SDN/NFV-based network resource management for converged optical-wireless network architectures

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ABSTRACT
This paper proposes a methodology for the efficient allocation of both optical and wireless resources in an SDN/NFV-based converged optical-wireless network architecture. Our approach considers a network slicing architecture where different network slices form end-to-end logically isolated networks, each one dedicated to a different type of service with diverse requirements. The target of the proposed approach is to optimally determine the network slices so that the specific delay and bandwidth requirements of the multiple services are met, by considering both the optical and wireless network resources.
Keywords: 5G networks, SDN, NFV, network slicing, resources management, converged networks.

1. INTRODUCTION

5G network on one hand is expected to provide high data rate, ultra-low latency, high user mobility, ultra-reliable, and ultra-dense communications. On the other hand, it should be able to provide a variety of services to the end-users, each with distinctive characteristics and requirements, such as autonomous driving, augmented and virtual reality, tactile Internet, and smart city to name a few. To overcome these challenges, the next generation networks are expected to be more agile, flexible, scalable and software configurable by utilizing a set of emerging technologies such as Software Defined Networking (SDN), Network Functions Virtualization (NFV), and Network Slicing (NS) [1]. The NS technique is running a number of logically isolated networks on top of a common shared physical infrastructure and dedicating each slice to a set of service types. Moreover, the NS essentially requires an automatic management and orchestration system [2], [3].

On one hand, SDN is a novel paradigm simplifying the data plane entities such as switches and routers and abstracts their intelligence using one or more SDN controllers as control plane entities. In other words, SDN is in charge of communicational resources management [4]. On the other hand, NFV is responsible for managing the computational resources residing inside Data Centres (DCs) including CPU, memory, and storage and moves legacy Physical Network Functions (PNFs) from dedicated hardware towards software applications, named Virtualized Network Functions (VNFs), which are run on general purpose commodity servers. The application of NFV results in a significant reduction of the delivery time of new services as well as of the Network's capital and operational expenditures [5].

In this paper, we consider the co-existence of SDN and NFV in a PON-based architecture and efficiently manage both the optical and wireless resources of the converged network. First, the network is being sliced into different logically isolated sub-networks with diverse QoS requirements. Then, the virtualized SDN controller locating in a DC allocates communicational resources to each slice in order to satisfy their service's QoS requirements. As the simulation results illustrate, the utilization of the SDN controller for the management of the converged network results in QoS requirements satisfaction of services offered by each slices to the corresponding User Equipments (UEs). Nevertheless, in the case that we do not supervise the sliced network by using an SDN controller, one or more slices service requirements might not be satisfied.

The remainder of the paper is organized as follows. In Section 2, the considered system model is described. The simulation results are discussed in Section 3, while we conclude the paper in Section 4.

2. SYSTEM MODEL

We consider a converged optical-wireless network fronthaul in which M ONUs, residing at the same places as M RRHs, are connected to a single virtual OLT (vOLT) virtualized inside one of the Data DCs via fiber links, as depicted in Fig. 1. Each PON supports the Wavelength Division Multiplexing (WDM) technique; by utilizing a wavelength router, the vOLT assigns different wavelengths to each ONU/RRH. Indeed, the wavelength router of each PON is the data-plane entity of the legacy OLT and the corresponding vOLT inside the DC is the control-plane part of legacy OLT, which is in charge of managing the wavelength assignment task of the router. In addition, in the wireless domain the available bandwidth of each RRH is denoted as W. Each RRH serves either the connected UEs or small cells supporting a number of UEs. Since we consider an analogue Radio over Fiber (RoF) approach for data transmission trough the fiber links, the same amount W of bandwidth will be available in the optical domain. Therefore, by dividing the available bandwidth W of each wavelength to C channels of the same bandwidth B ($W=C*B$) at the optical domain, these channels will be available at the wireless domain for the support of the uplink direction.

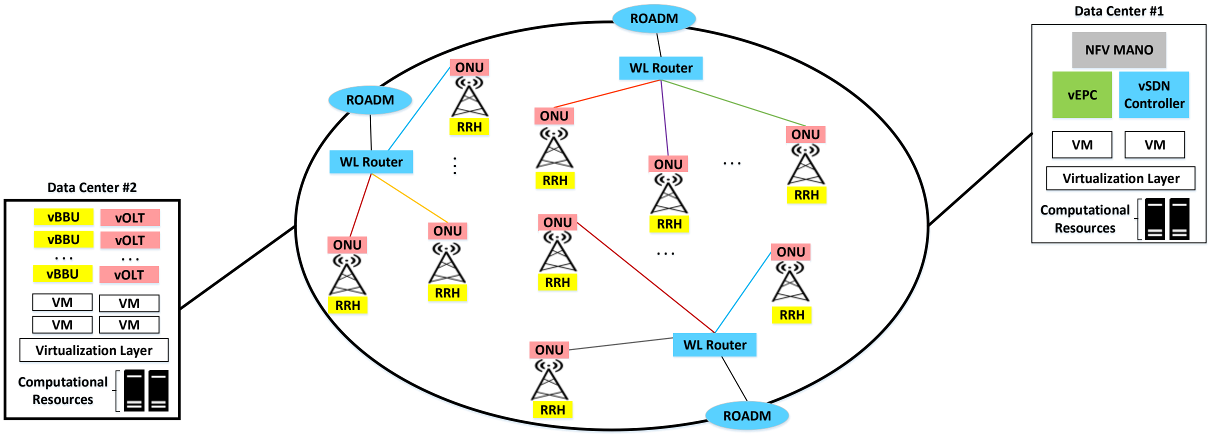

Figure 1. System architecture.

Furthermore, we slice our network into K slices by applying an E2E network slicing from the access network to the Core Network (CN). Every RRH serves a specific number of UEs per slice each generating UL traffic belonging to the corresponding slice. In other words, slice k is dedicated to a set of UEs (U_k) with specific throughput and latency requirements. We assume that the UL traffic generated by each UE follows a Poisson distribution and it is easily proven that the summation of multiple variables with Poisson distribution is considered as a new variable with Poisson distribution. The UL traffic flow of each slice at each RRH follows a Poisson distribution with the arrival rate of $\lambda_{m,k}$, where $m=1,\ldots,M$ presents the number of RRH.

Concerning the NFV part of the architecture, the NFV Infrastructure (NFVI) includes all the physical resources (CPU, memory, and storage) as well as the virtualized resources, which are, in practice, the abstraction of the underlying physical resources realized by the virtualization layer. Moreover, the widely employed Network Functions (NF) include routers, switches, and BBUs, and the network applications such as firewall and load balancing can be virtualized on the top of the physical infrastructure as various VNFs. From the NFV perspective, to form a network service, which is known as a Service Function Chain (SFC), a set of ordered VNFs should be connected together via virtual links. The order, type, and the number of the involved VNFs for each SFC are thoroughly described based on the specific policies.

On the other hand, the SDN controller, which could be defined as a VNF instance (vSDN controller) not only manages the corresponding vOLT for each PON and vBBU for each RRH in the network but also is in charge of flow creation by interconnecting different VNFs (according to the agreed order of the SFC). In addition, it installs the forwarding tables in the forwarding elements such as routers and switches supporting OpenFlow protocol. In order to satisfy the QoS requirements of different services, we consider specific QoS thresholds for each of them. To this end, we set different guaranteed data rate and maximum acceptable E2E delay for each service type offered by each slice. Since the vSDN controller has the real time statistics of all the slices, it will be able to check the thresholds in a real time manner. More specifically, in the case that the threshold of one slice is exceeded, the necessary alterations will be applied to the resources allocation policies by the vSDN controller in order to satisfy all the QoS requirements. In the case that the controller does not have any statistics from the slices for any reason, it allocates the available wavelength channels equally between the slices until it receives the required data to make more efficient decisions.

The NFV Management and Orchestration (MANO) entity in our architecture is responsible for performing all the management and automation tasks related to the NFV part of the system. It comprises three main parts named the Virtualized Infrastructure Manager (VIM), the VNF Manager (VNFM), and the NFV Orchestrator (NFVO). The VIM performs the management of both virtualized and physical resources residing in different DCs. Moreover, it is in charge of hardware virtualization in order to provide services to the UEs on demand. As the next part of the NFV MANO, the VNFMs, by the help of VIM, perform the lifecycle management of VNFs. They are also in charge of VNFs creation, deletion as well as scaling them up or down when is needed. Finally, the NFVO is responsible for orchestrating the SFCs by selecting the appropriate order of various VNFs. In addition, by composing different types of VNFs, it performs the network services' orchestration, which includes creation, deletion, and monitoring the delivered services. The NFVO also acts as the resource orchestrator with the help of the VIM by deploying the required VNFs to guarantee the resource requirement of deployed services.

Furthermore, since the computational resources are limited and the number of requested network services might dynamically change, migrating one or more VNFs from one DC to another one is unavoidable. The migration, which will be handled by the NFVO, will be done in a way that the QoS requirements of the service are satisfied during the process and the resources are efficiently utilized.

3. SIMULATION RESULTS

In this section, we present the simulation parameters and results of the proposed system model and subsequently evaluate its performance in terms of user-experienced average throughput and delay. In order to compare our results with a basic approach, we consider a non-SDN based converged optical-wireless network which is not able to distinguish different QoS classes and consequently does not apply network slicing concept.

The total length of fiber link starting from ONU to the vOLT inside the DC is considered to be d=20 km and the speed of light in the fiber is defined as $C_f=C/n$, where C is the speed of light in the vacuum and n=1.4475 is the refractive index of the fiber. We employ New Radio (NR) operating band n258 with 2.425 GHz and 2.75 GHz as lower and higher band, respectively [3]. Therefore, the total available bandwidth at each RRH will be W=3.25 GHz and by deploying suitable modulation techniques we would have total data rate of R=10 Gbit/s. By considering channel bandwidth B=50 MHz [6], a total of C=65 channels are available for the UL direction.

We perceive a converged network with M=1 RRH supporting maximum 50 active connected UEs/small cells. We also slice the network in K=3 slices. The slice k=1 supporting 15 UEs, needs to support high user experienced data rate of 300 Mbit/s and maximum delay of 10 milliseconds. The second slice (k=2) is assumed to support a large number of UEs with medium amounts of throughputs, then we assume it has 30 active UEs or groups of users (which are connected to the RRH directly or through small cells/lampposts). Each UE in this slice requires 150 Mbit/s of data rate and the 10 ms of delay. Finally, if a UE has a strict latency requirements (one millisecond at most) and maximum data rate of 50 Mbit/s, it belongs to the last slice (k=3) which provides service for 5 UEs. Every single UE belongs to only one slice and the generated UL traffic by each UE/small cell varies from 5 Mbit/s to 400 Mbit/s. At the beginning, the number of channels assigned to each slice is proportional to the corresponding number of UEs of the slice. In all simulation results, dashed lines present non-SDN approach while the solid lines refer to the SDN-based approach.

The effect of SDN-based resource management on experienced data rate and latency of UE in a particular slice with specific QoS requirements is illustrated in Fig. 2. As can be seen in Fig. 2a, by only slicing the network, UEs in slice k=1 have the maximum data rate of around 255 Mbit/s with guaranteed latency below 10 ms, which is less than the slice requirements. The same behavior is also noticed for the slice k=2, where the UE cannot experience neither the maximum delay nor the agreed throughput for this slice Fig. 2b. That is, maximum experienced UE’s throughput with sub 10 ms delay is close to 115 Mbit/s. Concerning the last slice, Fig. 2c, as the number of allocated channels is more than the requirements, the slice thresholds will not be exceeded. Controlling the network using a vSDN controller, results in all slices’ requirements satisfaction. To this end, the controller checks all the thresholds, while the UL traffic load varies, and modifies the number of assigned channels to each slice. As is shown in Fig. 2, SDN improves the performance of the converged network significantly. More specifically, for slice k=1 system reaches 320 Mbit/s data rates with the latency less than 10 ms up to UL load of 365 Mbit/s (110 Mbit/s more compared with non-SDN-based approach). Furthermore, the UE residing in the second slice (k=2) achieves the slice requirements and gains more 60 Mbit/s data rates with the guaranteed latency compared with non-SDN-based case. Nevertheless, as in the non-slicing-non-SDN approach there is not any service type differentiation, the performance of the network for all service types is the same. Fig. 1d illustrates that the maximum supported throughput for all service types is 200 Mbit/s with latency bellow 10 ms, which is not sufficient for some of the UEs and is more than their requirements.

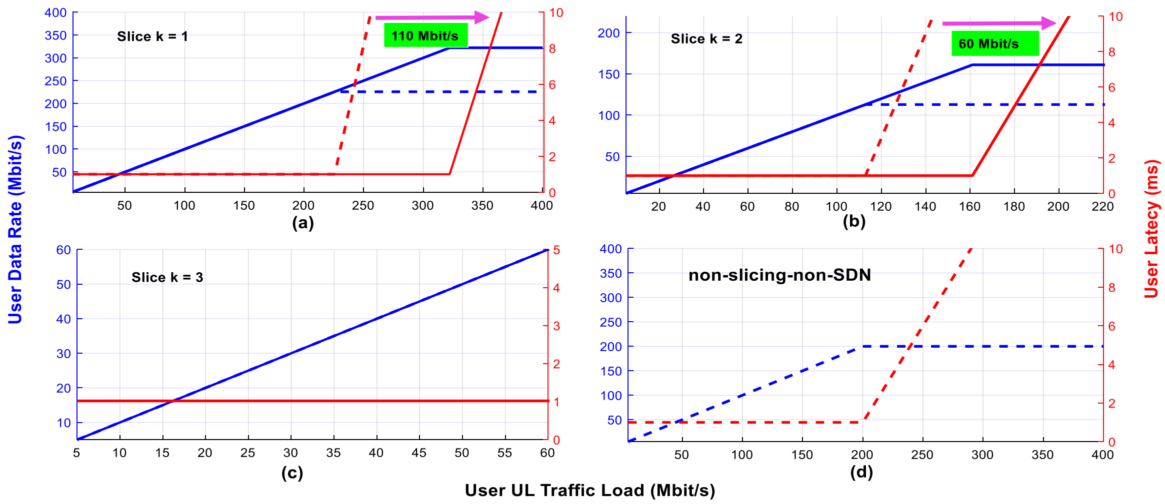

Figure 2. SDN-based vs. non-SDN-based resources management

We also investigate the effect of the number of channels (C) on the performance of the slices. To do this, we consider four different values for the total channels in each wavelength as C= 65, 32, 16, 8, with the equivalent channel bandwidth of B=50, 100, 200, 400 MHz, according to [6]. In the Fig. 3, all the values for the UE's load and the maximum UE's data rate are extracted for the case that the UE's latency is less than 10 ms for slices k=1,2 (Fig. 3a and Fig. 3b, respectively) and less than 1 ms for the slice k=3 (Fig. 3c). As is depicted in the Fig. 3a, for C=8,16 the data rate requirement of the UEs, which receive service by the slice k=1 are not satisfied (the red bars). On the other hand, for these amounts of C, both the data rates and maximum supported load per UE corresponding to the slices k=2 and k=3 are over-satisfied. By making the channel bandwidth more narrow (increasing the total number of channels to C=32, 64), the data rate and maximum supported load for the UE corresponding to the slice k=1 increases and is fully satisfied, while we see the reverse trend for the other two slices while the QoS requirements of all services offered by all the slices are satisfied. Therefore, it can be concluded that the larger the number of channels are, more efficient our SDN-based resource allocation algorithm will be.

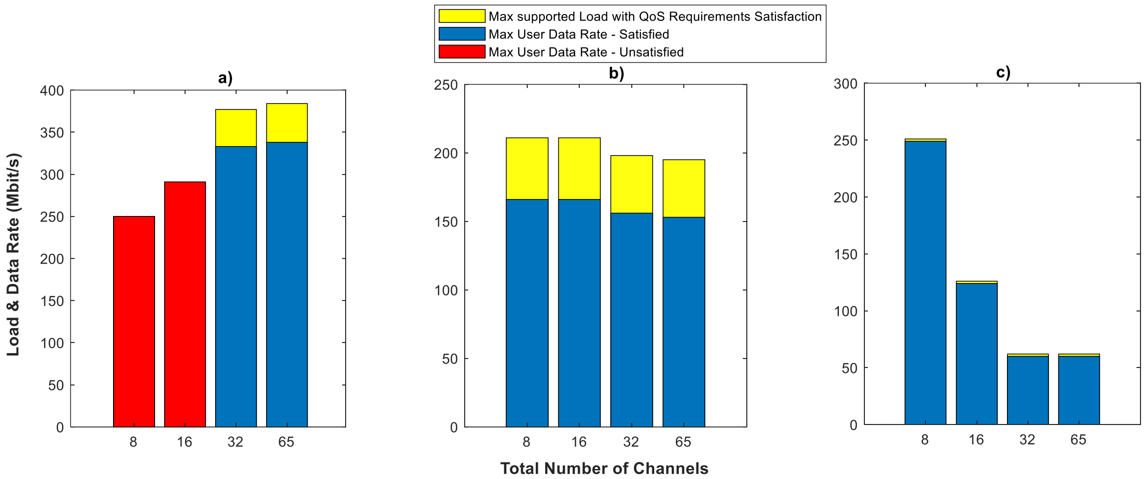

Figure 3. Impact of the total number of channels (C) on the resources management.

4. CONCLUSIONS

In this paper, we propose a novel approach to optimally allocate both optical and wireless resources in a converged network. We first slice the converged network to a specific number of different E2E logically isolated network slices each one dedicated to distinctive types of services with diverse characteristics. Employing SDN, as the simulation results illustrate, the proposed approach fully distinguishes the network slices and assigns efficient number of channels to each slice while the UL traffic loads of each slice changes. It performs the resources allocation by checking slices' thresholds in a real time manner and applies changes to the number of allocated channels to each slice if necessary. We investigated the impact of the channel bandwidth on the resource allocation procedure as well. It is illustrated that we have a more efficient and dynamic resources allocation as B gets smaller and smaller. In the future work, we plan to study a network of PONs, which deploys the TWDM approach to have a more dynamic network slicing scenario. In such networks, we also aim at investigating the case that the computational resources including CPU, memory, and storage are exceeded and one or multiple VNFs need to be migrated to another server residing in a different DC. Since VNF migration being done by the NFVO, imposes an extra delay to the network depending on the size of the corresponding VNF, we aim to mathematically model this delay and analyse the system performance under different conditions.

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