A SURVEY OF APPLICATIONS AND ARCHITECTURES IN SOFTWARE DEFINED NETWORKING (SDN)

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ABSTRACT

In recent years Software Defined Networking (SDN) has become very popular in computer networks. This is because of programmable network components enable a vast array of network functionality. This paper highlights some current SDN applications such as Internet of Things (IoT), Open Flow Networks, Scalable Video Coding, Resource Management, Dynamic Adaptive Streaming over HTTP (DASH-based), Quality of Service (QoS) Routing and Cognitive Networking. We then discuss some of the SDN-enabled architectures that provide these applications with their desired functionality.

Keywords: Software Defined Networking; SDN; IoT; DASH; Management; QoS; Cognitive; Networking.

I. INTRODUCTION

The concept of software defined networking or networks (SDN) follows from the paradigm of active networks. SDN breaks the vertical integration by separating the network's control logic (the control plane) from the underlying routers and switches that forward the traffic (the data plane) [11]. This parting of the control and data planes makes network routers become simple forwarding devices. This occurs as the control logic is implemented in a logically centralized controller or network operating system (NOS). It greatly makes things easier on policy enforcement and network (re)configuration and evolution [9]. Though the SDN architecture is logically centralized it may not guarantee a physically centralized system [10].

An SDN as a network architecture can be defined by control and data planes, flow based forwarding decisions (not destination based), NOS-based control logic, and programmable network devices running on top of the NOS (see Figure 1).

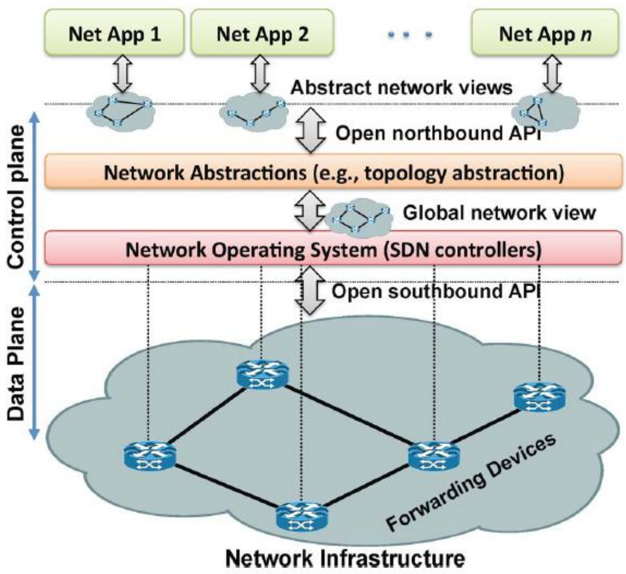

Fig. 1. SDN architecture [10].

This work consists of four sections. Section II presents a look at some SDN-based applications. Section III gives examples of these applications with their supporting architectures. Finally, the conclusion is given in Section IV.

II. SDN APPLICATIONS

SDN-based applications are categorized into Internet of Things (IoT), Open Flow Networks (OFN), Scalable Video Coding (SVC), Resource Management, Dynamic Adaptive Streaming over HTTP (DASH) [6], [7], [8], Quality of Service (QoS) routing and Cognitive Networking (see Figure 2).

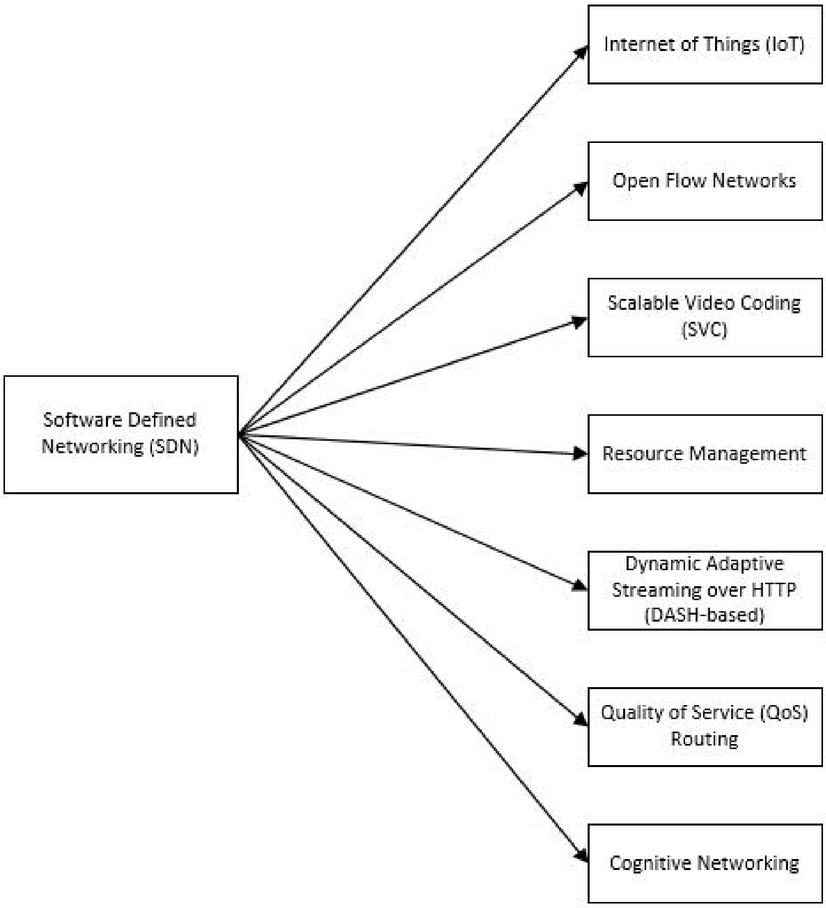

Fig. 2. Future DASH applications.

III. SDN-ENABLED ARCHITECTURES

A. Internet of Things (IoT)

The growing interest in the Internet of Things (IoT) has resulted in a number of wide-area deployments of IoT subnetworks, where multiple heterogeneous wireless communication solutions coexist: from multiple access technologies such as cellular, WiFi, ZigBee (see Figure 3), and Bluetooth, to multi-hop ad-hoc and MANET routing protocols (Figure 4), they all must be effectively integrated to create a seamless communication platform. Managing these open, geographically distributed, and heterogeneous networking infrastructures, especially in dynamic environments, is a key technical challenge. In order to take full advantage of the many opportunities they provide, techniques to concurrently provision the different classes of IoT traffic across a common set of sensors and networking resources must be designed. Authors in [14] design a software-defined approach for the IoT environment (see Figure 5) to dynamically achieve differentiated quality levels to different IoT tasks in very heterogeneous wireless networking scenarios. For this, the authors extend the Multinetwork INformation Architecture (MINA), a reflective (self-observing and adapting via an embodied Observe-Analyze-Adapt loop) middleware with a layered IoT SDN controller. The developed IoT SDN controller originally i) incorporates and supports commands to differentiate flow scheduling over task-level, multi-hop, and heterogeneous ad-hoc paths and ii) exploits Network Calculus and Genetic Algorithms to optimize the usage of currently available IoT network opportunities. Authors have applied the extended MINA SDN prototype in the challenging IoT scenario of wide-scale integration of electric vehicles, electric charging sites, smart grid infrastructures, and a wide set of pilot users, as targeted by the Artemis Internet of Energy and Arrowhead projects. Preliminary simulation performance results indicate that their approach and the extended MINA system can support efficient exploitation of the IoT multinetwork capabilities.

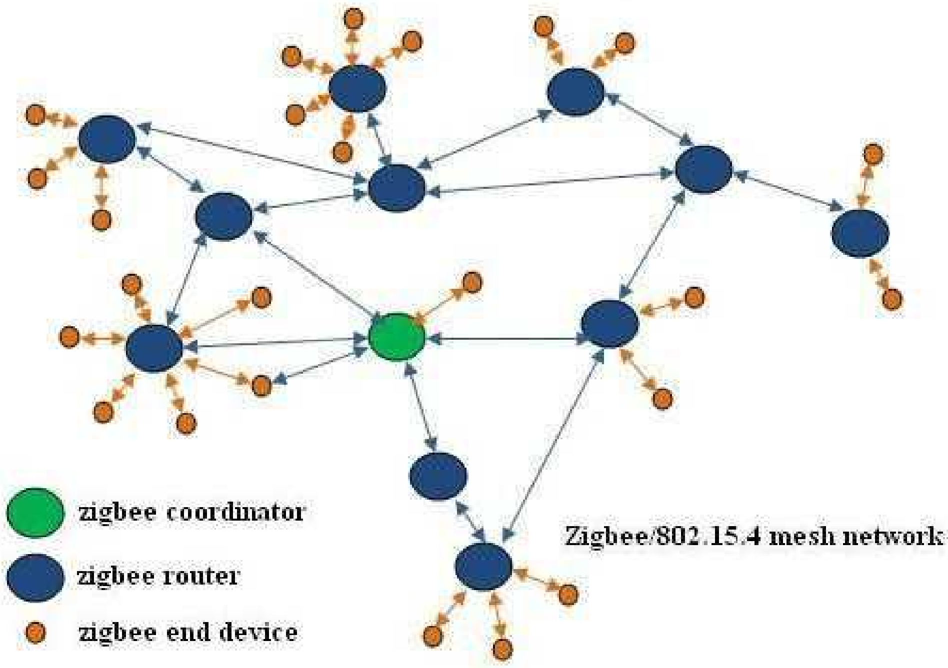

Fig. 3. Zigbee Mesh Network.

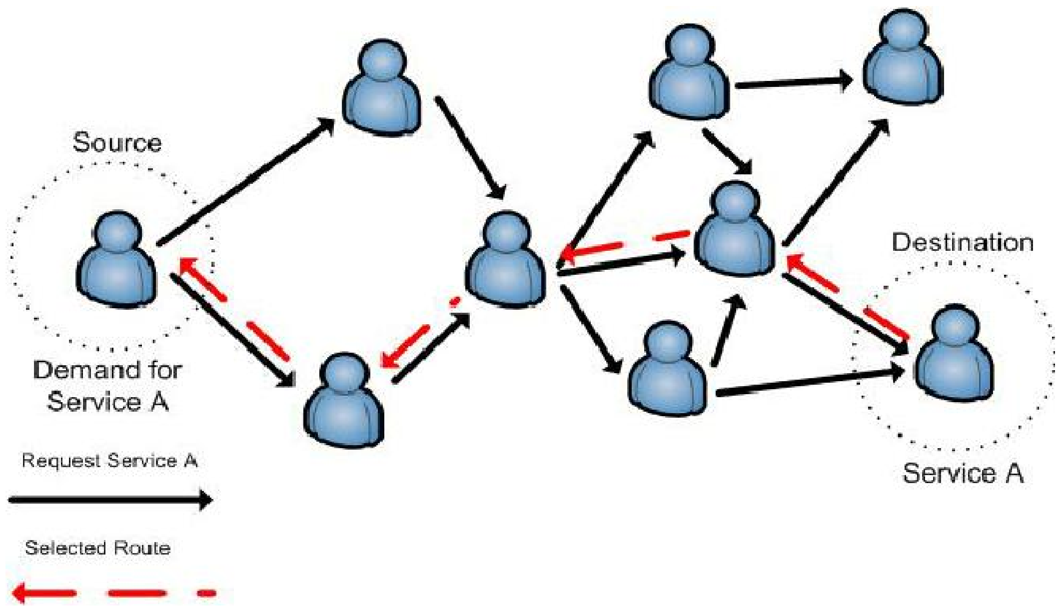

Fig. 4. MANET routing [16].

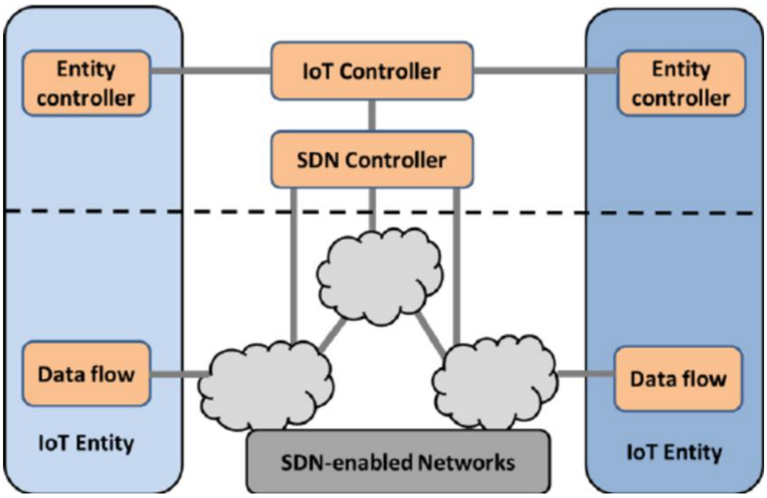

Fig. 5. SDN-enabled network with an IoT controller [15].

B. Open Flow Networks

OpenFlow is a Software Defined Networking (SDN) paradigm that decouples control and data forwarding layers of routing. Authors propose OpenQoS, which is a novel OpenFlow controller design for multimedia delivery with end-to-end Quality of Service (QoS) support [3]. Their approach is based on QoS routing where the routes of multimedia traffic are optimized dynamically to fulfill the required QoS. They measure performance of OpenQoS over a real test network and compare it with the performance of the current state-of-the-art, HTTP-based multi-bitrate adaptive streaming. Their experimental results show that OpenQoS can guarantee seamless video delivery with little or no video artifacts experienced by the end-users. Moreover, unlike current QoS architectures, in OpenQoS the guaranteed service is handled without having adverse effects on other types of traffic in the network (see Figure 6 and 7).

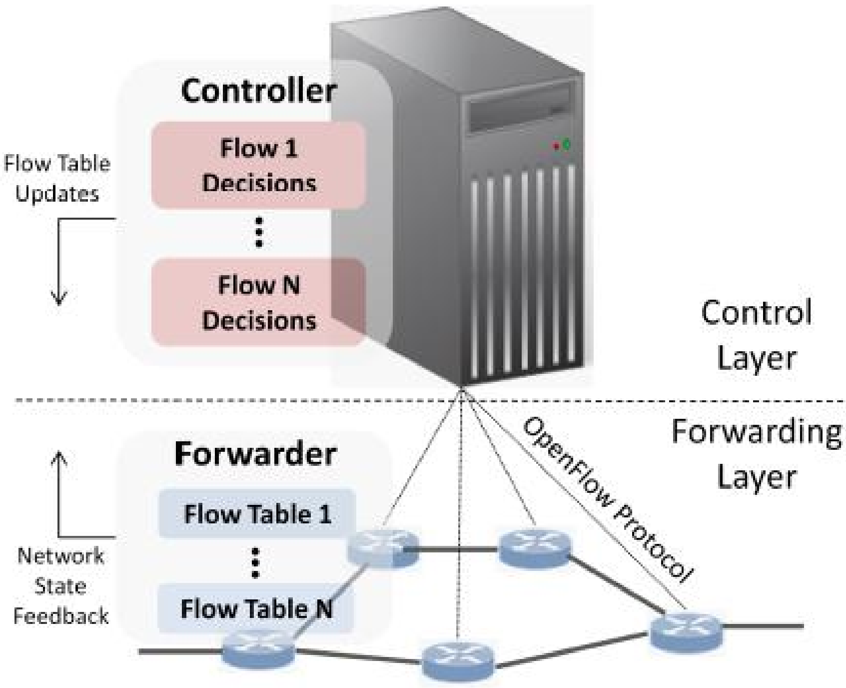

Fig. 6. OpenFlow Architecture [3].

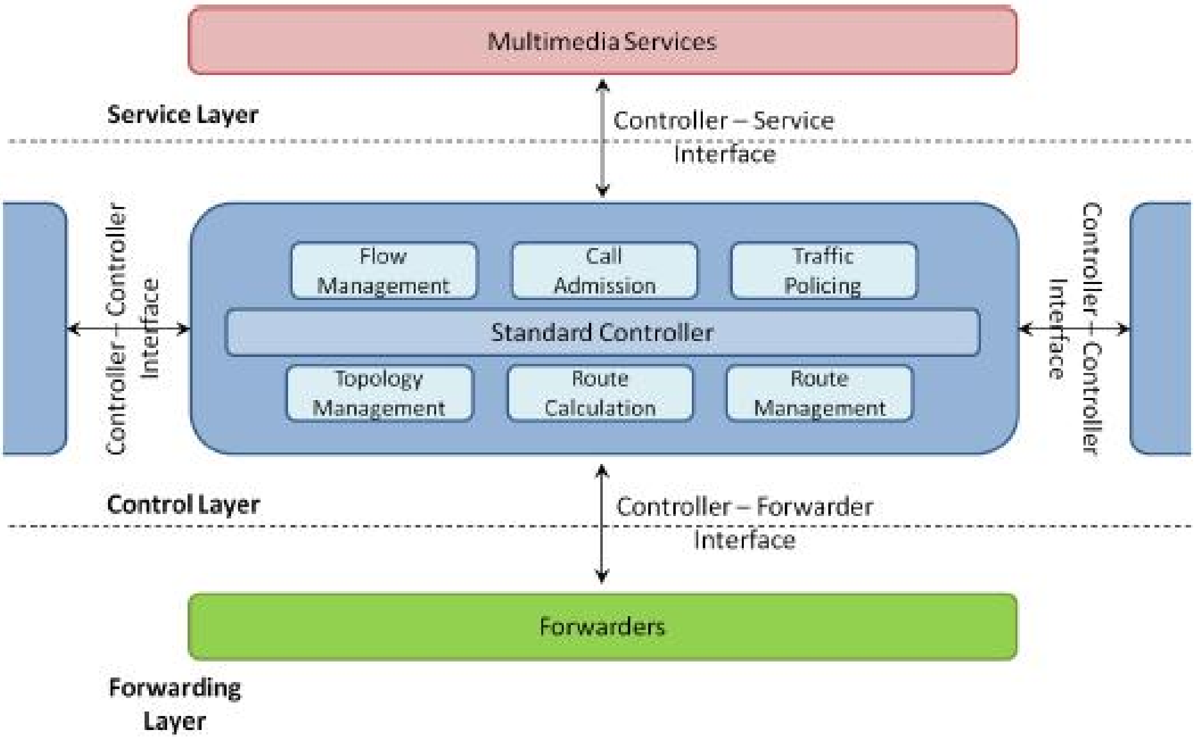

Fig. 7. OpenQoS Controller Design [3].

Video streaming is an increasingly popular way to consume media content. Adaptive video streaming is an emerging delivery technology which aims to increase user QoE and maximise connection utilisation. Many implementations naively estimate bandwidth from a one-sided client perspective, without taking into account other devices in the network. This behaviour results in unfairness and could potentially lower QoE for all clients. Authors in [5] propose an OpenFlow-assisted QoE Fairness Framework that aims to fairly maximise the QoE of multiple competing clients in a shared network environment (see Figure 8). By leveraging a Software Defined Networking technology, such as OpenFlow, the researchers provide a control plane that orchestrates this functionality. The evaluation of research approaches in a home networking scenario introduces user-level fairness and network stability, and illustrates the optimisation of QoE across multiple devices in a network.

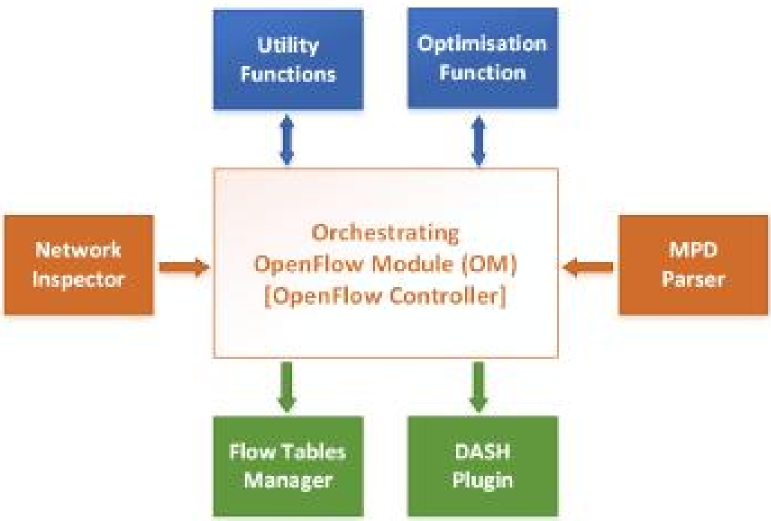

Fig. 8. OpenFlow-assisted QoE Fairness Framework [5].

OpenFlow is a programmable network protocol and associated hardware designed to effectively manage and direct traffic by decoupling control and forwarding layers of routing. Authors present an analytical framework for optimization of forwarding decisions at the control layer to enable dynamic Quality of Service (QoS) over OpenFlow networks and discusses application of this framework to QoS-enabled streaming of scalable encoded videos with two QoS levels [4]. They pose and solve optimization of dynamic QoS routing as a constrained shortest path problem, where they treat the base layer of scalable encoded video as a level-1 QoS flow, while the enhancement layers can be treated as level-2 QoS or best-effort flows (see Figure 9). Authors provide experimental results which show that the proposed dynamic QoS framework achieves significant improvement in overall quality of streaming of scalable encoded videos under various coding configurations and network congestion scenarios.

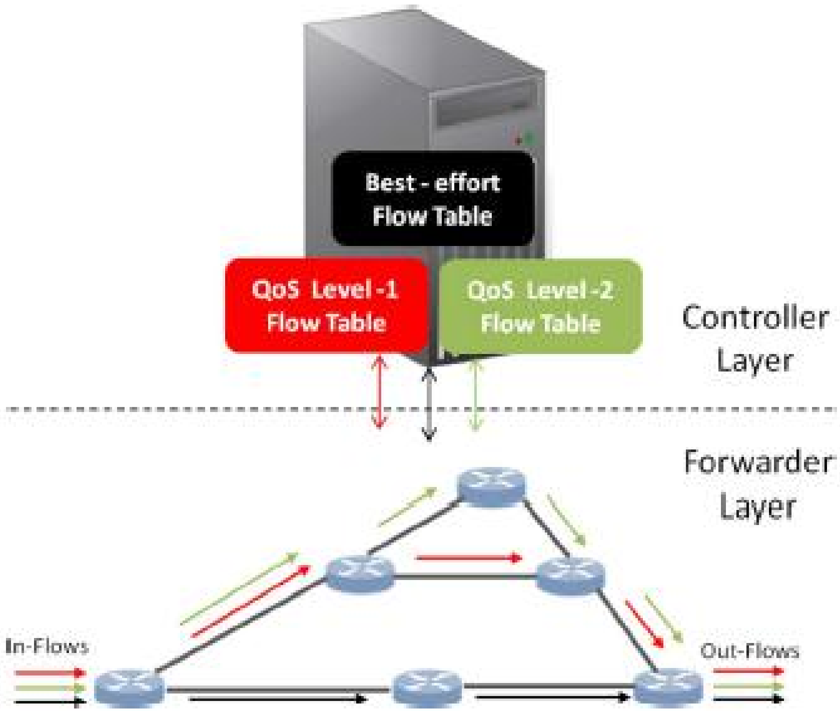

Fig. 9. OpenFlow controller and forwarder interaction with three QoS-levels [4].

C. Scalable Video Coding (SVC)

Scalable video coding is a promising technique to enable flexible video transmission for heterogeneous terminals and varying channel throughput. However, it is challenging to perform in-network adaptation in conventional networks because the network nodes are uncontrollable and transparent for media streaming applications. Software-defined networking (SDN) is an attractive network technology that supports the applications to collaborate with network nodes to achieve intelligent and dynamic service provisioning. Against this changing network landscape, authors in [17] redesign the scalable multimedia multicast streaming by exploiting the complete network knowledge of the SDN controller to enable intelligent scalable video transmission. The proposed scalable multimedia multicast streaming framework is capable of in-network identifying, processing, and manipulating the media streams. In order to achieve the in-network adaptation, researchers apply equivalent bandwidth theory to estimate the affordable video layers that a link may accommodate, and apply finite-state machine to implement adaptive enhancement layer switching for multicast paths. In contrast to IP multicast, the proposed method is a controllable multicast scheme, which provides admission control in a multicast context, in-network adaptation, and supporting heterogeneous devices having different display capability (see Figure 10). Authors further implement a prototype for illustrating the success of the proposed solution. The experimental results are also presented to show the effectiveness of the proposed equivalent bandwidth based adaptive enhancement layer switching algorithm.

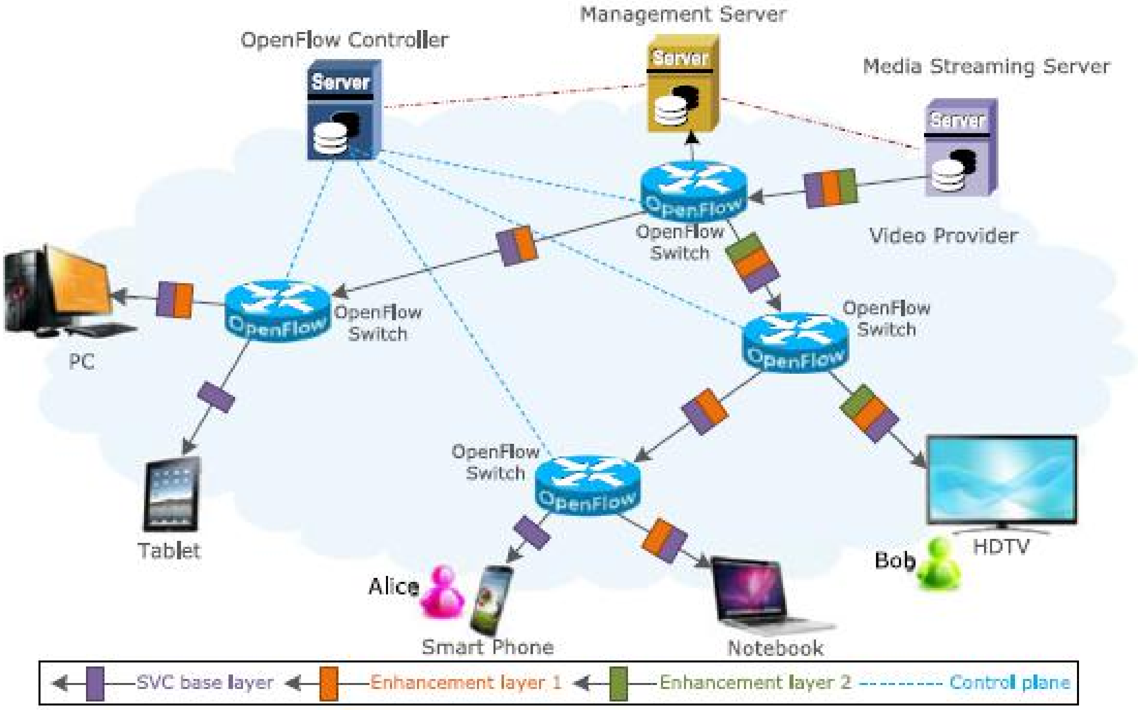

Fig. 10. Scalable multimedia multicast streaming system using OpenFlow [17].

D. Resource Management

Today's Internet does not provide an exchange of information between applications and networks, which may result in poor application performance. Concepts such as application-aware networking or network-aware application programming try to overcome these limitations. The introduction of Software-Defined Networking (SDN) opens a path towards the realization of an enhanced interaction between networks and applications. Hence, a more dynamic and demand-based allocation of network resources to heterogeneous applications can be realized [18] (see Figure 11). The implementation of the resource management action, however, may have an impact on the data transport and application quality.

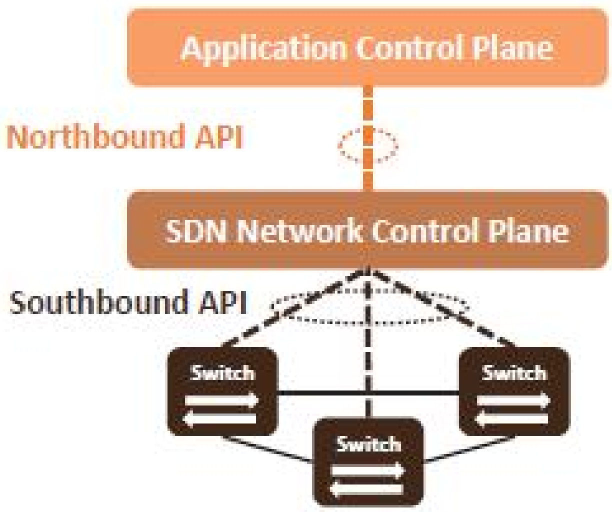

Fig. 11. SDN interfaces [18].

E. Dynamic Adaptive Streaming over HTTP (DASH-based)

HTTP adaptive streaming (HAS) is being adopted with increasing frequency and becoming the de-facto standard for video streaming. However, the client-driven, on-off adaptation behavior of HAS results in uneven bandwidth competition and this is exacerbated when a large number of clients share the same bottleneck network link and compete for the available bandwidth. With HAS each client independently strives to maximize its individual share of the available bandwidth, which leads to bandwidth competition and a decrease in end-user quality of experience (QoE). The competition causes scalability issues, which are quality instability, unfair bandwidth sharing and network resource underutilization. Authors propose a new software defined networking (SDN) based dynamic resource allocation and management architecture for HAS systems, which aims to alleviate these scalability issues and improve the per-client QoE [1]. The authors architecture manages and allocates the network resources dynamically for each client based on its expected QoE (see Figure 12). Experimental results show that the proposed architecture significantly enhances scalability by improving per-client QoE by at least 30% and supporting up to 80% more clients with the same QoE compared to the conventional schemes.

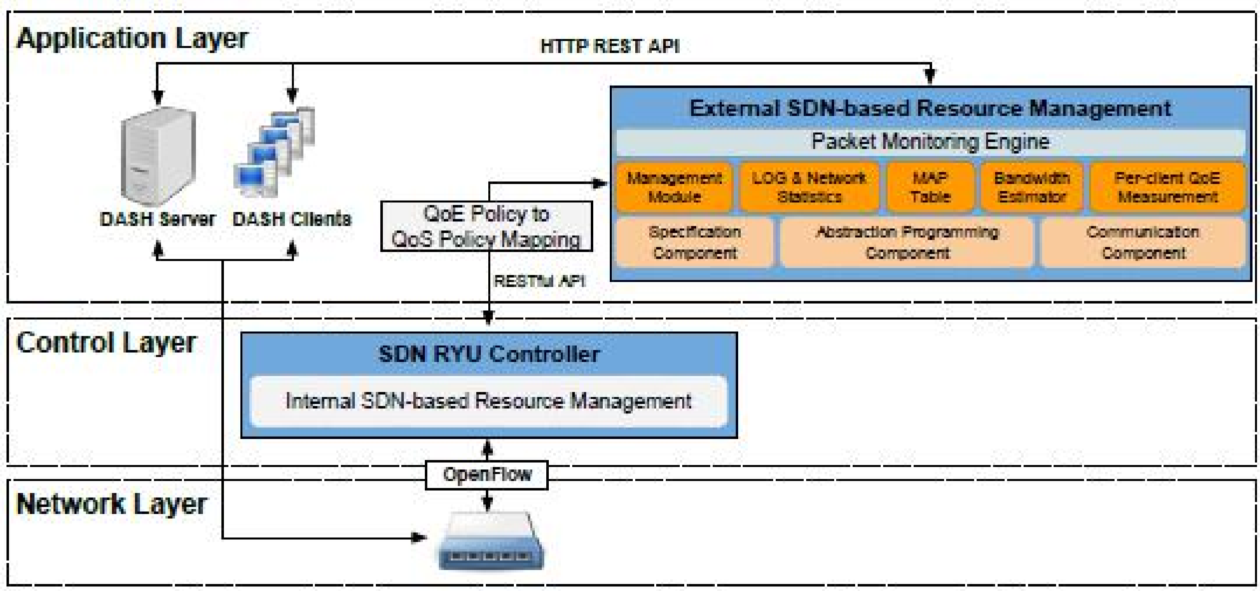

Fig. 12. SDNDASH architecture [1].

While video streaming has dominated the Internet traffic, video service providers (VSPs) compete on how to assure the best quality of experience (QoE) to their customers. HTTP Adaptive Streaming (HAS) has become the de facto way that helps VSPs work-around potential network bottlenecks that inevitably cause stallings. However, HAS-alone cannot guarantee a seamless viewing experience, since this highly relies on the mobile network operators' (MNOs) infrastructure and evolving network conditions. Software-defined networking (SDN) has brought new perspectives to this traditional paradigm where VSPs and MNOs are isolated, allowing the latter to open their network for more flexible, service-oriented programmability. Authors in [12] takes advantage of recent standardization trends in SDN and proposes a programmable QoE-SDN App, enabling network exposure feedback from MNOs to VSPs towards network-aware video segment selection and caching, in the context of HAS (see Figure 13). The video selection problem is formulated using Knapsack optimization and relaxed to partial sub-problems that provide segment encodings that can mitigate stallings. Furthermore, a mobility prediction mechanism based on the Self-similar Least-Action Walk model is introduced, toward proactive segment caching. A number of use cases, enabled by the QoE-SDN App, are designed to evaluate the proposed scheme, revealing QoE benefits for VSPs and bandwidth savings for MNOs.

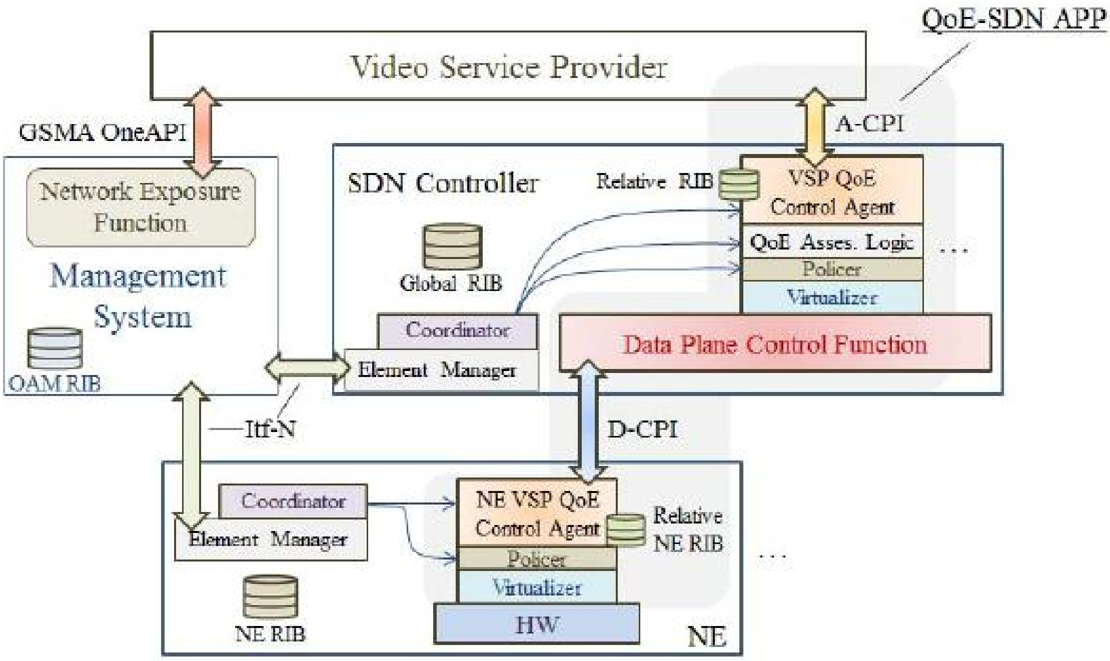

Fig. 13. QoE-SDN APP functions and architecture [12].

F. Quality of Service (QoS) Routing

Authors present novel QoS extensions to distributed control plane architectures for multimedia delivery over large-scale, multi-operator Software Defined Networks (SDNs) [2]. They foresee that large-scale SDNs shall be managed by a distributed control plane consisting of multiple controllers, where each controller performs optimal QoS routing within its domain and shares summarized (aggregated) QoS routing information with other domain controllers to enable inter-domain QoS routing with reduced problem dimensionality (see Figure 14). To this effect, authors propose (i) topology aggregation and link summarization methods to efficiently acquire network topology and state information, (ii) a general optimization framework for flow-based end-to-end QoS provision over multi-domain networks, and (iii) two distributed control plane designs by addressing the messaging between controllers for scalable and secure inter-domain QoS routing. They apply these extensions to streaming of layered videos and compare the performance of different control planes in terms of received video quality, communication cost and memory overhead. Authors experimental results show that the proposed distributed solution closely approaches the global optimum (with full network state information) and nicely scales to large networks.

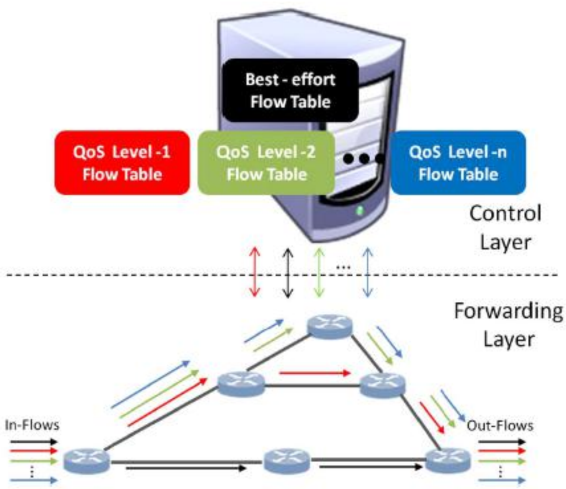

Fig. 14. The controller and forwarder interaction to support n QoS-levels [2].

G. Cognitive Networking

Adaptive media such as HTTP adaptive streaming (HAS) is becoming a standard tool for online video distribution. The non-cooperative competition of network resources between a growing number of adaptive streaming applications has a significant detrimental impact on the user experience and network efficiency. Existing network infrastructures often prioritise fast packet forwarding and not the quality of the delivered content. Future network management must leverage application and user-level cognitive factors (see Figure 15) to allocate scarce network resources effectively and intelligently. Authors in [13] have a software defined cognitive networking (SDCN) project aiming at incorporating new developments in human cognition, media technology and communication networks to ensure the user experience, user-level fairness and network efficiency of online adaptive media (see Figure 16).

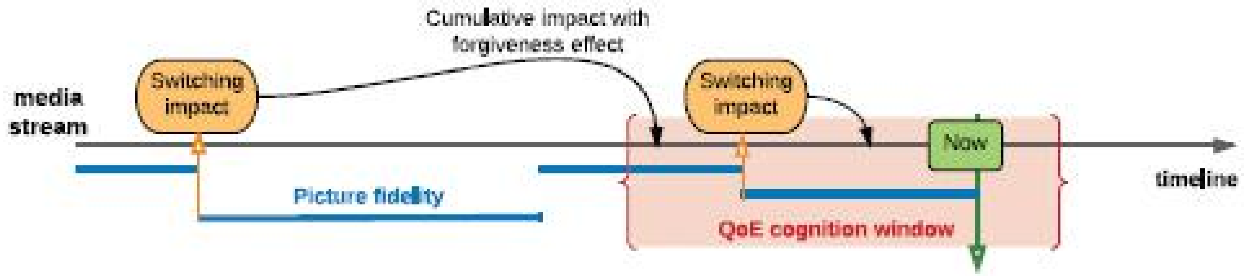

Fig. 15. Cognitive model [13].

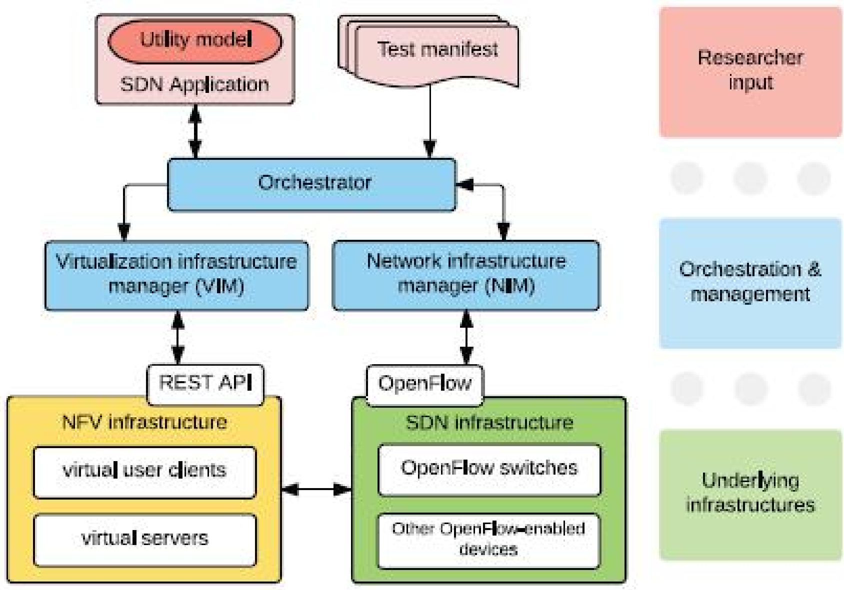

Fig. 16. Architecture of the SDN/NFV (Network Function Virtualisation) model [13].

IV. CONCLUSION

In recent years Software Defined Networking (SDN) has become very popular in computer networks. This is because of programmable network components enable a vast array of network functionality. This paper highlighted some current SDN applications such as Internet of Things (IoT), Open Flow Networks, Scalable Video Coding, Resource Management, Dynamic Adaptive Streaming over HTTP (DASH-based), Quality of Service (QoS) Routing and Cognitive Networking. We discussed some of the SDN-enabled architectures that provide these applications with their desired functionality.

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