

# A Centralized and Reconfigurable 4x2.5Gb/s Fiber-Wireless mmWave Fronthaul for Network Sharing Applications

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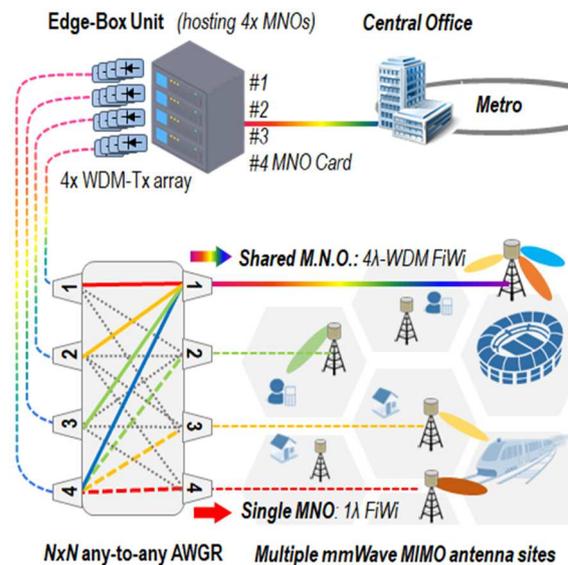
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**Abstract** A centralized, reconfigurable Fiber-Wireless fronthaul selectively allocating 4 $\lambda$ -WDM channels of 2.5 Gb/s 16-QAM IFoF to four 60 GHz Phased Array Antennas through an all-passive AWGR is experimentally presented for the first time towards multi-operator/tenant 5G C-RANs that interconnect any edge-unit interface to any cell-site.

## Introduction

The dawning of the 5G era has been driving a relentless growth of data traffic in the edge and Radio Access Network (RAN) through a series of new services [1], e.g. enhanced Mobile Broadband (eMBB), Fixed Wireless Access (FWA), etc... While such scenarios require peak data-traffic capacities of 10-20 Gb/s to the antenna cell site [2], the latest visions for the next-generation era (IMT 2030) [3] are forecasting abundant bandwidth everywhere with even 10 Gb/s links for indoor hotspots, setting clear targets for peak traffic demands. To efficiently transport such immense capacities, spectrally efficient analog Radio over Fiber (RoF) schemes [4] have started being interfaced with millimeter-Wave (mmWave) Phased Array Antenna (PAAs) [6], with up to 4 Gb/s WDM data-traffic delivered at a 4 $\lambda$ -FiWi V-band small cell with 360° coverage [7] or up to 6 Gb/s over a single PAA beam [8], yet most of these works target optimizing only a single dedicated link to a specific cell-site or single mmWave beam, requiring a viable path towards complete fronthaul system solutions.

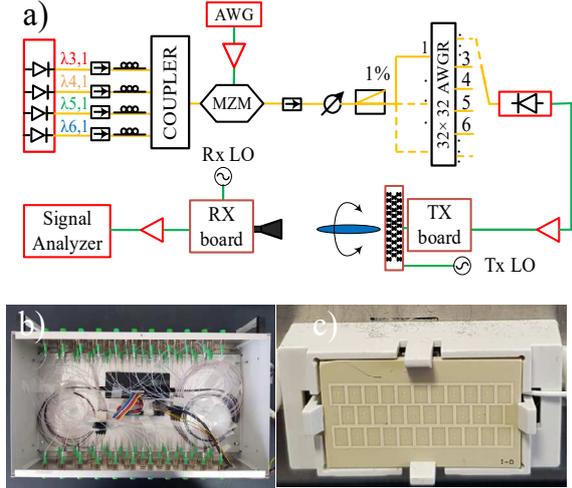
However, building complete FiWi fronthaul systems needs to take into account distinctive aspects of mmWave. On the one hand, C-RAN bearing promises to satisfy the long-term needs of mobile networks by dynamically connecting multiple Remote Radio Heads (RRHs) to a centralized pool of Based Band Units (BBUs) [9], forming Point-to-Multipoint (PtMP) architectures with statistical multiplexing of hardware. Building an adaptive, reconfigurable FiWi network that can steer the bandwidth and transported beams is only one side of the story. On the other hand, the penetration of mmWave in the RAN requires an ultra-densification of mmWave RRHs, where dense PAA installations may become prohibitively expensive for a single traditional wide-area Mobile Network Operators



**Fig. 1:** Conceptual diagram of the proposed point to multi-point FiWi C-RAN architecture allocating 4x 2.5Gb/s FiWi IFoF mmWave downlink of four Mobile Network Operators (MNO) either over a shared 4 $\lambda$ -WDM FiWi PAA system or to four dedicated single-wavelength links for each MNO.

(MNOs) of sub-6GHz RANs, especially in private areas, e.g. large-enterprise facilities, university-campuses. All the above have been stimulated the rise of new network management and business models, where infrastructure and service-provisioning can be handled by the actual property owners, referred to as micro-operators ( $\mu$ O), that may even share spectrum or fiber access to external MNOs [10]. To this end, centralized and reconfigurable FiWi mmWave fronthaul architectures are promising to interconnect various optical interfaces and BBU infrastructures of a multi-tenant MNO Edge-Box to several mmWave antennas.

In this work, we demonstrate for the first time a centralized and wavelength reconfigurable FiWi fronthaul architecture that can selectively allocate 4 $\lambda$ -WDM channels of 2.5 Gb/s 16-QAM IFoF to four 60 GHz PAAs with 90° degrees



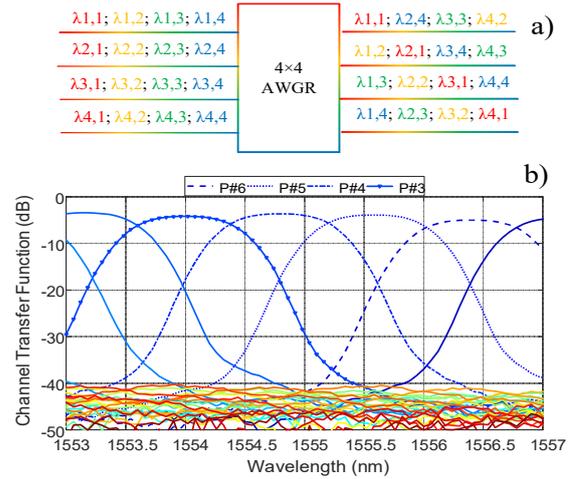
**Fig. 2:** a) Experimental setup of the FiWi fronthaul , b) Photo of rack-mounted AWGR, c) 60GHz Phased Array Antenna.

beamsteering capabilities and 1m V-band distance. Relying on an all-passive AWGR, the current architectures can effectively interconnect any optical fronthaul interface of a multi-tenant edge box unit to any mmWave PAA, achieving for the first time a 10 Gb/s aggregate FiWi IFoF/60GHz capacity through beamsteering mmWave PAA that satisfying the respective peak-traffic KPI for the cell-site traffic.

### Concept and Experimental Setup

An indicative illustration of our proposed centralized and reconfigurable FiWi architecture is shown in Fig. 1, comprising an Edge-Box that hosts  $N=4$  linecards dedicated to an equal number of M.N.O., that can backhaul the mobile traffic to their central offices. Specifically, each edge-box linecard would require a  $4\lambda$  multi-wavelength optical Tx array to generate four WDM streams. The  $4\lambda$  WDM output streams are fiber-connected to the four input-ports of a low-loss, polarization-independent AWGR, whose outputs are fiber-connected at various multi-beam mmWave PAAs.

Introducing an AWGR as an all-passive wavelength router to the front-panel of an Edge-Box facilitates any-to-any interconnectivity. As can be seen in Fig. 1, the proposed FiWi fronthaul supports reconfigurable allocation of a  $4 \times 2.5\text{Gb/s}$  WDM FiWi IFoF mmWave downlink traffic of the fourth MNO from input port #4 to four different AWGR output-ports, as indicated with colorful dotted lines in the AWGR, and respectively four different 60GHz PAAs deployed in the network. At the same time, the AWGR can concentrate four individual FiWi downlink-wavelengths from the four different AWGR input-ports, that stream from four different MNO, routing them to a single WDM

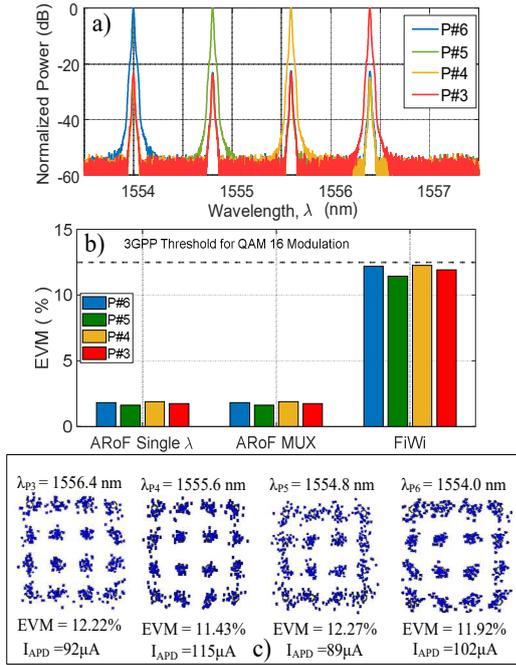


**Fig. 3:** a) A  $4 \times 4$  AWGR functionality; b) transfer function of the 4 used channels of  $32 \times 32$  AWGR for the experiment.

optical stream at the first AWGR output port, as indicated with the solid colorful lines in Fig.1, over common and shared FiWi link to a certain cell-site location, e.g. a hotspot with a temporarily high peak. This work emphasizes on 60GHz mmWave PAAs, yet the concept can be extended to multi-RAT technologies across different mmWave bands or macro-cell towers.

The physical layer of the proposed topology was validated using the setup in Fig. 2, which emulates the  $4\lambda$  WDM-transmission of the Edge-Box, AWGR operation, and the PAA-systems at the small-cell locations. Four output lasers at different wavelengths were combined through  $4 \times 1$  coupler and modulated by a  $\text{LiNbO}_3$  Mach Zehnder Modulator (MZM), by an IFoF radio signal. The signal was generated by an Arbitrary Waveform Generator (AWG). The  $4\lambda$ -WDM output of the MZM is connected to a  $32 \times 32$  AWGR with 100 GHz channel spacing, while each input port can demultiplex the traffic to four outputs. The AWGR optical output was then propagated through a 1km fiber distance before reaching a 10 GHz InGaAs Avalanche Photodiode (APD), where it was optoelectronically converted and fed to the PAA system with up to  $90^\circ$  degrees beam-scanning range in the horizontal plane. The PAA integrates 32 radiating elements with 6dBi gain, each connected to a phase shifter and a Power Amplifier. Adjusting the values of phase shifter, a scanning range of  $90^\circ$  is achieved at an operational IFoF bandwidth between 3-5GHz.

On the other side, the receiver consists of a high-gain (23 dB) horn antenna, connected to a receiver that can receive a signal in a range of 57-66 GHz and down-convert it to DC – 12 GHz signals, depending on the externally provided Rx LO frequency. In the current experiments it



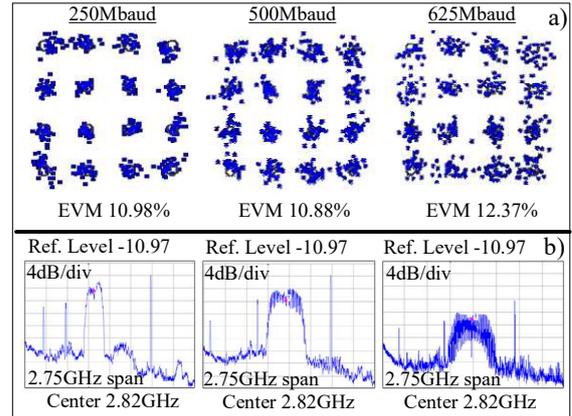
**Fig. 4:** a) Spectrum and crosstalk measurement and b) EVM and constellation diagrams of 4 $\lambda$  WDM FiWi 16-QAM 250 MBd and c) EVM degradation for single channel, 4 $\lambda$  WDM RoF and 4 $\lambda$  WDM FiWi transmission through the AWGR

was tuned between 9.3GHz and 9.5GHz. Finally, the received signal is amplified by and 25dB amplifier.

### Experimental Results

Initially, targeting to evaluate the suitability of the AWGR for fronthaul applications, we performed a static characterization, by feeding ASE noise or CW laser source at input port 1 to evaluate the transfer function at all output ports and the polarization dependence. The average losses of the AWGR were found to be only 4 dB, with a polarization dependence of <0.8 dB, indicating that it can be accommodated in fiber-access and fronthaul links of challenging power budgets. The transfer function for the four chosen channels is shown in Fig. 3(b), at wavelengths 1554.0 nm, 1554.8 nm, 1555.6 nm, and 1556.4 nm, confirming a flat top response with a 3 dB bandwidth of around 0.6nm. Channel crosstalk below -20 dB was measured, introducing non-detectable signal distortion.

To further validate the negligible crosstalk, two sets of data-transmission measurements were performed in the RoF section. The modulation signal used was a 16-QAM 250Mbaud PRBS7 signal with 700 mV<sub>pp</sub> placed on 4.9GHz IF carrier. In the first set of experiments in order to analyze the single lambda behaviour and wavelength tuning, each laser was opened sequentially with the rest of the lasers to be set OFF. The measured EVMs are shown in Fig.



**Fig. 5:** The 16QAM constellation diagram (a) and spectrum (b) for three different symbol rate signals.

4(b) as “ARoF Single  $\lambda$ ”, Next, all lasers were set ON and the EVM of each output of the AWGR was recorded. As clearly seen in Fig.4(b) as “ARoF MUX”, the performance is the same as in the previous case, confirming that coupling at the AWGR ports does not have a noticeable impact on signal quality.

Having evaluated the co-existence of 4 $\lambda$  WDM IFoF/RoF streams with negligible crosstalk, we performed a 4 $\times$  WDM FiWi data-transmission experiment through the PAA, by connecting the APD output to an amplifier and the PAA. After 1m of V-band wireless transmission at a 0 $^\circ$  beamsteering angle, while the constellation diagrams and EVM values of the received signals at the output of the horn-Rx antenna were recorded. The recorded EVM values shown in Fig.4(b) as “FiWi MUX” were at a roughly equal level for all four ports, being below the 12.5% threshold set by 3GPP, with clearly demodulated constellation diagrams, Fig. 4(c).

Finally, to evaluate the maximum transmission capacity, the symbol rate was increased from 250 to 500 and 625 Mbaud, which corresponds to an increase in the FiWi data rate from 1, to 2 and 2.5 Gb/s. The constellation diagrams of the signals received by the horn Rx after FiWi transmission are shown in Fig. 5, featuring EVM below 12.5% for all symbol rates, meeting the respective 3GPP EVM requirements, while at the same time satisfying for the first time to the author’s knowledge the respective 5G KPI requirement for a 10 Gb/s aggregate peak-data traffic capacity through FiWi mmWave/IFoF links with PAA beamsteering.

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## References

- [1] G. Brown, "Exploring 5G New Radio: Use Cases, Capabilities & Timeline," Qualcomm White Paper, Sept. 2016
- [2] Next Generation Mobile Networks Alliance, "5G White Paper," 2015.
- [3] R. Li, "Network 2030: Market drivers and prospects," ITU Workshop on Network 2030, New York, Oct. 2018.
- [4] C. Lim, Y. Tian, C. Ranaweera, N. Ampalavanapillai, E. Wong, K.L. Lee, "Evolution of Radio-over-Fiber Technology" *IEEE J. Lightwave Technology*, vol. 37, no. 6, pp. 1647-1656, Mar. 2019.
- [5] T. S. Rappaport et al., "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," in *IEEE Access*, vol. 1, pp. 335-349, 2013
- [6] W. Hong et al., "Multibeam Antenna Technologies for 5G Wireless Communications," in *IEEE Transactions on Antennas and Propag.*, vol. 65, no. 12, pp. 6231-6249, Dec. 2017.
- [7] A. Tsakyridis, et. al. "Reconfigurable Fiber Wireless IFoF Fronthaul with 60 GHz Phased Array Antenna and Silicon Photonic ROADMs for 5G mmWave C-RANs," *IEEE JSAC*, 2021, article in press
- [8] M.Y. Huang, et. al., "A Bi-Directional Multi-Band, Multi-Beam mm-Wave Beamformer for 5G Fiber Wireless Access Networks," *IEEE J. Lightwave Technology*, vol. no. 4, pp. 1116-1124, Feb. 2021|
- [9] A. Checko, H. L. Christiansen, Y. Yan, L. Scolari, G. Kardaras, M. S. Berger, L. Dittmann, "Cloud RAN for mobile networks—A technology overview," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 1, pp. 405-426, Sep. 2014.
- [10] M. Matinmikko, et. al. "Micro Operators to Boost Local Service Delivery in 5G," *Wireless Personal Communications* volume 95, pages 69–82 (2017)