An adaptive scheduling routing for multimedia services based on software-defined networks

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Abstract. We address the routing optimization problem in Software-Defined Networks (SDN) while satisfying multiple QoS constraints of multimedia services. In this paper, we 1) formally define the problem of routing optimization in SDN under multiple QoS constraints, and 2) suggest a novel architecture based on SDN for providing QoS services in the network. We propose an adaptive scheduling routing optimization approach in SDN that improves the classical Dijkstra routing algorithm. We report the results of experiments using the Mininet simulation framework that confirm the advantages of our proposed QoS routing optimization approach as compared to the state-of-the-art solutions.

1 Introduction

With the rapid expansion of network scale and the continuous enrichment of multimedia systems, multimedia routing computing is the area of intense current interest, software and hardware development, and future promise. There is a need for new techniques to aid the specification, design and construction of multimedia systems, in order to support and efficiently implement a range of multimedia service applications. Moreover, these multimedia service applications need to be deployed in the network by taking into account the specific QoS (Quality of Service) requirements. The QoS requirements of a particular multimedia service are typically specified as a set of QoS constraints. In this paper, we address *multi-constraints QoS routing for multimedia services*, i.e., routing algorithms should not only bring multimedia service data packets to their destinations, but also guarantee that multiple QoS constraints of different multimedia services are satisfied.

Satisfying QoS constraints of multimedia services is an important requirement for modern networks. For traditional networks, the Internet Engineering Task Force (IETF) defined three types of architectures for providing QoS services in the network: Integrated Services, Differentiated Services and Resource Reservation Protocol - Traffic Engineering. These architectures have a common disadvantage: they lack a unified global view of overall network resource distribution, which is one of the reasons why these approaches have not been widely deployed on a global scale.

Not only to compensate for this common disadvantage, but to satisfy the diverse QoS constraints for multimedia services, Software Defined Networking (SDN) is currently viewed as an alternative network architecture. A centralized SDN controller maintains a global view

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of the network, which allows dynamic optimization of network resources and efficient management of the network, including a flexible choice of the efficient routing algorithm that meets the multiple QoS constraints of multimedia services on particular network traffic flows.

Most of the existing routing algorithms, e.g., the Delay-Constrained Least-Cost (DCLC) algorithm [1], only satisfy a single QoS constraint (e.g., delay) of services. Pan et al. [2] use the analytic hierarchy process approach to address the complexity of the problem of meeting multiple QoS constraints. By assigning different weights to each QoS constraint, the multiple QoS constraints problem is reduced to a single constraint optimization problem. Then they utilize Dijkstra algorithm to select a communication path. However, the weight of each QoS constraint is determined subjectively, which cannot satisfy the actual requirements of multimedia service. Furthermore, Dijkstra algorithm always chooses the shortest path, rather than a path according to the global network status.

In this paper, we address the routing optimization problem in SDN while satisfying multiple QoS constraints of multimedia services, by considering it as a multi-constraints optimization problem. We propose an adaptive scheduling routing for obtaining the optimal route and the best network utilization, which guarantee multiple QoS constraints for multimedia services, such as latency, bandwidth, packet loss ratio, etc [3].

This paper is organized as follows. Section 2 provides a formal formulation of the multi-constraints QoS routing optimization problem that calculates a route while respecting multiple QoS constraints. To provide QoS in network with regard to supported multimedia service applications, we design a novel architecture based on SDN in Section 3, and then we propose an *Adaptive Scheduling Routing Approach (ASRA)* for multimedia services in our designed architecture, based on the classical Dijkstra algorithm, that finds the optimal route and obtains the best network utilization in Section 4. Next, we conduct a comprehensive experimental study using the Mininet simulation environment in Section 5.

2 Multi-constraints QoS routing optimization

To deal with the multi-constraints QoS routing optimization problem, we develop its formal definition. The SDN network is represented as a weighted graph $G(V,E)$, where V is a set of nodes (SDN switches) and E is a set of edges (switch links). Let v_1 and v_n be the source and destination nodes, respectively, and the intermediate nodes v_i be the relay nodes; each edge e connects two nodes. If the serial numbers of two adjacent relay nodes are i and j then the edge between these two nodes is $e = \{v_i \to v_j\}\{i \neq j\}$. A route from the source node to the destination node can be expressed as $p(v_1, v_n) = \{v_1 \to v_2 \to \cdots \to v_n\}$.

Each traffic flow of a particular service should be allocated to the route $p(v_1, v_n)$ that guarantees delay jitter $D_J(e)$, packet loss ratio $P_L(e)$, latency $L(e)$, and bandwidth $B(e)$, which reflect the QoS constraints of the particular service on the underlying network.

Delay jitter is the variation of delay time. The total delay jitter caused by flow transmission on the route $p(v_1, v_n)$ is computed as:

$$D_J(p(v_1, v_n)) = \sum_{e \in p(v_1, v_n)} D_J(e) \tag{1}$$

The total packet loss ratio generated by flow transmission on the route $p(v_1, v_n)$ is computed as follows:

$$P_L(p(v_1, v_n)) = 1 - \prod_{e \in p(v_1, v_n)} (1 - P_L(e)) \tag{2}$$

The latency of the route $p(v_1, v_n)$ depends on the characteristics of each link e forming the route. The total latency during flow transmission in $p(v_1, v_n)$ is computed as:

$$L(p(v_1, v_n)) = \sum_{e \in p(v_1, v_n)} L(e) \tag{3}$$

For effective transmission, each link e in the route $p(v_1, v_n)$ should have sufficient available bandwidth to carry the flows of the particular service. We express the fact that the minimum available bandwidth of link $min\{B(e)\}$ represents the available bandwidth of the route $p(v_1, v_n)$ as follows:

$$B(p(v_1, v_n)) = min\{B(e)\} \tag{4}$$

Our QoS routing optimization problem is finding a route $p(v_1, v_n)$ under QoS constraints of parameters $D_J(e)$, $P_L(e)$, $L(e)$ and $B(e)$ as defined in the following. For a particular service, let L_{max} denote the maximum latency acceptable by the service in the transmission route $p(v_1, v_n)$, and B_{min} denote the minimum available bandwidth demand to carry the flows of the service. Similarly, J_{max} and $P_{L_{max}}$ denote the maximum delay jitter and maximum packet loss ratio the service can accept, respectively. Then the optimal route $p(v_1, v_n)$ should satisfy the following multiple QoS constraints:

$$\begin{cases} L(p(v_1, v_n)) \le L_{max} \\ B(p(v_1, v_n)) \ge B_{min} \\ D_J(p(v_1, v_n)) \le J_{max} \\ P_L(p(v_1, v_n)) \le P_{L_{max}} \end{cases} \tag{5}$$

3 System framework

Based on our previous work [4, 5], we use the advantage of SDN centralized control, to deploy our ASRA as an SDN programmable application at the application layer. Consequently, it can flexibly choose an efficient routing algorithm during the running time of the multimedia communication, thus providing QoS guarantees for the transmission of multimedia service data packets.

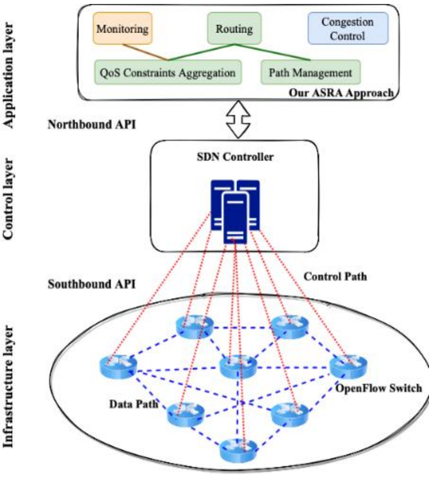


Fig. 1. Our designed architecture based on SDN: an Overview.

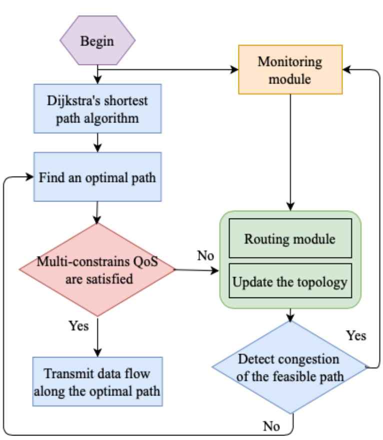
Fig. 1 illustrates the logical view of our designed architecture based on SDN, as follows. SDN consists of the Infrastructure Layer and the Control Layer that communicate with one another through a Southbound Application Programming Interface (API); this API allows the SDN controller to define the behaviour of the network switches in the network. The standardized and most common Southbound API is OpenFlow. Above the Control Layer resides the Application Layer that exercises its control over the network using a Northbound API: it allows the applications to influence the behaviour of the network.

Our ASRA approach includes three modules: routing module, monitoring module and congestion control module. The routing module is responsible for calculating the multiple paths for multimedia services (i.e., path management) and available network resources for each traffic flow (i.e., QoS constraints aggregation). The QoS constraints aggregation module is responsible for collecting QoS constraints of multimedia services from the monitoring module, and calculating the available network resources for each traffic flow depending on the monitoring information. The path management module is responsible for calculating the traffic assignment value of multiple paths while dynamically adjusted by the QoS constraints aggregation module, which can provide the best routing policy for multimedia services. Routing module interoperates with the monitoring module, which has the ability to entirely monitor and update the routing topology in real time. After collecting the monitoring information, our ASRA approach starts the congestion control module to detect the congestion status of each link on the transmission path. The goal of the congestion control module is to avoid congestion. Meanwhile, the controller generates and sends the flow table to the corresponding OpenFlow switches.

4 Designing a QoS routing optimization approach

This section presents a QoS routing optimization approach (i.e., ASRA) of our designed architecture which makes full use of network resources and avoids network congestion.

Our ASRA approach improves the classical Dijkstra algorithm as shown in Fig. 2 and described in the following. In our ASRA approach, the data flow of a particular multimedia service first transmits between two end nodes on the shortest path, which is calculated by the SDN controller according to the Dijkstra algorithm. If the shortest path does not satisfy multiple QoS constraints of the multimedia service, network-induced delays and packet losses will occur accordingly. Then our ASRA approach is triggered to calculate a candidate path to transmit the data flow under the multiple QoS constraints. The detail process of the calculation, formulated as Algorithm 1, is as follows.



Algorithm 1 Routing module in our ASRA approach.

Input: $G(V,E)$, L_{max}, B_{min}, J_{max}, $P_{L_{max}}$
Output: Calculate $p(v_1,v_n)$ depending on the multiple QoS constraints.
1: Fetch the information of monitoring module;
Deal with the packet of $packet\_in$;
Application of the Dijkstra algorithm, calculating path $p(v_1,v_n) = Dijkstra(G,v_1,v_n)$
2: **if** ($p(v_1,v_n)$ satisfies the multiple QoS constraints) **then**
3: Return $p(v_1,v_n)$
4: **else**
5: Every edge $e_{ij} = \{v_i \rightarrow v_j\} \in p(v_1,v_n)$ is replaced by $e_{ji} = \{v_j \rightarrow v_i\}$ in the v_n-to-v_1 direction
/* Bhandari's algorithm */
6: Application of the Dijkstra algorithm, calculating path $p^{'}(v_1,v_n)$
7: **if** ($p^{'}(v_1,v_n) \neq \varnothing$) **then**
8: $p^{'}(v_1,v_n) = Ture$
9: Goto step 2
10: **end if**
11: Undoes all changes required to obtain the candidate path $p^{'}(v_1,v_n)$, Restores $G(V,E)$
12: **end if**

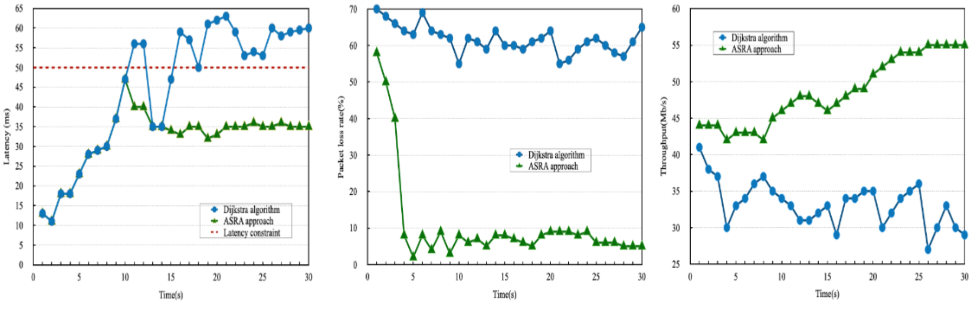
Fig. 2. The flowchart of our ASRA approach.

We firstly set a status for the routing module: the controller checks the multiple QoS constraints periodically, and finds an initial path using Dijkstra algorithm (line 1). If the path satisfies the multiple QoS constraints, then it will be used as flow transmission path (line 2-3). Otherwise, the controller needs to find the optimal path by using the routing module of our ASRA approach. Next, our routing module applies the Bhandari's algorithm to calculate the edge-disjoint path of the initial path as the candidate path, depending on the considered QoS routing optimization problem (line 5-12). Then, the congestion control module of our ASRA approach detects the congestion status of each link on the candidate path where the flow is located. Finally, if no congestion occurs and the candidate path satisfies the multiple QoS constraints, the iteration is exited.

5 Experimental evaluation

This section describes our experimental evaluation of the ASRA approach in SDN. We conduct three experiments to evaluate the performance of our ASRA approach by comparing ASRA against Dijkstra algorithm.

Fig. 3(a) shows the experimentally measured latency of the flow. At the beginning of the experiment, we observe that the flow is allocated to the Dijkstra's shortest path, but the latency is unstable when allocating the flow to the Dijkstra's path, which can be explained by the higher network congestion that leads to data-packet dropout and the degraded network performance, as already observed for Dijkstra in [6]. If the Dijkstra's shortest path does not satisfy multiple QoS constraints, our ASRA approach calculates a candidate path. We observe that the latency is always lower than the latency constraint when allocating the flow to the ASRA's route, and also the stability of latency achieved by ASRA is better than Dijkstra algorithm. Overall, our ASRA approach performs better in both aspects - the absolute latency and its stability.



(a) Comparison: flow latencies. (b) Comparison: average packet loss rate. (c) Comparison: throughput.

Fig. 3. Comparison experiments.

We observe that the ASRA approach outperforms Dijkstra algorithm in terms of the packet loss rate as shown in Fig.3(b). Dijkstra algorithm undergoes the higher packet loss rates owing to the lack of dynamically adjusting the transmission path, while our ASRA approach has the capability of adaptively adjusting the path to avoid network-induced distortion during the transmission. We also observe that the fluctuation of the packet loss rate is relatively smooth and less than 10 percent when using the ASRA approach because it makes full use of idle paths to transmit the flow, which reduces the adverse effects of congestion caused by Dijkstra's path during the whole process of the flow transmission. Correspondingly, the system throughput is increased as can be observed in Fig.3(c).

Summarizing, the experiments confirm the effectiveness of our ASRA approach and its implementation in SDN.

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