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Demonstration of 32-Gbit/s Terahertz-Wave Signal Transmission over 400-m Wireless Distance

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Abstract *In a photonics-aided THz-wave communication system, we achieve an experimental demonstration of a record-breaking 400-m wireless distance at 335 GHz by using PTFE lenses and advanced DSP algorithms. ©2022 The Author(s)*

Introduction

Photonics-aided scheme [1-3], which can effectively resist the bandwidth limitation and electromagnetic interference of electronic equipment, has been applied in Terahertz (THz)-wave (0.3~10 THz) communication system to meet the urgent demand in future 6G services [4-9]. As shown in table 1, by utilizing photonics-aided scheme, the generation and detection of >100 Gbit/s high-order QAM THz-wave signals above 300 GHz have been realized [10-15]. Single-channel 350-GHz THz-wave transmission with 106.2-Gbit/s data rate over 26.8-m wireless link has been reported [13]. Using the Kramers-Kronig scheme, 132-Gbit/s line data rate and 110-m wireless transmission distance are realized, which is the longest wireless distance reported for frequencies above 300 GHz [14]. However, achieving high-speed THz-wave communication with more than 200-m wireless distance remains a technical challenge.

In this paper, THz-wave signal over long-distance wireless transmission at 335 GHz is experimentally demonstrated by utilizing a commercial uni-travelling photodiode (UTC-PD), a low-noise amplifier (LNA) in transmitter and a pair of poly tetra fluoroethylene (PTFE) lenses. Thanks to the PTFE lenses, probabilistic shaping (PS) technology and advanced DSP algorithms, the record-breaking 200\400-m photonics-aided THz-wave wireless transmission of 56\32-Gbit/s single-line rate signal has been successfully achieved.

Experimental setup

The experimental setup for 200\400-m THz-wave wireless transmission system based on photonics-aided scheme is depicted in Fig. 1(a). For PS-64QAM symbol sequence generation, we adopt the probabilistic amplitude shaping (PAS) scheme in I and Q components, respectively. Constant composition distribution matcher (CCDM) is combined with DVB-S2 LDPC with 4/5 code rate (25% overhead), which supports bit-interleaved coded modulation (BICM). The information entropy of the PS-64QAM format is set as 5.6 bit/symbol. In the Tx-side DSP, a raised-cosine (RC) filter with a roll-off factor of 0.01 is deployed to eliminate the bandwidth limitation of optoelectronic devices. We use an arbitrary waveform generator (AWG) with 10-GSa/s sampling rate to generate the baseband electrical signals of I and Q paths, which are then amplified by parallel electrical amplifiers (EAs). The optical carrier at 1550 nm generated from the tunable 100-kHz linewidth ECL-1 is modulated by a 30-GHz bandwidth I/Q modulator. Subsequently, a cascaded polarization maintaining erbium-doped fiber amplifier (PM-EDFA) is utilized to amplify the modulated optical signal. ECL-2 with 100-kHz linewidth is utilized as the optical LO. We set the frequency space between these two ECLs as 335 GHz. The optical power of both optical beams is 7 dBm. After

Tab. 1: State-of-the-art THz-wave wireless transmission above 300 GHz.

Ref	Center Frequency	Modulation	Data Rate	Distance
[10]	300 GHz	16QAM	100 Gbit/s	0.5 m
[11]	450 GHz	64QAM	103.9 Gbit/s	1.8 m
[12]	408 GHz	16QAM	131 Gbit/s	10.7 m
[13]	350 GHz	PS-16QAM	106.2 Gbit/s	26.8 m
[14]	300 GHz	16QAM	115 Gbit/s	110 m
[15]	339 GHz	PS-256QAM	124.8 Gbit/s	104 m

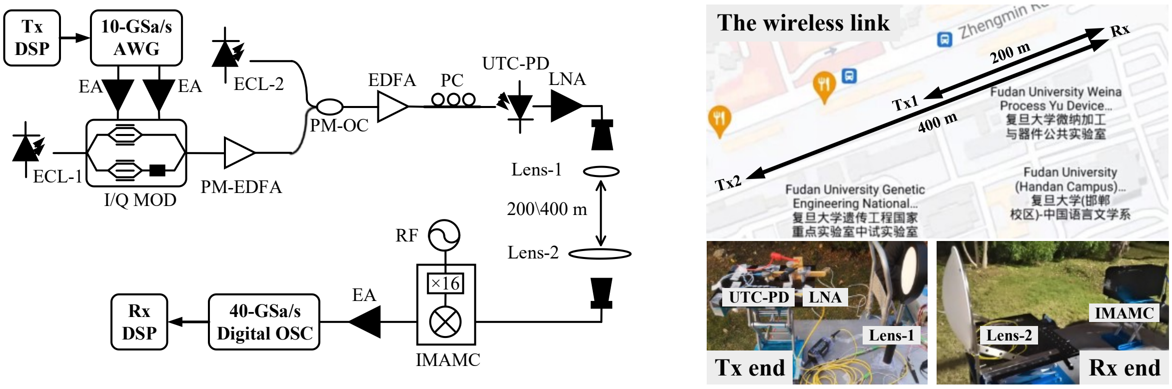

Fig. 1: (a) Experimental setup of 200\400-m THz-wave signal wireless delivery; (b) Photos of the 200\400-m wireless link and experimental setup on university campus.

coupled by a PM-OC, the optical power is controlled by an EDFA. A polarization controller (PC) is utilized to adjust the polarization state of the input optical signal into the UTC-PD to maximize the output THz-wave signal strength. Afterwards, the output THz-wave signal at 335 GHz is amplified by a THz-wave low-noise amplifier (LNA).

Fig. 1(b) gives the photos of the 200\400-m wireless link and experimental setup. We accomplish this experiment on a clear night on university campus. In the 200\400-m wireless link, we design a pair of plastic plano-convex lenses to focus the collimated THz-wave beam to maximize the input power of the receiving antenna with WR2.8 interface. This pair of dielectric lenses has a low dielectric constant of 1.96 at 520 GHz and an index of refraction of 1.4. Lens-1 has 10-cm diameter and 20-cm focal length while Lens-2 has 30-cm diameter and 50-cm focal length. This pair of lenses are aligned with the 200\400-m wireless delivery link. The height of Tx and Rx is 1.2 m above the ground and there is no any block between Tx and Rx. For 200-m wireless transmission, when the input power into UTC-PD is 8.5 dBm, the output power of UTC-PD is around -35 dBm. The THz-wave LNA has 25-dB gain while the transmitting horn antenna has 25-dBi gain. The summary of path loss and atmospheric loss for 200-m wireless delivery at 335 GHz is approximately 131 dB. Lens-1 and Lens-2 can provide 70-dBi gain. The receiving horn antenna has 25-dBi gain. Therefore, the received power is -21 dBm after 200-m wireless transmission. Meanwhile, for 400-m wireless transmission, the output power of UTC-PD is around -31 dBm when the input power into UTC-PD is 12.5 dBm. The sum of the path loss and atmospheric loss is approximately 139 dB. The received power is thus -25 dBm after 400-m wireless transmission.

In the receiver, down-conversion is realized via an integrated mixer/amplifier/multiplier chain (IMAMC), consisting of a 20.625 GHz RF source, ×16 frequency multiplier and a mixer. The obtained intermediate-frequency (IF) signal at 5 GHz (335-20.625×16=5 GHz) is then boosted via an EA and captured by a 40-GSa/s sampling rate digital oscilloscope. The off-line Rx-side DSP includes I/Q orthogonalization, 21-tap T/2-spaced likelihood-based selection radius-directed equalizer (LBS-RDE), frequency offset estimation as well as principal component-based phase estimation (PCPE) and blind phase search (BPS) algorithms. To eliminate the nonlinear damage caused by the optoelectronic devices, second-order Volterra nonlinear equalizer (VNLE) with 190 kernels is utilized. Finally, a 37-tap DD-LMS equalizer is added to compensate for the residual linear impairment before NGMI calculation.

Results and discussion

Fig. 2 (a) gives the measured NGMI performance of the received 10-Gbaud 16QAM and PS-64QAM signals versus input power into PD after 200-m wireless delivery. Since we use the DVB-S2 LDPC with 25% overhead for PS-64QAM signal generation, the NGMI threshold of 0.83 is utilized here [15]. The required input power into PD for 16QAM signal is 5.5 dBm at the 0.83 NGMI threshold. Meanwhile, post-FEC error free can be obtained for 10-Gbaud PS-64QAM signal when the input power into PD reaches 8.2 dBm. In addition, when the input power into PD is 8.5 dBm, the constellation diagrams of the recovered 16QAM and PS-64QAM symbols are also depicted. Then we extend the wireless distance to 400 m, the measured NGMI performance of the received 10-Gbaud QPSK and 5-Gbaud 16QAM signals versus input power into PD is shown in Fig. 2 (b). At the 0.83 NGMI threshold, the required input power into PD for 10-Gbaud QPSK signal is 9.5 dBm while it is 10.1 dBm for 5-Gbaud 16QAM signal. The constellation diagrams of the recovered QPSK and 16QAM

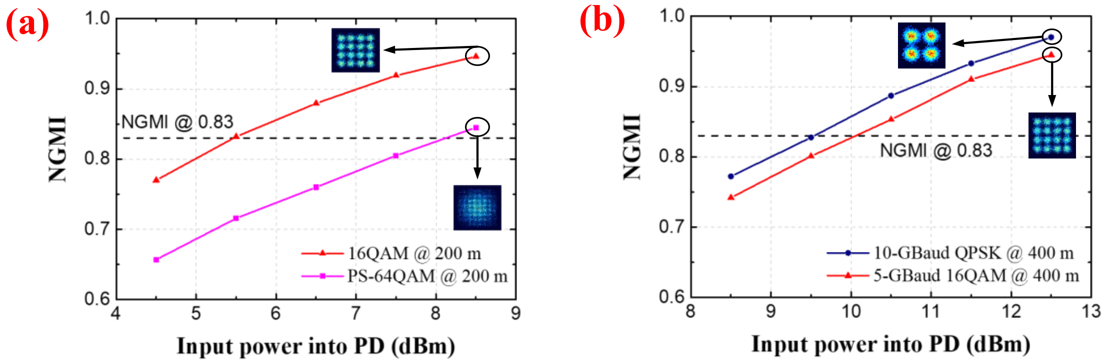

Fig. 2: (a) NGMI of received 10-Gbaud QPSK, 16QAM and PS-64QAM signals versus input power into PD after 200-m wireless delivery; (b) NGMI of received 10-Gbaud QPSK and 5-Gbaud 16QAM signals versus input power into PD after 400-m wireless delivery.

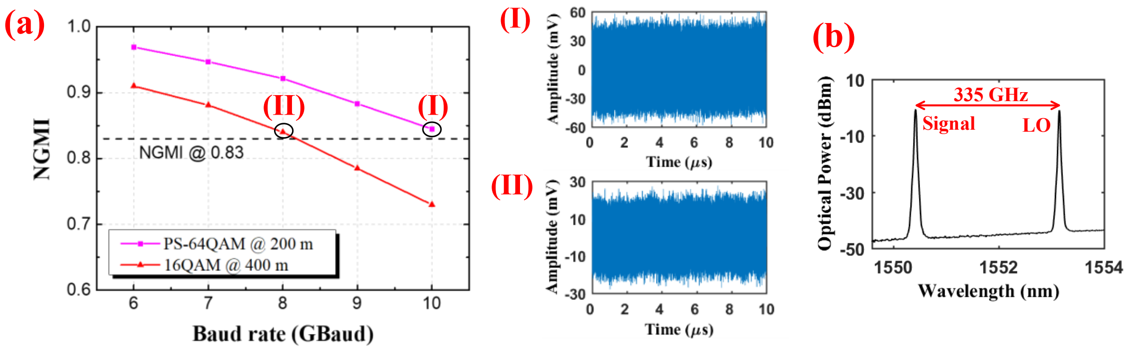

Fig. 3: (a) NGMI versus baud rate for PS-64QAM signals after 200-m wireless transmission and 16QAM signals after 400-m wireless transmission. Insets (I) and (II) are waveforms of the received 10-Gbaud PS-64QAM IF signal and 8-Gbaud 16QAM IF signal, respectively. (b) Optical spectrum of 8-Gbaud 16QAM optical signal into UTC-PD.

symbols at 12.5-dBm input power into PD are also illustrated. As depicted in Fig. 3 (a), we also compare the NGMI performance versus baud rate for PS-64QAM signals after 200-m wireless delivery at 8.5-dBm input power into PD and 16QAM signals after 400-m wireless delivery at 12.5-dBm input power into PD, respectively. Considering the 0.83 NGMI threshold, the highest baud rate for PS-64QAM signal 200-m transmission is 10 GBaud while it is 8 GBaud for 16QAM signal 400-m transmission. The waveforms of the received 10-Gbaud PS-64QAM IF signal and 8-Gbaud 16QAM IF signal are given in insets (I) and (II), respectively. In Fig. 3 (b), the optical spectrum of 8-Gbaud 16QAM optical signal and optical LO into the UTC-PD with 335-GHz frequency space is illustrated, where the resolution is 0.02 nm. Therefore, by employing PS-64QAM signal in 200-m wireless transmission, the highest line bit rate we can obtain is 56 Gbit/s (5.6×10=56 Gbit/s). Considering the SD-FEC with 25% overhead, the net bit rate is 44 Gbit/s ([5.6-6× (1-0.8)]×10=44 Gbit/s). Meanwhile, by employing 8-GBaud 16QAM signal in 400-m wireless transmission, the line bit rate is 32 Gbit/s (4×8=32 Gbit/s) and the net bit rate is 25.6 Gbit/s (32×0.8=25.6 Gbit/s).

Conclusions

10-GBaud PS-64QAM\8-GBaud 16QAM signal wireless transmission over 200\400-m distance at 335 GHz has been experimentally demonstrated in a THz-wave communication system based on photonics-aided scheme. Thanks to the pair of special dielectric lenses and advanced DSP in both Tx and Rx sides, we successfully realize 56\32-Gbit/s single line rate THz-wave signal wireless transmission over 200\400 m distance, satisfying the 0.83-NGMI LDPC threshold with 25% overhead.

Acknowledgements

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