International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 8, pp: 409-414 www.ijaem.net ISSN: 2395-5252

Channel Modeling for Wireless Optical Communication Systems

[1]Professor, Ameeta G. Sinai Amonkar, [2]Student, Depika Satish Prabhu,
Goa College of Engineering, Farmagudi, Ponda
Goa College of Engineering,Farmagudi, Ponda.

Date of Submission: 15-10-2020 Date of Acceptance: 02-11-2020

ABSTRACT: Radio Frequency (RF) portion of the electromagnetic (EM) spectrum has been in use for many years making it congested. New technologies demanding for high data rate and capacity services may not be satisfied by this finite spectrum and so a shift to Optical spectrum is required. For designing and implementation of optical wireless transmission systems, it is crucial that the characteristics of the channel are understood. Also for performance estimation in optical wireless communication (OWC), a precise evaluation of link behavior is important. Therefore accurate and efficient channel modelling is of importance for optical wireless communication link design. This paper first explores the optical channel characteristics that affect the link performance. Furthermore, a survey on various channel models accessible for indoor OWC systems is provided here. In addition, considering the line of sight (LOS) channel scenario a propagation model using Lambertian radiation is presented here. Also we have used LOS propagation model to estimate the channel impulse response (CIR) and DC gain for visible light communication (VLC) system. The results obtain show that CIR is approximately 3.86×10^{-6} for optical pulse sent from transmitter to the receiver and the power reaching the receiver emitted from continuous signal which is given as the DC gain is found to be 7.4×10^{-6}. Therefore modeling approach for VLC system having LOS propagation offered more convenient performance outcome.

KEYWORDS: Channel model, Deterministic model, LOS, Non-line of sight (NLOS), OWC and stochastic model.

I. INTRODUCTION

Currently, radio frequency is broadly used across various wireless applications which limit the power and bandwidth resources in these modern communication systems. There have been RF crisis, since demand for higher data rates continued to increase while the spectral efficiency is being saturated [1]. With the arrival of high-power light emitting diode and extremely sensitive photodiodes (PDs), OWC has become a practical medium for transmission of data [2]. In comparison with RF, OWC offers a flexible networking solution that delivers the essential combination of virtues necessary to bring the high-speed circulation to the optical fiber support, which is offering a free-license spectrum with almost an unlimited data rate, a low cost of development and ease and speediness of installation [3]. Also various technologies using different optical sub-bands have emerged [1][4]. In this paper, Section 2 delivers the channel characteristics required for evaluation of OWC system. Section 3 provides a survey on existing work based on various channel models. Considering the channel scenario, a LOS propagation model is presented in the Section 4. Within Section 5, the analysis of LOS and VLC system using LOS are discussed. Lastly concluding remarks are stated in Section 6.

II. CHANNEL CHARACTERISTICS

In optical wireless communication, to design and implement a system, the characteristics of channel must be known. Channel characteristics depend on the environment of communication and the orientation of the optical transmitter and receiver. Following is the brief explanation of major characteristics required for wireless optical channels [5].

Channel Impulse Response: Representation of a communication system is given by its channel impulse response. CIR is change in time of the signal received by optical receiver for every small optical pulse sent from the source.

Channel DC gain: A small amount of power emitted from a continuous wave transmitter that is detected by the receiver is referred as channel DC gain H(0)

Delay RMS spread: In NLOS and diffuse configuration optical signal takes various paths to reach a receiver and this multipath occurs due to

International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 8, pp: 409-414 www.ijaem.net ISSN: 2395-5252

different objects present in the surrounding of the transmitter. Due to multipath reflection the overall received signal acts as sum of delayed replicas of transmitted signal.

Optical Path Loss (PL) and Shadowing: Path loss due to large scale fading and optical shadowing is considered as primary characteristics for wireless optical communication channel. Optical shadowing occurs if any obstruction such as object or person blocks the path between optical transmitter and receiver.

III. CHANNEL MODELS

There are various channel models that measures the different characteristics for channel configurations. The channel models are categorized into two types deterministic and stochastic as shown in figure 1[5]. Deterministic models have acknowledged set of inputs which will produce distinctive set of outputs. Stochastic simulation model holds one or more than one random variables as inputs. Different deterministic approach includes, Recursive, Iterative, Dustin algorithm and Ceiling Bounce model (CBM) and the stochastic model can be further categorized into geometry based and non-geometry stochastic models. Monte Carlo algorithm, spherical model and modified ceiling bounce (MCB) model are types of stochastic model. This review highlights various models used to evaluate the channel characteristics of the optical wireless system.

Recursive and Iterative Model

Barry et al. proposed a work on wireless optical channel for indoor situation using the recursive model [6]. Here recursive model approach was used to evaluate channel impulse response h(t) (CIR) of multipath in wireless infrared communication system. In [6], an empty rectangular room, of configuration with different dimensions for both line of sight and diffuse scenarios were considered to calculate the multi-bounce impulse response. Up to three order reflections were measured and it was seen that total power decreases for higher order impulse response. Toshihiko Komine and Masao Nakagawa proposed optical wireless communication indoor system using white LED lighting [7][8]. This was extended work for Barry's model for non-line of sight visible light communication network to allow use of existing power line network [7]. In [8] up to two reflections were considered to estimate the ratio of effect of signal over noise along with the receiver field of view was also discussed.

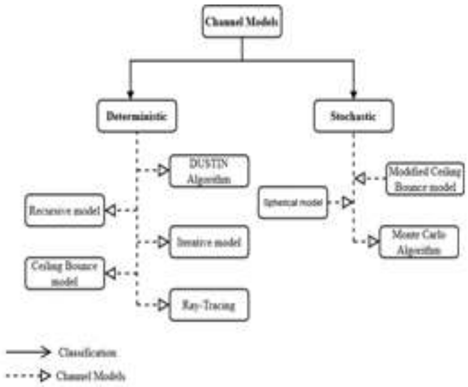


Fig. 1. OWC Channel Models

In[9], Fang Li et al introduced a cut down method for impulse response using recursive algorithm. Here, an empty room with reflection of three bounces is considered which offers a result of 22.7% decrease in impulse response for first reflection, 35.3% in second reflection and third reflection decline closely by 50% in comparison with classical recursive algorithm. Authors in [10] presented an improved recursive model for room environment VLC system which was used to analyze better inter-symbol-interference in VLC system application. A VLC recursive model for underground application is considered in [11] for estimation of path loss, Delay RMS and effect of shadowing.

Jeffrey B. Caruthers and Prasanna Kannan proposed a method for estimating channel impulse response of optical wireless infrared communication [12]. In this method CIR is calculated for multiple reflections in an indoor atmosphere for configurations mentioned in [6].

Dustin Algorithm

F.J. Lopez-Hernandez and M.J. Betancor developed an efficient and faster simulation model on infrared wireless indoor channel for the result of impulse response [13]. An vacant room is considered with diffuse form of channel scenario. In this algorithm the simulation of is sliced into time steps and not into number of reflections. This approach is not proficient of adapting different environment.Ceiling Bounce Model (CBM) and MCBM.

Zhongpeng Wang and Shoufa Chen proposed a Discrete Fourier Transform pre-coding scheme peak average power ratio decline in visible light orthogonal frequency-division multiplexing by means of this model for accurate representation of multipath dispersion in indoor OWC system [14]. Smitha et al. developed a model for estimation of impulse response by means of MCBM for non-

International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 8, pp: 409-414 www.ijaem.net ISSN: 2395-5252

directed indoor wireless optical system. Here the existing CBM is modified by combining it with DC gain computation & statistical model. Also a model for computing the more precise impulse response along with path loss and delay spread by means of MCBM [15][16].

Monte Carlo Algorithm and Ray tracing

Dimitrov et al. proposed a work on optical wireless system using the infrared band for path loss simulation in aircraft cabin[17]. Monte Carlo ray tracing, for both line of sight and non-line of sight, is used to determine the optical shadowing and path loss component. For LOS, path loss is estimated to be 1.92 and shadowing deviation to be 0.81dB and for NLOS, both path loss and optical shadowing varies. A reflection model using Lambert Phong, which is based on Monte Carlo ray tracing, is presented in[18]. Miramirkhani et al. developed a realistic mobile channel model for optical light communication[19]. Channel modeling is introduced on ray tracing feature of Zemax. Also in [20] a 3-D indoor atmosphere is constructed using Zemax software and presented into Matlab to obtain channel impulse result for the particular environment. A Monte Carlo model for multipath scattering to estimate impulse response ad channel path loss is presented in[21]. The model is analyzed and improved using sampling method providing higher computation efficiency.

Spherical Model

Su-il Choi presented a work on visible light communication setup using spherical model for white light LED lighting [22]. Here, signal to noise ratio, wireless optical channel bandwidth and inter-symbol interference is assessed. A room size of 5×5×3 m^3 with two types of LED configuration, placed at height of 2.5m and covering about 90% to 92% of the receiver field of view was considered. Type A and B gives a 3dB cutoff at 88.9MHz and 96.7 MHz respectively. Spherical model approach was offered to model wireless infrared communication system channels employing diffused channel scenario. For higher order reflections the reliability of this model was given by stochastic based ray tracing approach[23]. In[24], the authors analyzed the accurateness of the model in comparison to Barry's model for indoor system using VLC with distributed array source.

According to the analysis, in recursive modelling approach the computational time given as $N^k$and with time it increases exponentially. The maximum number of reflections considered are 3 and 4 bounce is not possible due to effect of path loss [6]-[11]. Reliability of recursive approach advances with the number of bounces, but accuracy is very less. It has been reported that for 3 bounces, iterative site-based model has very less computational complexity and is about 92 times faster compared to recursive model. More than 3 reflections are feasible using this method [12]. Dustin algorithm was developed to decrease the computational complexity in comparison with previous two models. Simulation in this approach is done by slicing the time steps. Drawback of Dustin algorithm is that it cannot adapt different environments [13].

Ceiling bounce is simple channel model and gives a close result for path loss, CIR and RMS delay in indoor environment. This method provides excellent similarity with the data measured and mostly employed in VLC systems due to ease of use. MCBM is similar to CBM but with more accuracy of channel impulse response with less computational complexity[14]-[16]. The ray tracing method computes all rays reaching the receiver making it more time consuming. Ray tracing is also known as site-specific model as it requires thorough depiction about the environment. Monte Carlo model was developed for better evolution of impulse response for lambertian and specular reflections. It is employed through generation of rays, wall processing and photo- detector response. Simulation time for Monte Carlo approach is less in comparison with recursive and Dustin channel model. Drawback of this method is that, number of rays send are more than rays received at optical receiver[17]-[21]. The spherical channel model considers all the higher order reflections providing better reliability. Estimation of impulse response is high for diffuse configuration using spherical model[22]-[24].

IV. CHANNEL CONFIGURATIONO

Spropagation model

systems uses LED as source and large area photo detectors. Angular dispersion of the radiation intensity pattern is modeled using lambertian radiant intensity with following distribution.

$$Ro(\emptyset) = \begin{cases} \frac{(m+1)}{2\pi} \cos^m(\emptyset); \emptyset \in [-\pi/2, \pi/2] \\ 0 \qquad ; \emptyset \geq \pi/2 \end{cases} \quad (1)$$

m= lambert's mode number expressing directivity of source beam.

Ø=0, is angle max radiated power.

$$m = \frac{-\ln 2}{\ln(\cos\emptyset)} \quad (2)$$

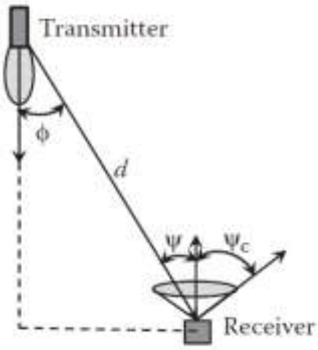


Fig. 2. Geometry LOS propagation model [3]

Lambertian emission 'm' is related to LED semi angle at half powerØ. Mode numberm$_l$ specify the directionality of light source, where higher 'm' means higher directionality of the optical light source. $\emptyset_{\frac{1}{2}}$ is the angle of half-power emission of the LED, namely □ □it is the view angle when radiant power is half of the intensity value at 0^o. Detector active area $A_r$collects incident radiations at angles φ(smaller than detector FOV). Effective area of detector is given by

$$A_{eff}(\psi) = \begin{cases} A_r\cos\psi & 0 \le \psi \le \frac{\pi}{2} \\ 0 & \psi > \frac{\pi}{2} \end{cases} \quad (3)$$

Optical gain of is given by

$$g(\psi) = \begin{cases} \frac{n^2}{\sin^2\Psi_c} & 0 \le \Psi \le \Psi_c \\ 0 & \Psi > \Psi_c \end{cases} \quad (4)$$

Consider OWC link with Lambertian transmitter, a receiver of transmission with an optical band pass filter $T_s(\varphi)$ and non-imaging concentrator at the receiver of gain g (φ). The gain of direct current for a receiver positioned at a distance d and angle φ w.r.t transmitter.

$$H_{LOS} = \begin{cases} \frac{A_r(m_l+1)}{2\pi d^2}\cos^{ml}\emptyset T_s(\psi)\, g(\Psi)\cos\Psi & 0 \le \Psi \le \Psi_c \\ 0 & elsewhere \end{cases}$$

Received power therefore becomes

$$P_{r-los} = H_{los}(0)P_t \quad (5)$$

When transmitter and receiver are aligned, the LOS signal is specified by

$$H_{los}(m) = \frac{(m+1)}{2}H_{los} \quad (6)$$

Optical LOS impulse response can be stated as

$$H_{los} = \frac{A_r(m_l+1)}{2\pi d^2}\cos^{ml}\emptyset T_s(\psi)\, g(\Psi)\cos\Psi\,\delta\left(\frac{-d}{c}\right)$$

Where c is the velocity of the light in free space, δ (.) is the Dirac function and δ (t − d/c) signifies the signal propagation delay. The expression assumes certain values to be ϕ < 90° and ψ < FOV and d ≫A.

Visible Light Communication (VLC)

VLC is a technology that uses the unregulated spectrum band between 380 and 780nm and offers a vast potential of high speed communication applications. Data transmission and illumination, both can be provided by VLC [25]. The impulse outcome of the VLC system is given by

$$H_{los} = \left(\frac{Apd}{hdist^2}\right) * \cos(Incidence) * R_0 \quad (7)$$

V. RESULT ANALYSIS

A room measurement of 5 m ×5 m× 3 m with the distance between the source and the receiver plane is 2.15m .The transmitter is at semi angle of 60^0 and FOV and region of the detector are 60(π/180) and 10^{-4} respectively. Channel characteristics estimated are impulse response and DC gain. Channel impulse response is the signal received by the optical receiver when a short pulsate is directed from the optical transmitter and DC gain is the amount of power emitted from a continuous wave transmitter that is identified by the receiver.

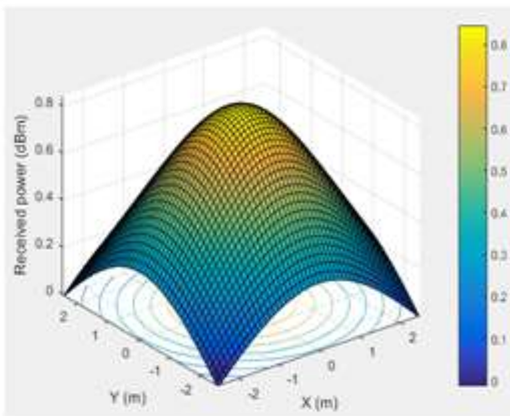
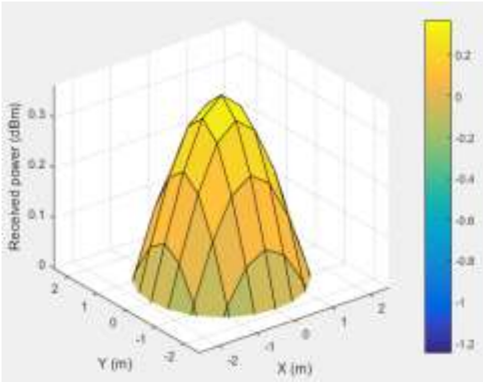


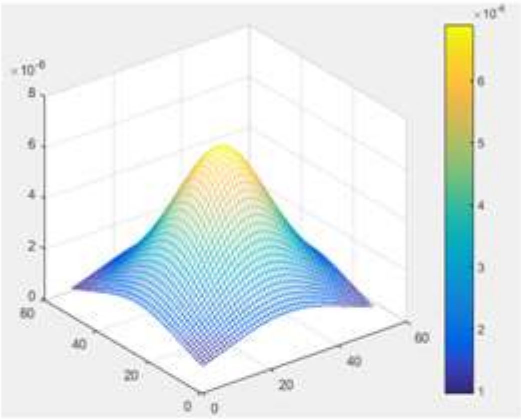
Fig. 3. (a) LOS Power received at height of 2.15m between OTX and ORX (in dB).
Fig. 4.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 8, pp: 409-414 www.ijaem.net ISSN: 2395-5252



(b) Maximum power received.

Figure 3a and 3b shows the received power by the detector and it can be seen that the room has been well lit within the standard illumination levels. The power radiated (in dB) is more concentrated at [XT, YT] =0 for height of 2.15m and the radiated power is equally distributed on the area of the optical receiver.



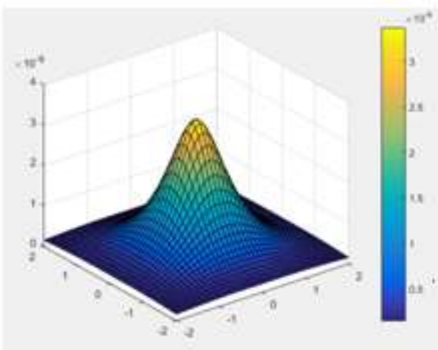


Fig. 5. DC gain at the optical receiver

Fig. 6. Impulse Response of the VLC system

For VLC system a room of 4m×4m×2m with transmitter field of view to be 70^0 is considered. The area of photo-detector and the receiver field of view is 10^{-4} and 90^0 respectively. Figure 4 shows the dc gain. The impulse result of visible light communication system using line of sight is displayed in figure 5. The time evolution of the signal received by optical receiver in visible light communication technique is approximately 3.86µs.

REFERENCES

[1]. M. Z. CHOWDHURY, M. T. HOSSAN, A. ISLAM and Y. M. JANG, "A Comparative Survey of Optical Wireless Technologies: Architectures and Applications," IEEE Access, vol. 6, p. 22, 2018.

[2]. O. Alsulami, A. T. Hussein, M. T. Alresheedi and J. M. H. Elmirghani, "Optical Wireless Communication Systems, A Survey," research gate, p. 22, 2018.

[3]. Z. Ghassemlooy, W. Popoola and S. Rajbhandari, Optical Wireless Communication, system and channel modelling, New York: CRC Press, 2019.

[4]. S. Riurean, T. Antipova, Á. Rocha, M. Leba and A. Ionica, "VLC, OCC, IR and LiFi Reliable Optical Wireless Technologies to be Embedded in Medical Facilities and Medical Devices," Journal of Medical Systems, pp. 1-10, 2019.

[5]. A. Al-Kinani, C.-X. Wang, L. Zhou and W. Zhang, "Optical Wireless Communication Channel Measurements and Models," IEEE COMMUNICATIONS SURVEYS & TUTORIALS, vol. XX, no. NO. X, pp. 1-24, 2018.

[6]. J. R. Barry, J. M. Kahn, W. J. Krause,, E. A. Lee and D. G. Messerschmitt, "Simulation of Multipath Impulse Response for Indoor Wireless Optical Channels," IEEE, vol. 11, p. 13, 1993.

[7]. T. Komine and M. Nakagawa, "Integrated System of White LED Visible-Light Communication and Power-Line Communication," IEEE, vol. 49, p. 9, 2003.

[8]. T. Komine and M. Nakagawa,, "Fundamental Analysis for Visible-Light Communication System using LED Lights," IEEE, vol. 50, p. 8, 2004.

[9]. F. Li, X. Li, W. Zou and J. Chen, "Simplified calculation method of indoor optical impulse response based on recursive algorithm," IEEE, p. 5, 2012.

[10]. G. Ren, S. He and Y. Yang, "An Improved Recursive Channel Model for Indoor Visible light communication Systems," Information Technology journal, vol. 12, p. 7, 2013.

[11]. J. Wang, A. Al-Kinani, W. Zhang, C.-X. Wang and L. Z. , "A general channel model for visible light communications in underground mines," China Communications, vol. 15, no. 9, pp. 1-11, 2018.
[12]. J. B. Carruthers, and P. Kannan, "Iterative Site-Based Modeling for Wireless Infrared Channels," IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, vol. 50, p. 7, 2002.
[13]. F. Lopez-Hernandez and M. Betancor, "DUSTIN: Algorithm for calculation of impulse response on IR wireless indoor channels," IEEE, vol. 33, no. 21, p. 3, 1997.
[14]. Z. Wang and S. Chen, "Grouped DFT Precoding for PAPR Reduction in Visible Light OFDM Systems," International Journal of Electronics Communication and Computer Engineering, vol. 6, no. 6, p. 4, 2015.
[15]. K. SMITHA, A. SIVABALAN and J. JOHN, "Modified Ceiling Bounce Model for Computing Path Loss and Delay Spread in Indoor Optical Wireless Systems," Int. J. Communications, Network and System Sciences, vol. 2, p. 5, 2009.
[16]. K. Smitha, A. Sivabalan and J. John, "Estimation of Channel Impulse Response Using Modified Ceiling Bounce Model in Non-Directed Indoor Optical Wireless Systems," p. 10, 2007.
[17]. S. Dimitrov, R. Mesleh, H. Haas, M. Cappitelli, M. Olbert and E. Bassow, "Path Loss Simulation of an Infrared Optical Wireless System for Aircraft," IEEE, pp. 1-6, 2009.
[18]. D. De-qiang and K. Xi-zheng, "A new indoor VLC channel model based on reflection," vol. 6, no. 4, pp. 1-4, 2010.
[19]. F. Miramirkhani, O. Narmanlioglu,, M. Uysal and E. Panayirci,, "A Mobile Channel Model for VLC and Application to Adaptive System Design," IEEE, pp. 1-4, 2016.
[20]. E. Sarbazi, M. Uysal, M. Abdallah and K. Qaraqe, "Ray Tracing Based Channel Modeling for Visible Light Communications," in IEEE 22nd Signal Processing and Communications Applications Conference, 2014.
[21]. J. M. P. S. Y. D. C. Renzhi Yuan, "Monte-Carlo Integration Models for Multiple Scattering Based Optical Wireless Communication," IEEE Transactions on Communications, vol. 68, no. 1, p. 15, 2019.
[22]. S.-i. Choi, "Analysis of VLC Channel Based on the Shapes of White-Light LED Lighting," in 2012 Fourth International Conference on Ubiquitous and Future Networks (ICUFN), Phuket, Thailand, 2012.
[23]. V. Jungnickel, V. Pohl, S. Nönnig and C. v. Helmolt, "A Physical Model of the Wireless Infrared Communication Channel," IEEE, vol. 20, p. 10, 2002.
[24]. J. Ding, K. Wang and Z. Xu, "Accuracy Analysis of Different Modeling Schemes in Indoor Visible Light Communications with Distributed Array Sources," in 9th International Symposium on Communication Systems, Networks & Digital Sign, 2014.
[25]. J. L.-R. G. J. R. R. P.-J. L.-H. A.M. Ramirez-Aguilera, "A Review of Indoor Channel Modeling Techniques for Visible Light Communications," Guadalajara, Mexico, 2018.