First Real-Time Demonstration of a Flexible multi-λ DRoF/ARoF/SDoF Transport for fiber/mmWave RAN

P. Toumasis(1), K. Kanta(1), C. Vagionas(2), G. Giannoulis(1), Z. S. He(3), G. Torfs(4), E. Kyriazi(1), G. Brestas(1), R. Maximidis(2), C. Meysmans(4), W. Wasko(5), D. Apostolopoulos(1), A. Miliou(2), N. Pleros(2), H. Avramopoulos(1)

(1)School of Electrical & Computer Engineering, National Technical University of Athens, Greece, ptoumasis@mail.ntua.gr
(2)*Department of Informatics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
(3)*Sinowave AB, Hovås, Sweden*
(4)*IDLab, Department of Information Technology, Ghent University - imec Ghent, Belgium*
(5)*NVIDIA, Poland*

Abstract *A reconfigurable, technology-agnostic X-haul optical infrastructure with active wavelength routing for converged A-RoF/D-Band, D-RoF/E-Band and SDoF streams was demonstrated. The deployed SDN-enabled AWGR-based transport topology supported real-world services including HD video and mobile traffic. ©2023 The Author(s)*

Introduction

As the discussion on the 6G architectures and technologies is ongoing in the scientific and business communities, there is no denial that increased flexibility and scalability are key characteristics that any future deployment must demonstrate, to effectively accommodate the diverse requirements of the various services expected to be supported. Satisfying this broad range of specifications is only possible by exploiting advanced radio technologies and optical X-haul interfacing schemes in parallel to traditional solutions [1]. Millimeter wave (mmWave) radio systems, providing access to expansive spectrum falls within this category, having shown its potential in a plethora of demonstrators, such as the high-speed railway communication system in [2], while commercial products with standard interfaces are also available. Meanwhile, promising to support broadband Central Unit (CU)/Digital Unit (DU)-to-Radio Unit (RU) connectivity and tight synchronization between Remote Radio Heads (RRHs), Analog Radio-over-Fiber (A-RoF) and Sigma-Delta-over-Fiber (SDoF)-based transport alternatives, have been adopted in trial testbeds applying to capacity-hungry hot-spot scenarios [3] and synchronicity-sensitive use cases [4].

Despite the numerous demonstrations revealing the potential of the above enabling technologies, the challenge of co-integrating them in a cooperative and cost-efficient manner into a flexible and sliceable network of a multi-tenant optical infrastructure still remains. In this regime, small scale laboratory experiments have shown that transparent optical nodes can concurrently handle heterogeneous data streams, aggregating the traffic stemming from different Mobile Network Operators' (MNO)s' transceivers (TxRx) and steer it to any RU, upon request, based on the profile of the service to be delivered, actively interconnecting the MNO's centralized CU/DUs to RUs in a flexible, low-latency, cost-efficient manner [5].

In this paper, we demonstrate real-time operation on the first deployment of a large-scale reconfigurable, protocol-agnostic, X-haul optical infrastructure, simultaneously accommodating Digital Radio-over-Fiber (D-RoF), SDoF and A-RoF streams and enabling active routing via Software-Defined Network (SDN) controllable tunable transmitters. The reconfigurable optical transport paths were deployed by using a passive, cost-efficient Array Waveguide Grating Router (AWGR) device, enabling internetworking among fiber and Fiber-Wireless (FiWi) links, comprising programmable optical interfaces and mmWave radio units. For the D-RoF segment, Small Form-Factor Pluggable (SFP)-compatible E-band units established Fiber-Wireless-Fiber

Fig. 1 Architectural layout of the proposed flexible, hybrid optical transport deployment including A-RoF, D-RoF, SDoF links.

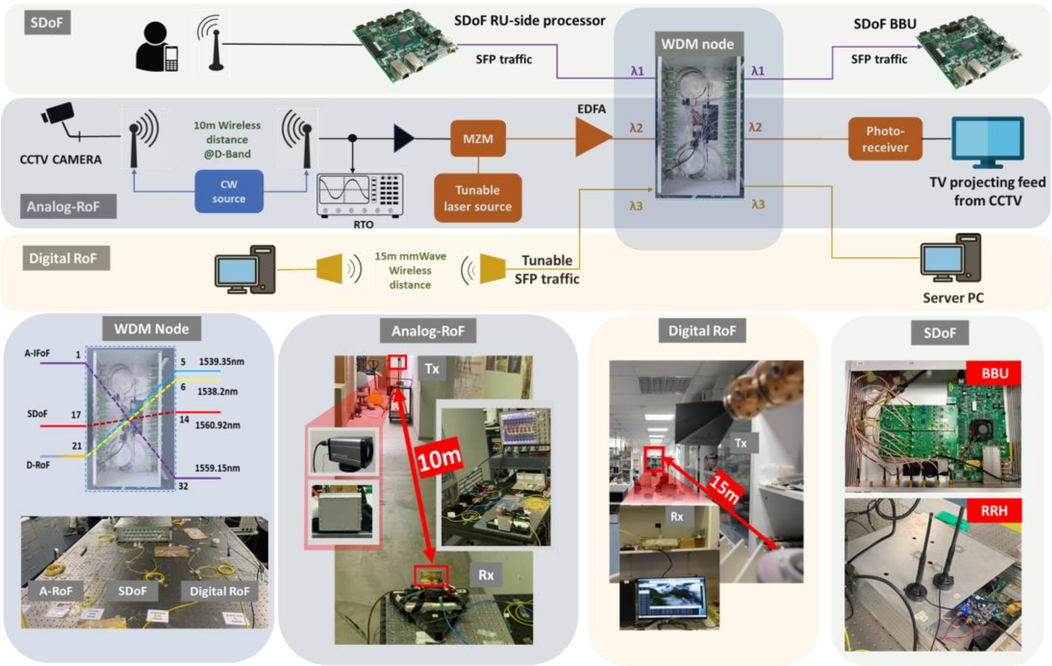

Fig. 2. Schematic of the proposed network deployment.

(FiWiFi) bridge connectivity for scenarios where the optical fibers are not available, while a set of prototype D-band TxRx units with analog interfaces were used to establish a high-capacity D-band/A-RoF layout to deliver Gbps Ultra High Definition (UHD) video transmission over an analog link. Over all three alternative paths, the delivery of mobile services was achieved simultaneously, including a 1.5Gbps video transmission over the analog path, as well standard mobile services over the SDoF link, enabled via the integration with an Amarisoft 5G Core.

Proposed RAN Architecture and Testbed Layout

Fig.1 shows the proposed multi-technology RAN architecture, which relies on the flexible optical interconnection of different MNOs' DU/CUs to heterogeneous remote radio terminals. The envisioned X-haul is capable to support access connectivity request with different Key Performance Indicators (KPIs). Enhanced capacity is delivered via the analog wired-wireless directional lanes, exploiting the extreme bandwidth offering of the mmWaves (i.e. D-band), while synchronization-critical use cases, including distributed MIMO communication, are accommodated through dedicated SDoF streams, in parallel to the standard 5G cells.

Fig. 2 depicts the proposed network deployment. The simultaneous transmission of the three transport schemes relied on a 32×32 AWGR with 100 GHz channel spacing [5]. For each one of the deployed links (analog, digital and SD), tunable laser sources were used, enabling dynamic routing through the node. The Wireless-Fiber (WiFi) link carried BPSK signals of 1.5 GHz bandwidth, generated by a HD CCTV camera, emulating the uplink segment of the analog-based transport path. The output of the camera was connected to a Tx D-band radio unit, comprising of a 12x multiplication mixing board for frequency up-conversion at 156 GHz, as described in [6]. An identical Rx antenna module located at 10m horizontal distance was used to setup a directional Point-to-Point (PtP) link. The output of the latter was amplified to drive a Mach Zehnder Modulator (MZM), which was fed with a Continues Wave (CW) optical signal at 1559.15nm. The modulated data signal was amplified, lead to the AWGR and then opto-electronically converted back to the initial signal by a 10GHz linear photoreceiver, the output of which was connected to a 4k TV via an HDMI cable. For the implementation of the digital stream, a set of tunable 10G SFP transceivers were connected to a pair of E-band radio boards placed at 15m distance, thus leading to the realization of a FiWiFi path, reconfigurable in real time via commercial Network Cards (NC). The SDoF part was based on the implementation reported in [4], extended to support real-time mobile traffic. To this end, mobile traffic originating from an Amarisoft 5G software implementation was modulated by the SDoF DU-module and transported over the fiber network. An SDoF compatible Remote Radio Unit (RRU) was used to transmit the signal, in bidirectional configuration, supporting live traffic with commercial User Equipment (UE).

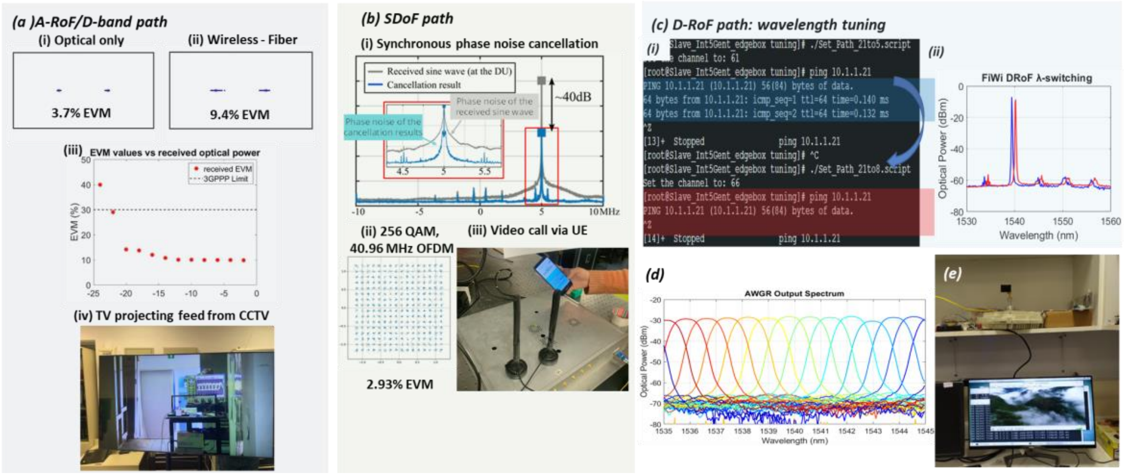

Fig. 3 (a) D-band/A-RoF (i) EVM results after analog fiber, (ii/iii) WiFi transmission and (iv) CCTV video projection, (b) SDoF (i/ii)data plane results and (iii) video call via UE connected to 5G, (c) Core D-RoF SFP wavelength tuning, (d) AWGR frequency channels and (e) UHD video transmission over D-RoF link.

Experimental Results and Real-Time Services

The proposed topology was initially evaluated towards physical layer KPIs, while excellent service delivery was later shown over all three X-haul links. The spectral response of the AWGR was characterized, featuring a flat-top channel response with a 3dB bandwidth of 0.6nm, as shown in Fig. 3(a) for 15 channels between 1535 nm and 1545 nm. For the analog link, Fig. 3(a) illustrates the EVM values and constellation diagrams that were captured after WiFi transmission. For performance evaluation purposes, an Arbitrary Waveform Generator and a Real Time Oscilloscope were used to generate and capture 1.5GBd BPSK signal emulating the CCTV camera traffic. The demodulated received signals exhibited 3.7% EVM in case of optical and 9.4% in case of FiWi transmission. In both cases, the EVM was well below the threshold set by 3GPPP for BPSK modulation [7], while acceptable EVM values were also achieved for optical power values above -22 dBm. Moreover, for the SDoF link, the phase synchronicity between two RRUs was validated (Fig. 3(b)). A sine-wave at 3.691 GHz (5 MHz offset of Carrier Frequency (CF)) was received by two different RRUs, the average and difference between the two received signals are shown after amplitude and phase alignment. The results show a 40 dB interference suppression. Further, a 4x1 Multiple Input-Single Output link was setup using 2 antennas of 2 RRUs. A 40.96 MHz 256-QAM OFDM signal was transmitted. Channels between the different TXs and the RX were estimated, and the different TX signals were compensated, to realize joint coherent transmission, owing to the tight phase synchronization of the SDoF network, resulting in -30.66 dB EVM.

As a next step, to demonstrate the capability of the proposed X-haul topology to support various service requirements, the D-band/analog, SDoF and D-RoF FiWiFi links, were simultaneously fed to the AWGR device, carrying HD video and mobile services. As shown in Fig. 3(a-iv), the HD video recording of the CCTV camera was projected to a 4K TV after analog WiFi propagation, while end-to-end service delivery was successfully demonstrated over the SDoF link via IP video calls performed through UE, interconnected to the Amarisoft 5G Core (Fig. 3(b-iii)). Parallel to these streams, the establishment of D-RoF/mmWave FiWiFi was showcased, using 4K UHD video streaming (Fig.3(e)). After establishing service-layer connectivity over all three lanes, the SDN reconfigurability capability of the node was demonstrated for the D-RoF case, relying of wavelength switching of the employed tunable SFP TxRxs. The switching functionality demonstrated via capturing ping traffic statistics and optical spectrum in Fig. 3(c), showing the live shift from 1539.35nm to 1541.7nm

Conclusions

We demonstrated for the first time a Gbps-scale radio access network, enabled by A-RoF/D-band, SDoF and D-RoF transport technologies, in a flexible optical X-haul layout for 6G. The installed topology was evaluated towards physical layer KPIs, while excellent service delivery was shown over all three X-haul links. Dynamic traffic routing was also showcased, relying on SDN-enabled flexible optical transmitters feeding a transparent AWGR-based node.

Acknowledgements

The work is supported by H2020 5GPPP Phase II project Int5Gent (957403).

References

[1] G. Kalfas, "Next generation fiber-wireless fronthaul for 5G mmWave networks," IEEE Com. Mag. 57 (3), 2019)..

[2] A. Kanno et al., "High-Speed Railway Communication System Using Linear-Cell-Based Radio-Over-Fiber Network and Its Field Trial in 90-GHz Bands," in Journal of Lightwave Technology, vol. 38, no. 1, pp. 112-122, 1 Jan.1, 2020.

[3] C. Vagionas et al., "End-to-End Real-Time Service Provisioning Over a SDN-Controllable Analog mmWave Fiber -Wireless 5G X-Haul Network," in Journal of Lightwave Technology, vol. 41, no. 4, pp. 1104-1113, 15 Feb.15, 2023, doi: 10.1109/JLT.2023.3234365

[4] C.-Y. Wu, H. Li, J. Van Kerrebrouck, C. Meysmans, P. Demeester, and G. Torfs, “A Bit-Interleaved Sigma-Delta-Over-Fiber Fronthaul Network for Frequency-Synchronous Distributed Antenna Systems,” *Applied Sciences*, vol. 11, no. 23, p. 11471, Dec. 2021,

[5] R. Maximidis *et al*., "A Centralized and Reconfigurable 4x2.5Gb/s Fiber-Wireless mmWave Fronthaul for Network Sharing Applications," *2021 European Conference on Optical Communication (ECOC)*, Bordeaux, France, 2021, pp. 1-4

[6] Yu, W.; Vosoogh, A.; Wang, B.; He, Z.S. Substrateless Packaging for a D-Band MMIC Based on a Waveguide with a Glide-Symmetric EBG Hole Configuration. Sensors 2022, 22, 6696. https://doi.org/10.3390/s22176696

[7] 3GPP TSG-RAN5 Meeting #94-eR5-220914 Online, 21st Feb 2022 - 4th Mar 2022