Enhancing Optical Multi-Pulse Pulse Position Modulation Using Hybrid BPSK-Modified MPPM

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Abstract: A hybrid binary phase shift keying-modified multi-pulse pulse-position modulation scheme is proposed as a new modulation technique to improve the performance of conventional optical multi-pulse pulse-position modulation (MPPM) scheme in optical fiber communication systems.
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1. Introduction and System Model

Multi-pulse position modulation (MPPM) has been proposed to enhance the bandwidth-utilization efficiency of ordinary single-pulse pulse-position modulation (PPM) scheme [1]. Toward further enhancement in the performance of ordinary multi-pulse pulse-position modulation (MPPM), we propose to combine it with ordinary binary phase shift keying (BPSK) format. Specifically, we propose a modified MPPM technique and modulate its signal pulses using ordinary BPSK format. The proposed modulation scheme is called hybrid binary phase shift keying-modified multi-pulse pulse position modulation (hybrid BPSK-modified MPPM). In this scheme, the number of transmitted bits is increased (compared to traditional MPPM) by encoding extra bits using the BPSK format. Precisely, for frames of size M slots, instead of simply transmitting n_M un-modulated optical pulses in the ordinary MPPM frame, BPSK is used to modulate n_H optical pulses in the hybrid frame. The frame structure of both the proposed hybrid n-BPSK-modified MPPM scheme and the coherent detection n-pulse MPPM scheme are explained in Figs. 1 and 2, respectively. The term modified MPPM comes from the ability to increase number of transmitted optical pulses per hybrid frame to values more than $M/2$. Clearly, for ordinary MPPM, the number of transmitted bits per frame is $\log_2\binom{M}{n_M}$ bits, whereas for the proposed hybrid n-BPSK modified MPPM scheme, the number of transmitted bits per frame is $n_H + \log_2\binom{M}{n_H}$ bits. Here, we propose to use coherent detection (either homodyne or heterodyne), for demodulating both BPSK and MPPM symbols in the hybrid frame. The transmitter and the receiver structures for hybrid BPSK-modified MPPM are shown in Fig. 3. At the transmitter side, the transmitted data bits are first fed to a digital signal processing (DSP) device, which divides them into several blocks. Each block contains $n_H + \log_2\binom{M}{n_H}$ bits. The first $\log_2\binom{M}{n_H}$ bits determine the transmitted MPPM symbol, while, the remaining n_H bits are used to modulate these signal pulses with ordinary BPSK modulation.

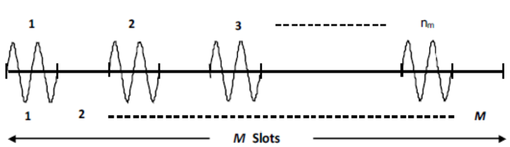

Fig. 1: Frame structure of coherent detection n-pulse MPPM.

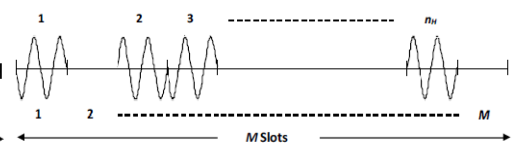

Fig. 2: Frame structure of hybrid n-BPSK-modified MPPM.

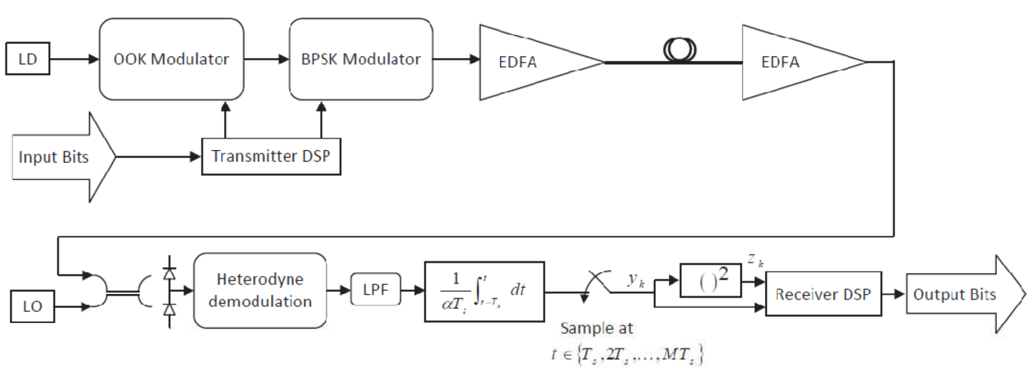

Fig. 3: Transmitter and receiver structures for the proposed hybrid BPSK-modified MPPM scheme.

Optimal Decoding Algorithm

1- Perform coherent detection for received hybrid frame by homodyne or heterodyne demodulation.
2- Get received signal amplitude in each slot.
3- Determine the energy received in each slot by squaring the integration of the received amplitudes.
4- Determine n_H signal slots of received hybrid frame by selecting the slots with the highest energies.
5- Decode the BPSK signals of these slots by comparing their integrated samples to zero.

2. Performance Evaluation

Here, we aim at evaluating the symbol-error rate (SER) for the proposed hybrid BPSK-modified MPPM. Toward that, the optical fiber is considered as the transmission medium and the system is assumed to be limited by the amplified spontaneous emission (ASE) noise generated from the optical amplifiers [2]. The SER for the hybrid BPSK-modified MPPM scheme is given by

$$\mathrm{SER_H} = 1 - (1 - \mathrm{SER_{MPPM}}) \times (1 - \mathrm{BER_{BPSK}})^{n_H} \qquad (1)$$

Where $\mathrm{SER_{MPPM}}$ and $\mathrm{BER_{BPSK}}$ are the symbol error rate for ordinary MPPM and the bit error rate of ordinary BPSK, respectively. The first parentheses in Eq. (1) accounts for the event that the MPPM symbol is correctly decoded and its pulses' positions are correctly determined. The second parentheses accounts for the event that all the BPSK symbols within the hybrid frame are correctly decoded.

3. Numerical Results

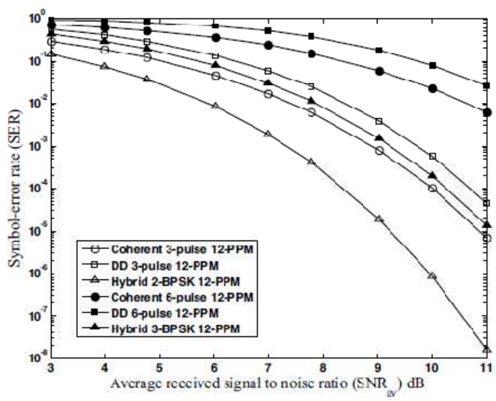

Fig. 4. Performance of hybrid scheme at M=12 slots.

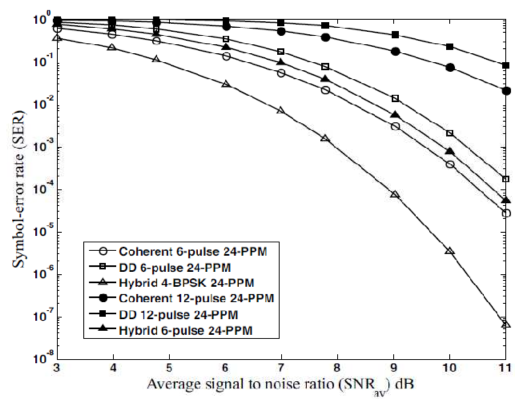

Fig. 5. Performance of hybrid scheme at M=24 slots

In this section we compare the performance achieved by the proposed hybrid BPSK-modified MPPM scheme with that achieved by ordinary MPPM schemes both coherent and direct detected under the average power constraint [3]. For fair performance comparison, we assume the usage of same frame size and same transmission rate for both schemes. For the case of $M = 12$, two comparisons are carried out. Firstly, 3-pulse 12-PPM is compared to hybrid 2-BPSK 12-PPM and secondly, 6- pulse 12-PPM is compared to hybrid 3-BPSK 12-PPM. For these hybrid schemes, the numbers of transmitted bits per frame are 8.04 bits and 10.78 bits, respectively, which are slightly larger than that of the ordinary MPPM schemes (7.78 bits and 9.85 bits, respectively). The symbol-error rates versus the average signal-to-noise ratio (SNR_{av}) are plotted in Figs. 1 and 2 for the cases $M = 12$ and $M = 24$, respectively. From these figures it is clear that at all levels of SNR_{av}, the hybrid schemes outperform their MPPM counterparts for both coherent and direct detection schemes. Numerically, as indicated in Fig. 1, at $SNR_{av} = 10$ dB, the hybrid 2-BPSK 12-PPM scheme achieves more than two order of magnitude less SER than those of the coherent detection and direct detection 3-pulse 12-PPM schemes. Moreover, with the same number of optical pulses per frame, increasing the frame size would result in better performance. Clearly, the performance of hybrid 4-BPSK 24-PPM scheme (worse than that of the hybrid 3-BPSK 24-PPM scheme) is always better than that of the hybrid 3-BPSK 12-PPM scheme.

4. References

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