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

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Abstract: A hybrid quadrature 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 quadrature phase shift keying (QPSK) format. Specifically, we propose a modified MPPM technique and modulate its signal pulses using ordinary QPSK format. The proposed modulation scheme is called hybrid quadrature phase shift keying-modified multi-pulse pulse position modulation (hybrid QPSK-modified MPPM). In this scheme, the number of transmitted bits is increased (compared to traditional MPPM) by encoding extra bits using the QPSK format. Precisely, for frames of size M slots, instead of simply transmitting n_M un-modulated optical pulses in the ordinary MPPM frame, QPSK is used to modulate n_H optical pulses in the hybrid frame. The frame structure of both the proposed hybrid n-QPSK-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-QPSK modified MPPM scheme, the number of transmitted bits per frame is $2n_H + \log_2\binom{M}{n_H}$ bits. Here, coherent detection is used for demodulating both QPSK and MPPM symbols in the hybrid frame. The transmitter and the receiver structures for hybrid QPSK-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 $\log_2\binom{M}{n_H}+2n_H$ bits. The first $\log_2\binom{M}{n_H}$ bits determine the transmitted MPPM symbol, while, the remaining $2n_H$ bits are used to modulate these signal pulses with ordinary QPSK modulation.

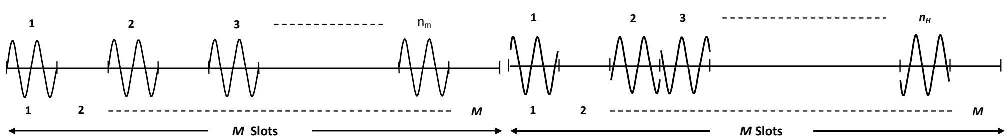

Fig. 1: Frame structure of coherent detection n-pulse MPPM. Fig. 2: Frame structure of hybrid n-QPSK-modified MPPM.

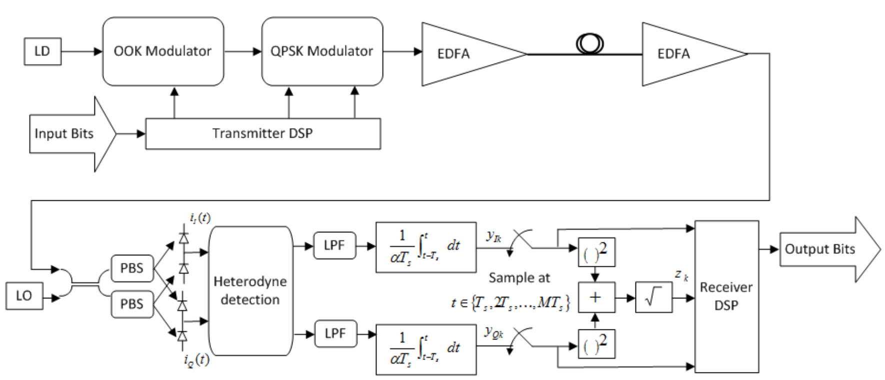

Fig. 3: Transmitter and receiver structures for the proposed hybrid QPSK-modified MPPM scheme.

Optimal Decoding Algorithm

1- Perform coherent detection and get signal amplitudes for both in-and quadrature-phase components.
2- Determine the energy received for the two components in each slot.
3- Get the square root of the sum of components' energies in each slot.
4- Determine n_H signal slots with the highest square root values.
5- Decode the QPSK signals of these slots by comparing their integrators outputs to zero.

2. Performance Evaluation

Here, we aim at evaluating the symbol-error rate (SER) for the proposed hybrid QPSK-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 QPSK-modified MPPM scheme is given by

$$\mathrm{SER_H} = 1 - (1 - \mathrm{SER_{MPPM}}) \times (1 - \mathrm{BER_{QPSK}})^{2n_H} \tag{1}$$

Where $\mathrm{SER_{MPPM}}$ and $\mathrm{BER_{QPSK}}$ are the symbol error rate for ordinary MPPM and the bit error rate of ordinary QPSK, 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 QPSK symbols within the hybrid frame are correctly decoded.

3. Numerical Results

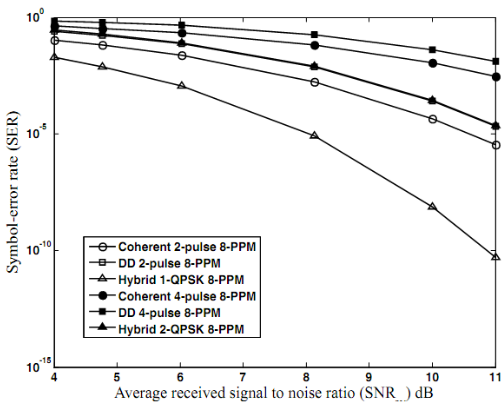

Fig. 4. Performance of hybrid scheme at M=8 slots.

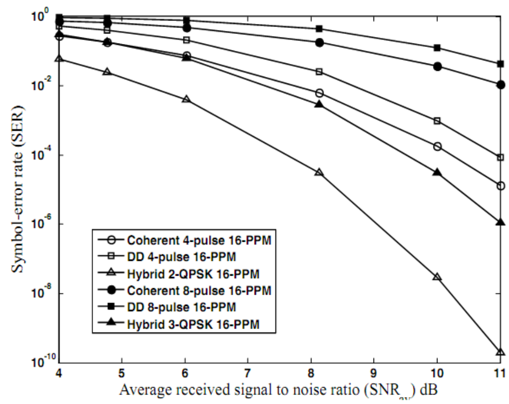

Fig. 5. Performance of hybrid scheme at M=16 slots.

In this section we compare the performance achieved by the proposed hybrid QPSK-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 $M = 8$, two comparisons are carried out. Firstly, 2-pulse 8-PPM is compared to hybrid 1-QPSK 8-PPM and secondly, 4- pulse 8-PPM is compared to hybrid 2-QPSK 8-PPM. For these hybrid schemes, the numbers of transmitted bits per frame are 5 bits and 8.8074 bits, respectively, which are slightly larger than that of the ordinary MPPM schemes (4.8074 bits and 6.1293 bits, respectively). The symbol-error rates versus the average signal-to-noise ratio (SNR_{av}) are plotted in Figs. 4 and 5 for the cases $M = 8$ and $M = 16$, 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. 5, at $\mathrm{SER_H} = 10^{-5}$, the hybrid 2-QPSK 16-PPM scheme achieves a reduction of 2 dB and 3 dB in the required SNR_{av} compared with coherent detected and direct detected 4-pulse 16-PPM schemes, respectively. Furthermore, with the same number of optical pulses per frame, increasing the frame size would result in better performance. Clearly, the performance of hybrid 2-QPSK 16-PPM scheme is always better than that of the hybrid 2-QPSK 8-PPM scheme. However, the improvement in the performance achieved by hybrid schemes comes with additional price of increasing peak power levels.

4. References

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