2019 5th International Conference on Web Research (ICWR)

# Multimedia Delivery Techniques over Software-Defined Networks: A Survey

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***Abstract*— In the recent years, many solutions have been proposed to deliver multimedia over the best-effort Internet. The objective of these approaches is to ensure high Quality of Service (QoS) and Quality of Experience (QoE) for multimedia delivery in the presence of bandwidth fluctuations made by factors like signal propagation and network congestion. However, many of these techniques faces severe limitations such as network bottleneck and congestion due to the lack of global network view. The separation of control logic and data plane in Software Defined Networking (SDN) architecture contributes to the smartness, flexibility, and controllability of computer networks and provides new opportunities for guaranteeing higher QoE for multimedia viewers. In this survey, we present a taxonomy of the state-of-art SDN-based solutions for multimedia communications and we shed light on the research gaps in this area.**

***Keywords*— *Multimedia Delivery; Quality of Experience; Quality of Service; Software Defined Networks***

## I. Introduction

Multimedia streaming has becomes a significant source of Internet traffic in the last decade. Cisco has reported that in 2017, 67% of the global Internet traffic was video, and it forecasts that it will reach 80% by 2021 [1]. Multimedia streaming applications have Quality of Service (QoS) requirements, which cannot be guaranteed in the best-effort Internet. Media service providers expect a network infrastructure that supports QoS and Quality of Experience (QoE) for multimedia traffic. Many approaches and solutions have been proposed over decades to satisfy the aforementioned requirements. However, most of these solutions are suffered from network congestion and bottleneck due to the lack of global network view and local decisions.

With the emergence of Software Defined Networking (SDN) paradigm, it has attracted much attention as a new approach to address the limitations of traditional and none-SDN networking architectures. The main advantages of SDN includes the centralized global network view and programmability which are rooted in the separation of the data plane from the control plane [2]. This architecture enables networks to become smarter, more controllable and less dependent on the hardware and therefore, their management will become more flexible and simpler. These features help the researchers to improving the quality of multimedia delivery over the Internet.

In this paper, we provide a complete taxonomy of the SDN-based techniques and solutions for multimedia delivery and we present two classifications based on the nature of the solutions. The first classification addresses the SDN-derived and the SDN-ready solutions, based on the features of SDN which have been used for multimedia communication. The SDN-derived approach is based on the unique characteristics of SDN which uses the notion of logically-centralized controller to deploy the designed solutions. In work [11], a specific controller named OpenQoS is designed for supporting end-to-end QoS in SDN-based multimedia delivery networks. Also, the authors in [12] use the unique features of OpenFlow protocol to design a modular and extensible QoS architecture that assures QoS level in multimedia applications over SDN. In SDN-ready category, the proposed solutions can be readily adapted to the characteristics of SDN. For example, in [17] authors propose a general multicast protocol to guarantee QoS for multimedia applications which has been deployed in a SDN setting. Table I illustrates the definition and related works of these categories.

The second taxonomy classifies the solutions from the perspective of users and network designers into two categories, called user-centric and network-centric, respectively. The network-centric schemes, from the network-planning viewpoint, focus on the QoS parameters and try to solve the problems of the end-to-end QoS guarantee for multimedia delivery over the SDNs, while in the user-centric schemes, the solutions are provided for QoE improvement for end users and the problem is formulated from the viewpoint of users. We review the state-of-the-art solutions in this classification and compare the features of these methods.

The rest of paper is organized as follows: Section II describes the background knowledge and definitions of multimedia streaming. In Section III and IV, the network-centric and user-centric approaches are classified and reviewed, respectively. We discuss about the main issues in this area in Section V and then, comprehensive comparison tables are provided for different schemes. Finally, Section VI provides concluding remarks.

Table I: SDN solutions and relevant works

| Multimedia delivery scheme | Definition | Relevant works |
|---|---|---|
| SDN-derived | The techniques that uses unique feature of SDN concept. | [7] [10][11] [12] [13][16][19][20] [21][22] [23] [24] |
| SDN-ready | The techniques that uses some feature of SDN concept. | [14] [15] [17] |

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## II. BACKGROUND AND DEFINITIONS

### A. HTTP Adaptive Streaming

Today, HTTP adaptive streaming (HAS) accounts for the most of Internet video traffic. It has been a mainstream for commercial solutions such as Microsoft's Smooth Streaming[3], Akamai's HD [4] and several open source solutions. The HAS uses TCP and HTTP as transport layer protocol and application layer respectively. In HAS system, content of video is encoded into multiple versions at different bitrates. Then, each encoded video is fragmented into small video segments or chunks, each containing a few seconds of video. As illustrate in Fig.1, the client pulls the data from an off-the shelf HTTP server and get corresponding chunk from it. To avoid fragmentation in the market, the 3rd Generation Partnership Project (3GPP) and the Moving Picture Experts Group (MPEG) started working on HAS and HTTP streaming of MPEG media, respectively. These efforts eventually resulted in the standardization of Dynamic Adaptive Streaming over HTTP (DASH). In DASH systems [5]. Content information such as video profiles, metadata, codecs, byte-ranges, server IP addresses, and download URLs is described as a Media Presentation Description (MPD) files. The MPD describes a piece of video content within a specific duration as a Period. In a Period, there are multiple versions of the content, each known as a Representation. In a Representation, there are multiple video segments or chunks. Video chunks and MPDs are then served to the clients through standard HTTP servers.

### B. Scalable Video Coding

Scalable Video Coding (SVC) enables the video stream to split into multiple layers or bit streams that often referred to as layers. [6]. Typically, SVC allows the stream of video to be split into three different dimensions of quality: temporal, spatial, and quality/Signal-to-Noise Ratio (SNR). In the temporal-based technique, the video is encoded into multiple frame rates for a given resolution. The lowest frame rate belongs to the base layer, while enhancement layers increase the frame rate to gradually improve video quality. In the spatial-based technique, the video is encoded at multiple spatial resolutions for a given frame rate. In case of the SNR-based technique, the video is encoded at a single spatial resolution, and the enhancement layers keep the resolution constant while improving the video quality.

### C. Multipath TCP and Segment Routing

Multipath TCP (MPTCP) [7], [8] is an ongoing effort of Internet Engineering Task Force (IETF) that improves network connectivity and provides higher data rate for end users. MPTCP was proposed as an extension of TCP that the main idea is to use a large flow and separates it into many derivative flows, called subflows. A subflow is a conventional TCP connection, which derived from a main MPTCP connection.

Segment Routing (SR) [9] is a source routing approach that can be used to steer traffic along any path in the network. It based on the tunneling technique and allows a host or an edge router to steer a packet through the network by using a list of segments. A segment is an identifier for an instruction that can be topological or service. SR provides an interface to the network infrastructure that flexible and without network resources and scalability issue.

### D. Software Defined Networking

Software defined networking paradigm [2] decouples the control plane from the data plane and provides a centralized

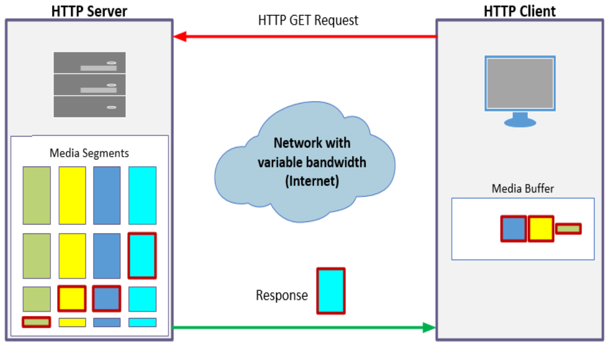

Fig. 1. HTTP adaptive streaming.

view of a network in support of more flexibility and efficient network resource management and monitoring. An SDN network provides a fine-grained control of an individual application and network devices that allows directly programmable, intelligent network management via a centralized element that refer to SDN controller. Leveraging its capabilities in the multimedia context, SDN provides an efficient central manager that can address the scalability issues.

## III. NETWORK-CENTERIC APPROCHES

In this section, we review network-centric multimedia delivery approaches elaborately based on the QoS parameters and we explain the solutions proposed in this area. Most of these approaches are based on the traffic engineering techniques to route the traffic such that low delay and high data rate constraints are satisfied. Some of them try to improve the Differentiated Service (DiffServ) or Integrated Service (IntServ) parameters to better support the multimedia streaming, and a few of them have proposed server load balancing solutions to improve the quality of multimedia streaming for end users.

Mostafavi and Dehghan [26-29] propose a game-theoretic framework for dynamic resource allocation in live P2P streaming systems. Yilmaz et al. [10] proposed a new server load balancing controller application to improve the QoS for video streaming. When one or more servers are overloaded, continuous monitoring of the load of the servers is performed and ongoing or new service requests are dynamically redirected to under-loaded servers in such a manner that quality of experience of end user with lowest distortion and delay is achieved.

OpenQoS [11] is an OpenFlow controller design for multimedia delivery which supports end-to-end QoS guarantee. The key concept in this architecture is the classification of the incoming flows into multimedia flows and data flows based on the packet header fields. The proposed architecture optimizes the routes of multimedia traffic and generates routes dynamically to respect the QoS requirements, such as packet loss and latency while data flows routed in a best-effort manner. This paper, however, does not consider the important Multi-Commodity Flow Problem that is the case especially when the SDN controller has to deal with different flow types. To address this problem, Ongaro et al. [12] defined a modular and extensible QoS architecture to reach an enhanced QoS and QoE by solving the problem of managing differentiated services (DiffServ) guaranteeing the quality requirements in wired and wireless environments. The authors present a Linear Programming (ILP) formulation that considers the Multi-Commodity Flow Problem in conjunction with the Constrained Shortest Path. The ILP formulation aims to find the shortest path between source and destination, considering both network constraints and application requirements such as packet loss and delay for guaranteeing a QoS in Software Defined Networks. The framework is composed of several components including a network topology mapping module, network status collection module, path selection module, and dynamic path configuration module. Network topology mapping and network status collection, responsible to continuously retrieves information about the network topology and network status respectively while path selection module selects appropriate paths according to QoS requirements of the networks and the dynamic path configuration is responsible for updating routing rules in the data-forwarding layer at the right time.

Another controller architecture and protocol for supporting end-to-end QoS for video applications over SDN networks has been presented in [13]. The paper attempts to address the problems of integrated service (IntServ) guarantee where one of the main problems in IntServ is its dependence on routing protocol. In VSDN, a routing module is introduced which uses the centralized controller to measure QoS parameters, selecting the best route based on requirements of video streaming application. A routing method for enhanced video delivery over SDN presents in [14] that proposed a genetic□algorithm named GA□SDN. The authors apply the genetic algorithm for routing in order to quickly find the best route among a number of possible solutions. In GA□SDN, when detecting congestion in a link, the weight of the link will be increased to decrease fitness of chromosomes, i.e. candidate paths, containing the congested link, making weaker chromosomes generating less offspring than other strong ones. This way, GA□SDN improves the quality of video transmission through path diversity.

Yu et al. [15] proposed a routing method for video streaming over SDN called ARVS that provides a novel QoS extension to distributed control plane architectures for multimedia delivery over large scale and multi-operator SDNs. In this approach, base layer and enhancement layer of video bit streams are treated separately as two levels of QoS and the delay variation considered as a constraint in CSP problem when the cost of each link was the weighted sum of the delay variation and packet loss rate on a path. If the CSP problem does not meet the delay variation constraint, the enhancement layers of video will stay shortest path and the base layers reroute to a calculated feasible path based on the available bandwidth of this path.

Another architecture based on routing is presented in [16] for multimedia delivery over large-scale, multi-operator SDNs. The proposed architecture leverages a distributed control plane consisting of multiple controllers to manage large-scale SDNs, where each controller performs optimal QoS routing within its domain and shares aggregated information of QoS routing with other domain controllers to enable inter-domain QoS routing. In this way, each controller acquires a global view of whole network and becomes capable of calculating an end-to-end QoS optimized route for flows.

Mohammadi et al. [17] proposed a novel multicasting technique to guarantee QoS for multimedia applications over SDN that models multicast routing as a delay constraint least cost (DCLC) problem. As DCLC is a NP-Complete problem, so the paper proposes a heuristic method based on TLBO (Teaching learning-based optimization) algorithm to solve it.

In this section, various network-centric multimedia delivery methods were described. Table II presents a summary of the reviewed network-centric multimedia delivery schemes in terms of QoS metrics including network bandwidth (BW), delay, jitter and packet loss.

## IV. USER-CENTERIC APPROCHES

This section reviews a list of user-centric schemes of interested for multimedia. As we mentioned in section I, the main idea of these approaches are provide QoE parameters for end user and address the problem of these parameters over the best-effort Internet with some feature of SDN concept.

In the recent research, adaptive bitrate streaming has been used to reduce buffering time and video freezing in video playbacks. This idea has its own advantages for overall user experience, while meets some issues such as network congestion and unstablility since the decision is local and without considering of others on the network. In recent years, many SDN-based approaches have been proposed to address the above problems. Fig. 2 represents the general architecture of these approaches [18].

Georgopoulos et al. [19] proposed an SDN-assisted QoE Fairness Framework (QFF) based on OpenFlow and MPEG DASH that aims to optimize QoE for all video broadcasting devices in a network. QFF leverages OpenFlow to monitor the quality of the video streams and allocates/manages network resources. Later the same authors proposed the SDN-based in-

Table II: summary of the different network-centric Multimedia delivery schemes with QoS parameters.

| Techniques | Description | BW | Delay | Jitter | Loss |
|---|---|---|---|---|---|
| Yilmaz et al. [10] | A server load balancing application that reroutes flows of video streams. | | | ✓ | ✓ |
| OpenQoS [11] | A controller design, for end-to-end QoS that routing of multimedia traffic delivery | ✓ | ✓ | | ✓ |
| Ongaro et al. [12] | A modular and extensible QoS architecture to reach an enhanced QoS and QoE. | ✓ | | | ✓ |
| VSDN [13] | A QoS-enabled routing architecture for video streaming that improve IntServ. | ✓ | ✓ | ✓ | |
| GA□SDN [14] | A genetic routing algorithm for enhanced video delivery over SDN. | ✓ | | | |
| ARVS [15] | A QoS-enabled dynamic optimization-based routing distributed architecture for scalable video streaming that support large scale and multi-operator SDNs. | | | ✓ | ✓ |
| Egilmez et al. [16] | A distributed QoS routing architecture for scalable video streaming over large scale and multi-operator SDNs. | ✓ | ✓ | ✓ | ✓ |
| Mohammadi et al. [17] | A novel multicasting technique with a delay constraint least. | | ✓ | | |

network QOE measurement framework (IQMF) [20] to improve the QFF. IQMF acts as a proxy, provides per-client monitoring of QoE during the video session, and continuously sends feedback to content providers and network through a well-defined API. However, Both QFF and IQMF take only two metrics of available bandwidth and device resolution, and do not consider the buffer level. Therefore, the clients may suffer from buffer starvation.

Kleinrouweler et al. [21] proposed an DASH-aware architecture based on SDN to provide stability and video delivery with high quality for DASH while avoiding the negative influence of TCP and bursty traffic on the streaming performance in busy networks. The architecture tries to keep the DASH protocol stack simple and scalable, while improving the quality of experience for the viewers. It consists of three layers: SDN network application controllers, SDN network management, and programmable network infrastructure. The SDN network application helps the set of competing DASH clients to select appropriate their bitrate while the SDN management that includes network controller is in charge of monitoring and configuring all network elements. However, the architecture does not support device heterogeneity and it requires DASH players to cooperate with the Service Manager for bitrate selection.

To address the heterogeneity issues, Bentaleb et al. [22] proposed different approaches for HAS scalability issues including video instability, QoE and unfairness that based on the information collected by the SDN controller. The proposed architecture, called SDNDASH, provides end-to-end resource allocation and management architecture for HAS that leverages SDN capabilities. It consists of the three layers: application, control, and network, as well as six core elements within those layers: DASH server, DASH clients, external SDN-Based Resource Management, SDN controller, SDN-based internal application, and forwarding devices. However, SDNDASH has scalability issue when the number of HAS players increased, causing communication overhead. In addition, it does not address the client heterogeneity. The same authors also proposed an improved version of SDNDASH called SDNHAS [23] to address these issues. SDNHAS was designed to resolve three limitations of SDNDASH, namely: (i) communication overhead, (ii) limited support deployments of HAS players in large-scale, and (iii) system heterogeneity supporting.

On the other hand, some proposed methods focusing on the traffic engineering (TE) with MPTCP which can utilize SDN and NFV to improve the QoE for end users.

Barakabitze et al. [7],[24] proposed a novel QoE-centric multipath routing algorithm (QoMRA) to address the limitation of MPCTP and using SDN controller to control the number of subflows dynamically. It performs source routing to these subflows using SR paradigms in order to achieve load balancing, reliable communication and better network resources utilization that leads to higher network throughput and the end-user's QoE for delivering multimedia services over 5G networks. The author uses segment routing(SR) [25] to address the limitation of SDN switches and store large number of rules. In [24] the author uses NFV and proposed the QoE-aware MPTCP SDN/NFV SR-based system that provides an efficient orchestration, QoE control and management of future multimedia services.

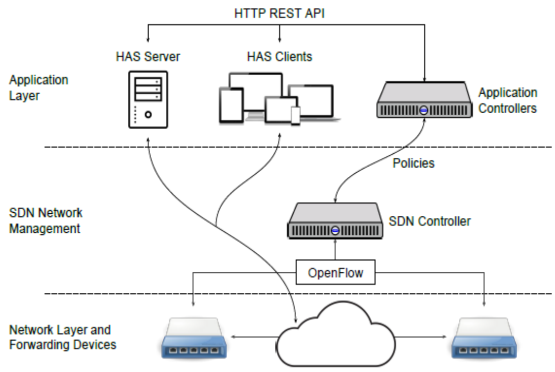


Fig. 2. Architecture for SDN-based bitrate adaptation [18].

Table III: summary of the diffrerent user-centeric multimedia delivery schemes with some feature.

| Technique | Description | Content | fairness | H | SVC | BG |
|---|---|---|---|---|---|---|
| QFF [19] | A SDN-assisted QoE Fairness Framework based on OpenFlow and MPEG DASH | VoD/Live | ✓ | ✓ | × | × |
| IQMF [20] | The SDN-based in-network QOE measurement frame that as proxy. | VoD/Live | ✓ | ✓ | × | × |
| Kleinrouweler et al. [21] | A DASH-aware architecture that provide stability and video delivery. | VoD | ✓ | × | × | ✓ |
| SDNDASH [22] | A modification of dash that improve HAS scalability. | VoD/Live | ✓ | ✓ | × | ✓ |
| SDNHAS [23] | A modification of dash that address the heterogeneity issues. | VoD/Live | ✓ | ✓ | × | ✓ |
| Barakabitze et al. [7] | A novel QoE-centric multipath routing algorithm (QoMRA) to address the limitation of MPCTP | VoD | × | × | × | × |
| Barakabitze et al. [24] | A QoE-aware MPTCP SDN/NFV SR-based system that provide an efficient orchestration. | VoD | ✓ | × | × | × |

### A. *Summary and insights*

In this section, various network-centric multimedia delivery methods were described. Table III presents a summary of the different user-centric multimedia delivery schemes, with the following features:

- Application type: video-on-demand (VoD) or Live.
- Fairness: the technique considers fairness or not.
- Heterogeneity (H): does the solution consider heterogeneous devices?
- SVC: does the technique supports the streaming of SVC-encoded video?

- Background traffic (BG): does the solution consider background traffic in its experimental test?

## V. DISCUSSION

We first present a benchmarking of the validation methods used in the studied SDN-based multimedia delivery approaches in different environments. Table IV summarizes the validation methods used by various multimedia approaches In the following subsections, we discuss about the different issues and research gaps in the current SDN-based solutions.

### *A. SDN-based HAS approaches*

Adaptive video streaming can benefit from SDN in two aspects. First, SDN provides flexibility and simplify the network resource programing due to its capability in controlling resources and monitoring the global network. Second, pure client-based bitrate adaption algorithm has limitation when the network size grows and a set of DASH clients compete in a shared network environment that resulting in issues such as quality oscillations, instability, unfairness, and underutilization. These problems happened due to the lack of coordination among the clients and a global view of the network that can be guarantees by a central coordinator. However, implementation of most SDN-based HAS approaches in the real-world remains challenging since they introduce some overhead that can be effect on the network performance and requires additional entities in the network.

### *B. MPTCP and software defined networking*

As explained in section II, MPTCP was proposed as an extension of TCP. Its main idea was based on the concepts of a large flow that is separated into many derivative flows, called subflows to improve network connectivity and provides higher data rate for end users. The main limitation of MPTCP is its considerable overhead due to maintaining large number of subflows. MPTCP has no control over the network or transmission routes used by each subflow from source to destination. This problem can be addressed with SDN by controlling the number of subflows. However, packet classification and packet forwarding in SDN produce overhead while the SDN switches support a limited size rules due to limitation in ternary content-addressable memory (TCAM) memory. Recently a new approach called Segment Routing (SR) was introduced which can greatly reduce the number of forwarding rules and resource consumption of TCAM. SR encodes routing information into packet header as an ordered list of labels that can be soled the scalability problem of SDN since there is no need to keep state path in each switch along the service delivery path.

Table IV: Evaluation setup for studied SDN-based multimedia delivery Approach

| Techniques | Tools | Environment | controller |
|---|---|---|---|
| Yilmaz et al. [10] | OpenDaylight SDN controller | Two servers, one client and two switches, one controller and a traffic loader to test different scenarios. | Single/ OpenDaylight |
| OpenQoS [11] | Floodlight | Experimental/real network with commercial OpenFlow-enabled switches. | Single/ Floodlight |
| Ongaro et al. [12] | Mininet, any SDN controller | Inside Mininet: 2 servers, 4 loader servers (that run the Iperf tool), 6 OpenFlow switches. Outside Mininet: 2 real mobile devices (smartphones and laptops), SDN controller, the Proposed QoS Management and Orchestration architecture. | Single/ any |
| VSDN [13] | NS-3 | A topology consists of 6 nodes in NS-3 simulator. | Single/ VSDN |
| GA□SDN [14] | Mininet | A topology consist of 9 hosts, 5 switches and one controller. | Single/ any |
| ARVS [15] | Mininet, Foodlight SDN controller | Used Mininet and create a topology with 30 nodes. | Single/ Foodlight |
| Egilmez et al. [16] | LEMON library | Implemented a simulator by using the network Optimization LEMON library, A network with 6 domains, and each domain with 30 nodes. | Multi(distributed)/ any |
| Mohammadi et al. [17] | Mininet, OpenDaylight Controller | Simulated two different test-bed scenarios: small and large. | Single/ OpenDaylight |
| QFF [19] | Any OpenFlow controller, DASH-JS | One controller, 3 clients (smartphone, tablet and HD TV), 1 HTTP server, 1 switch OpenFlow enabled. The topologies of the scenarios are generated with BRITE. | Single/ any |
| IQMF [20] | GOFF , virtual machines ,Floodlight controller | Implements an Experiments testbed over a large-scale SDN, namely GOFF, provided by G´EANT: include number of Open vSwitches and resources are located in five different countries across Europe. Run VoD servers, caches and video clients on virtual machines across different sites and a Floodlight controller. | Single/ Floodlight |
| Kleinrouweler et al. [21] | An OpenFlow-enabled Raspberry Pi. POX Controller | Four nodes shares a Wi-Fi network for video streaming (Raspberry Pi also use as an access point) that Wi-Fi network is a bottleneck. | Single/ POX |
| SDNDASH [22] | Mininet, RYU controller | Inside Mininet: create 50 clients and 100 Mbps total network bandwidth, 3 Open vSwitches Outside Mininet: 1 dash server,1 RYU SDN controller | Single/ RYU |
| SDNHAS [23] | Mininet, RYU controller | Implement topology consist of 100 HAS players,1 HAS Server,1 SDN controller and 170 Mbps total bandwidth and different content types, | Single/ RYU |
| Barakabitze et al. [7] | Mininet, POX controller | Two VMs installed with Linux (Ubuntu): one VM installed Mininet that creates a topology consists of three levels with 8, 4 and 2 OpenFlow switches at the edge, aggregation and core layers, respectively and One MPTCP client is attached at each access switch. Second VM installed POX controller. | Single/ POX |
| Barakabitze et al. [24] | Mininet, POX controller | An experimental testbed which including the core, aggregation and edge layer consists of 8, 4 and 2 SDN switches respectively. Two VMs both running Linux (Ubuntu V16.04 LTS) were installed with the MPTCP v0.92. | Single/ POX |

## VI. CONCLUSION

Software defined networking introduced a new architecture for computer network which decouple control level and data transfer level from each other. This architecture can be help to improve the delivery of multimedia over the Internet that designed for best-effort and data transmission.

In this paper, some SDN-based multimedia delivery methods reviewed. We classified the reviewed multimedia delivery methods into two categories, namely, user-centric and network-centric and we offered a description of each methods. The first category is based on the user perspective and it is mainly focused on the quality of experience requirements while the second category is based on the viewpoint of network designer and it addresses the quality of service parameters. Some research directions and insights for multimedia traffic routing were provided to improve the current multimedia delivery solutions.

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