EXPERIMENTAL DEMONSTRATION OF ADVANCED SERVICE MANAGEMENT IN SDN/NFV FRONTHAUL NETWORKS DEPLOYING ARoF AND PoF

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Abstract

We demonstrate two advanced services deployed in a novel SDN/NFV optical fronthaul network combining analog radio over fiber (ARoF) and power over fiber (PoF); vertical service management for virtual content delivery networks (vCDNs), and user mobility and remote optical power management for femto cells

1 Introduction

Current fronthaul transport networks are based on point-to-point optical/WDM links between the radio cells and the central office (CO) using digital radio over fiber (DRoF) transceivers [1]. In this paper we consider the novel optical fronthaul architecture shown in Fig.1 [2]. It deploys a passive optical distribution network (ODN) based on space division multiplexing (SDM) for further increasing the network capacity [3]. It makes use of the already deployed bundles of single mode fibers (SMF) or multi-core fibers (MCF). Analog radio over fiber (ARoF) transceivers are used between analog BBUs and RRHs instead of DRoF transceivers to reduce the bandwidth and latency requirements. ARoF transceivers in combination with SDM enable to directly modulate the radio waveforms onto light and transmit them in parallel over different spectral frequencies and spatial cores. Another novelty introduced is the transmission of optical power through the fiber. Although power over fiber (PoF) is at a very early development stage, the interest of this technology for 5G is big, given the high costs of deployment of base stations in areas where no power supply is easily available to feed femto cells [4]. It would enable to remotely sleep/awake the base station based on the user occupancy. Finally, the CO also deploys edge computing for virtual network funcitons (VNF) or mobile edge computing (MEC) applications.

This novel optical fronthaul architecture brings many innovations in the SDN/NFV management and orchestration (MANO) layer that need to be faced [5]:

- ARoF transceivers must be integrated in the SDN controller in order to provision optical transport connections
- The analog RRHs and BBUs must be managed as physical network functions (PNF) and integrated with the NFV orchestrator in order to provide NFV network services.
- A network slice manager (NSM) must be deployed on top of the NFV orchestrator to deploy network slices for vertical services
- PoF devices need to be managed and integrated with the user mobility manager to enable the optimization of the femto cells management based on the user occupancy.

This paper presents, first, the innovations of the target SDN/NFV fronthaul test scenario, and second, two use cases that will be experimentally demonstrated, the vertical service for virtual content delivery network (vCDN), and the user mobility and remote power management for femto cells.
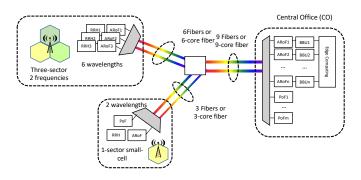

Fig. 1. Proposed optical fronthaul architecture

2   Experimental SDN/NFV fronthaul test scenario

This scenario implements a full NFV/SDN MANO layer as shown in Fig.2. It integrates an NFV service platform for the management of network services and network slices for verticals, a transport SDN controller operating the novel optical fronthal network, an edge computing controller allocating computing and storage resources in the CO, and the user mobility and power manager to sleep or awake the base stations based on the user occupancy.
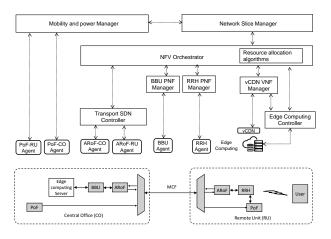

Fig. 2. SDN/NFV fronthaul test scenario

The NFV service platfom is composed of an NFV orchestrator (NFVO), dedicated virtual network function manager (VNFM) and physical network function (PNF) managers (PNFMs), and a network slice manger for vertical services. The NFVO manages the overall life cycle of the network services (NSs). Its prototype implements an internal information model and external REST APIs compliant with the ETSI NFV IFA specification and provides enhanced features for the management of PNFs and the automated setup of optical paths, deployed through the transport SDN controller. The Edge computing controller, based on OpenStack, acts as virtual infrastructure manager (VIM), allocating virtual machines (VMs) and virtual networks at the CO. The NFVO coordinates the configuration of both VNFs and PNFs through the VNFM and PNFM. The interaction with PNF equipment like RRHs and BBUs is mediated through the associated PNF Agents, which translate standard messages from the PNFM into hardware-specific protocol messages.

The control of the optical fronthaul network is delegated to the transport SDN controller, but still under the global coordination of the NFVO. This approach requires additional logic in the NFVO resource allocation algorithms to jointly perform the optical path computation, including the parameters of the transponders. The communication between the NFVO and the transport SDN controller is based on the transport API (TAPI) specification, with extensions to deal with the specific optical technologies of the fronthaul network experimentally validated

in [6]. The transport SDN controller is responsible for configuring and monitoring all network elements in order to manage the overall life cycle of the connectivity services (CSs). The transport SDN controller is extended with a dedicated transponder manager to interact with the ARoF transceivers (both at the CO and RU) through dedicated agents using a REST API [7]. The ARoF agents are responsible to map the high-level operations in the REST API coming from the SDN controller into low-level, hardware-dependent operations.

The NFV service platform is extended with a network slice manager (NSM) to improve the efficiency in the utilization of fronthaul resources by enabling the delivery of multi-tenant virtual environments. It is deployed as a client of the NFVO and it is responsible for the life cycle management of the network slice instances. It translates the vertical requirements into a suitable NFV network service with the required QoS which is instantiated and terminated at the NFVO. A client of the NSM is the mobility and power manager. On the one hand, it is responsible for the life cycle management of the optical power channels between the CO and the RU, and on the other, it implements user mobility logic, such as decisions about activation and deactivation of femtocells based on the users' location, coordinating this with the vertical service instantiation procedures. This PoF system is controlled by the PoF Agents that interacts with the mobility and power manager using a REST API.

3   Demonstration of Use cases

Two use cases cases will be experimentally demonstrated, a vertical service of a virtual CDN, and user mobility and remote power management for femto cells.

3.1 Vertical service management for virtual CDN

In Fig.3 we show the service provisioning workflow for a virtual CDN service [8]. As described in the picture, the workflow starts when the mobility and power manager requests the instantiation of the vertical service (VS) to the NSM. This request contains the virtual CDN service high-level parameters (i.e., the number of users to be supported) and further instance specific details (e.g., geographical location, SLAs, etc.). The NSM generates and returns an ID for the vertical service instance. Internally, it proceeds with the translation of the VS description into a set of network slices and NFV network services (NS) needed to run the required CDN. In this phase, the NSM elaborates the possible sharing of existing network slices and the deployment flavors and instantiation levels for the new NSs. Such services are then requested to the NFVO through a NS instantiation request.

The NFVO, through the resource allocation algorithms, determines the infrastructure resources where the VNFs of the CDN caches will be placed and selects the PNFs to be used in the service. In particular, these algorithms determine (i) the target BBUs and RRHs (both PNFs for the scope of the demo) with their configuration parameters (e.g., operation mode, subcarriers, modulation schemes and frequency); (ii) the

computing and network resources required for the VNFs and the virtual links, and (iii) the ARoF transceivers parameters' configuration. Starting from these outputs, the NFV manager instantiates the VNFs and the virtual networks interacting with the OpenStack-based VIM. As additional steps, specific for the proposed architecture, the NFV Service Platform also drives the configuration of the BBU and RRH PNFs and creates transport connections in the fronthaul segment.

The PNF configuration is handled through the PNFM, which interacts with the PNF Agents. For the configuration of the SDM/WDM enabled fronthaul, the NFVO interacts with the transport SDN controller using the TAPI interface. Such approach allows to abstract the network configuration complexity from the orchestrator perspective, handling all the SDM/WDM technology details within the transport SDN controller. In fact, as shown in Fig.3, the NFV service platform selects only the TAPI service interface points (SIPs) and the high-level path resources to carry the CDN traffic flows, while the enforcement of network connectivity is fully handled at the transport SDN controller level, including the configuration of the ARoF transceivers at the CO and RU.

3.2 User mobility and remote power management

The second use case demonstrated is user mobility and power management of remotely fed femto cell RRHs. User mobility is modelled by the mobility manager (top-left box on Fig.2). This entity models both the movement of user equipment (UE) through a 5G radio access network and its observable behaviour regarding cell binding, handovers, radio resource allocation and data packet transfer of that UE. This 5G signalling process is abstracted within the mobility manager but in reality it is carried out by several 5G entities: the UE, the gNBs (5G
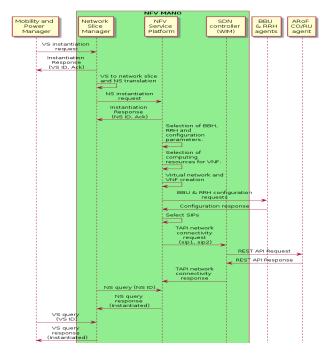

Fig. 3. NFV-MANO/SDN workflow for service provisioning

base stations), the mobility management entity (MME) and the 5G core (5GC). In our use case, we focus on the NFV/SDN-based provisioning of vertical services and powering resources implied by handovers to cells with the sleep/awake capability envisioned for 5G. To this end, user mobility is enhanced with a novel remote power management extension. Thus, whereas the mobility manager denotes what base station to sleep or awake, the power manager is in charge of deciding which cells need to be remotely powered by PoF at any given time, not just those with users. The concrete target simulated scenario is the phantom cell scenario with PoF pooling [4]. In this scenario, the geographical area is covered by a set of macro-cells, which are complemented with a set of low power millimeter-wave femto cells (a.k.a. phantom cells) equipped with batteries that are awakened and powered when the UE enters the cell. Under PoF pooling, a pool of high-power laser diodes (HPLDs) is shared by a large number of femto cells and the power manager tries to keep all their batteries at full charge.

In the demonstration, the following steps take place: (1) a user enters a phantom femto cell and the source gNB (the macro cell base station) issues a handover request ; (2) then the visited phantom cell is started by its owner macro cell; this is modelled by: (2.1) the mobility manager requests a vertical service for the phantom cell by calling the network slice manager (this implicitly launches the ARoF system for the cell); and (2.2) the power manager, which is subscribed to mobility manager events, starts a PoF session to feed the phantom cell (provided that this is the most suitable allocation for one of the HPLDs); this is done by: (2.2.1) selecting and configuring a HPLD by calling the CO-PoF Agent, (2.2.2) selecting and configuring a photovoltaic converter (PVC) by calling the RU-PoF Agent and, if HPLD and PVC are not statically attached, by (2.2.3) issuing a request to the SDN network controller to request a power fiber core to be switched between the HPLD and the PVC. (3) once the RoF session is started, the handover takes place and the UE makes use of the phantom cell; (4) the power manager polls periodically the PoF agents to supervise phantom cell battery status, temperature, output voltage, etc. (5) the UE leaves the cell and the resources are released. The demonstration includes a 2D graphical representation of UEs moving in an area covered by the CO with a number of macro and phantom cells.

4 Conclusions

This paper has provided a description of the implemented SDN/NFV MANO layer developed to control and orchestrate the resources and services of the novel optical 5G fronthaul network. A vertical service based on virtual CDN and remote optical power management to sleep/awake the femtocells based on the users' location have been presented.

5 Acknowledgements

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