6G Oriented 256Gb/s Photonics-assisted THz-over-Fiber Passive Optical Network Architecture Based on Optical Wavelength Routing Scheme

Bingchang Hua(1), Min Zhu(1,2)*, Jiao Zhang(1,2), Weidong Tong(2), Mingzheng Lei(1), Yuancheng Cai(1,2), Yucong Zou(1), Jian Chen(2), Xiang Liu(2), Guo Zhao(4), and Jianjun Yu (1,3)

(1) Purple Mountain Laboratories, Nanjing, Jiangsu 211111, China, *minzhu@seu.edu.cn
(2) Southeast University, Nanjing 210096, China
(3) Fudan University, Shanghai 200433, China
(4) Nanjing Wasin Fujikura Optical Communication Ltd., Nanjing, Jiangsu 210038, China

Abstract *We experimentally demonstrate a 4-channel terahertz-over-fiber passive optical network architecture based on optical wavelength routing scheme. This system achieves a data rate of 256 Gbit/s over a 22 km SSMF and a 3 m wireless link within the 400 GHz band. ©2023 The Author(s)*

Introduction

The terahertz (THz) band, ranging from 0.3 THz to 10 THz, is widely considered a critical component of future 6G mobile communication systems. This band possesses ultra-wideband resources and can support exceptionally high wireless communication rates, from 100 Gb/s to potentially 1 Tb/s [1-3]. Photonics-assisted THz wireless communication technology, which circumvents the bandwidth limitations of electronic devices and achieves ultrahigh speed, high carrier frequency, and extensive adjustment range, has experienced rapid development due to the explosive growth of data traffic in wireless communication systems [4-5].

In recent years, researchers worldwide have actively investigated photonics-assisted THz communication technologies [6-15]. In [6], the University of Duisburg-Essen achieved a coherent optical carrier THz wireless communication link supporting offline 59 Gbit/s 64QAM OFDM signal transmission at a carrier frequency of 328 GHz. In [7], X. Li et al. employed wireless 2×2 MIMO, high-order 64QAM modulation, and probabilistic shaping technologies to accomplish a photon-assisted THz communication system with a transmission rate of 132 Gbit/s on a single carrier in the 450 GHz frequency band and a wireless transmission distance of 1.8 m. In 2020, S. Jia et al. demonstrated a multi-carrier 600 Gb/s offline transmission system in the THz band [11], [12]. It is important to note that these research works are all based on point-to-point transmission systems that do not consider multi-user application scenarios in the optical access segment. In [16], the concept of an optical and THz integration access network is proposed, but the specific network integration structure is not provided. In our previous work [17], a real-time transparent point-to-multipoint photonics-assisted MMW-over-fiber passive optical network transmission scheme with a line rate of 4×125.516 Gbit/s was realized based on an optical wavelength routing scheme. However, this was achieved in the W-band.

In this paper, we successfully demonstrate a 4-channel QPSK THz-wave signal transmission with rates of 24-, 28-, 32-, or 36-Gbaud at the 400 GHz band over 22 km SSMF and 0.05/3 m wireless link in a point-to-multipoint THz-over-fiber passive optical network (ToF-PON) architecture, based on optical wavelength routing scheme. The achieved bit error rate (BER) is below the soft-decision forward error correction (SD-FEC) threshold of 2×10^{-2}. To the best of our knowledge, this constitutes the first demonstration of a point-to-multipoint photonics-assisted THz wireless transmission with a rate exceeding 200 Gb/s in the THz band.

Experimental Setup

The experimental setup of point-to-multipoint photonics-assisted ToF-PON system is shown in Fig. 1. <u>In the OLT</u>, four 12-dBm continuous waves (CWs) from four external cavity lasers (ECLs) with a linewidth of < 100 kHz are first multiplexed using a 1 × 8 Dense Wavelength Division Multiplexing (DWDM) module with 100-GHz spacing. Notably, the frequency spacing between CWs is set to 200 GHz. The optical spectrum of the four CWs at 0.1 nm resolution is shown in Fig. 1(a). Consequently, the CW is injected at 1-port intervals in the DWDM module. The multiplexed CWs from the DWDM module are equally divided into two branches through an optical coupler (OC), one of which is injected into an in-phase/quadrature (I/Q) modulator with a 3 dB bandwidth of 33 GHz for data modulation, while the other serves as the local oscillator (LO). The

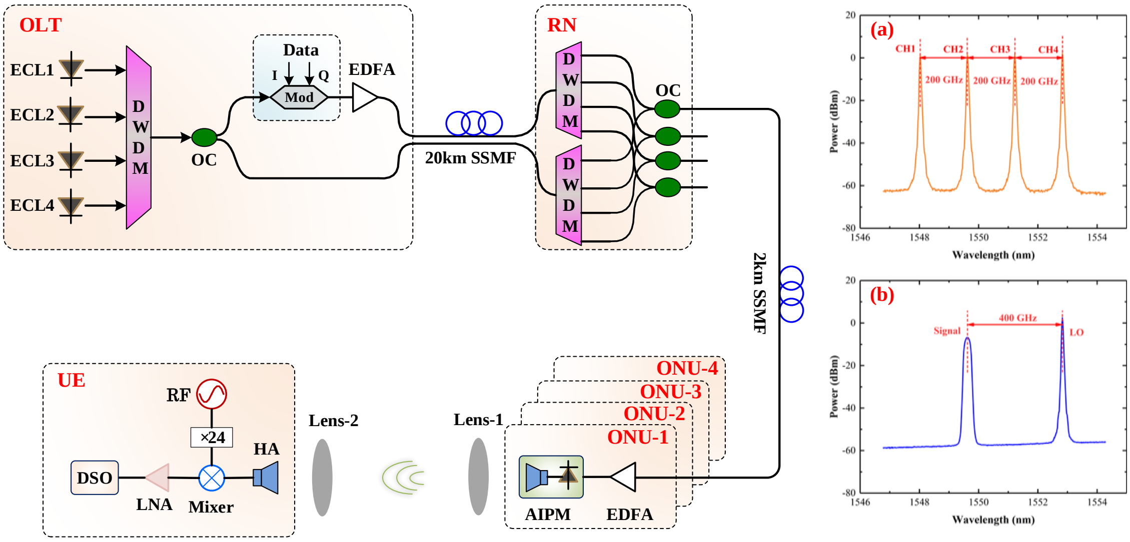

Fig. 1: Experimental setup of simplified point-to-multipoint photonics-assisted ToF-PON architecture. Optical spectra: (a) the four CWs; (b) the optical carrier and LO after optical coupler

24-, 28-, 32-, and 36-Gbaud electrical QPSK signals are generated by MATLAB software and converted into the analog domain by a 92-GSa/s arbitrary waveform generator, respectively. The modulated optical carriers are amplified by an erbium-doped fiber amplifier (EDFA) to compensate for the insertion loss of the modulator and then transmitted over a 20-km SSMF. The LOs are directly transmitted to the RN through a 20-km SSMF.

In the RN, one DWDM module is utilized for demultiplexing the optical carriers, while the other is employed for demultiplexing the LOs. A pair of optical carriers and LOs are coupled by an OC with a frequency spacing of 400 GHz, such as CH2 and LO4, and reach the ONU after 2 km of distributed SSMF transmission.

In the ONU, the optical carrier and LO are amplified by the EDFA to effectively drive the antenna-integrated photomixer module (AIPM, NTT Electronics Corp. IOD-PMAN-13001). The AIPM integrates a uni-traveling carrier photodiode (UTC-PD) and an antenna. Fig. 1(b) displays the optical spectrum of the coupled optical carrier and LO at 0.1 nm resolution, revealing that the frequency spacing between the optical carrier and LO is 400 GHz. Subsequently, the 400 GHz THz-wave signals, obtained by AIPM optical heterodyne beating, are transmitted over a 3 m wireless THz-wave link. A pair of lenses are utilized to focus the wireless THz-wave, maximizing the received THz-wave signal power. Lenses 1 and 2 are identical, each with a 20 cm focal length and 10 cm diameter.

In the UE, the THz-wave signal collected by lens 2 is received by a horn antenna (HA) and subsequently down-converted to a 20 GHz intermediate frequency (IF) by a mixer with a 40 GHz bandwidth. The mixer is driven by a 15.8333 GHz radio frequency (RF) source, amplified by a ×24 frequency multiplier chain. A low-noise amplifier (LNA) with a gain of 26 dB is employed to amplify the IF signal, and a DSO (Keysight, 128 GSa/s, UXR0594A) is used to capture IF signal. Finally, the captured IF signal undergoes offline processing by the offline digital signal processing (DSP) block in the digital domain.

Results and discussion

To evaluate the performance of the point-to-multipoint photonics-assisted ToF-PON system, experiments were conducted for two scenarios: a back-to-back (BtB) scenario with 22 km SSMF and 0.05 m wireless distance, and a 3m scenario with 22 km SSMF and 3 m wireless distance.

In the BtB scenario, first, we plot the BER versus Received Optical Power (ROP) for the 4 channels with a rate of 32Gbaud QPSK signal in the BtB scenario, as illustrated in Fig. 2(a). The BER performance of the 4 channels appears similar. When the ROP is less than 11 dBm, the BER performance significantly improves as the ROP increases. Conversely, when the ROP is greater than 11 dBm, the BER performance rapidly degrades as the ROP increases. The BER performance starts to deteriorate above 11 dBm due to saturation in the AIPM power. We also demonstrate QPSK signal THz wireless transmission at different rates. Taking CH3 as an example, Fig. 2(b) displays the measured BER performance of CH3 with rates of 24-, 28-, 32-, and 36-Gbaud. From Fig. 2(b), we observe that when the ROP is less than 11 dBm, the BER performance improves significantly as the signal rate increases. However, when the ROP is greater than 11 dBm, the system with a rate of 32

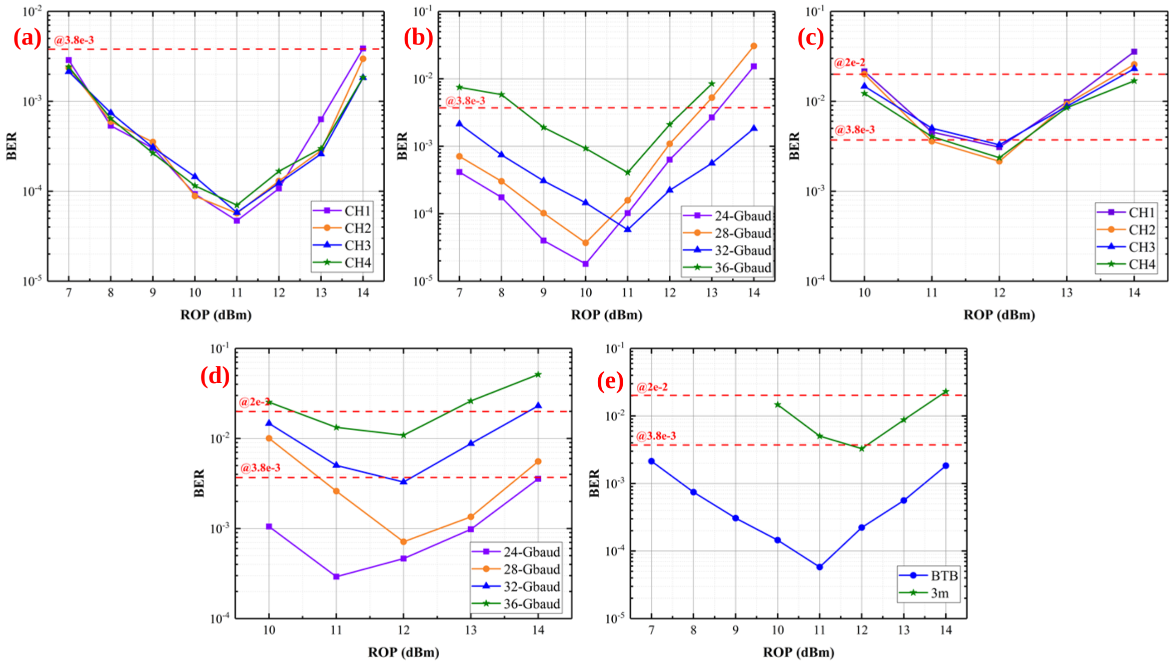

Fig. 2: (a) BER versus ROP of four channels with a rate of 32Gbaud in the BtB scenario; (b) BER versus ROP of CH3 with rates of 24-, 28-, 32-, and 36-Gbaud in the BtB scenario; (c) BER versus ROP of four channels with a rate of 32Gbaud in the 3 m scenario; (d) BER versus ROP of CH3 with rates of 24-, 28-, 32-, and 36-Gbaud in the 3 m scenario; (e) BER versus ROP of CH3 with a rates of 32Gbaud in the BtB and 3 m scenarios

Gbaud exhibits the best BER performance. Furthermore, the systems with rates of 24 Gbaud and 28 Gbaud achieve optimal BER performance at an ROP of 10 dBm. This represents a 1 dB reduction in the ROP at the best BER performance compared to systems with 32 Gbaud and 36 Gbaud rates. The primary reason for this phenomenon is that the saturation power of the AIPM varies with different signal rates. The AIPM saturation power increases as the signal rate increases.

In the 3 m scenario, Fig. 2(c) displays the BER versus ROP for the 4 channels with a rate of 32Gbaud QPSK signal in the 3 m scenario. The BER performance of the 4 channels in the 3 m THz wireless transmission scenario is also similar. The system's optimal BER performance in the 3 m THz wireless transmission scenario occurs at an ROP of 12 dBm, which is a 1 dB improvement over the BtB scenario. Moreover, the BER performance of all 4 channels can reach below the hard decision forward-error-correction (HD-FEC) threshold with a 7% overhead. The measured BER performance of CH3, as an example, is presented in Fig. 2(d) with rates of 24-, 28-, 32-, and 36-Gbaud in the 3 m THz wireless transmission scenario. The BER performance worsens as the data rate increases, due to the reduction of electrical SNR with fixed power. By comparing the BtB scenario, it can be concluded that wireless transmission loss has a more significant impact on high-rate signals. It is evident that systems with rates of 24-, 28-, and 32-Gbaud can support 7% HD-FEC, while systems with a rate of 36-Gbaud can support 20% SD-FEC. Furthermore, Fig. 2(e) displays the BER performance of CH3 with a rate of 32 Gbaud under the two scenarios. It can be observed that the BER performance of the 3 m THz wireless transmission scenario experiences a relatively large drop.

Conclusions

In conclusion, we have experimentally demonstrated a 4-channel QPSK signal transmission experiment with a rate of 256 Gbit/s over 22 km SSMF and 0.05m / 3 m wireless link at a carrier frequency of 400 GHz. The minimum BER achieved is less than the HD-FEC threshold of 3.8×10^{-3}. To the best of our knowledge, this is the first instance of realizing > 200 Gb/s point-to-multipoint photonics-assisted THz wireless transmission in the THz-band.

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