Experimental Validation of a Converged Metro Architecture for Transparent Mobile Front-/Back-Haul Traffic Delivery using SDN-enabled Sliceable Bitrate Variable Transceivers

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Abstract *We experimentally demonstrate transparent/dynamic delivery of mobile front-/back-haul in converged optical metro architecture, employing SDN-enabled S-BVTs based on adaptive multicarrier modulation. Network testbed experiments show successful BBU-RRU connectivity at distances up to 175km and capacities beyond 30Gb/s per flow.*

Introduction

5G is conceived around the joint use of different heterogeneous resources, including optical transport and mobile. For mobile networking, it is proposed to host applications and network functions in distributed data centres attached to different local metro nodes (MNs) and close to cell sites[1]. For example, these MNs can connect to virtual pools of baseband units (BBUs), with different functional splits, serving a majority of remote radio units (RRUs) located at the cell sites. Thus, mobile front-/back-haul traffic is significantly decreased when compared to a centralized approach, reducing the associated CapEx and OpEx[1]. Different radio access network (RAN) architectures can be envisioned for providing this connectivity. Interestingly, the adaptation of existing optical metro and access infrastructures for transparent mobile back-/front-haul constitutes a cost-effective approach. However, this converged approach is challenging, as it has to support the access subscribers and RAN traffic at the same time, while enabling transparent routing between metro and access.

In this paper, we propose and experimentally demonstrate a transparent and dynamic delivery of mobile front-/back-haul traffic in a converged metro/access network by combining software defined networking (SDN) and elastic optical networking. This combination enables the set-up of specific channels according to the requirements of the services to deliver, enabling the configuration of virtual RANs over the optical metro/access infrastructure, seeing them as private network slices. This is enabled at the data plane level mainly by the adoption of the flexible channel grid and SDN-enabled programmable sliceable bitrate variable transceivers (S-BVTs). The S-BVTs are able to transmit data flows with variable rate according to the network and path conditions. Specifically, we propose to use cost-effective S-BVTs based on orthogonal frequency division multiplexing (OFDM) and direct detection (DD).

Network scheme and signal delivery

The network and signal delivery scheme is depicted in Fig.1, along with the experimental scheme. There, programmable S-BVTs are present at the 5G MNs 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 configured by a suitable SDN controller for an optimal management of the network resources[2, 3]. The parameters to be configured at each (S-)BVT include wavelength, modulation format and power per flow. Precisely, the (S-)BVTs based on DD-OFDM are the most attractive for cost-effectively coping with the flexibility requirements of elastic optical networks[3]. In fact, OFDM provides advanced spectrum manipulation capabilities, including arbitrary sub-carrier suppression and bit/power loading. Thus, DD-OFDM transceivers can be configured for achieving a targeted reach and/or data rate adopting simple optoelectronic subsystems[3].

In order to ensure full compatibility with the deployed optical metro and access networks, a specific wavelength plan is envisioned. In fact, access standards (e.g. G(E)PON, 10G-EPON, XGPON), use 1490nm and/or 1575-1580nm for downstream; while upstream is performed in the 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. At the metro segment, standard operations include C-band switching/routing, since commercial standard flexi-grid spectrum selective switches (SSS) and optical amplifiers typically operate at C-band. Thus, at selected exchange nodes (ENs) of the metro network, the mobile front-/back-haul signals can be filtered out and transparently routed/dropped to the destination access tree, according to the scheme of Fig.1. Each EN includes the corresponding optical line terminals (OLTs) and SSSs for delivering access services to the optical network units (ONUs) across the corresponding access trees.

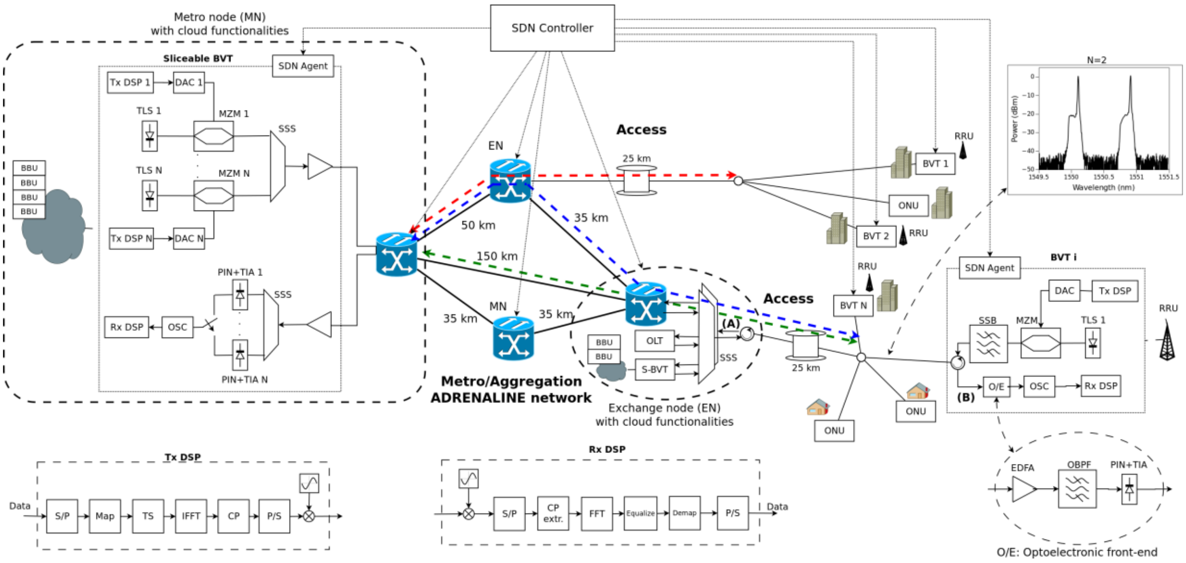


Fig. 1: Converged metro concept and experimental scheme for the proposed mobile front-/back-hauling.

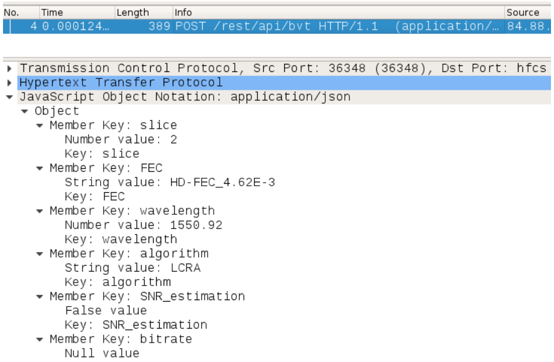
Since the most bandwidth hungry service is mobile front-haul, high bitrate variability can be expected, depending on the functional split adopted[4]. In case the split is set for full centralization of the base stations, several tens of Gb/s and low latency are required. To relax these constraints, more radio functions can be decentralized and adopted by the RRUs, trading latency/bitrate against flexibility. In fact, 1ms round trip delay can be expected for transmitting up to 100km. This requires a PHY2/MAC-PHY functional split and relaxes the bitrate[4].

A centralized SDN controller is proposed for efficiently managing the devices and provisioning the services. In fact, all the proposed network systems can be programmed by means of the corresponding SDN agents, allowing an automated path establishment between the MNs and the cell sites, across the two network segments.

We propose to employ the same wavelength for upstream and downstream for maximizing the utilization of the network resources. Since the access part of the network is a single fibre tree, this approach comes at the expense of the transmission performance degradation.

Experimental setup

Fig. 1 depicts the experimental setup for N=2 flows. The digital signal processing (DSP) and electrical up/downconversion at the transmitter/receiver are common to the S-BVT and BVT, either for downstream or upstream. This DSP is performed off-line, following the steps detailed in Fig.1 according to[3]. Adaptive bit/power loading is implemented using the Levin-Campello rate adaptive (LCRA) algorithm[3] in order to test the maximum capacity per flow that the system can offer. The OFDM signal after the digital to analogue converter (DAC) is fixed to be running at 20Gbaud and centered to 10GHz. This signal drives the corresponding Mach-Zehnder modulator (MZM) biased at the quadrature point and excited by a tuneable laser source (TLS). For the BVT, the resulting signal passes through a tuneable optical filter of 25 GHz, slightly detuned for obtaining an optical single sideband (SSB) signal. For the S-BVT, the flows after each MZM are aggregated using an SSS, configured to have 25GHz bandwidth per channel and detuned for SSB generation. Two flows are generated at 1550.12nm (flow 1) and 1550.92nm (flow 2), as shown in Fig.1 inset.



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No.   Time          Length  Info                                           Source
  4 0.000124…          389 POST /rest/api/bvt HTTP/1.1   (application/…  84.88.

▸ Transmission Control Protocol, Src Port: 36348 (36348), Dst Port: hfcs
▸ Hypertext Transfer Protocol
▾ JavaScript Object Notation: application/json
  ▾ Object
    ▾ Member Key: slice
        Number value: 2
        Key: slice
    ▾ Member Key: FEC
        String value: HD-FEC_4.62E-3
        Key: FEC
    ▾ Member Key: wavelength
        Number value: 1550.92
        Key: wavelength
    ▾ Member Key: algorithm
        String value: LCRA
        Key: algorithm
    ▾ Member Key: SNR_estimation
        False value
        Key: SNR_estimation
    ▾ Member Key: bitrate
        Null value
```

Fig. 2: Sample Wireshark for the configuration of the S-BVTs at maximum capacity.

The optical signal generated at the S-BVT is injected into the ADRENALINE testbed, whose simplified scheme is depicted in Fig.1. It is a 4-node photonic mesh network with amplified links of different lengths, ranging from 35km to 150km. A 25km fibre spool is attached to selected ENs in order to emulate the feeder section of the access trees. The power delivered to each tree is set to +5dBm. In the upstream, the signal at the BVT output (-4.2 dBm) is injected to the 25km fibre spool and suitably routed in the ADRENALINE testbed.

At the receiver, the incoming signal is filtered out and photodetected. At the BVT an optoelectronic front-end (O/E) that would include a high bandwidth avalanche photodiode is

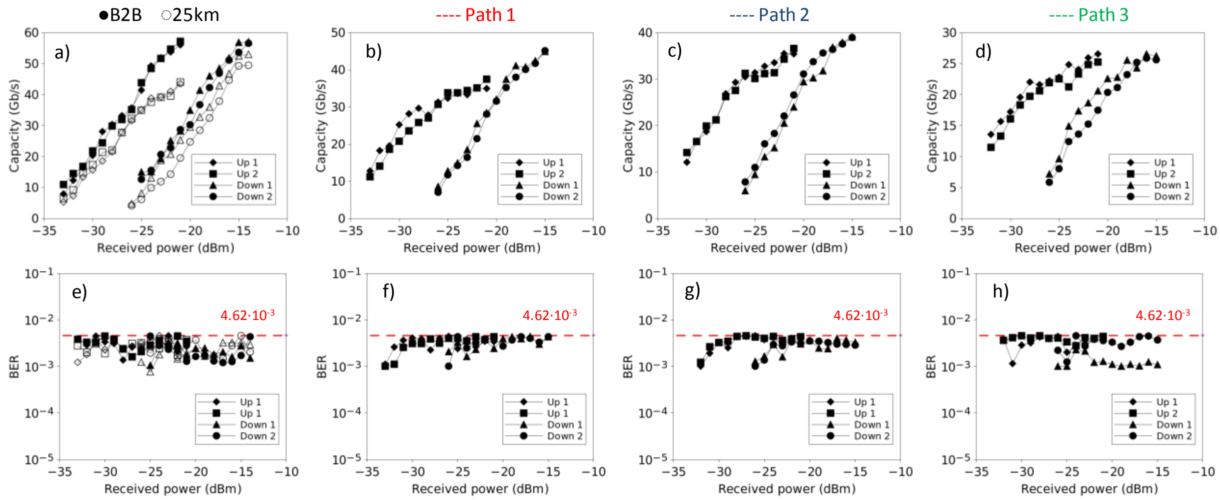

Fig.3: Experimental results in terms of maximum capacity (a, b, c, d) and BER (e, f, g, h) versus received power for the cases of: (a,e) B2B (filled markers), after 25km (open markers); (b,f) path 1; (c, g) path 2; (d, h) path3.

emulated by the combination of gain-stabilized EDFA, optical band pass filter (OBPF) and PIN diode. This combination is calibrated to obtain a -28dBm sensitivity at 10^{-3} BER for on-off keying transmission at 10.7Gb/s. At the BVT and S-BVT, the photodetected current is digitized by a real-time oscilloscope (OSC) running at 100GSa/s. Afterwards, the baseband OFDM signal is recovered after downconversion and off-line demodulated according to[3].

The SDN controller configures the (S-)BVTs by setting slices active, forward error correction (FEC), wavelength and bit/power loading algorithm. Also, it is able to switch between SNR estimation and data transmission modes. A sample configuration is shown in Fig.2.

Results

Fig.3 shows the results for the analysed cases, assuming a $4.62 \cdot 10^{-3}$ BER threshold for a 7% FEC overhead[5]. In all these cases, we ensure a BER below this value (Fig.3e-f). The received power is measured after optical attenuation at points (A) and (B) of Fig.1 for upstream and downstream, respectively. The network is envisioned to cover a power budget of 20dB in the access tree, plus 3dB margin. So, the received power threshold is set to -18dBm for downstream and -27.2dBm for upstream.

First, a back to back (B2B) configuration is tested (Fig.3a, filled markers) featuring a maximum gross capacity well beyond 55Gb/s per flow, either for upstream or downstream. At the received power threshold, the maximum aggregated capacity is >40Gb/s for downstream while for upstream is about 30Gb/s.

Next, the impact of transmission after 25km of fibre (Fig.3a, open markers) is assessed. We can observe that that these configurations are aligned with the B2B case, but with power penalties of ~2dB for downstream. For upstream the capacity is limited to about 27 Gb/s for both flows. This is due to the optical signal to Rayleigh backscattering ratio (OSRR) caused by bidirectional transmission over a single fibre. The OSRR measured is of 34.3dB for downstream and 18.5dB for upstream.

For proving the sliceable functionality while featuring full bidirectionality, the different flows are transmitted over the ADRENALINE testbed and the access tree, covering different paths of 50+25km (path 1, red), 85+25km (path 2, blue) and 150+25km (path 3, green). Results are shown in Fig.3b-d and Fig3f-h. There we can see how the accumulation of optical noise, and dispersion impacts on the system performance (besides the limited OSRR due to the optical tree). In the worst case (150+25km, Fig.3d), we observe a capacity penalty of less than 45% with respect to the B2B for all the cases, achieving 20Gb/s per flow and beyond.

Conclusions

A transparent delivery of mobile front-/back-haul in a converged metro networking scenario has been experimentally demonstrated with SDN-enabled DD-OFDM (S-)BVTs. Results show successful connections from BBUs to the RRUs when serving different paths up to 175km. Thus, the proposed architecture offers a promising solution for serving the multiple endpoints when featuring a flexible functional split.

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