300 GHz photonic-wireless transmission with aggregated 1.034 Tbit/s data rate over 100 m wireless distance

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Abstract: We present a long-distance ultrafast THz photonic-wireless communication system by combining frequency-, polarization- and spatial- division multiplexing techniques. An aggregated net rate of 1.034 Tbit/s over record 100 m at 300 GHz is successfully demonstrated.

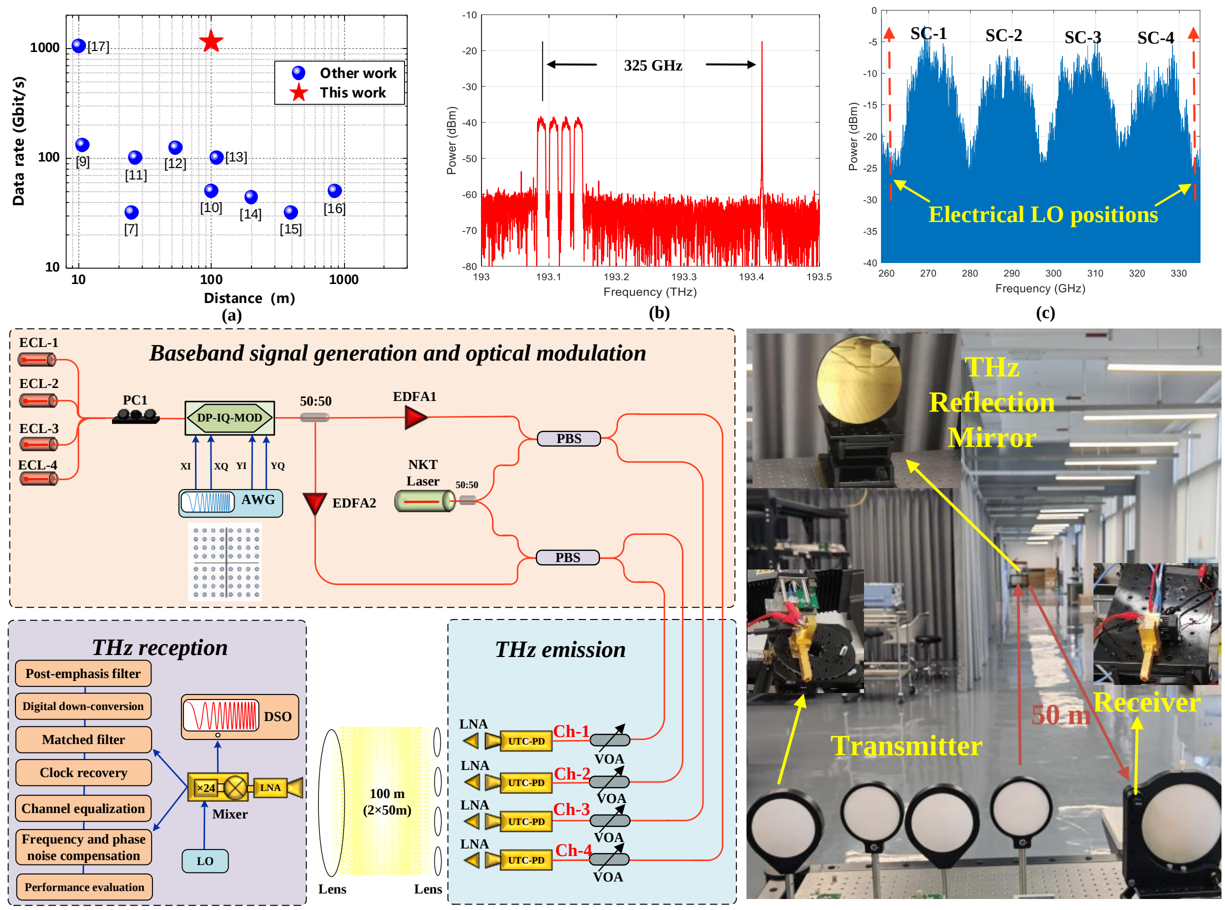
1. Introduction

In recent years, the rapid growth of wireless connections and number of Internet end users has dramatically driven the demand for high-speed and large capacity communication services. According to the Cisco report, wireless data traffic is currently doubling every 22 months, and the number of wireless users is anticipated to exceed 5 billion by 2023. In this case, wireless techniques supporting beyond 100 Gbit/s and even Tbit/s are of vital essence to accommodate the ever-increasing data traffic. In this context, the terahertz (THz) band (0.3–10 THz) featuring large bandwidth has recently received extensive attentions [1], [2]. Fig. 1(a) shows a summary of demonstrated data rates above 300 GHz. We can see that, benefiting from the wide deployment of optical fibers and the evolutionary development of THz devices, remarkable achievements have been well-witnessed in photonics-assisted THz systems [3]-[17]. For example, wireless transmission demonstrations of single-channel 106 Gbit/s at 400 GHz [3] and 128 Gbit/s at 300 GHz over 0.5 m [4] are experimentally obtained. Moreover, some multiplexing techniques have been also employed to improve the system capacity, such as wavelength division multiplexed (WDM) 260 Gbit/s at 400 GHz over 0.5 m [5], and 600 Gbit/s at 350 GHz over 2.8 m [6] using WDM and polarization division multiplexing (PDM) scheme. In addition to the multiplexing techniques, probabilistic shaping (PS) technique is also adopted to boost transmission performance, for instance, 100 Gbit/s at 350 GHz over 26.8 m [7] and 132 Gbit/s PS 64-QAM at 400 GHz over 1.8 m [8] have been achieved. Please note that on one hand, due to the weak emission power of opto-electronic transmitter and the bandwidth of individual components, the up-to-date capacity and transmission distance are still restrained. On the other hand, many other dimensions which are available in the photonics and wireless domains remain to be explored for handling Tbit capacity.

In this work, we propose and demonstrate an ultrahigh-speed and long-distance photonic-assisted THz wireless link operating in the 300 GHz band, by combining multiplexing gain in frequency, polarization and space dimensions, and an aggregated net data rate of up to 1.034 Tbit/s over 100 m is successfully achieved. In this demonstration, a cutting-edge uni-traveling carrier photodiode (UTC-PD) [18] and a Schottky diode mixer are used to radiate and receive the THz signals. The achievement represents the ever-first transmission of Tbit over a record distance of 100 m in the 300 GHz band, to the best of our knowledge.

2. Experimental setup

Fig. 1(d) depicts the experimental configuration of THz photonic-wireless communication system. First, four light beams centered at 193.143 THz, 193.125 THz, 193.107 THz, 193.089 THz, respectively, are generated from four external cavity lasers (ECL-1 to 4). Then all these optical signals are launched into a dual-polarization in-phase and quadrature optical modulator (DP-IQ-MOD) to implement 2-12 Gbaud baseband signal modulation (64-QAM). Here a 4-port arbitrary waveform generator (AWG, 120 GSa/s) is employed to generate a repetitive pseudo-random binary sequence (PRBS-15). In the experiment, the port 1 and 2 of AWG generate the baseband data information for X-polarization (X-Pol.), and the rest for Y-polarization (Y-Pol.). Subsequently, the modulated optical signals are divided into two copies via a 50:50 optical coupler, which are individually amplified by two erbium-doped fiber amplifiers (EDFAs), and coupled with a local oscillator (LO) light centered at 193.414 THz from the NKT laser. Then two polarization beam splitters (PBSs) are used to separately abstract the X-Pol. and Y-Pol. components for the purpose of space division multiplexing (SDM). After that, the two X-Pol. optical signals carrying X-Pol. data information are fed into two UTC-PDs (IOD-PMAN-13001, NEL) to generate THz signals named channel-1 (Ch-1) and channel-3 (Ch-3). Similarly, channel-2 (Ch-2) and channel-4 (Ch-4) THz signals carrying Y-Pol. data information are generated. Fig. 1(b) shows the optical spectra at the input of the UTC-PD of Ch-1, as an example. The modulated optical signals consist of four light beams equally spaced 18 GHz, and the one centered at 193.089 THz is 325 GHz away from the unmodulated LO light at 193.414 THz. Based on the photo-mixing approach, 4-subcarrier (4-SC) THz signals located at 271 GHz, 289 THz, 307 GHz, 325 GHz, named subcarrier-1 (SC-1), subcarrier-2 (SC-2), subcarrier-3 (SC-3), and subcarrier-4 (SC-4), are generated from each UTC-PD. Fig. 1(c) shows the electrical spectra of 4-SC THz signals of Ch-1. The THz signals from each UTC-PD are radiated into the free space and amplified by a low noise amplifier (LNA, 250-350 GHz, 22 dB gain). In the middle of wireless path, a reflective mirror is placed 50 m away from the transmitter and the receiver, to double the wireless transmission distance. The picture of the actual THz transmission link as shown in Fig. 1(e). After the 100 m wireless link, the 4-SC THz signals from each channel is individually received by a broadband THz receiver, which is composed of a horn antenna with 25 dBi gain, a LNA with 22dB gain, a Schottky mixer (24-order) driven by an electrical local oscillator, and a real-time digital storage oscilloscope (DSO, 160 GSa/s, 59 GHz bandwidth). Due to the bandwidth limitation of the Schottky mixer (40 GHz), each time the SC-1 and SC-2 THz signals are down-converted into two intermediate frequency (IF) signals centered at 8 GHz and 26 GHz by tuning the LO frequency to 263 GHz, and similarly the SC-3 and SC-4 are down-converted into two IF signals centered at 26 GHz and 8 GHz when the LO frequency is set as 333 GHz. The positions of the LOs are shown in Fig. 1(c). Subsequently, the IF signals are sampled in the digital domain for offline performance evaluation, until 4-channel multiplexing links with 16 SCs are all eventually analyzed.



(d) (e)

Fig. 1. (a) State-of-the-art wireless data rates versus transmission distance in the frequency region above 300 GHz, (b) optical spectra at the input of UTC-PD of Ch-1, (c) electrical spectra of the 4-SC THz signals of Ch-1, (d) experimental configuration of multi-dimensional multiplexing THz photonic-wireless communication link, (e) picture of the actual THz transmission link.

3. Experimental results and discussions

Fig. 2(a) shows the bit-error-rate (BER) performance of overall 16 SCs in four channels versus the optical power launched into the UTC-PDs. We can observe that the BER performance become better with the increase of optical power. When the incident optical power gets to around 8 dBm, the BER performances of all 16 SCs can reach below the soft decision forward-error-correction (SD-FEC) threshold with 20% overhead [19]. In particular, the BER performances of SC-1, SC-2 and SC-3 in four channels can reach below the hard decision forward-error-correction (HD-FEC) threshold with 7% overhead [20] when the incident optical power gets to around 14 dBm. While, due to the imperfect frequency response of UTC-PD, the SC-4 performance in all four channels is similar to be the worst. Nevertheless, each channel carries data rates of 288 Gbit/s (12 Gbaud × 6 bit/s/Hz × 4-SC), resulting in an aggregate line data rate of 1.152 Tbit/s (288 Gbit/s × 2 (PDM) × 2 (SDM)) after multi-dimensional multiplexing. Taking the SD-FEC and HD-FEC overhead into account, an aggregated net data rate of 1.034 Tbit/s (288 Gbit/s × 3 × 0.93 + 288 Gbit/s × 0.8) after wireless transmission is successfully achieved.

The 4-SC BER performance of Ch-1 versus various baud rates is also measured, as depicted in Fig. 2(b), when the optical power into the UTC-PD is fixed at 14 dBm. We can observe that the BER performance gets worse as the baud rate increases, mainly due to the increased crosstalk caused by decreased guardband between adjacent SCs. In addition, the emission THz power in this case is fixed, the higher baud rate is, the lower SNR is. Fig. 2(b) illustrates that all the BER performance of 2 -12 GHz baud rates on each SC can reach below the SD-FEC threshold, and the BER performance of SC-1 to SC-3 can be even below the HD-FEC threshold.

Finally, the system stability for 4-SC of Ch-4 is also illustrated in Fig. 2(c). We cumulatively record 150 traces in 5 hours to characterize the stability of system operation. For the Ch-4, the BER performance of SC-1, SC-2 and SC-3 is stable below the HD-FEC threshold, and the SC-4 is all the time below the SD-FEC threshold, which not only agrees with the aforementioned measurements, but also confirms that the communication system operates stably.

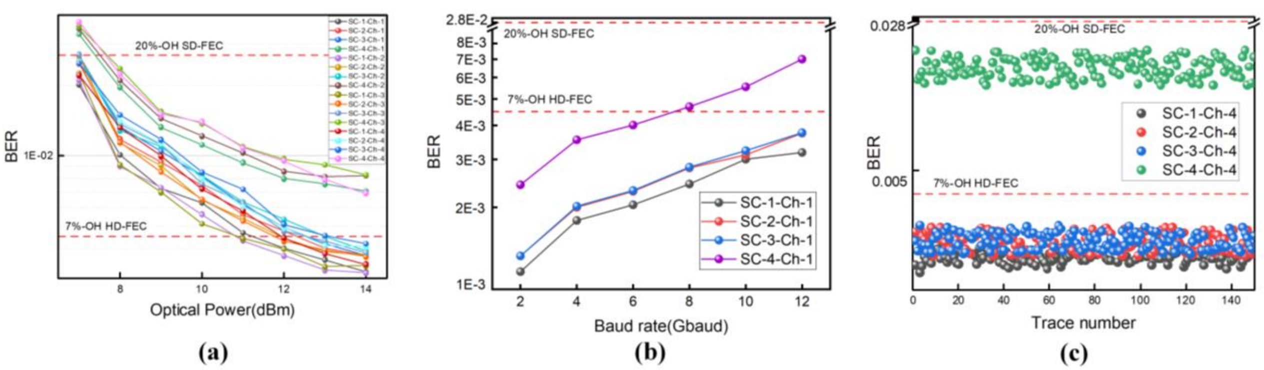


Fig. 2. Experimental results of Tbit/s wireless transmission, (a) measured BER performance of overall 16 SCs in four channels after 100 m wireless transmission, (b) measured 4-SC BER performance of Ch-1 versus baud rates when the optical power to UTC-PD is fixed at 14 dBm, (c) system stability by measuring 4-SC performance of Ch-4.

4. Conclusions

Based on WDM, PDM, SDM multi-dimensional multiplexing approach, we experimentally demonstrate a photonic-wireless transmission system in the THz region, achieving an aggregated net rate of 1.034 Tbit/s over a distance of 100 m, which represents the ever-first wireless delivery of Tbit over a record distance in the 300 GHz band and paves a way towards ultrafast wireless communication.

Acknowledgements

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