Experimental Demonstration of A-RoF SDN for Radio Access Sharing Applications

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Abstract: We experimentally assess a radio access A-RoF mobile interface with carrier-aggregated data-plane and intermediate frequency transposed Ethernet control-plane. We also demonstrate software-based management of two classes of services associated to different PHY layer parameters.

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1. Introduction

Optical fibers became a key-element for high-bit rate connectivity of mobile sites, especially with the imminent arrival of 5G. The optical last-mile connecting the antenna sites is predominantly used nowadays to transport the mobile backhaul interface in distributed radio access networks (D-RAN). Other topologies even more dependent of fiber connectivity have been explored in the last decade promoted by the advantages brought by the centralization of RAN processing (C-RAN) [1]. However, the severe bit-rate and latency constraints of a fully centralized fronthaul would make the burden of 5G C-RAN just too onerous to be bared by the optical access.

Today, a consensus seems to have been reached on the new possible functional splits of the mobile protocol stack allowing thus for the best compromise between centralization benefits and bit-rate/latency constraints imposed to the fiber networks. Besides the backhaul, high and low layer functional splits (HLS and LLS respectively) of the mobile stack have been defined. Those allow a separation of the RAN equipment into a central unit (CU), with layer 3 and higher layer 2 functionalities, a distributed unit (DU) with lower layer 2 and higher layer 1 and finally a radio unit (RU), with lower layer 1 (inset of Fig. 1). Whereas the 3GPP has started the standardization of the F1 HLS interface [2] between the CU and DU, the vendor-specific evolved common public radio interface (eCPRI) [3] could impose itself as the de-facto low-layer fronthaul interface (Fx) connecting the DU to the RU.

The consequence of such plurality of interfaces is that the last-mile segment could have to deal with different network constraints in the light of 5G. Moreover, even within a single interface, 5G is supposed to carry a large variety of services with very heterogeneous needs in terms of bit-rate, reliability, number of connected devices and latency not only for standard enhanced mobile broadband (eMBB) applications but also for new usages in ultra reliable low-latency communications (URLLC) and massive machine-type communications (mMTC).

Here, we experimentally assess a software based control approach that allows precisely the creation of different classes of services (CoS) for the access connectivity system shown in Fig. 1. In a nutshell, the hatched orange blocks in Fig. 1 allow connectivity sharing for different clients in fiber-poor zones by means of a complementary millimeter-wave (mmW) segment on top of a fiber link. The ”clients” are either operators with different RAN interfaces/functional splits (”ETH*” in Fig. 1 implies high bit-rate and latency needs) or even different services within the same interface. In the downlink, a Master Flexbox converts Ethernet packets (backhaul, HLS, LLS) of the clients (blue and green blocks) to an analog radio over fiber (A-RoF) link connecting it to a massive mmW multiple-input multiple-output (mMIMO) antenna. This distributed antenna system (DAS) A-RoF interface allows

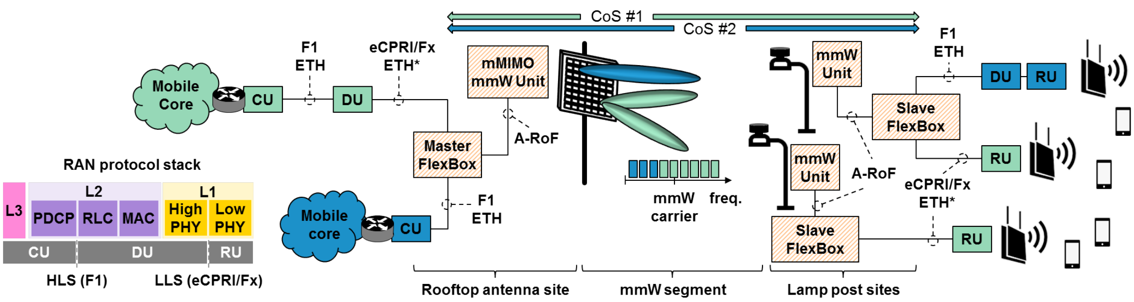


Fig. 1: Fiber-wireless (Fi-Wi) RAN architecture.

the use of power-efficient active phased array mMIMO antennas, where beam forming/steering is performed with electrical [4] or optical [5] phase shifters. After the mmW link, a lamp post unit recovers the signals and a Slave Flexbox converts them back to the original Ethernet interfaces, which are fed to the remaining client equipment.

Thanks to a software based abstraction of the shared underlying fiber-wireless (Fi-Wi) network, different CoS (arrows in Fig. 1) can be created by managing physical layer (PHY) parameters of the link. Here, we manage bandwidths, frequencies, modulation formats and powers of a carrier-aggregated (CA) orthogonal frequency division multiplexed (OFDM) signal. We demonstrate the use of a software defined network (SDN) controller that provides adaptation between the southbound application programming interface (API) of the different Flexboxes and a RESTCONF [6] northbound API. On top of the SDN controller, we build a RESTCONF management function where the CoS are defined. Last but not least, the control plane interface used for all SDN operations is transported inside our A-RoF link by a real-time intermediate frequency (IF) transposed Ethernet signal.

2. Experimental Setup

2.1. Hardware

Fig. 2a shows the hardware details of our experimental setup, where the light and dark orange blocks correspond to the data and control planes (DP and CP) respectively. Here, we concentrate on the downlink A-RoF link (please refer to [4] for a mmW segment report). The DP is associated to two real-time OFDM generators/analysers. The first corresponds to a ”High Quality” (HQ) CoS, where the bit-rate of the client is optimized. This is done by placing a 5×20 MHz carrier-aggregated OFDM signal with 64QAM Physical Downlink Shared Channel (PDSCH) at the best frequency response zone of the channel. The second corresponds to a ”Best-effort” (BE) CoS, with a single OFDM band whose modulation, bandwidth, RF power and IF vary according to the availability of the channel and the rules defined by the Fi-Wi manager. The DP is transposed to IF digitally.

The CP used to connect to the signal generators/analysers through the A-RoF link runs real-time between two single-board computers at 10 Mb/s. Auto-negotiation is disabled and medium-dependent interface crossover is set to allow the choice of a specific twisted pair that serves the Ethernet-SMA converters. The CP is frequency transposed electrically using local oscillators (LO), RF mixers and low-pass filters (LPF). Since only the TX+ component of the Ethernet interface is transmitted, an inverter is used at the receiver side. Also, the uplink CP transmission is bypassed with a direct connection. Both DP and CP signals are combined (insets of Fig. 2a) and electrically amplified (EA) before direct intensity modulation of a laser diode (LD) at 1310 nm. Transmission is performed through 1 km of standard single-mode fiber (SSMF) to show-case a local A-RoF interface at the mMIMO antenna site. After direct detection by a photodiode (PD), the signals are amplified and separated for processing.

2.2. Software

Fig. 2b details our SDN controller and RESTCONF client. From the bottom to the top, interfacing with the Flexboxes (southbound interface - SBI) is performed through Standard Commands for Programmable Instruments (SCPI) over TCP/IP. A first control layer hosts all SCPI functions needed to change the PHY parameters of the link. Those are set as the leaves of the YANG model of the Flexboxes. A model-driven service abstraction layer (MD-SAL) provides adaptation between the southbound API and the northbound interface (NBI) of the controller using data structures. This allows configuration of the Flexboxes with uniform resource locators (URL) without any knowledge of the SCPI functions. The server functions of the SDN controller are implemented with Flask.

On top of the controller, a look-up-table defines the PHY layer parameters associated to the HQ and BE CoS and a RESTCONF client performs the needed PUSH/PUT/GET/DELETE operations for configuring the underlying A-RoF link. Finally, a create, read, update and delete (CRUD) web frontend allows the Fi-Wi manager to choose the CoS according to the client profile and displays key-performance indicators such as error-vector magnitude (EVM) and bit-rate.

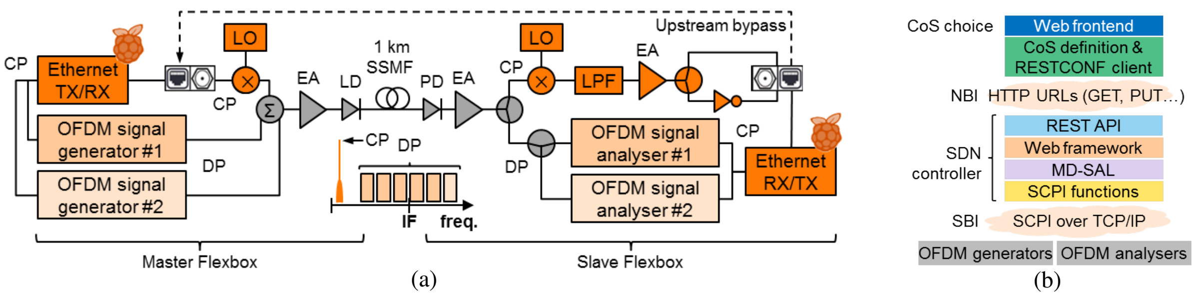
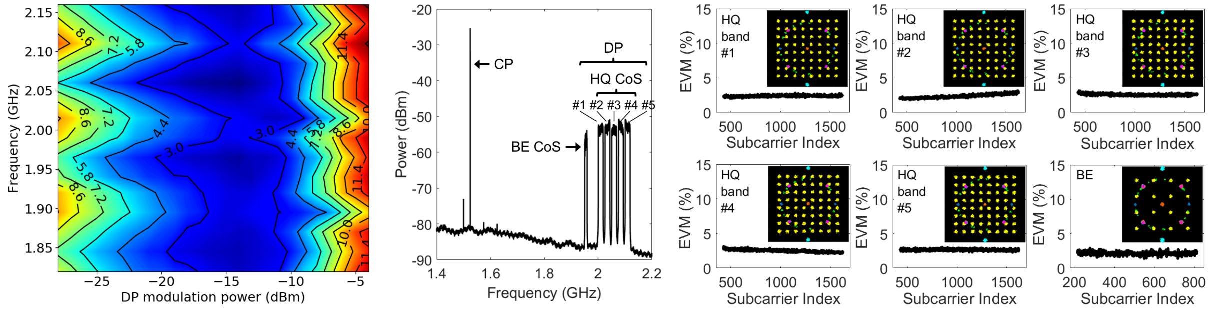


Fig. 2: (a) Hardware and (b) software details of the proposed experimental setup.



(a) (b) (c)

Fig. 3: (a) DP EVM (%) map. (b) A-RoF spectrum. (c) EVM (%) vs subcarrier & constellations (HP and BE CoS).

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PUT/restconf/data/AROF:test_bench/MASTERFB_HQ?rf_power=-11&bw
=20&bands=5&mod=64QAM&ifreq=2.06E9&offsets_dB=0,-1,-4,-1,2
PUT/restconf/data/AROF:test_bench/SLAVEFB_HQ?bw=20&bands=5&mod=
64QAM&ifreq=2.06E9
```

"SLAVE_FLEXBOX_HQ": {"bw": "20MHz", "evm_PDSCH":
"[1]:2.50%,[2]:2.35%, [3]:2.46%, [4]:2.37%, [5]:2.10%",
"ifreq": "2.06GHz", "ip": "192.168.4.2", "bands": "5",
"offsets_dB": "0,-1,-4,-1,2", "mod": "64QAM"}

(a) (b)

Fig. 4: (a) Inputs to SDN controller for HQ CoS configuration. (b) Example of structured data of OFDM analyser.

3. Results and Discussions

Fig. 3a shows the mean EVM (%) over all subcarriers of the received DP after propagation through 1 km SSMF and for different frequencies and RF powers. The optical power at the PD is fixed at -6 dBm. Performance degradation for modulating powers above -10 dBm are due to the non-linear operation of the laser. In its linear modulation regime, the channel presents an undulating EVM characteristic which is due to the frequency response of the electrical amplifiers. The EVM map of Fig. 3a is used for setting up the PHY parameters associated to each CoS.

Our engineering rules are as follows. The HQ CoS is prioritised and takes the 2.06 GHz IF, where the EVM is the lowest. The BE CoS is placed at the next best performance frequency span not overlapping with the HQ CoS bands, i.e., 1.95 GHz. If there is no HQ CoS in the link, the BE CoS takes the 2.06 GHz IF. If both HQ and BE are transmitted, their power densities are set respectively to 0.9 and 0.2 μW/MHz to ensure that the 5 $\times$ 20 MHz bands of the HQ CoS have a higher contribution to the overall modulating power of the laser than the single 10 MHz band of the BE CoS. This allows an optimal overall RF power after the electrical coupler of -15 dBm.

Figs. 3b and 3c show respectively the received A-RoF spectrum (CP and DP) and EVM vs subcarrier variation when both HQ and BE CoS are transmitted. EVM is below 3.2% for all bands. Notice from the insets of Fig. 3c that the BE PDSCH modulation was set to 16QAM by the network manager to allow an EVM below 3%.

Finally, Figs. 4a and 4b show respectively the input messages at the SDN controller for the HQ CoS set-up and the data structure of the associated OFDM analyser. An iperf evaluation of the CP (not shown for concision sake) shows datagram-loss free transmissions with 8 μs and 30 μs mean and maximum packet jitter respectively.

4. Conclusions

We have experimentally assessed a SDN controller enabling complete abstraction of a carrier-aggregated OFDM A-RoF link through a RESTCONF API. On top of the controller, two classes of services were defined associated to different PHY layer parameters such as frequency, modulation, RF power and number of transmitted bands. With the proposed setup, real-time transmission of both data plane OFDM signals and control plane southband API interface through the a fiber link has been demonstrated enabling EVMs below 3.2% for HQ and BE CoS.

Acknowledgements

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