Hybrid Phase Shift Keying-Multipulse Pulse-Position Modulated O-OFDM Signals for NG-PONs

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ABSTRACT
In this paper, Hybrid PSK-MPPM is proposed to improve the system performance of the conventional ACO-OFDM by modulating the subcarriers with less number of high power PSK modulated symbols while their positions will also be utilized to carry additional information. At the receiver, the position of the modulated subcarriers will be firstly identified on each sub-frame by selecting the subcarriers with the highest received power and the PSK symbols will be subsequently decoded. The performance of the proposed detection scheme is close to that of ML detection scheme with significant reduction in the computational complexity. Throughout simulations, we demonstrate enhancement in the receiver sensitivity and the PON reach compared to the conventional PSK modulation for the same spectral efficiency.
Keywords: Hybrid PSK-MPPM, OFDM, PON, ML, spectral efficiency.

1. INTRODUCTION

Orthogonal frequency-division multiple-access (OFDMA) has been extensively studied in the context of future gigabit optical access networks. OFDMA has attracted much research interest due to its resistance to inter symbol interference (ISI) caused by chromatic dispersion. Moreover, it simplifies the receiver design as equalization can be performed with single tap equalizers in the frequency domain [1]. The data transmission in the next generation passive optical networks (NG-PONs) can be achieved by the low cost intensity modulation and direct detection (IM/DD). In IM/DD systems the intensity of optical carrier is modulated by electrical signal. Therefore, the transmitted signal has to be real-valued and non-negative. A real-valued OFDM signal can be obtained when Hermitian symmetry is imposed on the OFDM subcarriers. After that to generate unipolar time-domain signals, there are two commonly used techniques [2], either by adding a DC bias to force the signal to be non-negative as in DC-biased optical OFDM (DCO-OFDM) or by adopting clipping based solution to generate asymmetrically OFDM signal such as asymmetrically clipped optical OFDM (ACO-OFDM) and pulse-amplitude-modulated discrete-multitone (PAM-DMT). In ACO-OFDM and PAM-DMT, imposing restrictions on the frame leads to a spectral efficiency loss, therefore several schemes have been recently proposed to avoid this spectral efficiency loss as in [3],[4].

In this paper, we propose using hybrid phase shift keying-multipulse pulse position modulation (hybrid PSK-MPPM) format [5] with ACO-OFDM for NG-PONs and this modulation scheme can also be applied to the other O-OFDM techniques for IM/DD systems. Hybrid PSK-MPPM, in comparison with conventional PSK modulation, has remarkable advantages including improvement in the receiver sensitivity for the same spectral efficiency of PSK modulation or increase the transmission capacity without altering the minimum required received power. In hybrid PSK-MPPM, less number of high power PSK symbols modulate the OFDM subcarriers compared to conventional PSK modulation, while their positions will also be utilized to carry additional user information. An efficient detection scheme has been proposed by selecting the subcarriers with the highest received power and then decode them as the PSK symbols of the received frame. The performance of the proposed detection scheme can yield near- maximum likelihood (ML) performance with more reduction in the computational complexity. We show that when using hybrid BPSK-MPPM and QPSK-MPPM, the spectral efficiency could be improved compared to the conventional BPSK modulation by 20% and 60% respectively. Improvement in the required receiver sensitivity and the PON reach is also reported for the proposed modulation technique and compared to conventional system for same spectral efficiency.

2. HYBRID PSK-MPPM O-OFDM SYSTEM MODEL

For the conventional ACO-OFDM, Hermitian symmetry has to be satisfied while setting to zero the even subcarriers and only modulating the odd subcarriers with PSK symbols, hence only one fourth of N-points FFT will be utilized for modulation with consecutive PSK symbols as shown in Fig. 1a. In hybrid PSK-MPPM format in Fig. 1b, the available $N/4$ subcarriers will be divided into sub-frames each of size k subcarriers and this modulation scheme can be extended by the same way to the other OFDM techniques for IM/DD systems.

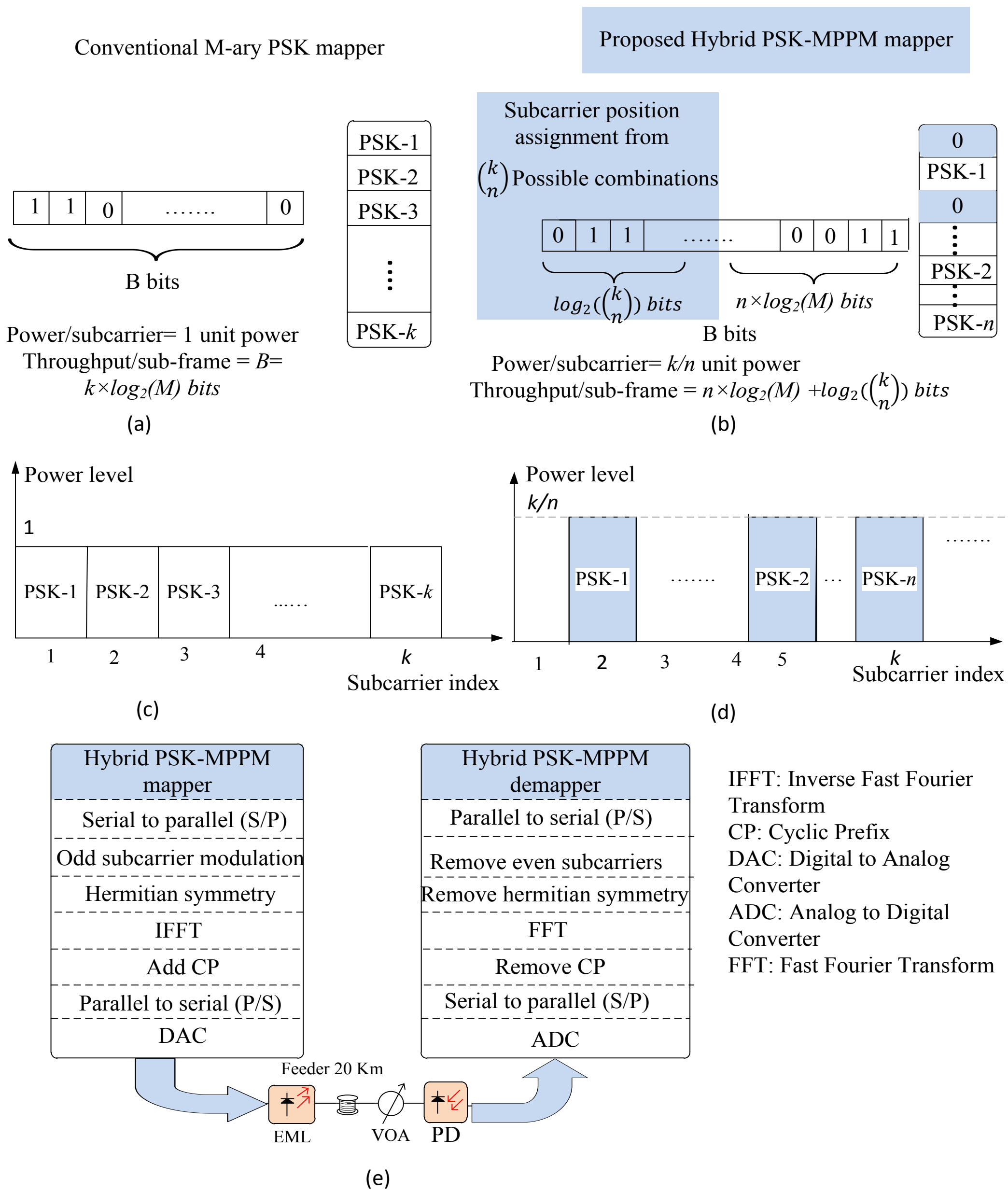

Figure 1. Proposed ACO-OFDM with hybrid PSK-MPPM modulation format Data encoding process using (a) conventional M-ary PSK and (b) hybrid PSK-MPPM, Power level vs. Subcarrier index for (c) conventional M-ary PSK and (d) hybrid PSK-MPPM, and (e) Block diagram of ACO-OFDM transmitter and receiver.

Only n subcarriers from the available k subcarriers will be modulated using M ary-PSK to encode $\log_2(M)$ bits on each subcarrier, while $\log_2\binom{k}{n}$ bits will be encoded using MPPM to identify the position of the n PSK symbols in the sub-frame from $\binom{k}{n}$ possible position combinations. Figures 1c and 1d show the power level of the modulated symbols at different subcarriers, it is clear that the transmitted power per subcarrier for the hybrid scheme is higher than the conventional PSK modulation under the same average power constraint. According to the optimum choice of the values of k and n, the hybrid scheme can improve the spectral efficiency with the same average transmitted power. The throughput per sub-frame for the conventional M-PSK B_{PSK} and our proposed hybrid scheme $B_{Hybrid\ PSK\text{-}MPPM}$ are following:

$$B_{PSK} = k \times \log_2(M) \quad \text{bits} \tag{1}$$

$$B_{Hybrid\ PSK\text{-}MPPM} = n \times \log_2(M) + \log_2\binom{k}{n} \quad \text{bits} \tag{2}$$

At the receiver side as shown in Fig. 1e, after the conventional demodulation of the ACO-OFDM signal, ML detection can be applied for the detection of both the position of the n subcarriers and the PSK symbols on these subcarriers. In ML decoding, the received codeword on each sub-frame is compared with the all possible

$\binom{k}{n}\times M^n$ codewords and the codeword which gives the minimum Euclidean distance is selected. We proposed another simple detection scheme for hybrid PSK-MPPM where the detection is performed through two stages. The position of the n subcarriers will be firstly identified on each sub-frame by selecting the n subcarriers with the highest received power and the PSK symbols will be subsequently decoded on these carriers using the conventional PSK demodulator.

3. SIMULATION AND PERFORMANCE EVALUATION OVER A PON LINK

Hybrid PSK-MPPM OFDM signal with 512-FFT length is generated using Matlab and passed to Optisystem to directly modulate a 1550 nm EML with output power of 5 dBm at 1.25 Gbaud. The signal is then passed through 20 km of optical fiber link. Figure 2a shows that hybrid BPSK-MPPM with ratio 2/7 and QPSK-MPPM with ratio 1/5 outperform the conventional BPSK modulation by 1dB and 1.5 dB respectively for the same spectral efficiency. In addition, 20% and 60% improvement in the spectral efficiency η can be achieved using hybrid BPSK-MPPM with ratio 2/5 and QPSK-MPPM with ratio 2/5 while having the same system performance of the conventional BPSK. Similarly, both hybrid QPSK and 8PSK improve the receiver sensitivity by 1 dB compared to the conventional QPSK and 8PSK modulation as illustrated in Fig. 2b. Simulation results show that our proposed detection scheme yields the same performance of ML detection for hybrid-BPSK-MPPM modulation while having negligible degradation compared to ML detection for hybrid-QPSK-MPPM modulation.

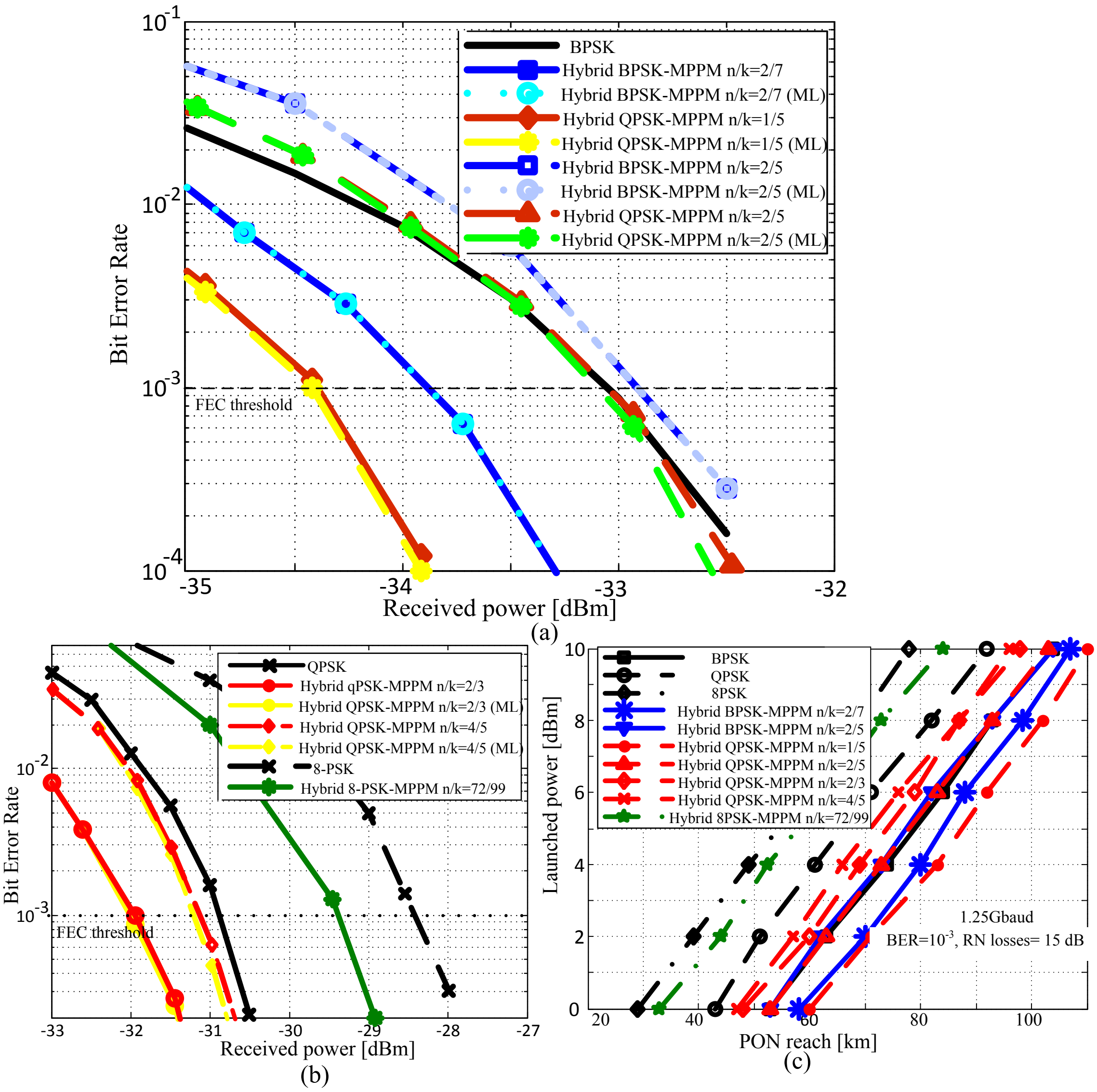

Figure 2: (a) Bit error rate versus received power for BPSK compared with hybrid BPSK-MPPM and hybrid QPSK-MPPM; (b) Bit error rate versus received power for QPSK compared with hybrid QPSK-MPPM and for 8PSK compared with hybrid 8PSK-MPPM; and (c) PON reach versus launched power for conventional PSK modulation and hybrid PSK-MPPM modulation for 32 optical network units (ONUs), which is equivalent to 15 dB losses at remote node (RN), at 1.25Gbaud.

Improvement in the PON reach using the proposed modulation scheme shown in Fig. 2c, where RN losses for 32 ONUs were considered. It can be seen that using hybrid QPSK-MPPM with ratio 1/5 improves the PON reach by ~8 km compared to conventional BPSK for the same spectral efficiency, whilst hybrid QPSK-MPPM with ratio 2/3 achieves ~7 km improvement in the PON reach compared to conventional QPSK. Table 1 illustrates how the sub-frame size can be optimally chosen in order to achieve better receiver sensitivity P_{Rx}, fluctuation in the receiver sensitivity occurs with changing the sub-frame size due to the change in the instantaneous power level per subcarrier for different modulation formats and spectral efficiencies η. For hybrid BPSK-MPPM and QPSK-MPPM, it's preferable to choose small sub-frame size with the high level of power per subcarrier since the majority of the system throughput comes from the position bits. On the other hand, 8-psk requires large size of sub-frame in order to achieve the desired spectral efficiency.

Table 1. Effect of changing sub-frame size on receiver sensitivity for different η and modulation formats.

M-ary							
		η=1	**η=1**	**η=1**	**η=1.2**	**η=1.2**	**η=1.2**
BPSK	*k*	3	7	15	5	20	25
	n	1	2	4	2	7	9
	P_{Rx} [dBm]	**-33.3**	**-34**	**-33.5**	**-32.9**	**-32.4**	**-31.7**
QPSK		**η=1**	**η=1**	**η=1**	**η=1.6**	**η=1.6**	**η=1.6**
	k	5	10	21	5	20	25
	n	1	2	4	2	5	6
	P_{Rx} [dBm]	**-34.5**	**-33.5**	**-33.6**	**-33**	**-32.2**	**-32**
		η=2	**η=2**	**η=2**	**η=2.2**	**η=2.2**	**η=2.2**
	k	3	5	14	5	10	20
	n	2	3	8	4	8	15
	P_{Rx} [dBm]	**-32**	**-31.5**	**-31.7**	**-31.2**	**-30.7**	**-31**
8-PSK			**η=3**	**η=3**	**η=3**		
	k		15	45	99		
	n		12	34	72		
	P_{Rx} [dBm]		**-28.2**	**-28.9**	**-29.4**		

4. CONCLUSIONS

Hybrid PSK-MPPM modulation scheme has been proposed for NG-PONs. In this scheme, OFDM subcarriers will be modulated with less number of high power PSK symbols while their relative position will be utilized to carry additional information. Enhancement in the spectral efficiency can be achieved when compared to the conventional PSK modulation. In addition, improvements in receiver sensitivity and PON reach have been reported using the proposed scheme compared to the conventional PSK modulation at same spectral efficiency.

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