Delivery of 138.88Gpbs Signal in a RoF Network with real-time processing based on heterodyne detection

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Abstract: We experimentally demonstrate 138.88-Gb/s PDM-QPSK signal delivery in a RoF network based on real-time processing based on heterodyne coherent detection, and error-free delivery can be realized if SD-FEC with 27% overhead is enabled.

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1. Introduction

High-speed radio-over-fiber (RoF) system, integrating high-mobility wireless link and large-transmission-capacity long-transmission-distance fiber-optic link, can be used to provide high-speed mobile backhaul between the wireless macro stations as well as emergency services when large-capacity long-haul optical cables are cut during natural disasters such as earthquake and tsunami [1-5]. In order to realize the high-speed RoF system, the wireless link needs to be developed to match the large transmission capacity of the fiber-optic link, while preserving transparency to bit rates and modulation formats. Due to inherent wide bandwidth available at higher frequencies, the wireless millimeter-wave (mm-wave) communication link is capable of accommodating Gb/s-class transmission capacity and it has been intensively studied in the research community [1-5]. Moreover, high-speed mm-wave signal generation, modulation, and detection enabled by integrated photonics technology effectively promote the seamless integration of wireless and fiber-optic networks. Recently, a series of >100-Gb/s wireless mm-wave signal delivery have been experimentally demonstrated, based on the RoF systems at Q-, V, W-, or D-band and offline digital signal processing (DSP) [6-14]. Among them, the wireless mm-wave signal delivery with the largest capacity of >1Tb/s up to now has been demonstrated based on the RoF system at D-band, employing high-level QAM modulation, various kinds of multi-dimensional multiplexing techniques, as well as advanced DSP techniques [14]. However, for the real-time demonstration of the RoF systems, only up to 24.08-Gb/s wireless mm-wave delivery at V- or W-band has been reported [15]. The reported wireless transmission capacity with real-time procession is evidently much lower than that with offline procession.

In this paper, we experimentally demonstrate the real-time delivery of over 100-Gb/s signal in a RoF network based on commercial real-time coherent optical transmitter and receiver. The 138.88-Gb/s (34.72-Gbaud) PDM-QPSK signal, carried by 24-GHz radio-frequency (RF) carrier frequency, can be generated, delivered over two spans of 20-km SMF-28, and then processed by real-time coherent detection. Error-free delivery can be realized if soft-decision forward-error-correction (SD-FEC) with 27% overhead is enabled. To the best of our knowledge, the net bit rate of 109.3Gb/s, after removing the 27% SD-FEC overhead, is the largest up to now for a real-time RoF network.

2. Experimental setup

Fig. 1 shows the experimental setup for our real-time delivery of >100-Gb/s signal in a RoF network. At the transmitter central office (TX CO), a commercial real-time coherent optical transmitter is used to generate an optical baseband signal. The parameters of the commercial real-time coherent optical transmitter, including signal baud rate, signal modulation format, signal PRBS length, FEC overhead, optical carrier frequency, output optical power, and so on, can be software defined. In our experiment, the output of the commercial real-time coherent optical transmitter is a 34.72-Gbaud PDM-QPSK modulated optical baseband signal with a PRBS length of 2^{31}, a SD-FEC overhead of 27%, an optical carrier frequency of 193.5THz, and an optical power of 0dBm. Its optical spectrum is given by Fig. 1(a). The 34.72-Gbaud PDM-QPSK modulated optical baseband signal is then delivered over one span of 20-km SMF-28 with 4-dB average fiber loss and 17-ps/km/nm chromatic dispersion (CD) at 1550nm. An EDFA is added before the 20-km SMF-28 to compensate for the fiber transmission loss.

At the transmitter base station (TX BS), a free-running external cavity laser (denoted by ECL1), operating at 193.476THz, functions as an optical local oscillator (LO). An integrated polarization-diversity phase-diversity 90º optical hybrid, which integrates two polarization beam splitters (PBSs) and two 90º optical hybrids, is used to implement polarization diversity of the received optical signal and optical LO in optical domain. The integrated polarization-diversity phase-diversity 90º optical hybrid has eight output ports, only two of which are used in our experiment since optical phase diversity is unnecessary for heterodyne coherent detection. Fig. 1(b) gives the measured optical spectrum from one of the two employed output ports, and it displays a 24-GHz optical RF signal. After optical-to-electrical conversion by two parallel balanced photodiodes (BPDs), the generated two 24-GHz optical RF signals by the integrated optical hybrid are converted into two 24-GHz electrical RF signals. It is worth noting that, each signal component after PBS1 as well as each 24-GHz optical or electrical RF signal contains both data encoded onto X- and Y-polarization at the optical transmitter end, due to polarization rotation caused by fiber transmission. The two generated 24-GHz electrical RF signals can be considered as a 24-GHz electrical RF signal employing PDM-QPSK modulation, which can be delivered in the air space by a 2×2 multiple-input multiple-output (MIMO) wireless link [6]. In our experiment, we do not consider the wireless air space transmission for simplicity.

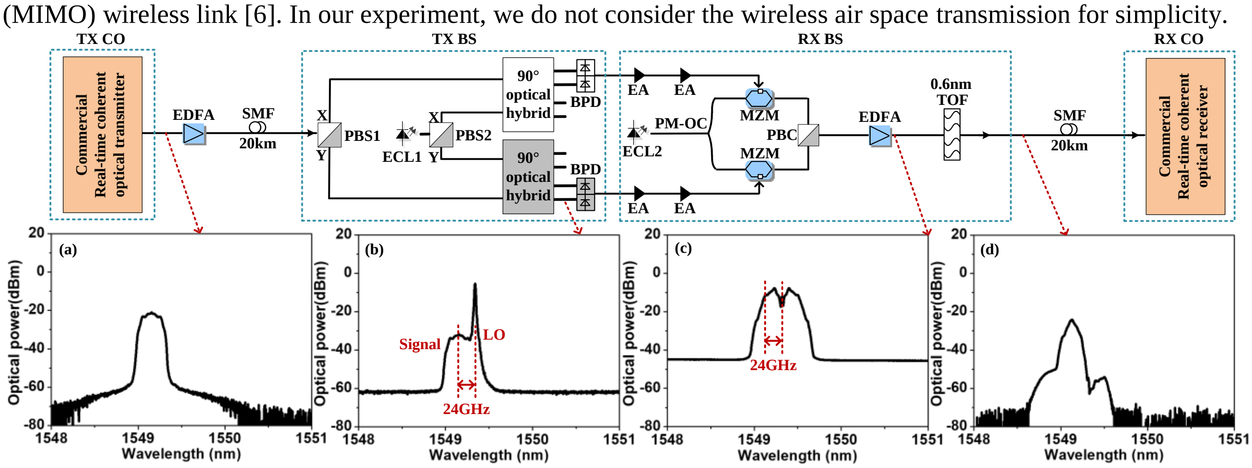

Fig. 1. Experimental setup for our real-time delivery of >100-Gb/s signal in a RoF network. Measured optical spectra at 0.01-nm resolution after: (a) real-time coherent optical transmitter, (b) optical polarization diversity, (c) OCS modulation and EDFA amplification, and (d) TOF.

At the receiver base station (RX BS), each signal component of the 24-GHz PDM-QPSK modulated electrical RF signal is boosted by two cascaded electrical amplifiers, each with 3-dB bandwidth of 40GHz, before it is used to drive a single-drive Mach-Zehnder modulator (MZM). The 193.476-THz continuous-wavelength (CW) lightwave from a free-running external cavity laser (denoted by ECL2) is first split by a polarization-maintaining optical coupler (PM-OC) into two branches, which are then individually used as the optical carrier input of the two single-drive MZMs. Each MZM has a 3-dB bandwidth of ~36GHz, a half-wave voltage of 2.8V, and an insertion loss of 5dB. Each MZM is DC-biased at the optical-carrier-suppression (OCS) point for E-field modulation. The two MZM outputs are combined by a polarization beam combiner (PBC) and then boosted by an EDFA. Fig. 1(c) gives the measured optical spectrum after the EDFA. The EDFA output has a residual central optical carrier and two PDM-QPSK modulated first-order sidebands separated by 24GHz from the central optical carrier. The relatively large power of the central optical carrier is due to a limited extinction ratio and the uncompensated driving voltage on the MZM. Then, a 0.6-nm tunable optical filter (TOF) is used to suppress the upper sideband and the central optical carrier as well as the ASE noise, only leaving PDM-QPSK modulated lower sideband. Fig. 1(d) gives the measured optical spectrum after the TOF, which can be considered as a PDM-QPSK modulated optical baseband signal carrying by 193.5-THz optical carrier frequency. Then, the optical baseband signal is delivered over the second span of 20-km SMF-28, and then received by the commercial real-time coherent optical receiver with signal processing capacity up to 600Gb/s. Figs. 1(a)-1(d) are all measured at 0.01-nm resolution.

3. Experimental results

Fig. 2(a) gives the measured BER performance without FEC for the real-time delivery of the 34.72-Gbaud PDM-QPSK signal versus the input optical power into the real-time coherent optical receiver under three different scenarios: 1) the real-time coherent optical transmitter and receiver are directly connected (denoted by back-to-back); 2) the real-time coherent optical transmitter and receiver are connected as shown in Fig. 1, but without the two spans of 20-km SMF-28 (denoted by RoF without fiber); 3) the real-time coherent optical transmitter and receiver are connected as shown in Fig. 1, with the two spans of 20-km SMF-28 (denoted by RoF with 20km+20km). We can see from Fig. 2(a) that, the introduction of the RoF network between the real-time coherent optical transmitter and receiver causes about 3-dB optical power penalty at the SD-FEC threshold of 3.9×10^{-2}, while the further introduction of the two spans of 20-km SMF-28 transmission almost causes no power penalty. The required input power for the RoF network based on the real-time coherent optical transceiver is -33dBm, in order to reach the SD-

FEC threshold of 3.9×10^{-2}. Here, it is worth noting that, if the SD-FEC with 27% overhead is enabled, the BER of 3.9×10^{-2} can be reduced to error-free and a net bit rate of 109.3Gb/s can be achieved after removing the 27% SD-FEC overhead. Fig. 2(b) gives the measured BER performance versus the RoF carrier frequency for the 34.72-Gbaud PDM-QPSK signal delivery in the RoF network with two spans of 20-km SMF-28 transmission based on the real-time coherent optical transceiver. The optimal BER performance is attained when the RoF carrier frequency is 22GHz. Figs. 2(c) and 2(d) give the recovered X- and Y-polarization QPSK constellations for the 34.72-Gbaud PDM-QPSK signal delivery in the RoF network with two spans of 20-km SMF-28 transmission. The corresponding input power and BER is -26dBm and 1.05×10^{-3}, respectively.

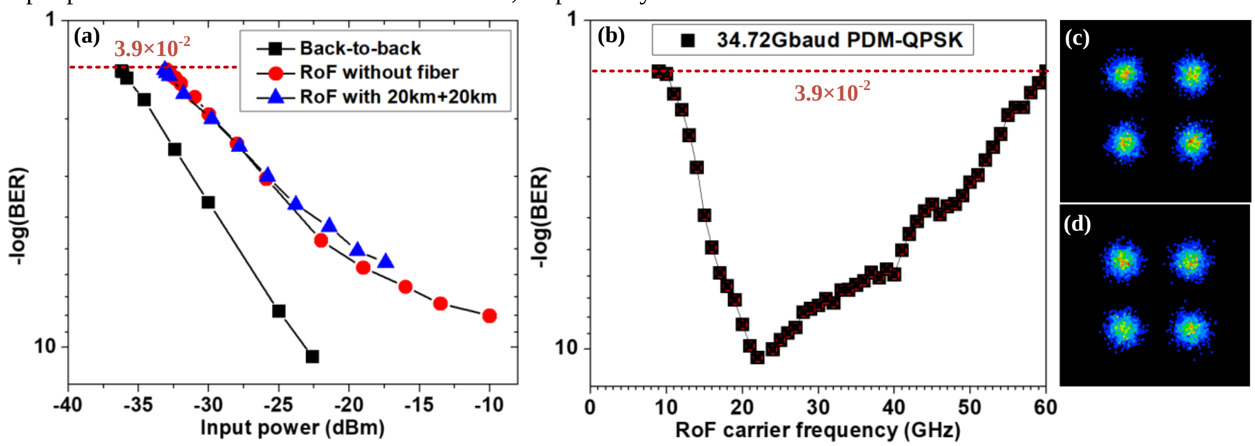

Fig. 2. (a) BER performance before FEC versus the input power. (b) BER performance versus the RoF carrier frequency. (c) Recovered X- and Y-polarization QPSK constellations..

4. Conclusions

We experimentally demonstrate the real-time delivery of 138.88-Gb/s (34.72-Gbaud) PDM-QPSK signal in a RoF network based on real-time coherent detection. Error-free delivery is realized when SD-FEC with 27% overhead is enabled. The 138.88-Gb/s (34.72-Gbaud) total bit rate corresponds to a net bit rate of 109.3Gb/s, which is the largest up to now for a real-time RoF network. The transmission bit rate can be further increased if higher-level QAM modulation, such as 16QAM, is employed.

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