Enhancing Multimedia Streaming with Weighted Multiple Transmission Paths in Software Defined Networks

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Abstract

With continuing advances in network and video and audio techniques, and the proliferation of mobile applications, the demand for multimedia streaming has grown exponentially in recent years. This study therefore proposes a multipath transmission scheme, designated as Weighted Stochastic Multipath (WSMP) scheme, for enhancing the efficiency of multimedia streaming transmissions by utilizing the data flow control ability in Software Defined Networks (SDNs). The proposed method searches for multiple transmission paths meeting the imposed QoS constraints, and then uses the stochastic switching mechanism based on the OpenFlow protocol in SDNs to transmit the data packets of single data flows through the multiple paths. In addition, the Analytic Hierarchy Process (AHP) method is used to set the transmission weights of the different paths in such a way as to optimize the transmission performance. Thus, the proposed multipath transmission scheme not only can avoid single path interruptions but also can split a single traffic flow among multiple paths. In comparison with the traditional single path transmission scheme and the well-known MPTCP scheme, the experimental simulation results show that, when the QoS parameter values of the multiple transmission paths are diverse, WSMP attains a higher throughput for data transmission and better PSNR values for video streaming, and thus yields a significant improvement in the efficiency of multimedia streaming transmissions.

Keywords: Software defined networks, OpenFlow protocol, Weighted multiple transmission paths, Analytic hierarchy process

1 Introduction

With the rapid development of network and video and audio techniques, multimedia streaming applications, such as net phone, video conferencing, and streaming video, have become ubiquitous nowadays. Thus, there has been a massive increase in demand for improved network transmission efficiency. Consequently, the problem of performing effective network planning and control in such a way as to meet these user demands with minimal hardware implications has emerged as a pressing concern.

Software Defined Networking (SDN) [1-3] is a programmable network paradigm which enables easy and flexible network configuration, monitoring and control. SDN divides the network architecture into two layers, namely the control layer and the data layer. The control layer is the core of SDN and contains the functionality required to perform routing or network control and to issue corresponding commands to the data layer. On receipt of these commands, the data layer forwards the data packets to the destination port through the prescribed route. Importantly, SDN enables the network administrator to implement centralized management in the control layer. As a result, the data routing and network device control tasks can be carried out by the controller without the need for additional hardware, provided that the network devices support the communication protocol, such as OpenFlow [4], with the controller.

In traditional networks, the optimal transmission path is generally taken as the path with the least cost or the shortest length. This concept has been adopted as the basis for many multipath transmission algorithms. For example, the QoS routing mechanisms reported in [5-8] focus on the problem of identifying the optimal transmission paths for different classes of traffic. Meanwhile, ECMP [9], WCMP [10] and MPTCP [11, 12] aim to improve network transmission efficiency through the choice of appropriate multiple paths. However, all of these methods do not have control over path selection for the packets in a single traffic flow. Consequently, they might result in poor utilization of the available transmission paths and even link congestion.

The data flow control ability of SDN provides a powerful and effective approach to accomplishing multipath transmissions in data networks. In particular,

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the Group Table [4] in the OpenFlow protocol provides a Select method allowing different egress ports to be assigned different weights while selecting the egress ports for performing packet forwarding. Thus, different egress ports on the switch effectively have different forwarding probabilities. The author in [13] exploited this feature of OpenFlow to design a stochastic switching transmission mechanism. The present study uses the OpenFlow protocol and a similar stochastic switching technique to design a multipath transmission method for QoS flows in SDN architectures. In the proposed scheme, designated as Weighed Stochastic Multipath (WSMP) scheme, multiple paths with different weights are allocated to the transmission of the various packets belonging to a single data flow for a certain traffic class. Notably, the packet transmission paths can be dynamically adjusted in accordance with changes in the network conditions. Thus, transmission failures due to single path interruption can be prevented, and the network throughput significantly improved as a result.

The remainder of this paper is organized as follows. Section 2 introduces the related studies and describes the major techniques employed in the present study. Section 3 presents the concepts and details of the proposed weighted multipath transmission scheme. Section 4 presents and discusses the simulation results and evaluates the efficiency of the proposed transmission method. Finally, Section 5 provides some brief concluding remarks.

2 Related Studies and Literature Review

2.1 Software Defined Networks and OpenFlow Protocol

Software Defined Networking (SDN) is a software-based network architecture approach that enables the network to be intelligently controlled using programs [1-3]. In the traditional networks, the function of the control plane is tightly coupled with the hardware of the network devices. By contrast, SDN decouples the software from the hardware and provides logically centralized control such that the services and applications can be abstracted from the underlying network. Furthermore, the applications interact with the network through APIs rather than interfaces tightly bound to the hardware. Thus, SDN enables network operators to write programs that utilize open APIs and to rapidly introduce innovative and new services as a result.

OpenFlow protocol, formally known as OpenFlow Switch Specification [4], was developed by Stanford university in 2008 as an open source protocol for supporting SDN network architectures. Its contents not only specify the basic module and functional requirements of the switch but also prescribe a protocol for the exchange of information between the controller and the switch. Note that the forwarding devices in an SDN network are generally referred to as switches.

In an SDN network compliant with the OpenFlow protocol, there is a centralized controller, namely the OpenFlow controller. The controller maintains the topology information of the network, and monitors the overall status of the entire network. Also, it communicates with the switches to set up the Flow Table within the switches using the OpenFlow protocol. The Flow Table contains a set of flow entries, each of which consists of fields including match, priority, counters, instructions, etc. The controller can update the Flow Table by adding and removing the flow entries. Therefore, the controller is able to command the switches to apply certain actions on the packets, such as forward, drop, and encapsulate. Furthermore, actions associated with flow entries may also direct packets to a Group Table, which specifies additional processing and sets of actions as well as more complex forwarding semantics, such as multipath, fast reroute, and link aggregation. The Group Table with Select type can be utilized to design a stochastic switching transmission mechanism [13]. Based on this mechanism, in this study, a weighted multipath scheme for enhancing multimedia steaming was developed. More details about the proposed scheme will be elaborated in Section 3.

2.2 QoS Routing

There are many diverse network applications such as e-mail, FTP, web browsing. In addition, there has been an increasing demand for multimedia applications such as video conferencing, high quality interactive games, and video on demand. Different network applications and services require different quality-of-service (QoS) constraints. In response to this demand, both the research and industry communities have been extensively investigating schemes to identify efficient transmission paths that can satisfy the given QoS constraints [5-8]. This is commonly known as the QoS-based routing problem.

Under normal conditions, traditional networks use the Best Effort transmission scheme to transmit packets, and use the shortest path algorithm to find the optimal transmission path. QoS-based routing takes into account both the application requirements and the availability of the network resources. Thus, in general, a QoS routing scheme adopts different routing for different data traffic depending on its priority, where this priority is determined based on some particular performance metrics such as bandwidth, packet loss rate, delay and delay variation (i.e., jitter). Many QoS routing schemes have been proposed to search for the optimal transmission path for a particular traffic class [5-8]. However, the transmission mechanisms in these schemes generally use only a single path to transfer the packets in a certain traffic class. Therefore, link congestion or failure may severely reduce the transmission efficiency, or even result in packet loss.

2.3 Multipath Routing

To resolve the problem described above, many multipath routing techniques have been proposed, such as Equal Cost Multipath Protocol (ECMP) [9], Weighted Cost Multipath Protocol (WCMP) [10], and Multipath Transmission Control Protocol (MPTCP) [11-12]. Multipath routing is a transmission technique to simultaneously use multiple alternative paths through a network. The above techniques are briefly described as follows.

ECMP forwards packets to a single destination over multiple best paths with equal routing cost. Usually, the best path is determined in terms of the shortest path. If multiple equivalent shortest paths exist, ECMP chooses between them using a load balancing mechanism. However, ECMP splits the traffic in flow level granularity. That is, all the packets in the same flow are transmitted through the same path. Consequently, if the flow sizes are significantly imbalanced, they might result in poor transmission performance. WCMP extends ECMP to alleviate the asymmetry problem by assigning weights to different paths proportional to their traffic capacity. However, in practical implementations, WCMP operates on the router's routing table, which usually takes significant time to converge after a network event such as link congestion or failure. Moreover, like ECMP, WCMP performs flow based traffic allocation, and hence it may not be efficient enough to properly balance the traffics among different paths.

The aforementioned mechanisms in general do not permit single data flows to be split and transmitted over multiple paths. MPTCP [11-12] addresses this problem by revising the TCP protocol to first establish a master sub-flow and then to add additional sub-flows when establishing a TCP connection. Each sub-flow operates as a regular TCP connection, and packets in different sub-flows traverse through different paths. In this way, packets belonging to a TCP connection are split over multiple paths. However, as a matter of fact, in MPTCP, all the packets in a particular sub-flow traverse through the same path. Thus, MPTCP will perform poorly, if the sizes of sub-flows are imbalanced or the QoS parameter values of different paths are diverse.

2.4 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a widely used multi-criteria decision making method [14-16]. It was originally proposed by Prof. Thomas L. Saaty of the University of Pittsburgh to support the contingency planning activities of the U.S. Department of Defense. However, it has since been applied to the solution of many uncertainty- and decision-type problems with multiple evaluation criteria. AHP evaluates competing alternatives according to some particular evaluation criteria, and hierarchically decomposes the problem into multiple layers, where the problem in each layer is evaluated using an appropriate quantification scheme such that the final decision can be robustly and objectively determined.

AHP mainly contains three parts: a decision goal, a set of evaluation criteria, and a set of alternatives (choices) among which the best decision is to be made. AHP derives a weight for each evaluation criteria according to pairwise comparisons of the criteria. Then, for a particular criterion, AHP computes the score of each alternative according to pairwise comparisons of the alternatives based on that criteria. Thus, the global score for a given alternative is derived as the weighted sum of the scores with respect to all the criteria, and therefore a consequent ranking among the alternatives can be determined.

In this study, we apply AHP and consider the bandwidth, the packet loss rate, the delay, and the jitter as the evaluation bases to determine the weights of different paths in our proposed multipath scheme for video streaming. More details will be presented in the following section.

3 The Proposed Scheme

This section presents the Weighed Stochastic Multipath (WSMP) transmission scheme proposed for SDN environments in the present study.

3.1 Path Search

In WSMP, the first step is to find multiple paths in the network for transmitting packets from the source to the destination. In the network, each link is associated with a cost and multiple QoS metrics, such as the bandwidth, the packet loss rate, the delay time, and the delay variation. Since this study focuses on multimedia streaming, the QoS constraints are taken into account while finding the available paths. Thus, the aim of the path search mechanism in WSMP is to identify the paths which have both the optimal cost and satisfy the required QoS constraints. This problem is known as the constrained shortest path problem [5-8]. Finding an optimal path subject to multiple QoS constraints is known to be an NP-hard [8]. Many heuristic algorithms have been proposed for developing efficient polynomial-time algorithms to give feasible or approximate solutions to this problem [8]. How to develop efficient algorithms for this problem is beyond the scope of this paper. In the present study, the path search process is performed based on the LARAC (Lagrange Relaxation-based Aggregated Cost) algorithm [17-18]. The main steps in the solution procedure are shown in Figure 1.

```
Procedure FindMultiPath(Graph, Src, Dst, m, costs,
constraints) /* to find m available paths */
  allpaths=[];
  no_path=0;
while(no_path<m){
  path =LARAC (Graph, Src, Dst, costs, constraints);
  if (path ==none)
     if(constraints != Null)
         relax constraints;
     else exit;
  else{
     add path to allpaths;
     subtract path from Graph;
     no_path=no_path+1; }
}
return(no_path, allpaths);
Endprocedure
```

Figure 1. Procedure of path search

3.2 Multipath Transmission Based on Stochastic Switching

After the path search process, multiple paths with different QoS parameters are available for transmitting the streaming videos. In order to enhance the transmission performance, the packets should be allocated to different transmission paths flexibly and proportionally. As discussed in Section 2, most existing multipath schemes cannot allocate the packets in a flow or sub-flow among different transmission paths. To tackle this problem, in the present study, we propose a transmission mechanism based on stochastic switching in the SDN environment [13]. In the stochastic switching mechanism, when a switch is required to forward a packet, the output port to which the packet should be sent is determined in accordance with a predefined probability value. In terms of the OpenFlow protocol, the output port selected for forwarding a packet is determined in accordance with the weights of the Action Buckets specified in the corresponding Group entry with Select type. Thus, in the proposed scheme, the controller can establish multiple transmission paths by sending configuration messages to all switches from the source to the destination. Afterward, the controller determines the probabilities of different transmission paths and make them effective by using the stochastic switching technique.

3.3 Determining Path Weights Using AHP

As discussed above, we have the problem of how to determine the packet forwarding probabilities (weights) of different transmission paths. In the present study, this problem is handled using the Analytic Hierarchy Process (AHP) [14-16], which is a widely used multi-criteria decision making method.

In the multipath transmission problem considered in the present study, the main decision goal is set as "determine the optimal transmission path", while the major evaluation criteria are set as the link bandwidth, the packet loss rate, the delay time, and the delay variation. Assume that the path search process identifies three paths, namely Path A, Path B, and Path C. The corresponding AHP hierarchical structure thus has the form of three layers as shown in Figure 2.

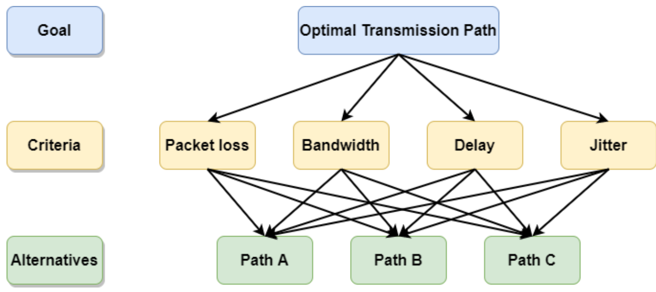

Figure 2. Hierarchical AHP structure for the path selection problem

In the AHP evaluation process, the relative importance of the various evaluation criteria on the decision outcome is determined by means of pairwise comparison between them. In performing the comparison process, the criteria are regarded as being of "equal importance", "essential importance", "very strong importance" and "absolute importance", where these markers are assigned measurement values of 1, 3, 5, 7, and 9, respectively, for the sake of convenience.

As a simple illustrative example, Table 1 presents a set of pairwise comparison results for the four evaluation criteria considered in the present study. Then, the pairwise comparison matrix A for the four evaluation criteria can be constructed as equation (1).

$$A=\begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} \\ \frac{1}{a_{12}} & 1 & a_{23} & a_{24} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & a_{34} \\ \frac{1}{a_{14}} & \frac{1}{a_{24}} & \frac{1}{a_{34}} & 1 \end{bmatrix}=\begin{bmatrix} 1 & 3 & 6 & 9 \\ \frac{1}{3} & 1 & 3 & 6 \\ \frac{1}{6} & \frac{1}{3} & 1 & 3 \\ \frac{1}{9} & \frac{1}{6} & \frac{1}{3} & 1 \end{bmatrix} \quad \textbf{(1)}$$

Table 1. Pairwise comparisons of evaluation criteria

Criteria	Packet loss	Bandwidth	Delay	Jitter
Packet loss	1	3	6	9
Bandwidth	1/3	1	3	6
Delay	1/6	1/3	1	3
Jitter	1/9	1/6	1/3	1

Having derived the pairwise comparison matrix, the Average of Normalized Columns method is used to compute the corresponding weight vector of the evaluation criteria, $W = [w_1, w_2, \ldots, w_n]^T$, using equation (2) below, where a_{ij} is the entry of the comparison matrix A in the ith row and the jth column, and n is the order (i.e., size) of A [14-16]. (Note that n

also is the number of the evaluation criteria.)

$$w_k = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right)\ i, j, k = 1, 2, ..., n \qquad \textbf{(2)}$$

Clearly, the weight vector W shows the relative weights among the evaluation criteria. However, their consistency should be checked. This is done as follows. At first, the consistency vector $V = [v_1, v_2, \ldots, v_n]^T$ is derived according to equation (3),

$$v_i = \frac{\sum_{j=1}^{n} a_{ij} \times W_j}{W_i}. \qquad \textbf{(3)}$$

Then, the consistency index (CI) is computed as

$$CI = \frac{\lambda - n}{n-1}, \qquad \textbf{(4)}$$

where λ is derived according to equation (5),

$$\lambda = \frac{\sum_{i=1}^{n} V_i}{n}. \qquad \textbf{(5)}$$

If the relative importance of the evaluation criteria is perfectly consistent, $CI = 0$ should be obtained. However, in practice, small inconsistency needs to be tolerated. The judgment of consistency can be done with the consistency ratio (CR), which is derived as

$$CR = \frac{CI}{RI}. \qquad \textbf{(6)}$$

If CR is less than 0.1, the inconsistency in the comparison matrix is tolerable. That is, thus, a reliable result is expected from the process. If inconsistencies in the process exist, the process should be repeated until a consensus is reached. In equation (6), RI is the random consistency index, whose values for different orders of comparison matrices can be found in [14]. For brevity's sake, they are not further discussed.

In the above simple example, one can verify that the weight vector of the evaluation criteria is obtained as $W = [0.2588, 0.0477, 0.5854, 0.108]^T$ according to equation (2). Also, the consistency vector $V = [4.1128, 4.0215, 4.1673, 4.0265]^T$ is obtained according to equation (3). Then, we have $\lambda = (4.1673 + 4.1128 + 4.0265 + 4.0215)/4 = 4.082$ according to equation (5), and $CI = (4.0820\text{-}4)/(4\text{-}1) = 0.0273$ according to equation (4). Since the order of the comparison matrix is four, we have $RI = 0.9$, which can be looked up in [14]. Thus, according to equation (6), the consistency ratio is computed as CR=0.0273/0.9=0.3. Since CR is less than 0.1, in this example, the derived weights of the evaluation criteria are consistent, i.e., judged to be acceptable.

After the weights of the evaluation criteria have been determined and have passed the consistency test, for a particular criterion, the score of each alternative is derived according to the process elaborated as follows.

Assume that three paths A, B, and C (i.e., three alternatives) are found by the path search procedure as described in Section 3.1. The values of the four evaluation criteria of these three paths are listed in Table 2 as a numerical example. (In fact, these values are the data used in our experimental simulations which will be described in Section 4.) Considering the evaluation criterion *packet loss rate*, the pairwise comparison of the three alternatives can be derived as shown in Table 3. Then, using the Average of Normalized Columns method again (see equation (2)), the score vector of the three alternatives based on the evaluation criterion packet loss rate can be derived as $S_{Packet\_loss\_rate}$ = [0.125, 0.625, 0.25]^T. In the same reasoning, we can derive $S_{Bandwidth}$ = [0.3846, 0.3077, 0.3077]^T, S_{Delay} = [0.2308, 0.4615, 0.3077]^T, and S_{Jitter} = [0.1429, 0.35714, 0.2857]^T. For brevity's sake, the computation details are omitted. That is, the scores of the three alternatives based on the four criteria can be derived as shown in Table 4. Finally, combining the criteria weights and the score of the alternatives, the global scores of all the alternative, denoted as a vector G, can be obtained with

$$G = SW, \qquad \textbf{(7)}$$

where S is the matrix whose columns are the score vectors of the three alternatives for different criteria, and W is the weight vector of the evaluation criteria. In this numerical example, we obtain G = [0.2012, 0.5083, 0.2904]^T. (Note that, for example, one can verify that 0.2012 = 0.125×0.2588 + 0.3846×0.0477 + 0.2308× 0.5854 + 0.1429×0.108.)

Table 2. Numerical values of evaluation criteria for different paths in the given example

	Path A	Path B	Path C
Packet loss rate	10%	2%	5%
Bandwidth	100Mbps	80Mbps	80Mbps
Delay	20ms	10ms	15ms
Jitter	2ms	0.5ms	1ms

Table 3. Pairwise comparisons of the three paths based on the packet loss rate

Alternatives	Path A	Path B	Path C
Path A	1	0.2	0.5
Path B	5	1	2.5
Path C	2	0.4	1

Table 4. Scores of the three paths for different criteria

Alternatives	Packet loss rate	Bandwidth	Delay	Jitter
Path A	0.125	0.3846	0.2308	0.1429
Path B	0.625	0.3077	0.4615	0.5714
Path C	0.25	0.3077	0.3077	0.2857

4 Experimental Simulations

The simulation experiments were conducted using the Mininet simulation platform [19], with which a virtual network for simulations was built. In the simulation network, the switches were implemented using Open vSwitch (OVS) [20], and they could be monitored and administered by the ovs-ofctl commands [21]. In performing the simulations, the transmission efficiency of WSMP was compared with that of the traditional Single Path (SP) scheme and the Multipath TCP (MPTCP) scheme [11, 12].

In our simulations, three paths for transmitting data in a traffic flow from a sender, host h1, to a receiver, host h2 are first identified using the path search procedure described in Figure 1. The simplified topology and relevant QoS parameters of the identified paths are shown in Figure 3. Note that the paths are diverse in the sense that their QoS parameter values are different. Also note that to facilitate our discussions, the QoS parameter values for each path shown in Figure 3 were also used in the example in Section 3 that illustrated the AHP process. Therefore, according to the numerical results presented in Section 3, the packets from the sender h1 should be transmitted through paths A, B, and C with the probability of 0.2012, 0.5083, and 0.2904, respectively. In our simulations, this was done by configuring the switch s1, as shown in Figure 3, to perform stochastic switching.

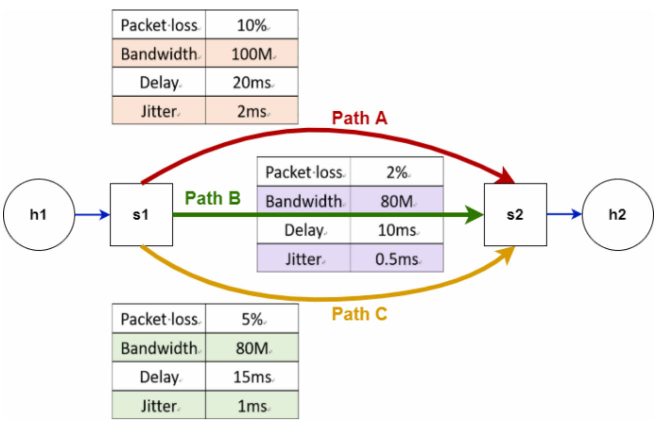

Figure 3. Simplified network topology of three transmission paths and relevant QoS parameters

The simulations commenced by using the iPerf utility [22] to simulate the TCP transmission of files consisting of 2M, 10M, and 100M bytes of data, respectively, from h1 to h2 over single paths and multiple paths. Path A was used in the SP scheme since it had the largest bandwidth. The transmission experiments were repeated ten times. Table 5 shows the averaged results obtained for the transmission time and throughput under each of the three transmission schemes. In general, the results show that WSMP achieves both a faster transfer time and a higher throughput than the SP or MPTCP scheme. In other words, WSMP outperforms both the two schemes in performing simple TCP packet transfers.

Table 5. Performance Comparison of the three transmission schemes for TCP data transfers

	2M		10M		100M	
	Time (sec)	Throughput (Mbits/sec)	Time (sec)	Throughput (Mbits/sec)	Time (sec)	Throughput (Mbits/sec)
SP	5.6	2.99	32.1	2.65	324.9	2.59
MPTCP	1.5	11.20	3.7	23.62	42.2	20.36
WSMP	0.8	23.30	3.5	24.06	35.3	23.80

In the second set of simulations, the UDP transmission efficiency of the three schemes was evaluated by using the VLC media player [23] to send 720P and 1080P of streaming video data from the sender h1 to the receiver h2. Figure 4 and Figure 5 show the corresponding Peak Signal-to-Noise Ratio (PSNR) [24] of the received videos under the three schemes, where a higher PSNR value indicates a better quality of the received image. The results show that for both video streams, WSMP yields a significantly higher PSNR value than either of the other two schemes. Notably, MPTCP supports only TCP but not UDP packets, and hence is unable to exploit multipath transmissions for UDP video streaming. Thus, its performance is similar to that of SP. Figure 6, Figure 7, and Figure 8 show illustrative examples of the images received under the three schemes for the 1080P video. It is clear that MPSS achieves a significantly better video quality than either SP or MPTCP.

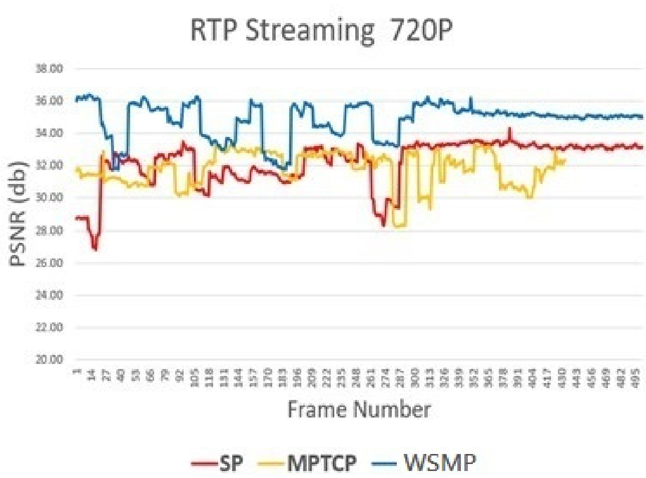

Figure 4. PSNR values of the three transmission schemes for 720P video stream

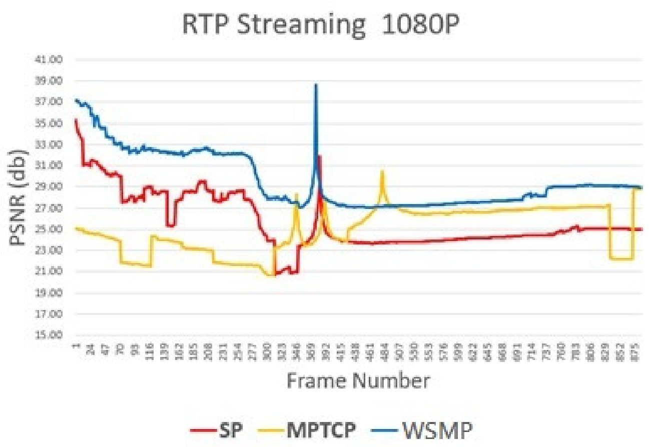

Figure 5. PSNR values of the three transmission schemes for 1080P video stream

Figure 6. SP transmitted 1080P image

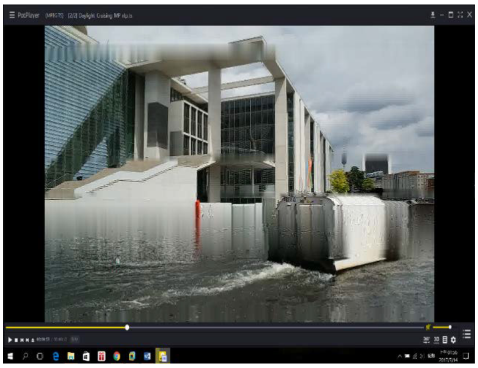

Figure 7. MPTCP transmitted 1080P image

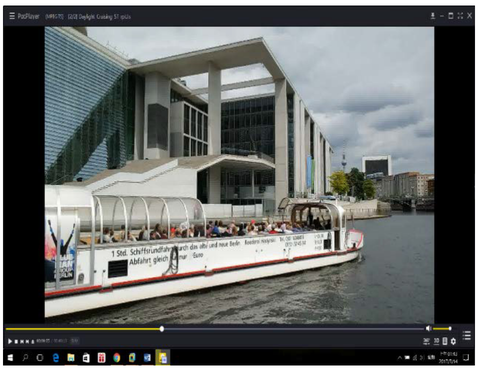

Figure 8. WSMP transmitted 1080P image

5 Conclusions

This study has proposed a scheme named WSMP to enhance multimedia streaming through weighted multiple transmission paths in SDN environments using a stochastic switching approach. In the proposed scheme, the available paths satisfying the required QoS constraints are first identified, and then the Analytic Hierarchy Process (AHP) method is used to determine appropriate weights for each path for transmission purposes based on some QoS metrics of the transmission links. Thus, data packets in single data flows can be appropriately split and transmitted over multiple paths using stochastic switch mechanism based on the OpenFlow protocol. The experimental results have shown that WSMP outperforms existing transmission mechanisms such as SP and MPTCP in terms of a higher throughput for data transmission and better PSNR value for streaming video, and leads to improved perceived quality at the user end as a result.

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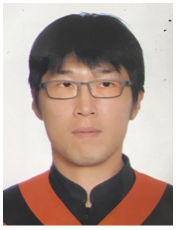

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