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SNR investigation for Visible Light Communication for Hospitals

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Abstract: This paper examines SNR characteristics of a hazardless alternative for data transfer using Visible Light communications (VLC) for radio frequencies (RF) restricted indoors areas such as aircrafts and health care systems. This communication system will be used for patients' health monitoring in addition to providing the users with high data rate for multimedia contents applications. Since RF can be hazardous for patient's health and could potentially damage the expensive instruments of the hospital, Visible light emerges victorious in communication battle. Room illumination and lux distribution simulations are created using Dialux evo and optical power distribution and power calculations are simulated in MATLAB. Further, the effects of three major factors in the wireless optical communication including Distance, Modulation and Data Rate are analyzed based on the SNR and BER of the communication channel.

Keywords: BER, Modulation, SNR, VLC, Wireless

I. INTRODUCTION

Communication plays a vital role in modern technologies. The advancements in wireless communication has significantly changed the communication structure in the world. Most networks are currently based on electrical signals and are guided through copper cables [1]. Introduction of fiber optics led to use of this technology in communications through which copper cables are replaced by fiber cables. Optical wireless communication is an unguided form of communication that uses light to transfer information. Wireless optical communication has been proven to be lighter, cheaper, less power consumption than copper cables and also reduce the Electromagnetic interference [1][2][3][4].This particular advantage is very important to places where RF can interfere with other networks, such as hospitals, airplanes and petrol stations [3][5].With the advancements in light emitting diodes (LEDs), specifically white LEDs, Visible Light communication growth rate dramatically raised as white LEDs emerged victorious with higher efficiency, longer life time and less power consumption in the battle with fluorescent and incandescent lamps [6][7]. Additionally, the quick switching ability alongside the low complexity (compared to RF) made white LEDS the ideal luminaire for VLC systems [6]. This research simulates the positioning methods and modulation techniques of the VLC network to enhance the Signal to Noise Ratio and achieve higher data rates. The positioning algorithm affects the power distribution significantly, hence the optimal layout will provide the network with uniform power with slight changes in the distance between transmitter and receiver.

II. PREVIOUS WORK

Cahyadi et al. [8] proposes a novel static indoor patient monitoring using Visible Light Communication, where general purpose sensors such as Electrocardiography (ECG) and location sensor collect the patient's health information and transmit that data via a VLC channel to the server. This method focuses on the uplink data transmission system using white LEDs to transfer patient biomedical data to the server. The patient (sender) is considered to be static due to limited movement under health monitoring [8]. The proposed system transmits three preloaded biomedical information for healthcare including ECG, body temperature and photo plethysmogram (PPG), using wireless VLC with On Off Keying (OOK) modulation. Although this method presents an alternative for RF in hospitals, the system only transmits patients' data to the server. The receiver side still has to use RF (Wi-Fi) to access the patients' profile.

Cheong et al. [9] suggests a VLC based downlink indoors network for biomedical transmission and monitoring. This system uses white beam light emitting diodes for both illumination and communication purpose [9]. The light signals are modulated via OOK technique which is the simplest form of amplitude shift keying (ASK) for bandpass data modulation [9]. The On-Off Keying (OOK) uses Non-Return to Zero (NRZ) line coding which utilizes half the bandwidth compared to Return to Zero (RZ) and short pulses [9]. The carrier frequency must be selected higher than a certain level to avoid flickering, in this paper, a carrier frequency of 100 kHz is chosen which satisfies the illumination condition [10].The experimental results of Cheong et al. for transmission of text data and analog physiological with OOK modulation achieves transmission rate of 56 kbps with Bit Error Rate (BER) of 10^{-6}[9].This method presents a viable communication for the hospital personnel to access patients' health profile. Furthermore, unlike other communication methods, this network is entirely based on visible light which reduces the hazards to patients' health and eliminates the RF interference with the hospital instruments. However, the transmission rate achieved is not sufficient to allow the receiver to stream videos or access the Internet.

Dhatchayeny et al. [11] recommends a visible-light communication system for EEG biomedical signal transmission by utilizing three color Red-Green-Blue (RGB) LEDs considering direct line of sight with OOK modulation. The receiver side also uses RGB filters on the photo diodes in order to capture the transmitted signals [11]. In this scheme the processed signals are sent via three parallel data streams in red, green and blue colors of the RGB LEDs to ensure the high efficiency and accuracy [11]. This system provides a highly accurate communication channel through the use of three colors of RGB LEDs with parallel transmission of data. Although this system has the potential of higher speed and accuracy due to parallel transmission, the RGB LEDs cannot be used for illumination purposes. Additionally, the cost of such communication channel would be significantly higher compared to the methods that utilize white LEDs.

This paper proposes a wireless optical communication that makes use of fast switching white LEDs as the transmitter of the data and illumination system of the room. Further, the data rate achieved in the previous work is sufficient for biomedical data but cannot reach transmission rate for video streaming or entertainment purposes.

III. SYSTEM DESIGN

In this paper a room with a size of 5m x5m x 3m for illumination and network layout. The distance between the transmitter and receiver (bed to ceiling) is to be 215 cm (0.85m bed height).This room is modelled in 3D via Dialux evo software that allows to simulate and calculate the lighting specifications such as luminance and power. To monitor patients' health and stability, two biomedical information are transmitted which are ECG and Temperature signals. Further, these signals will be multiplexed with patient information such as name, history and patient number to identify each patient. The data flow of the system can be categorized to uplink and downlink. Uplink is used for uploading patient information and biomedical signals from the patient to the server, shown in Fig.1.

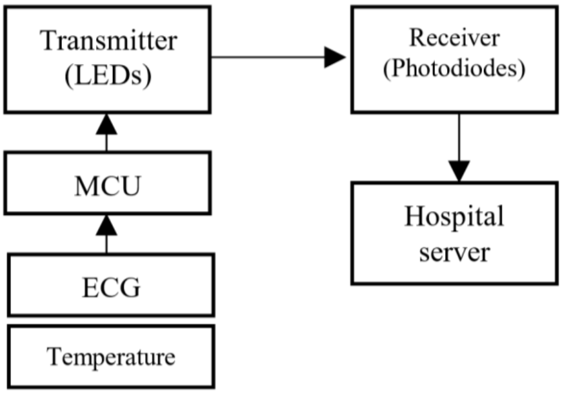

Figure 1Uplink system block diagram

Downlink system supplies both illumination and the patient health monitoring data to the physician's tablet or Laptop. It is also used for entertainment such as video streams, Internet access and other multimedia data as shown in Fig.2.

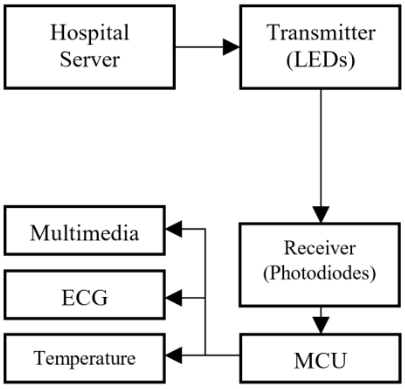

Figure 2 Downlink system block diagram

IV. SIMULATIONS AND RESULTS

A. Optical power distribution

The total received power from the LEDs, ignoring the reflected lights (Non-line of sight), averages about 1 dBm as calculated in MATLAB simulation [10]according to the parameters listed in Table 1. The power distribution is approximately uniform as in the room area as shown in Fig.3.

Table 1 Optical power parameters

Parameters		Values
Room	Size	$5 \times 5 \times 3$ m³
	Reflection coefficient	0.8
Source	Location (4 LEDs)	(1.25, 1.25, 3), (1.25, 3.75, 3), (3.75, 1.25, 3), (3.75, 3.75, 3)
	Location (1 LEDs)	(2.5, 2.5, 3)
	Semiangle at half power (FWHM)	70
	Transmitted power (per LED)	20 mW
	Number of LEDs per array	60×60 (3600)
	Centre luminous intensity	300–910 lx
Receive	Receive plane above the floor	0.85 m
	Active area (AR)	1 cm²
	Half-angle FOV	60
	Elevation	90
	Azimuth	0
	Δt	0.5 ns

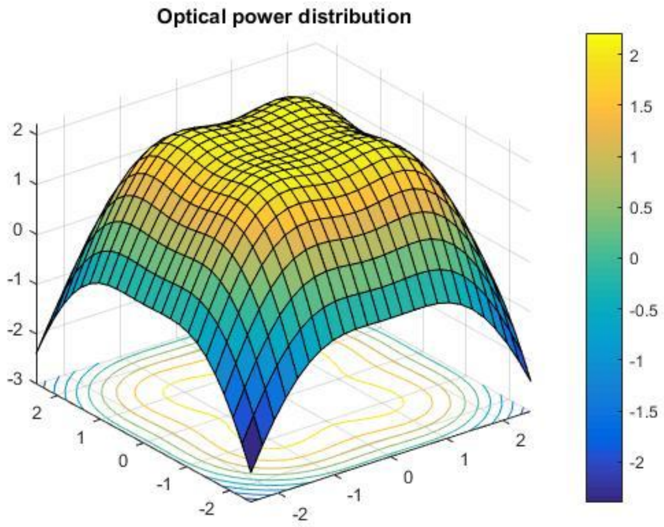

Figure 3 Optical power distribution

The optical power distribution reaches a maximum of 2.3 dBm and a minimum of -2.3 dBm with an average of 1 dBm. This uniformity allows the user to have a relatively constant signal in the room.

B. Distance between transmitter and receiver

In wireless communications, the distance between the transmitter and receiver tremendously affects the quality of the communication signal. According to Equation 1[10], the distance is inversely proportional to the received optical power. Hence, increasing the distance would decrease the received power resulting in lower SNR and higher BER.

$$H(0) = \begin{cases} \frac{(m+1)A}{2\pi D_d^2} \cos^m(\phi) T_s(\psi) g(\psi) \cos(\psi), & 0 \le \psi \le \Psi_c, \\ 0, & \psi > \Psi_c, \end{cases} \quad (1)$$

To visualize the effect of distance, this factor is varied between 1m to 3m in the room. The results of this simulation on MATLAB clearly indicate the decrease in received power as the distance increases. Similarly, the SNR drops significantly resulting in an increasing BER, as shown in Figures 4, 5 and 6.

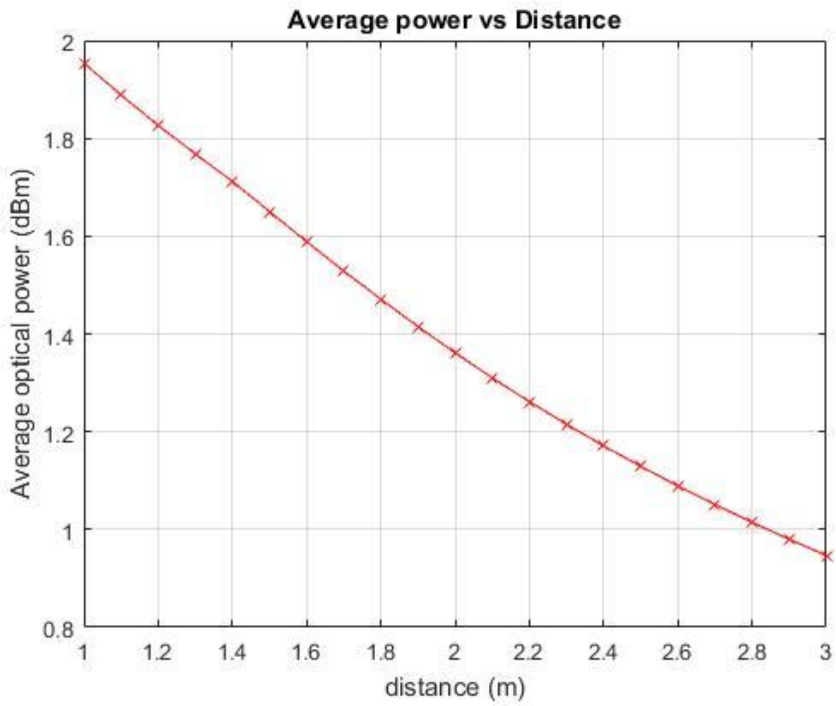

Figure 4 Total Received Optical power vs distance

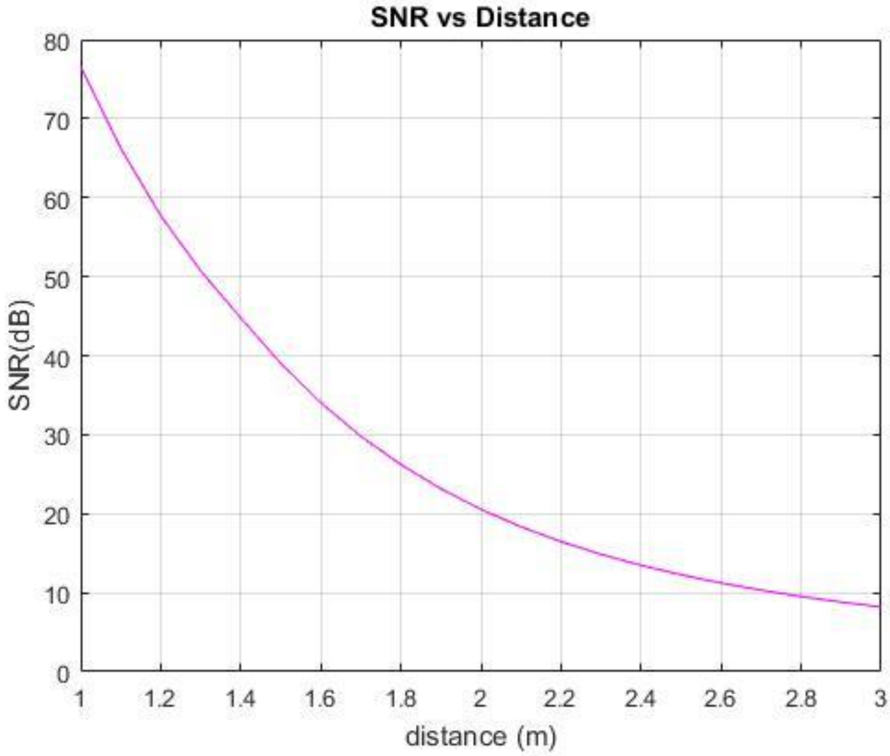

Figure 5 SNR vs Distance

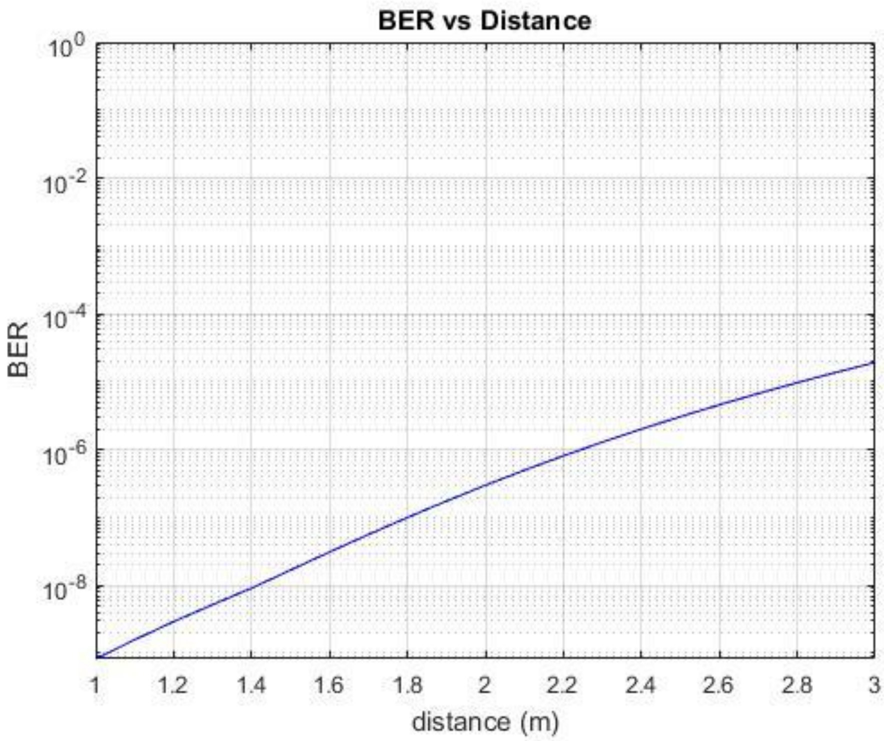

Figure 6 Bit Error Rate vs Distance

In this simulation, only Line of Sight (LOS) power is considered and reflected lights are ignored. It can be observed from the results that with this set of LEDs, the range of a reliable communication can be extended up to 2.4 meters which achieves the minimum accepted SNR level of 15 dB[12]. Relatively, The Bit Error Rate remains about 10^{-6} for the unmodulated signal. However, these parameters can be further modified by increasing the number of LEDs or using higher power LEDs.

C. Signal Modulation

Presently, Direct Detection and intensity modulation is the most popular scheme for OWC systems [10]. OOK falls under the same category. In contrast to RF systems where the modulation can be applied on phase, amplitude and frequency of the carrier signal, optical systems operating below 2.5 Gbps tend to modulate the intensity of the carrier signal [10]. In the MATLAB simulations, the BER and SNR parameters of a communication channel is analyzed for 5 different modulation schemes.

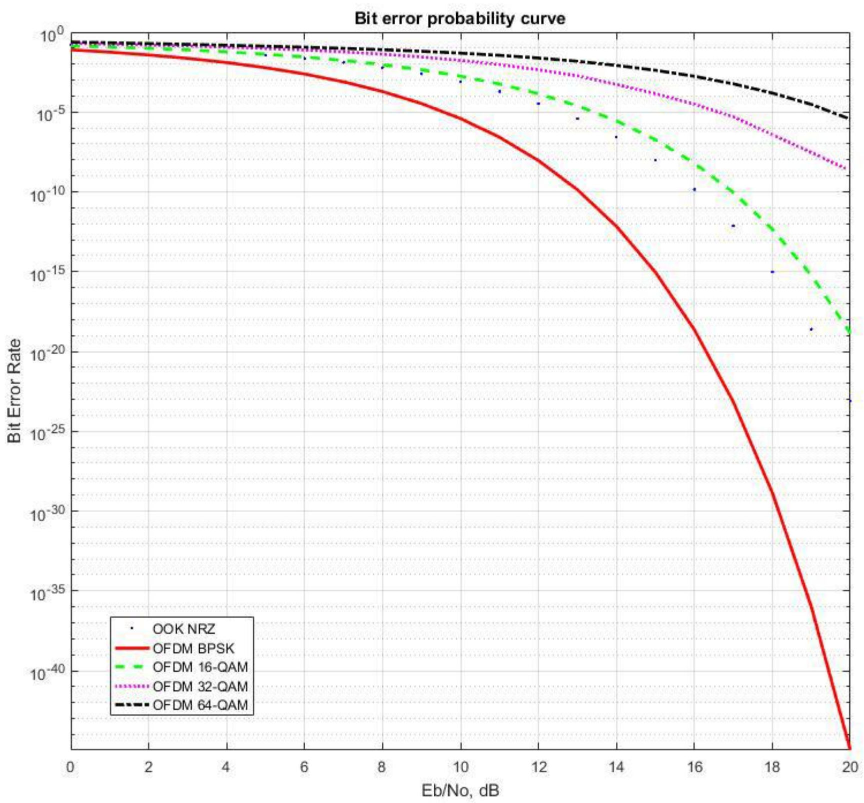

Figure 7 Signal Modulation

As can be seen from Fig.7, OFDM-BPSK results in the least error ratio followed by OOK (NRZ). Although OFDM 32-QAM and 64-QAM can achieve higher data rates compared to the OOK and OFDM BPSK.

D. Transmission Rate

Transmission rate of the network is inversely proportional to the SNR of the signal. This relation can be expressed as[13],

$$SNR = \frac{(R\,P_{rx})^2}{2qR(P_r+P_n)I_2R_b + i^2B_a} \quad (2)$$

Where R is the photodetector responsivity, Prx is the received optical power, q is electron charge, Pr and Pn represent the signal and noise power and Rb is the data rate. Ba, I2 and i refer to noise characteristics[13].
Using the optical power gained in previous sections, data rate simulation on MATLAB shows the maximum achievable transmission rate with an acceptable SNR value of 15-20 dB [12] in Fig.8.

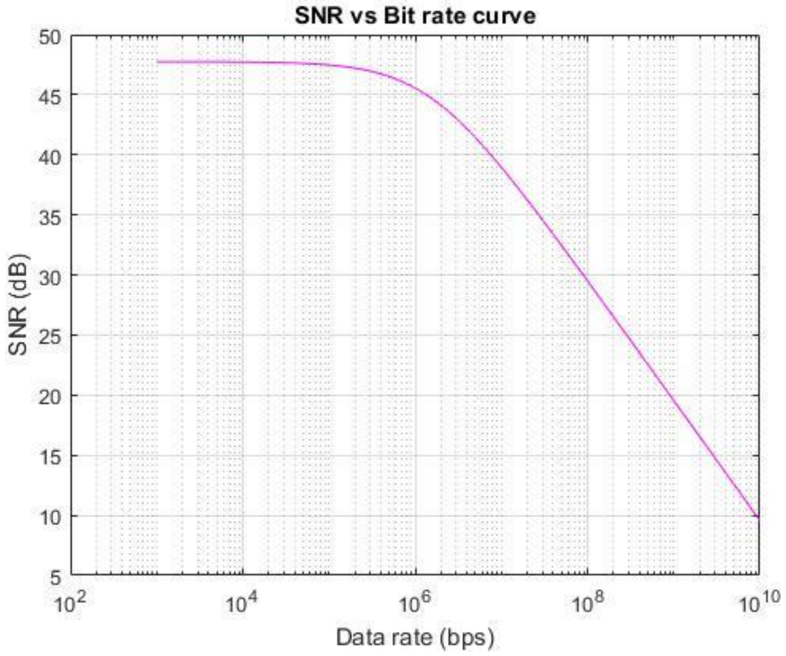

Figure 8 Data Rate simulation

As shown in Fig.8, the data rate is inversely proportional to the SNR of the signal. The SNR remains fairly stable until 1 Mbps and drops significantly after this critical point. Thus a maximum data rate with an accepted quality (SNR=20 dB) of 1 Gbps can be achieved. However, noise reduction techniques, higher optical power and modulation can highly enhance the data rate further.

V. CONCLUSION

In conclusion, based on the following research, Visible-Light communication shows great potential to overtake other communication modes in RF restricted zones in particular. VLC systems can be utilized in Intensive Care Units or Neonatal Intensive Care Units and other hospital rooms where patient health monitoring is essential. The available evidence seem to suggest that VLC systems are highly effective in extending the communication boundaries in such places. Preliminary results achieved shows the importance of the layout and distance between transmitter and receiver in performance of the system. The experimental findings lend support to the claim that optical power drops non-linearly as the distance between transmitter and receiver increases; which leads to lower SNR. Likewise, increasing data rate proves the mathematical equation for a rapid drop of SNR beyond 1 Gbps. Furthermore, an overall investigation on different modulation techniques indicate the lowest error rate of each with respect to data rate and SNR. Although OFDM BPSK achieves the lowest Bit Error Rate (BER), OOK is the most popular modulation scheme due to its simplicity. The system is expected to transmit biomedical data collected by the health sensors and transmit them to the server via white LEDs. Similarly, this network is to provide the patients with an access to the Internet for entertainment purposes.

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