Real Time Demonstration of Fronthaul Transport over a Mix of Analog & Digital RoF

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ABSTRACT
A real-time transport of fronthaul over a mix of analog and digital RoF is experimentally investigated. The obtained results show that up to 24 LTE channels can be transported with respect to the 3GPP requirements concerning EVM.
Keywords: Fronthaul, Analog RoF, Digital RoF, LTE, EVM

INTRODUCTION
In the coming years, a massive growth of data traffic is expected in the mobile networks due the ever-increasing number of smart devices and bandwidth-hungry services. In order to cope with this, the first studies on the next generation of mobile networks identified the Cloud Radio Access Network (C-RAN) as a key enabler [1] [2]. It proposes to centralize the Base Band Units (BBUs) where all the processing is performed thanks to a new network segment called fronthaul. The latter links the BBU hotel to the antenna sites where the Remote Radio Heads (RRHs) are located. Also, it uses a Digital Radio over Fiber (D-RoF) interface e.g the Common Public Radio Interface (CPRI) [3]. The digitization of the radio signal in the CPRI is based on a quantization with 15 bits which generates high bit rates in the fronthaul. For instance, a LTE downlink signal with 20 MHz bandwidth and 2x2 Multiple Input Multiple Output (MIMO) corresponding to 150 Mb/s is transported at 2.5 Gb/s in the fronthaul link. Moreover, each antenna site contains multiple radio technologies in multiple radio carriers which lead to very high bit rates to be transported in the fronthaul. Therefore, Wavelength Division Multiplexing (WDM) was an optimal candidate solution for fronthaul transport. Although, with the evolutions of the radio technologies and the network densification expected in 5G, WDM is starting to show limitations mainly because of the low spectral efficiency of the CPRI interface. Analog RoF (A-RoF) was then identified among the solutions to this matter [4] [5] [6] [7]. In fact, A-RoF has been of research interest for over 25 years and conducted to commercial solutions deployed mainly indoors (stadiums, subway stations…) known as Distributed Antenna Systems (DAS) [8].
Fig. 1 shows the different architectures for DAS deployment. On the left, the most common scenario is depicted where the radio signals from different operators are combined then converted to the optical domain before transmission over fiber. At the reception, after optical to electrical conversion, one antenna is used for all operators. *Fig. 1.b* depicts the emerging scenario where WDM is used which is relevant. Nevertheless, specific devices need to be deployed in the buildings (WDM multiplexor, Optical Add Drops, colored transceivers).*Fig. 1.c* shows the architecture that we propose. Analog to Digital (A/D) RoF converters are used to convert the CPRI to an analog signal and to aggregate multiple CPRIs coming from different central offices (different operators). This will allow to leverage the existing DAS infrastructures and to use CPRI compatible BBUs, for an A-RoF transmission permitting a bandwidth efficient fronthaul. It will also permit to each operator to deploy its RRHs to benefit from the interference mitigation brought by the beamforming features of the RRHs.

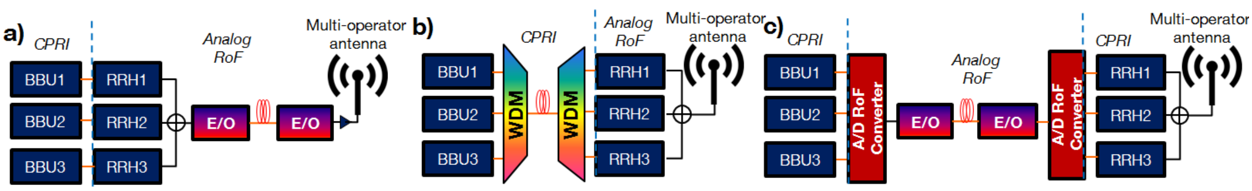

Fig. 1: Distributed Antenna System architectures

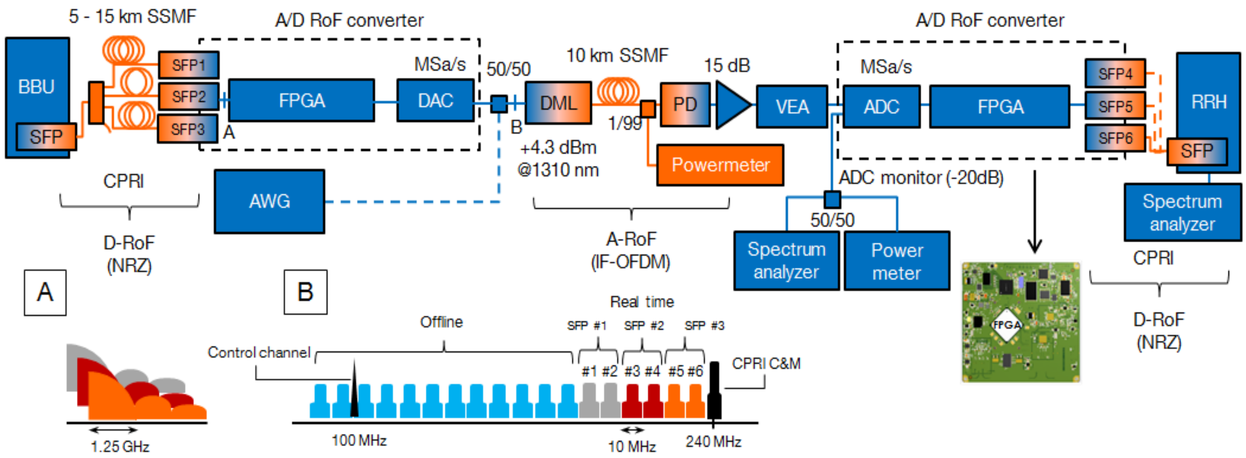

Fig. 2: Experimental setup

In this paper, we experimentally investigate in real time a hybrid architecture where A-RoF and D-RoF are used. Performance measurements are carried out with lab test equipment and commercial RAN equipment to evaluate the aggregation capacity in the analog domain. The performed experimental setup is described in section 2 and the obtained results are discussed in section 3.

2. EXPERIMENTAL SETUP

Fig. 2 shows the experimental setup carried out to evaluate in real time the performance of the proposed solution. A BBU test equipment is used for the generation of a CPRI signal corresponding to a 10 MHz LTE with 2x2MIMO. An optical splitter allows replicating this signal before transmission over different lengths (5, 10 and 15 km) of standard single mode optical fiber (SSMF). We used off-the-shelf Small Form-factor Pluggables (SFPs) for the D-RoF transmissions. A Field-Programmable Gate Array (FPGA) based card is used for D-ROF to A-ROF conversion. In fact, after the reception of each CPRI link, the Control and Management (C&M) data and the IQs are separated. The C&M data is M-QAM modulated and transmitted via a dedicated channel at 240 MHz. The IQs are transformed close to their original form (Orthogonal Frequency Division Multiplexing, OFDM) before aggregation with the IQs of the other channels using Frequency Division Multiplexing (FDM) [9]. An additional low bit-rate control channel for the A-RoF transmission is transported at 100 MHz.

In our setup, we have six real-time signals (two bands per SFP) and twelve overloading signals generated with an arbitrary waveform generator (AWG). Those are conveniently pre-distorted and adjusted in order to remove the influence of the AWG frequency response and to provide the same power levels as the real-time signals. The bands are separated by 500 kHz and the whole A-RoF spectrum (C&M channels included) occupies less than 200 MHz, as shown by the inset of *Fig. 2*.

The RF power of the A-RoF signal generated by the Head-End DAC is properly set to avoid nonlinear operation of the laser. The signal modulates a 1310 nm DML (Directly Modulated Laser) emitting at 4 dBm. After propagation through 10 km of SSMF, it is directly detected by an APD photodiode. A 15 dB electrical amplifier followed by a variable electrical attenuator (VEA) is used to set the optimum power at the input of the ADC at the remote site. The electrical analog signal is finally converted back to CPRI before being fed to an LTE analyzer for performance measurements. The study was done with lab test equipment (BBU and RRH emulators) and commercial RAN equipment.

3. EXPERIMENTAL RESULTS

The great advantage of an A-RoF transmission compared to D-RoF lies in its increased spectral efficiency. An a-priori analysis would give us a ~60 fold increase on the number of signals that could be A-RoF transmitted taking the bandwidth of one single D-RoF signal as reference. For instance, if we consider a 10 MHz downlink LTE single-input single-output (SISO) signal, we would need an optical transmitter with at least 614.4 MHz bandwidth to accommodate CPRI 1 data. Up to 58 frequency-transposed LTE signals could be transmitted in their native modulation format within the same bandwidth considering 500 kHz spacing between them. However, this value remains theoretical

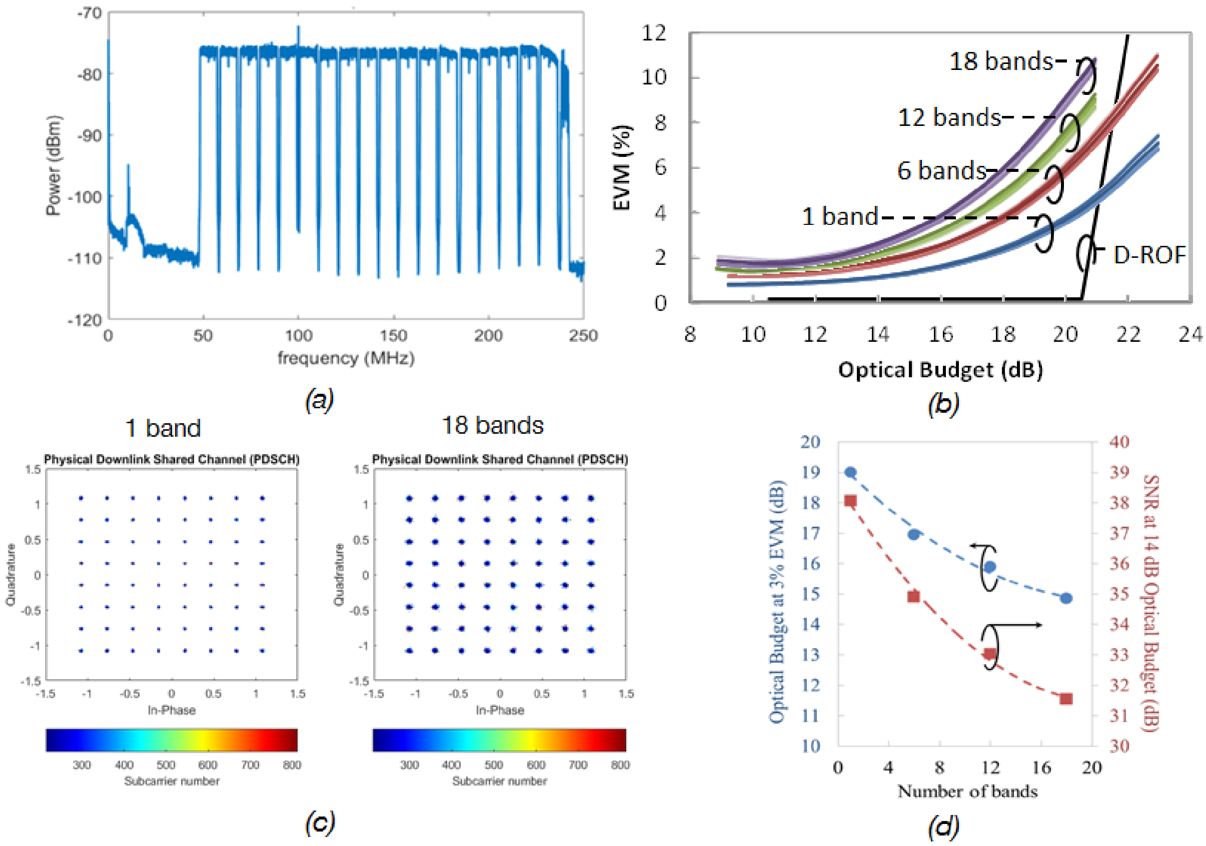

Fig. 3: (a) Received A-RoF spectrum. (b) EVM performances with received optical power. (c) Constellation diagram for 1 band and 18 bands transmission. (d) SNR and optical budget variation with the number of transmitted bands.

and unlikely relevant. This is because an actual A-RoF transmission is subjected to the power constraints on both electronic (DAC, amplifiers) and optical devices (laser) of the transmission chain. The SNR is inversely proportional to the number of bands (i.e., the overall signal bandwidth). This can be clearly seen in *Fig. 3*.b, which shows the EVM variation of the six real-time signals for different number of transmitted bands in the A-RoF link. The measurement was done at the output of the RRH test equipment. A D-RoF measurement is also shown in *Fig. 3.b* for reference. For the 1 band scenario, EVM was measured alternately on each band. The received spectrum measured at the monitor port of the ADC, with 18 bands, is shown in *Fig. 3.a*. In order to avoid degradation induced by nonlinear conversions on the laser while guaranteeing optimized modulation conditions, the amplitude of the signal is carefully set each time the number of transmitted bands is changed. Also, the offline signal generation is set to a maximum of 6 bands per AWG channel in order to enable proper power leveling with real-time bands. EVM penalties seen in *Fig. 3.b* when we increase the number of bands come thus exclusively from the RF power constraint of the DML.

Let us consider a target EVM of 3%, this gives us a 5% margin to accommodate extra penalties arriving from electrical amplification of a real RU with respect to the maximum value defined by 3GPP for 64QAM [10]. While one single band can be transmitted with received optical powers as low as -14.6 dBm, extra 4.2 dB would be needed to keep the same performances with 18 bands. This would correspond to decreasing the maximum possible fibre length from ~47 km (0.4 dB/km at 1310 nm) with 1 band to ~36 km with 18 bands. *Fig. 3.d* shows the optical budget penalty as a function of the number of bands for a fixed EVM of 3%. A different analysis can be made as well, at fixed received optical power. At -10 dBm (14 dB optical budget), the EVM is increased from 1.1% with 1 band to 2.7% with 18 bands. *Fig. 3.c* shows the received Physical Downlink Shared CHannel (PDSCH) constellation for the real-time band centered at 199.7 MHz when transmitting 1 band (left) and 18 bands (right).

Fig. 3.d also shows the measured SNR at the output of the RRH for 14 dB optical budget. We measured approximately 7 dB of added noise when we transmit 18 bands (1 band transmission as a reference).

Following this trend, we estimate that 24 bands could be transmitted with 14 dB optical budget while still respecting the 3% EVM constraint. Thus, the equivalent fronthaul bit rate of 14.74 Gb/s (24 CPRI1 links) can be transmitted over 250 MHz bandwidth with the proposed solution.

We observe similar results both with commercial RAN equipment and lab test equipment.

CONCLUSIONS

In this paper, we experimentally assessed a real-time, mixed analog/digital RoF architecture that enables more bandwidth efficient fronthaul transport while allowing full compatibility with currently deployed C-RAN. We also determined a realistic gain of the A-RoF link in terms of spectral efficiency when compared to CPRI using an off-the-shelf optical transceiver. The obtained results show that 12 CPRI2 links (14.74 Gb/s), each corresponding to a 10 MHz MIMO 2x2 downlink LTE signal, can be A-RoF transmitted while keeping end-to-end EVM below 3%.

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