Performance Evaluation of Routing Strategies over Multimedia-based SDNs under Realistic Environments

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***Abstract*—Most of the existing performance evaluation studies of various routing algorithms are done under limited experimental setups leading to an incomplete picture of the routing algorithm performance under dynamic network conditions. This paper presents a study that compares state-of-the-art routing algorithms over realistic multimedia-based Software Defined Networks (SDNs) with dynamic network conditions and various topology. Routing algorithms remain a key element of the networking landscape as they determine the path the data packets follow. The next-generation networking paradigm offers wide advantages over traditional networks through simplifying the management layer, especially with the adoption of SDN. However, Quality of Service (QoS) provisioning still remains a challenge that needs to be investigated especially for multimedia-based SDNs. This study investigates the impact of state-of-the-art centralized routing algorithms (e.g. MHA, WSP, SWP, MIRA) on multimedia QoS traffic under a realistic environment in terms of PSNR, Throughput, Packet Loss, Delay and QoS rejection.**

***Index Terms*—Software Defined Networks, Quality of Service, Routing Algorithms, Multimedia.**

I. Introduction

One of the most significant paradigm shifts within the networking industry is represented by Software Defined Networks (SDNs) that aim to make the existing networks more easy to supervise, configure, deploy and monitor. However, the significant growth in video traffic puts pressure on the underlying networks and service providers that need to find new solutions to enable efficient resource management while ensuring Quality of Service (QoS) provisioning to their customers with Quality of Experience (QoE) as the basis for network control [1].

A vital peripheral within the networking landscape is the routing algorithm which efficiently routes the flows over the underlying network. There is a wide range of existing routing algorithms, each with different properties and purpose. The choice of routing algorithm can heavily impact the QoS provisioning within multimedia-based SDNs. The simplest routing algorithm is MHA (Minimum Hop Algorithm), which finds a path with the minimum number of hops between source and destination nodes [2]. WSP (Widest Shortest Path) finds the maximum capacity path according to the bandwidth constraint of the flows. In this case, the number of hops and the available bandwidth are the metrics for routing. In case of multiple paths, WSP finds the highest candidate from the set of shortest feasible paths, while SWP (Shortest Widest Path) takes the widest feasible path from the candidate set [3]. MIRA (Minimum Interference Routing Algorithm) exploits the knowledge of ingress-egress pairs in the network, such that, the routing of ingress-egress pairs do not interfere with each other. Thus, MIRA identifies the mincut sets for all the ingress-egress pairs [4] and the link that belongs to the mincut set is marked as critical and avoided by the algorithm.

The study in [5] presents a survey of different routing algorithms under dynamic settings of performance guaranteed traffic tunnels in backbone SDNs. However, this is limited to specific scenarios. Lee et al. [6] compared standard routing algorithms. However, the simulation setup is relatively simple. Abdallah et al. [7] investigated the performance of SDN vs. OSPF (Open Shortest Path First) concluding that OSPF results in higher convergence delay for large networks. In [8] the Bayes' theorem and Bayesian network model were used to find the most feasible path that satisfies the QoS constraint.

This paper studies the impact of state-of-the-art routing algorithms (e.g., MHA, WSP, SWP, MIRA) on multimedia QoS traffic over SDN. A comprehensive performance evaluation in terms of PSNR, throughput, packet loss, etc. of the routing algorithms under realistic scenarios with dynamic network conditions and various topology is presented.

II. Experimental Setup and Evaluation Scenarios

A. Experimental Setup

The experimental setup deployed in this study consists of three main elements: (i) Mininet[1] - used to emulate the SDN data plane; (ii) external Floodlight controller[2] -

[1]Mininet: http://mininet.org
[2]Floodlight: www.projectfloodlight.org

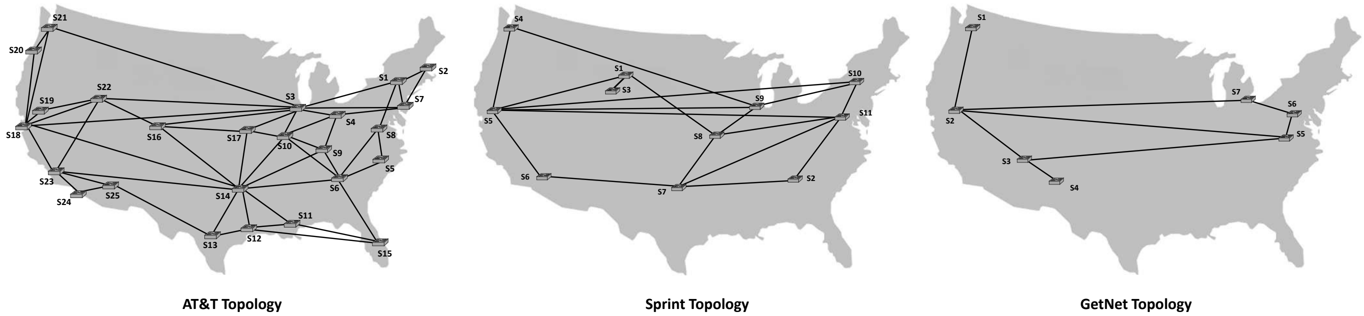

Fig. 1. Experimental setup under different topology: AT&T (large-scale topology), Sprint (middle-scale topology), and GetNet (small-scale topology).

provides RESTful API and network services and (iii) the application layer - containing routing and log management for performance evaluation. The SDN controller and the entire routing management application run on a Linux-Ubuntu Server virtual machine (2.2GHz, 4 CPUs, 16GB), while Mininet is running on another virtual machine (2.2GHz, 4 CPUs, 32GB). Open vSwitch[3] is used as SDN switch.

Variable-bit-rate (VBR) video traffic is generated using VLC player, while HTTP and FTP traffic is generated using Ostinato[4]. The traffic mix ratio is set according to Cisco [9] such that 80% of the total traffic is represented by video traffic (average bit-rate of 436Kbps, frame rate of 23fps, 640x360 resolution, 5min duration) and the remaining 20% is represented by HTTP and FTP traffic. The HTTP traffic is modeled as ON/OFF period, where ON represents the transmission time and OFF represents the packet inter-arrival time [10]. For each traffic request, the source and destination host pairs are selected randomly following an uniform distribution. The session used to transfer a file of a random generated size is modeled according to [10].

B. Evaluation Scenarios

To drive a dynamic network evaluation, the following parameters are considered: *(1) Network topology:* three different network topologies are employed: AT&T (large-scale topology), Sprint (middle-scale topology), and GetNet (small-scale topology). The network topologies were taken from Internet zoo topology [11] and listed in Fig. 1. *(2) Traffic type:* multiple QoS traffic flows are mixed with best-effort traffic (e.g., video, HTTP, FTP). For the guaranteed traffic, QoS-based video streaming is employed. *(3) Network load:* three different network load levels are considered: 0.5 (low load), 0.75 (medium load), and 1.0 (high load). The network load NL is given by:

$$NL = \frac{\sum_{i}^{N} \frac{LL_i}{LC_i}}{N} \tag{1}$$

where LL is the link load, LC is the link capacity, and N is the number of links in the network topology.

[3]Open vSwitch: http://openvswitch.org
[4]Ostinato: https://ostinato.org/

The entire experimental time is of 30min and is divided into several overlapped sessions in order to maintain a continuous traffic flow. The traffic arrival follows a uniform distribution over the duration of each session while the active period of each connection is distributed exponentially with a mean of $1/\mu$ seconds. The destination node is chosen at random, excluding the source node. However, because of the processing capacity limitations of the experimental setup, each link in the topology operates at the speed of 1 Mb/s. Thus, for the performance evaluation purpose, the scenarios' configurations were scaled down accordingly.

III. Results and Discussion

Various performance metrics are used for the performance evaluation,such as: average throughput, average packet loss, average latency, average PSNR, and the number of rejected QoS services. In this work, the average PSNR value is calculated using the PSNR values of the QoS-based videos belonging to a single scenario [12]. Moreover, in order to study the impact of the traffic load on the rejection of QoS-based traffic, the results show the number of rejections for the upcoming QoS-based requests along the experiment as a function of the network traffic load. When a new request of the QoS-based services arrives, the algorithm finds a feasible path where the links have residual bandwidth equal or greater than the demanded bandwidth. In case there is no path that satisfies the bandwidth constraint, the request is rejected.

A. Impact of Network Topology

This subsection studies the impact of the network topology on the performance of the four algorithms based on the traffic load level.

1) Low traffic load: Looking at the low traffic load, we notice that when the size of network topology increases, MIRA and SWP achieve better results than MHA and WSP in terms of the packet loss, throughput and latency. For example, we observe in Tables I to III that, as the size of the topology increases from GetNet to AT&T, the packet loss of quality traffic for MHA has risen by 6.1% as compared to MIRA with an increase of 3.6%. Similarly, the throughput of quality traffic for MHA decreased by 9.5% while MIRA decreased by 7.2%. In general, the results in Fig. 2 show

TABLE I

GETNET NETWORK TOPOLOGY: AVERAGED PERFORMANCE EVALUATION FOR ROUTING ALGORITHMS

	Performance Metrics	MHA			WSP			SWP			MIRA		
		low	medium	high	low	medium	high	low	medium	high	low	medium	high
Quality Traffic	Throughput [Kb/s]	507	474	322	511	**484**	**345**	511	**484**	321	**512**	480	331
	Packet Loss [%]	**0.1**	**2.2**	19.1	**0.1**	2.3	18.1	**0.1**	2.3	**17.1**	1.2	2.5	17.2
	Latency [ms]	50	1178	8034	**30**	**1159**	6703	46	**1159**	**6354**	60	1163	7034
Back-ground	Throughput [Kb/s]	77	52	54	74	50	48	79	63	53	79	56	49
	Packet Loss [%]	0.2	3.7	7.2	0.2	1.5	6.4	0.2	3.5	4.7	0.5	4.1	5.5
	Latency [ms]	22	1257	2552	18	408	2147	14	857	1731	30	1400	2161

TABLE II

SPRINT NETWORK TOPOLOGY: AVERAGED PERFORMANCE EVALUATION FOR ROUTING ALGORITHMS

	Performance Metrics	MHA			WSP			SWP			MIRA		
		low	medium	high	low	medium	high	low	medium	high	low	medium	high
Quality Traffic	Throughput [Kb/s]	465	403	319	477	426	411	485	453	**435**	**508**	**476**	371
	Packet Loss [%]	4.2	8.1	16.5	2.5	6.2	9.7	1.9	5.2	**6.5**	**1.1**	**2.5**	15.9
	Latency [ms]	1066	1311	1863	609	1124	1547	533	**431**	**1461**	**50**	660	1807
Back-ground	Throughput [Kb/s]	79	76	92	83	75	89	72	61	73	83	67	87
	Packet Loss [%]	0.6	2.6	4.3	0.9	1.5	3.3	0.6	0.8	3.5	0.2	1.5	2.1
	Latency [ms]	83	505	826	143	276	575	45	147	736	25	242	347

that the performance of all routing algorithms decreases noticeably when the network topology size increases. For example, when there is increase in the network size from GetNet to AT&T, the average PSNR for MHA, WSP, SWP and MIRA algorithms are decreased by 10.8, 7.7, 7, and 11.2dB respectively. Similarly, it can be observed that the number of rejection (Fig. 3) for quality traffic grows in proportion to the increase in topology size. In fact, as the topology size increases, higher volume of flows is generated in order to maintain the same load under various topologies.

When looking at maximizing the throughput for QoS-based video flows, we notice that MIRA, WSP and SWP perform best for GetNet small scale network. While for the Sprint medium scale network, MIRA outperforms other algorithms by achieving 508Kb/s throughput. For AT&T large-scale networks, WSP achieves better throughput for QoS-based video flows. In terms of minimizing the packet loss for QoS-based flows, MHA, WSP and SWP achieve best results for small scale networks, while MIRA achieves the best results for medium scale networks and SWP for large scale networks. In terms of minimizing the latency, WSP outperforms other algorithms for small scale networks, MIRA obtains the minimum latency for medium scale networks while for large scale networks WSP performs best.

2) Medium traffic load: As depicted in Tables I to III, the increase in network topology size from GetNet to AT&T shows that the packet loss for the quality traffic when employing MHA rises by 5.9%, while WSP and SWP has a rise of 3.7% and 4.2%, respectively. MIRA shows slightly better results with 2.7% packet loss for quality traffic.

In terms of PSNR, depicted in Fig. 2, there is a decrease for MHA, WSP, SWP and MIRA algorithms by 10.2, 11.3, 11.7, and 6.8 dB, respectively. Although the size of network topology affects the videos' quality, it is observed that the performance variation between the routing algorithms shows similar trends under the medium traffic load.

Thus, for GetNet small scale network, WSP and SWP perform best, giving the highest throughput for QoS-based video flows. For medium and large scale networks (e.g., Sprint and AT&T), MIRA achieves better throughput for QoS-based video flows. In terms of minimizing packet loss for QoS-based flows, MHA, WSP and SWP achieve best results for small scale networks. However, MIRA obtains better results for QoS-based video flows for medium and large scale networks. In terms of minimum latency, WSP and SWP outperform other algorithms for small scale networks. SWP achieves minimum latency for medium scale networks while for large scale networks, MIRA performs best.

3) High traffic load: The routing algorithms exhibit relatively lower packet loss in larger network topology than in smaller networks. For instance, SWP shows a decrease in packet loss for quality traffic from 17.1% (GetNet) to 13.9% (AT&T). In GetNet the traffic distribution is carried on smaller number of links than in AT&T. Thus, it is expected to have higher traffic congestion and packet loss.

The results in Tables I, II and III show that the average statistics for the background traffic are lower than the quality services. In fact, the background traffic contains

TABLE III
AT&T NETWORK TOPOLOGY: AVERAGED PERFORMANCE EVALUATION FOR ROUTING ALGORITHMS

	Performance Metrics	MHA			WSP			SWP			MIRA		
		low	medium	high	low	medium	high	low	medium	high	low	medium	high
Quality Traffic	Throughput [Kb/s]	459	428	**402**	**477**	431	385	472	430	390	475	**454**	395
	Packet Loss [%]	6.2	8.1	16.1	4.9	6.0	15.9	**4.2**	6.5	**13.9**	4.8	**5.2**	14.1
	Latency [ms]	1143	1372	1946	**1035**	1395	1654	1052	1341	**1604**	1090	**1235**	1679
Back-ground	Throughput [Kb/s]	176	87	73	180	87	66	193	81	60	159	84	95
	Packet Loss [%]	1.2	2.5	4.2	1.5	2.4	4.8	1.6	2.3	4.9	1.2	2.5	2.8
	Latency [ms]	273	425	872	240	323	574	478	613	1087	272	471	602

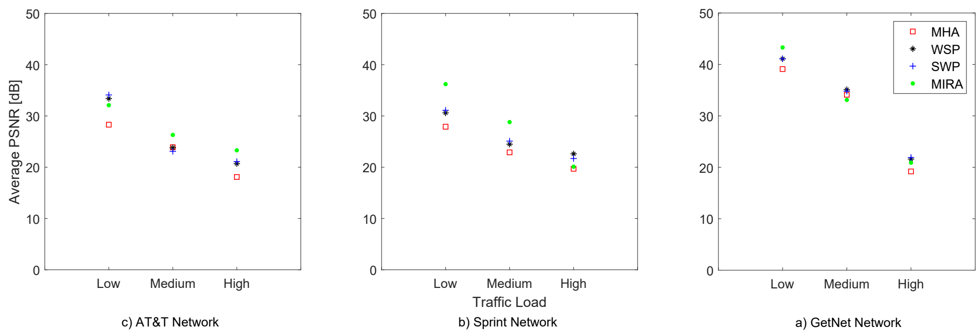

Fig. 2. The average PSNR under different traffic load and network topologies.

HTTP/FTP and video traffic, while the quality services contain QoS-based video traffic only. The HTTP/FTP traffic flows have much smaller load than video traffic, hence the averaging becomes smaller for background traffic.

Thus, the results (Tables I to III) show that WSP performs best in terms of throughput maximization for GetNet small scale network. For Sprint medium scale, SWP provides best results. However, for AT&T large-scale networks, MHA achieves better throughput for QoS-based video flows. In terms of minimizing the packet loss for QoS-based flows, SWP and MIRA perform better than other algorithms under small scale network. Similarly, SWP achieves better results for medium and large scale networks. In terms of minimizing the latency, SWP performs better than other algorithms for small, medium and large scale networks.

Figure 3 illustrates the number of rejections for quality services. It can be seen that under highly loaded network, the rejection rate of routing algorithms increases considerably. For example, under AT&T network, there is an increase of 97.2% for MHA when the load increases from low to high.

B. Impact of Traffic Load

This section presents the impact of traffic load on the routing algorithms performance under different topologies.

1) GetNet topology: Table I shows that all routing algorithms reach larger packet loss when the load becomes higher. For example, MHA, WSP, SWP and MIRA get an increase in packet loss of 19%, 18%, 17%, and 16%, respectively. On the other hand, it can be observed in Fig. 2 that with low traffic load, MIRA performs better with an average PSNR value of 43.3dB when compared to other candidates. Under higher traffic load, SWP performs slightly better than other algorithms reaching an average PSNR value of 21.9dB.

While looking at the results within the same network topology but under different traffic load, we can notice that under low traffic, the maximum throughput for QoS-based flows is obtained by MIRA. However, as the traffic load increases for medium traffic, WSP and SWP get the highest throughput for QoS-based traffic. While for high traffic load, WSP achieves the best results. In terms of packet loss minimization for QoS-based flows, MHA, WSP and SWP achieve the best results under low traffic, while for medium traffic load, MHA performs better and SWP achieves the minimum packet loss under high traffic load. In terms of minimizing the latency for QoS-based flows, WSP performs best for low and medium traffic, while SWP achieves the best results for medium and high traffic load.

2) Sprint topology: For Sprint network topology, Fig. 2 shows that MIRA performs better under low and medium traffic load. For example, at low traffic load, MIRA achieves an increase of 8.3dB in averaged PSNR when compared to MHA. In contrast, at high traffic load, WSP shows a slight improvement when monitoring the average PSNR as compared to other routing algorithms.

When looking at maximizing the throughput for QoS-based video flows, MIRA achieves better results than other algorithms under low and medium traffic load. However, as the traffic load increases from low to high, SWP maximizes the system throughput for QoS-based traffic. In terms of minimizing the packet loss for QoS-based flows, MIRA

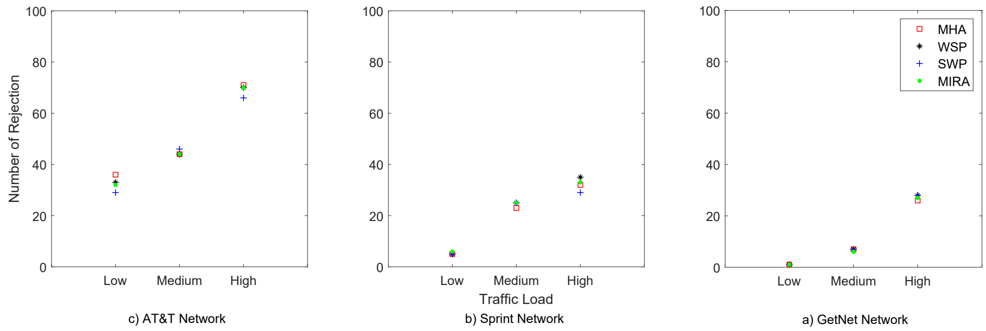

Fig. 3. The number of rejection for quality requests under different traffic load and network topologies.

outperforms others under low and medium traffic load. By increasing the traffic load, SWP achieves better results. In terms of minimizing the latency for QoS-based flows, MIRA performs best for low traffic load while SWP achieves the best results for medium and high traffic load.

3) AT&T topology: Table III shows that the throughput level decreases considerably as the traffic load increases, while the packet loss and latency increase. As the network load increases, the links experience higher congestion rate, increasing at same time, the latency and packet drop rate of the corresponding flows. Figure 2 indicates that as the traffic load increases from low to high, MIRA achieves a decrease in average PSNR of about 8.8dB. On the other hand, MHA, WSP and SWP obtain higher decrease of about 10.2dB, 12.7dB, and 13dB, respectively.

WSP achieves the maximum throughput for QoS-based flows under low traffic. For medium traffic, MIRA gets the highest throughput level. If the traffic load is high, then MHA achieves better results when compared to others. In terms of minimizing the packet loss for QoS-based flows, SWP achieves the best results under low and high traffic load, while MIRA reaches better results under medium traffic load. In terms of minimizing the latency for QoS-based flows, WSP performs the best for low traffic. For medium traffic, MIRA performs better than others, while SWP achieves the best results for high traffic load.

C. Impact on the QoS-based video traffic

Figure 2 shows the average PSNR for quality traffic. At low load under GetNet and Sprint, MIRA performs better than others. For example, under GetNet low load, MIRA achieves an increase of 4.2dB when compared to MHA. In fact, MIRA avoids placing the route requests along the links that lead to highly probable congestion. On the other hand, the results show that WSP and SWP have a close performance to MIRA under low traffic load and AT&T.

As the traffic load becomes high, the average PSNR decreases and the routing algorithms behave differently. For example, WSP and SWP show similar results under GetNet. Under Sprint topology, WSP gets better results than others with 2.9dB increase in PSNR when compared to MHA. In contrast, MIRA performs better than others with an increase of 5.2dB when compared to MHA for the AT&T network.

IV. Conclusions

This paper provides a comprehensive performance evaluation of four state-of-the-art routing algorithms (MHA, WSP, SWP and MIRA) over realistic multimedia-based SDN environments with dynamic network conditions and topology. The four algorithms were implemented and evaluated by using an experimental setup based on Mininet, Floodlight controller and Open vSwitch switches. The results show that there is no one single routing algorithm that can perform best under all considered scenarios and networking conditions. Thus, it is possible to integrate a machine learning-based traffic management solution as future work.

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