Demonstration of 8192QAM W-Band Signal Delivery over 4.6 km Wireless transmission Employing One bit DSM and Neural Network

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Abstract *We experimentally demonstrate a transmission of 1Gbaud 8192-QAM OFDM signal over 4.6-km wireless using Delta-Sigma Modulator (DSM) and Neural Network Technology.*

Introduction

Millimeter wave (MMW) communication systems are considered as a promising solution for broadband wireless access in the future and can easily support multi-Gbps services, making them a strong candidate for inclusion in future 5G and ultra-5G wireless networks. MMW provides good directionality and a large bandwidth, compared with traditional microwave wireless systems. Many studies and experimental demonstrations of 5G technology based on MMW communication systems have been reported [1-6].

However, the electronic device's limited bandwidth is a bottleneck for increasing capacity further. To address this issue and achieve multi-Gbps MMW transmission, photonics-assisted MMW technology with high-order quadrature amplitude modulation (QAM) and generation has been investigated [7-10]. Higher-order QAM signal transmission requires higher signal-to-noise ratios (SNR) and higher digital-to-analog converter (DAC) resolution. Delta sigma modulation (DSM) technology can convert high-order QAM signals to 1-bit signals for transmission, which alleviates these problems [11-13]. The one-bit quantized signals in QAM transmission are equivalent to quadrature phase shift keying (QPSK) signals, providing a higher SNR tolerance. However, transmitting over long distances can lead to decreased system signal-to-noise ratio due to uncertain factors, including nonlinearity from wireless channels and photoelectric devices, such as optical modulators and electrical amplifiers (EA). Neural network equalizers (NNEs) that can accurately represent and correct nonlinear effects are a promising solution for nonlinear compensation (NLC) [14-15]. With data-aided training, NNEs can adaptively fit the signals' time-delay nonlinearity using multi-layer weights-controlled accumulation of nonlinear activation functions, outperforming traditional Volterra-series based NLC [16].

In this paper, we experimentally demonstrate 8192-QAM orthogonal frequency division multiplexing (OFDM) signal transmission over a 4.6-km wireless distance at W-band, achieving a transmission rate of 1 Gbaud with the aid of DSM and NNE technologies. To our knowledge, this is the first time that 1Gbaud 8192-QAM OFDM signal transmission has been demonstrated over such a distance.

Experimental setup

Figure 1 illustrates the experimental setup for photonics-assisted, long-distance W-band polarization multiplexing wireless delivery over 4.6 km. The transmit-side (Tx-side) is located at the Guanghua Building, with a height of 142 m on Handan campus; the receiver-side (Rx-side) is located at the Physical Building, with a height of 24 m on Jiangwan campus. The photos of the Physical Building, transmission link, Guanghua Building, transmitter, and receiver are shown in Figs. 1(a) - (e), respectively. First, pseudo-random binary sequences (PRBS) are generated by offline MATLAB software, and then converted into higher-order Quadrature Amplitude Modulation (QAM) signals through QAM mapping. The length of the Fast Fourier Transform (FFT) is set to 1024, with the position of the first subcarrier of the Orthogonal Frequency Division Multiplexing (OFDM) signal at 0 for DC bias. Among the remaining 1023 subcarriers, 980 subcarrier signals are used to load high-order QAM signals, and the remaining subcarriers are zeroed. The signal is converted from the frequency domain to the time domain. The frame of OFDM signal consists of 100 OFDM signals, which are oversampled ten times. The same 1-bit quantization is used for the real and imaginary parts of the OFDM signal in the time domain, and the QPSK signal is obtained for transmission. The signal is then converted from digital to analog using an arbitrary waveform generator (AWG, Tektronix AWG7122C). At the optical transmitter, two tunable external cavity lasers (ECL-1 and ECL-

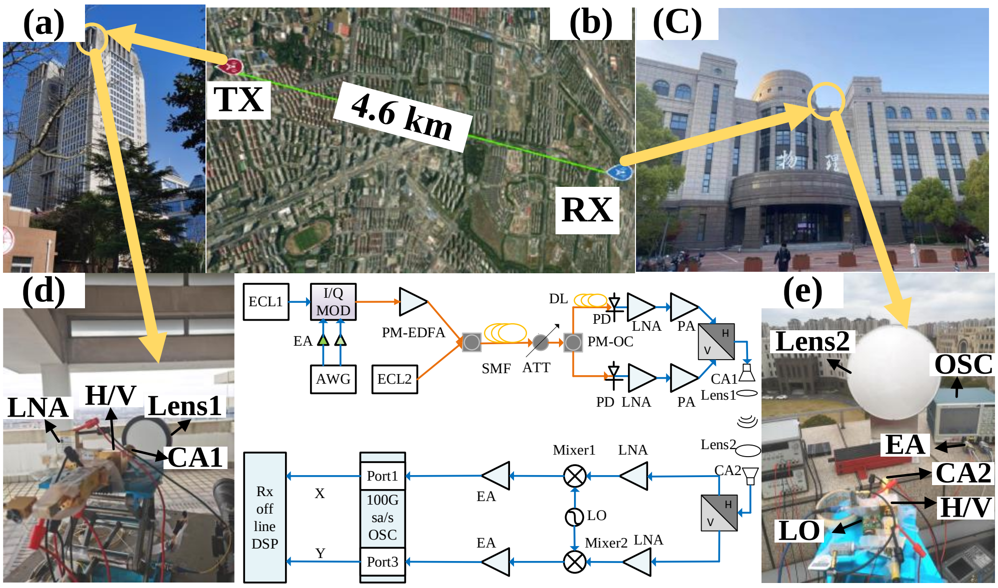

Fig. 1: Experimental setup of PDM-8192QAM W-band wireless delivery over 4.6 km. Photos of (a) Guanghua Building on Handan campus; (b) transmission link; (c) Physical Building on Jiangwan campus. (d) transmitter; (e) receiver.

2) with linewidths less than 100 kHz are used to generate W-band optical mm-wave signals. The ECL-2 at the wavelength of 1550.67 nm works as an optical local oscillator (LO) and has 88.5 GHz frequency offset relative to ECL-1. The 10 Gbaud electrical signal output from the AWG is first amplified by a pair of parallel electric amplifiers. The continuous-wave (CW) lightwave from ECL-1 is modulated by a 10 Gbaud electrical signal using an I/Q modulator with a 3 dB bandwidth of 30 GHz. Subsequently, the modulated optical signal is boosted by a polarization-maintaining Erbium-doped fiber amplifier (PM-EDFA) and coupled with the CW light wave emitted from the ECL-2 through a polarization maintaining optical coupler (PM-OC). The optical power of the signal is adjusted by an optical attenuator (ATT) before being transmitted over 100 m SSMF. After that, the signal is split into two branches by an OC, and an optical delay line (DL) is inserted in one arm to provide a delay of 100 symbols, thereby eliminating the correlation of the two polarization-direction signals. Two parallel photodiodes (PDs) with 90 GHz 3 dB bandwidth individually convert the optical signal to the electrical signal at W-band, respectively. Each 88.5-GHz electrical signal passes through a W-band LNA and a PA in serial. And then the two wireless signals are fed into a H/V polarization multiplexer with polarization isolation ratio larger than 23 dB to obtain a dual-polarized signal. Finally, the dual-polarized wireless signal is sent into free space by a transmitter conical antenna (CA) with a gain of 23 dBi. In the long-range wireless transmission link, two polytetrafluoroethylene (PTFE) lenses (Lens-1 and Lens-2) are adopted to collimate the radiation. After a transmission distance of 4.6 km, the dual-polarized wireless mm-wave signal is captured by another PTFE lens (Lens-2) and the CA at the receiver end. The received signal is fed into the H/V polarization de-multiplexer and divided into two orthogonal polarization directions (H- and V-polarization). Subsequently, the two

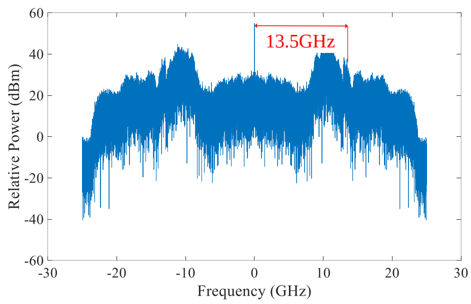

Fig. 2. Electrical spectrums of received 13.5-GHz IF signals.

polarization-direction signals are first passed through two parallel LNAs with 35 dB gain. intermediate frequency (IF) signals by a pair of mixers in the analog domain. Both the mixers are driven by a 75 GHz RF LO source, so the carrier frequency of the two IF signals are about 13.5 GHz. The electrical spectrum of received 13.5 GHz IF signal is shown in Fig. 2. The IF signals are further boosted by two identical EAs with a gain of 26 dB. Finally, the amplified IF signals are then analog-to-digital converted and recorded by a real-time digital oscilloscope (OSC) through port-1 and port-3, respectively. Afterwards, they are down converted into The deployed OSC (Tektronix, DSO73304D) has a sampling rate of 100 GSa/s and a 3-dB electrical bandwidth 33 GHz. The offline DSP at Rx is followed by down conversion, constant modulus algorithm (CMA) equalization, frequency offset estimation, NNEs, hard-decision, low pass filtering. At last, the OFDM signal in the time domain is converted into a QAM signal in the frequency domain, and the bit error rate of the signal is calculated.

Experimental results

The measured BER of DSM signal vs. power into PD at 88.5 GHz MMW frequencies in a 4.6 km wireless transmission is presented in Fig. 3 along with the corresponding optimal constellations. Fig. 3 shows that the system link has the optimal power into PD, where an excessive amount leads to signal saturation and an insufficient amount leads to a low signal-to-noise ratio. Long wireless transmission distances leads to a decrease in signal-to-noise ratio and an increase in nonlinearity due to wireless channel and optoelectronic device issues. So the BER of insetted constellation (i) in Fig. 3 is not so good when only DSM is adoptted. Based on the implementation of DSM technology, NNE technology was further added to effectively improve the system's nonlinearity and obtain constellation (ii) in Fig.3 with an ultra-low BER. All subsequent experimental results integrated both DSM and NNE technologies.

Perform hard-decision on DSM signals with ultra-low bit error rates, and then perform 10 times downsampling on the DSM signal to achieve low-pass filtering of the DSM signal,

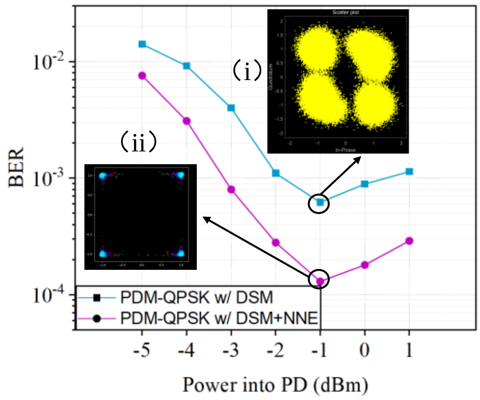

Fig. 3. The curves of BER versus power into PD at the case of 10 Gbaud PDM-QPSK signal. (i) the constellation with only DSM. (ii) the constellation with DSM and NNE.

and subsequently obtain the corresponding high-order QAM-OFDM signal. Fig. 4 shows the curves of BER versus power into PD of 1Gbaud high-order QAM signal. From the inserted constellation, we can see that as the order of the constellation increases, the constellation gradually blurs. However, the constellation of 1Gbaud 8192QAM OFDM signal is still below the BER threshold of 0.04.

Conclusion

1-GBaud PDM-8192QAM signal wireless transmission over 4.6km distance at 88.5GHz has been experimentally demonstrated in a W-band communication system, by using DSM and NNE technology. Thanks to the quantization gain brought by 1-bit quantized DSM and nonlinear compensation of NNE, we successfully realize the long-distance transmission of high-order QAM signals in the W-band.

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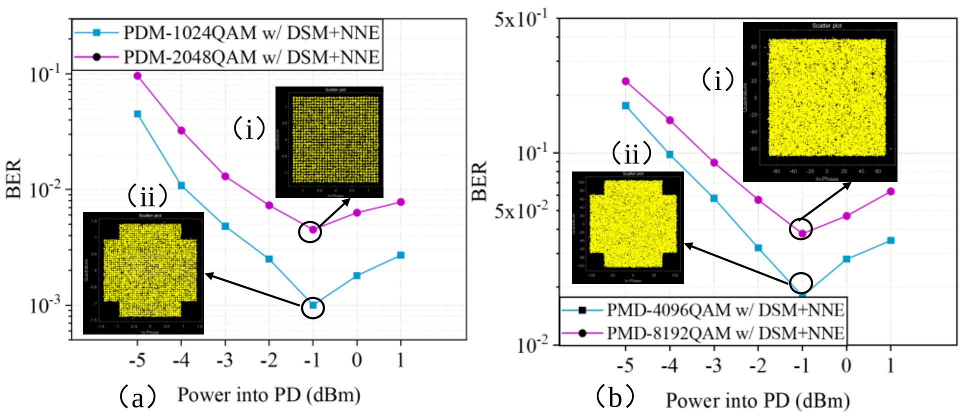

Fig. 4: The curves of BER versus power into PD at the case of 1 Gbaud PDM-OFDM signal. a:(i) the constellation of 1024QAM, a:(ii) the constellation of 2048QAM, b: (i) the constellation of 4096QAM, b: (ii) the constellation of 8192QAM.

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