A Dynamically Reconfigurable Optical Switching Node for Hybrid Analog/Digital RoF Transport

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Abstract We demonstrate a dynamically reconfigurable optical switching node interconnecting both Digital and Analog RoF interfaces. Successful optical/wireless transmission is verified, and real-world services are showcased over the deployed WDM infrastructure. © 2022 The Author(s)

1. Introduction

Towards the arising 6G era, vast user and multiple device connectivity dictates the evolution of transport networks not only to meet ever growing bandwidth requirements, but also to support flexibility and interoperability for the delivery of services with largely different Key Performance Indicators (KPIs) [1]. Cloud Radio Access Network (C-RAN) mobile topologies enable advanced flexibility and network scalability, interconnecting cloud-based processing resources with simplified radio terminals. However, current deployments are based on point-to-point optical interconnections of single Baseband-Unit (BBU) with a Remote Radio Head (RRH), introducing major scalability issues within the increasingly densified mobile networks.

The migration to mobile transport architectures that exploit the inherent dynamicity of flexible optical network paradigms, facilitates the reuse of centralized resources to support not only the traditional macrocells, but also evolving, beyond-enhanced Common Public Radio Interface (eCPRI) solutions, promising enhanced broadband connectivity over the same transparent optical layer. Following this rationale, reconfigurable Wavelength Division Multiplexing (WDM) nodes can support legacy eCPRI/CPRI connections, concurrently with Analog-Intermediate-Frequency over Fiber (A-IFoF) schemes, currently demonstrating up to 24Gbps throughput for broadband radio signals [2], and upgraded digital links based on up to 100G Small Form-factor Pluggable (SFP) connectivity [3]. The co-existence of both digital and analog mobile data streams in a unified, heterogenous optical network layout has been recently reported, using either static multiplexing for both analog and digital streams in the same wavelength [4], or based on passive WDM subsystems [5]. On top of these works, the use of dynamic reconfigurable Wavelength Selective Switches (WSSs), simultaneously handling 5G, Passive Optical Network (PON) and datacenter traffic in [1], and routing multiple eCPRI lanes in [6], showcase the potential of adding one more degree of flexibility, through employment of WSS-based optical nodes in the hybrid Analog/Digital Radio over Fiber (A-RoF/D-RoF) transport.

In this paper we aim to contribute in this direction by using a Software Defined Networking (SDN)-enabled optical node, supporting spatial-spectral flexible optical networking of four heterogenous analog/digital mobile transport segments. We experimentally demonstrate the optical routing of real-services traffic over both D-RoF and A-IFoF/mmWave links, co-integrated with custom high-capacity A-IFoF/mmWave links and 10Gbps digital optical links for beyond-5G connectivity scenarios. The successful operation of the WSS-based node was verified via physical layer performance evaluation metrics, as well via the delivery of services over mobile phones, including 4K video streaming and Internet Protocol (IP) calls.

2. Concept and Experiment

Fig.1 illustrates the architecture layout of the envisaged hybrid analog/digital optical network. The targeted architecture aims to integrate different transport technologies in a shared optical network segment, facilitating the transition from

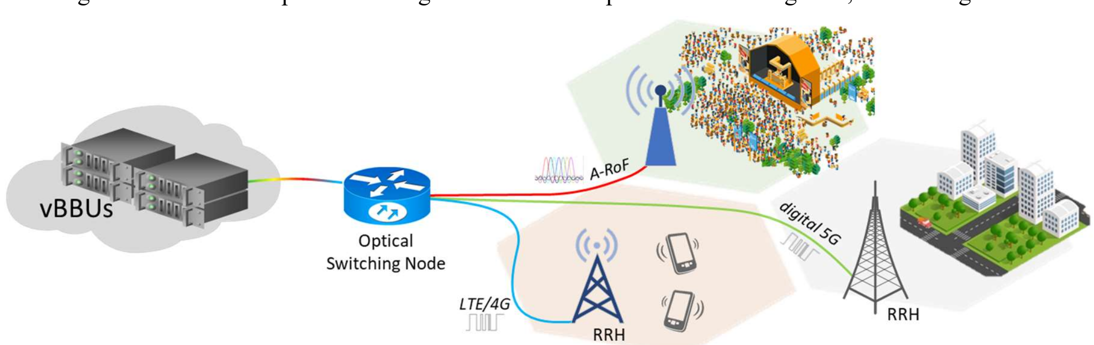

Fig. 1 A WSS-based hybrid optical transport architecture

existing fiber-based mobile transport networks, towards Beyond-5G (B5G) connectivity. In detail, the proposed approach relies on the coexistence of legacy CPRI connectivity (Long-Term Evolution (LTE)/4G), broadband binary streams for D-RoF 5G deployments and beyond-5G A-IFoF implementations to support extremely high capacities, such as hot spot areas [5]. Network flexibility is provided using a flexible WSS-based optical node. A dynamically controlled optical switching node for wavelength routing, provides dynamicity to the network and facilitates the protocol-agnostic coexistence of heterogenous streams. Moreover, considering that SDN is key part of the 5G and beyond networks, the compatibility of optical systems (passive and active photonic components) with the orchestration framework is necessary.

The proposed scheme was deployed and demonstrated using the setup layout illustrated in Fig. 2. This setup hosts a 4λ-optical transport layout, implemented by both D- and A-RoF transceivers. For the implementation of the optical switching node, an Arrayed Waveguide Grating (AWG) followed by an Erbium Doped Fiber Amplifier (EDFA) and a commercial 1×4 WSS (NISTICA FFLB-C04L000-4UC) was exploited to multiplex and dynamically route four different optical streams enrolled at λ_1=1558nm, λ_2=1558.3nm, λ_3=1560.6nm, and λ_4=1563.1nm. The dynamic operation of this optical switching node was achieved by controlling the WSS, being the only active block of the node, through a custom MATLAB script that was developed for the interfacing between the SDN agent and the WSS. Its main elements were a "listener" and a "controller", as shown in the block diagram of Fig. 3(a). This script could recognize any changes to a common text file (.txt) where the SDN agent wrote the network commands. In this way, the WSS was configured to route the wavelengths to the proper destination output according to the commands in this file. For the purpose of this experiment, the .txt file was changed manually, as the configuration script was running.

Furthermore, the optical streams at λ_1 and λ_2 carrying A-IFoF and optical binary signals respectively, were used for physical layer performance evaluation, while the optical streams at λ_3 and λ_4 were used for the demonstration of true mobile services. Regarding the RoF transceivers' implementation, a Signal Generator (Arbitrary Waveform Generator) was used for the generation of complex up-converted waveforms and of the Non-Return-to-Zero (NRZ) signals, supporting both Sub-Carrier Multiplexing (SCM) A-IFoF transmission at a center Intermediate Frequency (IF) of 1.6GHz and an up to 10GHz binary optical stream, respectively. The IF up-converted stream was fed to an externally modulated laser (EML) emitting at λ_1. After propagation over Single Mode Fiber (SMF), the analog stream was detected via a 10GHz avalanche photodiode (APD) equipped with a Transimpedance amplifier (TIA), transmitted over a wireless Point-to-Point (PtP) link operating at 60GHz and captured by a Real-Time Oscilloscope (RTO). For the post-processing of the IF waveforms a Vector Signal Analysis (VSA) software was used. The binary stream carrying D-RoF traffic was modulated via a Mach-Zehnder Modulator (MZM) at λ_2. After SMF transmission, the binary stream was detected by a 14GHz photoreceiver and fed to the RTO. Offline processing involving a 21-tap Feed-Forward Equalizer (FFE) was performed. For the demonstration of services, the existing mobile infrastructure of COSMOTE – the Greece's largest Mobile Network Operator (MNO) – was exploited, which among others included an Evolved Packet Core (EPC) and a Small Cell. These two network units were interconnected along the node via 1Gbps SFP transceivers emitting at λ_3. Finally, the MNO's equipment was also used for the delivery of services through A-IFoF waveforms enrolled at λ_4, transmitted over a converged fiber-wireless link. In this case, the implemented FPGA-based A-IFoF transceiver reported at [7] served as a bridge for the transmission of the 1Gbps SFP traffic, modulated by a 10GHz EML emitting at λ_4.

3. Results

The WSS-based optical node, described above, exhibits total insertion losses of 11dB (4.5dB coming from the AWG and 6.5dB from the 1×4 WSS), for this reason an EDFA was used to mitigate the optical loss. Fig. 3 comprises the experimental results regarding the performance of the abovementioned optical node routing different RoF transport lanes. Fig.3 (b) shows the constellations and corresponding Error Vector Magnitude (EVM) measurements after switching of λ_1 (SCM A-IFoF stream) between two output ports of the optical node. The EVM difference of 0.8% that was observed in the optical domain

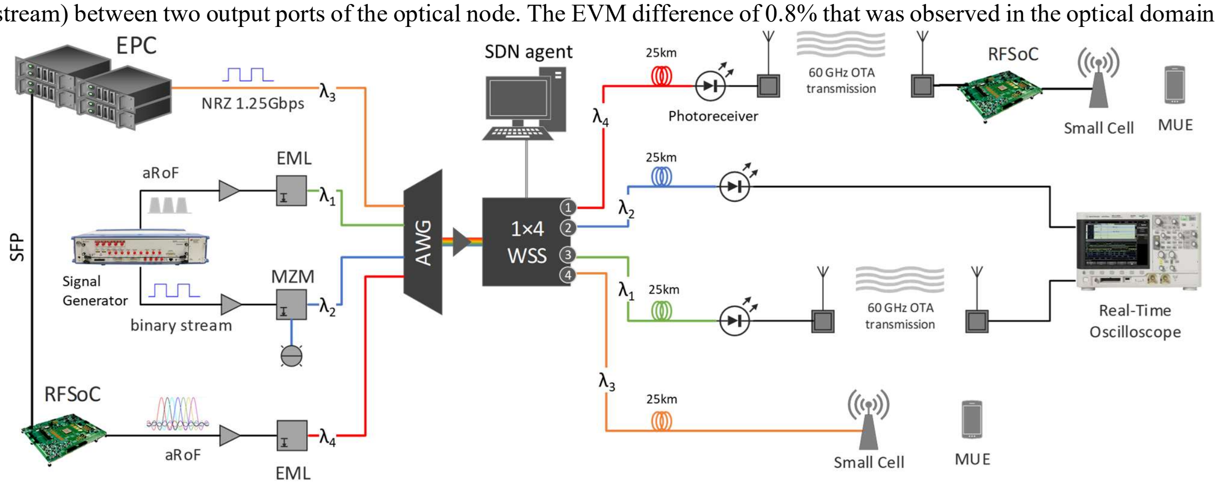

Fig. 2: The 4λ-optical transport experimental layout

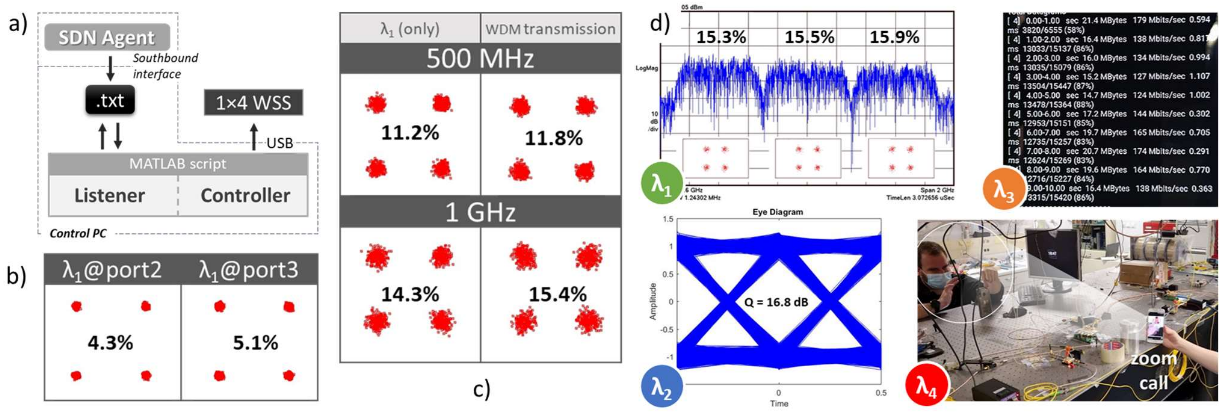

Fig. 3: (a) The SDN interface script for the WSS control, (b) Constellation diagrams corresponding to switching of λ_1 between port 2 and port 3 of WSS, (c) Performance evaluation of λ_1 after single and WDM transmission, (d) Evaluation of successful concurrent 4λ transmission.

only (without the radio boards) can be attributed to the use of different photoreceivers in the two links. Fig. 3 (c) illustrates two different transmission scenarios of λ_1 optical stream, carrying single-band Quadrature Phase Shift Keying (QPSK) signals. In the first case only λ_1 is propagated through the optical node, while in the second one, four optical streams are propagated through the node. In the WDM transmission, small EVM differentiations up to 1.1% were observed, associated with the gain competition on the used EDFA due to different power levels of incoming signals.

Fig. 3 (d) presents the successful evaluation of the concurrent transmission of four optical streams through the node. The wavelength λ_1 was modulated with 3-band QPSK signals of 500 MHz, corresponding to 1.5GHz analog aggregated radio traffic, and exhibited values well-bellow the 3GPP threshold of 17.5% EVM for successful demodulation of the QPSK modulation after the IFoF/V-band transmission [8]. The wavelength λ_2 was carrying 10GHz On–off keying (OOK) signals emulating 10G D-RoF traffic and the measured Q-factor indicated error-free transmission (Bit-error-rate < 10^{-9})[9]. The CPRI traffic transmitted over λ_3 was validated with the use of a Mobile User Equipment (MUE) performing *Iperf* measurements, exhibiting up to 180Mbps stable connectivity. Moreover, 4K online video streaming, uninterrupted live IP-video teleconferences and web browsing were successfully demonstrated over λ_4 where the A-IFoF/mmWave link was integrated by using the FPGA based A-IFoF platform in [7].

4. Conclusion

We presented the co-existence of heterogenous analog and digital optical transport solutions, supported by a dynamic reconfigurable WSS-based optical switching node. We demonstrate experimental evidence of the dynamic optical routing of both legacy CPRI, 1.5 Gbaud A-IFoF/mmWave and 10GHz binary optical waveforms, showing acceptable EVM values for complex radio waveforms and error-free operation for binary optical streams. Besides these high-capacity transport experiments, 4K video streaming and IP-calls over both analog and digital lanes were successfully demonstrated, showing the potential of our presented node to dynamically handle high-throughput links and services.

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