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Photonics-based high-speed long-distance fiber-wireless-integration communication at the W-band

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With the early approach of 5G period, beyond 5G communication has become an urgent need in the industry. Because of its rich bandwidth, the W-band (75–110-GHz) millimeter-wave (mm-wave) is capable of carrying ultra-high-speed signal [1–6]. Therefore, it is extremely competitive in the field of future beyond 5G communication. The feature of photonics-based W-band mm-wave generation technology is that it can effectively solve the problem of bandwidth limitation and electromagnetic interference in electronic devices. The photonics-based technique has been widely used in wireless communication experiments [7]. However, in these demonstrations, the length of the wireless link for signal transmission is severely restricted. In real outdoor applications, it is clearly not feasible to use the transmission methods in these demonstrations.

Figure 1(a) summarizes important experimental demonstrations of high-speed long-distance transmission at the W-band [1–6]. This year, we have experimentally demonstrated a photonics-based fiber-wireless-integration communication system that can achieve 47.45-Gb/s signal transmission over the fusion link of 10-km fiber and 4600-m wireless distance [6]. The record-breaking product of single-channel single-polarization wireless data rate and distance, i.e., 47.45-Gb/s $\times$ 4.6-km = 218.27 Gb/s·km, has been achieved. Instead of Cassegrain antennas, we use a pair of dielectric plano-convex lenses with a large gain and small beamwidth to extend wireless transmission distance, which is the first time to achieve long-distance transmission based on lenses and horn antennas (HAs) in the world. Orthogonal frequency division multiplexing (OFDM) technology has high spectrum utilization and strong anti-interference ability, which can resist dispersion effects in optical fiber transmission and wireless multipath effects in future application scenarios. Probabilistic shaping (PS) technology with Maxwell-Boltzmann distribution maximizes the entropy of given quadrature amplitude modulation (QAM) constellations under the constraint of mean energy. By reducing the probability of high-amplitude symbols, PS technology makes the PS-QAM signal less susceptible to nonlinearity introduced by some optoelectronic components, thereby limiting harmonic distortion. It can also support the flexible adjustment of data rate. The combination of PS technology and 256QAM modulation format is adopted to further improve the spectral efficiency in the long-distance fiber-wireless-integration system.

The experimental setup of photonics-based fiber-wireless-integration communication system is shown in Figure 1(b). The photos of the transceiver are shown in Figure 1(c). Two tunable external cavity lasers (ECL1 and ECL2) are used to generate continuous waves with 88.5 GHz frequency space. The photodiode (PD) (XPDV412xR) realizes photo-electric conversion to generate W-band mm-wave signal. The cascaded low noise amplifier (LNA, gain 30 dB) and power amplifier (PA) are used to amplify the signal. A couple of dielectric lenses (Lens1 and Lens2) made of Polytetrafluoroethylene (PTFE) with a low dielectric constant of 1.96 at 520 GHz are used in the wireless link. The Lens1 with a gain of 9 dBi is used to collimate the mm-wave from HA1. The Lens2 with a gain of 31 dBi is used to focus the collimated mm-wave beam into HA2. HA1 and HA2 have to be positioned at the focused points of Lens1 and Lens2, respectively, in order to realize the aligning of the transceiver. The combined gain of HAs and Lenses is 90 dBi, and the radiation power of the transmitter is 16 dBm. For 4600-m wireless transmission of 88.5-GHz signal, the atmospheric loss is 2.3 dB, and the path loss is about 144.63 dB calculated by the Friis formula. The received power we measured is -43.1 dBm, which is close to the theoretical value of -40.93 dBm considering the connector loss between the devices. At the wireless receiver, the W-band mm-wave signal is amplified by an LNA, then down-converted by a mixer. After being amplified by an electric amplifier (EA), IF signal

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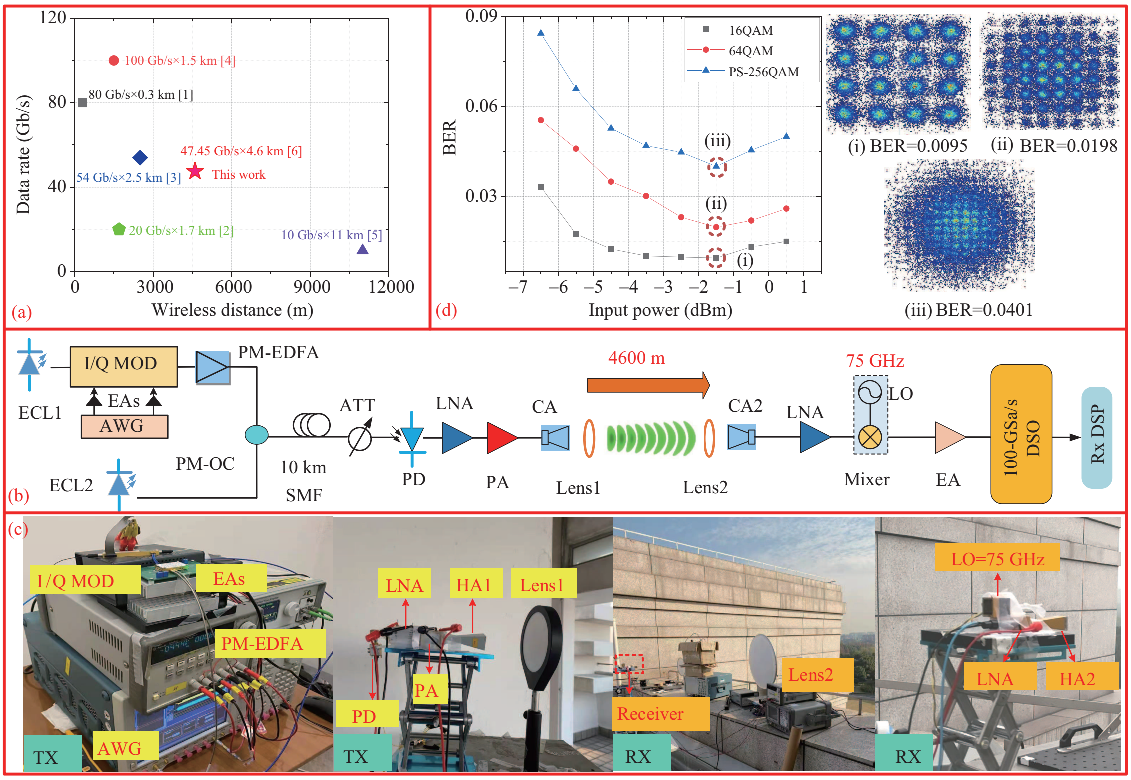

Figure 1 (Color online) (a) The important experimental demonstrations of high-speed long-distance transmission at the W-band; (b) experimental setup; (c) the photos of the transceiver; (d) BER curve of 9.6 Gbaud QAM signal.

is captured by the digital storage oscilloscope (DSO). The digital signal processing (DSP) at Rx includes digital down conversion, cyclic prefix removal, 1024-point fast Fourier transform (FFT), channel estimation, channel equalization, and bit error rate (BER) calculation. To further effectively improve the spectral efficiency and throughput, a series of algorithms are used, including the Volterra nonlinear equalization (VNE) algorithm to compensate for the nonlinear impairment, the intra-symbol frequency-domain averaging (ISFA) algorithm for channel estimation, and the cascaded decision-directed least mean square (DD-LMS) algorithm as well as least mean square (LMS) algorithm to reduce inter-symbol interference (ISI) and inter-carrier interference (ICI).

Figure 1(d) shows the BER performance of 9.6 Gbaud QAM signal versus the input power of PD. We can see that when the input power of PD increases from −6.5 to −1.5 dBm, the BER performance will be gradually optimized due to the increase in signal-to-noise ratio (SNR). However, due to the saturation effect of the LNA and PA, when the input power of PD continues to increase, the signal receives nonlinear interference, resulting in poor BER performance. At −1.5 dBm input power, the minimum BER for 9.6 Gbaud 16QAM, 64QAM, and PS-256QAM signal is $9.5 \times 10^{-3}, 1.98 \times 10^{-2}$, and 4.01×10^{-2}, respectively. The insets(i-iii) in Figure 1(d) show the recovered signal constellations. Excluding the system resources occupied by the OFDM structure and the SD-FEC threshold, the maximum net rate of the system is up to 47.45-Gb/s. This work pushes W-band fiber-wireless-integration technology closer to outdoor wireless applications.

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