Bidirectional Full-duplex Delivery of 103Gbps PS-256QAM Signals over 20-km SMF and 4600-m Wireless

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Abstract: We have experimentally demonstrated photonics-aided bidirectional full-duplex delivery of 103Gbps PS-256QAM signals over 20-km single-mode fiber wireline link and 4600 m wireless link based on the polarization-division-multiplexing scheme and advanced DSPs.

1. Introduction

The fiber-wireless-integration mm-wave system architecture can provide broadband delivery and rapid deployment at a low cost [1-4]. Based on the bidirectional system architecture, the photonics-based fiber-wireless-integration communication systems have been experimentally demonstrated in recent years [5-8]. In Ref. [5], 2 and 2.5 Gbps OOK signals carried by 74 and 84 GHz carrier frequencies can be transmitted with a low spectral efficiency. In Ref. [6], Li et al. have demonstrated the 54 Gbps 8QAM signals transmission at the W-band and 32 Gbps 16QAM signals transmission at the K-band over the fusion link of 20 km fiber-optic and 2500 m RF wireless. Although it created the record of rate-distance product (215 Gbps•km) at that time, the uplink and downlink channels in the system are completely independent, which leads to a complex system structure and high cost. In Ref. [7], Wang et al. have demonstrated the bidirectional full-duplex transmission over 100 Gbps date rate at the E-band. However, the system can only support a 2 m wireless transmission. In addition, the carrier frequencies of uplink and downlink links in above systems are different [5-7], which will undoubtedly occupy the limited radio spectrum resources [8-9].

In this paper, we have experimentally demonstrated photonics-aided bidirectional full-duplex delivery of 103Gbps PS-256QAM signals over 20-km SMF and 4600-m wireless based on the polarization-division-multiplexing scheme and advanced DSPs. Different from the previously demonstrated bidirectional full-duplex communication systems [5-7] in which there are low rate-distance products and different carrier frequencies for carrying signals, in our novel architecture only one carrier frequency is required to simultaneously support the high-speed signals transmission for both uplink and downlink. The adoption of polarization division multiplexing technology can double the transmission capacity and support bidirectional full-duplex communication [10-11]. In addition, the OFDM scheme can resist dispersion effects in fiber-optic transmission and the wireless multipath effects [11-12]. Advanced DSPs, including probabilistic shaping (PS) technology, high-order modulation format, and a series of algorithms, can enhance the throughput and spectral efficiency of system. For all we know, based on a photonics-aided bidirectional full-duplex system, this is the first time to realize a record-breaking rate-distance product at the W-band, i.e., 103 Gbps × 4.6 km = 473.8 Gbps•km.

2. Experiment Setup

Fig. 1 presents the experimental setup of our bidirectional full-duplex communication system. There are two orthogonal polarization channels centered at the same carrier frequency, one of which is horizontally polarized and the other is vertically polarized. For simplicity, we use 'Ch. H' and 'Ch. V' as labels in Fig. 1, respectively. The carrier center frequencies of Ch. H and Ch. V are both set as 88.5 GHz, which can simultaneously carry OFDM signals for transmission in two opposite directions. For Ch. V, ECL1 and ECL2 are used to generate CWs, which work at 1550 nm and 1550.708 nm, respectively. The CW generated by ECL1 is used to drive an I/Q modulator (I/Q MOD) with a 3 dB bandwidth of 30 GHz. The digital signals, including the real/imaginary parts of OFDM signals generated by MATLAB software, are converted into I/Q path analog signals with the help of an arbitrary waveform generator (AWG). The I-path and Q-path analog electrical signals output from the AWG are amplified by a pair of parallel electric amplifiers (EAs) with 25 dB gain, and then modulated by the I/Q modulator. Next, the output optical signals from the I/Q modulator, carrying the OFDM data, are amplified by a PM-EDFA to compensate for the insertion loss of the modulator. Then they are coupled with the CW generated by ECL2 through a polarization-maintaining optical coupler (PM-OC). After 20 km SMF transmission, the optical signals enter into a variable optical attenuator (ATT) to facilitate changing the input optical power into the photodiode (PD).

The mm-wave signals output from PD are boosted by a low noise amplifier (LNA1, 21 dB gain) and power amplifier (PA, 20 dBm Past) successively. Subsequently, we use a pair of Orthomode Transducers (OMT1 and OMT2) as H/V diplexers for communication links to separate the dual orthogonally polarized channels at the

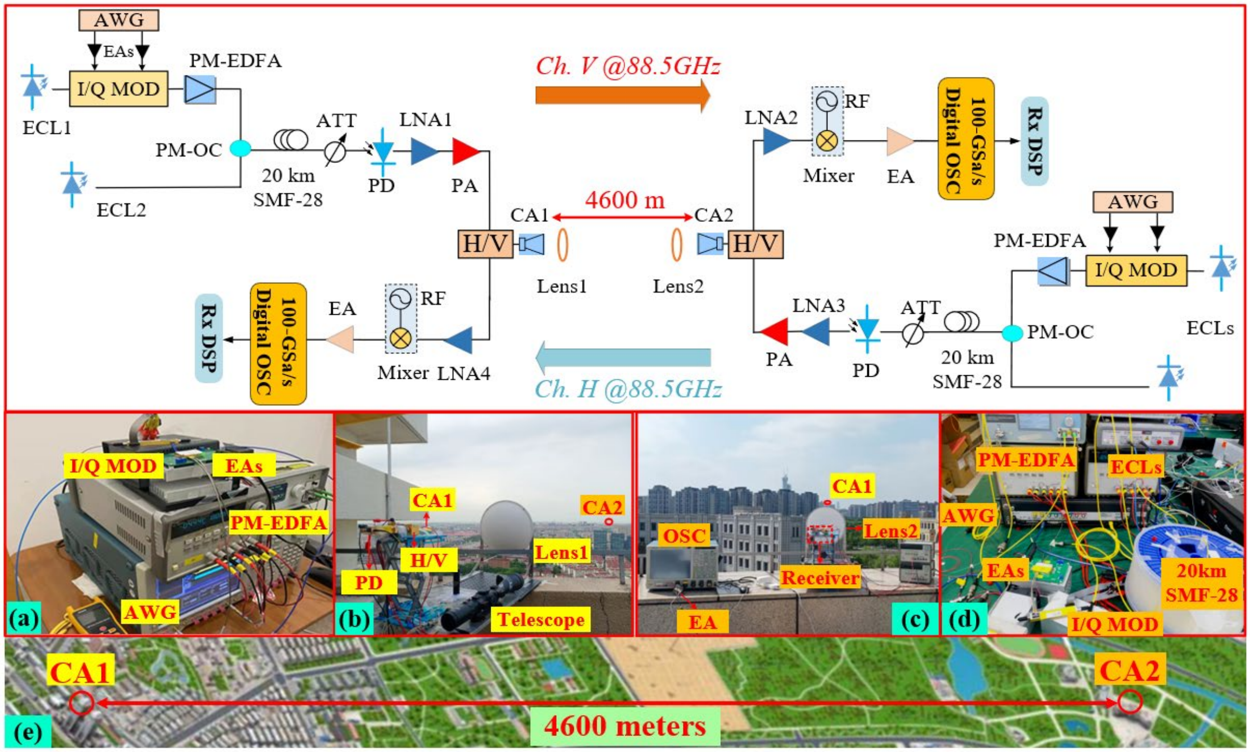

Fig. 1. Experimental setup of the bidirectional full-duplex system over the fusion link of 20 km SMF and 4600 m RF wireless. (a-b): The photographs of the setup located on the Handan campus; (c-d): The photographs of the setup located on the Jiangwan campus; (e): The map display of the wireless link.

W-band. The OMTs feature a typical isolation of more than 30 dB and a broadband operation of 75-110GHz, and they can also be used to couple two orthogonal linearly polarized signals simultaneously while providing polarization isolation between transmit and receive. In previous work, we have achieved a large-capacity long-distance unidirectional polarization-multiplexed transmission based on OMTs [13].

In the wireless free space, the transmission and reception of signals are achieved by a pair of Conical Horn Antennas (CA1 and CA2), which can provide a nominal gain of 25 dBi. The distance of the transceiver is 4600 m (between Handan Campus and Jiangwan Campus of Fudan University). Fig. 1(a-b) show the photographs of the setup located on the Handan campus. Fig. 1(c-d) show the photographs of the setup located on the Jiangwan campus. Fig. 1(e) shows the map display of the wireless link. To prolong the wireless distance, the CAs are combined with a pair of Lenses (Lens1 and Lens2). The diameter and focal length of Lens1 is 30 cm and 50 cm, respectively. It can be used to collimate the mm-wave beam from CA1. The specifications of Lens2 are the same as Lens1. It can be used to focus the collimated mm-wave beam into CA2. The combined gain of CAs and Lenses is about 90 dBi. What's more, they have a full-polarization orientation, which can support both linear and circularly polarized waveforms.

In the wireless receiver, the mm-wave signals output from OMT2 are first enhanced by LNA2 (22 dB gain) and then down-converted to 13.5 GHz intermediate frequency (IF) signals by a mixer actuated by a RF signal feed whose frequency is 75 GHz. A 26 dB gain EA is used to enhance the IF signals. Finally, we use a digital oscilloscope (OSC) to store the IF signals. The Rx-side DSP mainly includes digital down conversion, chromatic dispersion compensation, MIMO Volterra algorithm to compensate for the I/Q imbalance and nonlinear impairment, Intra Symbol Frequency-domain Averaging (ISFA) algorithm for channel estimation, and the cascaded LMS and DD-LMS algorithms for channel equalization [4,13]. For Ch. H, the setup is substantially the same as that of Ch. V. However, due to the lack of available components, the model of LNA3 (21 dB gain) used in the system is slightly different from that of LNA1, resulting in some differences in the performance of Ch. H and Ch. V.

3. Results and Discussion

Firstly, 10 Gbaud 16QAM signals are transmitted in both Ch. H and Ch. V. Fig. 2(a) presents the bit error rates (BERs) of 10 Gbaud 16QAM signals versus the input power of PDs. As the input power of PDs improves from -5 to -1 dBm, the BER performance becomes progressively optimized with the enhancement of signal-to-noise ratio (SNR). However, as the input power of PDs improves from -1 to 1 dBm, the BER performance gradually deteriorates because of the occurrence of the saturation effect. With -1 dBm input power of PDs, we have achieved the minimum BER values of 5.5×10^{-3} for Ch. H and 7.2×10^{-3} for Ch. V. The insets (i-ii) of Fig. 2(a) present the corresponding demodulation constellations of 16QAM signals for Ch. H and Ch. V.

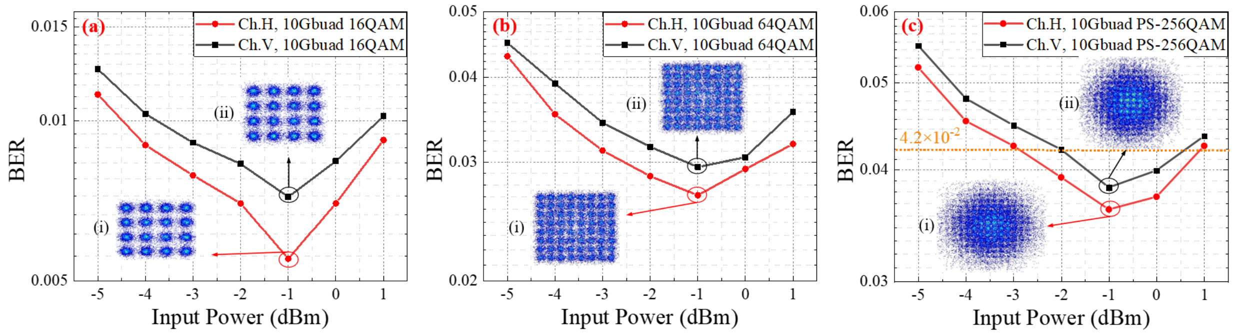

Fig. 2. Measured BERs of Ch. H and Ch. V as a function of input power of PDs. (a) For 10 Gbaud 16QAM signals. (b) For 10 Gbaud 64QAM signals. (c) For 10 Gbaud PS-256QAM signals.

Fig. 2(b) presents the BERs of 10 Gbaud 64QAM signals for both Ch. H and Ch. V. Compared with the simple and low-order modulation scheme, the high-order QAM format can effectively enhance the spectral efficiency and produce high-rate data to improve the system throughput. However, higher-order modulation increases the demand for SNR, resulting in poorer BER performance for 64QAM signals compared with 16QAM signals. With -1 dBm input power of PDs, we have achieved the minimum BER values of 2.68×10^{-2} for Ch. H and 2.95×10^{-2} for Ch. V. The insets (i-ii) of Fig. 2(b) present the corresponding demodulation constellations of 64QAM signals for Ch. H and Ch. V.

The combination of PS technology and high-order QAM format is adopted to further increase the throughput and spectral efficiency of the fiber-wireless-integration communication system. The PS technology can also support flexible adjustment of data rate [14]. The reduction of the probability of high-amplitude symbols makes the PS-QAM signals less susceptible to the nonlinearity introduced by PDs, LNAs, and PAs. In this experiment, the generated PS-256QAM signals (7.07 bit/symbol) are transmitted. Fig. 2(c) presents the BERs of 10 Gbaud PS-256QAM signals for both Ch. H and Ch. V. With -1 dBm input power of PDs, we have achieved the minimum BER values of 3.61×10^{-2} for Ch. H and 3.82×10^{-2} for Ch. V, which are less than 4.2×10^{-2} soft-decision forward error correction (SD-FEC) limit with 25% overhead [14]. The insets (i-ii) of Fig. 2(c) present the corresponding demodulation constellations of PS-256QAM signals for Ch. H and Ch. V. The cyclic prefix overhead in our OFDM scheme is 5.88%. In consideration of the overhead of the OFDM scheme and SD-FEC, the total maximum net rate of Ch. H and Ch. V is $2\times10\times[7.07-8\times(1-0.8)]\times(1-5.88\%)=103$ Gbps.

4. Conclusions

We have experimentally implemented a photonics-aided large-capacity long-distance mm-wave bidirectional full-duplex fiber-wireless-integration communication system at the W-band. Up to 10 Gbaud PS-256QAM signals whose entropy is 7.07 bit/symbol/Hz can be transmitted in two orthogonal polarization channels. The system can support the bidirectional transmission with 103 Gbps data rate over the fusion link of 20 km SMF and 4600 m RF wireless. For all we know, based on a photonics-aided bidirectional full-duplex system, this is the first time to realize a record-breaking rate-distance product at the W-band, i.e., 103 Gbps × 4.6 km = 473.8 Gbps•km. *This work is supported by National Nature Science Foundation of China (61720106015 and 62127802).*

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