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Cross layer optimization for cloud-based radio over optical fiber networks

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ABSTRACT

To adapt the 5G communication, the cloud radio access network is a paradigm introduced by operators which aggregates all base stations computational resources into a cloud BBU pool. The interaction between RRH and BBU or resource schedule among BBUs in cloud have become more frequent and complex with the development of system scale and user requirement. It can promote the networking demand among RRHs and BBUs, and force to form elastic optical fiber switching and networking. In such network, multiple stratum resources of radio, optical and BBU processing unit have interweaved with each other. In this paper, we propose a novel multiple stratum optimization (MSO) architecture for cloud-based radio over optical fiber networks (C-RoFN) with software defined networking. Additionally, a global evaluation strategy (GES) is introduced in the proposed architecture. MSO can enhance the responsiveness to end-to-end user demands and globally optimize radio frequency, optical spectrum and BBU processing resources effectively to maximize radio coverage. The feasibility and efficiency of the proposed architecture with GES strategy are experimentally verified on OpenFlow-enabled testbed in terms of resource occupation and path provisioning latency.

1. Introduction

Due to the rapid evolution of 5G mobile network, network operators are rethinking the way of their networks controlled to provide the efficient access between resources and users [1,2]. A large number of users or providers are deploying their services in radio access network with lower latency, power consumption and cost. Radio access network is characterized by supporting higher data rates, excellent end-to-end performance and ubiquitous user coverage [3]. To adapt the 5G communication, the cloud radio access network (C-RAN) is a paradigm introduced by operators. C-RAN aggregates all base stations computational resources into a cloud baseband unit (BBU) pool [4,5], while the distributed radio frequency signals from geographically distributed antennas are collected by remote radio head (RRH) and transmitted to the cloud platform through optical transmission system [6]. It aims to reduce capital and operating expenditures (CAPEX and OPEX), realizes the minimum cell sites with maintaining similar coverage and enhance real-time cloud computing while offering better services [7–9]. Recently, the interaction between RRH and BBU or resource schedule among BBUs in cloud (e.g., virtual migration inter-BBU) have become more frequent and complex with the development of system scale and user requirement. It can promote the networking demand among RRHs and BBUs, and force to form elastic optical fiber switching and networking [10–12] due to the characteristics of high bandwidth, low cost and transparent multi-rate traffic transmission. In such network, the multiple stratum resources of radio, optical and BBU processing unit have interweaved with each other. The traditional architecture cannot efficiently enough implement the resource optimization and scheduling for the high-level quality of service (QoS) guarantee [13]. Meanwhile, as a centralized software control architecture, the software defined networking (SDN) enabled by OpenFlow protocol can has gained popularity by supporting programmability of network protocols and functionalities [14–16]. SDN can provide a unified control over various resources for the joint optimization of functions and services with a global view [17–19]. Therefore, it is very important to apply SDN technique to control and optimize the resource assignment in such environment.

The cross stratum optimization (CSO) in data center optical interconnection has been researched with SDN controlling between data center application and optical resources in the previous works [20,21]. Those researches have studied the issue of resource optimization in the data center networking scenario. Based on the preliminary research achievement, this paper extends

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to consider the multiple dimensional resources optimization of radio, optical and BBU processing in the scenario of cloud-based radio over optical fiber networks in 5G age. On the basis of it, in this paper, we propose a novel multiple stratum optimization (MSO) architecture for cloud-based radio over optical fiber networks (C-RoFN) with software defined networking. Additionally, a global evaluation strategy (GES) is introduced in the proposed architecture. In the current C-RAN, the digitalized signal has transmitted in the fronthaul network between RRH and BBU, such as the solution of common public radio interface (CPRI). The digitization can abstract and sample the radio frequency signal and change it into discretized digital signal, while it can promote the radio's capacity of resisting disturbance in the process of transmission. However, the disadvantage of digitization has become more and more clearly here, especially with regard to the development of user requirements and number. Firstly, a mountain of traffic has been aggregated into fronthaul network, while the digitization may cause the larger bandwidth and bring the enormous overhead to optical network. Secondly, the digitized signal transmission needs the deployment of analog–digital conversion in antennas. Since different data compression technologies require different bandwidth, network operators expect to assign a just-right-size spectrum to each data path to improve the spectrum utilization. It causes that the multi-typed multi-standard signals should adopt different encoding and decoding modes, so as to increase the complexity of the system designment. Thirdly, in this scenario, the radio and optical resources have been separated due to the radio signal digitization. They can be controlled in various parts without the centralized control. Aimed at this issue, this paper proposes a cloud-based radio over optical fiber networks architecture with the elastic optical networking under the unified SDN orchestration. The advancement of the proposed solution is threefold. Firstly, the analog signal in the proposed architecture can reduce the fronthaul bandwidth caused by digitization, while keeping the original undistorted information to receiver, especially for the accurate clock synchronization. Secondly, since flexi-grid optical network is used to connect RRH and BBU, the multi-rate or multi-typed traffic can be carried with elastic spectrum switching capability through transparent transmission. Also, the additional processing time caused by digitization will be avoided to meet the delay requirement under millisecond in 5G. Thirdly, due to the same physical essence in electromagnetic wave theory, the radio and optical spectrum can be centralized controlled and scheduled with SDN orchestration in a unified manner to enhance the responsiveness to end-to-end user demands. It globally optimizes radio frequency, optical spectrum and BBU processing resources effectively to realize the multiple stratum resources optimization, maximize radio coverage and meet the QoS requirement with vertical integration and horizontal merging. The overall feasibility and efficiency of the proposed architecture with GES are experimentally verified on SDN-enabled testbed [21] in terms of resource occupation rate and path provisioning latency.

The rest of this paper is organized as follows. In Section 2, we propose the novel MSO architecture in C-RoFN and builds functional models. The global evaluation strategy under this architecture is introduced in Section 3. We describe the experimental environment and present the experimental results and analyzed in Section 4. Finally, we conclude the paper and give the future work suggestion in Section 5.

2. MSO in software defined cloud-based radio over optical fiber networks

The use of SDN enabled by OpenFlow protocol has been widely studied in terms of packet-switched and circuit-switched networks, especially including the optical networks employing packet, fixed and flexible grid technologies in the metro and backbone networks [22–25]. The multiple stratum optimization (MSO) architecture for software defined cloud-based radio over optical fiber networks (C-RoFN) can implement the multiple layer integration and cross stratum optimization based on OpenFlow-enabled C-RoFN with SDN orchestration. MSO can allocate and optimize the radio, optical network and BBU resources efficiently in a control manner of open system. In this section, the main core of the novel architecture are briefly pointed out. After that, the functional building blocks of MSO and coupling relationship between them are presented in detail.

The MSO architecture in software defined C-RoFN is illustrated in Fig. 1. The elastic optical network (EON) is used to interconnect the cloud BBUs, which are deployed network and processing (e.g., computing and storage) stratum resources respectively. The distributed RRHs are interconnected and converged into EON, which allocates the customized spectrum with finer granularity for radio signals. Note that, the C-RoFN consists of three stratums: radio resource, optical spectrum resource, and BBU processing resource. The networking mode for multiple stratum optimization extends in two directions. One is from the perspective of resource form. Optical and computing resources are interconnected cross optical network and BBU stratums along the east–west direction. It leads to the interconnection and networking of heterogeneous resources cross stratums in latitudinal direction, which is established as "heterogeneous-cross-stratum". The other is from the perspective of carrying capacity. The related entity with small granularity of switching can be abstracted as the high-layer network (e.g., radio network), while the related entity with large granularity of switching should be abstracted into the low-layer network (e.g., EON). The interconnection and networking of multiple layers are established along longitudinal direction, which is called "multi-layer". Based on the above-mentioned networking mode, three MSO applications in this architecture are formed, i.e., the interaction between RRHs (e.g., collaborative radio), the service from RRH to BBU and resource schedule among BBUs (e.g., virtual resource migration inter-BBU), which are marked in green circles of Fig. 1. The logical relationship among the networking modes and application scenarios for C-RoFN is shown in Fig. 1.

The difference between CSO and current work is threefold. Firstly, the application scenarios of them are different. The CSO researches the service accommodation in the scenario of data cen-

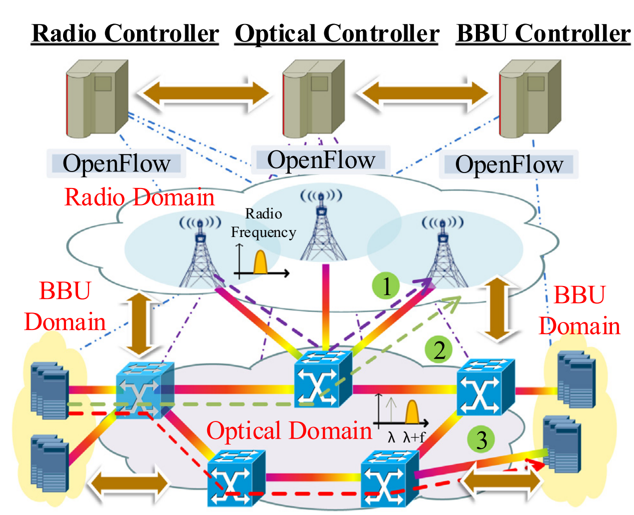

Fig. 1. The architecture of OpenFlow-based software defined elastic optical network.