An Indoor LOS & NON-LOS Propagation analysis using Visible Light Communication

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Abstract— A growing number of wireless gadgets and increasing traffic in the radio spectrum has accelerated for alternative to radio based communication. Visible light communication (VLC) has gained considerable momentum among others. The eminent adaptation of power efficient Light Emitting Diodes (LED’s) and has immense potential of high speed data communication offered by VLC has enormously contributed to the spread of visible light as competitive communication medium. Apart from communication, another field highly benefiting from visible light is localization/positioning. In this paper, we first demonstrate the lineaments for indoor system (direct line of sight (LOS) and non-line of sight (NLOS)). Numerical analysis were executed. The matlab simulation tool was implemented to classify the illuminance distribution in different scenarios to satisfy the required accuracy in some coarse location environments.

Index Terms—Visible light communication (VLC), Line of Sight (LOS), Non Line of Sight (NLOS), Indoor positioning.

1. INTRODUCTION

In comparison to RF communication, indoor visible light communication systems pledge a higher transmission bandwidth due to their inherent frequencies. The Global Position system (GPS) is the most popular positioning system in the world. However, its performance is substantially limited in indoor environment [1]. Previously, several other technologies, such as radio waves [10-11] and ultrasound [14] have been explored for indoor systems. Each has constraint that restrict its ubiquitous applications. The wavelength of ultrasound is relatively large, and its environment temperature affected its velocity. Which may result in large ranging and error. The onerous of radio frequency (RF) based indoor system lie in the multipath effect of radio signals [7]. The electromagnetic radiations limits the application in sensitive indoor environments such as hospital and airplanes [9]. Further, the radio frequency (RF) spectrum is choke and scanty, but the available optical spectrum of VLC is considerably broad. With soon-to-be- ubiquity of light emitting diodes (LED’s), indoor system based on visible light communication (VLC) is attaining tremendous research attention. Generally, VLC based indoor system makes full use of the data transmitted by VLC and the information measured form visible light signal for different attributes like localization, positioning [15][18]. The main advantages of visible light communication is given in table I.

<table>
<thead>
<tr>
<th>Property</th>
<th>RF</th>
<th>VLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bandwidth regulated</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2 Multipath propagation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3 Path loss</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td>4 Multipath fading</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>5 Input X(t)</td>
<td>Amplitude</td>
<td>Power</td>
</tr>
</tbody>
</table>

Table I. VLC—Radio comparison.

This visible light communication system is also an alternative system that adds high security as it is very difficult for anyone to pick up the signal from outside the as the light signals do not penetrate through walls or other opaque objects [12].

VLC can be applied in a various applications for both indoor and outdoor environment. But in this research, the recommended system setup considered an optical wireless communication system based on LED & Photodiode for indoor environments only.

There are two commonly types of indoor optical wireless

Manuscript received.

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communication systems

1. Direct line-of-sight (LOS) indoor OWC system
2. Non-directed LOS indoor OWC system

A direct LOS link normally engaging a photo detector (PD) with smaller surface offers a large bandwidth and improved sensitivity [2]. Such links require a very explicit adjustment between the transmitter and receiver especially when the object is motile as shown in the figure A. Additionally, in direct LOS configuration of the receiver’s field of view (FOV) is quite precise to ensure decreased ambient light noise, but at the cost of increased transmission path blocking [3].

Figure. A: Direct line-of-sight (LOS)

On the other hand, Non directed line-of-sight can provide a larger coverage range an excellent mobility and without any specific alignment technique as shown in Figure B, but at a cost low data rates, multipath induced inter-symbol interference (ISI) and high path losses [4].

Figure. B: Non direct line-of-sight

2. SIMULATION FOR INDOOR VLC SYSTEM

In this paper, we demonstrate the performance of visible light communication by considering LOS propagation model and Non-LOS propagation model. They are characterized by channel mode. In LOS propagation model we only consider direct path used one LED as transmitter. In the case of Non LOS propagation we consider single LED transmitter Non-LOS propagation.

2.1 EXPERIMENTAL SETUP

The experimental setup for the VLC system can be figure out in two cases. First scenario is the Line-of-sight propagation model and the second one is the Non-Line-of-sight propagation model. The room dimensions are 9m length, 9m width, and 9m height. One LED is placed as transmitter located at position (2, 8, 8) and a photo diode is used as receiver is at the desk level of 0.85 as shown in the following fig C.

Fig. C: The room dimension and orientation of transmitter and receiver

The power distribution of LOS link at receiver plane under mentioned room dimension is summarized in the following figure shows the illuminance distribution for single led transmitter with no reflection.

Fig. C: Illuminance distribution for single LED transmitter without reflection

2.1.1 LOS PROPAGATION MODEL

LOS propagation model comprise only direct path. It has been examined without taking into account the multipath reflections. The inherent line-of-sight (LOS) characteristic of LEDs involves transmitter (Tx) and the receiver (Rx) directly communication via high-frequency visible light channel in a confined space by ensuring LOS clearance between them. This integration would result in accurate data transmission with minimum errors [6]. The distance between transmitter (Tx) and receiver (Rx), the angle of irradiance and angle of incidence are calculated and given by.
The angle of incidence and angle of irradiance are calculated and are given by

\[ \theta = 10m = \{ \theta_d = 22^\circ, \theta_t = 25^\circ \} \]  

(1)

In LOS scenario, the received light power varies according to the alignment of transmitter (TR) and emitter (Tx). As this system uses LED’s which intensity radiation is modelled by a Lambertian distribution, as shown in Eq.2

\[
R_0(\Phi) = \begin{cases} 
\frac{m1 + 1}{2\pi d^2} \cos^m(\phi)T_s(\psi)g(\psi) \cos(\phi) & \text{for } \phi \in [-\pi/2, \pi/2] \\
0 & \text{for } \phi \geq \pi/2
\end{cases}
\]  

(2)

Where \( m_1 \) is the Lamberts mode number denoting directivity of the source point, related to the LED semi angle at half-power \( \Phi_{1/2} \) by

\[
m_1 = \frac{-\ln 2}{\ln(\cos(\Phi_{1/2})/2)}
\]  

(3)

The total loss is given by equation 4.

\[
R_{\text{los}}(0) = \begin{cases} 
\frac{Ar(m+1)}{2\pi d^2} \cos^m(\phi)T_s(\psi)g(\psi) & \text{for } 0 \leq \psi \leq \Psi_c \\
0 & \text{elsewhere}
\end{cases}
\]  

(4)

where \( A \) is the active area of the photodetector, \( \psi \) is the incident angle in the receiver, \( T_s(\psi) \) is the transmission of the optical band-pass filter, \( g(\psi) \) is the gain of the concentrator, \( d \) is the distance between transmitter and receiver, \( \Psi \) is the field of view (FOV) of the detector.

### 2.1.2 NON-LOS PROPAGATION MODEL

Some scenarios, such blockage, require a non-LOS scheme. In such conditions, the receiver must confide on reflections in the environment to receive the signal. The path loss is reasonably higher than in the previous case due to greater distance from transmitter and also due to the light absorption by the reflection surfaces. The received optical power \( P_r \) is given by applying the gain in Eq. 4 to the transmitted power \( P_t \)

\[
P_r = H_{\text{los}}(0)P_t + \int P_t H_{\text{ref}}(0) \]

(5)

Unlike LOS links [17] also reflected signal is considered \( P_t \) is total transmitted power by optical source. \( H_{\text{los}}(0) \) stands for DC gain on reflected path can be expressed as

\[
R_{\text{los}}(0) = \begin{cases} 
\frac{Ar(m+1)}{2\pi d^2} \cos^m(\phi)T_s(\psi)g(\psi) & 0 \leq \psi \leq \Psi_c \\
0 & \text{elsewhere}
\end{cases}
\]

(6)

Where \( d_1 \) and \( d_2 \) are distances between reflective point and LED and between receiver surface and reflective point \( m \) denotes the Lambert index of LED light source, \( dA_{\text{wall}} \) is a reflective area of small region, \( \rho \) is the reflectance factor, \( \psi_r \) is the angle of incidence from the reflective surface, \( \phi_i \) is the angle of irradiance to a reflective point, \( \alpha_{ir}, \beta_{ir} \) are the angles of incidence to a reflective point and the angle of irradiance from the reflective point to the receiver.

Here we discuss (single LED transmitter Non-LOS propagation model)

#### SINGLE LED NON-LOS PROPAGATION MODEL

In this scenario we use one LED as the transmitter (Tx) and consider both direct and reflected path. The propagation model is shown in figure. E

Fig. E: Single LED Non Light of sight
This model is similar to LOS propagation model and the only difference is that we assumed direct and reflected light path instead of direct path. The distance between emitter and the receiver, the angle of incidence and angle of irradiance in all the sides are calculated which is given by:

\[ l = 10m = \{\theta_{1s} = 22^\circ, \theta_{1d} = 25^\circ\} \]  
\[ l'_{2} = 8m = \{\theta'_{2s} = 50^\circ, \theta'_{2d} = 40^\circ\} \]  
\[ l''_{2} = 6m = \{\theta''_{2s} = 60^\circ, \theta''_{2d} = 40^\circ\} \]  
\[ l'''_{2} = 6m = \{\theta'''_{2s} = 43^\circ, \theta'''_{2d} = 48^\circ\} \]  
\[ l''''_{2} = 6m = \{\theta''''_{2s} = 40^\circ, \theta''''_{2d} = 60^\circ\} \]

Since the first reflection [13] from the wall has significant effect on the optical signal as given by figure F.

Table II: System Parameters for a VLC Link

<table>
<thead>
<tr>
<th>Entity</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>Transmitted optical power</td>
<td>1 W</td>
</tr>
<tr>
<td></td>
<td>Semi angle at half power</td>
<td>70°</td>
</tr>
<tr>
<td></td>
<td>Centre Luminous intensity</td>
<td>0.73 [cd]</td>
</tr>
<tr>
<td>Receiver</td>
<td>Detector area in PD</td>
<td>1.0 [cm²]</td>
</tr>
<tr>
<td></td>
<td>FOV at receiver</td>
<td>70°</td>
</tr>
<tr>
<td></td>
<td>Filter gain Ts</td>
<td>1</td>
</tr>
<tr>
<td>Oth. ers</td>
<td>dAwall</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Refractive Index</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Reflection coefficient (\rho)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Fig G: Illuminance distribution for single LED transmitter with 2nd reflection.

The cumulative distribution functions of each scenario (Direct, 1st reflection, 2nd reflection) are shown in following figure H.

Fig H. Cumulative distribution of luminance
(i) Direct path, (ii) first reflection (iii) 2nd reflection

Considering the above parameters and equations (6-11) we calculated \( R_{\Phi}(0), R_{\Phi}(0) \) both first and 2nd reflections, The received optical power is -2.8 to 4.2 dBm for all points in the room and the average received power is 1 dBm [8]
The position performance is evaluated on different signal-to-noise ratios (SNRs) [5]. It influences the positioning performance notably and depends on the orientation; the transmitter (Tx) and receiver (Rx) location.

3. DISCUSSION & ANALYSIS

The VLC system using Mat lab simulation was analyzed. The designed VLC model works only indoors. The main problem for using it outdoor is the interference from sunlight. Here we consider two propagation model i.e (LOS & Non-LOS). In LOS propagation model, the signals represents rectilinear propagation between Tx an Rx that could be used for high positioning accuracy. In Non Los propagation model, the received signal is attenuated compared to LOS propagation model. NLOS signal is considered as the sum of multipath signals. The amplitude of the received signal is very low as compared to LOS. It involves the propagation via scattering, reflection and so on. So the position accuracy is reduced by multipath effects. The signal is more noise effected. NLOS signal is filtered by comparing with LOS signal strength.

In channel delay spread investigation, we calculated powers in the first reflection, second reflection and direct path. As compared to LOS propagation model the NLOS propagation model with single LED contribute more received power among all positions.

4. CONCLUSION

In this paper, we simulate both line of sight and Non-LOS model’s characteristics. Here LOS signal in the receiver end the selected the several signals with highest power for position accuracy can be improved. The computer simulations and mathematical techniques provide insights into visible light communication model. In practical situation it is noticed that the received signal is more noise affected. In the future a generalized method of evaluating multiple transmitters and receivers can be used for synchronization. It will enhance the deformation due to the delay spread of multiple reflected optical signals.

ACKNOWLEDGMENT

We adore prompting our appreciation to Yanshan University, China for accompanying us in this research.

REFERENCES

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