Real-time 125-Gb/s DP-QPSK signal delivery over 150 m based on a dual-polarized single-channel W-band wireless link enabled by photonics

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Abstract: In a photonics-enabled fiber-wireless-fiber system, we successfully demonstrate the first real-time 125-Gb/s DP-QPSK signal delivery over a 150-m dual-polarized single-channel wireless link with a record of real-time transmission capacity and wireless distance at W band.
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1. Introduction

As is well known, the millimeter-wave (MMW) and terahertz (THz) technologies are important cornerstones for future 6G communications [1]. How to realize the real-time long-distance transmission of ultra-bandwidth and large-capacity MMW/THz signals is one of the key means to expedite 6G progress. In previous research, some typical works have demonstrated the real-time signal transmission in W band (75~110 GHz) [2-4]. A real-time 2.5-Gb/s error-free non-return-to-zero (NRZ) signal transmission over 15-km fiber and 50-m wireless distance at 83 GHz has been achieved [2]. Utilizing a pair of π/4-shift differential QPSK transceiver, a transparent fiber-wireless-fiber link enabling the real-time 5-Gb/s Ethernet frame transmission over two spans of 20-km fiber and 20-m wireless at 96 GHz has also been demonstrated [3]. With one FPGA-enabled real-time receiver, a 24-Gb/s OFDM-16QAM signal can be successfully transmitted over 20-km fiber and 3-m wireless at 91 GHz [4]. A more comprehensive summary of W-band real-time wireless transmission demonstrations is given in Fig. 1(a). It can be seen that for these existing real-time W-band MMW systems, the transmission capacity is no more than 30 Gb/s, and the wireless transmission distance is within 50 m. Recently, we have demonstrated an inspiring real-time 100-GbE fiber-THz-fiber transparent transmission over two spans of 20-km standard single-mode fiber (SSMF) and 3-m wireless at 0.33 ~ 0.5 THz band [5-7]. The 125-Gb/s dual-polarized QPSK (DP-QPSK) optical baseband (BB) signal, generated by one optical transport unit (OTU) with equipped two 100-GbE commercial digital coherent optical (DCO) modules, has been successfully transmitted using 2×2 multiple-input multiple-output (MIMO) links. However, due to the high air transmission loss and immature amplifier products at THz band, the THz wireless links generally have a restricted wireless coverage range within 10 m. In addition, the 2×2 MIMO wireless channels also lead to the system performance degradation and instability, due to the inter-channel interference and imbalance.

In this paper, we for the first time investigate and demonstrate a real-time fiber-wireless-fiber seamless integration system with a dual-polarized single-input single-output (SISO) W-band wireless link. A record real-time line rate of 125-Gb/s DP-QPSK signal delivery over 150-m wireless distance at 92.5 GHz and two spans of 20-km SSMF has been achieved by using the commercial 100-GbE DCO modules. To simplify the long-distance wireless link and improve the system transmission performance, two W-band orthomode transducers (OMTs) are used at the wireless transmitter and receiver ends, respectively, which can skillfully couple the dual-polarized optical signal into a dual-polarized SISO wireless link.

2. Experimental setup

Figure 1 shows the experimental setup for the 125-Gb/s DP-QPSK signal delivery over 150-m wireless distance at W band. At the optical transmitter, the real-time 31.379 GBd DP-QPSK optical BB signal (1549.315 nm, 3 dBm) with a rolloff of 0.2 is generated by one commercial 100-GbE DCO module in OTU1 [7]. The DCO module adopts centum form-factor pluggable 2 (CFP2) encapsulation type, and contains the integrated coherent transmitting (ICT) and integrated coherent receiving (ICR) units, as well as the corresponding real-time bi-direction digital signal processing (DSP) unit. After 20-km SSMF transmission, the output optical DP-QPSK BB signal is first filtered by a tunable optical filter (TOF1) to suppress out-of-band amplified spontaneous emission (ASE) noise induced from

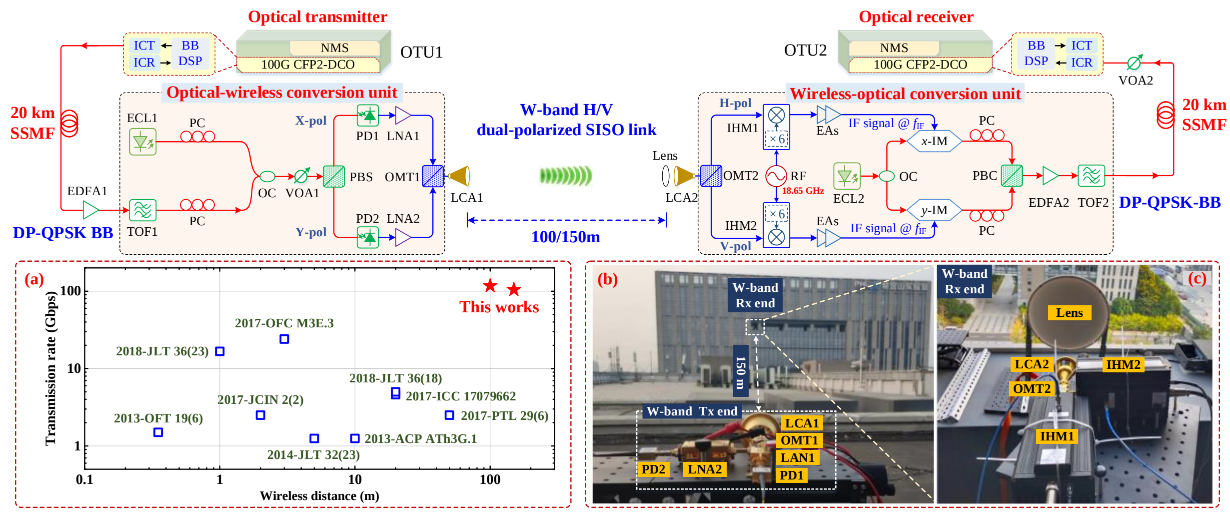

Fig. 1. Experimental setup for real-time 125-Gb/s DP-QPSK signal delivery over 150-m wireless distance at W band. (a) State-of-art on W-band real-time communication demonstrations. Photos of (b) outdoor experiment environment, W-band optical-wireless conversion unit and (c) wireless-optical conversion unit.

EDFA1. Then it is coupled with an optical local oscillator (LO) from ECL1 (1550.056 nm, 10 dBm) with < 100 kHz linewidth in optical-wireless conversion unit. The frequency difference between the two lightwaves is 92.5 GHz, as shown in Fig. 2(a). A polarization beam splitter (PBS) is employed to split the combined lightwaves into two orthogonal polarization components, i.e., X-pol and Y-pol, which are then down-converted to 92.5-GHz MMW signal via two separate photodiodes (i.e., PD1 and PD2) with 3-dB bandwidth of 100 GHz. After amplified by the W-band LNA1 and LNA2 with 35-dB gain, respectively, the two MMW signals centered at 92.5 GHz are combined together via a W-band OMT (i.e., OMT1) with 35-dB isolation between the H- and V-pol directions. A pair of lens corrected antennas (LCAs) with total gain of 2×30 dBi are used to establish a W-band dual-polarized SISO wireless link, which can avoid the crosstalk and gain imbalance incurred from the 2×2 MIMO channels in our previous work [6]. In our experiment, the dual-polarized MMW signal is delivered over 100/150 m in outdoor scene, and the photo of 150 m case is shown in Fig. 1(b). To enhance the MMW receiving power, a home-made polytetrafluoroethylene lens with a diameter of 30 cm and a focal length of 50 cm [8], which can provide about 50-dBi gain, is placed before the receiving antenna (i.e., LCA2) to focus the divergent MMW beam due to long-distance transmission.

At the wireless-optical conversion unit, as shown in Fig. 1(c), the received dual-polarized MMW signal is first re-split into H- and V-pol by another W-band OMT (i.e., OMT2), and then is down-converted to the IF signal via two identical W-band integrated harmonic mixers (i.e., IHM1 and IHM2), respectively. Each IHM consists of a mixer and a $\times6$ frequency multiplier chain, which is driven by an input electronic RF sources set to 18.65 GHz with 7-dBm power. After the electronic down-conversion, the output IF signal is centered at about 19.4 GHz. Then, the H-/V-pol IF signals are boosted by two cascaded electrical amplifiers (EAs) with 3 dB bandwidth of 47 GHz, to drive two independent intensity-modulators (IMs) biased at the null point with 3 dB bandwidth of 40 GHz, respectively. The ECL2 (1549.124 nm, 14.5 dBm) as an input optical carrier of the two IMs, with 23.8-GHz frequency spacing to the initial optical DP-QPSK BB signal, is split evenly by a polarization-maintaining OC into two branches. Two carrier-suppressed optical double-sideband (DSB) signals after IMs are shown in Fig. 2(b) for X- and Y-pol components,

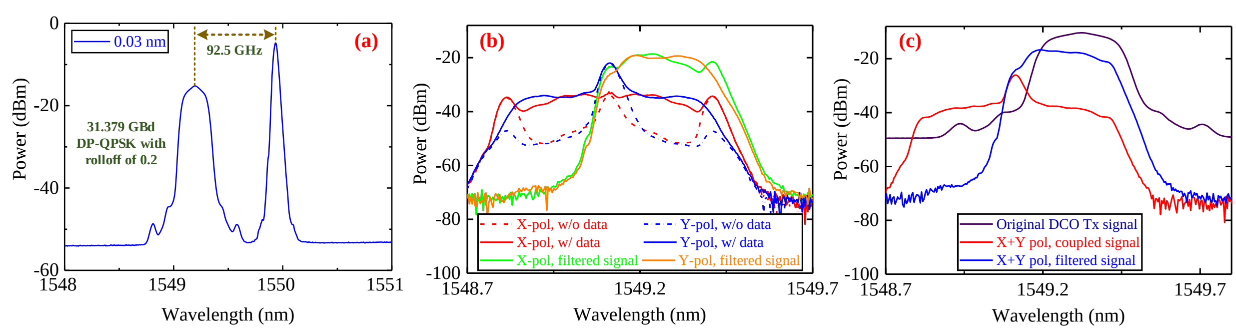

Fig. 2. Optical spectra of (a) Optical spectrum after OC, (b) X- and Y-pol components with and without 125-Gb/s DP-QPSK before PBC, and the filtered signal after TOF2; (c) Original DCO transmitted signal, coupled DSB signal after PBC and filtered BB signal after TOF2.

and are coupled again through one polarization beam coupler (PBC) and boosted by the EDFA2. It is noted that the optical carrier suppression for the Y-pol is slightly inferior to that of the X-pol, which is mainly due to the actual performance difference of the two independent IMs. Two polarization controllers (PCs) before the PBC are used to align the polarization direction to obtain the maximal output power. The TOF2 is set to filter the upper sideband and the central optical carrier as well as the undesired ASE noise, only leaving the lower sideband centered at 1549.279 nm. For comparison, the original 125-Gb/s DP-QPSK BB signal generated from the DCO Tx module is also given in Fig. 2(c). A few frequency spacing of about 4 GHz between the filtered optical BB signal and original DCO Tx signal is adopted, to obtain the optimal BER.

Finally, at the optical receiver end, after transmission over another span of 20-km SSMF, the filtered optical BB signal is fed to the receiving OTU (i.e., OTU2) for real-time reception and processing. The VOA2 is used to change the receiving optical power (ROP) for the 100-GbE DCO ICR module, thus the real-time BER and OSNR curves can be monitored through an embedded network management system (NMS) operation interface in OTU2.

3. Results and discussions

Figure 3(a) shows the spectrum of the down-converted IF signal, which centers at about 19.4 GHz and occupies a bandwidth of 37.65 GHz. It is worth emphasizing that such a wideband signal can effectively achieve full spectrum communications at W band. Fig. 3(b) shows the BER and OSNR performances versus input power into each PD over two spans of 20-km SSMF and 100/150-m wireless links. For 100 m and 150 m cases, the both BERs are below 15% overhead SD-FEC threshold (1.56×10^{-2}) when the power exceeds 4 dBm. With an input power range from 4 dBm to 7 dBm, the BER in 100 m case can even reach below the 7% overhead HD-FEC threshold (3.8×10^{-3}). Accordingly, the real-time transmission net rates of 31.379 GBd DP-QPSK for the 100 m and 150 m cases are 117.30 Gb/s and 109.14 Gb/s after excluding the FEC overhead, respectively. Moreover, when the PD input optical power is optimally set to be 6 dBm, only 0.9 dB OSNR penalty can be observed with the wireless distance expanding from 100 m to 150 m. If the input power is higher than 6 dBm, it would result in system performance degradation due to power saturation of the optoelectronic devices, such as the PD, LNA, EA and so on.

We also give the BER and OSNR curves versus DCO ROP in Fig. 3(c). For 150 m case, the BER meets 15% overhead SD-FEC threshold as long as the ROP is larger than -28 dBm. Whereas in 100 m case, this value decreases to -31 dBm, which exhibits a receiving sensitivity penalty of about 3 dB due to the additional 50-m wireless delivery. Additionally, the 7% overhead HD-FEC threshold can be just reached with an ROP as low as -23 dBm. On the other hand, the stable (also the best) OSNR for two distance cases are 14.1 dB and 13.2 dB, respectively. Within the stable OSNR region, an optical power margin of more than 10 dB can be observed.

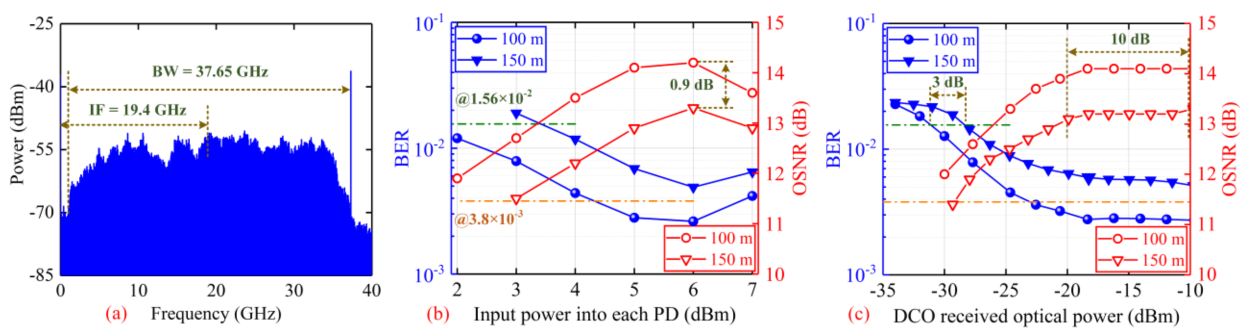

Fig. 3. (a) IF signal spectrum after electronic down-conversion. BER & OSNR curves versus (b) input power into each PD and (c) DCO ROP for real-time 125-Gb/s DP-QPSK transmission over two spans of 20-km SSMF and 100/150-m wireless links.

4. Conclusion

We have experimentally demonstrated the first real-time photonics-enabled fiber-wireless-fiber transmission of 125-Gb/s DP-QPSK signal in a dual-polarized SISO wireless link. The record real-time net rates of 117.30/109.14 Gb/s have been achieved at W band with the wireless distances up to 100/150 m, respectively. The demonstrated high-speed long-distance real-time fiber-wireless-fiber photonics-enabled MMW system can expedite the progress of the upcoming 6G communications. *This work was partially supported by the National Natural Science Foundation of China (62101121, 62101126, 62201393, 62201397 and 62271135), and the Natural Science Foundation of Jiangsu Province under Grant BK20221194.*

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