An Insight into the Modulation schemes for Visible light communication

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***Abstract*- Visible Light Communication is one of the hot topics in the research world today as it is the solution to radio frequency communication drawback. LED is the most popular material that is used in visible light for transmitter and it is easily available. This paper reviews the effect of various modulation techniques such as OOK, PPM, MPPM, and CSK for performance of communication. The paper also explores the performance of modulation schemes for VLC, the selected parameters and fundamental requirement of VLC system are power, spectral efficiency and the dimming factor of light sources. The efficiency and reliability of the communication system are analyzed based on evaluation of VLC technology such as data rate, Signal to Noise Ratio (SNR) and Bit Error Rate (BER) for modulation schemes like BPSK, QPSK, PPM, OOK, CSK and MIMO. This evaluation contributes a productive information for visible light communication with appropriate modulation techniques in terms of error performance and concludes that BPSK has better has error performance than other modulation schemes.**

***Keywords*- Visible Light Communication, Dimming, Flicker Mitigation, OOK, PPM, BPSK, QPSK, MIMO, CSK.**

I. INTRODUCTION

Nowadays, data rate and high-speed connections have become almost as important as internet itself. Service providers are encountering some difficulties for attempting to deliver high speed access to customers. In addition, lack of infrastructure, increasing in cost of communication. Therefore, engineers developed a powerful new solution. Visible light communication (VLC) technology is a new communication technology and it is using the concept of visible light. Visible light is small portion of electromagnetic spectrum as shown in Fig-1 which has wavelength of visible light ranges from 380 nm to 750 nm. In addition, the frequency visible light ranges from 400 Tera-Hz to 800 Tera-Hz so these ranges use in visible light[1]. There are some advantages of using visible light communication technology instead of radio frequency. One of the most important advantage, the visible light doesn't cause any health problem whereby no cancer, no skin cancers radiation and can protect birds. Therefore, visible is not affecting in our health as radio frequencies. The second advantage of visible light is that there is no electromagnetic interference. Moreover, the visible light doesn't require to purchase the spectrum, thus it is a free source. LED is the most popular material that is used in visible light and it is easily available because there is a huge market in LEDs, and it is not expensive. Finally, it can be used in hospitals where there is requirement that the technology may not cause any problem. Therefore, these are the various advantages of visible light communication system that is why it is required to use. Technology of light that every kind of low light source can be used as sender such as light emitting diodes (LEDs) because they are prominent choice for transmitters. Besides that, it is having a switching. Functionality that means off and on forever. In the other hand, it can use photodiode detector or image sensors in the receiver. These materials can be used as receiver in visible light technology. The two fundamental features defies for data communication with visible light spectrum are a flickering improvement and dimming sustainability to offer optimal data rates for communication. The variation of light intensity is considered as flickering, any possible fluctuation effecting from the modulated light source for communication, it should be minimized because fluctuation of light intensity can cause visible, negative impact on physiological changes in human beings. To mitigate fluctuations, there is a way to limit the light intensity fluctuations through maximum flickering time period (MFTP). The MFTP is characterized as to improve light fluctuations without human eye can recognize it. The accepted and optimal fluctuation number is considered as safe and sound over the frequency greater than 200 Hz (MFTP<5). The schematic view of transmitting and receiving data in indoor VLC is shown in Fig_2. Data undergo for modulation, so it can use modulation such as pulse position modulation (PPM), on-off-keying (OOK) and other types of modulations. Therefore, these data of modulation are required to pass through a light source which is used to transmit a data. At the receiver end, it requires photodiode detector or image sensor to detect light and convert it to the electrical or fiber signal, after that it demodulates data at demodulations process and finally obtain the original data [2].

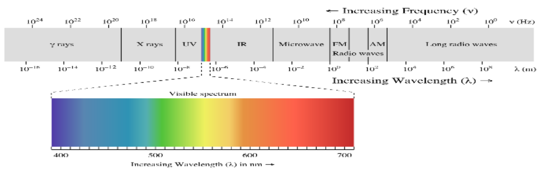

Fig. 1 Visible spectrum of VLC

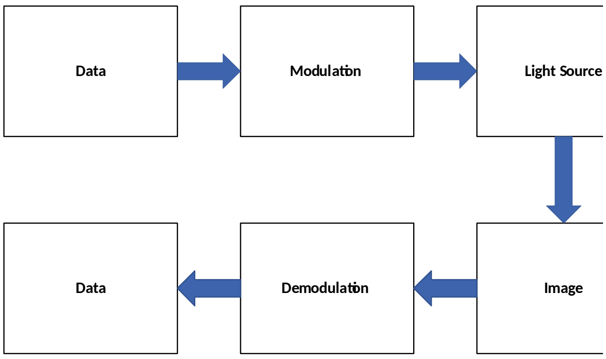

Fig. 2 Schematic view of transmitting and receiving data in VLC

BER analysis is carried out for several modulation schemes viz., BPSK, QPSK, CSK, PPM and MIMO-OFDM. The rest of paper is organized as follows. Section 2 describes the previous work that has been done in the area of modulation schemes for VLC. Results are discussed in Section 3. Finally, Conclusion is drafted in Section 4.

II. MODULATION SCHEMES

Sometimes the signal loss happens because of long distance and the solution is modulating the information. There are different modulation techniques used in visible light communication. VLC modulation techniques are different from the modulations in radio frequency (RF), since the modulation can't be in phase and amplitude of light wave such as radio frequency (RF). In the other hand, VLC modulation is done by intensity of emitting light [3]. Visible light communication (VLC) can provide high data rates with different types of modulations, but it needs to take caution from visible light effects on humans. Therefore, there are some techniques to solve this problem such as dimming and flicker reducing as explained below.

2.1 Dimming

The increased wireless data traffic from the rapidly growing wireless mobile devices is creating pressure on the dwindling radio frequency (RF) spectrum that is driving the need for alternative technologies. This concern about spectrum scarcity led to the formulation of a new technology called visible light communication (VLC), which generally uses fast switching light emitting diodes (LEDs) as its source and possesses the ability to provide illumination and communication for short range indoor links simultaneously. Dual functional VLC systems simultaneously providing illumination and communication must have dimming functionality. However, dimming has an adverse effect on communication, and this is a major concern hampering the rapid growth of VLC. Integrating efficient dimming techniques into VLC systems will significantly improve energy savings and allow users to have full control over the lighting output, making the adaptation of VLC for practical use more rational [4]. There are some advantages by using dimming into VLC, it offers system improvement, decrease the power and energy efficiency. The light intensity is measured in Lux and illuminance range of 30-100 Lux is sufficient for diminishing the darkness to perform the visual task in open spots. It is important to keep communication is ON during light turn off. In addition, knowing the levels of intensity of light which may affect negatively on human eye is very important. The human eye is able to acclimatize to the low level of illumination through expanding the pupil to permit more light to enter the eye. The calculated [5] perceived light from the measuring light as in Equation (1)

$$Perceived\,light\,(\%) = 100\,\% * \sqrt{\frac{Measured\,light\,(\%)}{100}} \quad (1)$$

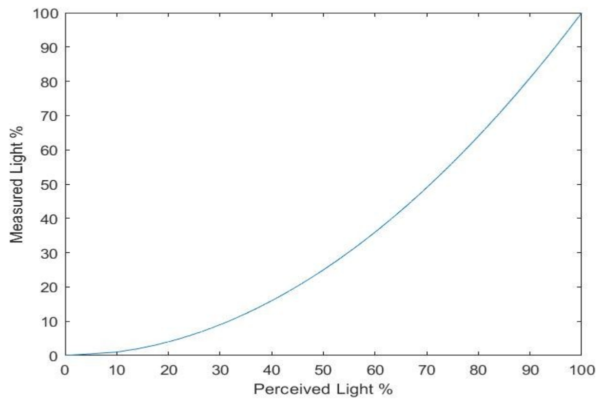

Fig. 3 Sensitivity of Human Eye to dimming

2.2 Flicker mitigation

There is another demand for modulations in VLC which is that the intensity of LED doesn't cause any fluctuations for human eyes. Thus, the human eyes should not realize the fluctuations in LED intensity whereby can send information by light intensity modulating faster than human eye stability. The transmitter power depends on various modulated signal. Average light power might change during information transmission which create a flicker [6]. Flicker is the fluctuation of brightness that eye human can look to. The modulations of VLC mitigate the fluctuations besides providing high data rate. The main idea that causes flickering is the sequence of 1s and 0s which minimize rate of changing of LED intensity that produce fluctuations. Run Length limited (RRL) codes can be mitigated the sequence of 1s and 0s which produce the fluctuations [7].

Modulation techniques that are used in VLC are divided into single-carrier and multi-carrier modulations. ONOFF Keying (OOK), Pulse-Position Modulation (PPM) and Pulse-Width Modulation (PWM) are some examples of single-carrier modulation. Finally, Color Shift Keying (CSK) modulation is example of multi-chromatic modulation which has more than one colour. These modulations support dimming parameter in visible light communication.

2.3 On-Off Keying (OOK)

The easiest modulation implementation for VLC is OOK which changes between zero and one bits to open and close light of LED, since bit-0 represents “off” and bit-1 represents “on”. The light is not exactly switched off when OOK with bit-0 “off”, but the intensity of light is minimized because bit-1 clearly represents “on” level [8]. Recently, the popular light that is used in OOK modulation for VLC is white LED which use both yellow phosphor and blue emitter colours. White LED suffers from its lower transmission velocity due to of responding delay of yellow phosphor. The responding delay of yellow phosphor can be removed by using blue filter [9]. J.Grubor and others in [9] achieved data rate of 100 Mbps by using OOK with discrete multi-tone (DMT) modulations. In [10], it has achieved data rate of 125 Mb/s over 5 meters by using OOK whereby bringing blue filter with simple equalization together at the receiver. Moreover, it can improve the performance of communication by choosing proper photodiode. By choosing avalanche photodiode (APD) and PIN diode, data rate is improved to 230 Mb/s and 125 Mb/s without using equalization respectively [11]. The key problem that encounters the white light is responding delay. The white light consists of three colours, red, green and blue (RGB). In [12] the writer achieved 477 Mb/s by modulating only the red light of RGB-white LED with PIN diode while the green and blue lights is used for illumination. Both “on” and “off” levels are allocated by various levels of intensity to achieve the required dimming level. The advantage of this operation is the required dimming level doesn’t need more bits. In addition, extra compensation periods which added if the light entirely turned off or on. For example, “off” periods are inserted if the desired level of dimming less than 50% and “on” periods are inserted if the desired level of dimming more than 50%. It can calculate the maximum efficiency of communication (E) by using information theory entropy where D is required dimming level with OOK [13].

$$E_D = D \log_2 D - (1-D)\log_2(1-D) \tag{2}$$

$$\gamma = \begin{cases} (2-2D)*100 : D>0.5 \\ 2D*100 : D \le 0.5 \end{cases} \tag{3}$$

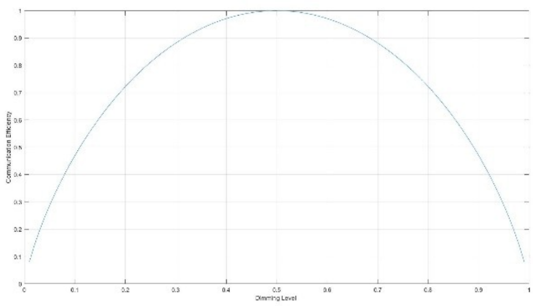

Fig. 4 Communication Efficiency in dimming levels

It is clear in Figure 4, the maximum communication efficiency in dimming level is 50%, thus the efficiency is reduced when the level of dimming minimizes to 0% or exceed to 100%. In addition, by using compensation periods the data rate is decreased. However, due to the intensity of modulated signals stay constant then the communication efficiency stays constant. TO accomplish high data rate with required dimming level, it has used inverse source coding as in [14].

2.4 Pulse Modulation Methods

On-Off-Keying modulation provides various advantages such as easy and viable execution, the key problem of OOK is its data rates not high especially when keeping different levels of dimming. Therefore, it had to be inventing a new modulation technique such as pulse width modulation (PWM) and pulse position modulation (PPM). Pulse width modulation (PWM) is controlled depending on the desired level of dimming. When the illumination of light is full, the information is sending. It can accomplish high data rate from any level of dimming zero to 100% with pulse width modulation scheme as writer explained in [15]. In PWM, changing of intensity of light is not important to accomplish the dimming which consider the great feature for PWM. Therefore, any colour switch is not needed for switching between on and off levels in the light. In [16] has demonstrated the dimming ways by using pulse width modulation or changing the modulation depth, but data rates is restricted up to 4.8kb/s. However, [17] has solved this limited data rate by combining discrete multi-tone (DMT) with PWM for communication and dimming control. Another pulse modulation called pulse position modulation (PPM) which is depending on position of pulse. In PPM scheme, the symbol duration is divided to time slots and each time slot has same duration, since the pulse is sent in one-time slot. Earlier work [18], pulse position modulation is employed in IR communications. While in [19] is used rate adaptive transmission where extra bits of coding minimize information throughput during bad channel condition exist. Another type of PPM which is overlap PPM. (OPPM) that can send more symbols duration in one pulse [16]. Figure 5, shows various symbols. [20] Explained that OPPM can be accomplished high data rate besides obtaining on spectral efficiency. There is another type of PPM called multi-pulse PPM. As shown in Figure5, MPPM allows to send multiple pulses in single symbol duration. However, the proportionate of these pulses in symbol duration is not needed. MPPM spectral efficiency outperforms on OPPM in [21]. In [22] writer introduced overlapping MPPM (OMPPM) which is mixture between OPPM and MPPM. In this mixture, single channel is represented by more than single pulse position. OMPPM can optimize the spectral efficiency of MPPM without extending capacity of transmission with noiseless photon channel, while the performance of noisy channel discussed in [22]. [23] has another type called differential PPM (DPPM) which eliminate OFF symbol and the next pulse begin directly after the last symbol. The differential overlapping PPM (DOPPM) has demonstrated in [24] which the deferential eliminating of OFF symbols is employed to OPPM and achieve greatest performance of cut off and spectral than OPPM, DPPM and PPM.

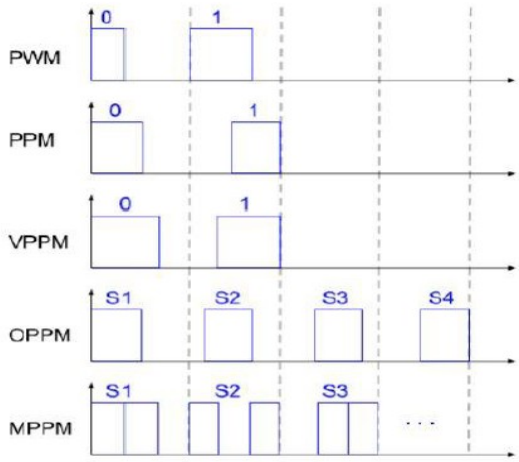

Fig. 5 Schematic diagram showing the difference between PWM, PPM, VPPM, OPPM, MPPM

2.5 Color shift keying (CSK)

To solve problems of reduced data rate and dimming strengthening cases of previous modulation techniques, IEEE 802.15.7 presented a new modulation technique called color shift keying (CSK). It can create white LED by combination of various colors. White LED can be created by blue emitting and yellow phosphor as explained before, but White LED suffers from its lower transmission velocity due to of responding delay of yellow phosphor. Interactively, white LED can be created by three different colors in the same time, red, green and blue (RGB) which have more advantage for communication [25]. The concept of using multi-color LEDs is the main idea behind choosing CSK. To determine different color for communication, IEEE 802.15.7 standard divided the spectrum to seven colors. Figure 6 displays the seven colors on x-y chromaticity values as determined by CIE 1931. Outer curve is the spectral place with wavelengths shown in nm and the bits in Figure 6 determine every band of 7 colors. The entire power for all CSK light sources is constant, despite every light has its power. CSK dimming guarantee that the average power of optical from the LED is constant and keeps the desired intensity of centre color of colors group. Therefore, the flicker will not occur with CSK because of amplitude changing [7]. CSK dimming works on reducing and control on brightness through changing of driving current for LED.

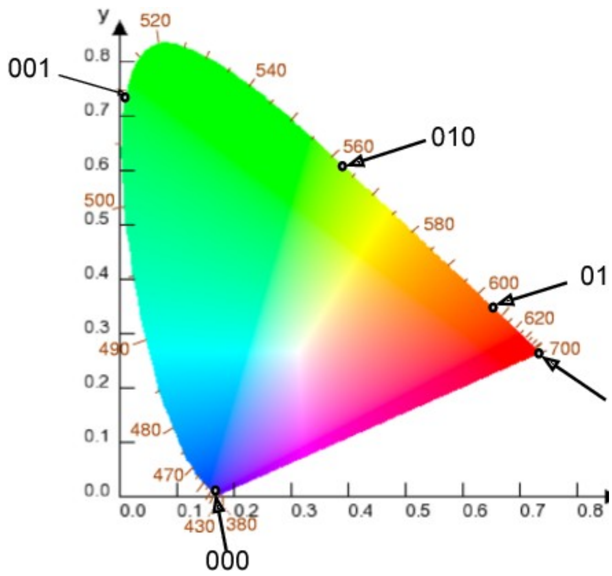

Fig. 6 CIE 1931 chromaticity diagram. The seven colour codes correspond to the centres of seven bands dividing the visible spectrum[26]

2.6 Binary Phase-Shift Keying (BPSK)

BPSK is the simplest form of phase shift keying or PSK. It uses two phases which are separated by 180°. It does not particularly matter exactly where the constellation points are positioned, as in this figure they are shown on the real axis, at 0° and 180°. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1 bit/symbol and so is unsuitable for high data-rate applications when bandwidth is limited. In[27] the authors designed BPSK to meet the qualification of the VLC system and found that it can perform properly with optical distance up to 40 cm with low complexity target. Using BPSK modulation, the maximum bitrate of ~13.4 kbps was obtained .

2.7 Quadrature phase-shift keying (QPSK)

Sometimes known as quaternary or quadriphase PSK, 4-PSK, or 4-QAM, QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, shown in the diagram with Gray coding to minimize the BER — twice the rate of BPSK. Analysis shows that this may be used either to double the data rate compared to a BPSK system while maintaining the bandwidth of the signal or to maintain the data-rate of BPSK but halve the bandwidth needed. Although QPSK can be viewed as a quaternary modulation, it is easier to see it as two independently modulated quadrature carriers. With this interpretation, the even (or odd) bits are used to modulate the in-phase component of the carrier, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier.

2.8 Multiple Input Multiple Output (MIMO)

A system which uses multiple antennas at the transmitter and a single antenna at the receiver is named Multiple Input Single Output (MISO). A technique known as Alamouti STC (Space Time Coding) is employed at the transmitter with two antennas. STC allows the transmitter to transmit signals (information) both in time and space, meaning the information is transmitted by two antennas at two different times consecutively. Multiple antennas (each with an RF chain) of either SIMO or MISO are usually placed at a base station (BS). This way, the cost of providing either a receive diversity (in SIMO) or transmit diversity (in MISO) can be shared by all subscriber stations (SSs) served by the BS.To multiply throughput of a radio link, multiple antennas (and multiple RF chains accordingly) are put at both the transmitter and the receiver. This system is referred to as Multiple Input Multiple Output (MIMO). A MIMO system with similar count of antennas at both the transmitter and the receiver in a point-to-point (PTP) link can multiply the system throughput linearly with every additional antenna. For example, a 2x2 MIMO will double the throughput.

III. RESULTS AND DISCUSSION

In this paper, different modulation techniques are explained especially the main modulation techniques OOK, PPM, CSK, BPSK, QPSK and MIMO modulation.

3.1 Parameters

Following are the parameters used in this paper.

3.1.1 Bit Error Rate

BER is a key property of the digital communication system. Various types of modulation methods are used in the digital information transmission system. BER can be demarcated as the number of received bits of a data stream over a communication channel that can be affected due to noise, interference and distortion or bit synchronization errors. The bit error rate can be calculated as

$$BER = \frac{ERRORS}{Total\ number\ of\ Bits}$$

BER of different modulation schemes are expressed as

For **BPSK**,

$$BER = 0.5\, erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \quad (1)$$

For **QPSK**,

$$\text{BER}=0.5\,erfc\left(\sqrt{\frac{E_b}{2\,N_o}}\right) \qquad (2)$$

For **NRZ-OOK,**

$$BER_{NRZ-ook}=0.5\,erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \qquad (3)$$

FOR **RZ-OOK,**

$$BER_{NRZ-ook}=0.5\,erfc\left(\frac{1}{2}\sqrt{SNR}\right) \qquad (4)$$

For **L-PPM,**

$$BER_{PPM}=0.5\,erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR\,\frac{L}{2}\log_2 L}\right) \qquad (5)$$

3.1.2 Additive white gaussian noise channel

AWGN is a noise which is added to the channel. Additive as a result of the arriving signal is equal to the transmitted signal. White as a result of rent less power spectral density, Gaussian is the probability distribution, noise distorts the received signal.

Fig.7 demonstrates the entailed power concerning dimming factor for modulation schemes such as VOOK, MPPM, and VPPM. VOOK and VPPM have the same requirement of power, however, MPPM requires less power in comparison to VOOK and VPPM. In MPPM each symbol duration is divided into n chips for dimming control, so MPPM with fixed (n=20) is shown in Fig 1. Hence from the figure, we have observed that VOOK and VPPM require more power around 8 dB to achieve the minimum value of diming factor 0.02, while MPPM has need of less value of power around 4.2 dB for the same value of diming factor. If the value of the diming factor is increased from its average value 0.5, the required value for power should increase accordingly. MPPM provides much better results than VOOK and VPPM both require more power.

Fig. 8 demonstrates the spectral efficiency relating to dimming factor. It is observed that VOOK with the same power as VPPM provides better results than VPPM regarding spectral efficiency. As for the minimum value of dimming factor around 0.02, the spectral efficiency of VPPM is low at 0.02, VOOK has the value around 0.1, MPPM with n=20 provides spectral efficiency of 0.2, and MPPM has the value of 0.3. For the average value of dimming factor 0.5, MPPM and VOOK provide maximum spectral efficiency, MPPM with n=20 provides better results except for few values of dimming factor, as VOOK drastically increases and decreases with dimming factor, therefore for better results MPPM is preferred. The spectral efficiency is a function of a diming factor with an inverse relation to its average value.

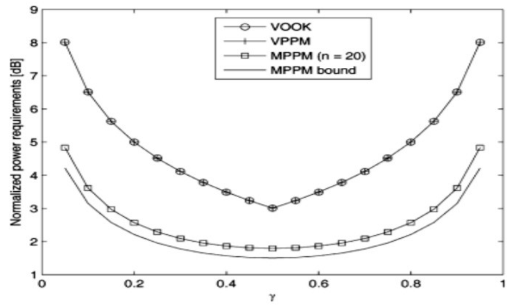

Fig.7 Normalized power requirements of Modulation schemes[28]

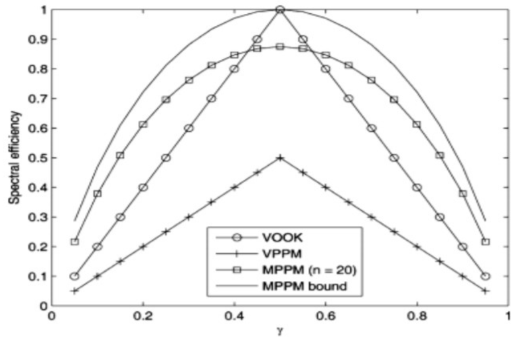

Fig.8 Spectral Efficiency of Modulation schemes[28]

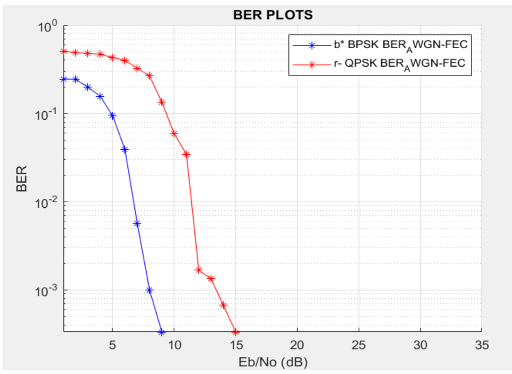

Fig.9 Bit Error Rate of BPSK and QPSK

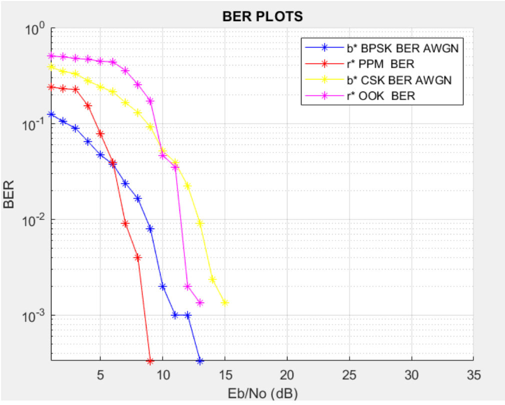

Fig.10 Bit Error Rate of Modulation Schemes.

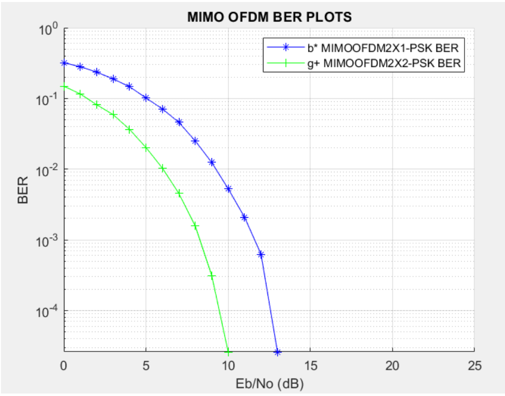

Fig.11 Bit Error Rate of MIMO-OFDM.

BPSK is always better in terms of BER performance. BPSK system encodes 1 bit per symbol, the decoder has a very good probability, and more margin of error, (50%) as shown in Figure 10. Thus, even if the symbol is added with noise chances of correcting it back are more. In Case of QPSK as it encodes 2 bits per symbol, the probability goes down to 25% and a lesser margin of error, hence BPSK performs better the QPSK. But the advantage of QPSK over BPSK is Double Data rate. Further adding FEC to both BPSK/QPSK improves BER further as it employs Convolution codes and Viterbi decoding. In Figure 10, BPSK has better error performance as compared to other modulation schemes. CSK modulation outshines the all other modulation schemes in terms of data rates , however OOK is very close to the CSK in terms of data rates. MIMO-OFDM 2x2 has better error performance as compared to MIMO-OFDM 2x1 as shown in Figure 11, the reason is an extra receiver.

IV. CONCLUSION

VLC has a large of number of applications such as used in vehicle and transportation, streets, underwater communication, hospitals, defense and security, Wi-Fi Spectrum and hazardous environments. In this paper performance of different modulation schemes are analyzed on VLC. Lights can provide a good quality signal for communication because of its dim feature and thus VLC makes use of it. It is necessary to choose such modulation scheme that can minimize the effects of dimming level and enhances the data rates as controlling the dimming level of VLC sources is an important factor in VLC. From the review and observation, it can be concluded that MPPM provides reliable communication, power requirements, spectral efficiency and data rates as compared to many other schemes used for VLC. Also, BPSK is always better in terms of BER performance. CSK has more data rates as compared to other modulation schemes. Finally, in MIMO-OFDM we conclude more the receivers better the bit error rate.

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