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A multi-channel full-duplex 60-GHz-band radio-over-fiber system

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ABSTRACT

We propose and simulate a novel full-duplex radio-over-fiber system using a single light source at central station (CS). The scheme is employed to generate 60-GHz optical millimeter wave at CS for down-link transmission while the same optical carrier is reused at base station for up-link connection. There is no additional laser source for the upstream data generation in the base station. The bidirectional full-duplex 2.5 Gb/s data are successfully transmitted over 40 km standard single-mode fiber (SMF). The power penalty for the down-link data after transmission over 40 km SMF is less than 0.6 dB, while for the up-link data, the power penalty after transmission over 40 km SMF is neglected. This system shows good performance over long-distance delivery and has important applicable value in high radio frequency (RF) sector and multi-channel full-duplex system.

1. Introduction

The radio-over-fiber (ROF) has been studied for many years as a promising technique for providing wireless broadband service. It has been expected that the millimeter wave (mm-wave) bands would be utilized to meet the requirement for higher signal bandwidth and overcome the frequency congestion in the future ROF-based optical-wireless [1,2] access networks. In this situation, it is necessary to construct a low-cost base station (BS) because the BS picocell has small coverage due to high atmospheric attenuation in the mm-wave band. Hence, the overall architecture design and the scheme of radio frequency signal generation transmission for the up-link and down-link play the key roles in the successful deployment in real networks. Therefore, a number of ROF design techniques have been proposed and investigated to explore cost-effective base stations [3–9]. For example, a technique for sharing a lightwave source for both a down-link and up-link system has been proposed and experimentally investigated to explore a cost-effective ROF system in [10]. But signal up-conversion using Mach–Zehnder modulator (MZM) has several problems. Its modulation characteristics depend on the incident wavelength and polarization [11], and it has low conversion efficiency [12]. In addition, the MZM modulation bandwidth can impose a limitation on the accessible frequency ranges for up-conversion.

In this letter, we propose a novel full-duplex ROF system. Optical mm-wave generated by using high nonlinear fiber (HNLF) based on cross-phase modulation (XPM) has been demonstrated to have a few advantages, such as the simultaneous all-optical frequency conversion, highly efficient conversion and the lowest bandwidth requirement for components. We demonstrate that this concept of wavelength reuse can be employed in our ROF architecture with a high bit rate and long-distance transmission.

2. Principle

Fig. 1 shows the principle of generating an optical mm-wave by using high nonlinear fiber based on XPM along with optical filtering and wavelength reuse for up-link connection. A continuous-wave (CW) lightwave is generated by a distributed feedback laser diode (DFB-LD). A dual-arm $LiNbO_3$ Mach–Zehnder modulator (LN-MZM) biased at v_π and driven by two complementary RF signals is used to generate 60 GHz pump pulse. The optical carrier and two first-order sidebands are separated by a demultiplexer. One of the first-order sidebands is modulated with the down-link baseband data. The optical carrier and two first-order sidebands are then recombined by an optical multiplexer and transmitted to the base station. At the BS, a fiber Bragg grating (FBG) is used to reflect the carrier while passing the optical mm-wave signal to the down-link receiver. The reflected carrier acts as the CW and modulated with the symmetric upstream signal, then transmitted back to CS, where a low-cost low-frequency receiver detects the upstream signal. Using this proposed system design, the bidirectional 2.5 Gb/s data channel is successfully transmitted over 40 km for both upstream and downstream simultaneously.

3. Simulative setup and results

The setup for the full-duplex ROF system is shown in Fig. 2. At the CS, a CW lightwave with a power of 0 dB m is generated by a tunable laser at 1560 nm. The lightwave generated by the DFB-LD

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at 1540 nm is modulated by a dual-arm LN-MZM biased at v_{π} and driven by two complementary 15 GHz clocks to generate pump pulse with a repetitive frequency of 30 GHz, as shown in Fig. 3 at point A in Fig. 2. Then the generated pump pulse is amplified by an erbium-doped fiber amplifier (EDFA) to get a power of 17 dB m, filtered by a tunable optical filter with the bandwidth of 45 GHz to suppress amplified spontaneous emission noise and then they combine with the CW lightwave via an optical coupler before they are transmitted over HNLF. The main parameters of the HNLF are shown in Table 1. CW lightwave is split into pulse sequence. Optical spectrum of converted pulse wave is shown in Fig. 4 at point B in Fig. 2. By using demultiplexer, the carrier and two first-order sidebands of the converted pulse wave are separated and 2.5 Gb/s down-link data are modulated on one of the sidebands by an intensity modulator. Then they are multiplexed and transmitted over single-mode fiber (SMF). The optical spectrum of the modulated first-order sideband is shown in Fig. 5 and measured at point C in Fig. 2. After mutiplexer, the optical spectrum of the signal is shown in Fig. 6 and measured at point D in Fig. 2.

At the BS, an FBG, which has a stop bandwidth of 20 GHz and reflection ratio of 40 dB at the reflection peak wavelength, is used to perform two functions simultaneously: one is to reflect the optical carrier to provide CW light source for up-link connection and the other is to pass the two sidebands generated by HNLF simultaneously, and as a consequence, it increases the carrier suppression ratio up to 40 dB. The spectrum of optical mm-wave with the down-link data as passing part shown in Fig. 7 is measured at point E in Fig. 2 and is detected by an optical–electrical converter after passing through an optical bandpass filter and a tunable attenuator. The converted electrical signal is amplified by an electrical amplifier with a bandwidth of 10 GHz centered at 60 GHz. We use the 60 GHz electrical local oscillator signal and a mixer to down-convert the electrical mm-wave signal to baseband signal. The down-converted 2.5 Gb/s signal is detected by a bit-error-rate (BER) tester. The eye diagram for down-link data after transmission over 40 km fiber is shown in

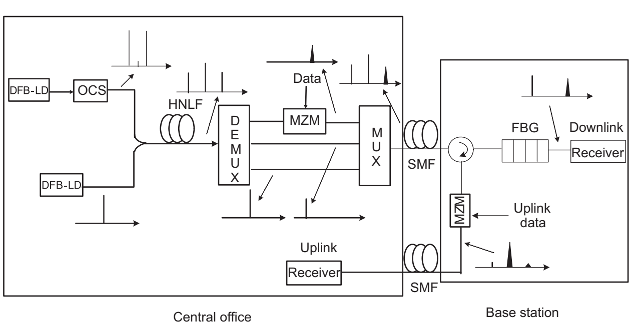

Fig. 1. Schematic diagram of a full-duplex ROF system.

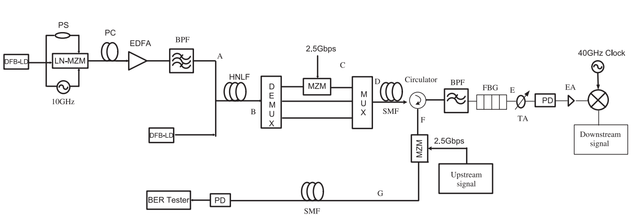

Fig. 2. Simulation setup of radio over fiber system. PS: phase shift. PC: polarization controller. DEMUX: demultiplexer. MUX: multiplexer. BPF: bandpass filter. TA: tunable attenuator. PD: photodetector. EA: electrical amplifier.

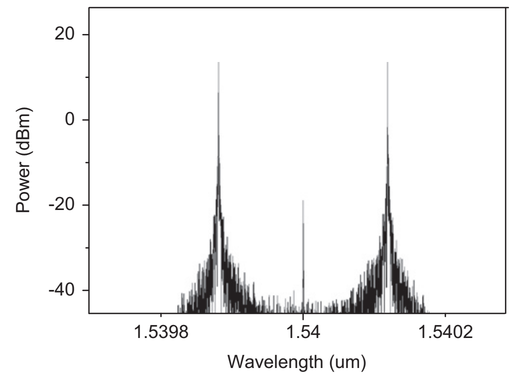

Fig. 3. Optical spectrum of pump wave.

Table 1
Main parameters of the HNLF.

Parameter	Value
Zero dispersion wavelength	1550 nm
Length	0.135 km
Attenuation-const	0 dB/km
Group Delay-const	4.9e+6 ps/km
GVD-constant	4.5 ps/nm/km
Dispersion slope-const	0.11 ps/nm^2/km
Nonlinear coef	20/w/km
Peak Raman gain coef	9.9e − 14 m/w

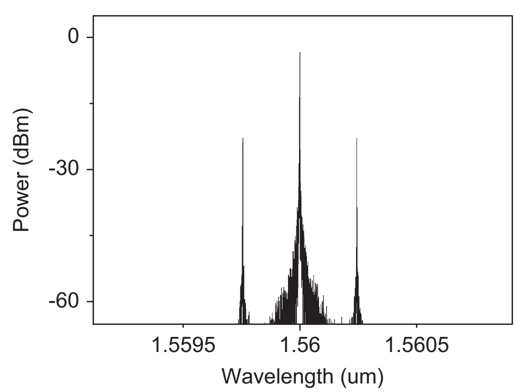

Fig. 4. Optical spectrum of up-converted signal after HNLF.

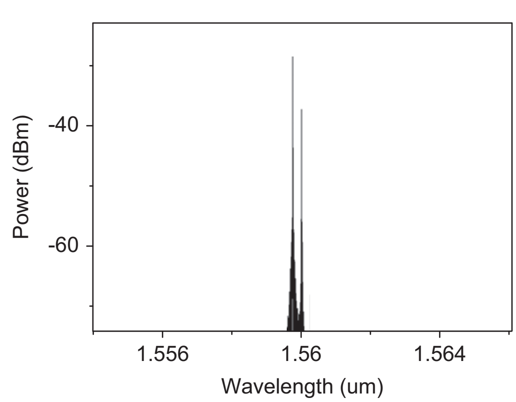

Fig. 5. Separated signals modulation by downlink data after demultiplexer.