Single-Lane 504-Gb/s Wireless Transmission at W Band Enabled by Dual-Polarized SISO Link and MIMO Equalizer

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Abstract *Utilizing a dual-polarized SISO wireless link and the nonlinear MIMO equalizer, we have successfully demonstrated the first photonics-assisted single-lane single-carrier 504-Gb/s wireless communication at W band (75~110 GHz). A net rate record of over 400-Gb/s is achieved without using traditional unwieldy MIMO wireless links. ©2023 The Author(s)*

Introduction

With the advent of new technologies that can change our lives, such as virtual reality, the Internet of Things, telemedicine services, and 8k or even 16k video, the wireless data rate required for these services are expected to be greater than 100 Gb/s and even moving towards the Tb/s level [1]. It poses a significant challenge to the wireless transmission capacity for the up-coming beyond 5G networks enabled by mm-Wave (30 ~ 300 GHz) communication [2, 3].

In recent years, the outstanding advantage of photonics-assisted solution has been proofed, which can significantly improve the capacity of mm-Wave wireless communications [4, 5]. Several mm-Wave large-capacity communication systems have been demonstrated, with the frequency range covering the entire mm-Wave bands [6-14], as shown in Fig. 1. For example, Wei et al. verified a raw 128.6-Gb/s wireless transmission at V band (50 ~ 75 GHz) [8]. Yu et al. achieved a line rate of 432-Gb/s polarization division multiplexing (PDM) 16QAM signal wireless transmission at W-band (75 ~ 110) [10]. Li et al. even realized an inspiring ultra-high capacity of 1.056-Tb/s wireless transmission on four-lanes four-carriers at D band (110 ~ 170 GHz) [12]. However, the overall capacities of the above systems are mainly achieved via either the multiple optical carriers and/or the multiple wireless lanes with multiple-input multiple-output

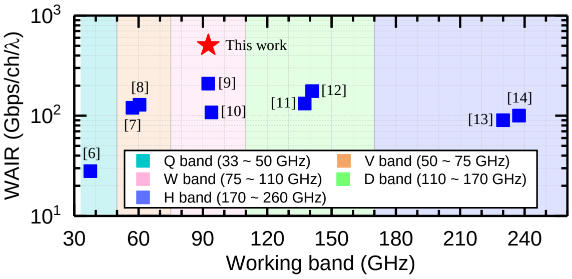

Fig. 1: State-of-the-art single-lane single-carrier wireless air interface rate (WAIR) at the typical mm-Wave bands.

(MIMO) scheme. In terms of single-lane single-carrier case, the maximum wireless air interface rate (WAIR) does not exceed 200 Gb/s, which can be observed from Fig. 1. Particularly, using the MIMO wireless link may also suffer from some inevitable problems, such as difficulty in multiple antenna alignment, performance degradation due to the crosstalk between the adjacent wireless channels and so on.

In this paper, we have successfully demonstrated a large-capacity photonics-assisted W-band wireless communication system just employing a simple dual-polarized single-input single-output (SISO) wireless link as well as an uncomplicated nonlinear MIMO equalizer. The transmitted ultra-wideband optical PDM signal is seamlessly and skillfully integrated into the dual-polarized SISO wireless link, achieving a record WAIR up to 504 Gb/s on a single lane and single carrier at mm-Wave band for the first time.

Experimental setup

Figure 2 shows the experimental setup of the large-capacity photonics-assisted W-band wireless communication system based on a simple dual-polarized SISO wireless link. At the optical transmitter, the ultra-wideband baseband signal generated by off-line Tx-DSP as shown in Fig. 2(a), is first produced by a 92-GSa/s arbitrary waveform generator (AWG) with a 3-dB analog bandwidth of 32 GHz and 8-bit resolution. After being amplified by two electrical amplifiers (EAs), the output two components are then used to drive one I/Q modulator with a 3-dB bandwidth of 25 GHz for optic-electro conversion. One external cavity laser (ECL1) operating at 1549.316 nm with a <100-kHz linewidth and 14-dBm output power, is used as the input optical carrier. Afterwards, one polarization-maintaining erbium-doped fiber amplifier (EDFA1) is used to boost the optical power. Then we build a polarization

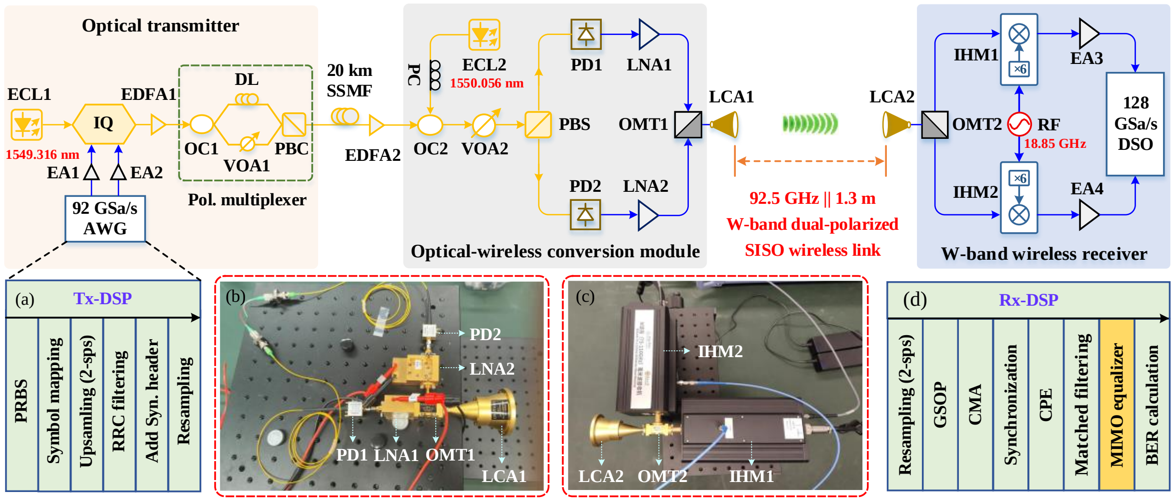

Fig. 2: Experiment setup of single-lane single-carrier 500-Gb/s wireless transmission at W band based on a simple dual-polarized SISO wireless link; (a) Tx DSP; Photos of the W-band dual-polarized (b) transmitter and (c) receiver; (d) Rx DSP.

multiplexer to simulate polarization multiplexing modulation. It mainly consists of a polarization-maintaining optical coupler (OC1), a 2-m fiber delay line (DL), a variable optical attenuator (VOA1) and a polarization beam combiner (PBC). Next, the obtained optical PDM signal goes through a 20-km standard single-mode fiber (SSMF) and the corresponding transmission loss is compensated by the following EDFA2.

At the optical-wireless conversion module, adopting the second OC (OC2) to couple the transmitted signal light with an optical local oscillator (ECL2), which has a frequency offset of 92.5 GHz from the ECL1 and an output power of 8 dBm. Subsequently, one polarization beam splitter (PBS) divides the combined PDM signals into X- and Y- polarizations, and then the optical heterodyne detection is performed on each branch through the photodetector (PD) with a responsivity of 0.6 A/W and 3-dB bandwidth of 100 GHz. The obtained two 92.5-GHz mm-Wave signals are amplified by two identical low-noise amplifiers (LNA1 and LNA2) with 35-dB gain, respectively, to maximize the mm-Wave WAIR. The above two W-band components are transparently transmitted by a dual-polarized SISO wireless link. It is mainly established via a pair of orthomode transducers (OMTs) with 35-dB isolation between two orthogonal polarization directions, and a pair of lens corrected antennas (LCAs) with a total gain of 2×30 dBi. Obviously, this SISO link structure simplifies the traditional complicated 2×2 MIMO wireless links, and thus the stability and robustness of optical wireless integrated system can be significantly improved.

After 1.3-m wireless transmission, the dual-polarized 92.5-GHz mm-Wave signals are re-split into two orthogonal polarization directions by OMT2 at the W-band wireless receiver. Next, two integrated harmonic mixers (IHMs) which consist of a sixfold frequency multiplier chain and a W-band mixer, are used to down-convert the mm-Wave signal to IF signal in each branch. By setting the input RF source to 18.85 GHz, thus we can obtain two IF signals with the central frequency of 20.6 GHz. After being amplified by other two EAs (EA3 and EA4), the two down-converted IF signals are fed together to a digital storage oscilloscope (DSO) for analog-to-digital conversion with an operating sample rate of 128 GSa/s and 3-dB bandwidth of 59 GHz. Fig. 2(b) and (c) show the photos of W-band transmitter and receiver, respectively. In offline Rx-DSP, the Gram-Schmidt orthogonalization procedure (GSOP) and 37-tap constant modulus algorithm (CMA) are first used to compensate for I/Q imbalance and linear polarization crosstalks,

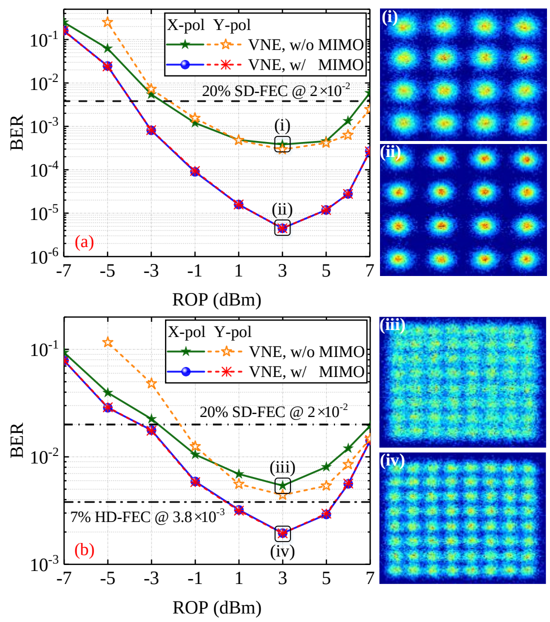

Fig. 3: BER performance comparison for different equalization schemes. (a) 23-GBd PDM-16QAM signal; (b) 23-GBd PDM-64QAM signal.

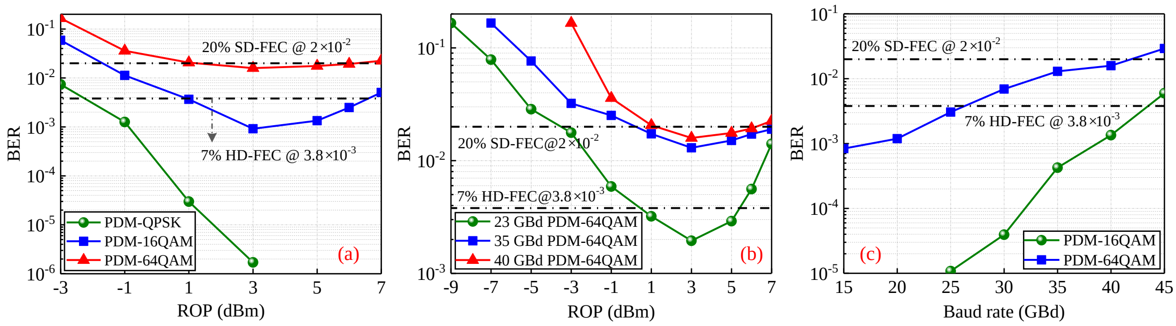

Fig. 4: (a) BER versus ROP for 40-GBd PDM signal with different modulation formats; (b) BER versus ROP for PDM-64QAM signal with different baud rates; (c) BER of PDM-16QAM and PDM-64QAM signals versus different transmitted baud rates.

respectively. Then, after carrier phase estimation (CPE), a 101-tap MIMO Volterra nonlinear equalizer (VNE) is used for channel equalization. Finally, the bit error ratio (BER) is calculated.

Results and Discussions

Figure 3 compares the BER performances of 23-GBd PDM-16QAM and 64QAM signals in the cases of the VNE with and without MIMO equalization. In the validation, we choose a second-order VNE with 3% training length (about 3000 symbols) and the memory length of (51, 5) due to compromise. For the VNE without MIMO case, the X- and Y-polarization signals are separately filtered by two independent second-order VNEs. Instead, the above two polarization signals are jointly equalized through a MIMO VNE in another case. In our fibre-wireless hybrid channels, the linear intra- and inter-crosstalks between the two polarization directions have been roughly overcome by the prior CMA filter. However, the nonlinear crosstalks still remain, which may degrade the system performance to a great extent. This can be verified by the results shown in Fig. 3. When without MIMO processing, we can observe an obvious imbalance between the two polarization components of the PDM-16QAM and 64QAM signals. Fortunately, due to the further elimination of inter nonlinear crosstalks via the VNE MIMO equalizer, it can not only keep the two BER balanced, but also improve both the PDM-16QAM and 64QAM performances significantly (see the constellation diagrams in Fig. 3).

Next, the BER versus received optical power (ROP) for 40-GBd PDM-QPSK, 16QAM, and 64QAM signals are also investigated, as shown in Fig. 4(a). For PDM-QPSK and 16QAM signals, the required ROPs to meet the BER threshold of 7% hard-decision forward-error-correction (HD-FEC) are -2.2 dBm and 1 dBm, respectively. With a same ROP of 1 dBm, the PDM-64QAM signal can exactly reach the 20% soft-decision FEC (SD-FEC). In addition, under an optimal ROP of 3 dBm, the best BER for PDM-16QAM and 64-QAM are 9.2×10^{-4} and 1.6×10^{-2}, respectively.

Figure 4(b) shows the BER versus ROP for the PDM-64QAM signal with three different baud rates of 23, 35 and 40 GBd. The corresponding RRC rolloff factors are set to be 0.1, 0.05 and 0.01, respectively, for limited system bandwidth. It should be emphasized that the full coverage of the W-band spectra is conducted for the latter two baud rates. For 23 GBd case, a receiving dynamic range of more than 4 dB is exhibited even at the 7% HD-FEC BER threshold. When the baud rate increases to 35 GBd and even 40 GBd, the available receiving dynamic ranges at the 20% SD-FEC BER threshold can still reach 7 dB and 5 dB, respectively.

To further explore the maximum capacity supported by this system, we finally measure the BERs of PDM-16QAM and PDM-64QAM signals from 15- to 45-GBd baud rate under a fixed ROP of 3 dBm, respectively, as shown in Fig. 4(c). At the 20% SD-FEC BER threshold, the supported maximum baud rate of the dual-polarized SISO link is around 42 GBd for PDM-64QAM signal, corresponding to a total capacity of 504 Gb/s. After subtracting the 3% training symbol and 20% FEC overheads, the single-lane net WAIR is 42 GBd × 6 bit × 2 pol × 0.97 / 1.2 = 407.4 Gb/s.

Conclusions

An ultra-wideband photonics-assisted W-band wireless communication system with a record single-lane WAIR rate of 504 Gb/s has been experimentally demonstrated over 20-km SSMF and 1.3-m wireless distance by using a simple dual-polarized SISO wireless link and nonlinear MIMO equalizer. Such a large-capacity wireless transmission solution can improve the system stability and robustness, and thus we believe it is a potential candidate for the future B5G networks.

Acknowledgements

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