Multi Header Interval Pulse Position Modulation for Visible Light Communication

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Abstract— **In this paper, a variant of pulse position modulation namely Multi Header Interval Pulse Position Modulation (MHI-PPM) is proposed for Visible Light Communication (VLC) system. A frame of this modulation scheme utilizes multiple header which always starts with a low pulse. The number of time slots of low pulse in header determines the header pattern which serves the purpose of synchronization and decoding of the frame. It is demonstrated that the proposed scheme provides dimming support which can be controlled by the number of input bits. The proposed scheme also has inherent flicker mitigation capability as it has short run length property which helps to keep fluctuations due to probabilistic dimming level under MFTP. The performance of MHI-PPM with various modulation schemes like PPM, DPIM, DH-PIM, MH-PIM and Unary code in terms of transmission rate and slot error rate for different values of source bit are reported in this paper. From results it is clear that the proposed scheme has best error performance compared to all other schemes and can also be considered as an alternative dimming scheme.**

Keywords— **PPM, MPPM, DPIM, DHPIM, MHPIM, VLC**

I. INTRODUCTION

Visible light communication (VLC) has emerged as a novel technology for indoor short-range wireless communication technology. With the large-scale deployment of LED as major energy saving lighting source this technology provides illumination as well as communication service [1]-[3]. VLC uses intensity modulation with direct detection (IM/DD) to transmit data, where the information signal or its modulated version directly modulates the intensity of the optical carrier.

Various pulse modulation techniques like On Off Keying (OOK), Pulse Width Modulation (PWM), Pulse Position Modulation (PPM), Interval Pulse Position Modulation (I-PPM), variable PPM (VPPM) and Overlapping-PPM (OPPM) are proposed [4]- [6] for IM/DD technique in VLC. Among these schemes VPPM is introduced in IEEE 802.15.7 and are also proposed for dimming control [7]- [8]. Since, OOK has signals with long duration of 1's and 0's it possesses flickering problem. Compared to OOK, PPM and its variants like VPPM, OPPM and Multi-PPM (MPPM) are beneficial for dimming control.

There are other PPM derivative methods which utilizes the concept of interval modulation like Dual Pulse Interval Modulation (DPIM), Dual-Header PIM (DH-PIM) and Multi Header-PIM (MH-PIM) [9]- [11]. Though these schemes are bandwidth efficient and uses less time slots compared to other schemes but number of time slots in these schemes are not fixed. In [12] a Unary coded method is presented which improves the dimming control of OOK. Unary coded scheme has a very simple coding method but like DPIM, DH-PIM and MH-PIM it too doesn't have fixed length and it also lacks synchronization compared to DPIM, DH-PIM and MH-PIM. Unary coded scheme achieves an average dimming level of 78% for 8 level Unary code or 3-bit OOK symbol. But, with the increase in number of M-bit OOK symbol the cardinality also increases given by 2^M.

In this paper, a Multi Header Interval-Pulse Position Modulation is proposed which has two parts- header and message part. It utilizes the concept of multiple header but not similar as in [11] to synchronize frame followed by data part which utilizes conventional PPM to transmit data. The header in the proposed method starts with a low pulse and number of time slots of low pulse determines which header is used. The proposed method has a fixed number of time slots in a frame compared to DPIM, DH-PIM, MH-PIM and Unary code and ensures continuous data transmission to be realized.

The rest of the paper is organized as follows. Section II explains the frame format of the MHI-PPM and its symbol structure. Section IIIanalyzes the dimming capability and flicker mitigation property of the scheme; Section IV shows the theoretical analysis and section V shows simulation results. Finally, section VI concludes the paper.

II. MHI-PPM FRAME AND SYMBOL STRUCTURE

In PPM information is transmitted through the position of pulse in the frame. For an M-bit input OOK symbol there are$n_{PPM} = 2^M$ time slots in a PPM frame and only one pulse which has one-to-one correspondence between the position of the pulse in the frame and an M-bit input OOK symbol. At thetransmitter of the proposed system, an M-bit OOK symbol is mapped into MHI-PPM symbol which starts with a header followed by data. In nth MHI-PPM frame structure as shown in Fig. 1, an OOK symbol of T duration is partitioned into $n_{MHI-PPM}$ slots, each of $T_S$duration.

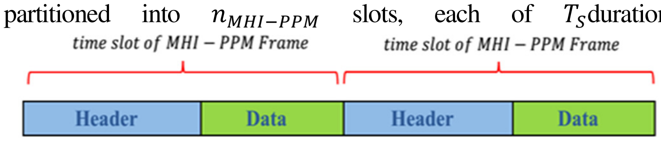


Fig. 1 Frame format of MHI-PPM

MHI-PPM frame has two parts- header and data. The selection and representation of header and data in MHI-PPM of any M input bits can be explained as follows:

i. For any M input bits given by $[b_M, \ldots . b_3, b_2, b_1]$, the data part of MHI-PPM is a PPM frame which depends on the decimal equivalent of $[b_2, b_1]$. Thus, data part of MHI-PPM always has 4 time slots.
ii. Now, MHI-PPM has multiple headers and the header selection depends on the following parameters-
    a. If number of input bits $M = 3$, then number of headers used is 2.
    b. If number of input bits $M > 3$, then number of headers required is calculated using-

$$i = \frac{2^M}{4} \qquad (1)$$

iii. Depending on the number of headers required, multiple headers can be mappedas per the input frame. Now, number of bits in a header is given by $(i + 1)$ bits, where, i is defined by eq. (1). Thus, for example mapping and selection of headers forM=4 bits, it is seen thatnumber of headers required for M= 4bits as per eq. (1) is i=4 and number of bits in a header is $(i + 1)$ bits, i.e., 5 bits.
iv. Since, number of headers required and number of bits in a header frame is calculated, now the different header H_i can be defined from the decimal weight of $[b_M, \ldots . b_3]$ for any M bit input. Here, an example of 4 bit input is considered and mapping of header for different decimal weight of $[b_4, b_3]$ is explained.
    a. If decimal weight of $[b_4, b_3]$ is '0' then the 5-time slots of header are represented by four '0' and one '1'. Thus, making header H_1 as '00001'.
    b. If decimal weight of $[b_4, b_3]$ is '1' then the 5-time slots of header are represented by three '0' and two '1'. Thus, making header H_2 as '00011'.
    c. If decimal weight of $[b_4, b_3]$ is '2' then the 5-time slots of header are represented by two '0' and three '1'. Thus, making header H_3 as '00111'.
    d. If decimal weight of $[b_4, b_3]$ is '3' then the 5-time slots of header are represented by one '0' and four '1'. Thus, making header H_4 as '01111'.

Thus, it is seen that headers have different interval spaces which helps torecognize the beginning and end of a frame correctly at the time of demodulation and also helps in synchronization. The symbol structure of MHI-PPM for four different OOK symbol with respective headers is shown in Fig. 2. As an example, the mapping of all possible combinations of 4-bit OOK symbol to MHI-PPM frame is shown in Table 1.

Comparing MHI-PPM with PPM it is seen that MHI-PPM removes the redundant time slots effectively and reduce the length of the frame considerably. Also, MHI-PPM has fixed frame length and has the ability to mitigate flicker problems which is discussed in section III.

The rate of information transmission can be determined from the average amount of source data that can be transmitted per time slot. MHI-PPM requires $n_{MHI-PPM} = [(i + 1) + 4] = (i + 5)$ slotsto transmit M-bit source data and thus its transmission information rate is given as:

$$\gamma_{MHI-PPM} = \frac{M}{[i+5]} \qquad (2)$$

Substituting eq. (1) in eq. (2),

$$\gamma_{MHI-PPM} = \frac{M}{[\frac{2^M}{4}+5]} \quad (3)$$

The performance of MHI-PPM varies with different values of M and information transmission rate given by eq. (3) is used to compare the information transmission rate performance of the system. The performance of MHI-PPM for different values of M is calculated and compared with PPM, DPIM, DH-PIM, MH-PIM and Unary code. The correspondence between M and γ is presented in Table 2 and it is observed that γ decreases with the increase of M for all modulation schemes.

Comparing with PPM, DPIM, DH-PIM and MH-PIM it is found that MHI-PPM has better performance than PPM and DPIM and $\gamma_{MHI-PPM}$ is almost doubled the γ_{PPM} for the value of M>4.

It is also seen that DH-PIM outperforms PPM, DPIM, MH-PIM and MHI-PPM in terms of transmission rate and bandwidth efficiency. DH-PIM has highest transmission rate, γ_{DH-PIM} when M=3 but its performance degrades faster when M increases and matches transmission rate of MHI-PPM for M=8. For Unary code, it is seen that $\gamma_{unary\ code}$ degrades very fast with increase in the value of M and is almost similar to γ_{DPIM} for M>5. Comparing Unary code with MHI-PPM it can be seen that Unary code doesn't sustain a stable transmission rate and has best performance for M=3 only.Though γ decreases with increase of M for MH-PIM and MHI-PPM but both of them maintains stable transmission rate reasonably.

Table 2: Comparison of PPM, DPIM, DH-PIM, MH-PIM and MHI-PPM based on γ

Sl. No.	M	3	4	5	6	7	8
1	γ_{PPM}	0.375	0.25	0.156	0.094	0.055	0.031
2	γ_{DPIM}	0.545	0.421	0.286	0.179	0.107	0.062
3	γ_{DH-PIM}	0.857	0.727	0.526	0.342	0.209	0.122
4	γ_{MH-PIM}	0.563	0.615	0.613	0.571	0.507	0.432
5	$\gamma_{unary\ code}$	0.667	0.47	0.303	0.185	0.108	0.062
6	$\gamma_{MHI-PPM}$	0.428	0.444	0.384	0.285	0.189	0.115

III. Dimming analysis of MHI-PPM and flicker mitigation

In the proposed scheme it is seen that multiple headers are used and thus depending on the type of header used the dimming level of a particular frame can vary. Hence, MHI-PPM can support different dimming levels for different MHI-PPM frame when number if bits in input is fixed. The dimming level in a single MHI-PPM frame is dependent on the header used and number of input data bits, M.

Hence, the resultant average dimming level for any M-bit input data can be calculated using eq. (4).

$$d = \frac{\sum_{j=1}^{i}(j+1)/i}{(i+5)} \quad (4)$$

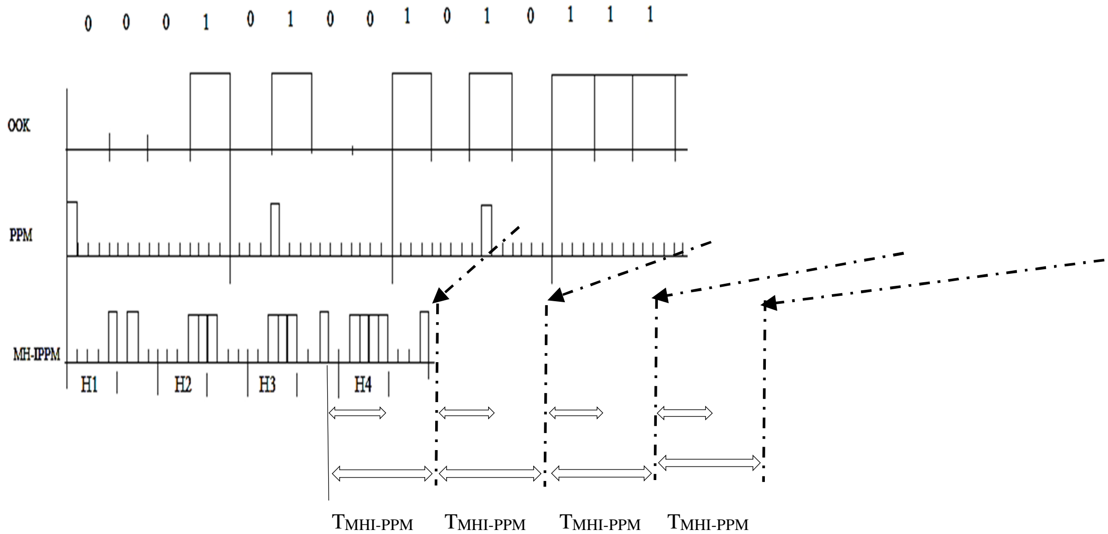


Fig. 2. Symbol structure of MHI-PPM for four different OOK Symbol

Table 1: Mapping of OOK into PPM, 16-DPIM, 16 DH-PIM, MH-PIM, MHI-PPM

Sl. No.	OOK	PPM	16-DPIM	16-DH-PIM	MH-PIM	MHI-PPM
1	0000	1000000000000000	10	100	10000	00001_1000
2	0001	0100000000000000	100	1000	100000	00001_0100
3	0010	0010000000000000	1000	10000	1000000	00001_0010
4	0011	0001000000000000	10000	100000	10000000	00001_0001
5	0100	0000100000000000	100000	1000000	11000000	00011_1000
6	0101	0000010000000000	1000000	10000000	1100000	00011_0100
7	0110	0000001000000000	10000000	100000000	110000	00011_0010
8	0111	0000000100000000	100000000	1000000000	11000	00011_0001
9	1000	0000000010000000	1000000000	1100000000	11100	00111_1000
10	1001	0000000001000000	10000000000	110000000	111000	00111_0100
11	1010	0000000000100000	100000000000	11000000	1110000	00111_0010
12	1011	0000000000010000	1000000000000	1100000	11100000	00111_0001
13	1100	0000000000001000	10000000000000	110000	11110000	01111_1000
14	1101	0000000000000100	100000000000000	11000	1111000	01111_0100
15	1110	0000000000000010	1000000000000000	1100	111100	01111_0010
16	1111	0000000000000001	10000000000000000	110	11110	01111_0001

Where, $i = \frac{2^M}{4}$, as given in eq. (1) and j is number of bits in i^{th} header frame.

As an example, considering an M=4 bit input data, the achievable average dimming level is $d = \frac{\sum_{j=1}^{4}(j+1)/4}{(4+5)} = 0.388$.

The achievable dimming level can be controlled by varying the M-input bit data. Table 3 shows the average achievable dimming level and transmission rate for different values of M for the proposed MHI-PPM scheme.

Table 3: MHI-PPM dimming control scheme for different values of M and its corresponding transmission rate

Sl. No.	M	$n_{MHI-PPM}$	$d_{MHI-PPM}$	$\gamma_{MHI-PPM}$
1	3	7	0.357	0.428
2	4	9	0.388	0.444
3	5	13	0.423	0.384
4	6	21	0.452	0.285
5	7	39	0.475	0.189
6	8	64	0.485	0.115

It is relevant to mention here that MHI-PPM maintains probabilistic dimming level and may deviate from the desired dimming target value. However, until and unless these fluctuations exceed the persistence of human eye and causes noticeable change in brightness, i.e. flicker. MHI-PPM dimming can be considered for dimming if the fluctuations are maintained within Maximum Flickering Time Period (MFTP), which is around 5ms [13]. To evaluate the impact of these fluctuations 1000 4-bit OOK symbol is considered, i.e. total input bit N=4000 bits. Here, each OOK symbol is mapped into MHI-PPM frame with different headers. In this experiment, an equiprobable header mapped MHI-PPM scenario is considered, i.e., there are 1000 MHI-PPM frame each with headerH_1, H_2, H_3 and H_4 respectively. From Table 1, it is seen that in a MHI-PPM frame with header H_1, the maximum run length of 1's is 2 and 0's is 7, similarly for H_2 it is 3, 1's and 6, 0's, for H_3 it is 4, 1's and 5, 0's and for H_4 it is 5, 1's and 4, 0's. Hence, with 1000 equiprobably mappedheader MHI-PPM frames it is seen that maximum run length of 1's is 5 and maximum run length of 0's is 7. Now, transmitting run length of 7 bits in a VLC system with the lowest optical clock rate (200KHz) requires only 0.035ms, which is far less than MFTP. Thus, the proposed MHI-PPM scheme dimming have an excellent short run length property and is capable of flicker mitigation.

IV. Analysis of the proposed VLC System

The block diagram for the proposed MHI-PPM based VLC system is shown in Fig. 3. The M-bit information is input of the proposed MHI-PPM modulator which maps the M-bit information to MHI-PPM data format by following the mapping process as discussed in previous section. The MHI-PPM frame, s(t), is emitted using LED as an optical signal, x(t) and is detected using a photodetector. Considering, the noise introduced by the system as additive white gaussian noise and having mean as zero and variance asσ_n^2. In addition, it is also assumed that the bandwidth of the receiver is very wide, so that we can assume that r(t) obtained at the input of decision generator is:

$$r(t) = \begin{cases} 1: \sqrt{P_s} + n(t) \\ 0: \quad\quad n(t) \end{cases} \quad (5)$$

Where, P_s is the peak signal power of the decision input [14].

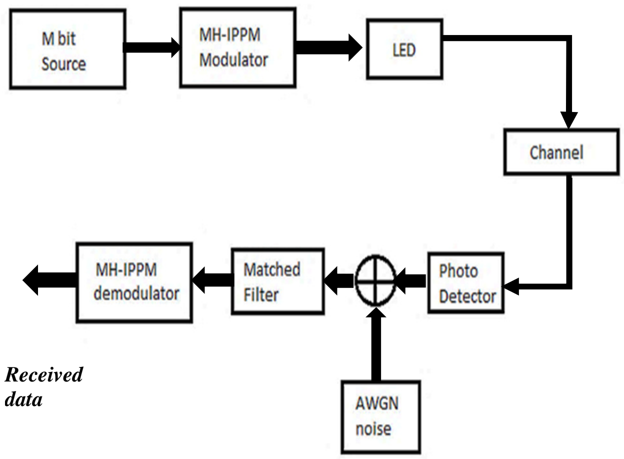


Fig. 3. Block diagram of MHI-PPM based VLC System

If the threshold value of decision generator is assumed as b, then the probability of misjudging a slot is given as:

$P_{0/1} = \frac{1}{2} erfc\left[\left(\sqrt{P_s} - b\right)/\sqrt{2\sigma_n^2}\right]$, when a pulsed slot is misjudged as non-pulsed slot (6)

$P_{1/0} = \frac{1}{2} erfc\left[b/\sqrt{2\sigma_n^2}\right]$, when a non-pulsed slot is misjudged as a pulsed slot (7)

Where, $erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^{\infty} \exp(-\tau^2)\, d\tau$ and $b = \frac{\sqrt{P_s}}{2} + \frac{\sigma_n^2}{\sqrt{P_s}} ln\frac{P_0}{P_1}$, where P_0 and P_1 are probabilities of transmitting bit '0' and bit '1' and P_0+$P_1 = 1$. Thus, the total slot error rate of the system is given as:

$P_{se} = P_{0/1}P_1 + P_{1/0}P_0$ (8)

Assuming the peak average power of all modulation types as P_{avg}, signal to noise ratio S_N, can be defined as:

$$S_N = \frac{P_{avg}}{\sigma_n^2} \quad (9)$$

Thus, the relationship between P_s and P_{avg} is given as:

$P_s = P_{avg}/P_1$ (10)

Using equations (3) -(7), the total slot error rate can be obtained as:

$$P_{se} = \frac{P_1}{2} erfc\left(\frac{\sqrt{S_{NR}}}{2\sqrt{2P_1}} - \frac{\sqrt{P_1}}{\sqrt{2S_{NR}}} ln\frac{P_0}{P_1}\right) + \frac{P_0}{2} erfc\left(\frac{\sqrt{S_{NR}}}{2\sqrt{2P_1}} + \frac{\sqrt{P_1}}{\sqrt{2S_{NR}}} ln\frac{P_0}{P_1}\right) \quad (11)$$

For PPM, $P_1 = \frac{1}{2^M}$ and $P_0 = \frac{2^M-1}{2^M}$, (12)

For DPIM, $P_1 = \frac{2}{2^M+3}$ and $P_0 = \frac{2^M+1}{2^M+3}$ (13)

For DH-PIM, $P_1 = \frac{3\alpha}{2+4\alpha+2^M}$ and $P_0 = \frac{2+\alpha+2^M}{2+4\alpha+2^M}$(14)

For MH-PIM, $P_1 = \frac{5\alpha}{10\alpha+2^{\left(\frac{M}{2}+2\right)}}$ and $P_0 = \frac{5\alpha+2^{\left(\frac{M}{2}+2\right)}}{10\alpha+2^{\left(\frac{M}{2}+2\right)}}$(15)

For MHI-PPM, $P_1 = \frac{7}{(2^{M-1}+10)}$and $P_0 = \frac{2^{M-1}+3}{(2^{M-1}+10)}$(16)

P_1 in the above equations is less than 0.5. MHI-PPM has highest average of the ratio of the number of pulses and number of time slots in a frame compared to all other modulation schemes, P_1 of MHI-PPM is higher than all other schemes. As P_1 becomes more and more less than 0.5 and SNR is the same, P_{se} increases which indicates that MHI-PPM has low slot error rate compared to other schemes.

V. EXPERIMENTAL SETUP

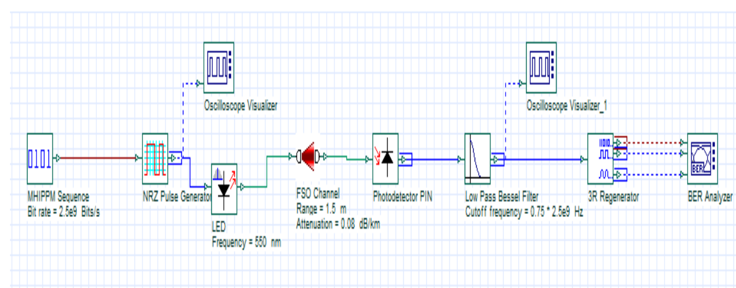
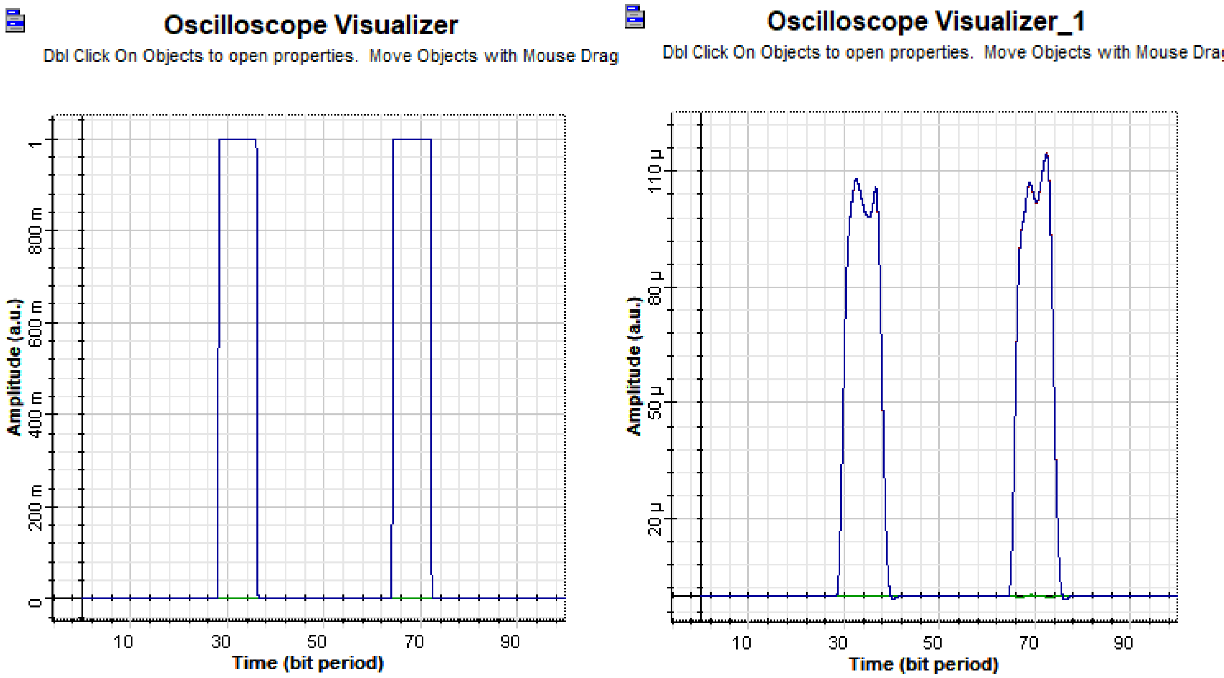


Fig. 4. Experimental setup of MHI-PPM based VLC system in OptiSystem



(a) (b)

Fig. 5. (a) Transmitted MHI-PPM Sequence ‘000011000’ (b) Received MHI-PPM Sequence ‘000011000’

Table 2: BER for different link range and varying bit rate

Bit Rate (Gbps)	Link Range= 1m		Link Range= 3m		Link Range= 5m		Link Range= 7m	
	BER	Log BER	BER	Log BER	BER	Log BER	BER	Log BER
1	1.85E-17	-16.732	2.22E-08	-7.65314	7.10E-04	-3.14904	1.95E-02	-1.71097
2	4.74E-39	-38.3245	4.27E-15	-14.3698	3.49E-05	-4.45747	1.10E-02	-1.95884
5	9.72E-24	-23.0124	2.69E-11	-10.5703	1.56E-04	-3.8056	1.36E-02	-1.86762
10	2.23E-24	-23.6512	9.67E-12	-11.0146	9.44E-05	-4.02524	1.43E-02	-1.84478

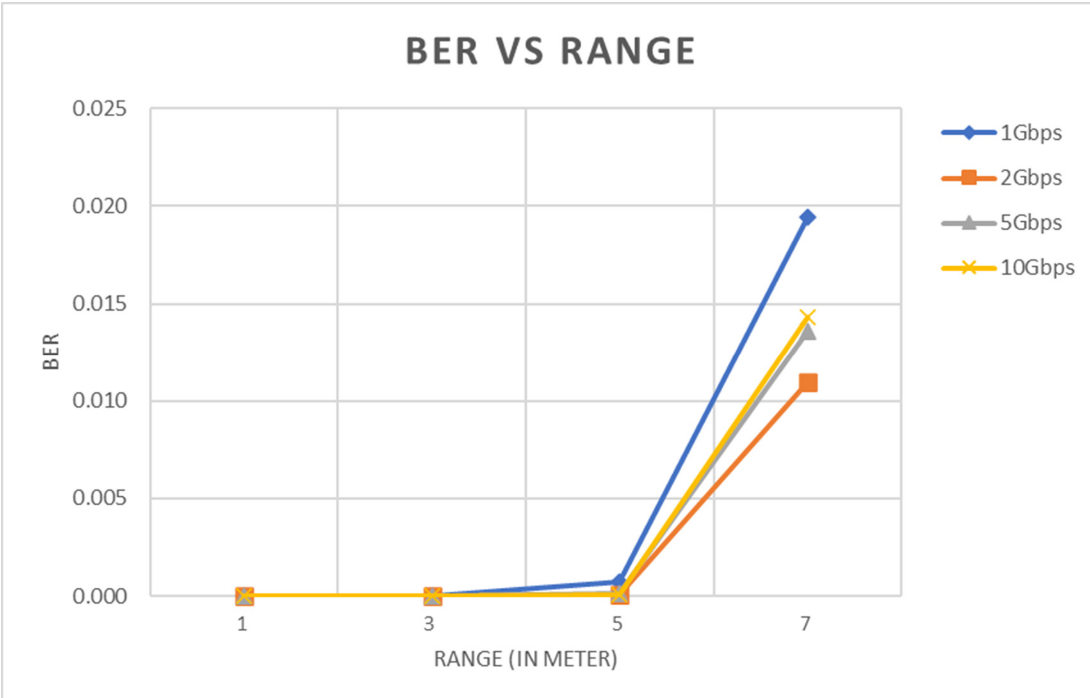


Fig. 6. BER vs link range for different bit rate

VI. Conclusion

An improved modulation scheme named MHI-PPM for visible light communication is proposed in this paper.It is a variant of PPM and presents a comparative study with fixed frame length PPM and different interval modulation schemes. It is also reported that MHI-PPM has an improved performance compared to PPM, DPIM, DH-PIM, MH-PIM and Unary Code. This paper has also studied the performance of each modulation scheme for different values of source data bits and it is seen that MHI-PPM performs at its best when number of source data bits contained in a frame is 4 but maintains reasonably stable transmission rate with increase in number of source bits. MHI-PPM being a variant of PPM has fixed frame length compared to DPIM, DH-PIM, MH-PIM and Unary Codeand supports dimming control and can mitigate flickering. As compared to PPM, frame length of MHI-PPM is small and doesn’t have long runs of zeros thus making MHI-PPM better modulation scheme in terms of flicker mitigation. Hence it is concluded that MHI-PPM can serve as an alternate modulation scheme for visible light communication which supports dimming control and has flicker mitigation property.

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