Delivery of Wireless and Wired Services Using a Single-drive Mach-Zehnder Modulator for Bidirectional Radio-over-Fiber Systems

Ming Zhu[1], Liang Zhang[2], Cheng Liu[1], Shu-Hao Fan[1], and Gee-Kung Chang[1]
[1]School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250 USA
[2]Shanghai Jiao Tong University, Shanghai 200240 China
mzhu39@gatech.edu

***Abstract*—We designed and experimentally demonstrated a cost-effective RoF system for downstream 1-Gb/s OOK/BPSK and 2-Gb/s 16QAM-OFDM signals using only one single-drive MZM by driving both RF and bias ports, and upstream 1-Gb/s OOK signal.**

I. INTRODUCTION

THE increasing demand for both wired and wireless gigabit communication has attracted strong research interests on radio-over-fiber (RoF) system. Especially for wireless services employing the 7-GHz license-free spectrum located at 60GHz are crucial to future super broadband wireless access system [1]. Orthogonal frequency division multiplexing (OFDM) technology, due to its high tolerance against fiber chromatic and polarization-mode dispersion, has been deployed to offer high bandwidth efficiency in millimeter-wave (MMW) RoF system. In previous works, independent downlink (DL) wired and wireless data are generated by two Mach-Zehnder modulators (MZM) [2], or by a dual-parallel MZM [3]. It was commonly believed that Single-drive MZM can only generate one or multiple identical channels. For the first time, we demonstrated that a simple and low-cost full-duplex RoF system with one single-drive MZM in transmitter can be deployed. It simultaneously delivers gigabit wireline data and multiband wireless services by driving both RF and bias ports of the MZM. We experimentally demonstrated dowstream 1-Gb/s baseband data using both on-off keying (OOK) and (BPSK) formats for wireline user and 2-Gb/s 16 quadrature amplitude modulation-OFDM (16QAM-OFDM) for wireless user, together with 1-Gb/s upstream OOK signal based on wavelength-reuse scheme. The interference between wired and wireless signal, as well as the proper design for uplink (UL) transmission are analyzed in this paper. The novel RoF system can reduce the cost for future broadband access network.

II. PRINCIPLE

Fig. 1 illustrates the conceptual diagram of the proposed scheme. The generated 16QAM-OFDM signal is mixed with a 30GHz local oscillator (LO) to drive the radio frequency (RF) port of the single-drive MZM. At the receiver the optical carrier and two subcarriers are separated by an interleaver (IL). After the high speed square-law photodiode (PD), the vector signal carried at 60GHz is sent to the wireless user. Linear term of the OFDM signal can be retrieved through LO enhancement [4]. The bias port of the MZM is driven by a small baseband signal with a direct current (DC) bias V_{bias}. The system will have the optimum performance when V_{bias} equals to V_{π}. In this case the bias voltage swing near V_{π} due to the applied wired data and MZM is operating close to the null power point, which is equivalent to the generation of a binary phase shift keying (BPSK) signal. At the same time the OFDM signal experience the minimun inteference because of the constant amplitude of the BPSK siganl. Therefore the amplitude of the OFDM signal

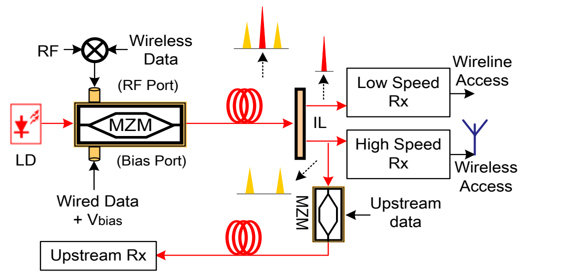

Fig. 1. Schematic diagram of the proposed RoF system with independent wired and wireless data driven by a single-drive MZM.

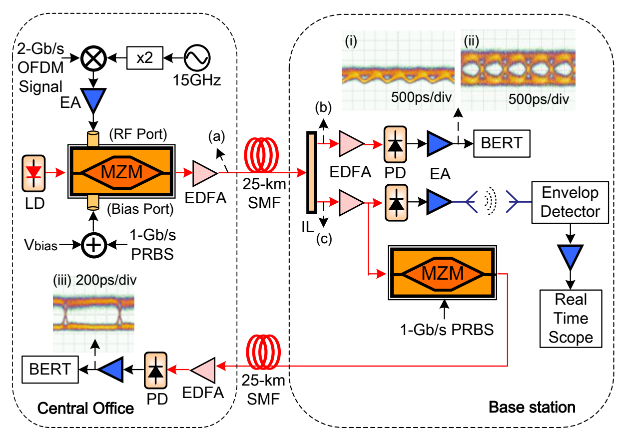

Fig. 2. Experimental setup for the proposed RoF system. Inset (i) The eye diagram of DL BPSK signal. (ii) The eye diagram of DL OOK signal. (iii) The eye diagram of UL OOK signal.

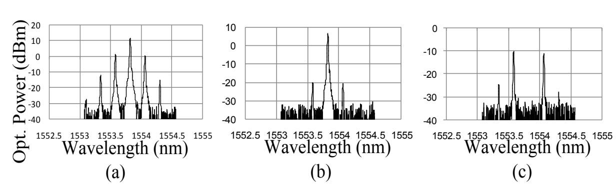

Fig. 3. Optical spectra at different locations labled in Fig. 2.

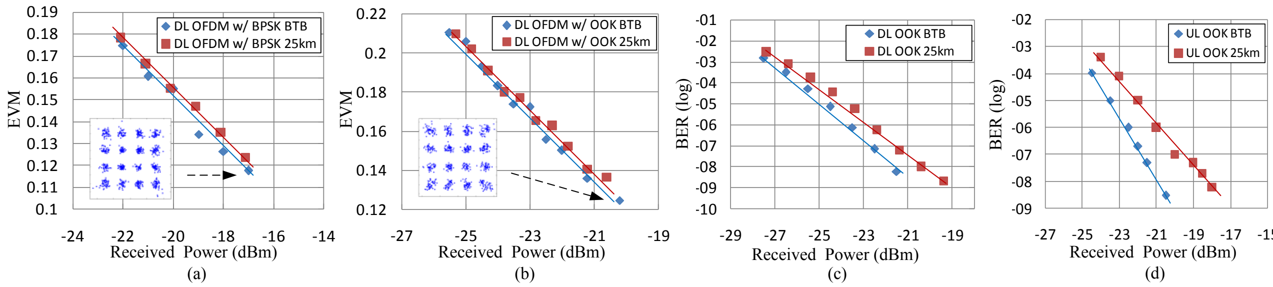

Fig. 4. EVM values and BER performances. (a) DL wireless OFDM signal with wired BPSK signal. (b) DL wireless OFDM signal with wired OOK signal. (c) DL wired OOK signal. (d) UL OOK signal.

can be small in order to obtain a better performance of the upstream OOK data based on the wavelength-reuse method. On the other hand, when V_{bias} equals to $V_{\pi/2}$ the center carrier can be viewed the same as an OOK modulated light. However the two subcarriers are also subjected to the changing bias voltage near $V_{\pi/2}$. The peak-to-peak voltage (Vpp) of the OFDM signal needs to be larger in order to overcome the inteference, which results in an inferior performance of UL transmission.

III. Experimental Setup and Results

Fig. 2 shows the experimental setup for the low-cost bidirectional RoF system. The downstream two-band 2-Gb/s OFDM signal is genenrated by the Tektronix arbitrary waveform generator (AWG) sampled at 2.5 GSa/s. The intermediate frequency (IF) for two different bands is 250MHz, 625GHz respectively, and each IF carries 250-Mb/s 16QAM-OFDM data with 512 subcarriers. This vector signal mixed with a 30-GHz RF source drives the RF port of a single-drive MZM. The 1-Gb/s pseudorandom binary sequence (PRBS) data with 0.5-V Vpp with a V_{bias} offset is sent to the bias port without electrical amplifier (EA). The output optical spectrum of the central office is shown in Fig. 3(a). After 25-km standard single-mode fiber (SMF) transmission lightwaves are separated by an IL in the base station to a center carrier and two subcarriers whose optical spectra are shown in Fig. 3(b) and (c). The wired user detects BPSK or OOK data from the center carrier with a low speed PD. The two subcarriers spaced at 60GHz are splitted by a 3-dB power splitter. One output is fed to a high speed PD and transmitted wirelessly. The received radio signal is downconverted by an envelop detector and sent to the 2.5-GSa/s LeCroy WM818Zi oscilloscope for the offline processing. The signal from the other output is OOK re-modulated through a MZM driven by 1-Gb/s PRBS upstream data.

We change the offset of the baseband signal fed to the bias port to obtain two sets of experimental results. First, the V_{bias} is set to V_{π} to achieve the best system performance. The eye diagram of the 1-Gb/s BPSK signal for wired user is shown as inset (i) in Fig. 2. Due to the insufficient facility, BPSK performance is not measure. The Vpp of OFDM signal generated by AWG is 0.1V. Fig. 4(a) illustrates the EVM measurements of downstream 16QAM-OFDM signal for both back-to-back (BTB) and 25-km fiber transmission cases. Next, the V_{bias} is changed to $V_{\pi/2}$ and wired user receives OOK signal correspondingly, shown as inset (ii) in Fig. 2. Vpp of OFDM signal increases to 0.3V in order to achieve desirable results. The EVM value vs. received optical power is shown in Fig. 4(b). The clear constellations are inserted in Fig. 4(a) and (b). The bit error rate (BER) performance vs. received optical power for the DL OOK is illustrated in Fig. 4(c). The DL OFDM signal experiences a small power penalty caused by fiber dispersion, while the OOK signal has 1-dB power penalty. For the UL, We only measure the performance in the first case, where the amplitude of OFDM signal is small. The eyediagram of the UL 1-Gb/s OOK signal is shown as inset (iii) in Fig. 2. As expected, the interference from the reused fluctuating light power is minor. The BER performance is illustrated in Fig. 4(d). 2dB power penalty due to fiber dispersion is observed.

The EVM limit of OFDM signal, compared to 0.1175 in the first case with OFDM and BPSK for DL services, is 0.1245 in the second case. The amplitude of OFDM signal is three times larger than the first case. On one hand, the large Vpp of OFDM signal deteriorates the UL transmission due to the unstable optical power for wavelength-reuse. However, on the other hand, the received optical power for OFDM is less required. In summary, V_{bias} at V_{π} overall gives a better bidirectional system performance, while V_{bias} at $V_{\pi/2}$ only offers satisfiable DL services.

IV. Conclusion

We proposed a novel scheme to transmit independent gigabit downstream wired and wireless services by employing a single-drive MZM in a bidirectional 60-GHz RoF system to reduce the system cost. 25-km transmission of 1-Gb/s OOK/BPSK and 2-Gb/s 16QAM-OFDM for downstream, 1-Gb/s OOK for upstream has been experimentally demonstrated. We believe it significantly simplifies the system design and reduces the operation complexity for simultaneously delivering independent broadband wired and wireless access services.

References

[1] A. M. J. Koonen, *et. al.*, “Radio-Over-MMF techniques-Part II: Microwave to millimeter-wave systems,” *J. Lightw. Technol.*, vol. 26, no. 15, pp. 2396-2408, Aug. 1, 2008.

[2] Y.-T. Hsueh;, *et. al.*, "A Novel Lightwave Centralized Bidirectional Hybrid Access Network: Seamless Integration of RoF With WDM-OFDM-PON," *IEEE Photon. Technol. Lett.*, vol.23, no.15, pp.1085-1087, Aug.1, 2011.

[3] W.-J. Jiang, *et. al.*, "Simultaneous Generation and Transmission of 60-GHz Wireless and Baseband Wireline Signals With Uplink Transmission Using an RSOA," *IEEE Photon. Technol. Lett.*, vol.22, no.15, pp.1099-1101, Aug.1, 2010.

[4] C. Liu, *et. al.*, "Multi-band 16QAM-OFDM vector signal delivery over 60-GHz DSB-SC optical millimeter-wave through LO enhancement," in *Proc. OFC/NFOEC 2011*, Paper OThJ2.