Error Rate Performance of Pulse Position Modulation Schemes for Indoor Wireless Optical Communication

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ABSTRACT

Error rate performance of pulse position modulation (PPM) schemes for indoor wireless optical communication (WOC) applications is investigated. These schemes include traditional PPM and multiple PPM (MPPM). Study is unique in presenting and evaluating symbol error behaviour under wide range of design parameters such symbol length (L), number of chips per symbol (n), number of chips forms optical pulse (w). Effect of signal to noise ratio levels and operating bitrates on symbol error performance is also discussed. A comparison between studying modulation schemes is done. Relation with IrDA and IEEE 802.11 indoor WOC standardization is also investigated. Results indicate that PPM achieve great symbol error performance at reasonable signal to noise ratio and high bitrates with large symbol length.

Keywords: Wireless optical communication, pulse position modulation, multiple PPM, Infrared Data Association (IrDA)

1. INTRODUCTION

Recently, the need to access wireless local area networks from portable personal computers and mobile devices has grown rapidly. Many of these networks have been designed to support multimedia with high data rates, thus the systems require a large bandwidth. Since radio communication systems have limited available bandwidth, a proposal to use indoor optical wireless communications has received wide interest [1]-[3].

An optical indoor wireless channel is usually a non-directed link which can be categorized as either line-of-sight (LOS) or diffuse. A diffuse link is preferable because no alignment is required and it is more robustness to shadowing. Normally, a diffuse link is corrupted by ambient light noise, high signal attenuation, and intersymbol interference caused by multipath dispersion. In addition, the average transmit optical power is constrained by concerns of power consumption and eye safety regulations [1]-[3]. Furthermore, high capacitance in a large-area photodetector limits the receiver bandwidth. Consequently, a power-efficient and bandwidth-efficient modulation scheme with relatively low error performance is desirable in an indoor optical wireless system [4].

Normally, an optical wireless system adopts a baseband modulation scheme, e.g. on-off keying or pulse position modulation. To yield more efficiency in terms of power and bandwidth with relatively low error performance, a number of modulation techniques have been proposed which vary the number of chips per symbol, e.g. multiple PPM (MPPM) , differential pulse position modulation (DPPM) and differential amplitude pulse position modulation(DAPPM) [5]-[7]. To evaluate a modulation scheme a detailed study should be done to test power efficiency, bandwidth efficiency and error performance of the scheme [2], [3].

This paper presents a detailed study for the symbol error performance for PPM and MPPM under wide range of operating and design parameters in an ideal, no (intersymbol interference) ISI channel with a system indicated in Sec. 2. This is one of key design parameters for indoor applications. Contributions in this work includes, First, testing error performance of PPM and MPPM-for the first time- under wide range of signal to noise levels and allowable bitrates relative to latest practical achievements. Second, discussing -for the first time- the effect of design schemes parameters such (n), (w) and (L) on the error performance. Finally establish a general comparison between schemes and relating results with today's standardizations with suggestion for future trends.

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Paper organized as follows: section 2 includes the mathematical model that used to evaluate the symbol error performance for PPM and MPPM for an ideal, no ISI channel. Section 3 presents numerical simulation results and discussion including observations on error behaviour, comparison between schemes and relation with IrDA and IEEE 802.11 standards indoor WOC standards. Section 4 contains conclusion of this work. Section 5 includes references.

2. MATHEMATICAL MODEL

This section present the simplified expressions used to evaluate symbol probability of error for both PPM and MPPM under condition of ideal channel without ISI.

One need to indicate that this simplified model is first introduced in [7] with a clear identification to PPM and MPPM used design parameters (n), (w) and (L). Then, applied to a system with unequalized receiver that used to carry the general complicated format of unequalized symbol error probability model for PPM schemes in [8]. After that and under condition of an ideal channel without ISI and using results of [8] with additional simplification of [9] following model appears.

First, consider multiple PPM, when the channel has no ISI, symbol probability of error is given by [8]:

$$\Pr[error] \le \sum_{k=1}^{w} a_k Q\left(\sqrt{\frac{ks^2}{2N_o}}\right) \tag{1}$$

where (a_k) is the number of code words with mutual distance *2k* as [8]:

$$a_k = \left(\frac{w!}{k!(w-k)!}\right)\cdot\left(\frac{(n-w)!}{k!(n-w-k)!}\right) \tag{2}$$

and *s* and L_{MPPM} is given by [7]-[9]:

$$s = \left(\frac{P}{w}\right)\cdot\sqrt{\frac{n\cdot\log_2 L_{MPPM}}{R_b}} \tag{3}$$

$$L_{MPPM} = \frac{n!}{w!(n-w)!} \tag{4}$$

The calculation of this useful performance metric requires that (1) be solved for *P*, a formidable task [9]. We can simplify the calculation by assuming that the error probability is dominated by the minimum distance term and neglecting the multiplicity a_k in (1), yielding the following approximation for the symbol probability of error [9]:

$$\Pr[error] \approx Q\left(\frac{P}{w}\cdot\sqrt{\frac{n\cdot\log_2 L_{MPPM}}{N_o R_b}}\right) \approx Q\left(\frac{s}{\sqrt{N_o}}\right) \tag{5}$$

For traditional PPM (i.e w=1 and L_{PPM}=n) eqn. 1 simplifies to [8]:

$$\Pr[error] \le \left(L_{PPM}-1\right)Q\left(\frac{s}{\sqrt{2N_o}}\right) \tag{6}$$

with *s* for PPM given by [8]:

$$s = P\sqrt{\frac{L_{PPM}\cdot\log_2 L_{PPM}}{R_b}} \tag{7}$$

using same technique used for MPPM symbol probability of error for PPM reduces to [8]:

$$\Pr[error] \approx Q\left(\frac{s}{\sqrt{2N_o}}\right) \qquad (8)$$

3. NUMERICAL RESULTS AND DISCUSSION

3.1. Pulse position modulation (PPM)

Figure 1 presents symbol probability of error for PPM under multi levels of signal to noise ratio (P/N_o) and symbol length (L). Simulation was done at R_b= 155 Mbps since this value was the highest achievable practical bit rate recorded for indoor WOC application by BT labs [2].

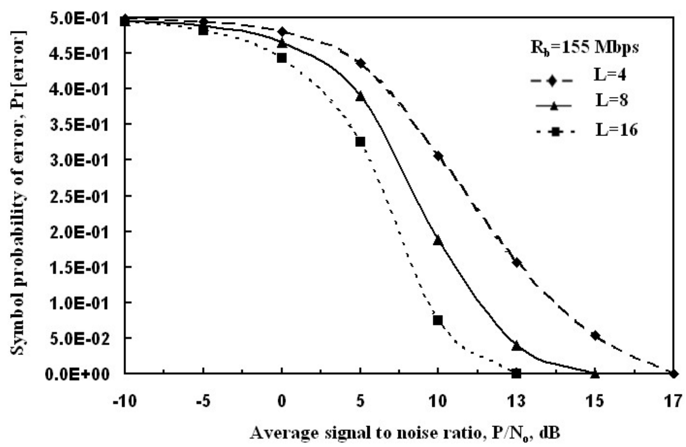

Fig 1. Symbol probability of error for PPM under signal to noise levels and symbol lengths.

As one can observe from Fig. 1 as signal to noise ratio (P/N_o) increase the symbol probability of error decrease. This is a nature behaviour for digital modulation schemes [10], [11]. However, for WOC one need to admit that PPM scheme which utilizes large symbol length requires less power to achieve same probability of error compared of low symbol length schemes at the same operating bit rate.

Simulation results indicates that to achieve ≈ 10^{-4} symbol error probability at 155Mbps for L=16, L=8 and L=4, PPM scheme requires P/N_o 14.1 dB, 16.2 dB and 18.5 dB respectively. Maximum level of symbol probability of error is 0.498, 0.496 and 0.494 for L=4, L=8 and L=16 respectively at P/N_o= -10 dB and R_b= 155Mbps.

Figure 2 presents symbol probability of error for PPM under multi levels of operating bit rate (R_b) and symbol length with a signal to noise ratio =10dB.

To discuss the effect of multi level of operating bit rate on a PPM scheme under fixed signal to noise ratio level one need to explore Fig.2. As operating bit rate increase under fixed (P/N_o=10dB) the probability of error increase. This is mainly due to the closeness between symbols as bit rate increase which increase the effect of background white noise and hence increase the error.

From Fig.2 and for WOC applications PPM scheme which utilizes large symbol length has lower symbol error probability compared with schemes uses small symbol length at the same operating bit rate and signal to noise ratio. In this simulation case study, maximum level of symbol probability of error at R_b= 155Mbps and P/N_o= 10dB for PPM scheme with L=4, L=8 and L=16 is 0.306, 0.189 and 0.075 respectively.

An important observation that as symbol length increase the range of bit rate that achieve low symbol error probability increase. (i.e PPM with L=16 R_b [1-40 Mbps] Pr[error]≤ 10^{-4} while PPM with L=8 R_b [1-20 Mbps] Pr[error]≤ 10^{-4}] at P/N_o= 10dB.

From these results one can conclude that designing a PPM scheme with large symbol length provides attractive advantages in error performance in high operating bit rates and with relatively low signal to noise ratio level. Also results

(Fig.1) provides that PPM with large symbol length is more power efficient than that uses small symbol length which in a fair agreement with [2], [7], [8]. But also this is done in a price of low bandwidth efficiency for large symbol length PPM scheme [7], [8].

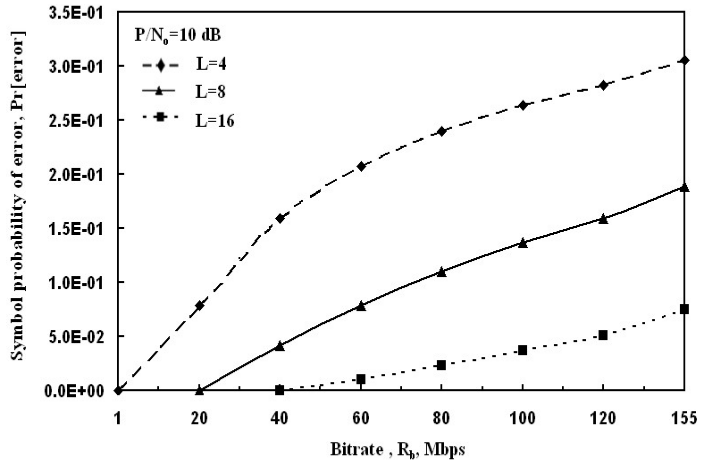

Fig. 2. Symbol probability of error for PPM under operating bitrate and symbol lengths.

3.2. Multiple pulse position modulation (MPPM)

3.2.1 Multiple pulse position modulation with low optical pulses (w=2)

In this section we are going to discuss symbol error performance of MPPM. Dealing with MPPM is more general and complex than PPM also this scheme is the basic for a coded modulation scheme as TC-MPPM [9].

Figures 3 presents symbol probability of error for MPPM scheme at low formed optical pulses (w=2) under multi levels of signal to noise ratio (P/N_o) and number of chips per symbol (n). As PPM, Simulation was done at R_b= 155 Mbps for reasons described in Sec. 3.1.

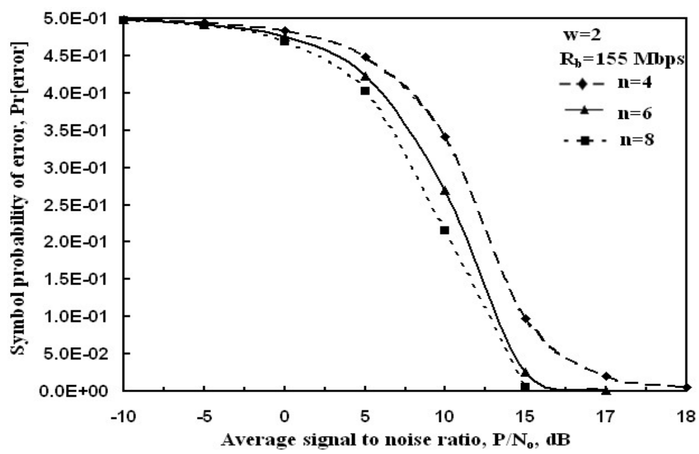

Fig. 3. Symbol probability of error for MPPM (w=2) under signal to noise levels and number of chips per symbol.

By observing Fig. 3, for MPPM at low formed optical pulses (w=2) as signal to noise ratio (P/N_o) increase the symbol probability of error decrease. We need to add for indoor WOC MPPM scheme which utilizes large number of chips per symbol (n) requires less power to achieve same probability of error compared of low number of chips per symbol (n) at the same operating bit rate and optical pulses (w).

Simulation results indicates that to achieve ≈ 10^{-4} symbol error probability at 155Mbps and w=2 for n=8, n=6 and n=4, MPPM scheme requires P/N_o 16.5 dB, 17.6 dB and 19.4 dB respectively. Maximum level of symbol probability of error is approximately equal in all previous cases ≈ 0.498 at P/N_o= -10dB, R_b= 155Mbps and w=2.

Figures 4 presents symbol probability of error for MPPM scheme at w=2 under multi levels of operating bitrates (R_b) and number of chips per symbol (n) with a fixed signal to noise ratio =10dB.

From Fig.4, as operating bit rate increase under fixed P/N_o and w value, MPPM symbol error probability increase. For indoor WOC applications MPPM scheme which utilizes large number of chips per symbol (n) has lower symbol error probability compared with schemes uses small number of chips per symbol (n) for the same R_b, P/N_o and w. In this simulation case study, maximum level of symbol probability of error at R_b= 155Mbps, P/N_o= 10dB and w=2 with n=4, n=6 and n=8 is 0.341, 0.269 and 0.215 respectively.

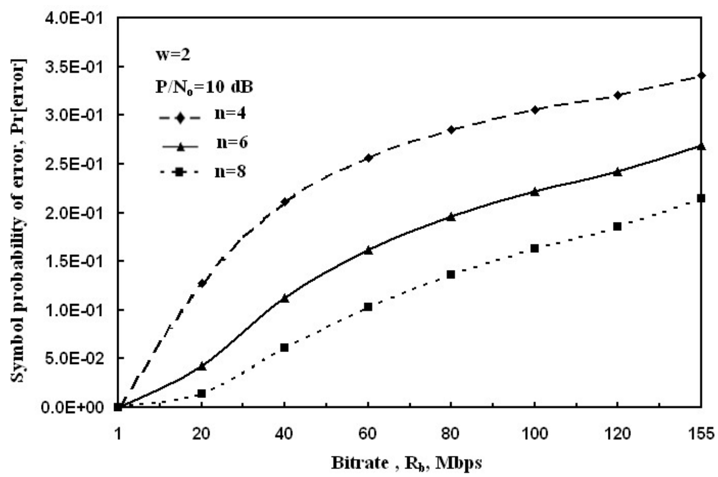

Fig. 4. Symbol probability of error for MPPM (w=2) under operating bitrate and number of chips per symbol.

Previous simulations indicates that, designing MPPM scheme with large number of chips per symbol (n) and low optical pulses (w) achieve low symbol error performance under wider operating bandwidths and reasonable signal to noise ratio P/N_o. As in case of PPM, and with a fair agreement to [7], [8] simulation results (Fig.3) indicates that as (n) increases under fixed (w), power efficiency of MPPM scheme increases. However we believe that these advantages in power and error performance is done with a price on the bandwidth requirement of the scheme. As mentioned in Sec.1 power efficiency, bandwidth efficiency and error performance are keys for evaluating an indoor WOC modulation scheme.

3.2.2 Multiple pulse position modulation with higher formed optical pulses (w≥4)

In this section we continue investigating behaviour of MPPM scheme at the same operating conditions as in previous section except the number of chips forms optical pulse (w) is changed. We will present simulation results at w=4 as a case study.

Also, this section will only present noticeable simulation results for MPPM with (w=4) and leave observations on error performance and comparison between these cases [i.e MPPM (w=4) and MPPM (w=2)] also with PPM to the following section.

Figures 5 presents symbol probability of error for MPPM scheme at high formed optical pulses (w=4) under multi levels of signal to noise ratio (P/N_o) and number of chips per symbol (n).

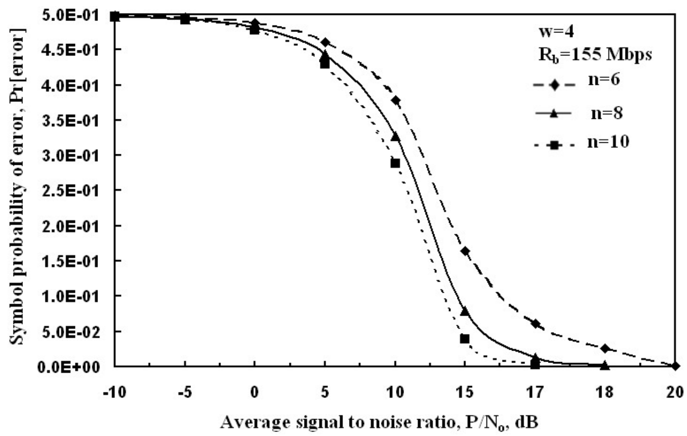

Fig. 5. Symbol probability of error for MPPM (w=4) under signal to noise levels and number of chips per symbol.

Simulation results indicates that to achieve ≈ 10^{-4} symbol error probability at 155Mbps and w=4 for n=10, n=8 and n=6, MPPM scheme requires P/N_o 18 dB, 19 dB and 20 dB respectively. Maximum level of symbol probability of error is approximately equal in all previous cases ≈ 0.498 at P/N_o= -10dB, R_b= 155Mbps and w=4.

Figures 6 presents symbol probability of error for MPPM scheme at w=4 under multi levels of operating bitrate (R_b) and number of chips per symbol (n) with a fixed signal to noise ratio =10dB.

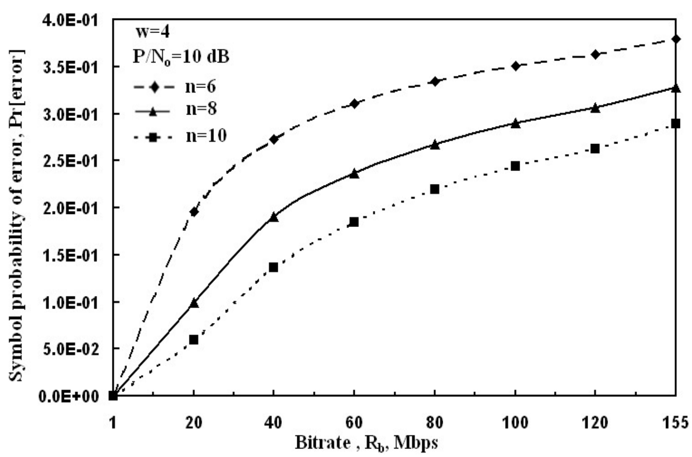

Fig. 6. Symbol probability of error for MPPM (w=4) under operating bitrate and number of chips per symbol.

Based on Fig.6, maximum level of symbol probability of error at R_b= 155Mbps, P/N_o= 10dB and w=4 with n=6, n=8 and n=10 is 0.379, 0.328 and 0.289 respectively.

3.3. Observations on error behaviour and comparison between schemes

This section presents observations and remarks that carried from simulation and help in designing or evaluating a scheme. A comparison between MPPM cases is done followed by a general one between PPM and MPPM.

For MPPM scheme under ideal channel and no ISI condition both cases (ie. w=2 and w=4) share attractive behaviours. First, naturally, as signal to noise ratio increase symbol error probability decrease. Second, MPPM scheme which utilizes large (n) requires less P/N_o to achieve same probability of error compared of low (n) at the same (R_b) and (w). Third, as (R_b) increase under fixed P/N_o and w, MPPM symbol error probability increase. Forth, MPPM scheme which utilizes large (n) has lower symbol error probability compared with schemes uses small (n) for the same R_b, P/N_o and w. Finally, at low P/N_o (ie. -10dB) there is no effect of the value of (n) or (w) on the symbol probability of error and all cases achieve approximately same high error at the same operating bitrate.

On the other hand, levels of such behaviour shows great deviations. By using previous simulation results as indicators, MPPM scheme with low (w) and large (n) (ie. w=2, n=8) achieve same low symbol probability of error ($\approx 10^{-4}$) of that of high (w) and large (n) (ie. w=4, n=8) at lower P/N_o values under same (R_b). This indicates that MPPM scheme with low (w) and large (n) is much power efficient and can be used as a design choice.

Also, MPPM scheme with low (w) and large (n) (ie. w=2, n=8) has lower error than that with high (w) and large (n) (ie. w=4, n=8) at the same R_b, P/N_o. Indicating that designing MPPM with low (w) and large (n) can achieve low error performance at high bitrates with a reasonable P/N_o value.

When comparing MPPM with PPM we observe that later one has two unique characteristics. First, at low P/N_o (ie. -10dB) as symbol length increase maximum error decrease slightly at the same operating bitrate. No effect for any design parameter for MPPM can produce such behaviour at low P/N_o (ie. -10dB). Second, as symbol length increase the range of bit rate (starting from low values) that achieve low symbol error probability increase at fixed P/N_o. No existence of such range in MPPM since all possible design parameters provide a degree of error at low bitrates.

Generally PPM has better error performance than MPPM specially with large (L) at any (R_b). Also results indicates that PPM can achieve same symbol probability of MPPM at the same (R_b) with lower P/N_o specially with large (L) indicating its more power efficient.

3.4. Relation with IrDA and IEEE 802.11 standards

There are presently two standardization bodies supporting worldwide standards for indoor wireless optical communication systems: the IEEE 802.11 group, created in July 1990, and IrDA, created in June 1993. While the focus of the IEEE 802.11 group is on the non-directed indoor optical wireless LANs, IrDA is mainly oriented to short-range low bit-rate line-of-sight systems. However, in recent years, IrDA initiated a new project, called Advanced Infrared (AIr), whose main objective was to establish a new standard for non-directed optical wireless LAN. Both AIr and IEEE 802.11 specifications use the PPM scheme [12]-[14].

From this work, one can understand the reason of using PPM for these standards since its power efficient and has great error performance specially in large symbol lengths. Also this scheme is a basic technique for coded modulation schemes for indoor WOC like convolutional -coded PPM [15] and trellis-coded PPM [16]. However these good behaviours done with a price of high bandwidth requirement as discussed in Sec. 3.1.
This work suggest more detailed study should be done to search for an optimum design parameters than can aquire mostly the operating requirements or combining schemes to try to combine advantages that may be useful for indoor WOC applications.

4. CONCLUSION

This work presents a view for evaluating WOC indoor PPM, MPPM schemes. Numerical results was carried to investigate the error performance of such schemes in ideal no ISI channel. Study is done under wide range of design and operating conditions to provide wider view on the error performance. The main aim is to provide indoor WOC designers with apart of necessary information may help in overcoming difficulties when establishing a WOC indoor network.

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