MULTIPATH DISPERSION IN OPTICAL WIRELESS NETWORKS EMPLOYING DH-PIM

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ABSTRACT

The performance of DH-PIM is analysed in the presence of intersymbol interference. The ceiling bounce model is used to model the non-directed indoor optical wireless channel. The packet transmission rate, channel impulse response, eye diagram and optical power requirements versus normalised delay spread are presented. Results are compared with other modulation schemes. Compared with PPM and DPIM, DH-PIM offers higher transmission rate and requires marginally higher optical power when the severity of the multipath dispersion is low. However, in a severe dispersive wireless environments, it shows better performance compared with its counterparts.

1. INTRODUCTION

Optical wireless networks offer significant advantages over radio systems for indoor high-speed applications. Among these advantages a plentiful unlicensed bandwidth, high data rates and immunity to electromagnetic interference and to multipath fading. Also the optical signal (infrared) doesn't penetrate walls resulting in a secure system and the possibility of using the same spectrum in adjacent rooms [1-4]. In diffuse systems, multipath propagation leads to dispersion, which results in intersymbol interference (ISI). ISI becomes significant for bit rates above 10 Mbps [5], therefore relatively high optical transmit power is required. However, the average optical power emitted by an infrared transceiver is limited by eye safety standards and electrical power consumption in battery-powered devices, therefore, the choice of a modulation scheme which provides a low cost, reliable, high speed and low power consumption wireless connectivity in indoor environments is desirable. Pulse position modulation (PPM) has been widely used for optical wireless applications, which offers very high average power efficiency, and better error performance compared with the digital pulse interval modulation (DPIM) scheme. However, it has lower transmission data rate and requires symbol synchronisation [5-8]. DPIM not only solves the problem of symbol synchronisation by locating a short duration pulse at the start of each symbol but it also improves the transmission data rate compared with PPM [7-8]. To increase data transmission rate further, dual header-pulse interval modulation (DH-PIM) was proposed in 1999. DH-PIM is the modified version of the DPIM. Compared with PPM and PIM, DH-PIM requires less bandwidth and offers higher bit rate and built-in symbol synchronisation [9-10]. The code properties, spectral behaviour and error performance of DH-PIM in dispersion-free environments have been studies and reported in the literature [9-10]. In this paper, we study the packet transmission rate and investigate the effect of multipath dispersion on diffuse wireless DH-PIM signals.

2. TRANSMISSION RATE

The symbol length in DH-PIM scheme is variable, which changes according to the decimal value of the input binary data, therefore from now on we will use the average symbol length in the analysis. A symbol starts with one of two different headers (H_1 & H_2) and followed by a sequence of d empty slots representing the information, see Fig. 1. H_1 and H_2, have the same duration $(\alpha+1)T_s$ and are composed of a pulse of duration $0.5\alpha T_s$ in H_1 and αT_s in H_2, followed by an empty guard band of the remaining duration of the header, where T_s is the slot duration, $\alpha > 0$ is an integer. According to the value of α we will refer to DH-PIM as DH-PIM$_\alpha$. Further details of the DH-PIM symbol structure and performance on non-dispersive channels can be found in [9].

The bandwidth requirement of DH-PIM signal can be defined by:

$$B = 2/\alpha T_s . \quad (1)$$

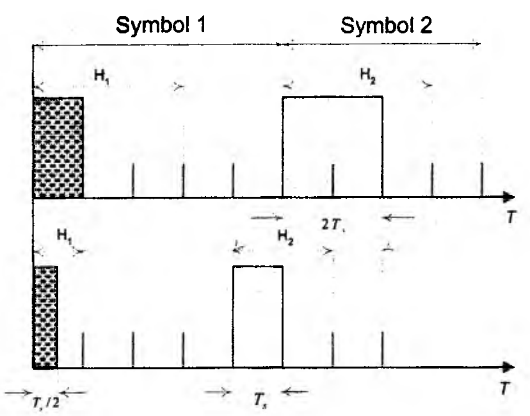

Figure 1. Example of mapping two input symbols (0010 and 1110) into DH-PIM$_2$ (top) and DH-PIM$_1$ (bottom).

and the average symbol lengths of DH-PIM is given by:

$$\overline{L} = (2^{M-1} + 2\alpha + 1)/2, \qquad (2)$$

where, M is the input bit resolution.

In an anisochronous modulation scheme such as DH-PIM where symbols have no fixed length, it is convenient to base the study on a packet of data bits, where the packet contains fixed number of symbols (N / M), where N is the packet length in bits. The symbol transmission rate of DH-PIM signal is given by:

$$R_{symb} = \alpha B / 2\overline{L}. \qquad (3)$$

Therefore the packet transmission rate is given by:

$$R_{spkt} = \alpha MB / N(2^{M-1} + 2\alpha + 1). \qquad (4)$$

Figure 2 displays the packet transmission rate of DH-PIM$_1$, DH-PIM$_2$, DPIM and PPM normalised to that of PPM versus M for a fixed bandwidth of 1MHz. This figure proves that DH-PIM$_2$ offers higher transmission rate than its counterparts especially at high bit resolution (M >= 8) where the improvement is around twice those of DH-PIM$_1$ and DPIM and 4 times that of PPM. This improvement results from the fact that the average symbol length of DH-PIM$_\alpha$ (see equation 2) is about half that of DPIM [$\overline{L}_{DPIM} = (2^M + 1)/2$] and quarter that of PPM ($L = 2^M$). However, DH-PIM$_2$ displays improved performance compared with DH-PIM$_1$ because the bandwidth requirement of DH-PIM$_1$ is twice that required by DH-PIM$_2$, as explained in equation 1.

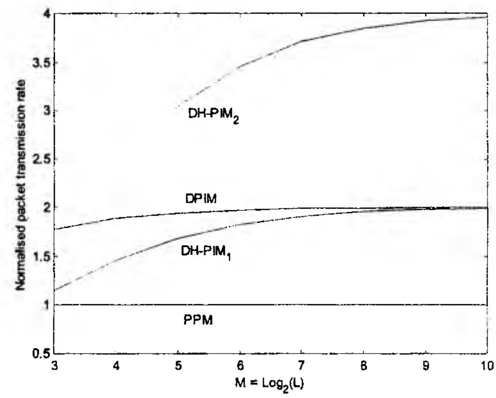

Figure 2. Packet transmission rate of DH-PIM$_1$, DH-PIM$_2$, DPIM and PPM normalised to PPM versus Log$_2$(L) for packet length N = 1Kbyte.

3. PERFORMANCE OF DH-PIM ON WIRELESS DISPERSIVE CHANNELS

3.1. Theoretical study

The multipath channel is modelled as a baseband linear system and is assumed to be a time invariant because the slow movement of people and objects within a room and high bit rates, mean that the channel will vary significantly only on the time scale of many bit periods. We base our study on the ceiling-bounce model [11] where the impulse response of the channel is given by:

$$h(t) = \frac{6\left(12\sqrt{11/13}D_{rms}\right)^6}{\left(t + 12\sqrt{11/13}D_{rms}\right)^7} u(t), \qquad (5)$$

where, $u(t)$ is the unit step function and D_{rms} is the RMS delay spread of the channel. The block diagram of the unequalised DH-PIM system on multipath optical channels used in simulation is shown in Figure 3. The input is composed of random OOK bits, which are assumed to be independent, identically distributed (i.i.d.) and uniform on {0, 1}. Each M-bit input block is encoded into one of L possible DH-PIM symbols according to the decimal value of the input code word, then the DH-PIM symbols are passed to the transmitter filter, which has a unit-amplitude rectangular impulse response $p(t)$ with a duration of one slot T_s.

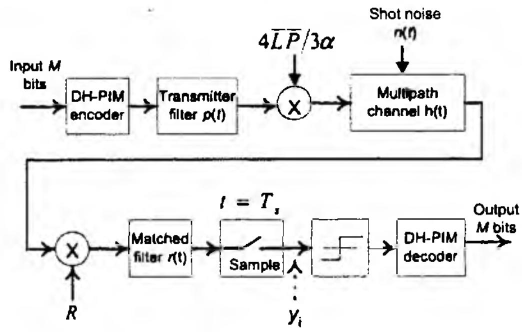

Figure 3. Block diagram of the DH-PIM_1 multipath channel.

The output of the transmitter filter is scaled by the peak transmitted optical signal power $4\overline{L}\overline{P}/3\alpha$, and passed through the multipath channel $h(t)$, where $\overline{P}$ is the average transmitted optical power. White Gaussian noise with a double-sided power spectral density of $\eta/2$ is added to the signal. The received optical signal power is converted into a photocurrent by multiplying it by the photodetector responsivity R and passed to a unit energy matched filter $r(t)$ whose output is sampled at the slot rate $(1 / T_s)$. A threshold detector is employed to produce for every slot a pulse or empty space. The impulse response of the cascaded system (c_t) can be given by [12]:

$$c_t = p(t) \otimes h(t) \otimes r(t), \tag{6}$$

where $\otimes$ denotes convolution. The discrete-time equivalent of c_t is:

$$c_k = c_t \big|_{t=kT_s}. \tag{7}$$

Suppose that c_k contains m taps. Let S_i be an m-slots DH-PIM sequence, and $s_{i,m-1}$ the value of the $(m-1)^{\text{th}}$ slot (penultimate slot) in the sequence S_i, where $s_{i,m-1} \in \{0,1\}$. c_k will contain m taps: a single precursor tap, a zero tap, which has the largest magnitude, and $(m-2)$ postcursor taps. The penultimate slot is the only slot, which is affected only by the dispersion of the signal appearing within the S_i sequence. Therefore, when calculating the optical power requirement, only the penultimate slot will be considered for each sequence. The input to the threshold detector in the absence of noise is given by:

$$y_i = \left(4\overline{L}R\overline{P}/3\alpha\right) S_i \otimes c_k \big|_{k=m}. \tag{8}$$

And the probability of slot error for the penultimate slot of sequence S_i is given by:

$$P_{se,i} = \begin{cases} Q\left(\dfrac{\rho}{\sqrt{\eta/2}}\right) & ;\ \text{if } s_{i,m-1} = 0 \\ Q\left(\dfrac{\sqrt{E_{p,i}} - \rho}{\sqrt{\eta/2}}\right) & ;\ \text{if } s_{i,m-1} = 1 \end{cases} \tag{9}$$

where, ρ is the optimum threshold level given as:

$$\rho = y_i \sqrt{T_s}/2. \tag{10}$$

We generate all possible sequences of length m and ignore the sequences which contains invalid DH-PIM sequences. $P_{se,i}$ is multiplied for each sequence by the probability of occurrence of that sequence $P_{occ,i}$, then results of multiplication for all sequences are summed up to obtain the average probability of slot error:

$$P_{se} = \sum_{\text{all } i} P_{occ,i} P_{se,i}. \tag{11}$$

Observing that a packet o slots is in error if one or more slots are in error, the corresponding packet error rate is given by:

$$P_{pe} = 1 - \left(1 - P_{se}\right)^{NL/M}. \tag{12}$$

The optical power requirement P_{req}, is calculated for a given value of D_{rms} as the $\overline{P}$ in equation 8 which results in $P_{pe} = 10^{-6}$ in equation 12.

The optical power penalty $P_{penalty}$ is the difference between the optical power required on dispersive channels P_{req} and the optical power required on ideal channels $P_{req,ideal}$ for a given value of D_{rm}:

$$P_{penalty} = P_{req} - P_{req,ideal}. \tag{13}$$

3.2. Results

Results are obtained assuming no optical path loss and DH-PIM_2 with a hard-decision detector is employed. The normalised delay spread (*NDS*) is the D_{rms} divided by the bit duration (T_b).

Table 1 shows the parameters used for calculation.

Table 1. Calculations parameters

Parameter	Value
Detector responsivity (R)	1
Bit rate (R_b)	1 Mbps
Packet length (N)	1 Kbyte
L	32 slots
Normalised delay spread (*NDS*)	0.001 – 0.5
m	9 slots

The impulse response of the cascaded system (c_t) given in equation 6, versus T_s is shown in figure 4.

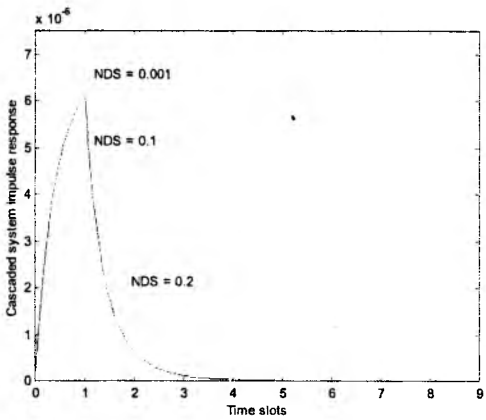

Figure 4. The system multipath channel impulse response versus T_s for *NDS* = 0.001, 0.1 & 0.2 and L = 32.

From figure 4 we can see that as the severity of multipath dispersion increases, c_t spreads over more slots and the amplitude of the zero tap (slot 1) decreases. This is best understood by looking at figures 5 & 6 where the eye diagram of the DH-PIM$_2$ transmission system versus T_s for *NDS* = 0.001 and *NDS* = 0.1 are shown. The eye is completely open in figure 5 because the delay spread is very low and channel is very close to ideal channels. However in figure 6, where *NDS* = 0.001, the eye starts to close and the severity of multipath dispersion is clear.

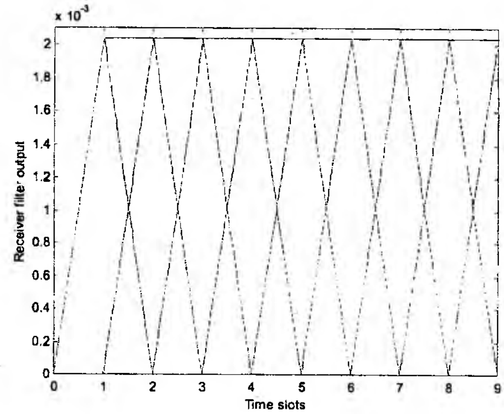

Figure 5. The eye diagram of the DH-PIM$_2$ transmission system for *NDS* = 0.001 and L = 32.

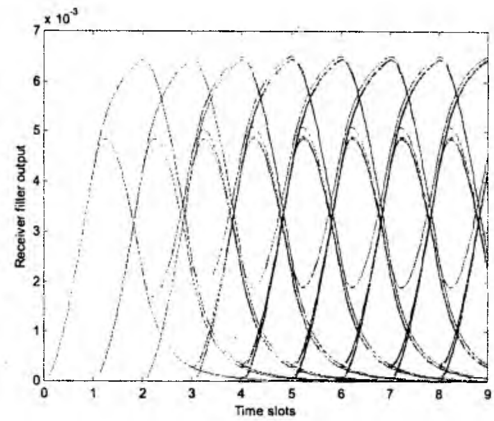

Figure 6. The eye diagram of the DH-PIM$_2$ transmission system for *NDS* = 0.1 and L = 32.

The optical power requirements, normalised to ideal OOK-NRZ, of DH-PIM$_2$, DPIM with no guard slot, and PPM with threshold detection versus *NDS* for L = 32 are shown in figure 7. At low values of *NDS*, DH-PIM$_2$ requires ~ 2.9 dB and 4.2 dB higher optical power compared with DPIM and PPM, respectively. As the delay spread increases to values higher than 0.1, the power requirement for DPIM and PPM increases much more rapidly than DH-PIM$_2$ and at *NDS* = 0.1, DH-PIM$_2$ requires ~ 0.4 dB and 2.5 dB less optical power compared with DPIM and PPM, respectively.

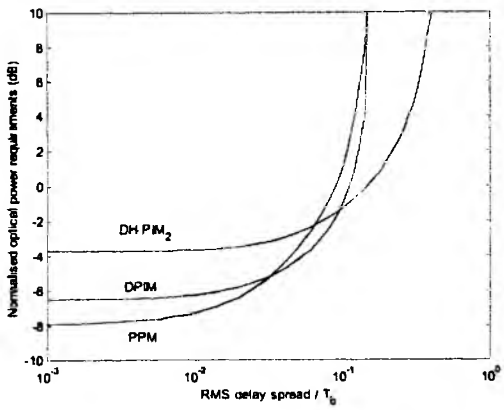

Figure 7. The optical power requirements of DH-PIM$_2$, DPIM and PPM versus *NDS* for $L = 32$.

4. CONCLUSIONS

The effect of multipath dispersion on DH-PIM is analysed using the ceiling bounce model. The channel impulse response, eye diagram and optical power requirements versus normalised delay spread are shown. Compared with PPM and DPIM, DH-PIM offers higher packet transmission rate, but requires marginally higher optical power at low *NDS*. However, as *NDS* increases above 0.1, DH-PIM2 starts showing better performance compared with its counterparts.

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