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BER Analysis in PS-SLIPT Architecture Using Different Modulation Schemes

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***Abstract*—Simultaneous Lightwave Information and Power Transfer (SLIPT) has emerged as a highly popular area of research in recent times. The basic idea behind SLIPT is to use light waves to simultaneously transfer power and transmit information. This could lead to significant improvements in the efficiency and sustainability of wireless power transfer systems and enable the development of novel applications such as wireless optical communication. In this paper, we presented the On-OFF Keying (OOK), Quadrature Phase Shift Keying (QPSK) and 8- Phase Shift Keying (8-PSK) constellation diagrams in the Power-Splitting SLIPT (PS-SLIPT) system. In addition, we expanded the work to BER analysis in the PS-SLIPT system with OOK, QPSK and 8-PSK modulation schemes.**

Keywords—PS-SLIPT, OOK, QPSK, Bit Error Rate (BER)

I. INTRODUCTION

In the latest version of SLIPT, Energy Harvesting (EH) has been incorporated alongside the traditional use of illumination and communication. The system, as proposed in [1], splits the received photon current into two components: Alternative Current (AC) and DC, which are used for ID and EH, respectively. The DC component, which is separated from the AC, is stored in the battery to provide backup power, while the remaining power is utilized for information detection [2-5]. Given its ability to convert optical signals into electrical signals, the use of solar cells is a dependable choice for developing the SLIPT receiver. The SLIPT system model is a subset of Visible Light Communication (VLC) [6]. There are a few reasons to over from analog modulation to digital modulation in wireless communication such as spectral efficiency, power efficiency, the robustness of channel impairment and the low-cost implementation. Digital modulation is transferring a digital bit stream over an analog channel at a high frequency. Moreover, digital communication schemes contribute to the evolution of wireless optical communication by increasing capacity, speed and quality.

The PS receiver splits the incoming signal into two separate power streams, both of which are transmitted to an information decoder and an energy harvester, thereby enabling simultaneous ID and EH. The conventional communication system's power-splitting design need not be modified, except for the receiver circuit. The PS ratio in each receiver can be optimized, and by adjusting these ratios, the information rate and harvested energy can be balanced to meet the system's requirements. Improving overall performance is also possible by optimizing the combination of the signal and PS ratios. The power-splitting coefficient value for EH is denoted by ρ, while (1-ρ) is used for the ID, as described in [7]. The VLC technology relies on Intensity Modulation and Direct Detection (IM/DD) to transmit data. This is achieved by varying the intensity of the LED and modulating the information signal. IM is always non-negative. Two carrier modulation schemes are available: single-carrier and multi-carrier. The former includes modulation techniques such as On-Off Keying (OOK), Pulse Amplitude Modulation (PAM), and Pulse Position Modulation (PPM), Phase Shift Keying (PSK), while the latter includes Orthogonal Frequency Differential Modulation (OFDM), as stated in [8].

A. Contributions

The main contributions of this work are listed as follows:

- Identified the different modulation schemes for PS-SLIPT architecture.
- Explained the behaviour of the constellation diagram using MATLAB simulation in the PS-SLIPT system.
- Described the BER analysis using OOK, QPSK and 8-PSK modulation schemes in the PS-SLIPT system.

B. Paper Organization

The remainder of the paper is organized as follows: Section II presents the system model of the PS-SLIPT communication system. Section III, results and discussion and V conclude the whole paperwork.

II. SYSTEM MODEL

In this section, we discuss the basic system model of SLIPT. Fig. 1. shows the basic system model of the VLC and considers LoS between the Transmitter (Tx) and the Receiver (Rx). This system model uses a wireless communication channel, and it is free space. Also, free space is a medium between Tx and Rx and it has high bandwidth and does not require a licence for visible spectrum. The α denotes the FoV of the LED, θ denotes the Photodiode (PD) and d is the distance between Tx and Rx.

Fig. 2. (a) shows the overall system model of the SLIPT system. It shows the variation of one domain to another domain. There are three parts of the system, namely the

transmitter, channel and receiver. The transmitter includes an information signal, modulator, and converter circuit of electrical signal into an optical signal and LED. The information signal is transmitted as binary data ($m(t)$) and used the modulation techniques to modulate the signal ($m'(t)$) to send the E to the L driver circuit. Here, (t) denotes sequence of binary data. On-Off Keying (OOK) modulation technique is generally used for VLC communication. Using the drive circuit, convert the electrical signal into an optical signal. Also, LED helps to send the optical signal to the receiver. Moreover, h is the channel gain coefficient between the transmitter and the receiver with AWGN. The AWGN ($n(t)$) is a basic noise model used for information theory to follow the effect of the many random processes that occur in nature in wireless communication. The receiver includes PD or solar cells, the converter circuit, demodulation, and the output data. The PD or solar cell detects the optical signal and sends it to the L to the E driver circuit. Using the drive circuit, convert an optical signal into an electrical signal and used demodulation to output data. Figure 2: (b) shows the PS-SLIPT receiver architecture. On the receiving side, there are two functions EH and ID. Further, the received signal is divided into two portions: the AC component and the DC component. The modulated signal gives an AC component and its support to transmit the information. Also, the DC component helps with energy harvesting. The ρ is the power splitting coefficient.

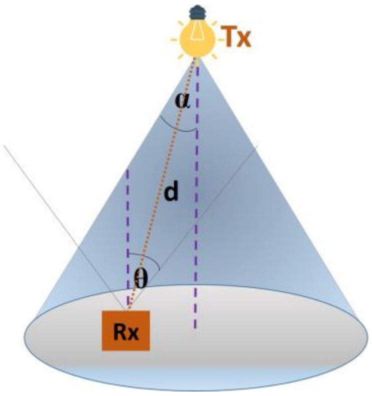
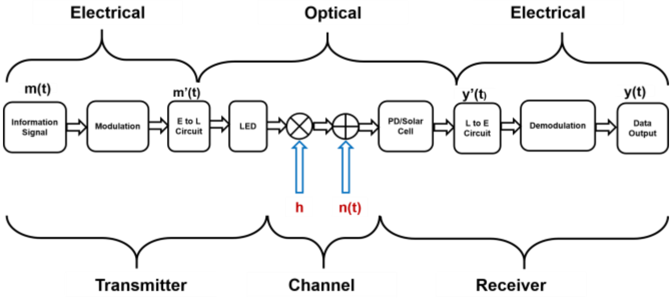
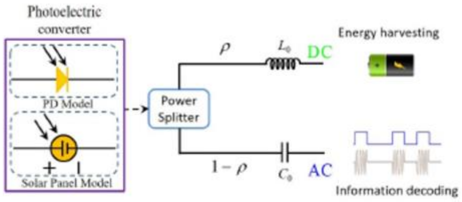


Fig. 1. Basic system model of the VLC and LoS between the Transmitter (Tx) and the Receiver (Rx)



(a)



(b)

Fig. 2. (a) Block diagram of the overall system model of the VLC. (b) PS-SLIPT receiver architecture.

$$h = \frac{A_r(m+1)(cos^m(\alpha)T(\theta)g(\theta)(cos(\theta)}{2(\pi)(d^2)}, \quad 0 \le \alpha \le \pi, \quad 0 \le \theta \le \pi,$$

h is the channel gain between the Tx and Rx [1].

Where d is the distance between the transmitter and the receiver, $T(\theta)$ defines the optical filter gain and Ar denotes as the physical area of the detector at the receiver end. The α denotes the FoV ($0 < \alpha < \pi$) and it is representing as the angle of irradiance of LED. The θ denotes the FoV ($0 < \theta < \pi$) and it is representing as the angle of incidence of LED.

$$m = \frac{-ln(2)}{ln(cos(\alpha))}, \qquad 0 < \alpha < \pi,$$

Where, m denotes the Lambertian's mode number, and it gives the direction of the source. Gain of the optical concentrator is given [1].

$$g(\theta) = \frac{n^2}{sin^2(\theta)}, \qquad 0 < \theta < \pi,$$

n denoted as the refractive index and $g(\theta)$ assign the optical concentrator gain.

The AC component of the signal use for the information decoding process. Signal to Noise Ratio (SNR) for PS SLIPT system denoted by [1],

$$\gamma_{PS} = \frac{(\eta h(1-\rho)P_{LED}A)^2}{\sigma^2},$$

Where the amplitude of the transmitted signal denotes A and $\boldsymbol{\rho}$ is the PS coefficient. $\boldsymbol{\sigma}^2$ denotes the noise power (thermal noise and shot noise).

III. RESULTS AND DISCUSSION

In this chapter, we present the simulation results of the proposed system models of the SLIPT architectures. Further, present the simulation results of BER for different modulation schemes such as OOK, QPSK and 8-PSK in PS SLIPT architecture.

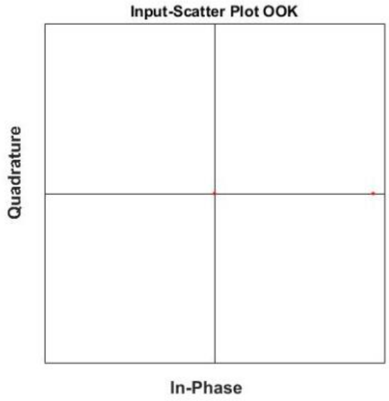


Fig. 3. Input constellation diagram of OOK

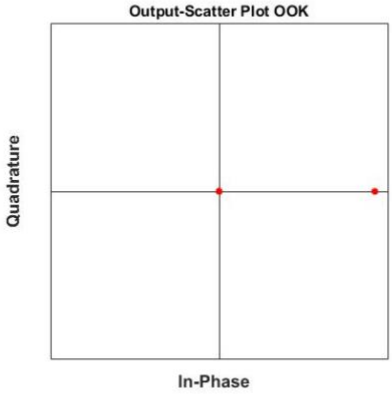


Fig. 4. Output constellation diagram of OOK

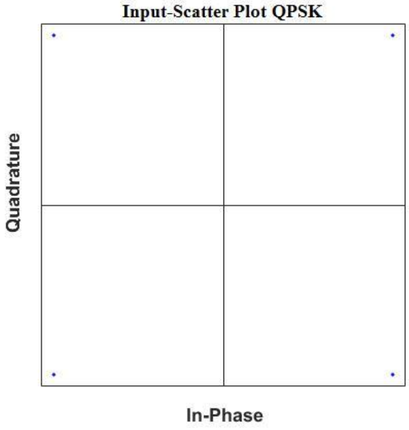


Fig. 5. Input constellation diagram of QPSK

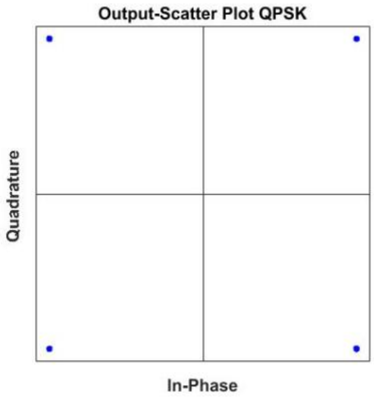


Fig. 6. Output constellation diagram of QPSK

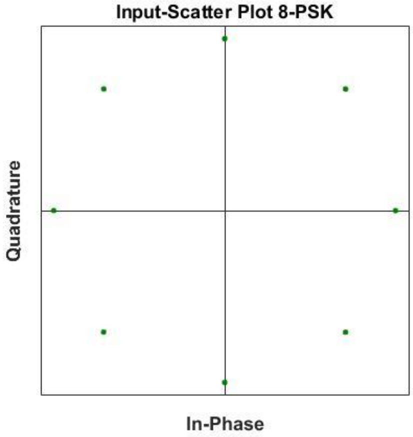


Fig. 7. Input constellation diagram of 8-PSK

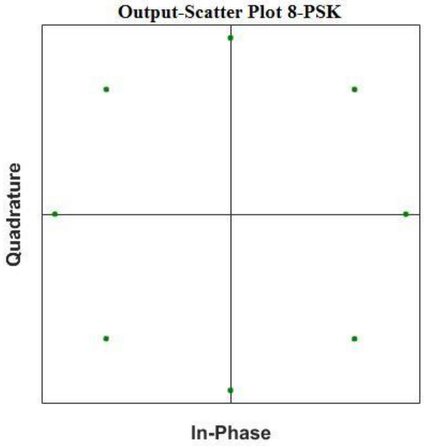
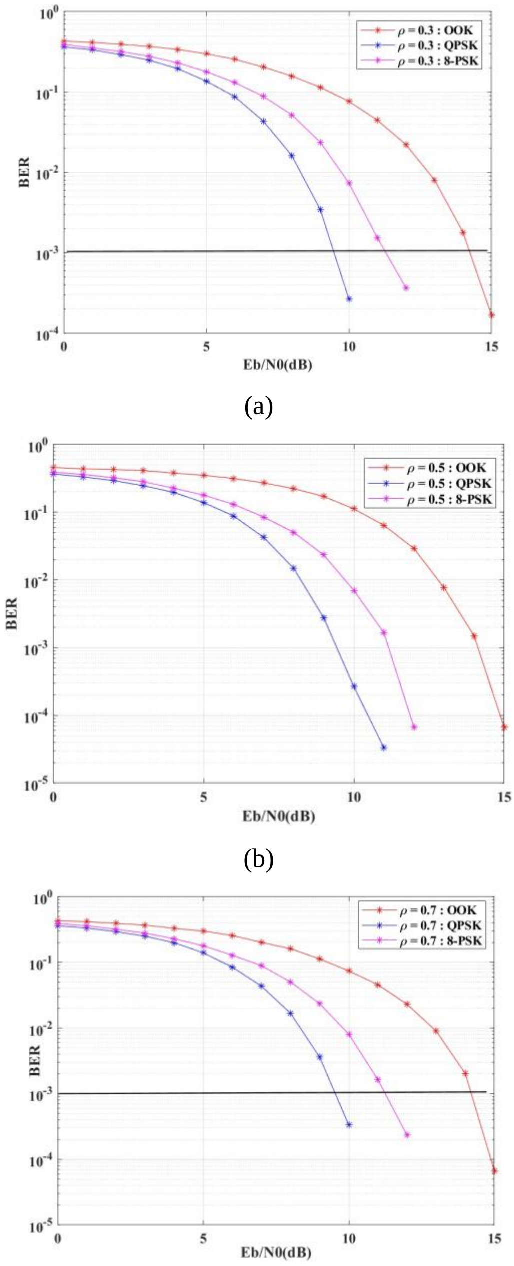


Fig. 8. Output constellation diagram of 8-PSK

Fig. 3. and Fig. 4. shows the input and output constellation diagram of the OOK modulation, Fig. 5. and Fig. 6. show the input and output constellation diagram of the QPSK modulation, Fig. 7. and Fig. 8. show the input and output constellation diagram of the 8-PSK and represent the effect of noises to the received signals at SNR is 30 dB at ρ=0.7. The OOK is the amplitude modulation scheme commonly used in optical communication applications and it is a lower-order modulation scheme. Further, we use two higher-order modulation schemes such as QPSK and 8-PSK. Both higher-order modulations are phase modulations. The M-PSK modulations are used for this system to enhance the bandwidth efficiency and advantage is by using smaller phase shift, more bits can be transmitted per symbol. This system uses AWGN noise and compared the input and output constellation of each modulation scheme. The constellation diagrams represent symbols in digital modulation schemes. Using visual inspection of constellation diagrams can help diagnose various types of signal impairments. The constellation diagrams show the difference between input and output points. In this system, errors are caused by the transmitter and channel noise. The output point is spread out over the input due to adding the noise and the spurious signal level.



(a)

(b)

(c)

Fig. 9. BER vs SNR of the OOK, QPSK and 8-PSK modulation schemes at (a) $\rho = 0.3$, (b) $\rho = 0.5$, and (c) $\rho = 0.3$.

Fig. 9. (a) shows the BER vs SNR of the OOK modulation scheme, Fig. 9. (b) shows the BER vs SNR of the QPSK modulation scheme and Fig. 9. (c) shows the BER vs SNR of the 8-PSK modulation scheme. It considers the different power splitting factors (ρ) such as 0.7, 0.5 and 0.3. The QPSK shows outperform the 8-PSK and OOK. The QPSK can transmit 2 bits per second and M=4. The 8-PSK can transmit 3 bits per second and M=8. When comparing the QPSK and 8-PSK, 8 PSK is more susceptible to noise as the symbols get closer together. Therefore, QPSK outperforms 8-PSK. Moreover, OOK shows the worst performance due to OOK being susceptible to noise as the bits get closer together than QPSK and 8-PSK.

IV. CONCLUSION

In this paper, BER analysis in PS-SLIPT architecture using different modulation schemes such as OOK, QPSK and 8-PSK. We observed the input and output constellation diagram of the PS-SLIPT system. In addition, we analyzed the BER of the PS-SLIPT architecture in OOK, QPSK and 8-PSK to identify the most suitable modulation scheme for PS-SLIPT communication scheme.

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