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MOBILE OPTICAL WIRELESS SYSTEM FOR HEALTHCARE CONTINUOUS MONITORING USING IR TECHNOLOGY

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ABSTRACT

In this paper, indoor optical wireless system using Infrared (IR) technology is developed for healthcare monitoring. This to insure the reliability, the security and the mobility of the patient during his/her stay in hospital. Various studies were performed to develop a mobile optical wireless system but using celling bounce model which considers just one reflection and the transmitter has to be pointed to the ground which limits the patient's mobility and movements. In this research, we consider an optical source (LED) coupled with the medical sensor and can randomly change its position within the xy-dimensions of the room and within height varying from 0 to 1.3 m which is the average height of the medical sensor to be put on the body. While the receiver is located on the centre of the ceiling. The line of sight and diffuse propagation links are considered to investigate the capability of the developed system to transmit the health information of the patient to the receiver after undergoing multiple reflections from different walls and objects placed in the room. Using MATLB simulation, the average received power, RMS delay spread, SNR and BER are calculated in order to evaluate the performance and capability of the system with LOS, first and second order reflections for all positions that patient can reach to.

Keywords: *Infrared; Optical wireless; Diffuse; LOS; RMS delay spread; Healthcare monitoring.*

1. INTRODUCTION

Wireless communication has been widely used in healthcare for patient continuous monitoring purpose in last couple of years. This to insure the reliability and the mobility of the patient during his/her stay in hospital [1]. In addition, it increases the safety of the patient, provides fast response and rehabilitation, and enhances the efficiency of the hospital staff. The exiting technology is generally based on radio frequency system (RF) which has several drawbacks when it is used in hospital environment. These drawbacks are mainly caused by the induced electromagnetic interference (EMI) which may cause malfunction to medical equipment, resulting in misdiagnosis, mistreatment and that may lead to dangerous medication[2,3]. Therefore, optical wireless based on infrared (IR) technology was introduced to overcome this problem, since it has several advantages over RF technology. These advantages are immunity to EMI, cost effective, supporting high data rates, operating in free licensed spectrum band, and security [4].

Optical wireless communication can be classified into two main configurations when IR technology is considered in indoor environment. These two configurations are Line Of Sight (LOS) configuration and Diffuse configuration. LOS requires alignment between transmitter and receiver. Therefore, it has better power efficiency and lower multipath dispersion. Besides, it has drawback due to the moving object across the direct path which causes shadowing. Diffuse configuration does not require any alignment between the transmitter and receiver, and instead, make use of reflections from walls, ceiling, and other reflectors. However, diffuse transmission links are usually affected by multipath dispersion (which causes pulse spread and significant ISI), poor power efficiency and higher collection amount of ambient light noise at receiver part [5,6].

In this paper, wireless infrared technology (IR) is investigated in order to ensure the quality of service of the communication channel between the coupled transmitter with the medical sensors which

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are placed on patient's body and the established base station on the ceiling of the hospital. Based on previous studies, first and second order reflections will largely contribute to the receiver optical power, unlike, the third and higher order reflections are ignored due to their small contribution. In this study, we consider that the transmitter can randomly change its position within the xy-dimensions of the room and within height ranging between 0 to 1.3 m which is the average height of the medical sensor to be put on the body. From the simulation analysis and before concluding the reliability of the developed mobile monitoring system. The average received power, RMS delay spread, SNR and BER are calculated to evaluate the performance and capability of the system with first and second order reflections for all positions that patient can reach. The data rate is set to be 10 Mb/s which is enough to transmit the health information of a patient such as ECG, EMG, pulse information and etc. [2].

The paper is organized as follows: in part 2 we describe the developed system. We analyze the received power in part 3. In part 4 we calculate the root mean square delay spread. Part 5 presents the result and analysis of SNR and BER, before concluding in part 6.

2. SYSTEM DESCRIPTION

In this research, LOS and diffuse propagation links are considered to investigate the capability of the system to transmit the health information of the patient to the receiver after undergoing multiple reflections from different walls and objects placed in the room. As shown in Figure 1, we consider an empty room with dimensions of 3x3x3 m^3 and each wall surface was divided into a number of equalled size of reflection elements with area of dA and reflection coefficient ρ. The reflections from windows, doors and objects are considered to be identical to the walls reflections [2]. We consider in our research that the patient will be freely moved within a volume of 3x3x1.3 m^3.

The transmitter part consists of an optical source (LED with eye safety) while the receiver part consists of a photo-detector which is placed on the centre of the ceiling with field of view (FOV) directed downward to the floor.

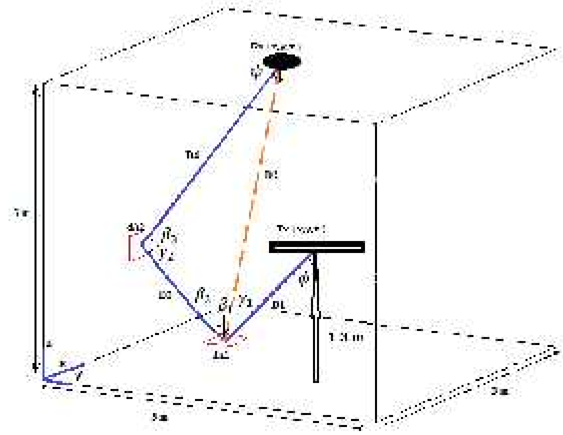

Figure 1: Architecture Of Infrared Diffuse Channel For Patient Monitoring System

3. RECEIVED POWER OF A MOBILE EMITTER

In this model, we consider up to two reflections, which can lead to a reasonably accuracy for the impulse response. Moreover, the third and higher order reflections are ignored due to their small contribution to the overall impulse response. The radiation intensity of the transmitter with a generalized Lambertain radiation can be modelled as:

$$R_0(\phi) = \frac{m+1}{2\pi} P_t \cos^m(\phi)\ , \quad -\frac{\pi}{2} \le \phi \le \frac{\pi}{2} \qquad (1)$$

where m is the Lambertian order of emission which is related to the half power semi-angle and represented as [7]:

$$m = \frac{-\ln(2)}{\ln(\cos \phi_{1/2})} \qquad (2)$$

The system consists of LOS propagation link which represents the direct path between the transmitter and receiver and its channel DC gain can be mathematically calculated as:

$$h(0)_{LOS} = \begin{cases} \frac{m+1}{2\pi D_d^2} A_R T_F(\psi) T_C(\psi) \ldots \\ x \quad \cos^m(\phi)\cos(\psi) & 0 \le \psi \le \psi_C \\ 0 & \psi > \psi_C \end{cases} \qquad (3)$$

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where D_d is the direct distance between the transmitter and receiver. A_R is the physical area of the photo-detector. $T_F(\cdot)$ is the gain of the optical filter. $T_c(\cdot)$ is the gain of the optical concentrator. ¤ is the angle of incidence and ψ is the reception angle. ψ_c donates the width of the field of view at the receiver [4]. The optical concentrator $T_c(\cdot)$ can be given as

$$T_c(\cdot) = \begin{cases} \dfrac{n^2}{\sin^2(\cdot\ c)} & 0 \le \psi \le \psi_C \\ 0 & \psi > \psi_C \end{cases} \quad (4)$$

n represents the refractive index.

Moreover, the channel DC gain for the first and second order reflections are given respectively as [7]:

$$h(1)_{ref} = \begin{cases} \dfrac{(m+1)(m_{element}+1)}{4® ^2 D_1^2 D_2^2} A_R dA_1 °_1 T_F(\cdot) T_c(\cdot) \cos^m(¤)\ldots \\ x \quad \cos(¥_1)\cos^{m_{element}}(\ _1)\cos(\cdot), \quad 0 \le \cdot \le \cdot_c \\ 0 \quad \cdot > \cdot_c \end{cases} \quad (5)$$

$$h(2)_{ref} = \begin{cases} \dfrac{(m+1)(m_{element}+1)^2}{8® ^3 D_1^2 D_3^2 D_4^2} A_R dA_1 dA_2 °_1 °_2 \ldots \\ x\ T_F(\cdot) T_c(\cdot) \cos^m(¤)\cos(¥_1)\cos^{m_{element}}(\ _2)\ldots \\ x \quad \cos(¥_2)\cos^{m_{element}}(\ _3)\cos(\cdot),\ 0 \le \cdot \le \cdot_c \\ 0, \quad \cdot > \cdot_c \end{cases} \quad (6)$$

where D_1, D_2, D_3, D_4, γ_1, γ_2, β_1, β_2 and β_3 are illustrated in Figure 1. ρ_1 and ρ_2 are the reflection coefficients of the first and second surfaces respectively. $m_{element}$ is considered as an ideal Lambertian reflector and equal to 1.

The obtained data using two reflections include three components (1) LOS, (2) first reflection off of floor surface, and (3) second reflection off of floor and all surfaces. The total received power resulting from all components can be calculated as

$$P_R = (h(0)_{LOS} \cdot P_t) + \sum_{n=1}^{N_{element}} (h(1)_{ref} \cdot P_t)_n \ldots + \sum_{n=1}^{N_{element}} (h(2)_{ref} \cdot P_t)_n \quad (7)$$

In which $N_{element}$ is the total number of reflecting element. P_t is the average transmitted power.

TABLE 1: SIMULATION PARAMETERS

Parameters	Values
Room dimensions *(x,y,z)*	3x3x3 *m3*
Reflection coefficient *(ρ)*	Walls, ceiling, floor: 0.8, 0.8, 0.3
Transmitted optical power	300 *mW*
Lambert's order	1
Position of receiver, *Rx* (*x, y, z*)	(1.5,1.5,3.0) *m*
physical area of a photodetector	1.0 *cm2*
Half-angle FOV	70 [*deg.*]
Semi-angle at half power	70 [*deg.*]
Pixel size *(Δx, Δy)*	0.11x0.11 *m*
Gain of an optical concentrator	1
Refractive index of a lens at a photodetector	1.5

In these analyses, the listed parameters in TABLE I were used.

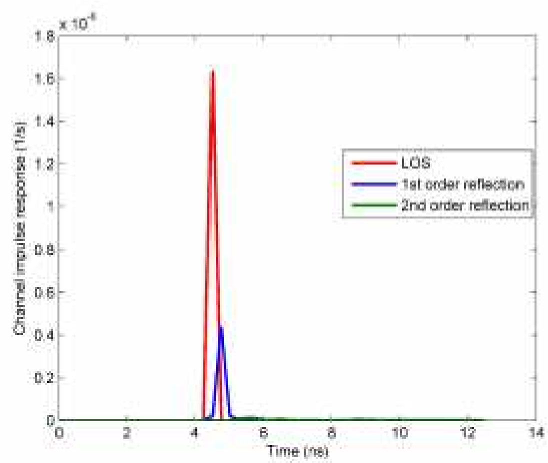

Figure 2: Impulse Response Of All Channels

As shown in Figure 2, the LOS path gives the highest contribution to the overall response, then the first and second order reflections come respectively. Therefore, the impulse responses will decline as the order of reflection increase. Previous studies performed based on the ceiling bounce which consider the first reflection only which lose the contribution of the second reflection [11].

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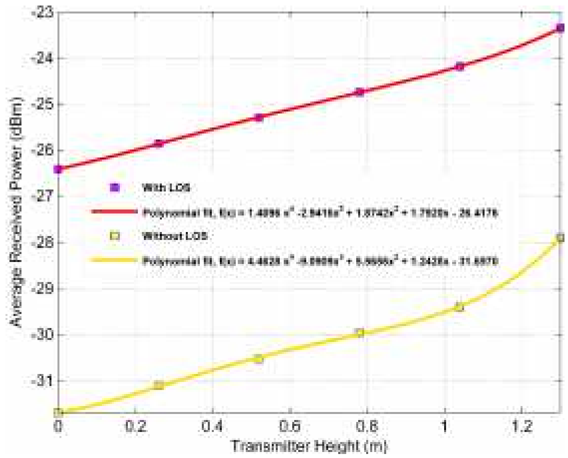


Figure 3: The Average Received Power With LOS Component And Without LOS Component At Different Transmitter Heights.

Figure 3 shows that the average received power increases gradually as the height of the transmitter increased. The obtained data were fitted into a 4th degree polynomial curve fitting. For instance, the average received power in the case of including LOS propagation is -26.4 to -23.4 dBm for all height points ranging from 0 to 1.3 m. The generated polynomial equation for that particular case is:

$$y_{p,LOS} = 1.41x^4 - 2.94x^3 + 1.87x^2 + 1.79x - 26.42 \quad (8)$$

In which y_p is the predictable average received power. x is the transmitter height.

For the case of excluding LOS propagation, the average received power is -31.7 to - 27.9 dBm and the obtained polynomial equation is:

$$y_{p,nLOS} = 4.46x^4 - 9.10x^3 + 5.57x^2 + 1.24x - 31.70 \quad (9)$$

The average received power with LOS component is about -5 dBm larger than the case of excluding LOS.

By looking to the residuals for both curves as shown in Figure 4, it is illustrated that both equations have good accuracy, although eq.8 performs better than eq.9. The highest residual values for eq.8 and eq.9 are at transmitter height of 0.52 m and 0.78 m which are equal to 0.012 and 0.039 respectively.

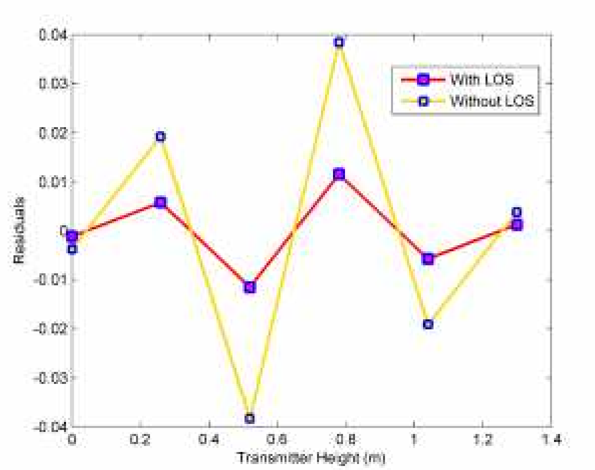


Figure 4: Residuals For Eq.8 And Eq.9

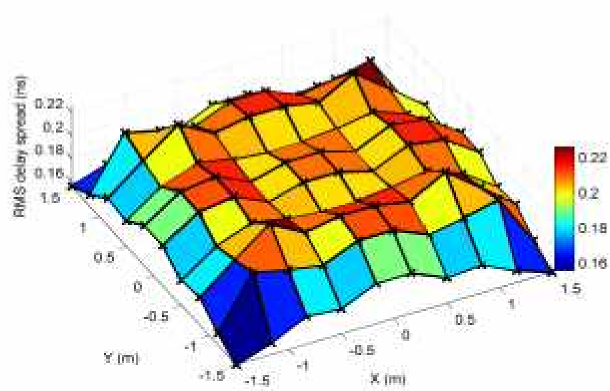
4. ROOT MEAN SQUARE DELAY SPREAD

RMS delay spread defines the delay of reflections. Taking into account the LOS path, first order reflections and second order reflections. The RMS delay spread is computed using the impulse response h(t) as follows [8,9]:

$$D_{rms} = \left[\frac{\int (t-\mu)^2 h^2(t)dt}{\int h^2(t)dt} \right]^{1/2} \quad (10)$$

where μ , the mean delay spread and calculated as:

$$\mu = \frac{\int t h^2(t)dt}{\int h^2(t)dt} \quad (11)$$



(a)

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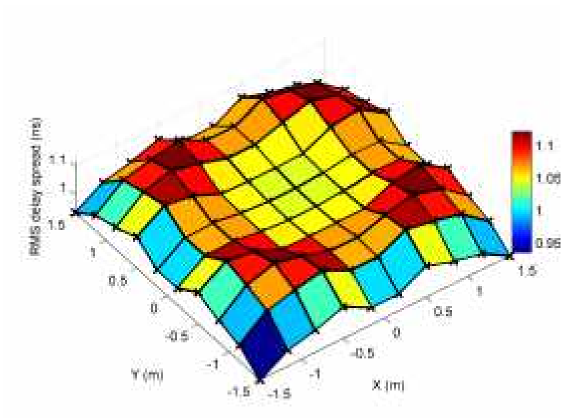


(b)

Figure 5: Distribution Of RMS Delay Spread: (A) With LOS Component (B) Without LOS Component

Figure 5(a) and (b) obtain the RMS delay spread versus width and length of the room for measured multipath channels. The channels without LOS path suffer of higher delay spread because the power received of LOS component is much stronger than the received power of the first and second order reflections. Therefore, in the presence of LOS component, the RMS delay spread is ranging from 0.16 ns to about 0.22 ns. Unlike, in the case of absence of LOS path where the RMS delay spread is slightly increasing to a range of 0.95 ns to about 1.1 ns. Since the maximum value of RMS delay is 1.1ns, thus maximum acceptable bit rate that can be transmitted within the channel without requiring equalizer is about 91 Mb/s. the relationship between the maximum bit rate and the RMS delay is given as [4,10]:

$$R_b \leq \frac{1}{10 \cdot D_{rms}} \qquad (12)$$

5. SYSTEM ANALYSIS AND PERFORMANCE OF SNR AND BER

The intensity modulation and direct detection (IM/DD) scheme is employed to transmit the patient data which means that the signal received by the photo detector is mainly depended on the incident optical power and the detector sensitivity *R*. The IR channel with received signal *y*, channel gain state *H* and Additive White Gaussian Noise *n* can be modelled as [7]:

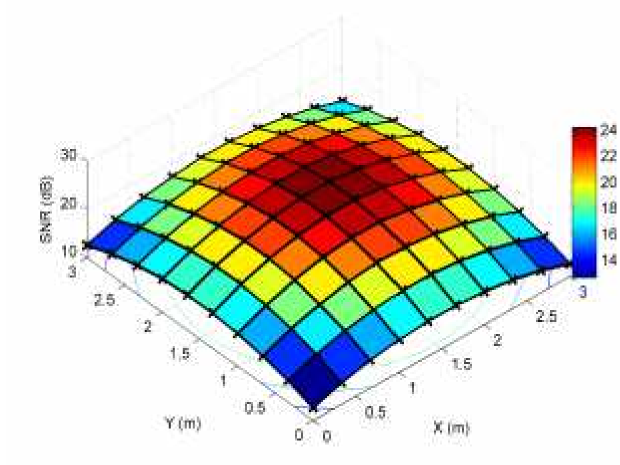
$$y = R.H.\, x + n \qquad (13)$$

where *x* is the input signal.

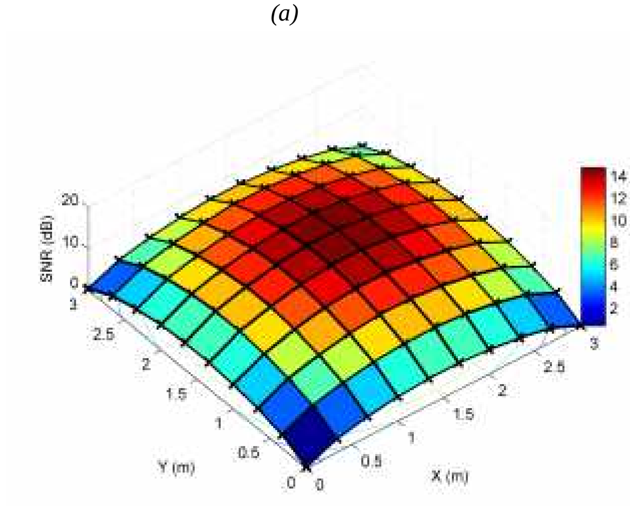
For the OOK modulation, symbols are transmitted over the Infrared channel. And the electrical SNR of equiprobable symbols such as $x \in \{0,2Pt\}$ at the reception is defined as

$$\text{SNR} = \frac{R^2 H^2 2P_t^2}{R_b N_0} \qquad (14)$$

where R_b is the data rate. N_0 is the shot noise since it is considered as the dominant noise source $N_0 = 2I_b q = 6.4\text{x}10^{-23}$ W/Hz, by considering $I_b = 200$ µA and $q = 1.6\text{x}10^{-19}$ C [11].



(a)



(b)

Figure 6: Distribution Of SNR For All Channels: (A) With LOS Component, (B) Without A LOS Component.

The SNR can determine the quality of the developed communication system. As a result, Figure 6 (a) shows the performance of all channels including LOS component. The minimum SNR value is 14 dB and its maximum value is 24 dB. On the other hand, Figure 6 (b) represents the

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distribution of SNR with no LOS component which gives SNR values ranging from 2 dB to 14 dB. From these two obtained cases, case (a) has better performance than case (b) because case (a) includes LOS component which generates stronger signal due to the direct path between the transmitter and receiver. Furthermore, the received power is inversely proportional to the direct and indirect distances between the transmitter and receiver

Moreover, the BER (bit error rate) for OOK modulation is given as

$$BER = Q \cdot \sqrt{2 \cdot SNR} \quad (15)$$

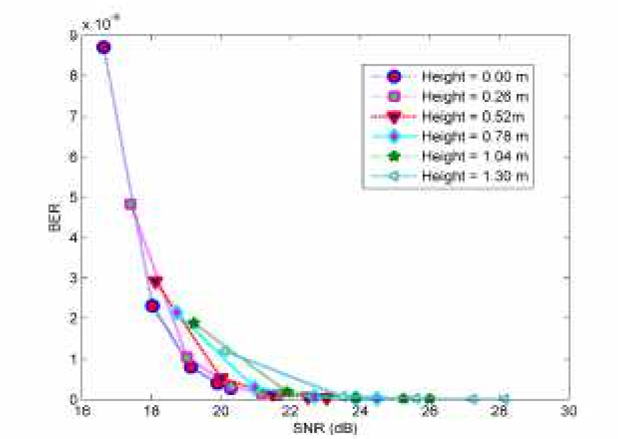

Figure 7: SNR Vs. BER For Different Heights

Figure 7 shows the relationship between the BER and SNR. The transmitter height is taken into account and varied from 0 m to 1.3 m. by increasing the value of transmitter height, better SNR and BER are achieved. In this case, LOS component was considered in obtaining the results.

We have evaluated the performance of the developed system based on NZ-OOK modulation. The achieved BER for different positions of the transmitter is reduced as the transmitter height increases from 0 to 1.3 m throughout the room. The best achieved BER is equal to 10^{-9} at height of 1.3 m for data rate of 10 Mb/s which is enough to transmit the medical information (EEG, ECG and etc.). Noting that, the acceptable BER level in optical communication is 10^{-9} and below.

6. CONCLUSION

In this paper, we have reported an optical wireless communication system that tends to enhance the efficiency of the hospital staff. Through the simulation, we investigated the average received power at different transmitter heights and showed the effect at each height point. Then we analysed the distribution of SNR and RMS delay spread within the room. Moreover, we analysed the of the transmitter height on the bit error rate. The overall performance of the system has improved to the acceptable level, and the direction of the transmitter has become more mobile by considering different directions.

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REFRENCES:

[1] M. Paksuniemi, H. Sorvoja, E. Alasaarela, and R. Myllyla "Wireless sensor and data transmission needs and technologies for patient monitoring in the operating room and intensive care unit," *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the* , vol., no., pp.5182,5185, 17-18 Jan. 2006

[2] A.M, Khalid, G. Cossu, and E. Ciaramella, "Diffuse IR-optical wireless system demonstration for mobile patient monitoring in hospitals," *Transparent Optical Networks (ICTON), 2013 15th International Conference on* , vol., no., pp.1,4, 23-27 June 2013

[3] J. B. Carruthers, and P. Kannan, "Iterative site-based modeling for wireless infrared channels," *IEEE Transactions on Antennas and Propagation*, vol. 50, pp. 759–765, May 2002

[4] H.Q. Nguyen, J. Choi, M. Kang, Z. Ghassemlooy, D.H Kim, S. Lim,T. Kang, and C.G. Lee, "A MATLAB-based simulation program for indoor visible light communication system," *Communication Systems Networks and Digital Signal Processing (CSNDSP)*, 2010 7th International Symposium on , vol., no., pp.537,541, 21-23 July 2010

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[5] R. J. Green, H. Joshi, M. D. Higgins, and M. S. Leeson, "Recent developments in indoor optical wireless systems," *IET Communications,* vol. 2, pp. 3-10, 2008.

[6] S. Jivkova and M. Kavehrad, "Indoor wireless infrared local access, multi-spot diffusing with computer generated holographic beam-splitters," in *Communications, 1999. ICC '99. 1999 IEEE International Conference on*, vol. 1, pp. 604-608,
1999.

[7] J.M. Kahn, and J.R. Barry,"Wireless infrared communications," *Proceedings of the IEEE* , vol.85, no.2, pp.265,298, Feb 1997.

[8] B. Carruthers, S. M. Caroll, and P. Kannan, "Propagation modelling for indoor optical wireless communications using fast multi-receiver channel estimation," *IEE Proceedings-Optoelectronics,* vol. 150, pp. 473-481, 2003.

[9] Z. Ghassemlooy, W.O. Popoola, and S. Rajbhandari,"Optical Wireless Communications – System and Channel Modelling with Matlab," *CRC publisher*, USA, August 2012.

[10] Y. Tanaka, T. Komine, S. Haruyama and M. Nakagawa, "Indoor Visible Light Data Transmission System Utilizing White LED Lights," *IEICE Trans. Commun*. **E86-B,** 2440-2454 (2003).

[11] S.S. Torkestani, N. Barbot, S. Sahuguede, A. Julien-Vergonjanne, and J.P. Cances, "Performance and transmission power bound analysis for optical wireless based mobile healthcare applications," *Personal Indoor and Mobile Radio Communications (PIMRC),* 2011 IEEE 22nd International Symposium on , vol., no., pp.2198,2202, 11-14 Sept. 2011