

Design and analysis of infrastructure to vehicle visible light communication channel modeling

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Abstract—Visible Light Communication (VLC) is a promising alternative for the presently used radio wave communication. VLC uses LED illumination to transmit data without the use of fiber cable. In this paper a attempt has been made to model a channel for infrastructure to vehicle communication for visible light. The proposed channel model is for three lane road where the transmitter is at the side of the road. The channel modeling has been done of three radiation patterns namely Lambertian, Elliptical and Batwing. The results are depicted in the form of power received verses the angle the vehicle makes with transmitter and power received vs the distance the vehicles travel as it passes the transmitter. Channel is always effected by various environment factors like rain, fog, sandstorm etc, to make the channel model as accurate to the real world the effect of sandstorm is also incorporated.

Index Terms—Radiation pattern, Signal to noise ratio, Channel modeling.

I. INTRODUCTION

Better communication system between vehicles and the infrastructure around it can enhance the safety, security of the passengers and will provide safe secure driving. Self-driving cars can be hugely reward by having good communication systems. So far research and practical implementation has been only in RF domain. Due to increased traffic in the available RF channel the maximum data rates that can be provided has reduced due to which technology like self-driving cars have still not been able to be utilized to the full extend, these problems can be unravelled by Visible light communication (VLC).[1] To make Visible Light Communication a reality we need an effective channel model to predict the channel condition. In case of Vehicular Visible Light Communication, channel modelling is directly related to radiation pattern of headlight of vehicles and the transmitter LEDs at the side of the road.

The Light Emitting Diode (LED) is one of the most rapidly developing technology and has made a revolution in visible light communication (VLC).[2] As compared to other light sources LEDs have longer life time, are more durable and provide better lightening quality. The development in LED technology and in its improved manufacturing process has led to the development in LEDs with radiation pattern other than Lambertian like Elliptical

and Batwing. VLC solves many problems of the present RF communication like data rate, limited bandwidth, interference etc. RF communication is also not suitable for use in petrochemical plants, airplanes, underwater submarines and hazardous environments. Moreover providing RF access points everywhere is a costly affair which further strengthens the need for VLC.[3]

The channel model that has been considered in this paper is road which has three lanes and the transmitter is at the side of the road. This radiation pattern varies differently with line-of-sight distance between the transmitter and the receiver and the angle made by the transmitter with receiver.[4] Depending upon this line of sight distance and the angle made by transmitter and receiver the radiation patter for Lambertian, Elliptical and Batwing vary differently. For some radiation pattern the line of sight distance has more effect on it and for others the angle made with receiver.[5]

Weather phenomenon like sandstorms frequently occurs in the Arab peninsula and many other parts of the world. Similar to how fog and rain contribute to the loss in VLC sandstorm also absorb and scatter the light to produce loss, Sandstorm always plays the dominating role as compared to the losses made by fog and rain.[9] However sandstorms affects differently depending on factors like nature of sandstorm particles, sizes of particles and refraction indices when compared with rain and fog particles.[6]

II. VLC MODEL

A. Channel Model Considered

The scenario for which the channel modeling is being done is shown in the Fig 1. The transmitter is installed at the side of the road. The type of road considered for modelling is a three lane road with each lane having a width of 3.75 meters. Due to the different radiation patters of the LEDs and varying distance of the vehicles from the transmitter, vehicles experience different radiation intensity as move along in front of the transmitter.

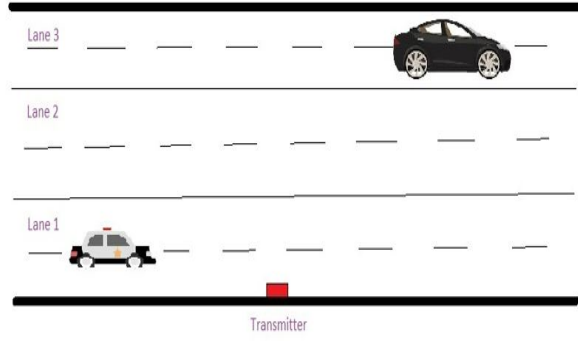


Fig. 1. Channel Model

B. Radiation Pattern of LEDs

Radiation pattern of Lambertian, Elliptical and Batwing are plotted in polar coordinate system. The figure shows us that the Lambertian radiation pattern has maximum intensity in the normal direction, where as elliptical radiation pattern has a bell shaped structure. Batwing pattern have maximum intensity at the side[10]

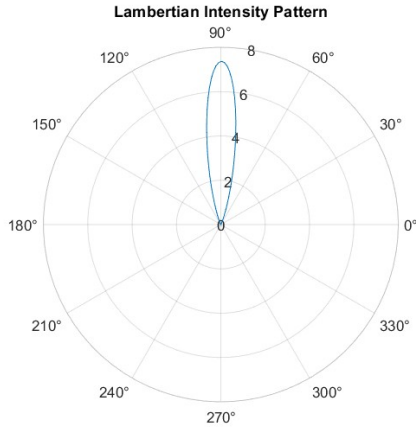


Fig. 2. Lambertian intensity pattern

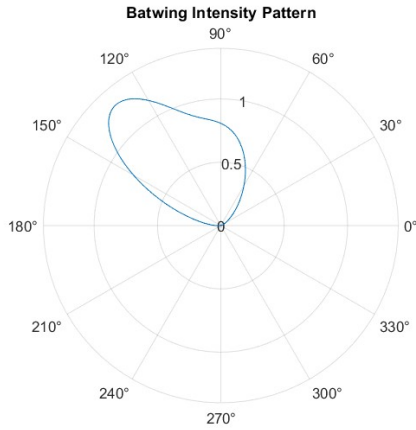


Fig. 3. Batwing intensity pattern

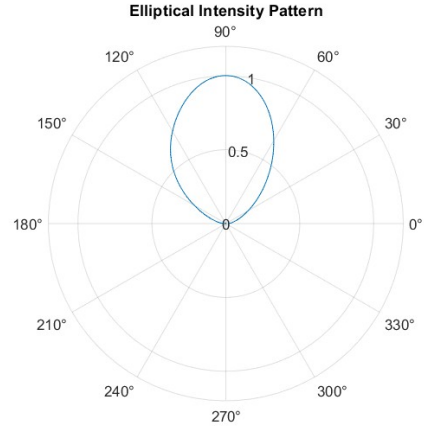


Fig. 4. Elliptical intensity pattern

The radiation intensity of Lambertian is cosine function and is characterised by semi-half power angle [8]

$$\varphi_{1/2}$$

$$I(\varphi) = \frac{m+1}{2\pi} \cos^m(\varphi) \quad (1)$$

where m is Lambertian order given as $m = -\ln(2)/\ln(\cos \varphi_{1/2})$ and φ is spherical polar angle w.r.t normal axis.

The intensity distribution of Batwing pattern is given by [8]

$$I(\varphi) = \sum_i h1_i \exp \left[-\ln 2 \left(\frac{|\varphi| - h2_i}{h3_i} \right)^2 \right] \quad (2)$$

where $h1_1 = 0.76$, $h2_1 = 0^\circ$, $h3_1 = 29^\circ$, $h1_2 = 1.10$, $h2_2 = 45^\circ$ and $h3_2 = 21^\circ$. The Elliptical radiation pattern is described by [8]

$$I(\varphi, \varnothing) = \sum_i h1_i \exp \left[-\ln 2 (|\varphi| - h2_i)^2 \left(\frac{\cos^2 \varnothing}{(h3_i)^2} + \frac{\sin^2 \varnothing}{(h4_i)^2} \right) \right] \quad (3)$$

where the terms $h1_1 = 0.13$, $h2_1 = 45^\circ$, $h3_1 = h4_1 = 18^\circ$, $h1_2 = 1$, $h2_2 = 0$, $h3_2 = 38^\circ$, $h4_2 = 22^\circ$ and \varnothing is the azimuthal angle along the plane which is perpendicular to the normal axis. The impulse response due to the LOS signal from source-S to receiver- R is given as [7]

$$h^{(0)}(t; S, R) = \begin{cases} \frac{1}{r_1^2} A_r I(\varphi_0) \cos(\varphi_0) \cos(\Psi_0) \delta(t - \frac{r_1}{c}), & 0 \leq \Psi_0 \leq FOV \\ 0 & \Psi_0 \geq FOV \end{cases} \quad (4)$$

where $I(\varphi_0)$ is the radiant intensity of the LED in the direction of the emission angle φ_0 w.r.t normal axis.

C. SNR calculation and parameters

The electrical SNR is expressed in terms of the received optical power, noise variance and photo detector responsivity R as [7]

$$\text{SNR} = \frac{(RP_r)^2}{\sigma_{\text{shot}}^2 + \sigma_{\text{thermal}}^2} \quad (5)$$

The thermal and shot noise variances are given by [7]

$$\begin{aligned} \sigma_{\text{shot}}^2 &= 2qRP_rB + 2qI_B I_2 B \\ \sigma_{\text{thermal}}^2 &= \frac{8\pi\kappa T_k}{G_{\text{ol}}} C_{\text{pd}} A I_2 B^2 + \frac{16\pi^2 \kappa T_k \Gamma}{g_m} C_{\text{pd}}^2 A^2 I_3 B^3 \end{aligned} \quad (6)$$

where the bandwidth of the electrical filter that follows the photo detector is represented by B Hz, I_B is the photocurrent due to background radiation, κ is the Boltzmann's constant, Γ is the FET channel noise factor, T_k is absolute temperature, G_{ol} is the open-loop voltage gain, g_m is the FET trans conductance and noise-bandwidth factors $I_2 = 0.562$ and $I_3 = 0.0868$, C_{pd} is the fixed capacitance of photo detector per unit area [11].

Table 1. Parameters and their values

| Parameters | Value |
|-----------------------------------|---------------|
| VLC Channel Model | |
| Number of Lanes on Road | 3 |
| Width of each Lane | 3.75 |
| Receiver | |
| Active area of Photodetector | 1Cm2 |
| Responsivity of Photodiode | 0.5 W/A |
| Noise | |
| Open loop Voltage gain | 10 |
| Equivalent Noise Bandwidth | 100MHz |
| Transconductance g_m | 14mS |
| Background noise current | 5100uA |
| Absolute Temperature | 298k |
| Noise Bandwidth Factor I_2, I_3 | 0.562, 0.0868 |
| Total input capacitance | 2PF |
| FET channel noise factor | 1.5 |

D. Sandstorm effect on Visible light communication

To calculate the actual power received in the photo diode due to sandstorm we investigate the signal attenuation. Beer-Lambert-Bouguer law can be used to calculate attenuation affect due to sandstorm which is as follows: [9]

$$P_r = P_t \cdot e^{(-l\varepsilon)} \quad (7)$$

Where:

P_t : Power Transmitted.

P_r : Power Received.

l : Length between the transmitter and the receiver.

ε : Extinction coefficient.

To apply the Beer-Lambert-Bouguer law, first we need to calculate the extinction coefficient. The main components that form the extinction coefficient are aerosol absorption, Rayleigh scattering and aerosol scattering. Here we will be only considering the Rayleigh scattering [12]

Due to the particles in atmosphere which are smaller than light and due to illumination of light it causes Rayleigh scattering. The extinction coefficient for Rayleigh scattering can be calculated as follows [9]

$$\beta_m(\lambda) = \frac{24\pi^3}{\rho\lambda^4} 10^3 \left(\frac{[n(\lambda)]^2 - 1}{[n(\lambda)]^2 + 2} \right) \left(\frac{6 + 3\gamma}{6 - 7\gamma} \right) \quad (8)$$

Where:

$\beta_m(\lambda)$: Molecular scattering coefficient (km^{-1})

λ : Wavelength (μm)

ρ : Molecular density (m^{-3})

γ : Depolarization factor of the air ($\cong 0.03$)

$n(\lambda)$: Refractive index of air.

An approximate value of $\beta_m(\lambda)$ is:

$$\beta_m(\lambda) = U \lambda^{-4} \quad (9)$$

Where:

$$U = 1.09 \times 10^{-3} \frac{A}{A_0} \frac{T_0}{T} \text{ k}^{-1} \text{m}^4$$

And

A: Atmospheric pressure (mbar).

A_0 : 1013 mbar.

T: Atmospheric temperature (K).

T_0 : 273.15 K.

III. RESULT

Below Figures 5, 6 and 7 shows the variation in SNR value for different lanes of road as the emission angle increases. Lambertian radiation pattern provides the highest SNR directly in front of the LED or at zero degrees of emission angle with respect to the normal axis.

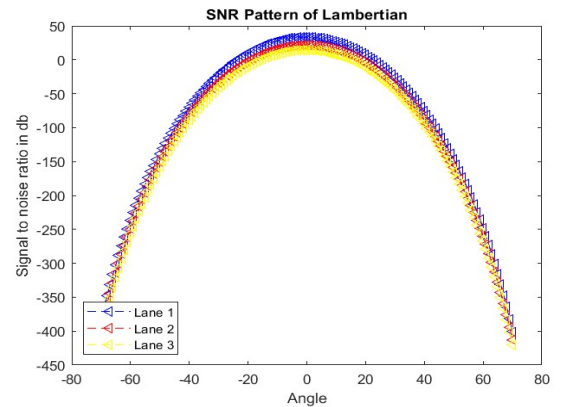


Fig. 5. SNR Pattern of Lambertian

Variation in SNR for Lambertian pattern is very steep and the distance do not play a huge role in the SNR. Batwing pattern is suitable to get better SNR to the right of transmitter.

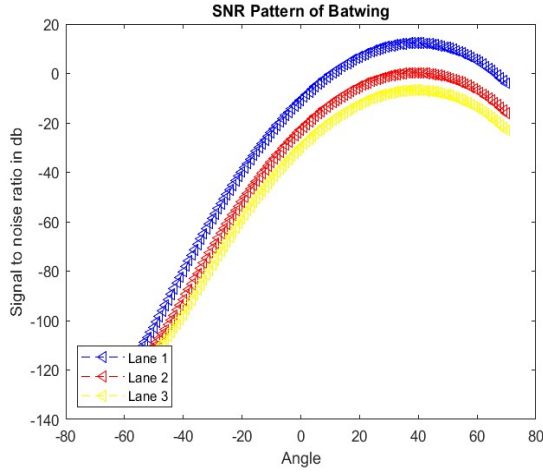


Fig. 6. SNR Pattern of Batwing

Elliptical pattern has a very gradual reduction in its SNR value as the emission angle increases.

Table 2,3 and 4 shows the effect on the variation in SNR values after the incorporation of the sandstorm effect and the inferences from this output are as follows: The shape of the radiation pattern is not changed with the incorporation of losses. The attenuation in the pattern increases as we go from lane 1 to lane 3. The change in the received signal power is not the same as the emission angle increases. Elliptical radiation pattern has encored most loss through the various emission angles as compared to Lambertian and Batwing.

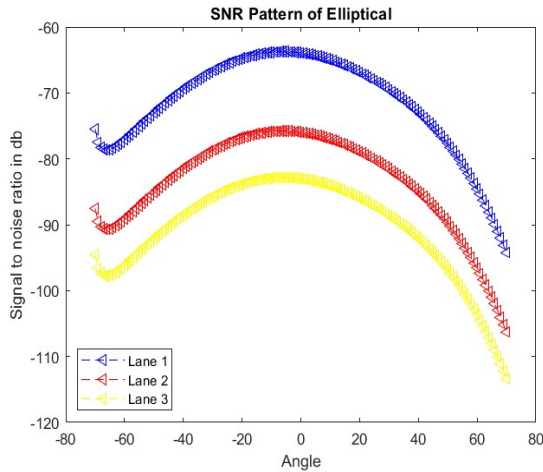


Fig. 7. SNR Pattern of Elliptical

There is a marginal increase in the losses for all the radiation pattern as the emission angle increases.

Table 2. Lambertian Pattern variation

| Lambertian Pattern | | |
|--------------------|-------------------------|----------------------------|
| Degree | No Sandstorm Effect(dB) | With Sandstorm Effect (dB) |
| 0 | 252.10 | 239.57 |
| -21 | 237.72 | 221.03 |
| 43 | 144.85 | 120.85 |
| -65 | -62.81 | -86.81 |
| 58 | 14.81 | -9.19 |

Table 3. Ellipital Pattern variation

| Elliptical Pattern | | |
|--------------------|-------------------------|----------------------------|
| Degree | No Sandstorm Effect(dB) | With Sandstorm Effect (dB) |
| 0 | -24.67 | -53.01 |
| -21 | -25.62 | -53.97 |
| 43 | -34.89 | -63.23 |
| -65 | -39.31 | -67.66 |
| 58 | -43.70 | -72.05 |

Table 4. Batwing Pattern variation

| Batwing Pattern | | |
|-----------------|-------------------------|----------------------------|
| Degree | No Sandstorm Effect(dB) | With Sandstorm Effect (dB) |
| 0 | 28.49 | 8.84 |
| -21 | -2.39 | -22.05 |
| 43 | 51.32 | 31.66 |
| -65 | -82.97 | -102.63 |
| 58 | 45.73 | 26.07 |

IV. CONCLUSION

In this paper modeling of a channel has been done for visible light communication. In a scenario where the transmitter is placed at the side of a three lane road. The variation in the SNR values as the vehicles pass through the various lanes for different radiation pattern where plotted. To incorporate the non idealities in the channel effect of sandstorm was also considered. The variation in the SNR values at various points due to the effect of sandstorm for all the three radiation pattern are listed. We observe that the SNR values of the three radiation pattern vary differently with respect to the incident angle and thus can be deployed based on the required SNR requirement.

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