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A Novel Hybrid Routing Forwarding Algorithm in SDN Enabled Wireless Mesh Networks

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Abstract—**As an essential part of next generation Internet, Wireless Mesh Networks (WMNs) have attracted much research attention due to its potential advantages including low up-front cost, ease of deployment, enhanced capacity and service coverage. However, the inherit features of wireless multi-hop networks have put forward a severe challenge for traffic engineering problem. Conventional traffic engineering techniques either locally manipulate network traffic or adopt unreliable best-effort delivery mechanism. Software Defined Networking (SDN) is a new networking paradigm that separates the network control plane from the packet forwarding plane and provides applications with an abstracted centralized view of the distributed network state. A logically centralized controller that has a global network view is responsible for all the control decisions and it communicates with the network-wide distributed forwarding elements via standardized interfaces. Considering the current price of SDN equipments and deployment cost, this paper proposes an idea that gradually increases the number of SDN forwarding element in the networks. In other words, partly deployment of the SDN forwarding element in the networks can achieve fast forwarding traffic. On this basis, a new traffic engineering algorithms named Hybrid Routing Forwarding Algorithm (HRFA) which is based on SDN forwarding and OSPF (Open Shortest Path First) protocol is designed. This hybrid routing scheme divides the network nodes into conventional nodes and SDN forwarding elements (SDN-FE), and chooses effective forwarding strategies for different network elements, which will improve the overall performance of the networks. In order to verify the performance of the proposed algorithms, a number of simulation experiments are carried out in the NS-2 simulation platform. The results show that compared with the traditional routing forwarding method, HRFA can well increase the normalized throughput, and reduce the delay and packet loss.**

Keywords- hybrid protocol; traffic engineering; control plane; Software Defined Networking (SDN); Wireless Mesh Networks (WMNs)

I. INTRODUCTION

As a new type of broadband wireless access technology, wireless mesh networks (WMNs) [1, 2] have been regarded as a more competitive technical solution for wireless terminal to access the next generation Internet. Each node in WMNs operates as both hosts and routers, forwarding packets for other nodes that may not be within direct transmission range of destination nodes. WMNs are dynamically self-organized and self-configured, with routers in networks automatically establishing and maintaining mesh connectivity among themselves. These features bring many characteristics such as low up-front cost, ease deployment, enhanced capacity and service coverage, etc. However, despite their widespread popularity, traditional IP based WMNs are complex and very hard to manage. It is very difficult for operators to configure the WMNs according to predefined policies. Also, it is very inconvenient to reconfigure the network to respond to unexpected faults, traffic load and network state changes.

At present, traditional OSI network architecture has been still employed in the protocol stack design of WMNs. Worse still, traditional IP based WMNs are also vertically integrated: the control and forwarding planes are tightly coupled together. Traditional Wireless Mesh Networks (WMNs) are comprised of mesh routers with complicated structure and function, which employ closed and proprietary internal interface, and run a large number of distributed protocols. Due to the above defects, equipment manufacturers cannot timely innovate to meet customers' needs, operators cannot customize and optimize networks as required, and research fellows cannot validate their new ideas. Network management requires a lot of complex manual configuration, and takes high operation and maintenance cost. Software-Defined Networking (SDN) [3-8] is an emerging paradigm that promises to change this state of affairs, by breaking vertical integration, separating the network's control logic from the underlying routers and switches, promoting logical centralization of network control, and introducing the ability to program the network. Software Defined Networking (SDN) enabled WMNs will apply SDN technology into WMNs. By separating network control logic from data forwarding, automatic control and update functions would be achieved by software-driven control logic, which improves network performance and shortens the cycle of network innovation.

Traffic engineering is the task of mapping business to existing physical topology. It can control the use of network resources and the rational allocation of traffic on the existing network topology, which will optimize the utilization of network resources, and solve the imbalance problem of network resources, so that the network will reach a high degree of reliability, robustness and operability. Therefore, the design and simulation implementation of traffic engineering algorithms in SDN enabled WMNs has important theoretical significance and practical value.

In this paper, we propose to integrate Software Defined Networking (SDN) principles in Wireless Mesh Networks

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(WMNs) formed by OpenFlow mesh routers [9-12]. The use of a centralized network controller and the ability to setup arbitrary paths for data flows make SDN a handy tool to deploy fine-grained traffic engineering algorithms in WMNs. There has been extensive study on traffic engineering of traditional networks [13-14]. The model considered in these studies, however, assumes that each node is functioning independently and is closely coupled with both control and date planes. This model could not be applied to the SDN enabled WMNs architecture. In [15], Caesar et al presented a logically centralized routing control system. By separating inter-domain routing from individual routers, this decoupled architecture can make routing systems more manageable, less complex and be accommodative of new service needs. Agarwal et al in [16] firstly addressed network performance issues in an incrementally deployed SDN, and formulated the SDN controller's optimization problem and outline a fully polynomial time approximation scheme to solve the controllers problem.

conventional traffic engineering techniques [17-20] either locally manipulate network traffic or adopt unreliable best-effort delivery mechanism. Considering the current price of SDN equipments and deployment cost, this paper proposes an idea that gradually increases the number of SDN forwarding element in the networks. In other words, partly deployment of the SDN forwarding element in the networks can achieve fast forwarding traffic. On this basis, a new traffic engineering algorithms named Hybrid Routing Forwarding Algorithm (HRFA) which is based on SDN forwarding and OSPF (Open Shortest Path First) protocol is designed. This hybrid routing scheme divides the network components into conventional nodes and SDN forwarding elements (SDN-FE), and chooses effective forwarding strategies for different network elements, which will improve the overall performance of the networks. In order to verify the performance of the proposed algorithms, a number of simulation experiments are carried out in the NS-2 simulation platform. The results show that compared with the traditional routing forwarding method, HRFA can well increase the normalized throughput, and reduce the delay and packet loss.

The remainder of the paper is organized as follows: section II gives the system model, section III describes the design process of HRFA in detail, and section IV presents our simulation results and analysis. We finally conclude our paper in section V.

II. SYSTEM MODEL

In our proposed network model, An SDN comprises of two main components: SDN Controller (SDN-C) and SDN Forwarding Element (SDN-FE). The controller is a logically centralized function. A network is typically controlled by one or a few controllers. The controllers determine the forwarding path for each flow in the network. The SDN-FEs constitute the network data plane. The logic for forwarding the packets is determined by the SDN controller and is implemented in the forwarding table at the SDN-FE. We consider a network where a centralized SDN controller computes the forwarding table for a set of SDN forwarding elements. We assume that all of the nodes in the networks are SDN forwarding elements. We assume that the SDN-C peers with the network and gathers link-state information. The SDN-FEs forward packets and the logic for computing the routing table at the SDN-Fes resides at the centralized SDN -C. In addition to forwarding packets, the SDN-FEs do some simple traffic measurement which they forward to the controller. The controller uses this traffic information along with information disseminated in the network to dynamically change the routing tables at the SDN-FEs in order to adapt to changing traffic conditions. The controller also exploits the fact that it can make co-ordinate changes across the different SDN-FEs that it controls to manage changing traffic effectively.

III. DESIGN OF HYBRID ROUTING FORWARDING ALGORITHM

In this section, we shall describe the design process of HRFA in detail. In our proposed network model, the SDN forwarding elements and conventional network nodes can coexist well, and SDN forwarding element is a subset of the set network nodes. Since the conventional node functions do not make any change, these non- SDN elements do not even aware the existence of SDN network forwarding elements. In our Hybrid Routing Forwarding Algorithm, the conventional nodes still use standard OSPF routing protocol when there is a data stream arriving. On the other hand, the SDN-FE describes the delineation of flows and the actions to be executed on packets associated with each flow, and forwards the flow table.

When a data stream firstly arrives at the SDN-FE, the following procedure will be triggered: (1) Construct the network topology; (2) Calculate the optimal route for traffic; (3) Feedback optimal path to the corresponding SDN-FEs; (4) Data forwarding and link status information monitoring.

A SDN controller asks its responding SDN-FEs to run topology discovery protocol for collecting information of all network nodes and links, to construct the network topology. Each SDN-FEs periodically sends probe packets to all ports in the network. These probe packets contain a sequence number, the switch ID, port ID, available port bandwidth, the number of available flow tables hardware parameters and other information. On receiving the corresponding probe packets, the SDN-FEs encapsulate them and sent to the controller to handle. Based on probe packets each switch sends, the controller generates neighbor information table and constructs complete network topology, in which the number of available hardware streams and available bandwidth information for each link are listed.

Once the SDN-FE has not received reply message within the specified period, it determines whether the current network link is abnormal or not, and sends packets identifying the current link failure to the network controller. based on the above packets, network controller reconstructs the topology. After it optimizes, network controller maintain or alter the flow information. When the SDN-FE receives a reply for the probe packet, it sends link recovery advertisement to the network controller. Network controller recalculates network topology and flow optimization.

Therefore, one SDN controller should include the following modules: (1) Calculation module for topology and link state information; (2) Flow optimization and path calculation module; (3) Advertisement module for optimal path.

Each router running OSPF would maintain a unified database describing the topology construction of autonomous system. This database is composed of the local state information of each router (the router available interface information, neighbor information), the network state information connected to the router (the routers connected to this network), external state information (the external routing information of this autonomous system) and other components. Different from the distance vector routing protocols, each router running OSPF spreads the corresponding status information within an autonomous system-wide. All routers run the same OSPF algorithm in parallel, and construct the shortest path tree rooted the router itself based on the topology database of routers. The leaf nodes of this shortest path tree are other routers in autonomous system. Finally, the routing table can be calculated according to this shortest path tree.

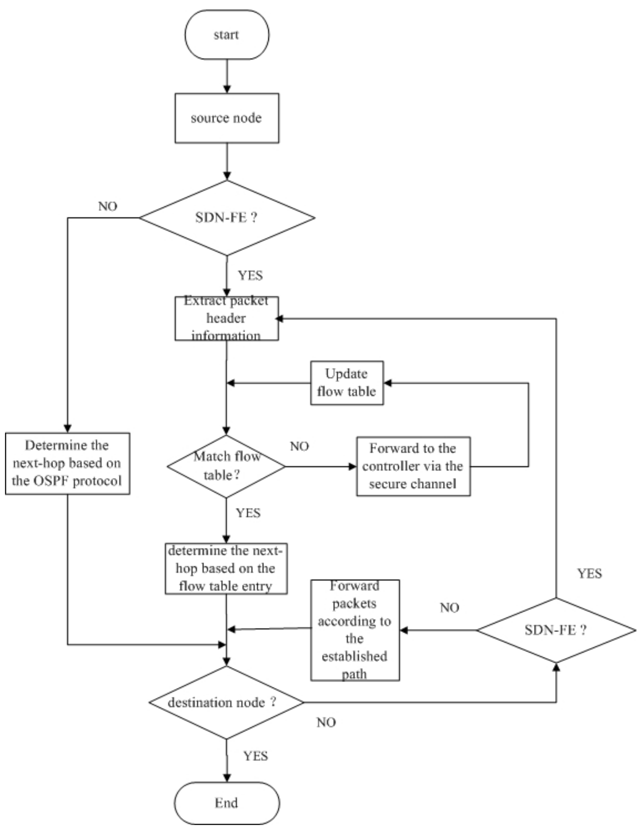

Figure 1. Flow chart of HRFA

The route calculation process in OSPF protocol is described as follows:

(1) Each OSPF router generates Link State Advertisement (LSA) according to the surrounding network topology, and delivers the LSA to other OSPF routers in the network by renewing messages.

(2) Each OSPF router will collect the LSAs advertised by other router advertisements, and all LSAs put together to generate Link State Database (LSDB). LSA gives the topology description around the router, while LSDB gives the topology description of the whole autonomous system.

(3) OSPF router transforms the LSDB to a weighted directed graph, which is the true reflection based on the whole network topology. The weighted directed graph achieved by all routers is the same.

(4) Based on the directed graph, each router calculate a shortest path tree rooted itself. This tree gives the routes to all other nodes in autonomous system.

In order to further explain how the algorithm works, the flow chart of HRFA is given in Fig. 1 above.

IV. PERFORMANCE EVALUATION

To study the overall performance of the proposed HRFA, a lot of simulated experiments have been carried out in NS2 simulation platform in this section. Evaluation metrics of average network throughput, packet loss ratio, average end-to-end delay are measured. In the simulation, nodes are randomly distributed in a static network region. The packet size is set to 1025 Bytes. Other parameters adopt default setting in NS-2. The simulation topology is illustrated in Fig. 2 and Fig. 3 below.

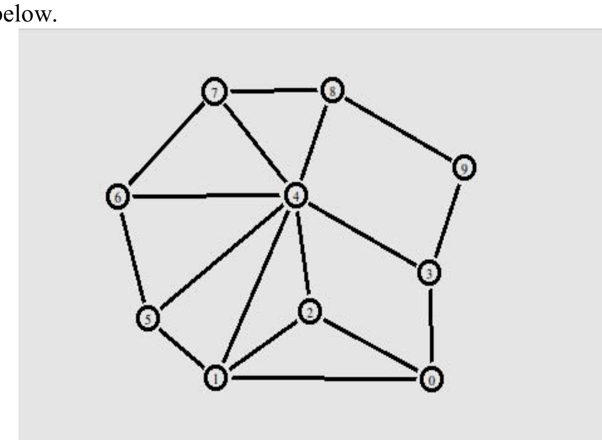

Figure 2. The random topology I for simulation

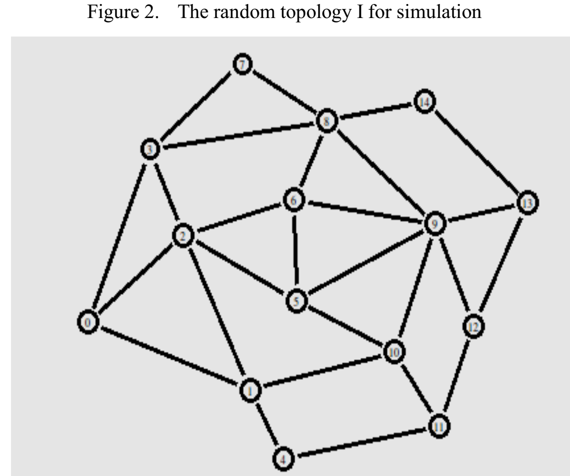

Figure 3. The random topology II for simulation

Fig. 4 gives the average network throughput performance under different number of SDN-FEs. As is shown in Fig. 4, it gives the comparative analysis of average network throughput between the proposed HRFA and traditional OSPF scheme by varying the number of SDN-FEs deployed in WMNs. Here note that when the number of SDN-FEs gets to zero, this extreme situation for HRFA becomes the traditional OSPF protocol in fact. From Fig. 4, it can be seen that the average network throughput in topology I and topology II both raises gradually with the increase in the number of SDN-FEs. Particularly, the average network throughput in topology I gets close to the maximum as the number of SDN-FEs increases to four, while the average network throughput in topology II gets close to the maximum as the number of SDN-FEs increases to five. It indicates that even partial deployment of SDN elements in networks could approach the upper bound throughput, which cut down the high expense of deployment and maintenance for SDN equipments. Meanwhile, it can be observed that the proposed HRFA outperforms OSPF in term of average network throughput.

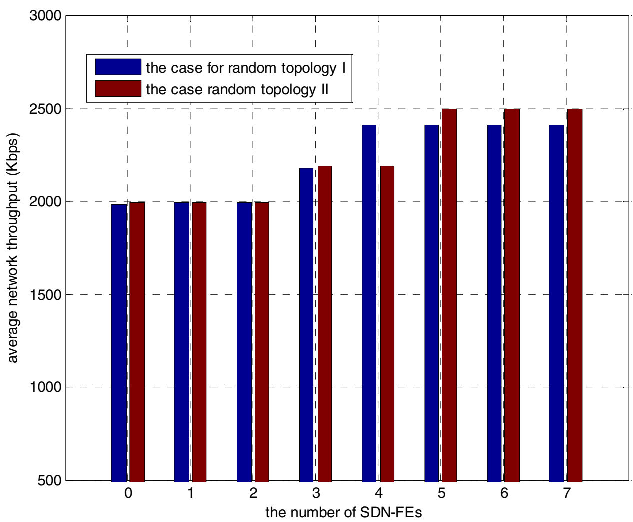

Figure 4. The average network throughput performance under different number of SDN-FEs

Since throughput is one of the most important performance indicators in WMNs, here the Normalized network throughput comparison under various number of SDN-FEs has also been given in Fig. 5 below. As shown in Fig. 5, the normalized network throughput in two kinds of topology conditions both sharply goes up with increase in the number of SDN-FEs. In topology one, the normalized network throughput with the number of SDN-FEs 4 could match the maximum average throughput when all the network elements are SDN equipments. While in topology two, the normalized network throughput can even reach 100% as the number of SDN-FEs increases to 5. It is implied that by using the proposed HRFA, the normalized network throughput could get to the maximum value without all network nodes being equipped as SDN-FEs. In addition, the normalized network throughput of HRFA is obviously better that of traditional OSPF scheme.

In order to study the reliability of HRFA, another group of simulation implements were conducted under different topology conditions to test the performance of packet loss ratio. As is shown in Fig. 6, it gives the performance comparison of packet loss ratio between HRFA and OSPF. From Fig. 6, it can be seen that the packet loss ratio under both topology conditions declines with the increase in the number of SDN-FEs. What's more, the packet loss ratio rapidly drops to zero as the number of SDN-FEs increase to certain value. Also, it can be observed that the packet loss ratio of HRFA is significantly lower than that of OSPF. The reason lies in that compared with the traditional network node, the SDN-FEs can (metits). Therefore, it can be concluded that Even if there is only a small number of network SDN-FE, the network packet loss rate can have a significant performance improvement.

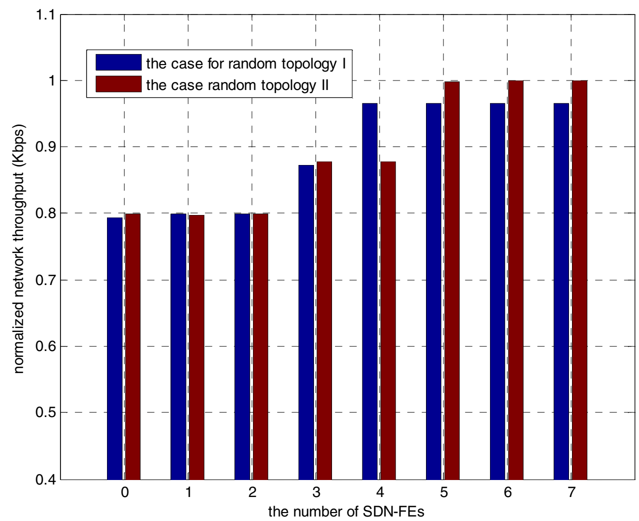

Figure 5. The normalized network throughput performance under different number of SDN-FEs

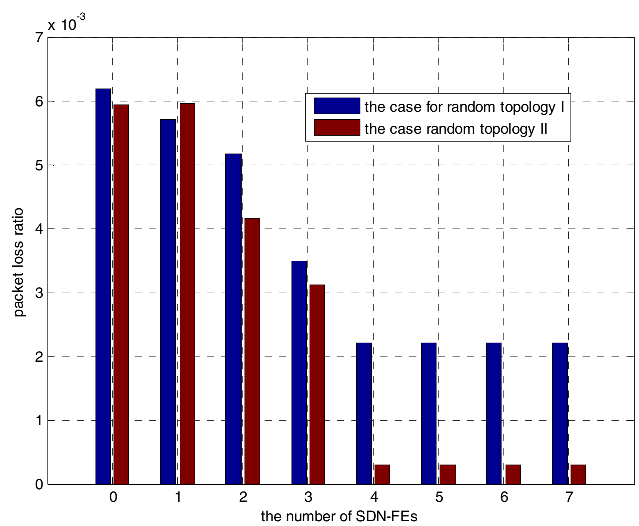

Figure 6. The packet loss ratio performance under different number of SDN-FEs

Fig. 7 gives the average end-to-end delay performance under different number of SDN-FEs. As is shown in Fig. 7, it gives the comparative analysis of average end-to-end delay between the proposed HRFA and traditional OSPF scheme by varying the number of SDN-FEs deployed in WMNs. Here note that when the number of SDN-FEs gets to zero, this extreme situation for HRFA becomes the traditional OSPF protocol in fact. From Fig. 7, it can be seen that the average end-to-end delay in topology I and topology II both decline with the increase in the number of SDN-FEs. Particularly, the average end-to-end delay in topology I runs sharper than that in topology II. It means that even partial deployment of SDN elements in networks could reduce the average end-to-end delay performance. Meanwhile, it can be observed that the proposed HRFA outperforms OSPF in term of average end-to-end delay.

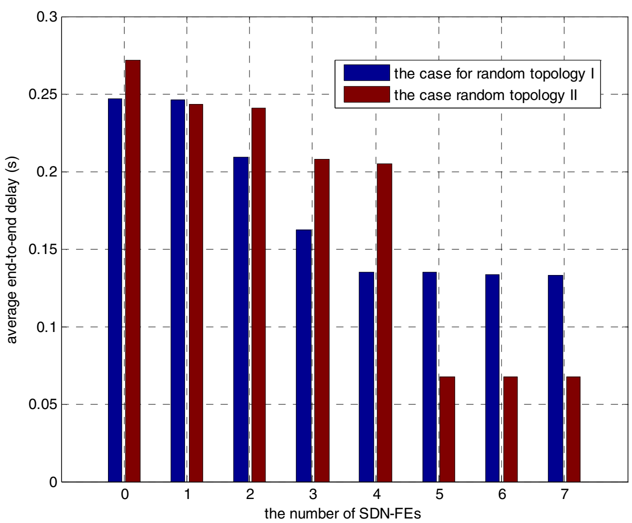

Figure 7. The end-to-end delay performance under different number of SDN-FEs

V. CONCLUSION

This paper focuses on traffic engineering problem in software-defined WMNs and introduces its concept, current development and related technologies in detail. Considering the current price of SDN equipments and deployment cost, this paper proposes an idea that gradually increases the number of SDN forwarding element in the networks. In other words, partly deployment of the SDN forwarding element in the networks can achieve fast forwarding traffic. On this basis, a new traffic engineering algorithms named HRFA which is based on SDN forwarding and OSPF protocol is designed. This hybrid routing scheme divides the network nodes into conventional nodes and SDN forwarding elements (SDN-FE), and chooses effective forwarding strategies for different network elements, which will improve the overall performance of the networks. This scheme takes the number of hops and link utilization paths into account to forward the data, so as to achieve the network load balance and reduce the network congestion. Simulation results demonstrate that our proposed HRFA scheme performs better in terms of average end-to-end throughput, average end-to-end delay and packet loss ratio than traditional routing protocol. It can be concluded that even if there is only a small number of network SDN-FE, the network overall performance can have a significant improvement. In the future, we are going to implement the HRFA on a real prototype test-bed and conduct practical experiments to verify the practicality and applicability of the proposal.

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REFERENCES

[1] F. Akyildiz, X. Wand, and W. Wang, "Wireless mesh networks: a survey[J]," Computer Networks, 2005, 47(4): 445-487.

[2] R. Bruno, M. Conti, and E. Gregori, "Mesh networks: commodity multi-hop ad hoc networks[J]," IEEE Communications, 2005, 43(3): 123-131.

[3] D. Kreutz, F. M. V. Ramos, P. E. Verissimo, C. E. Rothenberg, S. Azodolmolky, S. Uhlig. Software-Defined Networking: A Comprehensive Survey[J], Proceedings of the IEEE, 2015, 103(1): 14-76.

[4] K. Hyojoon, N. Feamster. Improving network management with software defined networking[J], IEEE Communications Magazine, 2013, 51(2): 114-119.

[5] N. Mckeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, J. Turner. OpenFlow: Enabling innovation in campus networks[J], ACM SIGCOMM Computer Communication Review, 2008, 38(2): 69-74.

[6] M. Casado, M. J. Freedman, J. Pettit, J. Luo, N. McKeown, S. Shenker. Ethane: Taking control of the enterprise[J], ACM SIGCOMM Computer Communication Review, 2007, 37(4): 1-12.

[7] K. Greene. R10: Software-defined networking[R], MIT Technology Review, 2009.

[8] A. Gavras, A. Karila, S. Fdida, M. May, M. Potts. Future Internet research and experimentation: The FIRE initiative[J], ACM SIGCOMM Computer Communication Review, 2007, 37(3): 89-92.

[9] P. Dely, A. Kassler, N. Bayer. Openflow for wireless mesh networks[C], Proc. of IEEE ICCCN, 2011, pp. 1-6.

[10] A. Detti, C. Pisa, S. Salsano. Wireless Mesh Software Defined Networks (wmSDN) [C], Proc. of IEEE WIMOB, 2013, pp. 89-95.

[11] K. Kerpez, J. Cioffi, G. Ginis, M. Goldburg, S. Galli, P. Silverman. Software-defined access networks[J], IEEE Communications Magazine, 2014, 52(9): 152-159.

[12] C. J. Bernardos, A. De La Oliva, P. Serrano, A. Banchs, L. M. Contreras, H. Jin, J. C. Zúniga. An architecture for software defined wireless networking[J], IEEE Wireless Communications, 2014, 21(3): 52-61.

[13] A. Sridharan, R. Guerin, C. Diot, ”Achieving Near-Optimal Traffic Engineering Solutions for Current OSPF/IS-IS Networks[J]”, IEEE/ACM Transactions on Networking, V. 13, No.2, April 2005.

[14] F. Huang, Y. Yang, L. He. A flow-based network monitoring framework for wireless mesh networks[J], IEEE Wireless Communications, 2007, 14(5): 48-55.

[15] M. Caesar, D. Caldwell, N. Feamster, J. Rexford, A. Shaikh, and K. vander Merwe, "Design and Implementation of a Routing Control Platform", Networked Systems Design and Implementation, May 2005.

[16] S. Agarwal, M. Kodialam, and T. V. Lakshman. "Traffic Engineering in Software Defined Networks[C]", Proceedings of IEEE INFOCOM 2013, pp. 2211-2219, April 2013.

[17] J. A. Wickboldt, W. P. Jesus, P. H. Isolani, C. B. Both, J. Rochol, L. Z. Granville. Software-Defined Networking: Management Requirements and Challenges[J], IEEE Communications Magazine, 2015, 53(1): 278-285.

[18] G. Bhanage, Y. Zhang, D. Raychaudhuri. Virtual Wireless Network Mapping: An Approach To Housing MVNOs On Wireless Meshes[C], Proc. of the IEEE PIMRC, 2011, pp. 187-191.

[19] N. Beheshti, Y. Zhang. Fast Failover for Control Traffic in Software-defined Networks[C], Proc. of the IEEE GLOBECOM, 2012, pp. 2665-2670.

[20] D.-H. Shin, S. Bagchi. An optimization framework for monitoring multi-channel multi-radio wireless mesh networks[J], Ad Hoc Networks, 2013, 11(3): 926-943.