A critical review of OpenFlow/SDN-based networks

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Abstract

The separation of the data and control planes simplify the implementation of SDN applications. The centralised architecture of a controller based on the OpenFlow protocol is appealing to the network operators. We have reviewed the concept of SDNs and its extension to optical networks, and constrained and unconstrained wireless access networks. The current status of the proposed and implemented SDN architectures is such that the fulfilment of a SLA is an open issue. This aspect is left to be tackled by the SDN applications and the proposed architectures do not provide means to describe the interplay between different technology domains. In this paper we make an in depth analysis of the current proposed architectures and identify important challenges to be addressed by a novel integrated SDN architecture.

Keywords

Software Defined Networks - SDN; OpenFlow - OF; Service Level Agreement (SLA); Quality of Service (QoS); Quality of Resilience (QoR); Quality of Energy (QoEn); Quality of Network Economics (QoNE).

I. Introduction

Currently lots of effort is being put on the design and development of technologies that simplify the assignment and management of resources of telecommunications networks. Another very important aspect is to take into account the heterogeneity of the telecommunications networks in which an end-to-end path may involve very different technological domains. An attempt to jointly address the packet and circuit switched networks has been provided by the GMPLS. The Generalized Multi-Protocol Label Switching (GMPLS) is a protocol suite extending MPLS to manage further classes of interfaces and switching technologies other than packet interfaces and switching, such as time division multiplex, layer-2 switch, wavelength switch and fiber-switch. The GMPLS is a very mature technology but its control plane failed to provide automatic switching functionalities due to the complexity associated to deploy its peer model, and its adoption by network operators is being postponed [1].

On the one hand, one of the most promising approaches to simplify the assignment and management of resources of telecommunications networks consists in the separation of the data and control planes that enables easier implementations of Software Defined Networks (SDN) applications.

The centralized architecture of a controller based on the OF protocol is appealing to the network operators. OF has been originally specified to work with Ethernet-based switches and IP-based routers and later extended to work with circuit switched networks.

On the other hand, the relationship between a client and a network or service provider is ruled by means of a Service Level Agreement (SLA). A SDN should be able to select paths and assign network's resources in such a way that the SLA is fulfilled. As it will be shown the current proposed SDN architectures have not solved this problem yet and the SLA fulfillment remains an open issue.

In recent years, a great number of papers dealing with SDN have focused on the separation of the control and data planes using OF to configure the network elements [2] [3] [4]. In addition, in [5] the authors propose a combined software/hardware framework for the SDN configuration. In [6] it is suggested the extension of the SDN techniques used in packet switching to optical circuit switching. In [7] it is defined a SDN architecture on the basis of a shared multilayered network infrastructure, and in [8] and [9] it is proposed an architecture model that integrates not only the core network but also the access networks under the umbrella of OF. Other authors also suggest the integration of the Path Computation Element (PCE) with OF [10], the PCE with GMPLS [11], or analyze the role of the PCE in SDNs [12]. In [13] the design, implementation and experimental evaluation of a centralized control plane based on a stateful PCE, acting as an OF controller are described. The extensions of the OF and the PCE communication protocol (PCEP) are also presented.

Other SDN architecture proposals consider the explosion of services based on Internet of Things (IOT) and the consequent increase in traffic coming from the Machine-to-Machine (M2M) transactions. They also include the Cloud Computing model in the OF-based SDN architecture [14] [15] [16].

Even though some research works analyze the performance of the SDN networks at the physical level with software-defined transponders [17] and the Quality of Transmission (QoT) [18], or define a QoS-aware SDN architecture [19], it has not yet been proposed a SDN architecture that takes into account the concept of a comprehensive Quality of Service as a global end-to-end design objective function to be satisfied to ensure the SLA fulfillment.

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After this Introduction, Section II describes the adopted SLA model along the different quality metrics; Section III analyzes some of the most relevant SDN architectures proposed in the literature to support QoS [20] [21] [22]. The section focuses on the identification of gaps that must be covered to identify the design requirements of an architecture able to guarantee the SLA fulfillment. Section IV summarizes the conclusions and future work.

II. SLA ADOPTED MODELS

The Service Level Agreement (SLA) is a list of requirements that the client (e. g., a content provider) agrees with the (Internet) network provider in order that the end-user (residential or business) gets the expected quality. In the wide sense, the expected quality is usually obtained out of several Quality of Experience (QoE) tests, the traffic demand rate versus the available network resources, the estimated failure and repair frequencies of the network elements, monitoring the network behavior, etc.

Accordingly, a wide scope approach of the SLA concept, which is the one we assume in this paper, consists of different type of requirements namely QoS (Quality of Service), Quality of Transmission (QoT), GoS (Grade of Service), Quality of Resilience (QoR), and Quality of Energy (QoEn). The QoS items of the SLA indicate thresholds in transmission delay, data losses, and throughput experienced due to the level of congestion in the network. The QoT items collect the tolerance to the physical impairments (BER, OSNR, Q-factor, etc.) impacts in the optical/wireless connections. The QoR items relate to the service sensitivity outage time from a failure to its restoration. The QoEn has to do with minimizing the levels of energy consumption and maximizing the green to dirty ratio of the energy consumed. Finally, the Grade of Service imposes a lower bound in the network resources utilization to optimally satisfy the estimated traffic demand with the available network resources.

Given the aforementioned quality criteria, our approach of a SLA focuses on achieving a trade-off between them and what we designate as Quality of Network Economics (QoNE), in the sense that the resources assignment has to optimize the relationship between Cost (C) and Revenue (R) which can be measured, for example, by the C/R ratio.

III. CRITICAL ANALYSIS OF SOME OF THE MOST RELEVANT PROPOSED SDN ARCHITECTURES

Core networks transport a mix of packet and circuit services. According to [20] and as shown in Fig. 1 different multi-layer node architectures exist. Client interfaces consist of 10 GbE packet and 10 Gb/s OTU2 circuit interfaces. Line interfaces are 100 Gb/s OTU4 signals on DWDM wavelengths. In the layered architecture, the packet traffic is passed through an ODU switch before of being mapped onto a wavelength. Such an approach can mix packet and circuit traffic on the same wavelength. In the parallel architecture, both traffic types are independently mapped and transported as wavelengths in the optical layer. In the integrated architecture, a hybrid ODU-MPLS switch processes both types of traffic. This kind of node allows full flexibility in aggregating circuit and packet services on individual wavelengths. These different node architectures differ in terms of number of required interfaces and switching flexibility. All of them may benefit from the separation of data and control planes offered by an OF-OSDN architecture. By themselves, they are not QoS-aware and are not necessarily equivalent in terms of fulfilling a established SLA.

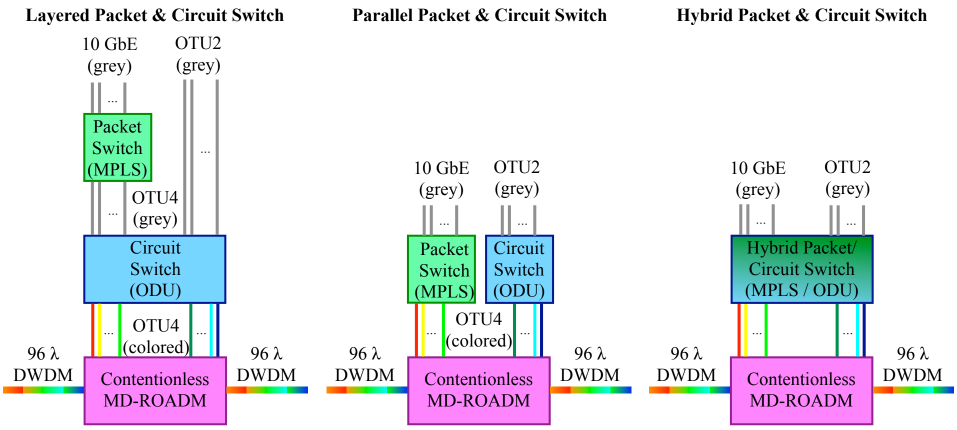

Fig. 1. Multi-layer node architecture for transport of packet and circuit services over a converged optical layer. Adapted from [20].

In [21] the authors introduce a software defined optical network architecture that has similar features as IP/Ethernet-based electrical SDN architecture. The centralized controller controls network equipments using OpenFlow over standardized programmable interfaces. Fig. 2 illustrates the proposed architecture that consists of two elements: (1) software defined optics (SDO) and optics defining controller (ODC). The SDO comprises the physical hardware such as transmitter, receiver, modulator, switching node, amplifier, etc., which are software programmable to perform flexible operations. The ODC manages the network and performs network optimization to utilize the SDO's flexibility. Various control plane functionalities as routing and resource allocation, access control, QoS management, protection and restoration, defragmentation, energy optimization, etc., are implemented as network applications in the ODC. The proposed QoS-aware unified control protocol consists of adaptive-burst assembling, latency-aware burst routing and scheduling, and OpenFlow based signaling. Despite of the proposed architecture explicitly introducing QoS management, it is technology specific, it does not promote the convergence between the electrical and optical layers and it is not able to fulfill a established SLA.

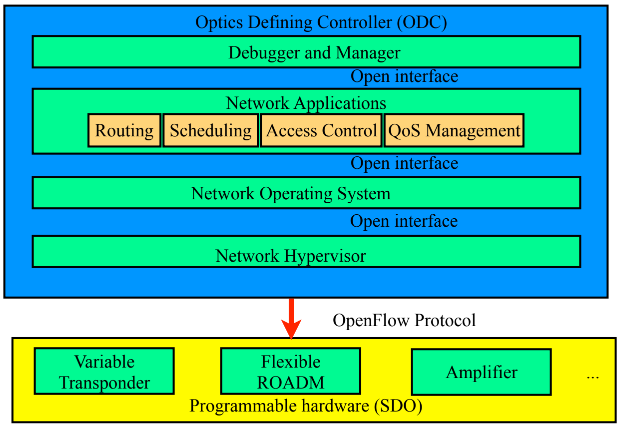

Fig. 2. OBS-SDON architecture. Adapted from [21].

In [22], Simeonidou et al. identified that in order to enable SDN based unified control and management of an optical network the following challenges need to be addressed:

- definition of a unified optical transport and switching granularity (e. g. optical flow) that can be generalized for different optical transport technologies (e.g. fixed DWDM, flexi DWDM, sub-wavelength switching, etc.);
- design and implementation of an abstraction mechanism that can hide the transport technology details and realize the aforementioned generalized switching entity definition;
- taking into account physical layer specific features of different optical transport technologies such as power, impairments, switching constraints, etc.;
- cross technology constraints for bandwidth allocation and traffic mapping in networks comprising heterogeneous technological domains e. g. packet over single or hybrid optical transport technologies.

Fig. 3, adapted from [22], shows the architecture of a SDN enabled optical network control plane based on OpenFlow. The architecture proposed in [22] relies on an abstraction mechanism, implemented by an extended OF controller and the OF protocol. This mechanism generalizes the flow switching concept for the underlying heterogeneous optical transport technologies as well as its integration with packet switched domains. The control plane, by means of the extended OF protocol and the controller can abstract the switching technology and transport format of each technological domain in the form of generic flows and to configure network elements using technology specific flow tables (i. e. intra-domain flow tables). The architecture also uses an inter-domain flow table for enforcing cross technology constraints for bandwidth allocation when traffic traverses from one technology domain to another.

For the architecture described in [22] the authors propose two implementation methods: (i) integrated GMPLS and OpenFlow; (ii) stand alone OpenFlow. In the integrated GMPLS-OpenFlow approach, the OF controller receives information regarding the topology and resources using extended OF protocol. However, path computation, lightpath establishment and teardown are performed using the GMPLS control plane. In the stand alone OpenFlow approach, the OF controller is able to specify the full details of the lightpath (i. e. address all switches and ports along the lightpath), to verify the feasibility of the lightpath and perform its establishment.

To the best of our knowledge, the architecture proposed in [22] is the most comprehensive one aiming at the integration of the packet switched and circuit switched domains. However, there are still several gaps to be overcome. As far as the fulfillment of a established SLA is concerned the architecture itself does not address this issue. In fact, the paper only mention that aspects concerning QoS requirements are left to be addressed by the SDN applications and the whole purpose of the architecture is to provide means of assessing technology specific parameters and to configure NEs by means of the OF protocol. The translation of inter-domain parameters interplay in terms of SLA impact is not addressed at all.

As described in Section I, many papers have been published to describe and promote the SDN concept to be also applied in optical networks. In fact, none of them explicitly address the SLA fulfillment issue that is left to be solved by the SDN

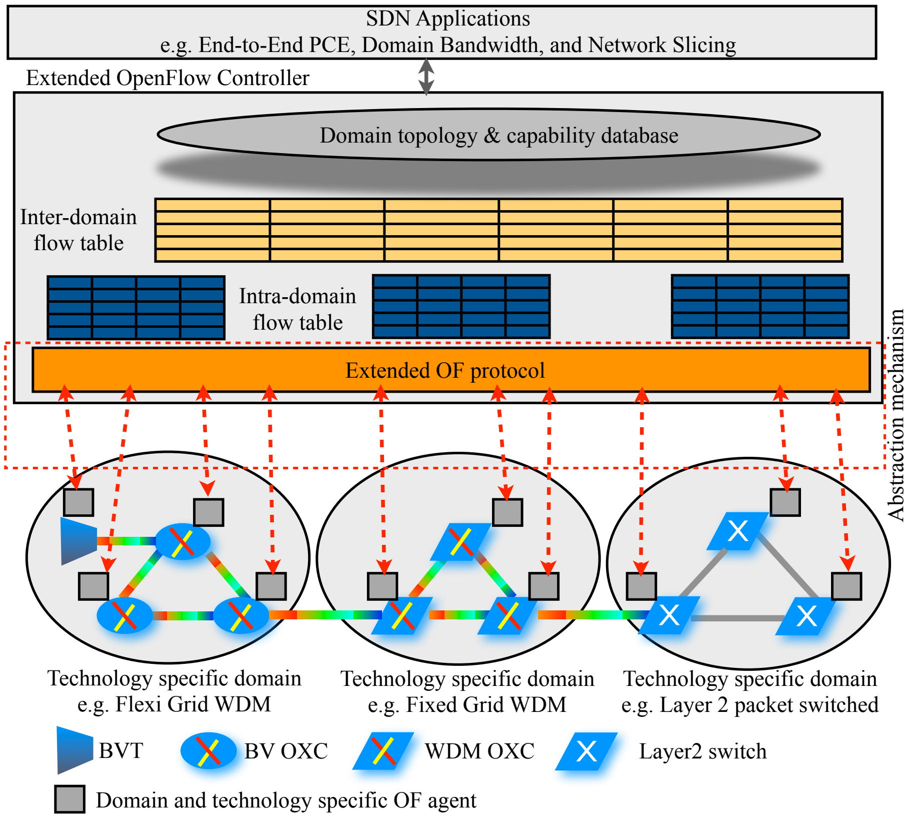

Fig. 3. Architecture of a SDN enabled optical network control plane based on OpenFlow. Adapted from [22].

applications. Their concern is exclusively focused on extending the OF protocol in order to be able to transport optical networks related parameters. This being so, a number of challenges remain to be looked upon:

- develop a virtualized description of the underlying heterogeneous paths between source and destination nodes such that a comprehensive QoS comparison between them can be performed. The SLA metrics should be multi-dimensional to include technical performance, economic result in terms of cost/revenue and availability in terms of resilience;
- develop a virtualized description of the underlying heterogeneous paths between source and destination nodes, **when such nodes belong to different autonomous systems**, such that a comprehensive QoS comparison between them can be performed. Extend the OF protocol in such a way that network elements in different autonomous systems can be adequately configured.
- consider the new communications paradigm defined by the Internet of Things (IoT) (in some cases designated as Machine-to-Machine (M2M)) in which a huge number interconnected objects need to form a network and to communicate. In this case, scalability and resilience issues are of paramount importance. To the best of our knowledge, none of the works published in the literature has extended the SDN concept to consider the IoT and how to integrate it to the transport network.

In summary, a new architecture has yet to be developed to provide the following characterisitcs:

- to address the scalability issue by limiting the number of nodes that communicate directly to the SDN controller;
- to be flexible allowing the operator to choose the best signaling technique for each technological domain;
- to allow either a centralized or distributed recovery mechanism implementation. In the distributed approach, the backup paths should be computed and stored in each OF-SCP. In the centralized approach, when a failure occurs it is locally detected and reported to the SDN controller that will compute a new path;
- to promote a fully integrated topology view regardless of the involved technologies;
- to include a SLA-aware NVF controller that can deal simultaneously with different kinds of quality metrics.

IV. Conclusions and Future Work

In this paper we have reviewed the concept of Software Defined Networks and its extension to optical, wireless and constrained resources networks. The separation of the data and control planes simplify the implementation of SDN applications.

The centralized architecture of a controller based on the OpenFlow protocol is appealing to the network operators.

The state of art study reveals that the OpenFlow technology is still immature and lacks many features required by carrier grade operators. The study has also revealed that the fulfillment of SLAs is an open issue and the proposed architectures do not provide means to describe the interplay between different technology domains.

We have identified three important challenges to be addressed by a novel integrated SDN architecture: (i) develop a virtualized description of the underlying heterogeneous paths between source and destination nodes such that a QoS comparison between them can be performed; (ii) develop a virtualized description of the underlying heterogeneous paths between source and destination nodes, when such nodes belong to different autonomous systems; (iii) consider the new communications paradigm defined by the IoT in which a huge number interconnected objects need to form a network and to communicate.

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