ISD-WiFi: An Intelligent SDN Based Solution for Enterprise WLANs

Daikai Tu, Zhifeng Zhao, Honggang Zhang
York-Zhejiang Lab for Cognitive Radio and Green Communications
College of Information Science and Electronic Engineering
Zhejiang University, Zheda Road 38, Hangzhou 310027, China
Email: {dktu, zhaozf, honggangzhang}@zju.edu.cn

***Abstract*—With the development of SDN(Software-Defined Networking) and WiFi, it is very important and useful to integrate them under one unified architecture. SDN controller can manage routers, switches and WiFi's APs with standard OpenFlow protocol and provide end-to-end control, by which flexible management strategies can be achieved to satisfy various requirements of future network. In this paper, we propose an intelligent SDN based solution for enterprise WLANs and put forward an unified management architecture in the solution. New mobility and interference management schemes are designed under this architecture. Simulation results show that our solutions perform better than current solutions in mobility and interference management.**

Keywords*: *SDN; OpenFlow; WLANs; Mobility; Interference

I. Introduction

Traffic generated by mobile devices has experienced a burst growth in recent years. Most of us have been getting used to relying on WLANs for its convenience. It is quite important to manage and control the WLANs(Wireless Local Area Networks) when it gets to a large scale. CAPWAP(Control And Provisioning of Wireless Access Points) [1] protocol has been proposed by IETF to implement centralized management of wireless termination points. Certainly, CAPWAP is a relatively comprehensive protocol which defines the separate function implementation for IEEE 802.11 [2] protocols in access points(APs) and access controller(AC). CAPWAP focuses on centralized authentication of users and management of access devices. It lacks the ability to dynamically configure wireless network according to varying network conditions.

SDN aims to decouple the data plane and control plane through an open interface. In this architecture, the underlying network devices are abstracted to provide programmable interface to SDN controller. OpenFlow [3] is an open southbound interface through which controller communicates with OpenFlow switch.

Through SDN was proposed to reshape the architecture of wired networks originally. Researchers have recently imported SDN to wireless networks. [4] aims to use LVAP to record user's state in AP and implement seamless handoff by removing and adding LVAP. While it is useful in handling user's access and handoff, but keeping a LVAP for each user increases beacon overheads and it's infeasible for dense WiFi networks. In [5] SDWLAN proposed to implement client-unaware fast AP handoff. The main idea is to take all APs as one big AP by letting them work on the same channel. But in this architecture interference between APs is ignored and the throughput will decrease when all APs share the same channel resources. Solutions for IP mobility support in SDN have also been investigated, but they do not concern the specific mobility management problem such as inter-controller mobility and the utilization of Layer 2 access information in WLANs. We put forward an intelligent SDN based architecture which integrates WiFi with SDN to solve the problems [6], because SDN controller can manage routers, switches and APs with standard OpenFlow protocol and provide end-to-end control.

The main contributions of this paper include:

- We propose ISD-WiFi(Intelligent Software-Defined WiFi), a programmable networking architecture for enterprise WLANs. ISD-WiFi provides centralized access control, interference management and mobility management. ISD-WiFi satisfies the requirements of future network for its ability to make flexible management strategies, analyze and handle massive data.
- Based on ISD-WiFi, we put forward a flexible mobility management mechanism which can provide smooth and client unaware Layer 3 handoff.
- A interference graph and predicted traffic oriented algorithm is proposed to solve interference problem in ISD-WiFi. Using the algorithm, we could reduce interference significantly.

The rest of the paper are organized as following. In Section II, we describe ISD-WiFi and its elements. We introduce ISD-WiFi based application scenarios in Section III. The Layer 3 handoff problem has been considered and we give our solution in Section IV. We analyze interference problem and give our algorithm in Section V. In Section VI, we demonstrate the simulation performance of the proposed mobility management mechanism and interference management algorithm. At last, we make the conclusion about this paper in Section VII.

II. Architecture and Design Principles

In this section, we will give the definition and description about the intelligent SDN architecture for WLANs. Based on ISD-WiFi, we aim to implement centralized access management, dynamic network configuration to alleviate wireless

978-1-5090-2860-3/16/$31.00 ©2016 IEEE

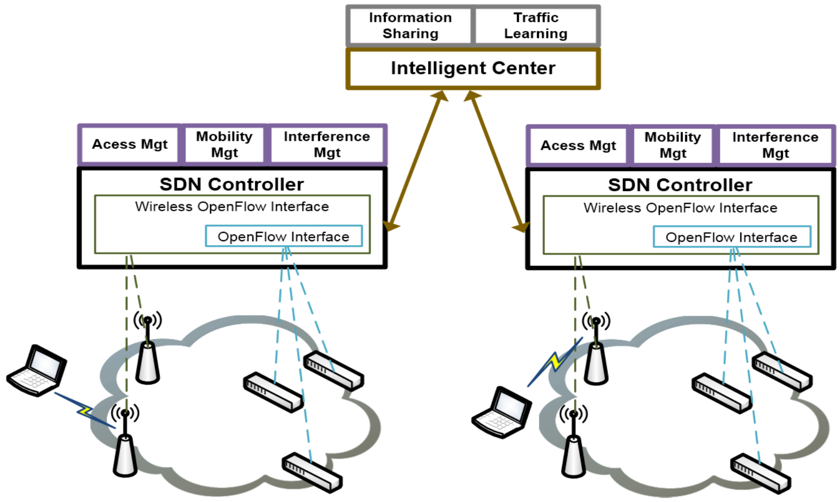

Fig. 1. ISD-WiFi architecture

interference, and provide flexible mobility management mechanism. Hereinafter, we introduce the elements of ISD-WiFi and the function implementation of ISD-WiFi.

A. The Architecture Overview

The proposed ISD-WiFi architecture is represented in Fig.1. The line connecting SDN controller and intelligent center means that they exchange necessary information and data with each other.

In the architecture, underlying network devices consist of APs and OpenFlow-enabled switches. These devices are controlled by SDN controller. Current version of OpenFlow could not support IEEE 802.11 protocol related messages, which means controller has no ability to manage APs. We extend OpenFlow to a wireless-enabled protocol, through which controller could control the APs and switches in a unified way. The extension of OpenFlow has no negative effect on the function of OpenFlow itself. APs connect to SDN controller through wireless OpenFlow interface and switches through OpenFlow interface. We will describe the extension implementation details in the following section.

B. Design Principles and Framework Details

We split IEEE 802.11 MAC layer functions into AP and SDN controller, according to the need of centralized management, and make the mapping of 802.11 functions for ISD-WiFi architecture as following.

1) Basic Functions: Management frame like Beacon generating and Probe Response are done in AP for its realtime requirement. Authentication/Reauthentication Request and Association/Reassociation Request are handled by SDN controller.

2) IEEE 802.11 QoS and RSN: Considering OpenFlow is a control channel and can not be used to transmit data frames, APs locally bridge client data and provide the encryption and encryption services, and the IEEE 802.11 QoS such as classifying, scheduling and queuing functions are managed in AP. The security authentication functions like IEEE 802.1X and RSNA Key management reside in the SDN controller.

C. Acess Points, SDN Controller and Intelligent Center

To describe the extensions of OpenFlow and function implementation clearly, we give explanation about the following elements.

Access Points. According to the function mapping mentioned above, APs generate beacon frames periodically and make probe response when receiving probe request from STA(station). APs capsulate the authentication and association request frames in the Packet-in message defined in standard OpenFlow and send them to SDN controller for further processing. In addition, wireless datapath is responsible for collecting interference statistics information and traffic statistics information.

SDN Controller. As shown in Fig.1, SDN controller communicates with APs through wireless OpenFlow. SDN controller is responsible for processing the authentication and association request frames encapsulated in OpenFlow Packet-in message and makes responses by sending OpenFlow Packet-out message to AP through the extended interface. We add new reason type for Packet-in message and new actions for Packet-out message in the extensions of OpenFlow. Controller could periodically request APs for interference and traffic statistics information by the new added statistics message types. The collected statistics from controller will send to intelligent center for storage and further analysis.

Intelligent Center. In ISD-WiFi, intelligent center is responsible for learning about the STA's traffic pattern and making prediction. User's traffic often shows periodicity for regular movement and we can learn each user's traffic pattern using historical traffic statistics. Traffic learning is carried out by intelligent center to reduce the burdens of controller. Besides, controllers share information through intelligent center to cooperate with each other, when there is more than one controller in the whole network. In our mobility management mechanism, intelligent center provides sharing information between controllers for corporation.

III. Application Scenarios in ISD-WiFi

Based on intelligent SDN, ISD-WiFi could offer programmability and flexible management mechanism for enterprise WLANs. We introduce these advantages in the following three application scenarios.

A. Access Control

Through wireless OpenFlow protocol, SDN controller implements centralized access authentication. WLANs slicing could be easily achieved to offer different services for different types of users by configuring multiple SSIDs in the same AP. Access control strategies can be deployed in either wireless authentication rules or in switch forwarding rules according to the needs of network managers.

B. Mobility Management

Mobility management promises a continuous IP service when STA is moving. In ISD-WiFi, a sooth and client unaware Layer 3 handoff which means that STA locates at different subnet after handoff can be achieved by using 802.11 access information and the flexible forwarding ability of OpenFlow at the same time. Controller could sense mobility trend of a moving STA instantly and place flowtables before the reconnection phase is finished. The flexible mobility management mechanism shorten handoff latency and does not occupy extra network resources.

C. Interference Management

Interference management is quiet important when APs are densely deployed. In ISD-WiFi, each AP collects interference statistics and airtime utilization, and sends it to SDN controller. Analyzing interference statistics from all APs, SDN controller builds a interference graph which demonstrates current network condition. In addition, each user's traffic statistics will be sent to controller and dumped in intelligent center. By learning historical traffic behavior of users, intelligent center makes prediction about user's traffic behavior and offers prediction information to controller. Based on interference graph and traffic prediction information, controller makes optimal channel assignment scheme to alleviate wireless network interference and improve network throughput.

IV. Flexible Mobility Management Mechanism in ISD-WiFi

When a STA is moving from one subnet to another subnet, in order to guarantee the service is not interrupted, the STA keeps its IP address unchanged in the handoff process. Various Mobile IP protocols have been proposed to solve this kind of problem. Hierarchical Mobile IPv6(HMIPv6) [7] and Fast Mobile IPv6(FMIPv6) [8] could reduce the handover latency. However, they are host-based and Mobile Node(MN) needs to modify its protocol stack to participate signaling interaction. Proxy Mobile IPv6(PMIPv6) [9] is network-based, and MN

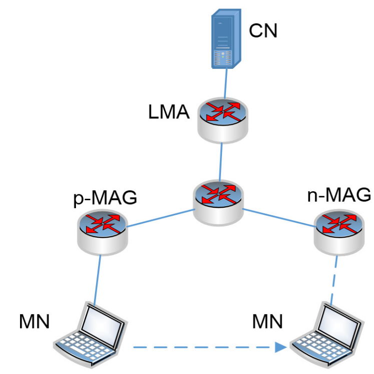

Fig. 2. PMIPv6 mobility architecture

does not need to do any work about the protocol implementation process in handover. These advantages make PMIPv6 is more suitable to be used in real network. The related works in [10] and [11] focus on solving mobility problem with SDN, while they do not consider WLAN scenario. In ISD-WiFi, the mobility management is also considered. Different from those traditional mobile IP solutions, the handoff event is easily caught by controller and routing or forwarding path is configured instantly when the access event happens. SDN controller adds or modifies flowtables in related OpenFlow switches when it receives the association request message from the AP that STA wants to associates with. Mobility management mechanism in ISD-WiFi could be more flexible and efficient. We will introduce PMIPv6 briefly and then describe the mobility management mechanism in ISD-WiFi.

1) PMIPv6: As illustrated in Fig.2, mobile access gateway(MAG) senses the attach event when MN enters PMIPv6 domain. MAG then sends a Proxy Binding Update(PBU) message including MN-ID to the MN's local mobility anchor(LMA) to update the location of MN, informing LMA the subnet that MN belongs to. Upon accepting PBU, LAM sends a Proxy Binding Acknowledgement(PBA) message including MN's home network prefix, creates the Binding Cache entry and sets up its endpoint of the bi-directional tunnel to MAG. MAG sets up its endpoint of the bi-directional tunnel to LMA, when receiving PBA. Then MN and Correspondent Node(CN) communicate with each other through the established bi-directional tunnel.

Supposing MN is leaving from the previously attached mobile access gateway(p-MAG) to newly attached mobile access gateway(n-MAG), p-MAG detects the event and sends PBU to LMA to execute de-registration procedure. LMA deletes Binding Cache entry of MN and sends PBA to p-MAG. Then a new tunnel is established between n-MAG and LMA.

2) Proposed Approach in ISD-WiFi: Through PMIPv6 can be easily implemented in SDN/OpenFlow networks, problems such as excessive signaling overhead and non-optimal communication path still exist. In ISD-WiFi, we could use more flexible mobility management mechanism to solve these problems. Fig.3 illustrates a comprehensive handoff process in ISD-WiFi. In our proposal, MN or STA disassociates from the

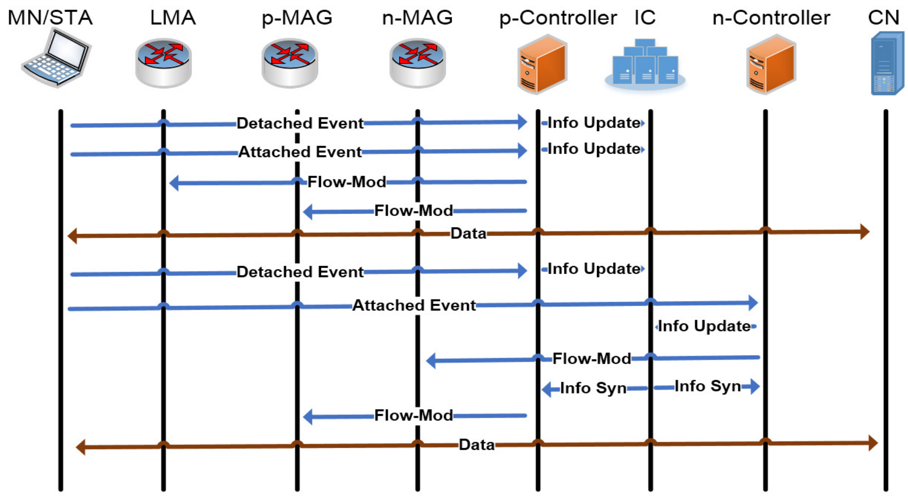

Fig. 3. Layer 3 Handoff process in ISD-WiFi

old AP and then associates with new AP, being totally unaware about the Layer 3 handoff. Besides, tunnel between LMA and MAG is not needed any more because SDN controller could configure a optimal routing path for MN and CN by modifying or deleting flowtables in OpenFlow switches, neither triangle routing problem exists.

Handoff process is simple when handoff occurs in one controller domain. Controller regards the disassociation request from STA as a detached event. When detecting STA's detached event, controller updates the access information about STA in intelligent center(IC). Intelligent center stores each STA's access information which includes associated AP, belonging controller, access state, STA's MAC address, STA's IP address and so on. The sharing information is useful because cooperation between controllers is needed in inter-controller handoff. Then, STA associates with a new AP in the same controller domain. Controller updates the access information and rewrites flowtables of the related switches. STA could communicate with CN directly.

If the p-MAG and n-MAG locate in different SDN controller domain, the handoff process is a little more complicated. The previous controller(p-Controller) still updates detached event to intelligent center when receiving disassociation request from STA. When new controller(n-Controller) senses the STA attached event, it proceeds with access information updating and place the flowtable in the related switches. When intelligent center finds the controller which STA belongs to before and after handoff is not the same one, it sends broadcast synchronization messages to all controllers that participate the access information sharing. In usual occasion, intelligent center periodically sends synchronization messages to controllers. The p-Controller modifies flowtables for the STA in its domain using synchronization messages when it finds STA's state changes. Since controllers have already configured flowtables, STA and CN are able to send packets to each other through the new path.

V. Interference Management in ISD-WiFi

Based on the global interference graph and user traffic statistics, interference problem in WLANs can be easily analyzed and solved. In this section, we model the overlapping channel interference, and give an interference graph and traffic oriented channel assignment algorithm(GTOA) in ISD-WiFi. Working channel and activity state of AP are regarded as the two main factors that cause interference.

We use the following symbols to formulate the dynamic channel assignment problem.

n is the total number of APs.

N is the set of APs.

M is the set of total available channels which contains number from 1 to 11.

c is the overlapping channel factor.

C_i is the assigned channel of AP i and the value of it belongs to M.

$\mathrm{A_{i,j}}$ donates if AP i could sense signal from AP j.

T_i is the predicted traffic that will be transmitted by AP i in next period and the traffic value is normalized.

$\mathrm{W_{i,j}}$ is the predicted transmission interfering weight between AP i and AP j. The interfering weight value is determined by the relative value and absolute value of two APs at the same time for the interfering influence is small when traffic of AP i is large and traffic of AP j is small though the sum of traffic is large.

$\mathrm{I_{i,j}}$ is the overlapping channel degree between AP i and AP j. The interference between two APs exists when the difference value of their working channel number is less than five.

To minimize the interference in the system, the channel assignment problem is given as:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{n} c A_{i,j} W_{i,j} I_{i,j} \quad (1)$$

subject to

$$W_{i,j} = \frac{T_i T_j}{T_i + T_j} \quad (2)$$

$$I_{i,j} = 5 - \min(|C_i - C_j|, 5) \quad (3)$$

$$C_i \in M, \forall i \in N \quad (4)$$

$$T_i \geq 0, \forall i \in N \quad (5)$$

Finding the optimal channel assignment is known to be NP-hard. We propose an efficient algorithm GTOA to give a close-to-optimal channel assignment for the objective. The algorithm is simple and does not need complex computation. We sort the node in the interference graph by its suffering degree. Specifically, we compute node's suffering degree by its out-degree and the predicted traffic to be transmitted by it. The algorithm is described as following.

```
Input: out-degree O_i of node i and traffic T_i of node i
Output: assigned channel C_i for node i
foreach i in N do
    P_i = O_i * T_i;
end
[P',S]=sort(P);
foreach i in N do
    C_{S_i} = arg min sum_{j=1}^{n} A_{S_i j} W_{S_i j} I_{S_i j}
end
```

Algorithm 1: GTOA Algorithm

In the algorithm, the P_i describes the predicted interference strength of node i. The main idea of GTOA algorithm is to find key nodes in the graph and assign channels to them with high priority. The sort function in algorithm represents the process of searching highly suffering nodes. Using GTOA, we could reduce interference significantly. And we will show the preference of GTOA algorithm in next section.

VI. Simulation and Performance Analysis

In this section, we show the simulations of mobility and interference management in ISD-WiFi and give performance analysis of them.

A. Mobility Management in ISD-WiFi

We implement a simple simulation about the mobility in ISD-WiFi and HMIPv6 and compare the performance of them. The simulation is based on Mininet-WiFi [12] and we use RYU as our SDN controller. Mininet-WiFi extends the functionality of Mininet by adding virtualized WiFi stations and access points based on the standard Linux wireless drivers and the 80211_hwsim wireless simulation driver. Mininet-WiFi offers traffic control(TC) in user-space. TC is responsible for controlling the rate, delay, latency and loss, applying these attributes in virtual interfaces of stations and APs, representing with higher fidelity for the behavior of the real world. Particularly, Mininet-WiFi supports mobility models, so that we can simulate the handoff process directly. We make patches to the mobility module of Mininet-WiFi to make AP support the extentions OpenFlow as we describe in Section II. We implement a simple topology and run the simulation on Ubuntu-12.04.

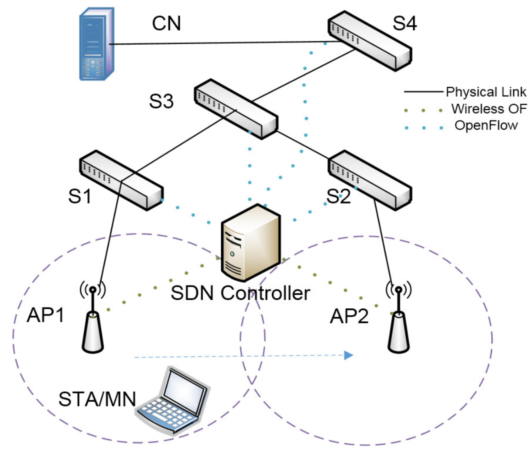

Fig. 4. Experiment topology

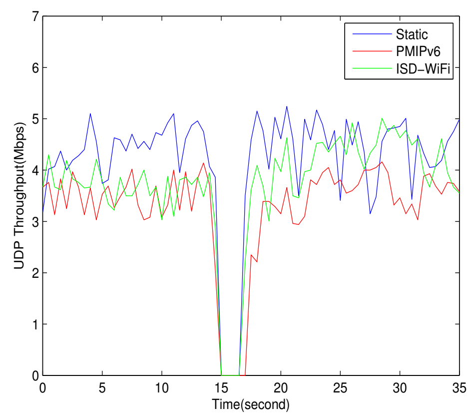

Fig. 5. UDP throughput in PMIPv6 and ISD-WiFi

1) Experiment Topology: The experiment topology is shown in Fig.4. The topology consists of four OpenFlow switches, 2 APs, one STA, one CN and a SDN controller. All switches and APs are connected to RYU controller through OpenFlow or wireless OpenFlow. In the topology, STA serves as MN and H1 keeping as immobile serves as CN. We divide the topology into three subnets to simulate the Layer 3 handoff. For PMIPv6, S1 serves as LMA and S2 as MAG. We implement PMIPv6 in a relative simplified way, which will help to improve its performance. The STA is initially associated with AP1 and moves to AP2 after a few seconds. Because we do not use special Layer 2 handoff methods for the consideration of generality, AP will disconnect with the old AP first and then reconnect with the new AP. We use iPerf to measure the UDP datagram throughput variation, and take CN as iPerf client and MN as iPerf server. CN sends UDP datagrams to MN in a relatively consistent rate continuously.

2) Simulation Performance: As illustrated in Fig.5, CN sends UDP datagrams at about 4Mbps, and the receiving rate at MN varies when the sending rate of CN fluctuates. We notice that UDP throughput drops when the handoff process starts. The latency in ISD-WiFi mobility is about 2 seconds

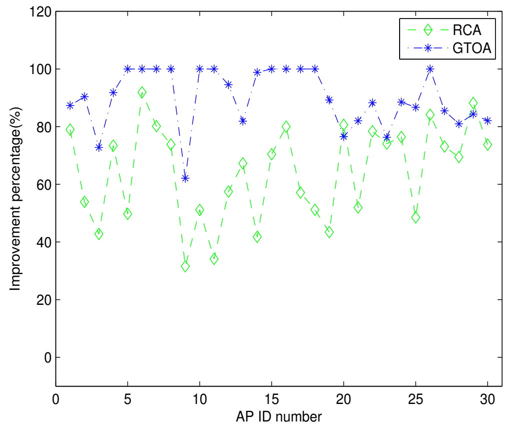

Fig. 6. Interference improvement percentage for each AP

and in PMIPv6 is about 2.5 seconds. Throughput recovers more quickly in ISD-WiFi mobility than in PMIPv6 for the communications between LMA and MAG and the creation of tunnel between them take some time. Meanwhile, throughput in PMIPv6 after handoff drops a little, and this may be caused by the usage of tunnel. Through the mobility performance in ISD-WiFi is better than PMIPv6, the latency in handoff is still a little long. So we measure the static disconnection and reconnection time as a reference. The simulation is done in the same topology, and we keep STA immobile and execute disconnecting and reconnecting command continuously. Then we can see the disconnection starts at about 15th second and UDP throughput dropping time is about 2 seconds. The result shows that the routing and forwarding path have been configured and the process takes little time. Compared with PMIPv6, our proposed mobility management mechanism requires less signaling interaction and does not need to establish tunnel.

B. Interference Management in ISD-WiFi

In the interference management simulation which is done with matlab, we construct interference graph with 30 APs. The link relation in the interference graph and the predicted traffic of each AP is generated randomly. We compare the performance of GTOA algorithm with single channel assignment method and random channel assignment method. We assign channel 6 to all APs when using single channel assignment method and assign a randomly selected channel to each AP when using random channel assignment method. As illustrated in Fig.6, the blue dash line describes the interference improvement percentage of GTOA algorithm, compared with single channel assignment method, and the green dash line is for random channel assignment method. We can see the average interference improvement percentage is about 90 percentage for GTOA algorithm and about 60 percentage for RCA(random channel assignment) algorithm. The numerical results show that our algorithm in interference management performs better than the traditional channel assignment methods.

VII. Conclusion and Future Work

In this paper, we present an intelligent SDN based solution for enterprise WLANs. In the solution, SDN controller could make flexible policy in access control, mobility and interference management. In our proposed mobility management scheme, SDN controller could make routing and forwarding policy in a proactive way, which shortens handoff latency and does not need other network resources. By analyzing statistics, our interference management method performs better than current solutions.

For the future works, we will focus on the usage of intelligent center and the improvement of the architecture.

Acknowledgment

This paper is partially supported by the National Basic Research Program of China (973Green, No. 2012CB316000), the Key Technologies R&D Program of China (No. 2015BAH18F02), the Program for Zhejiang Major Industrial Projects of Major Science and Technology Projects (2015C01075), and the Program for Zhejiang Leading Team of Science and Technology Innovation (No. 2013TD20).

References

[1] P. Calhoun, M. Montemurro, and D. Stanley, “Control And Provisioning of Wireless Access Points (CAPWAP) Protocol Specification,” Internet Requests for Comments, RFC Editor, RFC 5415, March 2009. [Online]. Available: http://www.rfc-editor.org/pdfrfc/rfc5415.txt.pdf

[2] “IEEE 802.11-2007: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,” *IEEE 802.11 LAN Standards 2007*, 2007.

[3] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, “OpenFlow: enabling innovation in campus networks,” *ACM SIGCOMM Computer Communication Review*, vol. 38, no. 2, pp. 69–74, 2008.

[4] L. Suresh, J. Schulz-Zander, R. Merz, A. Feldmann, and T. Vazao, “Towards programmable enterprise WLANS with Odin,” in *Proceedings of the first workshop on Hot topics in software defined networks*. ACM, 2012, pp. 115–120.

[5] D. Zhao, M. Zhu, and M. Xu, “SDWLAN: A flexible architecture of enterprise WLAN for client-unaware fast AP handoff,” in *Computing, Communication and Networking Technologies (ICCCNT), 2014 International Conference on*. IEEE, 2014, pp. 1–6.

[6] Y. Zhou, Z. Zhao, and H. Zhang, “Towards 5G: heterogeneous cellular network architecture design based on intelligent SDN paradigm,” *Journal of Telecom Science*, vol. 32, no. 6, pp. 28–35, June 2016.

[7] H. Soliman, C. Castelluccia, K. E. Malki, and L. Bellier, “Hierarchical Mobile IPv6 Mobility Management (HMIPv6),” Internet Requests for Comments, RFC Editor, RFC 4140, August 2005. [Online]. Available: http://www.rfc-editor.org/pdfrfc/rfc4140.txt.pdf

[8] R. Koodli, “Mobile IPv6 Fast Handovers,” Internet Requests for Comments, RFC Editor, RFC 5568, July 2009. [Online]. Available: http://www.rfc-editor.org/pdfrfc/rfc5568.txt.pdf

[9] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, “Proxy Mobile IPv6,” Internet Requests for Comments, RFC Editor, RFC 5213, August 2008, http://www.rfc-editor.org/rfc/rfc5213.txt. [Online]. Available: http://www.rfc-editor.org/rfc/rfc5213.txt

[10] K. Tantayakul, R. Dhaou, and B. Paillassa, “Impact of SDN on Mobility Management,” in *2016 IEEE 30th International Conference on Advanced Information Networking and Applications (AINA)*. IEEE, 2016, pp. 260–265.

[11] Y. Wang and J. Bi, “A solution for IP mobility support in software defined networks,” in *2014 23rd International Conference on Computer Communication and Networks (ICCCN)*. IEEE, 2014, pp. 1–8.

[12] R. R. Fontes, S. Afzal, S. H. Brito, M. A. Santos, and C. E. Rothenberg, “Mininet-WiFi: Emulating software-defined wireless networks,” in *Network and Service Management (CNSM), 2015 11th International Conference on*. IEEE, Nov. 2015, pp. 384–389.