104-m Terahertz-Wave Wireless Transmission Employing 124.8-Gbit/s PS-256QAM Signal

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Abstract: We experimentally demonstrate 16-GBaud PS-256QAM signal transmission over 104-m wireless distance at 339 GHz in a photonics-aided THz-wave communication system, achieving a record single line rate of 124.8 Gbit/s and net SE of 6.2 bit/s/Hz.

1. Introduction

Terahertz (THz)-wave communication based on photonics-aided scheme with its ultra-wide bandwidth (0.3~10 THz) has become a promising candidate technology to meet the urgent demand for large-capacity transmission in future 6G networks [1-4]. Moreover, advanced high-order modulation has been adopted in THz-wave signal generation to improve the spectral efficiency (SE) and transmission speed [5-13]. However, it is still a technical challenge to realize long-distance THz-wave wireless communication at a transmission rate exceeding 100 Gbit/s. In a 2×2 MIMO THz-band communication system, 132-Gbit/s line rate transmission at 450 GHz over 1.8-m wireless distance has been realized [5]. Via an integrated DFB laser chip to generate 408-GHz carrier, 10.7-m distance THz-wave delivery employing 131-Gbit/s net rate 16QAM OFDM signal has been reported [6]. A 115-Gbit/s net bit rate wireless transmission over 110-m distance at 0.3 THz has been experimentally demonstrated by using the Kramers-Kronig scheme and a Schottky-barrier diode (SBD) [7]. However, the net SE above is only 3.5 bit/s/Hz by employing 33-GBaud 16QAM signal. Much higher order modulation formats combined with probabilistic shaping (PS) technology urgently need to be adopted to further improve the SE in long-distance THz-wave wireless communication system.

By employing PS technique, advanced DSP algorithms and a pair of special dielectric lenses, we have experimentally demonstrated 104-m THz-wave wireless delivery of 124.8-Gbit/s single line rate signal. To the best of our knowledge, it is the first time to realize >100 m and >100 Gbit/s single-carrier 256QAM THz-wave signal wireless delivery, achieving the net SE of 6.2 bit/s/Hz.

2. Experimental setup

Fig. 1(a) depicts the experimental setup for photonics-aided THz-wave transmission system. The off-line DSP of transmitter is given in Fig. 1(b). For PS-256QAM symbols generation, we use constant composition distribution matcher (CCDM) and adopt the probabilistic amplitude shaping (PAS) scheme in I and Q components, respectively. The SD-FEC is DVB-S2 LDPC with 4/5 code rate (25% overhead). We set the information entropy of the PS-256QAM format as 7.8 bit/symbol. The generated PS-QAM symbol sequence is then ×2 up-sampled before a root-raised-cosine (RRC) filter. The RRC filter with a roll-off factor of 0.01 is deployed to overcome the system bandwidth limitation. The baseband electrical I/Q signals generated from a 64-GSa/s sampling rate arbitrary waveform generator (AWG) are boosted by two parallel electrical amplifiers (EAs). The optical carrier from the tunable ECL-1 with 100-kHz linewidth is modulated via a 30-GHz bandwidth I/Q modulator. The output optical signal is then amplified by a cascaded PM-EDFA. Another 100-kHz linewidth ECL-2 is utilized as the optical LO. The frequency space between the two ECLs is set as 339 GHz. The two optical beams with the same optical power of 7 dBm are then coupled by a PM-OC. Subsequently, an EDFA is utilized to adjust the input power into the commercial uni-travelling photodiode (UTC-PD). The operation frequency of the UTC-PD ranges from 300 GHz to 2500 GHz. Since the fiber pigtail of UTC-PD is sensitive to the polarization state, we use a cascaded polarization controller (PC) after the EDFA to adjust the polarization state of the input optical signal into the UTC-PD to maximize the output THz signal strength. The generated THz signal at 339 GHz from the UTC-PD is then amplified by a THz-wave low-noise amplifier (LNA) with 25-dB gain before delivered over 104-m wireless distance. Photos of the THz-wave transmitter, receiver and 104-m transmission link are given in Fig. 1(c).

Since the THz-wave receiving antenna has a very small aperture, about 5 mm and the output signal from the transmitting antenna is divergent, it is difficult to realize long-distance wireless delivery under normal signal power without special dielectric lenses. To solve this problem, we design a pair of plastic plano-convex lenses to focus the collimated THz-wave beam to maximize the received power by the receiving antenna. Lens-1 has 10-cm diameter and 20-cm focal length while lens-2 has 30-cm diameter and 50-cm focal length. The pair of dielectric lenses has a low dielectric constant of 1.96 at 520 GHz and an index of refraction of 1.4. The typical operation frequency ranges from 0.1 to 2 THz. When the centers of lens-1 and lens-2 are aligned with the 104-m wireless transmission link, the pair of dielectric lenses provide more than 80-dB directivity gain.

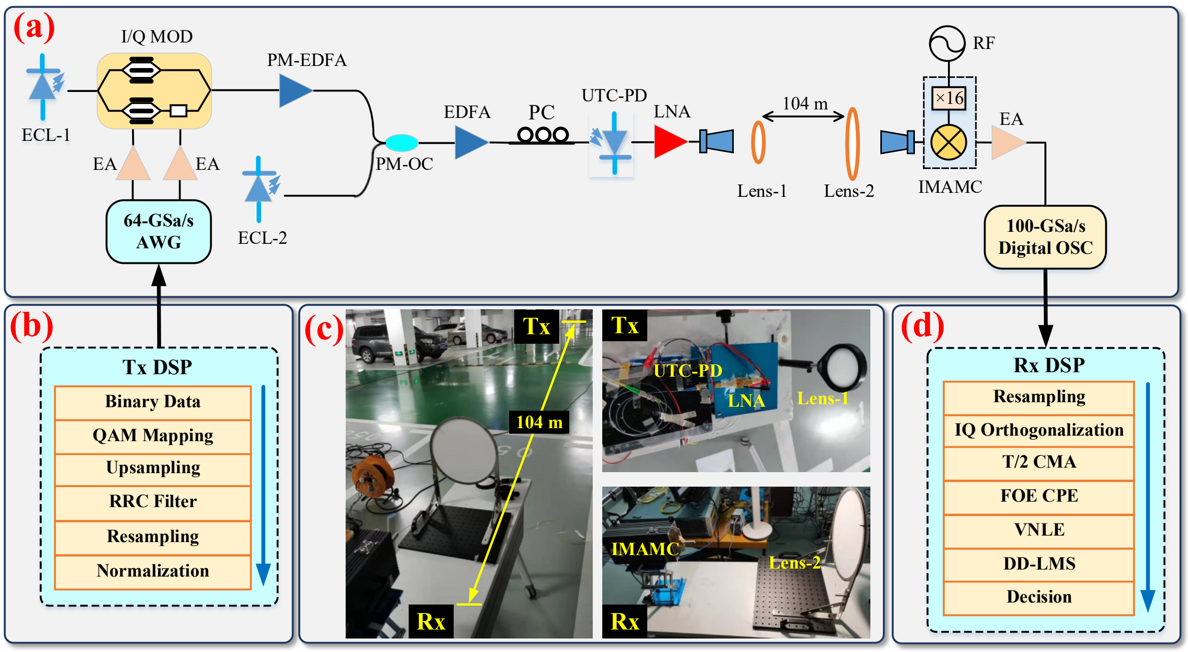

Fig. 1. (a) Experimental setup of THz signal wireless transmission system; (b) Tx-side offline DSP procedure; (c) photos of experimental setup; (d) Rx-side offline DSP procedure.

The received THz signal is down-converted by an integrated mixer/amplifier/multiplier chain (IMAMC), which is integrated by a mixer, a ×16 frequency multiplier and a 20.625 GHz RF source. The intermediate-frequency (IF) is thus 339-20.625×16=9 GHz. Finally, the amplified IF signal after an EA is sampled by a digital oscilloscope with 33-GHz electrical bandwidth and 100-GSa/s sampling rate. The off-line DSP of receiver is illustrated in Fig. 1(d), which includes resampling, I/Q orthogonalization, 21-tap T/2-spaced CMA equalizer as well as frequency offset estimation. In the carrier phase estimation step, we deploy hybrid principal component-based phase estimation and blind phase search (PCPE-BPS) algorithms [14]. Second-order Volterra nonlinear equalizer (VNLE) with 190 kernels is utilized to reduce the nonlinear damage resulting from the optoelectronic devices, such as modulator, UTC-PD, amplifiers and so on. Afterwards, in order to compensate for the residual linear impairment, DD-LMS equalization with 43 taps is added. Finally, the recovered PS-QAM symbols are sent into normalized generalized mutual information (NGMI) calculation.

3. Results and discussion

For 16-Gbaud PS-256QAM THz signal generation, Fig. 2(a) gives the optical spectrum with 0.01-nm resolution of the optical signal into UTC-PD, where the frequency space is 339 GHz. Therefore, the generated THz signal has a center frequency of 339 GHz. After THz signal detection, the electrical spectrum of the received PS-256QAM IF signal at 9 GHz is illustrated in Fig. 2(b).

As shown in Fig. 2(c), We use two post-equalization algorithms: 197-tap linear FFE and 190-kernel second-order VNLE, and respectively compare the NGMI of 16-Gbaud 64QAM and PS-256QAM signals versus power into PD after 104-m wireless delivery. When we use the DVB-S2 LDPC with 4/5 code rate, error-free post-FEC results can be obtained when the NGMI of the pre-FEC QAM data reaches 0.83 [15]. Therefore, we use the 0.83-NGMI LDPC threshold here. Considering the 0.83-NGMI threshold, the required input power into PD for 64QAM signal with FFE processing is 9.4 dBm. With the aid of VNLE, the input power drops to 8.2 dBm and the sensitivity penalty is about 1.2 dB. Meanwhile, thanks to the VNLE processing, post-FEC error free can be obtained for PS-256QAM signal when the input power into PD reaches 10.6 dBm. Furthermore, at 11-dBm input power into PD, the constellation diagrams of the recovered 64QAM and PS-256QAM symbols are given in insets (I) and (II) of Fig. 2(c), respectively. For 16-Gbaud PS-256QAM signal transmission, the line bit rate is $7.8 \times 16 = 124.8$ Gbit/s. Considering the code rate of 4/5, the net bit rate is $[7.8-8\times(1-4/5)]\times 16 = 99.2$ Gbit/s. The net SE is thus 6.2 bit/s/Hz.

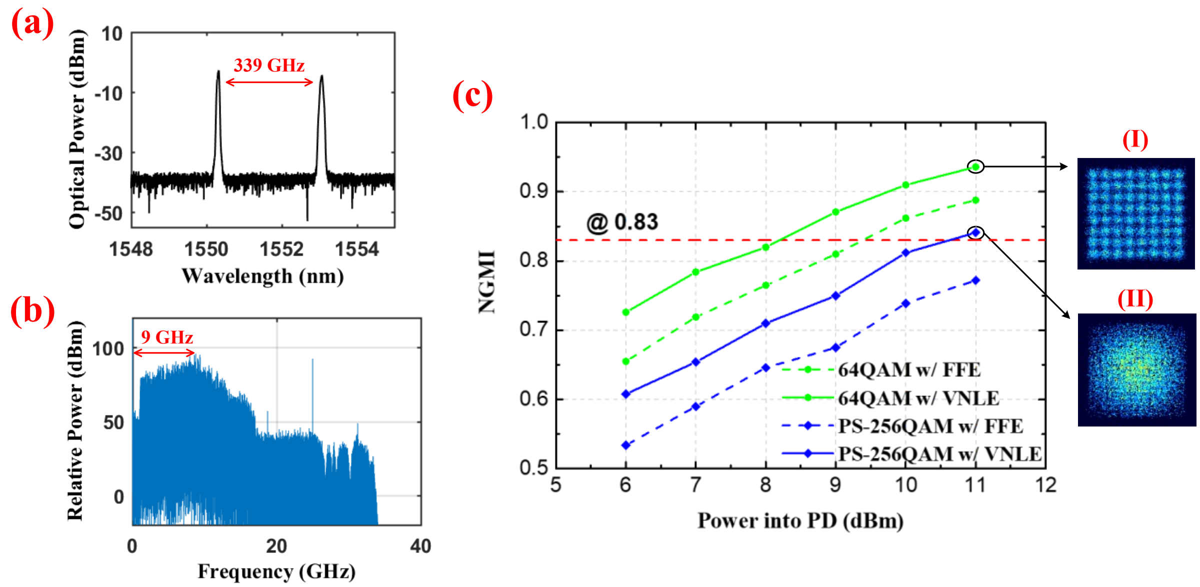

Fig. 2. (a) Optical spectrum of 16-Gbaud PS-256QAM optical signal into UTC-PD; (b) electrical spectrum of the received 16-Gbaud PS-256QAM IF signal; (c) NGMI of the received 16-Gbaud 64QAM and PS-256QAM signals with different DSPs versus input power into PD after 104-m wireless transmission. Insets (I) and (II) are recovered constellation diagrams of 64QAM and PS-256QAM symbols at 11-dBm input power into PD, respectively.

4. Conclusions

We have experimentally demonstrated 16-GBaud PS-256QAM signal wireless transmission over 104-m distance at 339 GHz in a photonics-aided THz-wave communication system. Thanks to the pair of special dielectric lenses and advanced DSPs, 124.8-Gbit/s single line rate (99.2-Gbit/s net bit rate) transmission with net SE of 6.2 bit/s/Hz can be successfully realized, satisfying the 0.83-NGMI LDPC threshold with 25% overhead.

5. Acknowledgement

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