Mobile Front-/Back-Haul Delivery in Elastic Metro/Access Networks with Sliceable Transceivers Based on OFDM Transmission and Direct Detection

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ABSTRACT

A transparent and dynamic delivery of mobile front-/back-haul for converged metro/access elastic networking is experimentally demonstrated employing sliceable bandwidth/bitrate variable transceivers based on orthogonal frequency division multiplexing and direct detection. Testbed experiments show successful transmission after 60 km and up to 100 Gb/s data rate.

Keywords: Elastic optical networking, multicarrier modulation.

1. INTRODUCTION

5G services are conceived around the joint use of different heterogeneous resources (including transport, fixed and mobile), while combining networking and cloud functions. Precisely, for mobile networking, it is proposed to host 5G core functionalities in distributed data centers located at different local metro nodes and close to cell sites [1]. For example, these 5G metro nodes can contain virtual pools of baseband units (BBUs), with different functional splits, that are connected to a majority of remote radio units (RRUs) located in the cell sites. Thus, mobile front-/back-haul traffic is significantly decreased when compared to a centralized approach, reducing the associated CapEx and OpEx. Different radio access network (RAN) architectures can be envisioned for providing this connectivity. Interestingly, the overlay of mobile back-/front-haul over existing fixed optical metro/aggregation and access infrastructures constitutes a cost-effective approach. However, approaching such a converged architecture is challenging, as it has to cope with the needs of the network subscribers while supporting the new traffic.

The advent of elastic optical networking, enabled by the adoption of the flexible channel grid and programmable transceivers, opens the door to a truly dynamic management of optical networks [2][3]. This is especially interesting for achieving the pursued integration between optical metro/access and RAN. In fact, approaching this paradigm, specific channels can be set up according to the requirements of the services to deliver. Furthermore, elastic networking also enables to transparently set a RAN network over the optical metro/access. For example, a pool of BBUs would be located at a selected node of the metro network segment, while the RRUs could be scattered along one or multiple access trees, both interconnected by a mesh of exchange nodes (ENs). In this scheme a highly centric traffic pattern is expected, posing different requirements in terms of cost and data rate compared to typical transmission technologies for the transport/core networking.

In this paper, we propose to transparently and dynamically deliver mobile front-/back-haul in a converged metro/access environment, following the elastic networking paradigm in order to take advantage of the already deployed fiber infrastructure. In order to cope with that in a cost-effective way, we propose to use sliceable bandwidth variable transceivers (S-BVTs) based on orthogonal frequency division multiplexing (OFDM) employing direct detection (DD). Therefore, a first experimental proof-of-concept in a photonic meshed network (the ADRENALINE testbed) is provided for downstream, underlining the potential of these transmission technologies for the envisioned scenario.

2. NETWORK SCHEME AND SIGNAL DELIVERY

The network and signal delivery scheme is depicted in Fig.1. There, programmable S-BVTs are present at the 5G metro nodes in order to concurrently serve different cell sites. At the other end of the network, each cell site has a programmable BVT. The (S-)BVTs can be remotely configured by the control plane, for an optimal management of the network resources [3][4]. The parameters to be configured at each (S-)BVT include wavelength, spectral occupancy and modulation format/power per flow. So, the proposed (S-)BVTs deliver data flows with variable spectral occupancy and rate, according to the network and path conditions.

Among all the options for implementing the (S-)BVTs, those based on DD-OFDM are the most attractive for cost-effectively coping with the flexibility requirements of elastic optical networks [4]. In fact, OFDM provides advanced spectrum manipulation capabilities, including arbitrary sub-carrier suppression and bit/power loading. Thanks to these features, DD-OFDM transceivers can be ad hoc configured for achieving a certain reach and/or coping with a targeted data rate adopting low complex optoelectronic subsystems [4][5].

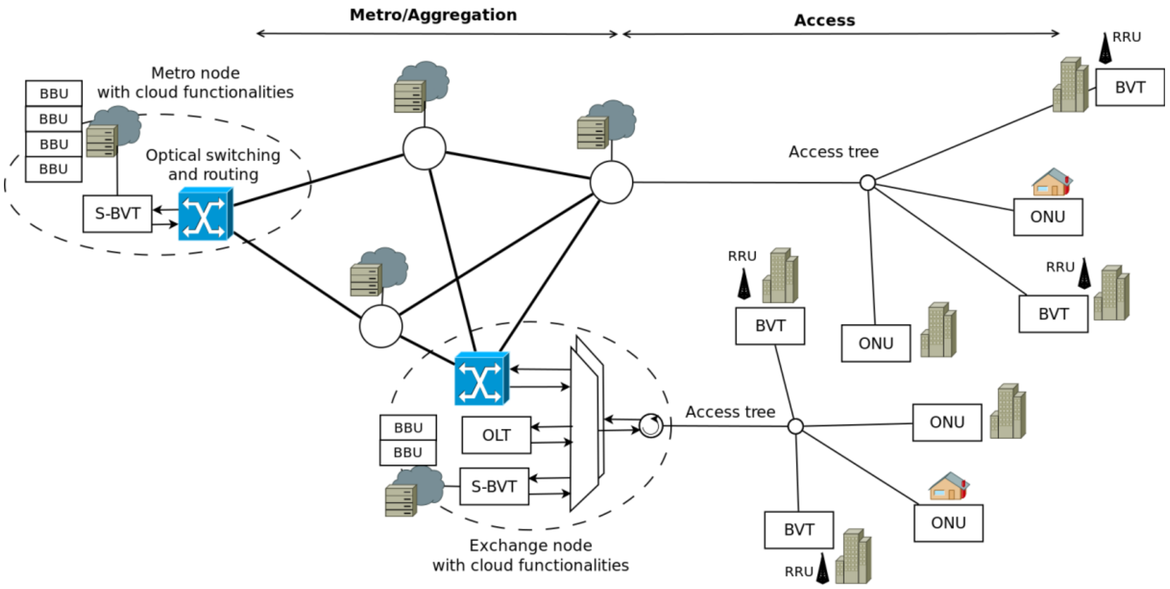

Figure 1. Network scheme.

In order to ensure full compatibility with the deployed optical metro and access networks, a specific wavelength plan is envisioned. In fact, legacy access standards (e.g. GEPON, GPON) use 1490 nm for downstream; while late standards (10G-EPON and XGPON) recommend the range of 1575-1580 nm also for downstream. Regarding the upstream, all the cited standards envision the use of O-band. Thus, the entire C-band is available for performing a wavelength overlay of channels in order to provide different additional services over the same access infrastructure [6]. Interestingly, NGPON2 also offers the option to establish virtual point-to-point (PtP) links within the C-band, assigning different wavelength division multiplexing (WDM) channels to different metro nodes and/or services [7].

At the exchange nodes of the metro network, the mobile front-/back-haul signals are filtered out and transparently routed/dropped to their destination access tree. This fact does not pose any strict constraint, since commercial standard flexi-grid spectrum selective switches (SSS) and optical amplifiers typically operate at C-band. Also, each exchange node includes the corresponding optical line terminals and aggregation switches/units for delivering fixed access services to the network users across the corresponding access trees.

The main challenge of this signal delivery scheme is regarding the establishment of bidirectional transmission over this converged infrastructure. Precisely, the metro part of the network usually relies on a dual fiber duplex, while the access segment typically implements a dual-wavelength duplex. Nevertheless, in order to optimize the usage of the network resources, the same wavelength should be used for upstream and downstream. At this point, we should note that the feeder cables of the access segment cover the majority of the distance (from the exchange node to the splitter distribution hub) and typically have a loose-tube design containing several fibers [8]. Thus, in case the RRUs can be directly attached to the splitter distribution hub, a dual-fiber duplex across the entire transmission link (including metro and access segments) can be ensured with no need for deploying new cables.

Regarding the dimension of traffic to support, it should be noted that the most bandwidth hungry service is the mobile front-haul based on the common public radio interface (CPRI), which on the other hand does not allow any dynamic management of the capacity in the transport network, since this kind of traffic requires high constant bit rate independently of the cell loads. In order to relax these requirements, several radio functions can be decentralized and adopted by the RRUs, trading latency and data rate against flexibility. In fact, for transmitting up to 100 km, 1 ms minimum round trip delay should be expected. This requires a functional split at PHY2 or MAC-PHY level, relaxing the bitrate requirement [9]. With these other functional splits it is desirable to have mechanisms for dynamic management of the bandwidth/capacity in the transport network, being (S-)BVT one of the suitable technologies for that because it can be adapted now to the actual load at radio cell level as it is aggregated.

3. EXPERIMENTAL SETUP

Fig. 2 shows the experimental setup for N=2 signal flows. The digital signal processing (DSP) and electrical up/downconversion at the transmitter(Tx)/receiver(Rx) are performed off-line, following the steps detailed in Fig.2, indicated as Tx DSP and Rx DSP. At the transmitter side, per each flow, randomly generated data are mapped into the corresponding constellation (ranging from BPSK up to 256 QAM). Adaptive bit/power loading is implemented using the rate adaptive version of the Levin-Campello algorithm [4]. Then, 4 training symbols

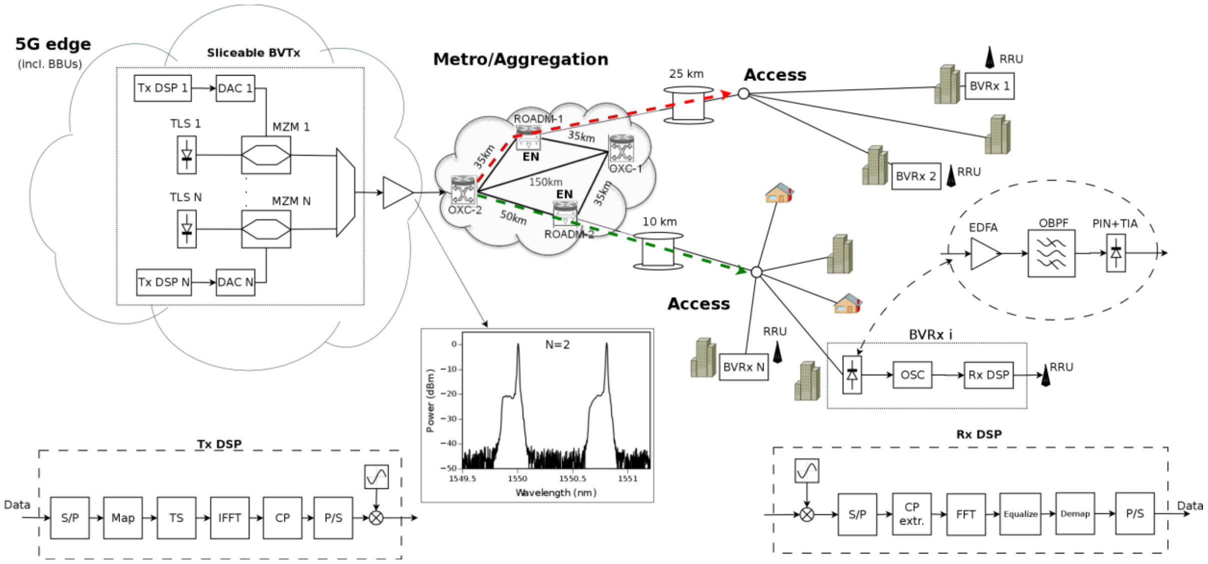

Figure 2. Experimental setup. DSP schemes of the transmitter (Tx DSP) and the receiver (Rx DSP). In the inset, aggregated flow injected to the ADRENALINE testbed.

are included every 100 OFDM frames. The resulting symbols feed an inverse fast Fourier transform (IFFT) of 512 subcarriers. Afterwards, a 2 % cyclic prefix (CP) is added and the obtained OFDM symbols are serialized. The digital OFDM signal, fixed to be running at 20 Gbaud, is clipped and upconverted to an intermediate frequency of 10 GHz by mixing with a digital oscillator. The resulting signal is converted to the analogue domain by a digital to analogue converter (DAC) at 64 GSa/s. This analogue signal is conditioned and injected to the corresponding Mach-Zehnder modulator (MZM) biased at the quadrature point and excited by a tunable laser source (TLS). The flows resulting after each MZM are then aggregated using an LCoS reconfigurable optical SSS, configured to have 25 GHz bandwidth per channel and slightly detuned in order to obtain an optical single sideband (SSB) signal. Two flows are generated in the C-band, centered around 1550.12 nm and 1550.92 nm, according to the wavelength plan detailed in section 2 (see inset of Fig.2).

The optical signal resulting from the transmitter is injected into the ADRENALINE testbed, whose simplified scheme is depicted in Fig.2. It is a 4-node photonic mesh network with amplified links of different lengths, ranging from 35 km to 150 km [10]. The feeder section of the access trees, attached to selected exchange nodes, is composed of different standard single mode fiber spools (10 km, and 25 km). The power delivered to each tree is set to +5 dBm. Then, a variable optical attenuator is used to emulate the power splitters.

At the receiver, the incoming signal is filtered out and photodetected. Finally, in order to emulate a high bandwidth avalanche photodiode in the set-up, a combination of gain-stabilized EDFA, optical band pass filter (OBPF) and PIN diode is calibrated to obtain a -28 dBm sensitivity at 10^{-3} BER for on-off keying transmission at 10.7 Gb/s. The detected current is then digitized by a real-time oscilloscope (OSC) running at 100 GSa/s. The baseband OFDM signal is recovered after downconversion, off-line demodulated, equalized and demapped.

4. RESULTS

Fig. 3 shows the sensitivity measurements for the different cases analyzed, assuming a BER threshold of $4.62 \bullet 10^{-3}$ for a 7% hard decision forward error correction (HD-FEC) overhead [11]. The sensitivity level considered is -18 dBm, which corresponds to a 20 dB power budget for the transmitted power, including a 3 dB margin. Nevertheless, other sensitivity levels may be considered according to the specificities of each deployment.

First, a back to back (B2B) configuration is tested, featuring a maximum aggregated gross capacity of 105.2 Gb/s at -14 dBm of received power. At -18 dBm, the maximum aggregated capacity is 79.9 Gb/s. In this case, each slice when individually transmitted is featuring around 50 Gb/s.

Next, the impact of 10 km and 25 km of feeder fiber is assessed. Fig.3 shows that these configurations are well aligned with the B2B case, with power penalties of less than 1 dB for all the analyzed distances.

For proving the proposed sliceable functionality, the different flows are transmitted over the optical meshed network of the ADRENALINE testbed, through two different links (35 km and 50 km). Next, signal paths continue through the different access segments to cope with a total maximum distance of 60 km. In this case, we observe a capacity penalty of less than 42 % with respect to the B2B at -18 dBm, achieving about 50 Gb/s when detecting both flows. When detecting the slices individually, the maximum capacity ranges between 26.2 Gb/s and 34.3 Gb/s at -18 dBm. In all the analyzed cases, the BER is below the HD-FEC threshold, as shown in Fig.3.

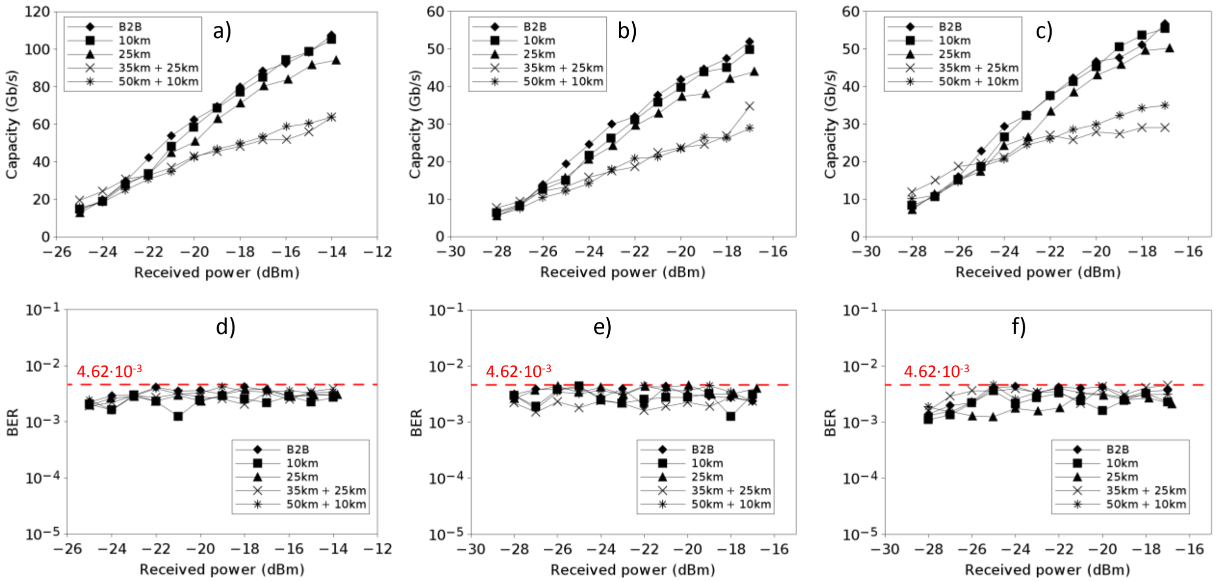

Figure 3. Experimental results for the cases of detecting both the two flows (a, d), and single slice individually, at 1550.12 nm (b, e) and1550.92 nm (c, f). (a, b,c) Maximum capacity versus received power. (d, e, f) BER versus received power.

5. CONCLUSIONS

A transparent delivery of mobile front-/back-haul for converged metro/access elastic networking has been experimentally demonstrated when serving different paths with DD-OFDM S-BVTs. Results show successful connections from BBUs to the RRUs, covering distances up to 60 km and achieving datarates beyond 50 Gb/s. Thus, it is a promising solution for serving the multiple endpoints employing S-BVT(s) at the 5G metro nodes.

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