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A Low Complexity and High Accuracy Frame Synchronization for Optical OFDM and PolMux-Optical OFDM

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Abstract

Coherent optical OFDM frame synchronization over 2,000 km of optical fiber at a sampling rate of 28 Gs/s is presented. A short training sequence is applied, which slightly affects to the OFDM frame efficiency.

I. INTRODUCTION (SIZE 10, BOLD)

Coherent optical orthogonal frequency division multiplexing (CO-OFDM) provides high tolerance to channel impairments, such as chromatic dispersion (CD) and polarization-mode dispersion (PMD) by adding a cyclic prefix (CP) extension [1]. The main disadvantage of OFDM is the need for frame synchronization, given that inter-symbol interference (ISI) and inter-carrier interference (ICI) would occur if the starting point of the FFT window were mismatched and, the frame synchronization technique should be tolerant to frequency offset (f-offsets). The conventional technique for frame synchronization, from Schumidl and Cox [2] and many papers such as [2-4], loses one whole frame for synchronization. This lowers OFDM frame efficiency and the correlation peaks get plateaus. Recently, X.Q Jin [3] proposed OFDM frame synchronization by correlating the CP with the data which is the copied into the CP itself. The noise in the CP is suppressed by a Gaussian window.

To avoid these disadvantages, we propose a simple and accurate OFDM frame synchronization method. It uses short training sequences (TS), with marginal impact on efficiency. Computation complexity is very low. Additionally, if we get the correct FFT window position, we also can calculate the f-offset more correctly in the same fashion as in [2,5]. At the RX, phase noise and accumulated CD compensated in the electrical domain by pilot assistance.

In addition, our technique can be adapted to polarization-division-multiplexed coherent optical orthogonal frequency division multiplexing (PoLMux CO-OFDM), which enables highly spectrally efficient transmission. In this work, we also present how to deal with PoLMux CO-OFDM without cross-talk effects being considered.

II. SYSTEMS DESCRIPTION

In this simulated setup. The IFFT/FFT employs 1024 points, CP and cyclic suffix (CS) amount to 12.5% together (128), zero padding to 30%, and there is one pilot for phase noise compensation. Useful data is 56.5% (about 578 useful subcarriers). Totally, one OFDM frame including CP and CS is 1152 (=1024+128) points long. Additionally, with 28Gs/s

For PolMux, the signal from the two TX is fed into polarization beam combiner (PBC). At the RX, the received optical signal is split into *x*-polarization (*x*-pol.) and *y*-polarization (*y*-pol.) by a polarization beam splitter (PBS. The *x*-pol. is used for synchronization by transmittion of the TS, while the *y*-pol. does not transmit any data (stays silent (0) or transmits only zeros) to avoid crosstalk, as shows in Fig 1A. Besides, crosstalk effects can be assumed to be negligible. However, the two transmitters should have a common clock.

For only one polarization, at the transmitter, the TS sequence is inserted to the head of OFDM frame, after adding CP and cyclic suffix(CS), as depicted in Fig 1A-*x*-pol. The training pattern is chosen from [6-7].

III. PROPOSED OFDM FRAME SYNCHRONIZATION

In the receiver, the real component of the received data which includes the TS is correlated with the known patterns as shown in Fig. 1B. The correlation is given by Eq. 1,

$$P(d) = \sum_{k=d-L}^{d} C_k \Re\{r(d+k)\}, \tag{1}$$

where C_k denotes the TS, $\Re\{r(d+k)\}$ is the real

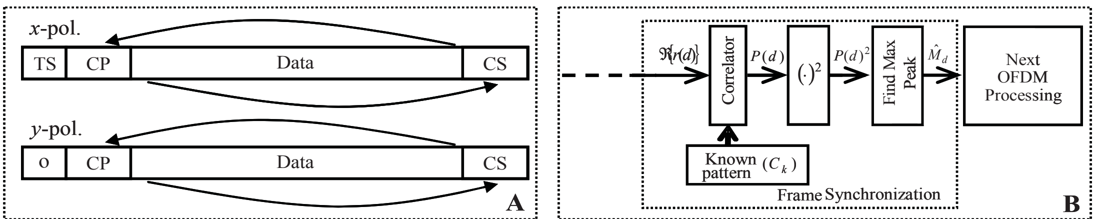

Fig. 1. A: Proposed OFDM frame in simulation for two polarizations (x-pol and y-pol)

B: Proposed Frame Synchronization.

component of received data sample, and L the length of the TS. The square $P(d)^2$ of the correlator output signal is used to avoid negative values. The algorithm searches for the maximum peak,

$$\hat{M}_d = \max_d \left(P(d)^2\right). \qquad (2)$$

IV. Simulation Results and Discussions

The results are evaluated by Monte-Carlo simulation, considering correlation peaks, efficiency of OFDM frame, and mean-square error (MSE). Optical fiber with 17 ps/nm/km of CD is assumed, without dispersion compensating fiber (DCF). Total fiber length is 2000 km in 25 spans. TS length is 16, laser linewidth is 2 MHz and sampling rate is 28 Gs/s.

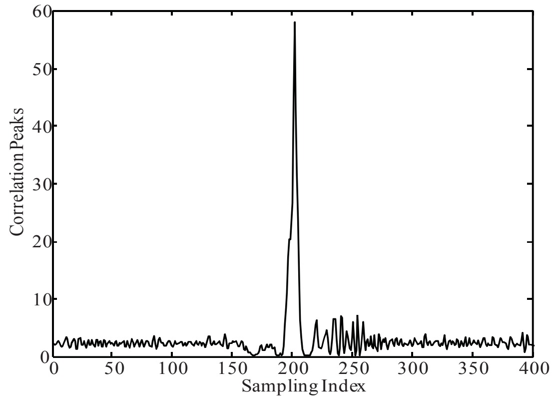

Fig. 2 Starting point of OFDM frame position index.

Fig. 2 shows the correlation peaks versus sample index, at an OSNR of 30 dB and with f-offset between TX laser and RX laser of 20MHz. The correlation peak is very sharp and there is no plateau, other than in the conventional method [2-4]. In addition, the given laser linewidth does not affect the peak and the correlation sidelobes are also low.

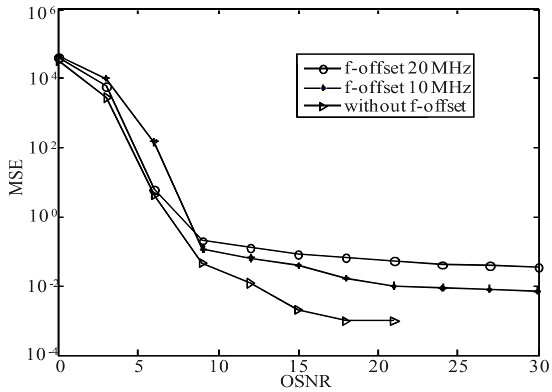

Fig. 3 MSE errors of OFDM frame

Fig. 3 illustrates the MSE by simulation of 1,000 frames with the same parameters as in Fig. 3A. Furthermore, the f-offsets are taken into account, which are 0 Hz (without f-offset), 10 MHz and 20 MHz. By increasing the f-offset from 0 to 20 MHz, the MSE got worse. However, if we can correct frequency before feeding the received signal to the correlator, the MSE becomes 0.0001 when the OSNR is increased to 21. From without f-offset, when the OSNR increases from 21 dB to 30 dB, the MSE is zero, so it is invisible.

TABLE 1. Efficiency Comparison of OFDM Frame

R	$L = 16$	Old scheme
50	0.8886	0.8734
25	0.8884	0.8584
12	0.8879	0.8276

Table 1 presents OFDM frame efficiency. R = 12, 25 or 50 is the number of frames after which a new synchronization is needed. L = 16 is the TS length. The results show that the efficiency of OFDM frame with short TS is better than old scheme (using one whole frame[2,4]) in all cases. So, the overhead is reduced.

In the correlator, we do not need complex multiplication, not even real multiplication. Since the TS contains only +1 and −1 symbols only additions and subtractions are needed. The simulation results confirm that our technique is robust.

V. Conclusions (size 10, bold)

We have proposed a very simple OFDM frame synchronization scheme for CO-OFDM and PulMux CO-OFDM, using a short training pattern, and have simulated its performance over 25 spans of optical fiber at 28 Gs/s sampling rate. The correlation peak is high and clear, and the OFDM frame efficiency is just slightly degraded. The correlator needs no multiplication, just additions and subtractions. Therefore, our technique reduces computing efforts.

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