6G Oriented 100 GbE Real-time Demonstration of Fiber-THz-Fiber Seamless Communication Enabled by Photonics

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Abstract: We demonstrate 6G-oriented 100 GbE real-time streaming service applications in fiber-THz-fiber seamless transmission with a record net data rate of 103.125 Gbps at 370 GHz enabled by photonic up-/down-conversion and digital coherent modules. © 2022 The Author(s)

1. Overview

The Terahertz-band (THz-band, i.e., 0.3 THz to 10 THz) are attracting extensive attention in interdisciplinary fields of electronics and photonics, which can offer hundreds of Gbps or even Tbps data capacity due to its huge available bandwidth [1,2]. In line with World Radio Communication Conference 2019 (WRC-19) decision, 275~296GHz, 306~13GHz, 318~333GHz, and 356~450GHz spectrum bands are released for land mobile and fixed service applications. Photonics-aided THz-wave technique can break the bottleneck of electronic devices and facilitates seamless integration with high-speed optical fiber access networks, which is expected to become an extremely promising application prospect for future 6G communication.

Recent years, the generation, modulation and detection of broadband millimeter-wave and THz-wave signals based on photonic technology have effectively promoted the seamless integration of wireless networks and optical fiber networks [3-5]. Extensive fiber-wireless integration transmission systems have been demonstrated at Q-, V-, W-, or D-band based on offline digital signal processing (DSP). The transparent optical-THz-optical link providing line-rates up to 240 and 190 Gbps over distances from 5 to 115m at 230GHz is demonstrated using a plasmonic modulator with a built-in low noise amplification [6,7]. The transparent fiber-radio-fiber bridge at 101 GHz is also demonstrated using an optical modulator, where 32-/64 QAM OFDM and single-carrier (SC) signal with line rates of 71.4 and 57.5 Gbps are transmitted based on direct photonic down-conversion, respectively [8]. However, the above research works are all based on off-line DSP. For the real-time transmission, with aid of the high-speed real-time commercial digital coherent optics (DCO) modules, the fiber-THz-fiber transmission of 100 Gbps net capacity via a pure electronic THz wireless link at 300 GHz over 0.5 m has been successfully demonstrated [9]. Note that the photoelectric conversion of baseband signal is necessary before the THz signal generation via frequency multiplier. In addition, the real-time delivery of 109.3 Gbps net data rate at 24 GHz based on DCO module are experimentally demonstrated enabled by photonic heterodyning technique [10]. Hence, the commercial DCO module is proved to be a promising solution to realize real-time seamless integration fiber-Radio-fiber link.

In this work, we show a real-time transparent fiber-THz-fiber 2×2 MIMO transmission system based on photonic up-/down-conversion at 370 GHz THz band for the first time. By using two commercial Centum form-factor pluggable (CFP2) DCO modules, the 31.379 GBaud (125.516 Gbps) DP-QPSK signal providing 103.125 Gbps net capacity is successfully transmitted over two spans of 20 km SSMF and 1 m wireless link under 15% SD-FEC for pre-FEC BER of 1.56×10^{-2} (post-FEC BER<10^{-15}). We develop and demonstrate a 100GbE streaming service platform to play real-time video and live surveillance video, and verify the stability of the transmission system.

2. Innovation

In this demonstration, we demonstrate the first 100GbE real-time transparent fiber-THz-fiber communication at 370 GHz based on photonic up-/down-conversion. The main innovations of this demonstration are as follows:

(1) Design a practical real-time transparent fiber-THz-fiber 2 × 2 MIMO transmission system over two spans of 20 km SSMF and 1 m wireless link based on photonic remote heterodyning, photonic down-conversion, with the aid of the CFP2-DCO modules. To work around the bandwidth, sampling rate and accuracy limitations of high-speed digital-analog/analog-to-digital converters (DAC/ADC), we first prove that the DCO module is a promising solution to realize practical seamless integration fiber-THz-fiber link for future 6G communications.

(2) Develop a 100GbE (103.125 Gbps) streaming service platform to play real-time video and live surveillance video, and verify the stability of the transmission system. Photonics-aided THz-wave technique exhibits the superior characteristics of high frequency, large bandwidth, and low transmission loss of optical devices, compared with the

pure electronic way. Prospective fiber-THz-fiber integration link can be used for high-speed point-to-point scenario.

3. OFC relevance

THz communications and fiber-wireless converged transmission enabled by photonics have attracted the interest of the community, both topics being hot trending in OFC. This demo is tailored particularly for the OFC audience, and 100GbE real-time video and live surveillance video transmission at 370 GHz will be demonstrated. It's a promising scheme to pave the way towards practical seamless integration fiber-THz-fiber link for future 6G communication. This work may be also of great interest for industry players and optical module manufactures.

4. Description of Demonstration

We build a 100GbE (103.125 Gbps) transmission platform including two displayers, two servers, and two optical transport units (OTUs), between which QSFP28 modules are used on the client side, and two CFP2-DCO modules are equipped on the line side, as shown in Fig. 1. The100GbE server network card is connected with the OTU through QSFP28 modules supporting 4×25.78125 Gbps over 2 m multi-mode fiber (MMF). The CFP2-DCO module can support DP-QPSK modulation, polarization diversity homodyne detection, and high-speed real-time DSP demodulating. In our demonstration, 31.379 GBaud DP-QPSK modulated optical baseband signal is generated by setting the module in network management system (NMS). The optical signal carrier frequency is 193.5 THz, and the optical power is 3 dBm. The CFP2-DCO module has built-in optical transport network (OTN) framer and can be directly used for 100GbE transponder application. The streaming service platform base on EasyDarwin® open source software installed at the master server is developed to support real-time video and live surveillance video service. Real-time video is a 4K movie stored in the server with video rate of 35 Mbps. Four 4K surveillance cameras are connected to the server via modem and switch based on Ethernet with TCP/IP protocol. The live surveillance video rate of each camera is 16 Mbps after H.265 compression. Then, the optical baseband modulation signal is delivered over one span of 20 km SSMF with 17-ps/km/nm chromatic dispersion (CD) at 1550nm.

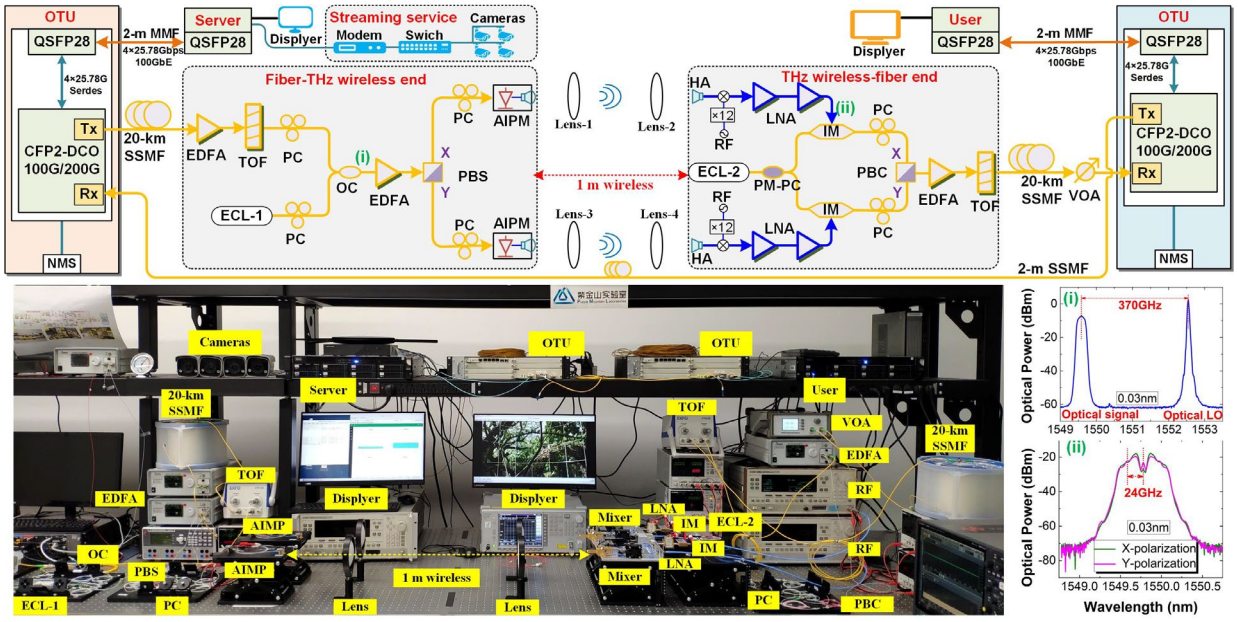

Fig. 1. Testbed setup of 100GbE real-time transparent fiber-THz-fiber transmission system.

At fiber-THz wireless-fiber end, a free-running tunable ECL-1 is used as an optical LO that has a linewidth less than 100 kHz. The optical signal with 9 dBm optical power and ECL-1 with 12 dBm output power are combined by an optical coupler (OC) and then amplified by an EDFA to effectively drive antenna-integrated photomixer module (AIPM), which integrates a uni-traveling-carrier photodiode (UTC-PD) and a bow-tie or log-periodic antenna. A PBS is used to separate the X- and Y-polarization components of the combined lightwaves. In our demonstrated system, photonic heterodyning is utilized to generate 370GHz THz-wave wireless signal. Note that the AIPMs are polarization sensitive, and hence four polarization controllers (PCs) are necessary to adjust the incident polarization direction to maximize output power from AIPMs. The measured optical spectrum for 370 GHz at 0.03 nm resolution is shown in Fig. 1(i). Then, the THz-wave signals are delivered over a 1m 2×2 MIMO wireless THz-wave transmission link. Two pairs of lenses are used to focus the wireless THz-wave to maximize the received THz-wave signal power. The lens 1-4 are identical, and each of them has 20 cm focal length and 10 cm diameter.

At THz wireless-fiber end, THz-wave wireless signals are received with two parallel THz-band HAs with 26 dBi gain. For X and Y-polarization THz-wave wireless signals, two identical THz receivers operating within 330 GHz to 500 GHz are driven by electronic LO sources to implement analog down conversion, and each consists of a mixer, a ×12 frequency multiplier chain and an amplifier. Then, the down-converted X- and Y-polarization intermediate-frequency (IF) signals at 24 GHz is boosted by two cascaded electrical low-noise amplifiers (LNAs) with 3 dB bandwidth of 47 GHz to drive two intensity-modulators (IMs) with 3 dB bandwidth of 40 GHz, respectively. The output amplitude of the amplified IF signals is 168 mV. The ECL-2, as optical carrier input of the two IMs, has the 24GHz frequency spacing to the initial optical baseband signal and 14.5 dBm optical power, and is split into two branches by a polarization-maintaining OC (PM-OC). Each IM is DC-biased at optical-carrier-suppression (OCS) point. Fig. 1(ii) shows the measured spectra after the IM in the case of the 370 GHz THz signal. Then, the X- and Y-polarization are combined by a PBC and boosted by another EDFA. Two PCs are used to adjust the polarization direction to obtain the maximal output power. Another tunable optical filter (TOF) is set to filter out the upper sideband and the central optical carrier as well as the ASE noise, preserving only the lower sideband. The obtained optical baseband signal is delivered over the second span of 20 km SSMF, and then received by the CFP2-DCO module. The symmetric reverse transmission path is directly connected via a 2 km SSMF.

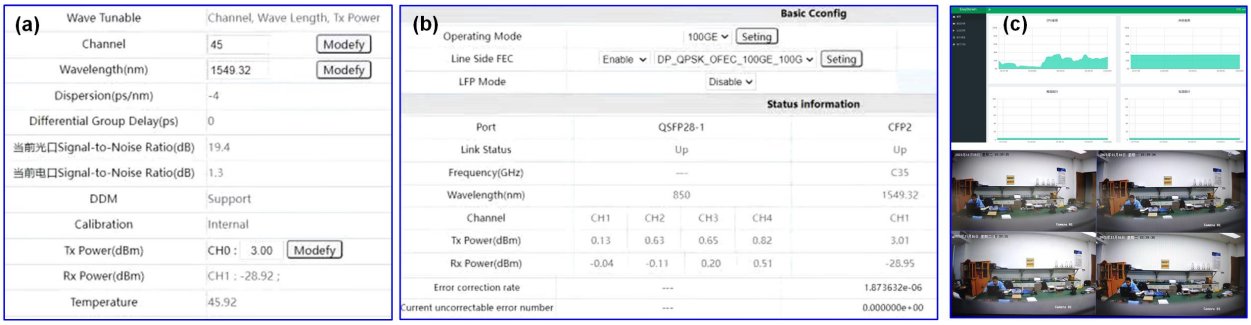

Fig. 2. Network management system: (a) Parameters of CFP2-DCO module; (b) Status information. (c) Streaming service platform.

Figures. 2 (a) and (b) show the NMS interface, where the parameters of CFP2-DCO module can be set, and status information such as operating mode, optical power and BER can be shown. In the developed streaming service platform, as shown in Fig. 2(c), we test the stability of the transmission system after the parameters of CFP2-DCO are optimized. Note that, due to the limitation of server performance, we only test one user, but the 100 GbE transmission rate is constant. Real-time movie and live surveillance video are played successfully. Table. 1 gives BER variation versus test time at 370GHz with 12.5 dBm input power into each AIPM. This system can transmit stably within 120 minutes under 15% SD-FEC threshold for pre-FEC BER of 1.56×10^{-2} (post-FEC BER<10^{-15}). This demonstrated fiber-THz-fiber seamless system can support hundreds of users for bandwidth-consuming services.

Table. 1. Transmission system stability test

Test time (min)	20	40	60	80	100	120
BER (15% SD-FEC)	4.27×10^{-3}	4.24×10^{-3}	4.39×10^{-3}	4.59×10^{-3}	4.67×10^{-3}	4.91×10^{-3}

5. Conclusion

In summary, we demonstrate a real-time transparent fiber-THz-fiber transmission over two spans of 20 km SSMF and 1 m wireless link at 370 GHz based on photonic up-/down-conversion. We successfully develop a 100 GbE (103.125 Gbps) streaming service platform to play real-time movie and live surveillance video. This demonstration is a promising solution for the seamless integration fiber-THz-fiber link applications in future 6G communication.

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