A Review of Various Modulation Techniques for Indoor Optical Wireless Communication System

Ankita Aggarwal and Dr. Gurmeet Kaur

Background: There are different tweak strategies utilized as a part of Indoor Optical Wireless Communications, for example, OOK, PPM, DPPM, DAPPM, DPIM, and some all the more, each with its own particular elements and difficulties. Objective: In this paper, a brief portrayal of ordinary regulation methods for Optical wireless communications is talked about. Results: OOK (On-Off Keying) and PPM (Pulse Position Modulation) are favored for high power effectiveness. Pulse interval modulation (PIM) procedures are utilized presumed for its intrinsic synchronization pulse. Trellis coded PPM (TC_PPM) enhances the execution of the PPM on multipath channels. Subcarrier balance offers expanded throughput, and pulse position regulation (PPM) gives the unparalleled force productivity in observable pathway i.e. Line of sight (LOS) joins. Multiple PPM (MPPM) minimizes the impact of multipath scattering. Conclusion: DPPM, DPIM and DH-PIM are the substitutes of PPM due to their better execution in force proficiency and transfer speed productivity. Tremendous work has been now accomplished for some more adjustment systems with various conditions.

INTRODUCTION

Wireless Communication technology is developing very fast day by day. In Optical Wireless Communication (OWC) system, line of sight transmission in done to convey information on the band beyond the RF band, where the usage of the spectrum needs no license and the available bandwidth is much larger than the RF band. OWC provides extremely high data transmission rates, and becomes an important complement to RF wireless solutions (Meng Yu, 2008). Aside from point to point communication systems, wireless networks are becoming ubiquitous. And to achieve better performance, wireless networks demand more flexible system infrastructure. It is a technology which using light propagating in free space to send information and so also called as free space optical (FSO) communication. Optical Wireless Communication has many advantages such as it is quickly-deployable, support high data rates, cost effective and provides security over RF wireless or wired communication. On the other side, Optical wireless communication has many disadvantages (Hu Zm, Tang Jx, 2005), which include atmospheric absorption, scattering, scintillation.

Applications range from short range wireless system provides network access to portable computers. Expansion of network bandwidth resources and improvement of communication flows has become an important issue. So, selecting a modulation technique is one of the key technical decisions in the design of any communication system.

The primary attention in this work is indoor Optical wireless modulation techniques. They are equally applicable in both optical fiber and free space optical communication links.
I. Various Modulation/Signaling Schemes for Optical Wireless Communications:

In these modulation schemes, the data has not been translated to a much higher carrier frequency prior to intensity modulation of the optical source, so a significant portion of the signal power is restricted to the DC region.

i) ON-OFF Keying (OOK):

OOK is a most simplest modulation technique for IM/DD in Optical wireless Communication. In this technique, one bit is simply represented by an optical pulse that occupies the entire or part of the bit duration while a bit zero is represented by the absence of an optical pulse. For an additive Gaussian noise (AWGN) limited infrared communication channel, the optimum receiver for an OOK signaling is the match filter followed by a threshold detector set at midway between the zero bit and one bit energies. In diffuse optical links, multipath induced dispersion limits the achievable data rate. The maximum like-hood sequence detector should be adapted to perform optimally in multipath channel for OOK. The implementation of which is not practical because of its complexity and the prohibitive processing time. A sub-optimal but practical approach would be to use an equalizer. Various other equalization techniques have been proposed for OOK scheme and their detailed analysis are available in (Kahn, J.M., J.R. Barry, 1997; Hayasaka, N., T. Ito, 2007; Carruthers, J.B., J.M. Kahn, 1997; Rui Hou, et al., 2015).

ii) Pulse Position Modulation (PPM):

PPM is an orthogonal baseband modulation technique, used in optical communication. It is well suited for handheld devices, where lower power consumption is the key factors. PPM technique with L possible time slots, L-PPM symbol consists of a single pulse of one slot duration within with the remaining slots being empty. The position of the pulse corresponds to the decimal value of the M-bit input data. In order to achieve the same throughput, PPM pulse duration is shorter than the OOK pulse duration by a factor L/M. And, superior power efficiency is achieved at the cost of increased bandwidth requirement.

PPM schemes with L=2 would be a desirable option, because most of the indoor optical channels are power limited rather than bandwidth limited. Another key advantage of a PPM is that it provides improved immunity to the noise induced by fluorescent lamps, because it has a much lower DC component compared with OOK (Kahn, J.M., J.R. Barry, 1997). The limiting factors of the performance of PPM schemes are symbol and slot synchronization as well as the multipath induced ISI. Because of the presence of the L-1 empty slots in diffuse infrared communication links, the incurred power penalty due to the ISI is lower than that of the OOK. A decision feedback equalizer and a linear equalizer have both reportedly applied in (Hayasaka, N., T. Ito, 2007; Carruthers, J.B., J.M. Kahn, 1997; Rui Hou, et al., 2015; Wong, K.K., et al., 2000) to mitigate the induced ISI in diffused links. Most recently a neural network has been applied as an equalizer to reduce the effects of ISI.

iii) Differential Pulse Position Modulation (DPPM):

DPPM is the improved version of PPM and provide improved power efficiency, bandwidth efficiency and throughput by removing all the empty slots that follow a pulse in a PPM symbol (Shiu, D. and J.M. Kahn, 1999; Sethakaset, U., T.A. Gulliver, 2006). Hence the length of DPPM symbol varies from $T_s$ to $LT_s$ time slots. In DPPM, the average number of slots per symbol is almost half that of PPM i.e. $L_{DPM} = (L + 1)/2$ which provides possibility in improving data throughput or bandwidth efficiency (Ghassemlooy, Z., et al., 2003). With every DPPM symbol ending with a pulse, there exists an inherent symbol synchronization capability, in fact, all the baseband modulation schemes described hereafter have a built in symbol synchronization capability. The variable symbol length nature of the DPPM can pose real challenges in applying error detection and correction.

iv) Differential Amplitude Pulse Position Modulation (DAPPM):

This scheme has advantages over other schemes like PPM and DPPM in terms of bandwidth requirements, capacity, and peak to peak power ratio (Sethakaset, U., T.A. Gulliver, 2005). The DAPPM is a combination of DPPM and PAM. The symbol length varies from 1 to L and the pulse amplitude is selected from 1 to A, where L and A are integers. The average number of empty slots preceding the pulse can be lowered by increasing the number of amplitude levels A thereby increasing the achievable throughput in the process. When compared with similar modulation techniques, a well designed DAPPM will require the least bandwidth. DAPPM suffers from a high average power and a large DC component, thus restricting its use to applications where power is not a premium. It is also susceptible to the baseline wandering due to its large DC component (Sethakaset, U., T.A. Gulliver, 2005 Hayes, A.R., et al., 2002).

v) Digital Pulse Interval Modulation (DPIM):

In DPIM, each block of log2 L is mapped to one of L possible symbols, each different in length. Every symbol begins with a pulse, followed by a series of empty slots, the number of which is dependent on the decimal value of the block of data bits being encoded. DPIM symbols are the mirror image of DPPM symbols,
so they require the same bandwidth and average power. The slot error rate and spectral properties of DPPM are also valid for the DPIM. To reduce the channels induced inter symbol interference, the use of one or more guard band immediately after the pulse has been introduced by (Ghassemlooy, Z., et al., 2003). But for a highly dispersive channel, to achieve an acceptable error performance one would still require an equalizer at the receiver.

vi) Dual Header Pulse Position Modulation (DH-PIM):

In this method, a symbol can have one of two predefined header depending on the input information. The \( n_h \) symbol \( S_h \) of a DH-PIM sequence is composed of a header \( h_0 \) which indicates the symbol and information slots \( d_0 \). Depending on the MSB of input code word, two different headers are considered \( H_0 \) and \( H_1 \). \( H_0 \) and \( H_1 \) have equal duration of \( T_h = (\alpha + 1)T_s \), where \( \alpha > 0 \) is an integer and \( T_s \) is the slot duration. For \( H_0 \) and \( H_1 \) the pulse duration is \( \alpha T_s / 2 \) and \( \alpha T_s \). A guard band with a duration of \( T_g \in (0.5\alpha + 1)T_s \) corresponding to \( h_0 \in \{H_0,H_1\} \) provides symbols representing zero. The information section is composed of \( d_0 \) empty slots. The value of \( d_0 \in \{0,1,\ldots,2^{M-1}-1\} \) is simply the decimal value of the binary input if MSB is 0 else it is equal to the decimal value of the 1’s complement of the input data word when the symbol starts with \( H_1 \). The header pulse has the dual functions of symbol initiation and time reference for the preceding and succeeding symbol resulting in built-in symbol synchronization (Aldibbiat, N.M., 2001).

Since the average symbol length can be reduced by a proper selection of \( \alpha \), DH-PIM can offer shorter symbol lengths, improved transmission rate and bandwidth requirements compared with the DPIM, DPPIM and PPM. Theoretically, it is possible to use a larger value of \( \alpha \), however, this option increases the average symbol length unnecessarily thus resulting in reduced data throughput.

vii) Multilevel Digital Pulse Interval Modulation (MDPIM):

It emanated from the concept of DH-PIM combined with PAM where the two headers differ in amplitude level as against duration in the case of DH-PIM. Here, each block of \( M \)-bit input OOK data is mapped to one of \( L = 2^M \) possible symbols. Each symbol starts with a pulse of amplitude \( A \) or \( 2A \) followed by a guard slot and information slot of length 1 to \( L/2 \) (Ghassemlooy, Z., N.M. Aldibbiat, 2006). The information slot length is equal to the decimal value of the binary input if MSB is 0 else it is equal to the decimal value of the 1’s compliment of the binary input (Ghassemlooy, Z., N.M. Aldibbiat, 2006). MDPIM not only removes the redundant slots that follow the pulse as in PPM, but also reduces the symbol length compared with the DPIM and DH-PIM, resulting in increased data throughput. The minimum, maximum and the average symbol length of MDPIM are \( L_{\text{min}} = 2 \), \( L_{\text{max}} = 2^M-1 \), and \( L = (2^M+3)/2 \), and the slot duration \( T_s = 2M/(2^M+3)R_b \).

viii) Subcarrier Intensity Modulation:

Optical subcarrier modulation operates by combining one or more RF carriers and using the composite RF signal to modulate the intensity of an optical source. The data stream is pre modulated on the subcarrier frequencies using evolved modulation schemes such as PSK and QAM (Rongqing, H., et al., 2002). At the receiver, a direct detection is employed followed by a standard RF demodulator to extract the data.

SIM can also be implemented with the subcarrier signals made orthogonal to one another to achieve orthogonal frequency division multiplexing (OFDM). This is particularly interesting as it can be easily implemented via IFFT/FFT in available signal processing chips. By ensuring the each subcarrier transmits at relatively low data rates, the need for an equalizer can be avoided while maintaining the same aggregate data rate. It also offers a greater immunity to near DC noise from the fluorescent lamps. However, with a DC offset, multiple SIM results in a \( 10\log N \) (dB) increase in optical power requirement compared with a single subcarrier. Also, multiple SIM suffers from both inter modulation and harmonic distortions due to the inherent optical source non-linearity.

ix) Pulse Interval Modulation (PIM):

PIM increases the system’s transmission capacity by truncating unused slots from each symbol and doesn’t require any synchronization as every symbol starts with a header pulse. A more recent scheme, PIM-Dual Header (PIM-DH), further reduces the bandwidth requirement, (Aldibbiat, N.M., 2001). In PIM-DH one variable width header precedes the bit sequence depending on the most significant bit (MSB). Hence, when \( \text{MSB}=0 \), this header will have some specific duration pulse followed by the input sequence and when \( \text{MSB}=1 \), the header will have a wider duration pulse and the 2’s compliment of the data sequence. As with PIM, one guard slot will take care of zero length frames. PIM-DH is more bandwidth efficient than PIM because of the reduction in average frame length.

x) Trellis Coded PPM (TC-PPM):

TC-PPM improves the performance of the PPM on multipath channels by maximizing the minimum
Euclidean distance between signal sequences (You, R., J.M. Kahn, 2001). Usually the distance between any two symbols is the same in PPM as it is an orthogonal scheme; but multipath distortions make the distances unequal. As delay spread increases, trellis codes exploit the differences in symbol distance and improve the system performance.

**xi) Differential PPM (DPPM):**

In DPPM, each symbol is deleted after the high pulse. Hence, no synchronization is needed. DPPM gives improved power and bandwidth efficiency for low bit rate or directed LOS links (Rongqing, H., et al., 2002). Because of unequal symbol duration, it has non-uniform throughput and prior to detection, symbol boundaries are unknown. Hence MLSD is needed for the optimal soft detection of DPPM.

**xii) Multiple PPM (MPPM):**

In MPPM (You, R., J.M. Kahn, 2001), the total symbol duration \( T \) is divided into \( n \) parts each of duration \( T/n \). Only \( w \) numbers of chips are transmitted during one transmission. Hence, bandwidth of MPPM gets reduced approximately a factor of \( n \) as compared to that of PPM. For \( n=L \), hamming distance \( d=2 \) and \( w=1 \), this scheme will become L-PPM.

**xiii) Overlapping PPM (OPPM):**

In OPPM (You, R., J.M. Kahn, 2001), some constraint \( w \), is imposed on the number of consecutive ones in any symbol duration \( T \). MPPM requires \( L = \alpha \) number of chips. In case of OPPM, because of the constraint \( w \), \( L \) gets reduced to \( n-w+1 \). Hence pulses are partially overlapped. This results in reduction in the bandwidth. This scheme can also be looked as a special case of MPPM in which the pulsed slots are spread over the interval \( T \). For \( w=1 \), \( n=L \) this scheme will become PPM.

**xiv) Trellis Coded OPPM (TC-OPPM):**

If a convolutional code is used to reduce BER, there will generally be a definite increase in the required bandwidth. But Trellis Coded Modulation (TCM) improves performance without increasing bandwidth. In no multipath case TCM will offer no advantage. But for OPPM, trellis coding is advantageous because it has a fixed, low duty cycle (You, R., J.M. Kahn, 2001). The duty cycle, \( D \) in this case will be \( w/n \) and it increases the number of chips in any symbol duration to \( (2L-1)/(1-D) \) which reduces the minimum distance between two symbols. But due to high coding gain BER is maintained.

**Conclusion:**

Various modulation techniques for indoor optical wireless communication channel have been discussed here in this paper. The modulation techniques presented here are in terms of power efficiency, bandwidth, and error performance. The selection of a particular modulation technique depends greatly on the intended application and channel configuration. The comparison for the few of above mentioned techniques in terms of Optical power and bandwidth requirement are given in table 1.

### Table 1: Comparison of Normalized power and bandwidth requirement for different modulation techniques

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Modulation Technique</th>
<th>Normalized Optical power requirement</th>
<th>Bandwidth requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OOK(NRZ)</td>
<td>0</td>
<td>1/D</td>
</tr>
<tr>
<td>2</td>
<td>PPM(soft)</td>
<td>(-5 \log_{10} \left( \frac{L \log_{2} L}{4} \right))</td>
<td>( \frac{L}{\log_{2} L} )</td>
</tr>
<tr>
<td>3</td>
<td>PPM(hard)</td>
<td>(-5 \log_{10} \left( \frac{L \log_{2} L}{4} \right))</td>
<td>( \frac{L}{\log_{2} L} )</td>
</tr>
<tr>
<td>4</td>
<td>DPPM</td>
<td>(-5 \log_{10} \left( \frac{L \log_{2} L}{4} \right))</td>
<td>( \frac{L+1}{2 \log_{2} L} )</td>
</tr>
<tr>
<td>5</td>
<td>MPPM</td>
<td>( \frac{2w}{n + d \log_{2}(n-w+1)} )</td>
<td>( \frac{n}{\log_{2} L} )</td>
</tr>
<tr>
<td>6</td>
<td>OPPM</td>
<td>( \frac{2w}{\sqrt{2n \log_{2}(n-w+1)}} )</td>
<td>( \frac{n+1}{\log_{2}(n-w+1)} )</td>
</tr>
<tr>
<td>7</td>
<td>TC-OPPM</td>
<td>( \frac{4(2L-1)d^2}{d \log_{2} L} )</td>
<td>( \frac{n}{\log_{2} L} )</td>
</tr>
</tbody>
</table>

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