Computers and Electrical Engineering 57 (2017) 104–117

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

An evolvable, scalable, and resilient control channel for software defined wireless access networks☆

Kien Nguyen*, Kentaro Ishizu, Fumihide Kojima

National Institute of Information and Communications Technology 3–4 Hikarinooka, Yokosuka, Kanagawa, Japan 239–0847, Japan

ARTICLE INFO

Article history:
Received 25 February 2016
Revised 13 September 2016
Accepted 13 September 2016
Available online 19 September 2016

Keywords:
Openflow
SDWAN
Control channel
Scalability
Resilience
Evolvability

ABSTRACT

This paper presents a novel multipath communication-based OpenFlow channel for Software Defined Wireless Access Networks (SDWANs), namely mOpenFlow. The advantageous features of mOpenFlow include the following: (i) resilience and scalability in wireless environments, (ii) evolvability of the existing access networks and the OpenFlow standard, (iii) a novel network calculus-based model for performance analysis of mOpenFlow. By leveraging the multipath communication for conveying OpenFlow traffic, mOpenFlow enhances both robustness (i.e., resilience) and throughput (i.e., scalability) of the control channel. To achieve the evolvability, mOpenFlow adopts the multipath transport control protocol, which conforms to SDWANs and the OpenFlow standard. We evaluate mOpenFlow in an emulated SDWAN in relation to the standard channel. The results show that mOpenFlow outperforms the standard channel, both in terms of robustness and scalability. Additionally, the numerical results indicate that the model provides a fast and reliable way for analyzing the end-to-end delay on mOpenFlow.

1. Introduction

Software Defined Networking (SDN) is recognized as one of the key technologies contributing to the proliferation of mobile device adoption, which requires significant improvements in network performance and network control [1]. Accordingly, many improvements are proposed for Software Defined Wireless Access Networks (SDWANs) [2–4]. In an SDWAN, an SDN controller logically centralizes control functions and manages distributed networking devices (e.g., middleboxes, packet gateways, mobile devices, etc.). The devices and the controller exchange the control and update information on the control channel (i.e., OpenFlow channel), which is the most important component of the SDWAN.

As the control channel has to deal with novel requirements, it must be robust and scalable. However, the standard OpenFlow, which was originally designed for wired networks, proves inefficient when applied directly in SDWANs. Specifically, the SDWAN's control traffic is indeed conveyed on both wired and wireless infrastructures, which may contain a mix of inband and out-of-band deployments. Those specific deployments are not fully specified in the OpenFlow standard [5]. On the other hand, when the standard channel experiences failure, the SDN devices could not work properly (i.e., fall into fail

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. S. Smys.
* Corresponding author.
E-mail addresses: kienng@nict.go.jp (K. Nguyen), ishidu@nict.go.jp (K. Ishizu), f-kojima@nict.go.jp (F. Kojima).

http://dx.doi.org/10.1016/j.compeleceng.2016.09.014

modes). Consequently, severe damages or huge data loss may occur in the SDWANs. Therefore, it is of great importance to design a new control channel that conforms to the requirements of the SDWAN and the standard.

This work first analyzes the disadvantages of standard OpenFlow, and then addresses the requirements necessary for the control channel in SDWANs (i.e., robustness, resilience, and evolvability). We then propose the novel OpenFlow channel, namely mOpenFlow[1], which appropriately satisfies the requirements. The following are the advanced features of mOpenFlow:

- mOpenFlow achieves robustness and scalability by leveraging its advantage of multipath communications.
- mOpenFlow evolves seamlessly on the mix deployment and the OpenFlow standard by using the transport layer multipath's solution (i.e., the standard multipath TCP (MPTCP)).
- mOpenFlow is modeled by a newly proposed framework, which is based on the theory of network calculus.

To validate the effectiveness of mOpenFlow (mOF), we evaluate its performance in an emulated SDWAN, in relation to that of the standard OpenFlow channel (sOF). The results show that mOF outperforms sOF in terms of both robustness and scalability. On the other hand, the theoretical model and analytical results show that the proposed framework is capable of modeling mOpenFlow and revealing its performance bounds.

For the scalability and robustness of OpenFlow channel, the focus of previous works has been mostly on designing distributed SDN controllers [7]. In contrast to this, our design targets the case of a single controller. However, our design can be integrated with the existing ones to further improve the channel performance. Other works that focus on improving the scalability depend on either devolving control functions to SDN devices or using multi-thread controllers [8]. For robustness improvement also some contributions are available, but they are for the OpenFlow wide area network [9] or require the changes of OpenFlow standard [10]. Those approaches can not bypass the requirement of evolvability. We reckon our work is unique in that it considers the scalability, robustness, and evolvability of OpenFlow channel of SDWAN.

The rest of paper is organized as follows. Section 2 briefly reviews related works. Section 3 presents the requirements of control channel in SDWANs and the proposed mOpenFlow channel. Section 4 includes the approach of modeling mOpenFlow. Section 5 deals with the evaluation method and results. Finally, Section 6 sums up the conclusions drawn from this study.

2. Related works

The explosive increase in mobile devices will result in a huge demand for usage data, various levels of QoS and mobility. Hence, the existing wireless access networks should be upgraded to cope with the novel levels of dynamic and scalability. The fast evolving SDN technology shows great potential for improvement of the access networks. SDN has been proven to be efficient in the wired network for scalability and resilience [11,12]. In the wireless domain, there have been increasing SDWAN proposals, which aim to solve new challenges in future access networks.

In [2], SDN shows its efficiency in handling mobility in an SDWAN including Wi-Fi and WiMax. In [3], the authors show that SDN is the key technology in bypassing the current limitations in large scale cellulars (i.e., path inflation, lack of routing function, lack of scalability, vendor-dependency). In [4], a novel SDN-based architecture has been proposed to provide an open platform for making innovations on wireless access networks. These works use the standard OpenFlow as a southbound interface in SDWANs. However, its robustness and scalability have been seldom discussed.

The focus of previous works on the robustness and scalability of the standard channel has been mainly on wired networks. The common solutions include introducing multiple controllers and designing a scalable controller [7,9]. The OpenFlow standard also specifies a resilience method for the channel by using a secondary controller. In [10], to effectively deal with the failure of OpenFlow channel, the authors propose a new type of message and a failure handling method, which requires adding more intelligence to SDN devices. The method can be used in SDWAN but requiring modification of OpenFlow standard.

Our approach is unique in that it aims at designing a novel channel, which is scalable, robust, and evolvable for SDWANs. The mOpenFlow channel leverages multipath communications for scalability and robustness. mOpenFlow selects the standard multipath transport layer (i.e., MPTCP) for the sake of compatibility with both the OpenFlow standard and the physical deployment of SDWANs. Along with increasing popularity of SDN, efforts for improving its theoretical performance analysis have also been increasing concurrently. Regarding the OpenFlow channel's analysis, in [13] the authors use queuing theory to investigate the performance of OpenFlow architecture. Although the work inspires others to explore the domain of performance analysis in SDN, it still shows some limitations. The Markovian servers are assumed for both SDN controllers and SDN devices. Moreover, it considers only the standard OpenFlow channel. The authors of [14] initially propose to use the network calculus theory for modeling and analyzing SDN components. They show that the basic models of network calculus provide a convenient way to find the bound performance values in SDN. Compared to the previous work, our analysis is for a newly proposed multipath OpenFlow channel. We extend the basic model to capture the state of the new channel.

[1] The first version of mOpenFlow has been published in [6]. In this version, the modeling and theoretical analysis, as well as, numerical results parts are added.