A Novel Min-Cost Qos Routing Algorithm for Sdn-Based Wireless Mesh Network

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***Abstract*—Software Defined Networking (SDN) is a novel architecture, which is suitable for managing and controlling networks in a centralized way with global view, and can provide more effective and fine-grained resource allocation for routing management. Compared with traditional wireless mesh network (WMN), the SDN-based WMN (SDN-WMN) can guarantee the Quality of Service (QoS) more effectively. In this paper, we propose a novel min-cost QoS routing algorithm (MCQRA) for SDN-WMN to find out the path with minimum cost more efficiently, meeting the demands of QoS (e.g. bandwidth, delay and packet loss). To solve the NP-hardness problem, Lagrange relaxation method first is utilized to optimize multi-constraints problem. In the algorithm, a new dynamic step size is presented in the weight factor, which changes the corresponding proportion in link weight and influences by effectively feedback of the historical search results. And then the heuristic is utilized weight to gradually iterate, and quickly converge to discover optimal path. An out-of-band mode is employed for SDN-WMN performance simulations. Simulation results indicate that the proposed approach can obtain better performance than conventional routing scheme in terms of QoS satisfaction ratio and bandwidth utilization, with reduced overhead.**

Keywords-SDN; QoS; lagrange relaxation; heuristic; optimal path

I. INTRODUCTION

Software Defined Networking (SDN) as a new type of network innovative paradigm has attracted more attentions in recent years. SDN decoupling data plane and control plane, have potential for software programmable [1]. It adopts a centralized control plane and distributed forwarding plane, which are separated mutually. Controller in centralized manner controls of network devices via the communication interface for controller-forwarding, whose control signals transport between controller and network device. Traffic from control signals is independent of business traffic generating from subscribers terminals. After accepting control signal, network terminal device generate forwarding table, which can determine how to transport the business traffic. Meanwhile, forwarding data eliminates the need to traditional complex and distributed network protocol.

Presently, traditional wireless mesh networks (WMNs) consists of scattered mesh routers adopting traditional IP protocol and other distributed protocols, which result in complicated manual configuration, higher communication latency and poor security. Recently, SDN architecture and design based on wireless environment has been explored as better scheme for many scenarios. In [2], it summarized SDN paradigms in wireless network, part of which provide a feasibility scheme of applying OpenFlow in WMNs. It solved the primary problem by periodical updating topology when nodes moved, arrived and left continual. In [3], contexts proposed a SDN based wireless mesh network architecture, which is based on traditional router, adding Openflow switch flow table function and OLSR-to-OpenFlow (O2O) modules, realization of the IP routing table in OLSR protocol converting to Openflow flow table, to avoid controller failure suddenly. Work in [4] presented centralized, distributed and hybrid architecture and show us hybrid SDN architecture lower routing overhead.

Recently, improving performance of Quality of Service (QoS) in software-defined wireless network was researched in article [5, 6]. Energy-Aware routing algorithms including alternative greedy algorithms and global greedy algorithm were supported to minimize the power under constraints of link utilization and latency in [7]. Based on the proposed architecture, research in traffic engineering was explored eventually. A fast heuristic algorithm using relaxation and rounding techniques is proposed in [8]. Peng designed a dynamic traffic grooming algorithm which optimize the utilization of software-defined WMNs [9].

In this paper, we propose a min-cost routing algorithm to route the packets under constraint of QoS. We first transform the problem to integral linearity. To achieve to solve the NP-hard problem, traditional Lagrange relaxation algorithm [10, 11] is supported to adopt to relax function, and then the relax function is converted to a novel heuristic function. Through analysis and discussion to Lagrange multiplier, we introduce new step length distinct from traditional Lagrange relaxation algorithm to our scheme. A method called a polynomial-time heuristic algorithm is proposed in [12], but it only maximum throughput considering bandwidth as constraint, ignoring delay and packet loss rate. our scheme is compared to both NFB-S algorithms in [12] and a classic routing protocol OSPF, and demonstrate its superiority.

The rest of the paper is organized as follows: The process of Deploying OpenFlow over WMN is presented in Section 2. Section 3 proposes a min-cost QoS routing algorithm (MCQRA) applying heuristic method. Section 4 shows simulation of three routing schemes. Finally, we conclude this paper in Section 5.

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II. OPENFLOW DEPLOYMENT IN WMN

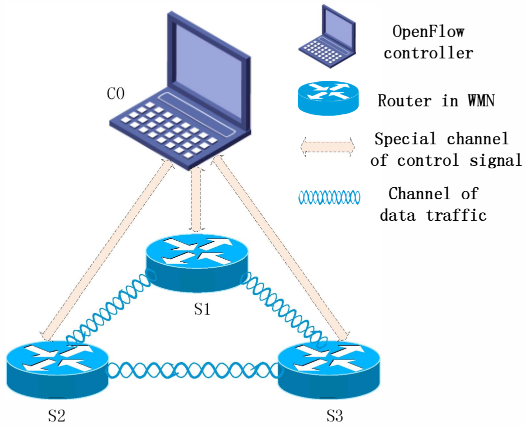


Figure 1. The architecture of deploying scheme.

As implemented in [13], the importance is to fill the gap between SDN and WMN. The first problem is to handle with wireless interface mode, including in-band and out-of-band. The two modes directly decide to network architecture. Control signal and data traffic need share link to transport in network by management of in-band. Considering the situation that a mass of data traffic emerge, it will affect control signal transporting in the same link, and then influence the performance of whole network. Consequently, we manage network by out-of-band mode, where it can realize the management of the network through specialized network channel.

Figure 1 represents the architecture of deploying Open-Flow over WMNs in out-of-band mode, which separate control traffic and data traffic. Control signal possesses special channel where only management data, statistical information and billing information can be transported, so that it don't occupy the channel of data traffic. Therefore it has the higher efficiency and reliability, also to improve the security of network data. We deploy our wireless experiments in the out-of-band mode.

III. A MIN-COST QOS ROUTING ALGORITHM FOR SDN-BASED WIRELESS MESH NETWORK

A. Problem Description and Model

The controller is in charge of monitoring the global mesh network and gets a network topology graph used to route packet. To update the topology periodically, we regularly use Iperf [14] to measure link properties e.g. link capacity and packet loss rate. We first build topology in Python and set link properties in the scripting language. In our graph (figure 1), a directed graph defined by $G(N,E)$ of which N denoting the set of network nodes and E the set of links. Each link $e \in E$ has a positive properties including cost denoted as c_e, delay denoted as $delay_e$ packet loss rate called $loss_e$, and residual link bandwidth as bw_e. The path of a flow requests to minimize routing overhead, while satisfy the constraints of QoS. By analysing the above conditions and hypothesis, we make out formulas as following integer linear programming

$$\min \sum_{e \in E} c_e x_e \quad (1)$$

$$s.t.\begin{cases} \sum_{e \in E} delay_e x_e \le D & (2) \\ \prod_{e \in E} loss_e x_e \le L & (3) \\ bw_e x_e \le BW, e \in E & (4) \\ x_e = \begin{cases} 0, e \notin path \\ 1, e \in path \end{cases} & (5) \end{cases}$$

where x_e is a binary variable that denotes whether *path* contain the link $e \in E$ or not, s and t is source and destination of a flow, D denotes latency request, L packet loss rate and BW bandwidth request of a traffic. Constraints of (2), (3), (4) ensure that path meet the fundamental request of QoS.

B. Relaxation Constraints of QoS

The model is a NP-hard problem. To achieve it, we first handle the above conditions by transforming multiply into addition in (3) by taking logarithm on either side of inequality, for $\sum_{e \in E} \log(loss_e) x_e \le \log L$. To solve the above integer linear programming, we consider relaxing the constraints of (2), (3) by Lagrange relaxation algorithm as follows

$$\begin{aligned} L(\alpha,\beta) &= \min[\sum_{e \in E} c_e x_e + \alpha(\sum_{e \in E} delay_e x_e - D) + \beta(\sum_{e \in E} \log loss_e x_e - \log L)] \\ &= \min(\sum_{e \in E} c_e x_e + \sum_{e \in E} \alpha delay_e x_e + \sum_{e \in E} \beta \log loss_e x_e - \alpha D - \beta \log L) \\ &= \min[\sum_{e \in E} (c_e + \alpha delay_e + \beta \log loss_e) x_e - (\alpha D + \beta \log L)] \end{aligned} \quad (6)$$

$$s.t. \quad bw_e x_e \le BW, e \in E$$

$$x_e = \begin{cases} 0, e \notin path \\ 1, e \in path \end{cases}$$

Since $\alpha D + \beta \log L$ is a constant value for constant α and β, to fast obtain the result, we only simplify (6) as $\min \sum_{e \in E} (c_e + \alpha delay_e + \beta \log loss_e) x_e$. Assuming that weight of each link is denoted by w_e, where it is computed as

$$w_e = c_e + \alpha delay_e + \beta \log loss_e , \quad (7)$$

the above equation is translated into formula $\min \sum_{e \in E} w_e x_e$ which is a simple routing problem. Therefore the most importance of handling the problem is how to evaluate α and β.

C. Optimization Model

By analyzing w_e, we can learn that $w_e = c_e$ means only minimizing cost of routing, while latency and packet loss rate take up increasingly ratio of w_e as weight multiplier α

and β increase gradually. As a result, we consider that both of α and β should be monotonic increasing functions. Meanwhile, considering traditional method of handling linear programming problem which uses gradient method to iterate to obtain optimal solution, we implement the method to optimizing search. We take the partial derivative of function $L(\alpha,\beta)$ with respect to α and β, respectively computed as:

$$\frac{\partial L(\alpha,\beta)}{\partial \alpha} = \sum_{e\in path} delay_e x_e - D \tag{8}$$

$$\frac{\partial L(\alpha,\beta)}{\partial \beta} = \sum_{e\in path} \log loss_e x_e - \log L \tag{9}$$

Considering that results of (8) and (9) may be a non-negative number, we adopt the below formula to compute the partial differential, denoted respectively as

$$\Delta_{delay} = \max\{\frac{\partial L(\alpha,\beta)}{\partial \alpha}, 0\} \tag{10}$$

$$\Delta_{loss} = \max\{\frac{\partial L(\alpha,\beta)}{\partial \beta}, 0\} \tag{11}$$

To satisfy weight multipliers increasing progressively, we need to set: $\alpha \leftarrow \alpha + \sigma\Delta_{delay}$ and $\beta \leftarrow \beta + \gamma\Delta_{loss}$. As a consequence of analysing, we have the weight multipliers α^t and β^t denoted the t-*th* iteration. Therefore, we can obtain the (t+1)-*th* iterative result updated as:

$$\alpha^{t+1} = \alpha^t + \sigma^t \Delta_{delay} \tag{12}$$

$$\beta^{t+1} = \beta^t + \gamma^t \Delta_{loss} \tag{13}$$

where step length σ^t and γ^t are computed as:

$$\sigma^t = \frac{\pi_t(\sum_{e\in path^t} c_e x_e - C_{\min} + 1)}{(\sum_{e\in path^t} delay_e x_e - D)^2 + (\sum_{e\in path^t} \log loss_e x_e - \log L)^2} \tag{14}$$

$$\gamma^t = \frac{\lambda_t(\sum_{e\in path^t} c_e x_e - C_{\min} + 1)}{(\sum_{e\in path^t} delay_e x_e - D)^2 + (\sum_{e\in path^t} \log loss_e x_e - \log L)^2} \tag{15}$$

where $C_{\min}$ represents the minimum cost of path without the constraint of QoS. Scalar π_t and λ_t is a non-negative constants updated as follows:

$$\pi_1 = \frac{C_{\min}}{D}, \pi_t = \frac{\pi_1}{2^{\lceil \frac{t}{3} \rceil}} \tag{16}$$

$$\lambda_1 = \frac{C_{\min}}{\log L}, \lambda_t = \frac{\pi_1}{2^{\lceil \frac{t}{3} \rceil}} \ . \tag{17}$$

where $\left\lceil \frac{t}{3} \right\rceil$ is a function rounded down to take the nearest integer. With regard to constraint of link capacity, we handle the simple constraint by pre-processing link before searching path.

Applying the approach presented in the above section, we can fast obtain the optimization or suboptimal but feasible solution for the original integer linear programming problem. Assuming that latency or packet loss rate of previous path can't meet the demand of traffic flow, we must increase corresponding weight multiplier to improve ratio of latency or packet loss in total weight. In this way, we can search an optical path or feasible path by gradually iteration. And we can determine whether to meet the constraints of (2) (3) of primitive problem.

D. *Heuristic Routing Algorithm in SDN*

Through the above analysis of optimization model, we represent a fast heuristic routing algorithm in SDN. Firstly, we must handle with residual capacity which is available on the link. Consequently, it's required that the mesh routers must report the left link bandwidth to the controller periodically. Then we can update bandwidth metric promptly.

Algorithm 1. Pre-treatment of bandwidth constraint

Input: a graph $G(N,E)$ and bandwidth request of a flow BW

Output: a graph of processing $G'(N,E)$, including cost matrix $Cost'$, latency matrix $Delay'$ and bandwidth matrix $Bandwidth'$ after process

```
n ← length of bandwidth metric
Cost' ←cost matrix of an original graph G(N, E)
Delay' ←delay matrix of an original graph G(N, E)
Bandwidth' ← bandwidth matrix of an original graph G(N, E)
for i=1; i<=n; i++ do
    for j=1; j<=n; j++ do
        if bandwidth(i, j) < BW then
            Cost'(i, j) ←0
            Delay'(i, j) ←0
            Bandwidth'(i, j) ←0
        end if
    end for
end for
```

Finally, algorithm 2 is invoked to search available path of satisfying the demand of QoS. We need calculate the minimum cost of path under no circumstance of QoS demand. Supposing the path satisfy (2) and (3), we can ensure this path is the minimum cost path that we are searching.

IV. SIMULATION AND RESULTS

Algorithm 2. Heuristic routing algorithm

Input: a graph $G'(N,E)$, a source-destination *(s, t)* of a flow and QoS demand of a flow

Output: a path of a source-destination (s, t), and updating residual bandwidth of link

1: $\alpha^1 \leftarrow 0$, $\beta^1 \leftarrow 0$

2: $t \leftarrow 1$

3: $\pi_1 \leftarrow \frac{C_{\min}}{D}$, $\lambda_1 \leftarrow \frac{C_{\min}}{\log L}$

4: Calculate minimize cost of path, denoted by $C_{\min}$ in Dijkstra algorithm

5: **while** ($\pi_t \ge 0.01$ or $\lambda_t \ge 0.01$) **do**

6: **for** t=1; t < M; t++ **do**

7: $\pi_t \leftarrow \frac{\pi_1}{2^{\lfloor \frac{t}{3} \rfloor}}$, $\lambda_t \leftarrow \frac{\pi_1}{2^{\lfloor \frac{t}{3} \rfloor}}$

8: Calculate σ^t , γ^t by formula (13) and (14)

9: $\Delta_{delay} \leftarrow \max\{\frac{\partial L(\alpha,\beta)}{\partial \alpha}, 0\}$

10: $\Delta_{loss} \leftarrow \max\{\frac{\partial L(\alpha,\beta)}{\partial \beta}, 0\}$

11: $\alpha^{t+1} \leftarrow \alpha^t + \sigma^t \Delta_{delay}$, $\beta^{t+1} \leftarrow \beta^t + \gamma^t \Delta_{loss}$

12: $w_e \leftarrow c_e + \alpha^{t+1} delay_e + \beta^{t+1} \log loss_e$

13: Calculate path by updating weight w_e ,called $path^{t+1}$, path delay and packet loss

14: **if** $path^{t+1}$ satisfy (2) and (3) **then**

15: *Candidate path* $\leftarrow path^{t+1}$

16: **end if**

17: **end for**

18: **end**

19: m ← length of *Candidate path*

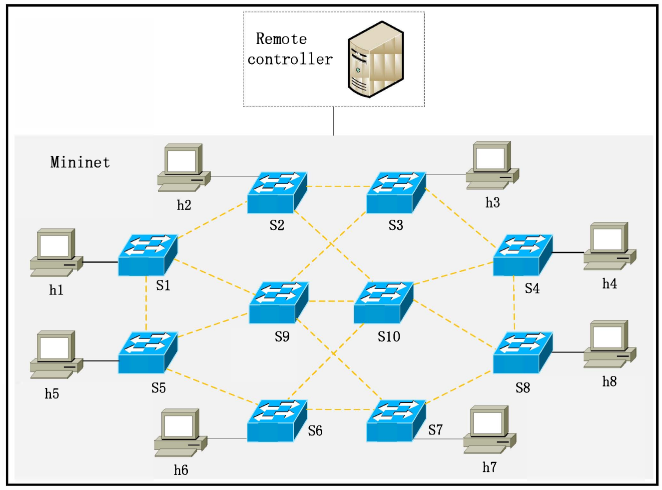
20: **for** j=1; $j \le m$;j++ **do**

21: choose minimum cost path in *Candidate path*

22: **end for**

Presently the simulator applying the fundamental Linux TC tools to simulate the wireless channel by adding link priorities such as packet loss rate, latency, and channel capacity. Article [15] presents Mininet-WiFi, inheriting from Mininet but available to establish wireless environment by adding virtualized base Station and Access Points, based on Linux wireless operating system. Wireless channel is replaced by an artificial virtual model which can support a convenient approach to simulate the channel environment in this way. Meanwhile, to appoint type of remote controller, we stop built-in controller of Mininet. ODL [16] is an open source software and tool for programming in upper application layer, so that we manage our network architecture based on ODL controller and determine the performance of routing. The remote controller can manage network topology, and then call routing algorithm by application programming interface. Figure 2 is the data traffic network topology generated by Mininet and the remote controller, where controller overviews the whole network topology. Finally, the properties of the wireless channel between routers are statically configured by the addLink class based on Linux kernel. The bandwidth of the link is configured to 100 Mbps, the latency is set randomly from 1ms to 3ms, and loss is configured by 2%.

Figure 2. This is emulation topology.



After that, our evaluation results are shown to evaluate performance of our demonstrated scheme. The topology in our emulation is consisted of 10 routers and 34 unidirectional links. The traffic is randomly generated in terminal of corresponding hosts by Iperf, which can ensure bandwidth of flow, set by 5Mbps. Meanwhile, latency and packet loss rate of flow is respectively set to 6ms and 8% in the application layer. Moreover, we compare our proposed MCQRA to OSPF and NFB-S to demonstrate its good performance.

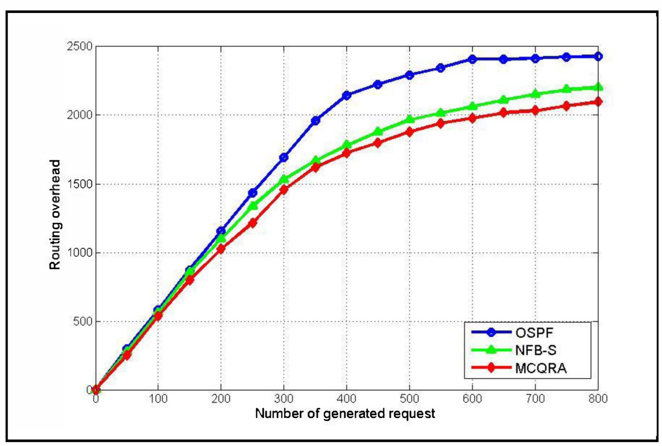


Figure 3. Routing overhead of the three schemes in rela-tion to number of generated request.

Figure 3 shows the result of routing overhead of three routing algorithm in relation to number of generated re-quest.

Firstly, we can see that the OSPF has relatively higher routing overhead as number of generated request increases, for OSPF always routes the flow to shortest path regardless of cost, bandwidth, latency and packet loss ratio. Besides, it clearly shows that MCQRA has smaller routing overhead than NFB-S only for data traffic as number of generated request. It is for that NFB-S only considers to weight by leveraging data and control traffic, ignoring importance of multiple constraints such as delay and packet loss, while MCQRA search a minimal cost path from candidate paths satisfying demands of QoS.

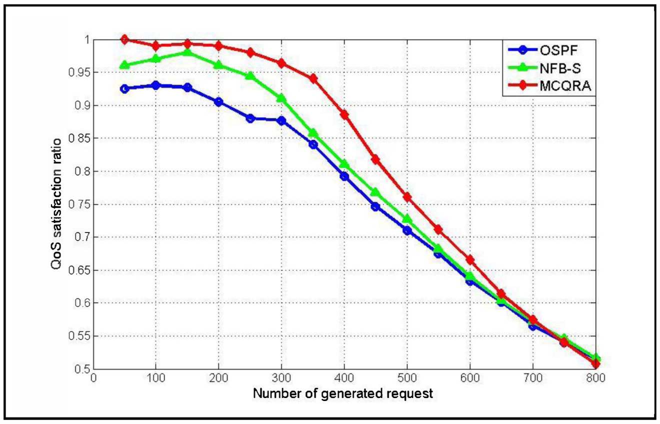


Figure 4. Qos satisfaction ratio of the three schemes in relation to number of generated request

Figure 4 exhibits the result of the QoS satisfaction ratio as number of generated request. We can see the display that ratio of the three algorithms increase with increasing data traffic request because a large amount of flow request would rapidly consume the bandwidth resources. We can clearly see the OSPF always has smallest QoS satisfaction ratio as the traffic demands increase. It is because that the OSPF search a shortest path for flow without regard to demands of latency and packet loss, while the NFB-S algorithm considers bandwidth without latency and packet loss rate. Moreover, MCORA has highest QoS satisfaction ratio in the three algorithms because it gradually generates weight considering latency and packet loss.

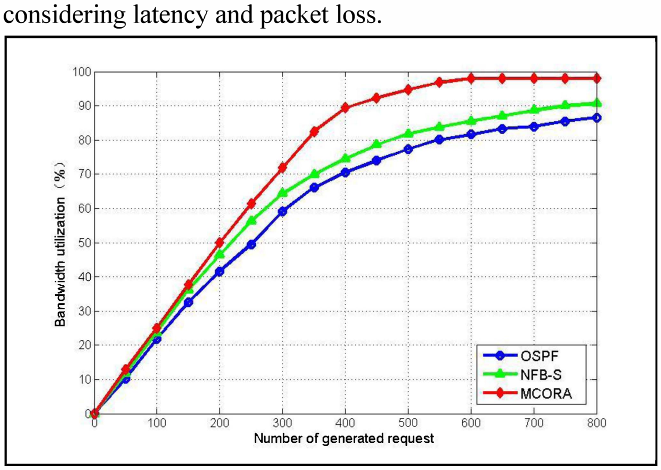


Figure 5. Bandwidth utilization of the three schemes in relation to number of generated request

Figure 5 show increasingly bandwidth utilization of the three algorithms along with incremental flow request. It is the reason that residual bandwidth degrades with number of request flows increasing. We can find out that MCORA always demonstrate the improved performance in bandwidth utilization with respect to the other schemes especially under the condition of numbers of data traffic requests. The NFB-S has slightly higher utilization than the OSPF scheme, but is lower than MCORA scheme. Meanwhile, we can also figure out that the bandwidth utilization is mainly saturated when number of generated request is up to 450 in MCORA scheme. The supreme bandwidth utilization achieves the 98%.

V. CONCLUSION

In this paper, we propose a novel routing algorithm called MCQRA with the objective of minimizing cost of path, under constraints of bandwidth, delay and packet loss. To solve the NP-hardness problem, a heuristic algorithm is presented to optimize the model. And then it iteratively searches an optical path by dynamically updating weight factor of delay and packet loss rate. Meanwhile, emulation platform is deployed with ODL and Mininet in out-of-band mode to evaluate the good performance on routing overhead, QoS satisfaction ratio and bandwidth utilization. As a result, it outperforms the traditional OSPF and NFB-S schemes.

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