Dynamic Optical Fiber Delivery of Ka-Band Packet Transmissions for Wireless Access Networks

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***Abstract*—A Reconfigurable Radio Access Unit is presented and experimentally demonstrated. In the unit, an optical switching system is set to dynamically deliver different packets to different points in the network. The packets are transmitted wirelesslty on the Ka-band (26-40 GHz), achieving BER values below the limit for 7% of overhead. The proposed system can easily be implemented in a centralized radio access networks (C-RAN) providing an extra degree of flexibility in 5G networks.**

Keywords*— *Ka-band communications, Mobile communication, Optical fiber networks, Optical switches.

I. Introduction

As we move towards the upcoming 5th generation of mobile networks new challenges have emerged, creating the need for the implementation of new and different architectures and technologies to tackle its requirements [1].

The transition from a distributed radio access network (D-RAN) to a centralized radio access network (C-RAN) has been proposed. In the C-RAN, the central office becomes the responsible of receiving, coordinating and modulating, simplifying the radio access unit (RAU) to be the interface between the optical fronthaul and the wireless channel. This change serves to reduce the costs of implementation (CAPEX) and operation (OPEX) and decrease the latency of the network [2], [3].

In order to accommodate the wireless signal in the optical domain, Radio-over-Fiber (RoF) techniques [4]–[6] alongside the concepts of optical up- and down-conversion processes [5]–[8] have been proposed to connect the central office and the RAU, allowing an increase in data rate and the reuse of the already deployed fiber network. The use of these techniques will allow the wireless access networks to accommodate the signals in the millimeter-wave frequencies. In particular, the Ka-band channel (26.5 – 40 GHz) has been studied and proposed as the wireless link in future cells, being able to fulfill the capacity requirements of 5G, while allowing the desired coverage in both line of sight (LOS) and non-line of sight (NLOS) scenarios of the typical urban environment [8, 9]. One of the main limitations on these frequencies comes in the terms of the coverage, due to the need of high directive antennas needed in the transmission, that leads to the densification of the RAUs, more sectorization in the stations and the implementation of beamforming system [1], [11]. Moreover, scenarios like moving cells and indoor distributed antenna systems have been included as part of the large densification of the RAUs [6], [12], [13], using passive optical systems in their design.

Within the development of RoF systems, flexible systems have been already introduced by the use of optical switching and labeling [14], [15], allowing tenability and reconfigurability to the system, using more effective the resources while avoiding the loss of power due to splitting.

In this paper, we present the dynamic delivery of optical packets for Ka-band wireless applications based in an optical switching system. This concept is set to be implemented in the RAU for applications of moving cells or redirection of the signals to different sectors, in order to give an extra layer of

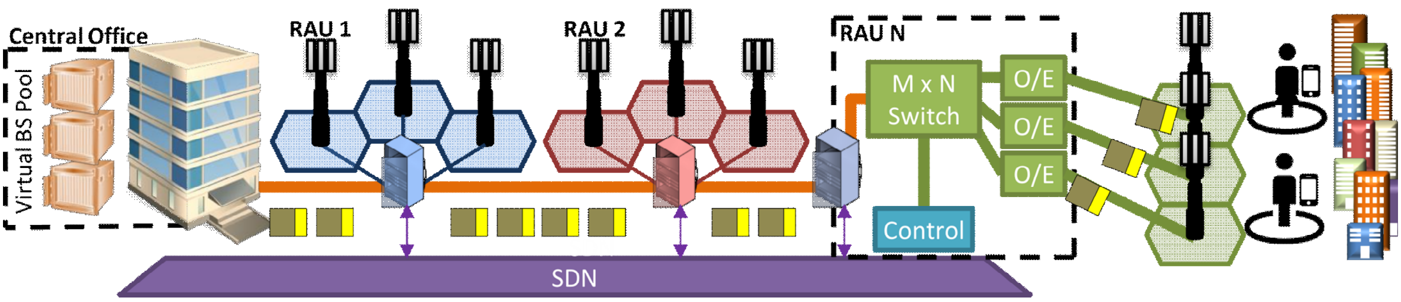

Fig. 1. Proposed architecture. Integration of a Reconfigurable radio access unit (RAU) implemented as part of a software defined network (SDN) under a C-RAN architecture.

flexibility to future wireless access networks.

II. Proposed Architecture

Fig. 1 shows the proposed architecture. Here a single central office delivers the data modulated signal to the different RAUs. This central office is responsible of all the complex processing and tasks. Two wavelengths are used, one with the baseband data and the other as a remote delivered optical local oscillator (LO), needed for the optical up-conversion. The RAU is then reduced to the necessary elements for the system up- and down-conversions and the optical switching, allowing the network to deliver both the signal to be transmitted and the received signal, through the optical domain, between the central office and the RAU.

In the RAU a switching system is set to dynamically distribute the optical signal to different antennas. The switching process can be controlled by the CO through a SDN, allowing the CO to deliver different packets in the system and dynamically redirect them to different sectors, enabling time division multiplexing of wireless data for the implementation of environments with shared resources or moving cells.

The switching system is composed of two elements: The optical switch and a control circuit. The control circuit is designed with both the biasing stage and a transistor – transistor logic (TTL) based logic that will change the selected output of the switch between a set of enabled outputs. The outputs of the switch are enabled with dual in-line package (DIP) switch in the control circuit.

III. Experimental Setup

Fig. 2 shows the setup used in the experiment. At the transmitter, a Pulse Pattern Generator (PPG) is used to feed a 2.5 Gbit/s, 2^{11}-1 bit long pseudo-random bit sequence (PRBS11) non-return-to-zero (NRZ) signal into a commercial small form-factor pluggable module (SPF+) to generate a modulated optical signal. This signal is combined with an external cavity laser (ECL), which serves as the remote delivered LO with the optical input power adjusted with a variable optical attenuator (VOA). The optical signals are launched into 10 km of standard single-mode fiber (SSMF) and amplified by an erbium-doped fiber amplifier (EDFA). A tunable optical filter is used to reduce the amplified spontaneous emission noise (ASE). The signal is taken by an optical switching system in order to be dynamically distributed to one or more outputs. A second VOA is placed for bit-error-rate (BER) measurements. Here a 40 GHz bandwidth photodiode (DSC20S) is used to perform the up-conversion process by direct heterodyning. The result is a double side band modulated signal with a central carrier of 29 GHz, achieving the transmission on the Ka-band (26.5 – 40 GHz). The signal is then boosted by using a set of amplifiers with a total gain of 36dB. The signal is fed to a horn antenna with a gain of 20 dBi and wirelessly transmitted. The distance of 2 m was selected due to constrains in the power budget..

At the receiver, a second 20 dBi horn antenna recovers the signal and an amplification stage boost the signal with a total of 46 dB. The down-conversion process is performed using the optical envelope detector explained in [6]. The signal drives the MZM in order to modulate the laser, and then transmits the signal to the PD which has a BW of 10 GHz in order to recover the data.

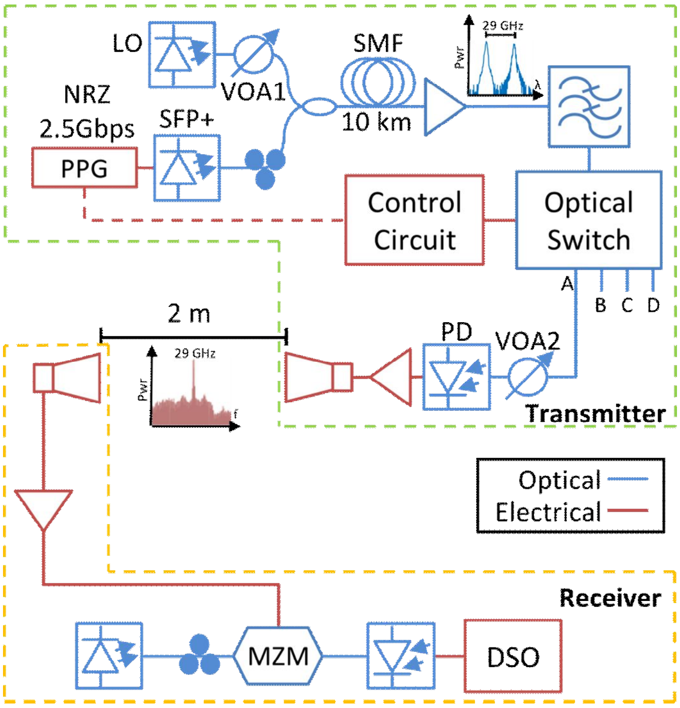

Fig. 2. Experimental setup. PPG: Pulse Pattern Generator, NRZ: Non-Return to Zero, VOA: Variable Optical Attenuator, SFP: Small Factor Pluggable, SMF: Single Mode Fiber, PD: Photo Diode, MZM: Mach-Zehnder Modulator, DSO: Digital Storage Oscilloscope.

The switch used in the experiment has a switching time around 0.3 ms, so a time slot of 0.6 ms was constructed using a data packet followed by a gap of zeroes. In order to proof the concept of the redirection, a data packet was programmed in the PPG composed of 800 times a PRBS11 (for a total of 800 x (2^{11}-1) bits). The time gap between different packets had an equivalent length of 700 PRBS11 of zero values programmed, to compensate for the switching time. The switching system was set to change between its output using a reference signal from the PPG- Each packet was demodulated and then individually captured on a digital storage oscilloscope (DSO) for offline DSP.

IV. Experimental Results

To verify the correct operation and measure the performance of the system, the switch was set to dynamically switch between up to four outputs. For each output, the packet was captured and evaluated in order to obtain the BER of the system. The BER performance of the system was measured both in a back to back (B2B) scenario before transmission, by deactivating the remote LO and measure before the antenna, and after being received and demodulated. Fig. 4 shows the obtained BER traces in both scenarios for the 4 different outputs of the switch.

The BER traces are compared with the standard FEC limit for a 7% of overhead. As it can be observed, the receiver sensitivity of the system ranges from -11.1 to -10.1 dBm on the B2B, and from -8.2 to -7.7 dBm in the wireless transmission case. In both scenarios, the traces for the different scenarios present similar tendencies, being the difference the attenuations for the individual channels. After the transmission, the traces have a similar slope to the corresponding B2B counterpart; meaning that the effect of the wireless transmission is the additional penalty of around 2.2 dBm due to the attenuation of the channel.

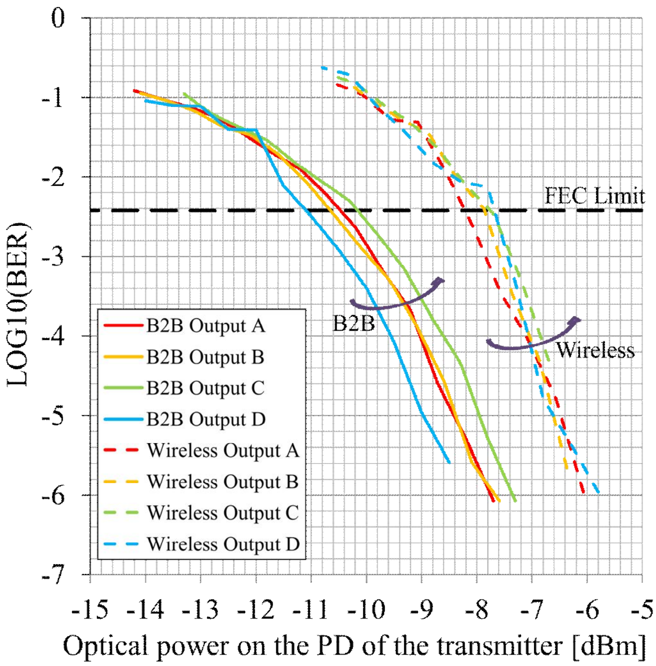

Fig. 4. Measured BER of the packets vs average optical power on the PD

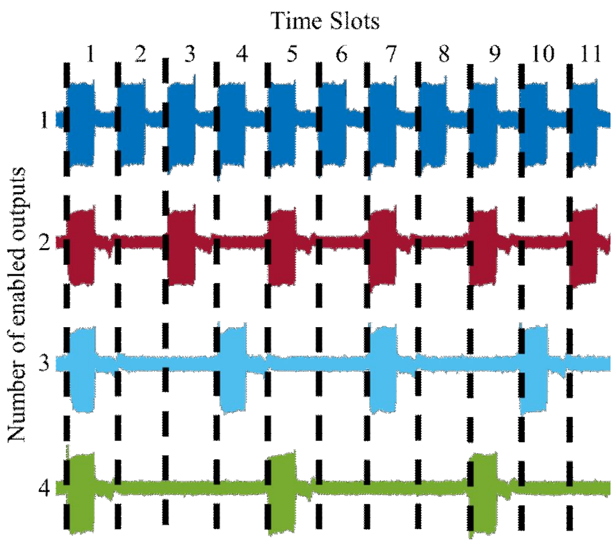

Fig. 5. Received packets dynamically delivered to different amounts of enabled outputs.

Additionally, time signals for the transmission of various time slots of the packet were captured. The switching system was set to dynamically change between the outputs and the time trace was taken in one of the outputs. Four time traces were capture measuring in output A, in each new trace a new output was enabled, allowing to show the dynamic delivery of the system. These traces can be observed in Fig. 5, for a total of 11 time slots. As can be noted, the packets are correctly delivered to the different outputs.

V. CONCLUSIONS

An optical switching system to dynamically deliver the signal of an optically generated Ka-band (26.5 – 40 GHz) transmission has been presented and experimentally evaluated. The resulting RF packets have been transmitted over a wireless distance of 2 m, presenting values below the limit for 7% overhead with a measured sensitivity of -8.2 dBm, for the worst case. Comparing the results of the B2B and the Wireless scenario, it can be noted that the main penalty is the effects of the attenuation of the wireless channel. This can be compensated by using antennas with higher gain or power amplifiers, which will extend the results to higher distances through higher distances.

The optical switching system was able to correctly and dynamically switch between its different outputs without major effects to the signal. Moreover, the implementation of this kind of switches will allow the transmission of higher modulation formats through the optical domain, while being controlled by an external signal, enabling an extra layer of management and control to the wireless access network.

The optical switch can be implemented as part of a radio access unit targeted for the implementation of the C-RAN architecture, marking the way for the next generation of backhaul and access in emerging 5G wireless access networks.

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