract*—This paper proposes an efficient multi-channel utilization method that reduces packet loss on software defined multi-channel wireless mesh network (SD-WMN). In SD-WMN, multiple channels can be used in parallel along with a route. To utilize multiple channels efficiently, we proposed a channel utilization method that balances the channel load by exploiting the flow-based control of OpenFlow. However, packet loss often occurs under this proposed method. Specifically, this method balances the network load, thereby decreasing the available capacity of each channel. Along to this, an acceptable flow also becomes smaller. A channel may run out of capacity when a large flow arrives, even if the total available capacity provided by SD-WMN is sufficient for that flow. Thus, in this paper, we propose a new method that is optimized to increase the available capacity on some of all channels by intentionally making the channel utilization imbalanced. When a new flow arrives, the flow is transmitted on the channel, thereby minimizing the possibility of packet loss. We then conduct some experiments in various scenarios and show that the method can extremely decrease the packet loss at the time when a flow arrives.**

***Keywords*—capacity management; traffic engineering; multiple channels; OpenFlow; wireless mesh network.**

I. INTRODUCTION

With the popularization of smart devices, the amount of mobile data traffic from such devices is expected to increase nearly tenfold between 2014 and 2019 [1]. To offload this heavy traffic from cellular networks, access points (APs) which are base stations on a wireless local area network (WLAN) are spreading. However, APs tend to be densely placed near each other and often suffer from severe radio interference. Furthermore, the coverage area of each AP overlaps with each other, thereby resulting in small service coverage. From these reasons, the amount of offloading traffic is still limited under current WLAN environments. Therefore, it is essential to extend WLAN coverage.

Wireless mesh network (WMN) is a good solution to extend WLAN coverage. In WMN, all APs construct a multi-hop wireless backbone network (WBN) by using the same channel and only some specific APs provide the Internet connectivity to other APs through the WBN. The multi-hop network contributes to large coverage but limits the network capacity because the capacity of a single channel is theoretically limited. In order to exploit WMN for the purpose of coverage extension, we need to increase the network capacity by effectively aggregating multiple channels.

In the previous work, we proposed a novel WMN architecture that utilizes multiple channels in parallel [2]. However, the network capacity provided by a WBN strongly depends on how to utilize multiple channels. We thus proposed a channel utilization method to maximize the network capacity. The method balances the network load by switching transmission channels for each flow while considering the impact of radio interference inside the WMN. This method is called Traffic Volume Balancing Method between Interference APs (TBI) [3]. However, TBI often causes packet loss when a new flow arrives. Since TBI utilizes all channels equally, the available capacity of each channel is decreased in accordance with the increase of flows. More specifically, the acceptable flow size of every channel becomes smaller. As a result, when a flow arrives, no channel can transfer the flow without packet loss even if the available capacity provided by all channels is enough for transmitting the flow. To avoid such situation, the available capacity of some channels should be maximized as much as possible even when there are multiple flows.

In this paper, we further develop the channel utilization method to avoid packet loss at the time of flow arrival. The method tries to maximize the available capacity on some of the channels on a WBN. That is, the method fills channels with flows, thereby making the channel utilization imbalanced. The channel is selected in order from least available capacity for keeping channels with large available capacity to carry a new flow with minimum possibility in packet losses.

The rest of the paper is organized as follows. Section II is an overview of related work. In Section III, we outline an overview of our previous studies and point out potential packet loss on channel utilization methods which balance the

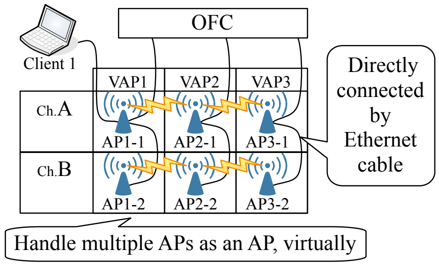


Figure 1. WBN architecture with virtual AP.

network load on multiple channels. Section IV develops the channel utilization method to avoid packet loss by making the channel utilization imbalanced. In Section IV, we implement and examine the proposed method in a real testbed and demonstrate the effectiveness of our method. Finally, we conclude this paper with conclusions and future work in Section VI.

II. Related work

To date, many studies focusing on routing protocols, channel assignment, and a MAC protocol, have been conducted for increasing network capacity [4–9]. Furthermore, many multi-channel routing protocols are conducted in conjunction with channel assignment [5–9]. In essence, these studies dynamically switch paths by updating the routing table in response to the change in the network condition. However, these protocols cannot simultaneously use multiple paths between two neighboring APs because the routing table generally contains only a single path (i.e., one channel) to reach a neighboring AP. Thus, it is necessary to propose a channel utilization method that uses all available channels between neighboring APs effectively and simultaneously.

III. Previous work

This section outlines an overview of our previous studies [2][3]. We first introduce the architecture of our WBN in Section III-A and then briefly describe TBI in Section III-C. Finally, we point out potential packet loss on TBI in Section III-C.

A. Multi-channel WBN based on OpenFlow control

Single channel WMN can suffer from serious network capacity degradation due to the nature of the wireless medium. Therefore, in order to increase the network capacity, effectively aggregating multiple channels is needed. To increase the number of channels used for the WBN, we employ a virtual AP (VAP) as shown in Figure 1. The VAP consists of multiple APs, each of which uses a single but different channel for the WBN and are directly connected by Ethernet cable. From this structure, we can flexibly increase the number of channels used for the WBN in accordance with the number of APs belonging to the VAP. Note that, to easily indicate each VAP, a VAP have its own identification number (VAPID) denoted as "VAPX". In addition, each AP is uniquely identified as "APX-Y", which combines a VAPID ($= X$) and a sequential number (APID) ($= Y$).

To flexibly use channels on the WBN, we employ OpenFlow, which enables us to use programs to control flow transfer. In this study, a flow is identified by 4-tuples (source/destination IP address and port number). An OpenFlow network consists of an OpenFlow Controller (OFC) and an OpenFlow Switch (OFS). The OFC connects with all OFSs (=APs) and determines flow control rules (flow entries) when necessary. All OFSs actually handle flows by following flow entries which are cached in a local database (flow table). By exploiting flow based control mechanism of OpenFlow, we can flexibly select a path (channel) for each flow at each hop. That is, we dynamically control channel utilization on the WBN.

B. Proposed channel utilization methods

We introduce a channel utilization method, TBI, which was proposed in the previous work[3]. The method balances the network load by controlling transmission channels of each flow. TBI treats the byte count transmitted for certain duration as the network load. Since there is radio interference between hops in a multi-hop network, TBI also considers radio interference inside the WBN. More specifically, the OFC makes all OFSs (APs) send probe packets to each other and then identifies interference APs for each AP. Then, based on this recognized interference (i.e., radio range), the OFC calculates the total amount of bytes transmitted within radio range and uses this as the network load.

TBI tries to balance the network load, however, the network load caused by new flows is unknown at first. Therefore, the OFC cannot find an appropriate channel for a flow so as to balance the network load at a flow arrival. Thus, in TBI, the OFC tentatively selects a channel to carry the flow. Once the OFC identifies the traffic volume of the flow, the OFC tries to change the channel to carry the flow to balance the network load among all channels in the WBN. TBI achieves these two allocations by two types of processing: the initial allocation and the late binding, respectively.

In the initial allocation, the OFC tentatively selects a channel with lesser network load to avoid packet loss as much as possible. The initial allocation is conducted upon the arrival of each new flow. On the other hand, the late binding process tries to make the traffic volume of each channel on a VAP balanced in case of imbalance utilization of channels. For the late binding, the OFC periodically checks the transmitted byte count of each flow. Then, in order to obtain the network load of each channel, the OFC calculates the sum of transmitted byte counts of each flow on each channel. If the OFC identifies an imbalanced channel utilization, the OFC switches the transmitting channel of some flows in the WBN.

C. Potential packet loss due to balancing mechanism

TBI balances the network load by equally transmitting flows in terms of transmitted bytes as shown in Figure 2. Along with the increase of flows, the available capacity decreases on all channels. Although TBI transmits a new flow on a channel with the lowest network load, the available capacity of a single channel may not be enough for the flow and packets

 ISBN: 978-1-61208-450-3

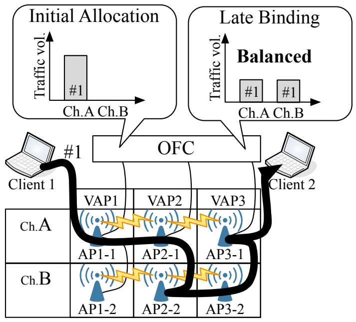


Figure 2. Example of flow allocation with TBI.

are inevitably dropped. However, even in this case, the WBN may still have sufficient available capacity for the flow with regards to the sum of available capacity in all channels. From these considerations, we conclude that the balancing channel utilization method increases the possibility of packet loss.

IV. Proposed Method

We propose a new channel utilization method to minimize the number of packet losses. Since the reason for packet loss is the balancing mechanism as described in Section III-C, we intentionally create an imbalanced channel utilization. That is, the available capacity is maximized on some of the channels and other channels are filled by flows. If at least one channel can have a large available capacity, the possibility of packet loss could be minimized by transmitting a new flow on such a channel. In order to fill the channel with flows without packet loss, it is necessary to calculate the available network capacity of each channel. The calculation method of these capacity is described in Section IV-A. To achieve flow allocation according to the concept, an arriving flow is (1) initially transmitted on a tentative channel and then (2) moved onto a channel to fill the channel. Also, some flows are switched to a channel whenever a flow transmitted on the channel is ended. These processes are described in Section IV-B, Section IV-C and Section IV-D, respectively.

A. Calculation of available capacity

To maximize the available capacity in some channels, flows should be packed into the smallest number of channels. To design a method according to the concept, it is necessary to precisely know the available capacity on every channel because without this information, a channel may be saturated due to running out of capacity.

In the wireless network, it is easy to measure the amount of transmitted traffic but the available capacity is not so. In this study, we estimate the available capacity based on the information about transmitted traffic. We first obtain the statistical information on transmitted traffic (i.e., the number of transmitted packets and the amount of transmitted traffic) for every channel on every VAP. In this measurement, we collect it twice for the predetermined interval (0.5 seconds in this study) and calculate its difference. This means that the calculated packets are transmitted during the interval. We also measure the physical link rate of every channel on every hop.

We next estimate the time that was necessary to transmit the packets (i.e., channel occupancy time). It can be calculated by dividing the amount of traffic (including frame/packet headers) by the physical link rate and then adding overhead (e.g., DIFS and SIFS) of every packet transmission. Since the statistical information was measured for the predetermined interval, we can easily find the duration that was not occupied, i.e., the differences between the predetermined and the calculated channel occupancy time. Finally, we can calculate the available capacity by multiplying the unoccupied duration by the physical link rate.

B. Tentative channel allocation for arrival flow

In order to minimize the possibility of packet loss in TBI, new flows are transferred with a channel which has largest available network capacity. However, it is important to note that the available network capacity should be shared by some flows. For example, when multiple flows arrive almost simultaneously, TBI uses the same information about available network capacity to select a tentative channel to transmit each of them. As a result, they are transmitted on the same channel and share the available network capacity of a single channel. If other channels are free, these channels should be selected for some of the flows to avoid packet loss as much as possible. From this consideration, we additionally consider the expected occupation capacity on a channel for each arriving flow. That is, we take into account the number of flows, which is transmitted on a channel but its occupation capacity is not identified yet. The detailed process is described below.

The tentative allocation is conducted at each arrival of flow. The OFC first obtains the available network capacity of each channel (referred to as Ac) as described in Section IV-A. Then, the OFC collects the number of flows which are supposed to be sharing the available network capacity (this number is referred to as n). To obtain this, the OFC checks the number of flows whose statistical information (i.e., the number of transmitted packets and the amount of transmitted traffic) has not yet been identified. Note that, to calculate the expected occupation capacity, we increase the number by one as if the focusing flow is transmitted on the channel.

The OFC next estimates the expected occupation capacity of the flow on each channel by $Ac/(n+1)$. Then, the OFC identifies the channel with the largest expected value. Note that this process is performed on all hops upon which the flow will pass. Finally, the OFC allocates the flow to the identified channel by registering flow entries to OFSs.

C. Packing flows into the smallest number of channels

Since the OFC cannot obtain the statistical information of a flow at its arrival, the OFC tentatively allocates the flow to the channel. To minimize the possibility of packet loss in the tentative channel allocation, the WBN should keep some channels free. To achieve this, we pack as much flows into the smallest number of channels. Note that in accordance with the increase of flows, the number of channels which are filled by flows inevitably increases. In order to obtain largest available capacity among these channels, we select a channel to be filled next in order from the least available capacity to the largest.

After the tentative channel allocation at arrival of a flow, the OFC tries to move the flow to a specific channel. For this migration, the OFC periodically collects statistical information for every flow and calculates the available capacity on each channel as described in Section IV-A. Then, once the statistical information on flows which are transmitted on a tentative channel is acquired, the flow should be migrated to a specific channel.

The OFC then tries to find a channel to migrate the flow. The channel is selected in order of the least available capacity at that time. Then, the OFC compare the available capacity of the selected channel with the amount of the flow. If the amount of the flow is smaller than the available capacity, the flow is switched onto the channel. Otherwise, the OFC selects a next candidate channel and conducts the same process until finding a channel to be used. If the flow cannot be allocated to any channel other than the current channel, the flow remains on the channel.

D. Handling flow completion

When a flow is ended, the available network capacity increases at the channel that transferred the flow (this channel is referred to as B). In this case, some other flows can be packed into channel B, thereby increasing the available capacity on other channels. Therefore, we try to move flows to channel B and fill the gap caused by the completion of the flow so that other channel could be used for a tentative channel at flow arrival. To achieve this, the flow is selected on a channel that carries flows but have the largest available capacity. If no flow is found on the channel, the OFC focus on the next channel that has the next larger available capacity. Note that, if any flow cannot fit the gap, the OFC left the gap to pack a new flow that should arrived later. The detailed procedure is described step by step below.

OpenFlow has a function in which the OFS (AP) automatically notifies the OFC about the inactiveness of flow entries which handle the packet transmission of each flow on the OFS. Therefore, we regard the flow as completed when this notification is generated. When the OFC finds the channel whose flow is completed (this channel is referred to as B), the OFC tries to change transmitting channel of flows from other channels to channel B as shown in Figure 3. Specifically, once the OFC finds the channel B, the OFC checks the available network capacity of each channel in descending order. If the available capacity of the channel is greater than that of channel B, the OFC checks flows on the selected channel.

The OFC tries to identify flows on the channel to fill channel B. To achieve this, the OFC calculate the occupancy network capacity of each flow in the same way described in Section IV-A. The OFC then compares this and the available capacity of the channel, then decides whether the flow can be sent on the channel without packet loss. At this time, in order to migrate flows as much as possible, the OFC selects target flows in descending order of the occupancy network capacity. Finally, the OFC changes the transmission channel of the identified flow to channel B. In this way, the OFC keeps a specific channel to be filled by flows whenever a flow ends.

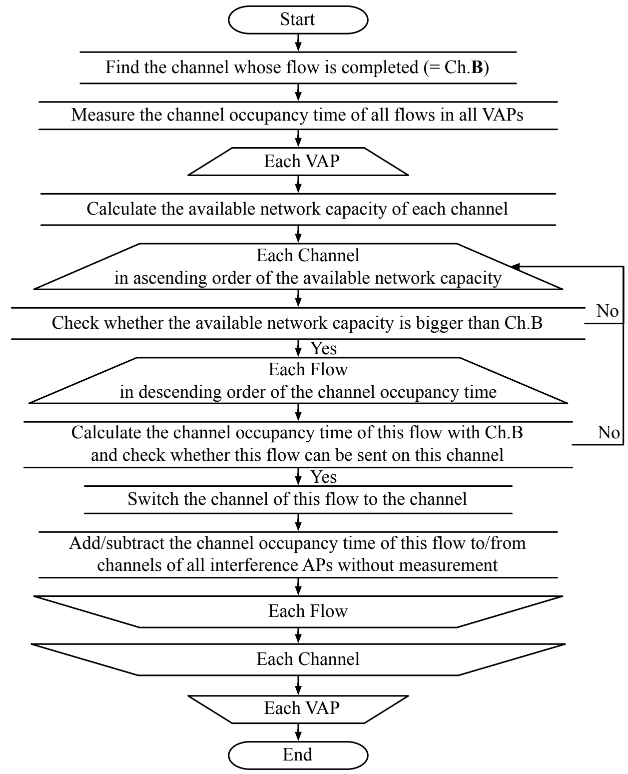


Figure 3. Flowchart of handling flow completion.

V. Performance evaluation

We evaluate the effectiveness of the proposed methods in two types of traffic. In Section V-A, we describe the experimental environment. In Section V-B, we evaluate the effectiveness with simple traffic and use the flow allocation to show how our method works. Finally, in Section V-C, we evaluate the practical effectiveness of our proposed method by complex traffic.

A. Experimental environment

The experimental topology is a 3-hop 4-channel WBN. Each AP is placed 70 cm apart as shown in Figure 4. A Buffalo WZR-HP-AG300H with OpenWrt [10] firmware was used as the AP hardware. We additionally installed the Open vSwitch [11] to the OpenWrt firmware, which allows us to operate an AP as an OFS. In the WBN, we use IEEE802.11a operating on channels 100, 112, 124 and 136. In addition, physical link rate on each channel is fixed as 54 Mbps. With this WBN, we also prepare two PCs (Client 1 and Client 2) to send/receive experimental traffic and connect them to AP1-1 and AP4-1, respectively.

We employ Trema [12] as an OFC framework on which the proposed method is implemented. Since we focus on the performance of the channel utilization method, the following

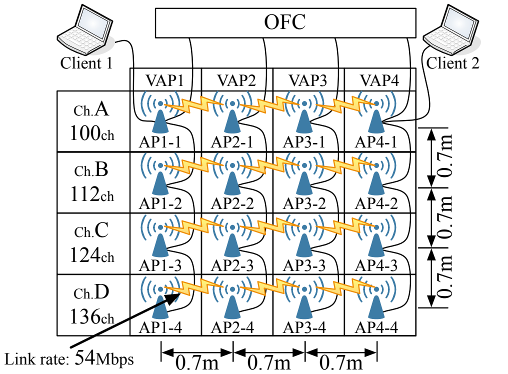


Figure 4. Network topology as in performance evaluation.

pairs of <OFS, OFC>, <Client 1, AP1-1>, and <Client 2, AP4-1> are directly connected by Ethernet cable to avoid the degradation of the communication performance inside the pair.

B. Basic performance evaluation: Simple traffic scenario

In this section, we examine the effectiveness of the proposed methods with a simple scenario. We prepare two types of WBNs, TBI-based WBN and proposed method based WBN. Note that in this experiment, we use only two channels in a testbed. In this experiment, two UDP flows of 5 Mbps and one UDP flow of 10 Mbps with 1500 byte packets ware transmitted from Client 1 to Client 2 in turns at 5 second intervals. Figure 5 demonstrates the time series variation of the packet loss. The TBI-based WBN has many packet losses after starting the third flow. In TBI, each 5 Mbps flow is transmitted on each channel at that time as shown in Figure 6(a). The network loads are actually balanced among these channels. However, this balanced utilization causes saturation on one of the channels after the third flow arrives. Moreover, the number of packet losses fluctuates drasticallly. Once packet loss occurs as a result of channel saturation, the statistical information (i.e., the number of transmitted packets and the amount of transmitted traffic) of each flow is changed to randomly smaller value than actual one. Therefore, the late binding processing attempts to balance the network load among all channels based on incorrect statistical information. The late binding is periodically conducted and thus flow transmission is frequently changed. This causes fluctuation on the number of packets which are lost.

By contrast, the proposed method based WBN does not experience any packet loss during this experiment. Two 5 Mbps flows are packed into a single channel and thus there is enough network capacity for the third flow on either channel as shown in Figure 6(b). Thus, we can say that the proposed channel utilization method can avoid packet loss at flow arrival.

C. Practical performance evaluation: Complex traffic scenario

The reason for packet loss in TBI is unpredictability of new flow arrival and its specification. In this section, we compare

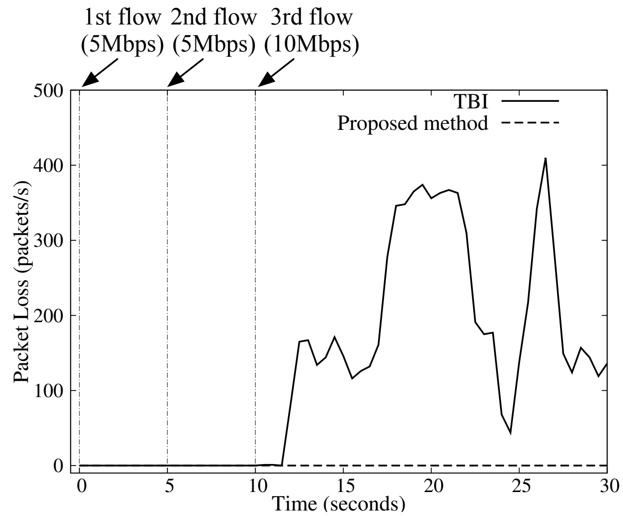
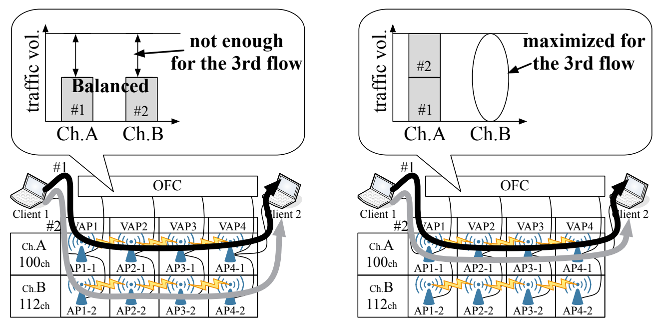


Figure 5. The time series behavior on packet loss.



(a) with TBI (b) with proposed method

Figure 6. Flow allocation after the 2nd flow arrival.

our method with TBI by random traffic scenario. We first measure the maximum network capacity by a single channel in our testbed. We transmit a flow from Client 1 to Client 2 by only one channel. The maximum data rate without packet loss on every channel was 9 Mbps. Thus, we generate random traffic for this experiment. Specifically, the traffic is generated by the following rules and the experiment is concluded after 100 flows are generated.

1) The flow arrival interval should be less than 1 second.
2) Each flow is kept for more than 1 second but not more than 10 seconds.
3) A data rate of each flow is fixed but should be less than 9 Mbps (i.e., the maximum network capacity in the single channel).
4) The total amount of traffic generated in parallel is kept less than 36 Mbps (i.e., the maximum network capacity in the WBM).

In this experiment, the generated traffic is transmitted from Client 1 to Client 2 shown in Figure 4. This experiment was conducted 9 times on the same traffic pattern. The number of packet losses was calculated by comparing the

 ISBN: 978-1-61208-450-3

TABLE I. THE NUMBER OF PACKET LOSSES WITH COMPLICATED TRAFFIC (PACKETS).

Applied Method	Maximum	Median	Minimum
TBI	6826	4229	1196
Proposed	8	7	4

transmitted/received bits captured by tcpdump on Client 1 and Client 2 during this period. Note that the number of transmitted packets was 197,906 packets.

The maximum, median, and minimum number of packet loss are listed in Table I. The traffic should be carried on this WBN without any packet loss because the maximum amount of traffic generated in parallel is less than the maximum network capacity in the WBM. Furthermore, the data rate of each flow is under the network capacity of a single channel. Therefore, the WBN have enough available capacity at any time in this experiment. However, in the case of TBI, there is a significant amount of packet loss. With late binding processing in TBI, flows are allocated in order to balance the network load between each of the channels. As we pointed out in Section V-B, the statistical information of each flow is calculated to be smaller than actual information in TBI. As a result, even if we conduct experiments with the same traffic, the flow allocation on each experiment will differ. This is why there is a big difference between the maximum number of packet loss and the minimum one on TBI. In contrast to TBI, the proposed channel utilization method successfully reduces the number of packet losses significantly in a stable manner. Even if a new flow arrives and its specifications are unpredictable, the proposed method allocates these flows to channels providing enough capacity and packed the flow into specific channels soon, thereby avoiding saturation of all channels in a WBN. Therefore, the proposed method has a potential to avoid packet loss by utilizing multiple channels efficiently.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a channel utilization method that enables the consideration of the available network capacity on each channel in a WBN. With channel utilization methods which equally utilize all channels, the available capacity of each channel is also decreased and accordingly the acceptable flow size of each channel becomes smaller. As a result, even if enough available capacity provided by all channels still remains for new flow, one channel may be saturated due to running out of the capacity once a flow arrives.

In this study, we propose a new flow allocation method that makes the channel utilization imbalanced. That is, the method maximizes the available capacity on some of the channels and fills other channels with flows. In case of flow arrival, this method allocates new flows to the channel that brings the largest expected occupation capacity for the flow. As a result, the possibility of packet loss is minimized by utilizing multiple channels efficiently. We then implemented the method based on the OpenFlow framework and conducted performance evaluations in a real testbed. In the experiment, we used complex traffic that should be carried on the WBN without any packet loss. From the results, we conclude that the proposed method can reduce the number of lost packets significantly. In the future, we plan to continue with the examination of methods for effectively utilizing multiple channels in environments having more clients (i.e., more complex topology).

ACKNOWLEDGEMENTS

This study is partly supported by The Telecommunications Advancement Foundation, Japan.

REFERENCES

[1] Cisco Visual Networking Index, Global Mobile Data Traffic Forecast Update, 2014-2019, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf [retrieved: Jan. 2016].

[2] Yuzo Taenaka and Kazuya Tsukamoto, "An efficient traffic management framework for multi-channel wireless backbone networks", IEICE Communications Express, vol. 3, no. 3, 2014, pp. 98–103.

[3] Yuzo Taenaka and Kazuya Tsukamoto, "A radio interference aware dynamic channel utilization method on software defined WMN", In Proceeding of the 10th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC 2015), Nov. 2015.

[4] A. Antony Franklin, Athula Balachandran, and C. Siva Ram Murthy, "Online reconfiguration of channel assignment in Multi-Channel Multi-Radio wireless mesh networks", Elsevier Computer Communications, vol. 35, no. 16, Sept. 2012, pp. 2004–2013.

[5] Weisheng Si, Selvadurai Selvakennedy, and Albert Y. Zomaya, "An Overview of Channel Assignment Methods for Multi-radio Multi-channel Wireless Mesh Networks", Journal of Parallel and Distributed Computing, vol. 70, no. 5, May 2010, pp. 505–524.

[6] Saad Mustafa et al., "Stable-path multi-channel routing with extended level channel assignment", International Journal of Communication Systems, vol. 25, no. 7, 2012, pp. 887–902.

[7] Eiman Alotaibi and Biswanath Mukherjee, "Survey Paper: A Survey on Routing Algorithms for Wireless Ad-Hoc and Mesh Networks", Computer Network, vol. 56, no. 2, Feb. 2012, pp. 940–965.

[8] Parth H. Pathak and Rudra Dutta, "A Survey of Network Design Problems and Joint Design Approaches in Wireless Mesh Networks", IEEE Communications Surveys and Tutorials, vol. 13, no. 3, Sept. 2011, pp. 396–428.

[9] Djohara Benyamina, Abdelhakim Hafid, and Michel Gendreau, "Wireless Mesh Networks Design - A Survey", IEEE Communications Surveys and Tutorials, vol. 14, no. 2, 2012, pp. 299–310.

[10] OpenWrt, https://openwrt.org/ [retrieved: Jan. 2016].

[11] Open vSwitch, http://openvswitch.org/ [retrieved: Jan. 2016].

[12] Trema, http://trema.github.io/ [retrieved: Jan. 2016].

 ISBN: 978-1-61208-450-3