A Novel Direct-Modulation Envelope-Detection Pol-Mux MIMO RoF System based on Blind Equalization Techniques

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Abstract: We demonstrate for the first time a polarization-multiplexed multiple-input multiple-output radio-over-fiber system with direct-modulation and envelope-detection architectures. Based on blind equalization techniques, cross-channel interferences in both optical fiber and wireless channels are cancelled simultaneously without incurring additional overhead.
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1. Introduction

Multiple-input and multiple-output (MIMO) technologies have been adopted in current wireless communication standards to provide significant increase in data throughput (corresponding to *multiplexing gain*) [1], reliability and link range (corresponding to *diversity gain*) [2]. On the other hand, polarization multiplexing (Pol-Mux) techniques are typically used in optical communications to double the channel capacity. Therefore, in the future-proof converged optical-and-wireless access networks, the combination of both technologies provides a promising solution to upgrade the system capacity without additional optical or wireless bandwidth. However, the trade-offs between multiplexing gain and diversity gain in the conventional fast-fading wireless channel requires optimized space-time coding at the transmitter side [3]. In addition, training sequences are added to the transmitted data streams and are used to estimate the transmission channel at the receivers to eliminate the cross-channel interference, which induces additional overhead and increases system complexities. In the previous work [4], we have proposed and demonstrated a Pol-Mux MIMO converged optical-and-wireless access system based on radio-over-fiber (RoF) technologies for high-speed wireless transmission at millimeter-wave (mm-wave) band. In [4], the conventional training-sequence approach is adopted for the channel estimation and crosstalk cancellation. However, due to the line-of-sight nature at mm-wave band, limited crosstalk and minimal fading effect is present in the mm-wave MIMO channel. It is possible to use simplified signal processing techniques for the crosstalk cancellation. Therefore, in this paper, we propose and demonstrate a novel system architecture using blind equalization techniques to reduce the system complexity. In addition, in the proposed system, high-level modulated signals carried on intermediate frequencies (IF) are directly modulated on to optical carriers, and envelope detected after wireless transmission to further simplify the transceiver design. With the proposed system and blind equalization algorithm applied, 4-dB improvement of signal-to-crosstalk ratio is observed after 30-km Pol-Mux optical transmission and 3-ft mm-wave MIMO wireless transmission.

2. Proposed System Architecture and Blind Equalization Algorithm

The conceptual diagram of proposed Pol-Mux MIMO mm-wave RoF access system is shown in Fig.1. At the headend office, two independent high-level modulated data streams (Data 1 and Data 2) are carried on the same intermediate frequency (IF). Then the two signals are directly modulated on two orthogonal polarizations (X and Y polarizations) of a single wavelength and multiplexed together through a polarization beam combiner (PBC). The

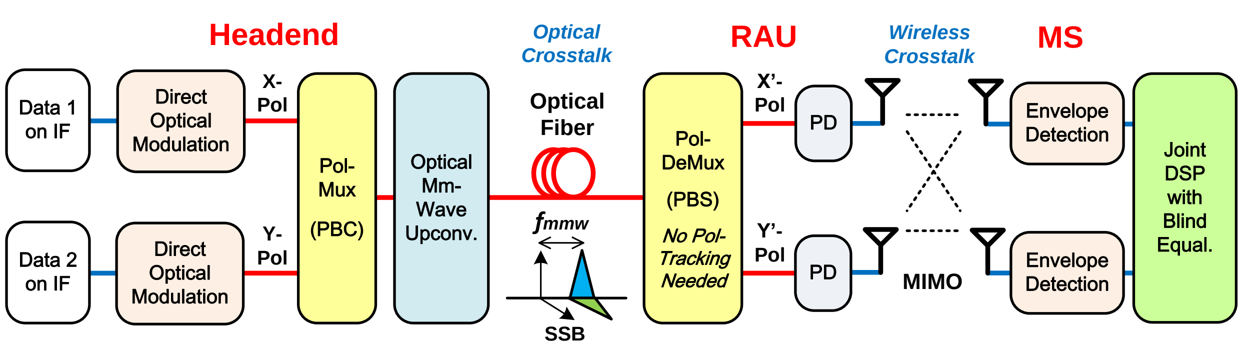

Fig. 1 Block diagram of the proposed Pol-Mux MIMO millimeter-wave RoF access system.

advantage of the direct optical modulation of IF signals is that more advanced modulation formats can be easily achieved first in electrical domain instead of using I-Q optical modulators in optical domain. Notice that no training sequence and space-time coding of the transmitted signals is needed in this proposed system. Then this Pol-Mux signal is passed through an optical mm-wave up-conversion stage, where a single-sideband (SSB) optical mm-wave is generated. For the SSB optical mm-wave up-conversion (shown in Fig.1 inset), two optical carriers are generated with a mm-wave frequency spacing, where only one of them carrying data information while the other is a pure optical carrier. Then the SSB Pol-Mux optical mm-wave signal is delivered over optical fiber to remote antenna unit (RAU) for optical-to-RF conversion. Before the photo-detection (PD), the Pol-Mux signal is first de-multiplexed into two orthogonal polarizations through a polarization beam splitter (PBS). Therefore the de-multiplexed polarizations (denoted as X' and Y' polarization) may not align with the transmitted polarizations after fiber transmission, which induces optical crosstalk between the two channels before wireless transmission. Notice that a polarization-tracking function is not needed in the proposed scheme since both optical and wireless crosstalk is handled in joint DSP. After the two optical mm-wave signals being detected by two separate PDs , the mm-wave RF signals are generated and fed into two mm-wave antennas for wireless transmission. After the MIMO wireless transmission, the two-channel signals are received by two antennas, down-converted, synchronously sampled, and demodulated by joint off-line DSP with proposed blind equalization algorithm. For the mm-wave down-conversion, instead of using conventional 60GHz mixers with 60GHz local oscillators and phase-lock loops, we propose to use envelope detectors (ED) which only detect the envelope variation on 60GHz and eliminate the carrier phase information. This greatly simplifies the 60GHz receiver design, but notice the envelope detectors only apply to amplitude modulated signals (e.g. OOK signal or vector signals carried on IF, etc.) because of the eliminated phase information.

The proposed joint DSP demodulation process with the blind equalization algorithm is shown in Fig. 2. The synchronously sampled two-channel signals are first input to timing synchronization stage to find the start of the data streams. Since QPSK-IF signals are used as the transmitted signals in this experiment, IF down-conversion is needed to shift the signals to baseband. After low-pass match filters, the baseband signals are down-sampled to 1sample/symbol. Then a blind equalizer is used to cancel the crosstalk occurred in both optical and wireless channels. The blind equalization is based on a butterfly architecture with four adaptive filters built-in, in which $H_{i,j}$ represents the inversed crosstalk from channel i to channel j. There are a few time-domain taps in each filter to compensate the PMD in optical transmission and any sampling mismatch between the two channels. The filter coefficients are updated adaptively based on the constant-modulus algorithm (CMA). This is based on the assumption that the modulated signal constellation is on a constant module (e.g. the QPSK signals in this case). However, for an arbitrary modulation format, other blind equalization techniques (e.g. least mean square algorithm) can be used and these are left as future works. After blind equalization, the BER of the two data streams are calculated through error counting. Therefore, based on this adaptive blind equalization technique, both optical and wireless cross-channel interference can be cancelled without

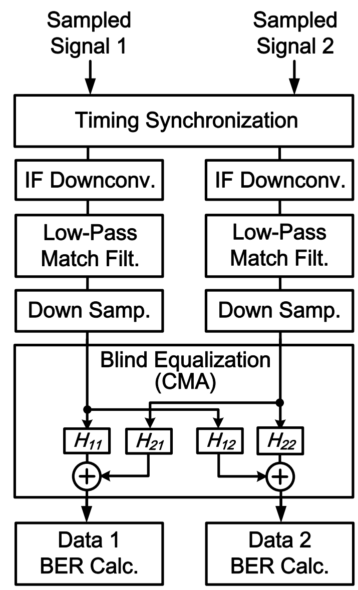

Fig. 2 Joint DSP for Pol-Mux MIMO signal demodulation with proposed blind equalization.

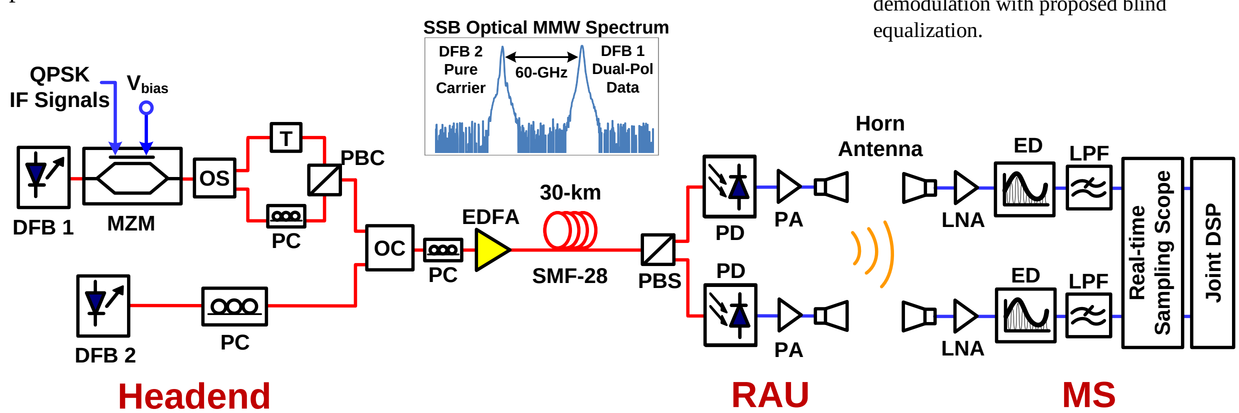

Fig. 3 Experimental setup of the Pol-Mux MIMO mm-wave RoF system with proposed joint DSP.

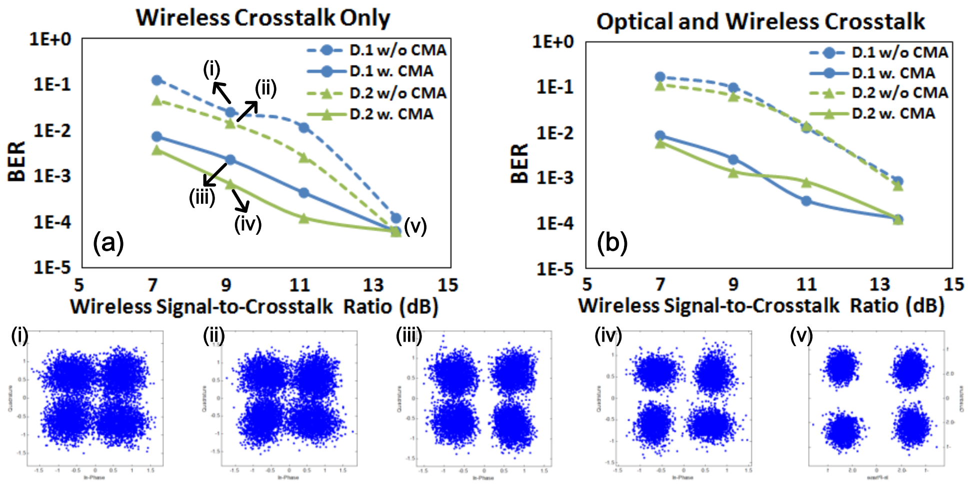

Fig. 4 BER performance of both data streams with and without blind equalization at wireless crosstalk only case (a), and with both optical and wireless crosstalk case (b), respectively. Insets (i) - (v) show the constellations of corresponding data points in (a).

inducing additional overhead (space-time coding and training sequences).

3. Experimental Setup and Results

Fig. 3 shows the proof-of-concept experimental setup of the proposed Pol-Mux MIMO mm-wave RoF system. In the headend, 400-MBaud/s (800-Mb/s) QPSK signal carried on an 800-MHz IF is generated by an arbitrary waveform generator (AWG). This QPSK IF signal is used to drive an optical intensity modulator biasing at the linear regime. The modulated optical signal is split into two paths, and one path is delayed and polarization rotated by 90 degree. The two paths with two orthogonal polarizations are then multiplexed by a PBC. The SSB optical mm-wave is generated by coupling a pure optical carrier with 60-GHz frequency spacing as illustrated in the inset of Fig. 3. The polarization of the coupled carrier is adjusted to distribute even power on two orthogonal polarizations. After an EDFA and 30-km fiber transmission, two polarizations are separated by a PBS and detected by two 60-GHz PDs. Two pairs of horn antennas with 15dBi gain are used for the wireless MIMO transmission at 60GHz. The received signals are first down-converted to the IFs through two envelope detectors (EDs), which are explained previously. After ED and low-pass filters, the two-channel signals are synchronously sampled by a real-time sampling scope at a sample rate of 20GS/s. The sampled signals are demodulated through the proposed joint DSP.

The performance of proposed blind equalization algorithm is tested under different system configurations (see Fig. 4). We first adjust the polarization controller (PC) right before the EDFA to align the polarizations of transmitter side with the receiver side to eliminate the optical crosstalk (Fig. 4(a)). With the crosstalk only from the wireless MIMO channel, the BER performance for both data streams with and without blind equalization is compared at different wireless signal-to-crosstalk (StC) ratios. The different StC ratios are achieved by adjusting the spatial distance between the two pairs of antennas. With blind equalization algorithm applied, 4dB StC-ratio improvement is observed for both data streams. The constellations before and after blind equalization at corresponding data points in Fig. 4(a) are shown from (i) to (v). Then with the same setup, we add optical crosstalk by intentionally rotate the PC before EDFA by a fixed offset (20 degree). The measured BER performance with both optical and wireless crosstalk is shown in Fig. 4(b). The similar trend is found with improved StC ratio of 4dB. These results demonstrate the feasibility of proposed blind equalization algorithm to cancel both optical and wireless crosstalk in Pol-Mux MIMO mm-wave RoF systems.

4. Conclusions

A novel Pol-Mux MIMO mm-wave radio-over-fiber system by using simple direct modulation and envelope detection is proposed and experimentally demonstrated. Based on blind equalization techniques, the crosstalk in both optical and wireless channels is cancelled without incurring additional overhead. The proposed architecture is implemented and validated through experimental results, and 4-dB improvement of signal-to-crosstalk ratio is observed with the proposed algorithm.

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