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Performance of Two-Level Two Pulse Position Modulation Scheme in Optical Communication

Puneet Chandra Srivastava[1] & R. K. Singh[2]

[1]Associate Professor,ECE Dept.Raj Kumar Goel Institute of Technology, Ghaziabad, Mahamaya Technical University, Uttar Pradesh, India, (E-mail : cs.puneet@gmail.com)

[2]Professor, ECE Dept. Kumaon Engg. College, Dwarhat (Almora), Uttarakhand, India

Abstract: This paper investigates a new modulation scheme to achieve good power and spectral efficiencies with a coded modulation system. For IM/DD in optical Communication, PPM and MPPM have good power efficiencies but low spectral efficiencies. On the other hand, PAM achieves excellent spectral efficiencies. This new modulation scheme combines multiple level and multiple pulse position. The performance of this new modulation scheme present in terms of uncoded BER and cutoff rate.

Keywords: Two level Two Pulse Position Modulation (2L2PPM), Uncoded Bit Error Rate (BER), Spectral Efficiency, Cutoff Rate.

1. INTRODUCTION

1.1. Two-Level-Two Pulse Position Modulation

Multi-level modulation techniques are powerful in terms of spectral efficiency, whereas pulse position modulation is strong in terms of power efficiency. This new modulation scheme has two pulses for every symbol time period and each pulse can take two amplitude levels instead of one amplitude level, as in PPM and MPPM. This new modulation scheme is called two-level two-pulse position modulation (2L2PPM).

1.2. Modulation Format

In this modulation format, each word of b bits is mapped into one of $L=2^b$ waveforms and transmitted to the channel. The symbol interval of duration T is partitioned into n chips. Each chip has a duration T/n. Of the n, only two contain pulses, each of which can take one of two levels (A_1, A_2) to convey one of the L symbols. The two levels are introduced to increase the spectral efficiency. In the conventional pulse position (PPM), only one amplitude level and one position is used. In conventional multiple pulse position modulation (MPPM), two or more pulses are used, but each pulses takes only one amplitude level. The new modulation scheme achieves more spectral efficiency than conventional PPM and MPPM modulation schemes because 2L2PPM allow pulses to have two amplitude levels. The two amplitude levels A_1 and A_2 are chosen so that the average optical power is P, and the relationship between the two levels is a design parameter. In addition to that the number of the signal waveforms in the 2L2PPM signal set is

$$L = 4\binom{n}{2} = \frac{2n!}{(n-2)!} = 2n(n-1), \qquad (1)$$

Where n is the number of pulse position. L is usually not a power of two, so discard some of the resulting signals to achieve $L = 2^b$.

2. PERFORMANCE OF 2L2PPM

To evaluate the effectiveness of this modulation scheme two different performance measures are used: I. Uncoded bit-error rate II. Cutoff rate

2.1. Uncoded Bit-error Rate

In determining error probability, assume maximum-likelihood (ML) detection. The transmitter sends information at a rate of R_b bits/s by transmitting one of its L available signals $\{x_1(t), x_2(t), \ldots\ldots, x_L(t)\}$ every $T = \log_2 L/ R_b$ seconds. The channel adds white Gaussian noise with power spectrum $N_0/2$. The signal set satisfies the constraint of power limitation

$$\frac{1}{T}\int_o^T x(t)dt = P$$

where P is the average optical power. Assume high SNR, which allows to approximate the BER from the Euclidean distance [1] between the nearest two signals $d_{\min}$, where

$$d_{\min}^2 = \min_{i \neq j} \int (x_i(t) - x_j(t))^2 dt. \qquad (2)$$

And the BER is roughly bounded by

$$BER \approx Q\left(\frac{d_{\min}}{\sqrt{2N_o}}\right). \quad (3)$$

For the uncoded 2L2PPM the ratio between the 2nd amplitude level to the first is

$$A_2 = \left(1+\sqrt{2}\right)A_1. \quad (4)$$

By using the power constraint A_1 and A_2 can find as

$$A_1 = (nP)/\left(2+\sqrt{2}\right), \quad (5)$$

$$A_2 = nP\left(1+\sqrt{2}\right)/2\left(2+\sqrt{2}\right). \quad (6)$$

Looking to the signal constellation of 2L2PPM modulation scheme, it is not difficult to show that the minimum Euclidean distance square of this modulation scheme is going to be:

$$\left(d_{2L2PPM}\right)^2 = \frac{2nP^2\log_2(2n(2n-1))}{\left(2+\sqrt{2}\right)^2 R_b} \quad (7)$$

Similar to the discussion in [2]. The ratio between the power needed for 2L2PPM to the power needed for OOK for the same BER as the inverse ratio between the minimum Euclidean distance of the two modulators can write as

$$P_{2L2PPM}/P_{OOK} \approx d_{OOK}/d_{2L2PPM} = \frac{2\left(2+\sqrt{2}\right)}{\sqrt{2n\log_2(2n(n-1))}}. \quad (8)$$

2.1.1. Simulation Result

Figure 1 shows the power efficiency versus the spectral efficiency of 2L2PPM for different values of n. The performance-PPM, (n,2)-MPPM and (n,3)-MPPM modulation schemes also shown for comparison purposes. The Y-axis represents the normalized power requirement for BER = 10^{-6}. The X-axis represents the spectral efficiency in terms of bits/s/Hz. The figure shows that 2L2PPM modulation scheme is more spectrally efficient than PPM and MPPM modulation schemes. It also shows that the power efficiency of 2L2PPM is still better than OOK for n ≥ 5. The curve shows that the power efficiencies of 9-2L2PPM and 12-2L2PPM are -2.2 dB and -3 dB, respectively.

2.2. Spectral Efficiency

There are several ways to define the bandwidth of signals in communications [3]. One of the simplest estimates of the bandwidth requirement of 2L2PPM is the inverse of the shortest pulse width, and the estimate is equivalent to the width of the main spectral lobe of the modulation scheme [2]. More accurate measures of the bandwidth requirement come after specifying the power spectral density (PSD) of

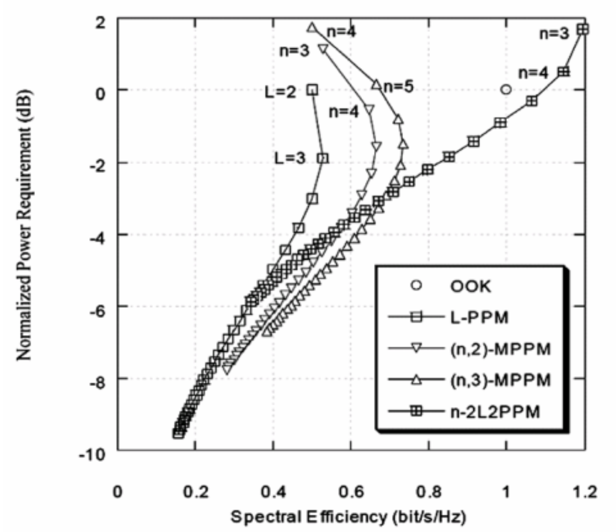

Figure 1: Power Efficiency versus Spectral Efficiency for n-2L2PPM, OOK, L-PPM, (n, 2)-MPPM, and (n,3)-MPPM Modulation Schemes at High Optical SNR

the modulation scheme and the bandwidth that includes an X-percentage of the signal power is called B_x [4]. If the input symbols to the modulator are assumed to be chosen independently and with equal probability, then a general expression for the PSD of any L-ary modulation scheme is given in [5] as:

$$P(f) = \frac{1}{L^2T_s^2}\sum_{n=-\infty}^{\infty}\left|\sum_l P_l\left(\frac{n}{T_s}\right)\right|^2 \delta\left(f-\frac{n}{T_s}\right) + \frac{1}{T_s}\left[\sum_l \frac{1}{L}\left|P_l(f)\right|^2 - \left|\sum_l \frac{1}{L}P_l(f)\right|^2\right], \quad (9)$$

Where $P_l(f)$ is the Fourier transform of the signal corresponding to the l-th symbol, and T_s is the symbol period. The first term is discrete and represents the spectral lines. The second term represents the continuous part of the spectrum.

2.2.1. Simulation Result

Figure 2 shows the continuous part of the PSD of 9-2L2PPM and 12-2L2PPM for rectangular pulses. In each curve, the

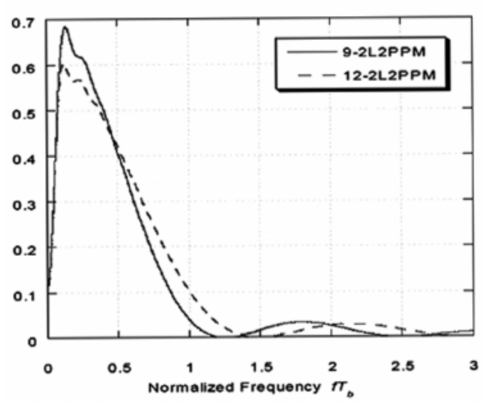

Figure 2: Continuous Power Spectrum of 9-2L2PPM and 12-2L2PPM

first null of the spectrum corresponds to the inverse of the shortest pulse-width .which is used as an approximation for the bandwidth requirement of the modulation scheme .According to this approximation, the normalized bandwidth requirements of the two cases are 1.26 and 1.49 and they contain 91.4% and 91.1% of the signal power respectively. Since more than 90% of the signal power is contained in main spectral lobe, the above approximation of the bandwidth requirement is justified. In addition to that the spectral density is defined as the inverse of the bandwidth requirement. When above approximation is used, the spectral efficiency of 2L2PPM modulation scheme can be shown as:

$$\eta_{2L2PPM} = \frac{\log_2 L}{n} = \frac{\log_2(2n(n-1))}{n}. \quad (10)$$

Out of 144 possible signals in 9-2L2PPM modulation scheme, 128 signals are used with a serial concatenated encoder to get 128-SCTCM-2L2PPM system. Similarly, only 256 of 264 signals in 12-2L2PPM modulation scheme are used with serial concatenated encoder to form 256-SCTCM-2L2PPM system.

2.3. Cutoff Rate

The cutoff rate is believed to be a figure of merit for all modulation schemes [6]. For an arbitrary L-ary modulation scheme, the cutoff rate R_0 is defined when input code words with a uniform distribution $P(x_k)= 1/L$ as

$$R_o = -\log_2\left(\frac{1}{L^2}\sum_{l=0}^{L-1}\sum_{m=0}^{L-1}\exp(-\|v_l - v_m\|^2/8\right) \; Bits/codeword, \quad (11)$$

Where $v = x/\left(\sqrt{N_o}\right)$.

The Cutoff rate is used to evaluate efficiency of the above modulation scheme.

2.3.1. Simulation Result

Figure 3 shows that when n = 9 than R_0 = 5 at -6.8 dB normalized power efficiency. For n = 12, R_0= 6 at a normalized power efficiency of -7.1 dB.

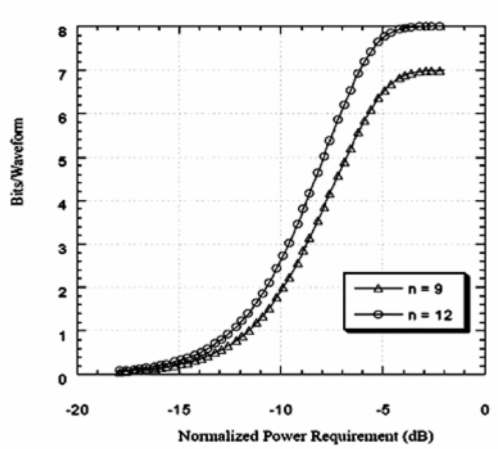

Figure 3: The Cutoff Rate of 9-2L2PPM and 12-2L2PPM Modulation Schemes

3. CONCLUSION

In this paper, a new modulation scheme which is suitable for optical communication has introduced. The new modulation is a combination of MPPM and multilevel modulation techniques. The uncoded BER performance of this modulation technique shows that it is more spectrally efficient than PPM and MPPM. The cutoff rate curves of the new modulation indicate that up to 6.7 dB- 7.1 dB of power efficiencies and 0.55 bits/sec./Hz- 0.50 bits/sec./Hz spectral efficiencies could be obtained by using 128 and 256 symbols 2L2PPM modulation.

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