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Optical Transceiver Section Design and Optical Link Analysis for Wireless Sensor Node

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Abstract : *In this paper we proposed a model of transceiver section for wireless sensor node. This transceiver section uses optical signal for communication link. Currently communication in wireless sensor network is based on the radio frequency. Frequency 2.5GHz comes under the ISM band which is license free. But the use of same frequency creates interference problems in WSN. We also analyzed optical link for sufficient illumination and signal to noise ratio. New design of transceiver section of sensor node makes possible to route the data. Cost of sensor node will be low because of no regulation of frequency and use of white light emitting diode and photo detector pair.*
Keywords : *Light Emitting Diode, Transceiver, Radio Frequency, Visible Spectrum, Wireless Sensor Network.*

I. INTRODUCTION

The WSN [8] contains large amount of deployed sensor nodes. These sensor nodes have recognition and processing of data and wireless communication ability with other node. Development in electronics chip makes it possible to make it very small sensor node. So it consumes less power and have long lifetime. Such features enable use of WSN in various application areas and solving several problems. There are three ways to communicate the data, optical, infrared and radio frequency. The main feature is optical communication channel high security because it does not broadcast and there is no need of antenna. It needs line of sight.

Recent improvement in LED design and manufacturing process make LED light provide better luminescence as compared to traditional filament bulb. It’s fast switching enables it to use for communication in Wireless Optical Communication system. LED consumes less power than filament bulb.

II. RELATED WORK

Wireless home link [6] provides visible light communication for short range. It have large LED panel contains about hundreds of 3mWatt LEDs. The Corner Cube Retro reflector (CCRs) [3] seems as a part of cube in shape which contains three mutually perpendicular surfaces of mirrors. It uses ambient light for modulation of information signal. Therefore there is no needed of light source at any sensor node. In nuclear reactor metallic chamber contains WSN node equipped with IR communication capability. An optical gateway [9] designed for metallic chambers. This optical gateway performs the task of conversion of optical signal to radio signal vice versa. To avoid it infrared wave is used in place of radio wave. TerraLink [7] uses laser beam for long distance transmission of information. Line of sight link provide more security and uninterrupted connectivity.

III. PROPOSED MODEL OF OPTICAL TRANSCEIVER SECTION

Here we proposed a design of optical transceiver section is cubic in shape having one empty face and other face contain LED – Photodiode pair. Each faces out of five faces divided into two parts one have LED and other part have photo detector. It is shown in Figure1 and 2. By using such arrangement of LED and photodiode every sensor node can communicate in full duplex mode and can transmit its data to every node in the network.

Transceiver section equipped with Cree XM-L LEDs [12]. It provides luminous flux of 590lm. It operates on low power voltage of 3.1V so sensor node can be driven by small batteries. Silicon photo diode provides higher sensitivity at 550nm in visible spectrum. An optical concentrator covers up PIN diode so that incident light can be focus on the detector surface.

Optical transceiver has following advantages over RF transceiver.

- Less complex and cheap due to use of LEDs and Photodiode.
- It illuminates the area of network during communication

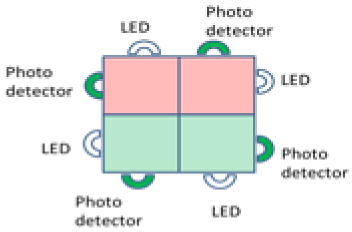

Figure 1 Top view of Transceiver section

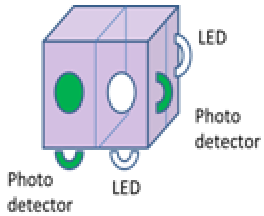

Figure 2 Side view of Transceiver section

IV. OPTICAL LINK ANALYSIS

Any channel for communication can be modeled as a transfer function whose charaacterstics varies with the variation in its parameter. Figure 3 shows optical link between two sensor node. Here impulse response *h(t)* of wireless channel for optical communication given by the equation. In an optical link channel DC gain H(0) for directed path is represented by Gfeller and Bapst model [1] equation 1 and 2 are given below.

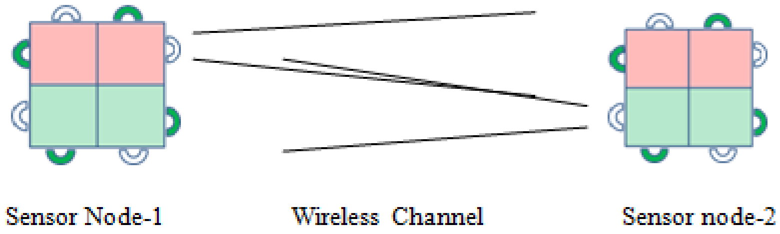

Figure 3 Optical link between two LED- photo detectors of sensor node

$$H(0) = \int_{-\infty}^{\infty} h(t)\,.dt \quad (1)$$

$$H(0) = \begin{cases} (m+1)\frac{A}{2\pi d^2}.\cos^m(\varphi).Ts(\psi).g(\psi).cos(\psi) & 0<=\psi<=\psi c \\ 0 & 0>\psi c \end{cases} \quad (2)$$

Where A is Physical area of Photo detector, d is distance between transmitter and receiver at ground. Angle of incidence is ψ and φ is the angle of irradiance. $Ts(\psi)$ is gain of optical filter. Gain of optical concentrator [1] $g(\psi)$ is given by the following equation

$$g(\psi) = \begin{cases} \frac{n^2}{\sin^2 \psi c} & 0<=\psi<=\psi c \\ 0 & \psi > \psi c \end{cases} \quad (3)$$

Where n, ψc denote the refractive index of concentrator and field of view of receiver respectively. Sharpness of emission increased with the value of m. Directivity of emission pattern given by the order of lambertian emission [2] depends on the semi angle of half power $\Phi_{1/2}$

$$m = -\frac{\ln 2}{\ln \cos\left(\Phi_{1/2}\right)} \quad (4)$$

A. Horizontal illuminance

Illuminance [5] by bottom LEDs of transceiver section at any point P*(x, y, z)* is given by the mathematical expression 6. Where I(0)is center luminous intensity of transceiver section.

$$E_{hor}(x,y,z) = \frac{I(0).cos^m(\phi)}{d^2.cos(\psi)} \quad (5)$$

B. Noise

In this optical wireless channel we assumed that noise is an Additive White Gaussian Noise (AWGN). Signal received at the receiver will contain noise given by

$$y(t) = x(t)*h(t) + n(t) \quad (6)$$

where y(t) represent the received signal current, x(t) represent the transmitted optical pulse , n(t) represent AWGN noise and symbol ' * ' denote convolution. Here noise is modeled as AWGN which is equivalent to 9.6mW of sunlight [2].

$$N_0 = qRP_{bg} \tag{7}$$

Where q is charge of free electron in the photo detector generated due to light intensity. R is the Optical to electrical conversion efficiency and P_{bg} is background noise by sunlight

C. SNR

Received power [10] *Pr* at the photo detector given by equation 8.

$$P_r = H(0).P_t \tag{8}$$

$$SNR = \frac{P_r^2 R^2}{N_0 B} \tag{9}$$

Where B is the noise equivalent bandwidth for OOK modulation data rate assumed as 100Mbps

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To analyze optical link we deployed three sensor nodes S1 S2 and S3 on celling of room size 8mX 8m X 3m. It is shown in figure 4 below

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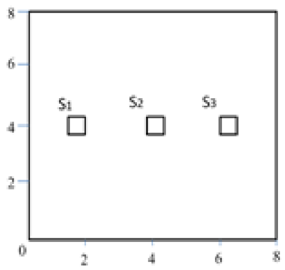


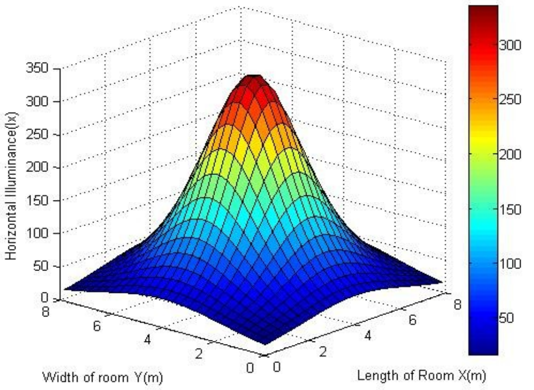
Figure4. Sensor node deployed on ceiling at 3 meter height within room.

V. SIMULATION RESULTS

Here we calculated and analyze the performance of sensor node. Parameter given in table 1 is used. Figure 5(a) shows illuminance of single node and 5(b) shows the illuminance of bottom LED transmitter of each sensor node. Resultant light illuminance (lx) by the all three sensor node is shown in figure 6(a). Maximum 550lx, minimum 100lx and average is 450 lx. Which is suitable for office work and it follows the standard value range given by International Organization for Standardization (ISO). According to ISO value [10] of illuminance should not be less than 300lx. Figure 6(b) shows signal to noise ratio distribution at the receiver end at ground surface detector. Optical power level received by vicinity sensor node is sufficient to detect and recover signal. Figure7 shows received power between two sensor nodes placed 2 meter apart.

TABLE I .SIMULATION PARAMETERS

Parameters	**Value**
Room Size	8X 8 X 3 [m^3]
Angle of incidence (ψ)	0 [deg.]
Angle of irradiance (φ)	0[deg.]
Half power angle ($\Phi_{1/2}$)	60[deg.]
Centre luminous intensity (I(0))	46.95 [cd]
Height of receiver terminal	0.85[meter]
Physical area of detector (A)	1 [cm^2]
Optical filter gain *Ts(ψ)*	1
Detector (R)	0.53 [A/watt]
Refractive index of lens of concentrator (n)	1.5
Background noise	5100 [µA]
Data rate	100Mbps
Primary modulation	OOK NRZ
Secondary modulation	IM/DD



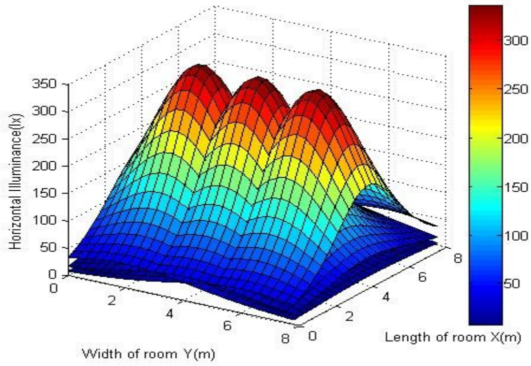
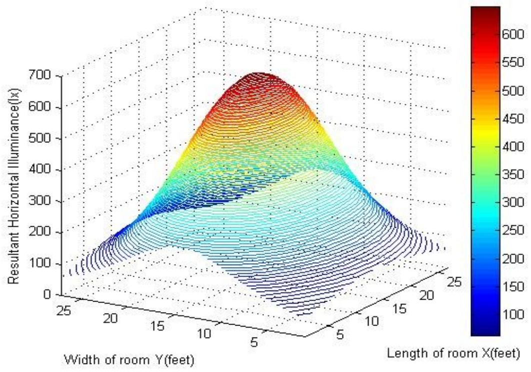


Figure 5(a) Figure 5(b)

Figure 5(a) shows Horizontal illuminance(lx) of single WSN node and Figure 5(b) shows Horizontal illuminance of each node among three WSN node.



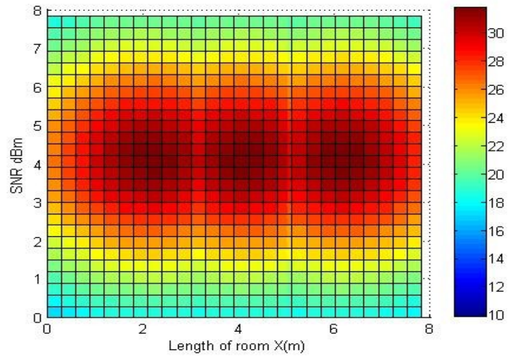


Figure 6(a) Figure 6(b)

Figure 6(a). Resultant horizontal illuminance of all three WSN node. Figure 6(b) Shows SNR distribution of three sensor nodes.

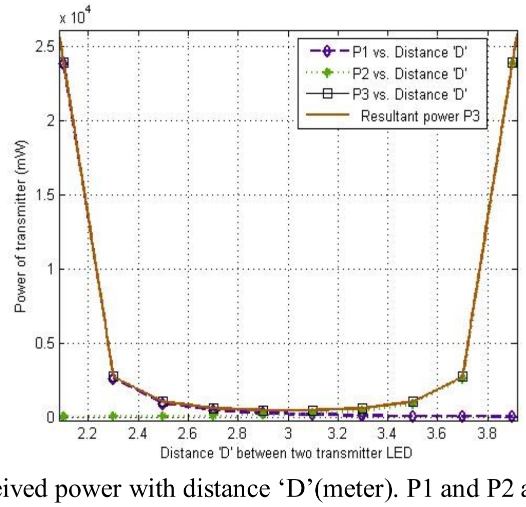


Figure7. Degradation in received power with distance 'D'(meter). P1 and P2 are the transmitter LED power.

VI. CONCLUSION

Our proposed design model is successful to provide sufficient light signal level for communication. Illumination in the area of deployment is 550lx here we analyzed light distribution by bottom LED only. After considering side LED's horizontal illuminance will become large up to 1300 lx which is sufficient for office as well as home. It's Illuminance and signal intensity level not affects human eye and skin also. Here we achieved average 19.6dB of SNR which is large as compared to 13.6 dB (required to achieve 10^{-6} BER). Here we have not consider energy problem of sensor node because these node will deployed in smart home and buildings where it can be operate by low power supply.

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