A Hybrid DPSK-MPPM Technique for High Sensitivity Optical Transmission

Ahmed E. Morra*, Hossam M. H. Shalaby**
Department of Electronics and Communications Engineering
Egypt-Japan University of Science and Technology (E-JUST)
Alexandria 21934, Egypt
*ahmed.morra@ejust.edu.eg; ahmedmorra@yahoo.com, **shalaby@ieee.org

Zen Kawasaki
Graduate School of Engineering
Osaka University
Osaka 565-0871, Japan
zen@comm.eng.osaka-u.ac.jp

***Abstract*—A new class of optical modulation formats, based on combinations of both MPPM and DPSK modulation techniques, is proposed. This technique has a better performance than traditional ones and is suitable for high sensitivity transmission.**

***Index Terms*—DPSK, hybrid DPSK-MPPM, MPPM, optical amplifier noise limited systems.**

I. Introduction

One of the most important issues to many optical communications systems is the receiver sensitivity. Indeed, when increasing the receiver sensitivity, less number of signal photons per bit can be transmitted to achieve a given bit-error rate (BER) [1]. One of the preeminent modulation schemes for increasing the receiver sensitivities in optical communications systems is direct-detection differential phase shift keying (DD-DPSK). DD-DPSK can be demodulated using an optical delay demodulator so that it avoids the need of an optical local oscillator [2]. Of course using DD-DPSK significantly simplifies the receiver implementation. In this paper we propose a hybrid differential phase shift keying-multipulse pulse-position modulation (DPSK-MPPM) technique assuming optical amplifier-noise limited systems in an attempt to increase further the receiver sensitivity of optical communications systems. The key idea here is to use DPSK on top of an energy efficient modulation scheme, e.g., MPPM, in order to gain the advantages of both schemes. It turned out that the proposed system would enhance the performance of both traditional DPSK and MPPM techniques.

II. Hybrid DPSK-MPPM System Model

Our proposed hybrid DPSK-MPPM transmitter is shown in Fig. 1. The transmitter sends data symbols within time frames.

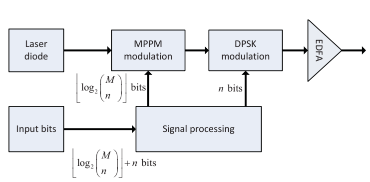

Fig. 1. Block diagram of the hybrid DPSK-MPPM transmitter.

Each time frame has a duration T and is composed of M disjoint slots. Optical pulses (each of pulsewidth $\tau = T/M$) are signaled within n slots of each time frame. A block of $\left\lfloor \log_2 \binom{M}{n} \right\rfloor + n$ bits are transmitted each time frame as follows. The first $\left\lfloor \log_2 \binom{M}{n} \right\rfloor$ bits are encoded using MPPM scheme. These bits would identify the positions of the n pulses within the frame. Each MPPM optical pulse is then DPSK modulated using an additional bit. That is, compared with traditional DPSK, instead of transmitting a consecutive stream of DPSK pulses (each with a relatively low power), we transmit less number of high-power DPSK pulses. The positions of these pulses within the frames are identified using more data bits. An example of the transmitted signal of a hybrid DPSK-MPPM scheme with $M = 4$ and $n = 2$ is shown in Fig. 2.

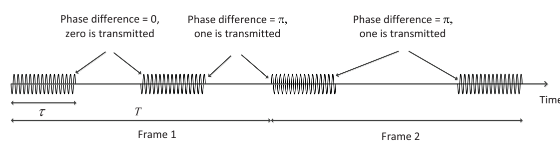

Fig. 2. An example of the transmitted signal of a hybrid DPSK-MPPM scheme with $M = 4$ and $n = 2$. The phase differences due to DPSK modulation are also shown.

At the receiver side, the received signal is first split into two branches using a 3-dB coupler, Fig. 3. The lower branch

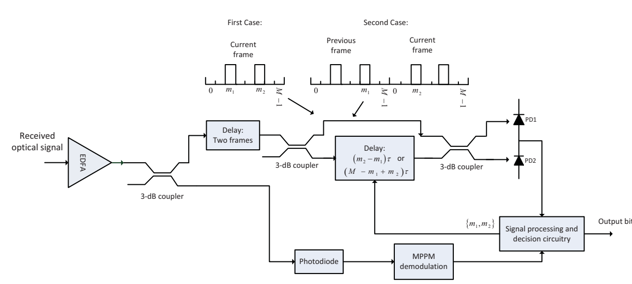

Fig. 3. Receiver of the hybrid DPSK-MPPM technique adopting DPSK optical delay detection.

is composed of a traditional direct-detection MPPM receiver in order to identify the positions of the received n pulses within the frame. In the upper branch, the DPSK data is directly detected.

The DD-DPSK receiver is implemented using an optical delay demodulation receiver (also called an optical delay interferometer) with balanced detection [2]. As shown in the figure, the received optical signal is further divided into two parts, one part is variably delayed depending on the positions of the previous and current signal slots being compared. If the previous and current signal slots being compared exist in the same frame, the delay is $(m_2 - m_1)\tau$, where $m_1 \in \{0, 1, \ldots, M-2\}$ and $m_2 \in \{m_1+1, m_1+2, \ldots, M-1\}$ are the positions of the previous and current signal slots, respectively. On the other hand, if the previous and current signal slots being compared exist in different frames, the delay is $(M - m_1 + m_2)\tau$, where $m_1, m_2 \in \{0, 1, \ldots, M-1\}$ are the positions of the previous and current signal slots, respectively. The output of DPSK receiver depends on the phase difference between any two neighboring pulses and is used by the decision circuit to determine the DPSK bit. It should be noticed that the delay by two time frames in the upper branch is to guarantee the availability of information about both m_1 and m_2 from the lower branch. As seen from Fig. 3, the BER of the hybrid system depends on both current and previous frames. We obtain an upper bound of the BER of the proposed hybrid DPSK-MPPM technique by considering the worst case scenario. That is, we assume that all the n positions are incorrectly decoded whenever an MPPM frame is incorrectly detected. This upper bound can be written as:

$$\begin{aligned}\mathrm{BER}_{Hybrid} \leq \frac{1}{N+n}\Bigg[&\mathrm{SER}_{MPPM}\left(\frac{N2^N}{2(2^N-1)} + \frac{n}{2}\right)\\ &+ (1-\mathrm{SER}_{MPPM})\,\mathrm{SER}_{MPPM}\left(\frac{1}{2} - \mathrm{BER}_{DPSK}\right)\\ &+ (1-\mathrm{SER}_{MPPM})\,n\,\mathrm{BER}_{DPSK}\Bigg]. \end{aligned} \tag{1}$$

where SER_{MPPM} is the symbol-error rates (SER) of MPPM data, BER_{DPSK} is the bit-error rate (BER) of DPSK data bits on top of the current MPPM frame, and $N = \left\lfloor \log_2 \binom{M}{n} \right\rfloor$. The SER_{MPPM} is given by [3] with slight modifications. Also, BER_{DPSK} can be found in [2].

III. Numerical Results

In Figs. 4 and 5 we plot the bit-error rate (BER) versus average received optical power for both hybrid DPSK-MPPM and traditional systems. All systems under comparisons are assumed to have same transmission data rate and receiver bandwidth. It can be seen from both figures that the performance of the hybrid system improves as M increases. Indeed the energy efficiency of the system improves by increasing M. Also it can be seen that the proposed DPSK-MPPM system performs better than corresponding traditional DPSK and MPPM systems. Specifically, for the proposed system with $M = 22$ and $n = 6$, there is an improvement of about 1.8 dB at $\mathrm{BER} = 10^{-9}$ when compared to the polarized DPSK system. And there is an improvement of about 2.2 dB at $\mathrm{BER} = 10^{-9}$ for the proposed hybrid system (of $M = 16$ and $n = 3$) when compared with traditional MPPM system (of $M = 16$ and $n = 5$).

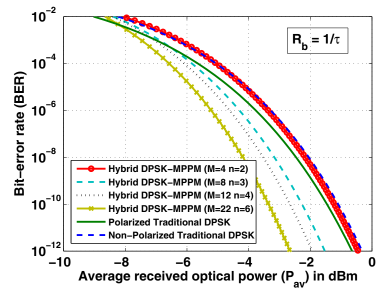

Fig. 4. Average bit-error rate versus average received optical power for both hybrid DPSK-MPPM and traditional DPSK systems with $\sigma_n^2 = 1.6 \times 10^{-5} A^2$ under the constraints of same bandwidth and transmission rate.

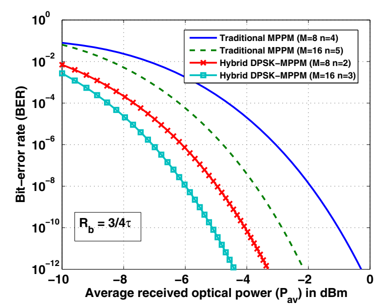

Fig. 5. Average bit-error rate versus average received optical power for both hybrid DPSK-MPPM and traditional MPPM systems with $\sigma_n^2 = 1.6 \times 10^{-5} A^2$ under the constraints of same bandwidth and transmission rate.

IV. Conclusion

A hybrid DPSK-MPPM modulation technique has been proposed for optical communications systems in order to increase the receiver sensitivity. A simple detection mechanism, based on direct-detection DPSK receivers, has been proposed and studied. The BER of the proposed system has been derived and compared numerically to that of corresponding systems adopting DPSK and MPPM techniques. It turned out that the proposed technique is more power efficient than traditional ones and has an improved BER and receiver sensitivity.

Acknowledgement

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