Polarization Crosstalk Reduction by Successive Interference Cancellation for Polarization-Tracking-Free PDM Radio over Fiber Mobile Fronthaul System

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Abstract: We propose a novel polarization-tracking-free PDM fiber-wireless mobile fronthaul system by using SIC to reduce the crosstalk caused by imperfect PDM demultiplexing. Our experimental results show this proposed PDM demultiplexing scheme greatly relieves spectral limitation.

1. Introduction

As the mobile devices significantly involve into our daily life, the associated communication technologies have been desperately evolving in the past decade. The capacity demands for 5G enhanced mobile broadband (eMBB) can easily be fulfilled by upgrading the wireless channels to millimeter wave regimes [2]. Moreover, radio-over-fiber (RoF), which transmits radio-frequency signals through optical fiber, has gradually become a potential candidate in mobile fronthaul networks to meet the bandwidth and latency requirements of the cross-haul transmissions. [1] To further enhance transmission efficiency in optical domain, polarization-division-multiplexing (PDM) is a promising solution to double the data rate. However, due to the circular symmetry nature of the optical fiber, signals' polarization states are roaming all the time during transmission, especially when the external environments change. Thus, it's impractical to simply demultiplex the orthogonally polarized signals with a passive polarization beam splitter (PBS) at the receivers. Conventional PDM demultiplexing typically employs a coherent detection scheme or applies a polarization tracking mechanism to eliminate crosstalk for direct detection [3-4], which are too complicated, nor is cost efficient, for future 5G mass-deployed millimeter wave (mmW) base stations scenario [5]. Another polarization demultiplexing technique by combining both PDM and MIMO channel estimations was also proposed to mitigate the influences caused by polarization crosstalk [6]. However, this approach requires very complicated data assignments and can't successful demultiplex the signal at a specific polarization, i.e., linearly polarization at 45° with respect to the two orthogonal axes of PBS.

In our previous work [7], we intentionally inserted two orthogonally polarized optical carriers at different frequencies and simply applied an individual optical filter to suppress the other optical carrier in front of the photo-detector to achieve polarization-tracking-free PDM demultiplexing. Although such a passive PDM demultiplexing scheme can achieve satisfactory performance, the stringent spectral demands on the applied optical filters make it impractical in physical deployment. In this paper, we propose an algorithm that employs successive interference cancellation (SIC) to eliminate the PDM crosstalk due to imperfect passive PDM demultiplexing filters. Through mutual references between the two PDM demultiplexed signals, the interference from the other polarization state can be greatly reduced. We evaluate the system performance of the proposed approach through 25 km single mode fiber (SMF) transmission and 3 meters mmW wireless transmission at 28 GHz band for future 5G applications.

2. Operating Principles

A conceptual diagram of the proposed algorithm is depicted in Fig.1. The two mutually interfered signals, $r_x(t)$ and $r_y(t)$, on the orthogonal polarizations are denoted as $h_x(t)\cdot(S_x(t)+\alpha\cdot S_y(t))+n_x(t)$ and $h_y(t)\cdot(\beta\cdot S_x(t)+S_y(t))+n_y(t)$, with the normalized crosstalk coefficients α and β, and $h(t)$ and $n(t)$ are the channel responses and noises, respectively. The DSP steps are described as follows. At the first step, a zero-forcing (ZF) equalizer is applied to compensate for the channel responses. It's worth noting that the training symbols of x-polarization and y-polarization are interleaved in the OFDM subcarriers to simultaneously estimate the channel responses h and normalized crosstalk coefficients α and β. After QAM demodulation, the signal is restored through QAM modulation, channel insertion and normalized crosstalk coefficient insertion for SIC procedure. Finally, the algorithm will subtract the crosstalk from the opposite-polarization signal by using the reconstructed signal. Theoretically, clearer signal can be obtained through the SIC if there is no error propagation. Thus, an iterative process between the two orthogonal polarized signals will gradually

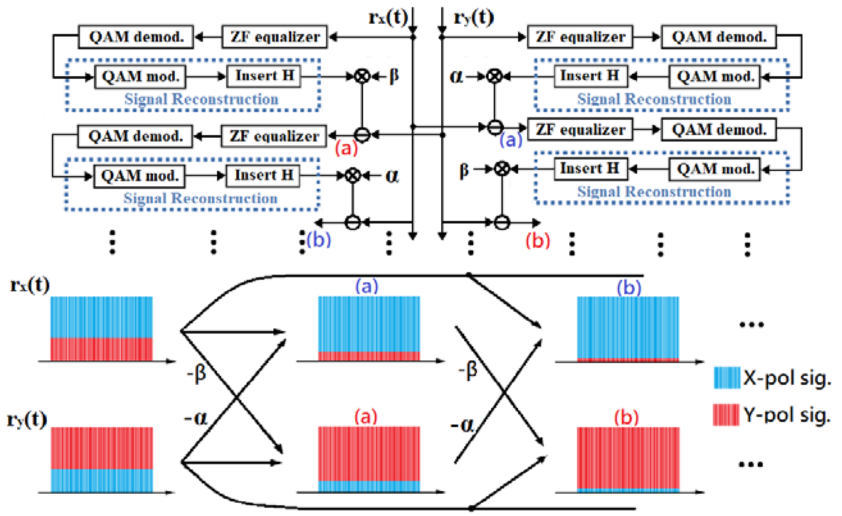

Fig. 1 The conceptual diagram of SIC to eliminate PDM crosstalk.

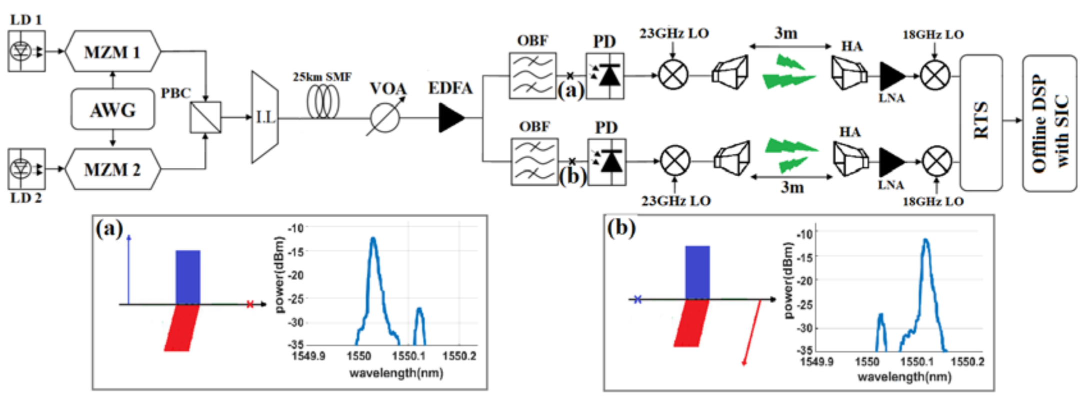

Fig. 2. The experiment setup and spectra of (a) *x*-polarization received signal after the optical filter. (b) *y*-polarization received signal after the optical filter.

eliminate the crosstalk. The convergent rate of this iterative process depends on the severity of crosstalk and signal to noise ratio (SNR).

3. Experimental Setup and Results

The experiment setup is shown in Fig. 2. A 12G sample/sec arbitrary waveform generator (AWG) generates two independent 1-GHz 16QAM-OFDM at an intermediate frequency of 5-GHz. Two 10-GHz Mach-Zehnder modulators are employed to convert the electrical signals to optical domain with two lasers at 1550.076 nm and 1550.156 nm, respectively. Then, these two signals are combined with a polarization beam combiner (PBC) to generate the PDM signal, and a 12.5/25-GHz optical interleaver is employed to reject the undesirable sidebands of both polarized signals. After 25km SMF transmission, an optical filter with 10-GHz bandwidth is applied to suppress the optical carrier of the opposite polarization to extract the desired signals at each receiver. The conceptual and measured optical spectra of each optical filter output are shown in Fig. 2(a) and (b), respectively. The filtered signal is then received by a 10-GHz photo-detector. The received IF signal is up-converted to 28 GHz with two mixers and emitted via a pair of horn antennas. After 3-m wireless transmission, a low noise amplifier (LNA) is used to amplify the mmW signal and then down-convert the signal to 10 GHz. An 80G sample/s real-time oscilloscope (RTS) analog-to-digital converts the signals for following offline DSPs to evaluate signals' BER performances.

In our experimental demonstrations, the BER curves are all measured after 3 m wireless transmission. Figure 3(a) illustrates the convergent rate of the proposed SIC algorithm in which we intentionally tune the central wavelength of the optical filter in front of each photo-detector to get a power ratio of 6-dB (solid line) and 12-dB (dashed line) between the two orthogonally polarized optical carriers to represent bad and good carrier rejection, respectively. For the bad carrier rejection case, i.e., 6-dB power ratio, the desired signal is highly contaminated by the residual signal of the opposite polarized signal. Inset (i) illustrates the received constellation diagram by directly demultiplexing the received signals without any SIC iteration with only optical filter. It is clearly seen that the two independent 16-QAM OFDM signals are superimposed into a 256-QAM-like OFDM signal. After the iterative SIC algorithm, the crosstalk from the other polarization is gradually wiped out and the demultiplexed signal's 16-QAM constellation diagrams become clearer, as shown in Insets (ii)~(iv). Meanwhile, BER performance is improved as well. However, after 3 iterations, the BER performance saturates. This is because of error propagations, resulted from imperfect demultiplexing in the very first step of the iterative SIC processes. On the other hand, when the carrier power ratio is enhanced to 12 dB, since the signal has better crosstalk rejection, the BER performance quickly achieves the FEC threshold after first iteration and gradually saturates after 2 iterations. The slight difference between *x*-pol and *y*-pol signals is because of non-identical spectral responses of the employed optical filters. We can also observe that, due to better PDM demultiplexing in the first step, the 12 dB case outperforms the one with 6-dB power ratio. Since in both scenarios, the BER performances saturate after 3 iterations, the iterations will be fixed to 3 hereafter in the experiment.

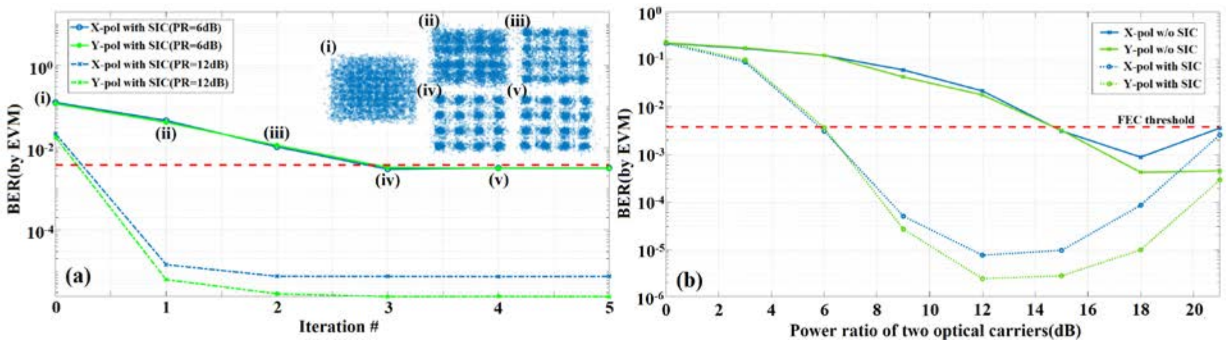

Fig. 3 (a) BER versus SIC iteration number, (b) BER versus the optical carrier power ratios of the PDM signals.

In Fig. 3(b), we exhibit the BER performance as a function of power ratio between the two orthogonally polarized optical carriers. We can see that, to achieve an FEC threshold of 3.8×10^{-3} BER, the required extinction ratio is 15-dB for optical filtering only with no SIC, while it only requires 6-dB power difference after 3 SIC iterations. A 9-dB power margin has been achieved with the proposed SIC algorithm because the polarization crosstalk brought from imperfect optical filtering can be eliminated through the SIC processes, which greatly relieve the stringent spectral requirements of optical filter employed for the proposed polarization tracking free PDM demultiplexing. We can also see that the performance is best obtained at 18-dB power ratio and then degrades as power ratio further increases for the filter only without SIC case. This is because to achieve such a high power ratio, we need to adjust the spectral range of the employed optical filter to take the advantage of its sharp spectral roll-off, which will also impair the desired signal due to insufficient filter bandwidth. On the other hand, the best performance is obtained at 12-dB with SIC. Though the performance degrades as power ratio grows as well due to limited filter performance, it provides an operation window for more than 15-dB power ratio range. Thus, the demands on the optically polarization demultiplexing filter is not so stringent. However, we have to note that, as mentioned, higher power ratio distorts the signal in the meantime, which interferes accurate estimations of α and β in the SIC algorithm. Such a deviation in α and β estimations will result in error propagations in the iterative process.

4. Conclusions

In this work, we experimentally demonstrated a polarization-tracking-free PDM RoF mobile fronthaul over 25-km SMF and 3-meter wireless transmission system. By simply aligning the two optical carriers to the orthogonal polarizations respectively, a simple optical filter can demultiplex the PDM signal in a real-time manner. An interactive SIC process can further reduce the residual crosstalk from the other PDM signal. With the assist of the SIC algorithm, the operation range of the power ratio between the two orthogonally polarized optical carriers can be extended by 9 dB, which greatly relax the stringent spectral demands on the employed optical filters. Thus, the proposed technique exhibits significant tolerance to hardware specifications and provides an alternation for future massive and high-dense base station demands in mobile front-haul systems.

5.Reference

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