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Review On Impact Of Ambient Light Noise Sources And Applications In Optical Wireless Communication Using LED

K.Sindhubala [1,*] and B.Vijayalakshmi [2]

[1]Research Scholar,
Department of Electronics and Communication Engineering
[2]Professor,
Department of Electronics and Communication Engineering
B.S Abdur Rahman University, Chennai, India
Email[1]:sindhubala_ece_phd_2014@bsauniv.ac.in*

Abstract

There is a huge demand for Visible Light Communication, since it acts as an added supplement to RF signal transmission because of the advantages like license free, energy efficient, high security and it can be used even in the RF prohibited areas like hospitals and airplanes. VLC uses White LEDs which is used for both illumination and data communication. Today's existing Radio Frequency (RF) communication systems through VLC has limitations like restricted bandwidth, radiation hazards, environmental hazards, exposure to interception and interference. Designers of free space optical communication must have knowledge on ambient light noise sources in order to improve the performance of the communication system from above said limitations and other environmental effects. In this paper, review of impact of one of the main challenge relating with the existence of ambient light noise in visible light communication and the role of VLC in real time applications is presented.

Keywords- Ambient light noise, Data communication. Illumination, Light Emitting Diode, Radio Frequency, Visible Light Communication

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I. INTRODUCTION

Visible light exists everywhere around us. It uses the spectrum of wavelength from 380nm to 750nm. Visible light is less hazardous as human beings can perceive and thus it helps to protect our eyes from damage. VLC can be mostly used for indoor applications and it is highly secure due to the property of light as it cannot pass through the solid objects such as walls, doors etc. In the recent years the usage of LED for communication purposes is increased, as LED has the ability to switch on and off very fast in a very short interval of time, long life span of about 50,000 hrs, room temperature is not increased compared to incandescent lamps and fluorescent lamps. Visible Light Communications Consortium, Japan carried out an initial research on visible light communication [1]. Now Asia, Europe, Wireless World Research Forum are also working in VLC research [2]. Currently, a life where the light used daily is replaced by LEDs, which serves for both illumination and also as data communication.

II. VLC DATA TRANSMISSION

This section provides a brief overview of data transmission in Visible light communication. It uses LED, where the data is transmitted using intensity modulation (IM) technique. The detected intensity is converted as electrical signal by Photodetector. This process is called direct detection (DD). IM / DD methods are advantageous over the other methods, since they are simple and easy to implement.Fig.1. Represents basic blocks of VLC data transmission.

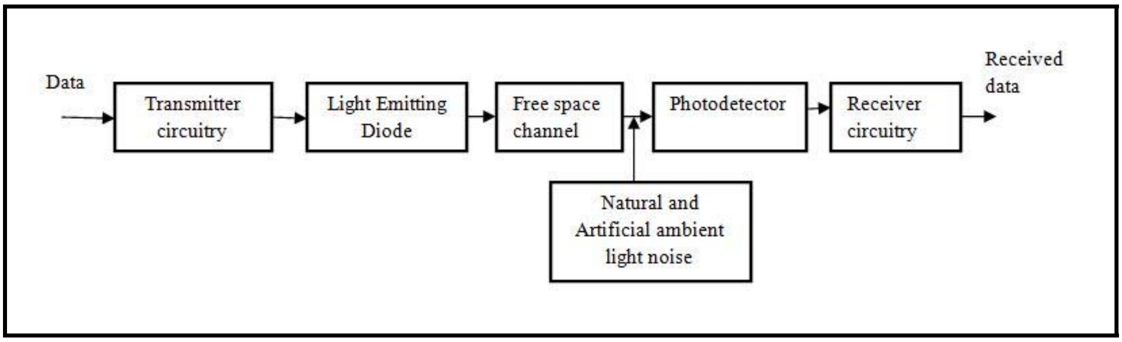

Figure.1.VLC Data Transmission

A. VLC Transmitter

VLC uses LED light as a transmitter which converts the electrical signal to the optical signal. Light Emitting Diode (LED) is used as a capable light source in the transmitter side, when compared to the other light sources such as incandescent and fluorescent lamps. LEDs are not driven by ballast and do not contain toxic mercury, so the environmental and health hazards are less. White LEDs are expected to serve as next generation of lamps due to its properties such as high brightness, low power consumption and more life span. There are two methods to generate white light by using LEDs. Devices which use blue emitter in combination with a yellowish phosphor and trichromatic (RGB) LEDs are used to generate white light. VLC is demonstrated by using both the types of white LEDs [4].

$$I = d\left(k_m \int_{380}^{780} v(\lambda) \varphi_e(\lambda) d\lambda\right) / d\Omega \quad (1)$$

Where the energy is flux φ_e, v (λ) is the standard luminosity curve, k_m is the maximum visibility.

The horizontal luminance is given by eq. (2)

$$Eh = I_0 \cos^m(\theta)\cos(\varphi / r^2) \quad (2)$$

Transmitted optical power is the integral of the energy flux φ_e in all directions is given by eq. (3)

$$p_t = \int_{\Delta \min}^{\Delta \max} \int_0^{2\pi} \varphi_e \, d\theta \, d\lambda \quad (3)$$

Where $\Delta \max$ and $\Delta \min$ are calculated by using the sensitivity curve of the photodiode.

B. *Channel Modeling in VLC*

It is important to understand the characteristics of the channel to design and operate efficient Visible Light Communication system. In this section research works on channel modeling in VLC is presented. Depending on the application the appropriate channel model is chosen.

1. *Line of sight (LOS) channel model*

The LOS channel model is presented. The path loss and received optical power results give the guidance to the selection of suitable White LEDs [32, 33, 34].

The total luminous flux of transmitter LED (F_s) is given by eq. (4

$$F_s = I_0 \int_0^{\theta max} 2\pi g_s(\theta) \sin\theta \, d\theta \quad (4)$$

Received luminous flux is given by eq. (5)

$$F_r = I_0 g_s(\beta) \Omega_r \quad (5)$$

The luminous path loss is given by eq. (6)

$$L_L = \frac{F_s}{F_r} = \frac{I_0 \int_0^{\theta max} 2\pi g_s(\theta) \sin\theta d\theta}{I_0 g_s(\beta) \Omega_r} \quad (6)$$

The received optical power for indoor VLC system using intensity modulation and direct modulation schemes is given by eq. (7)

$$P_r = \int_{\lambda rL}^{\lambda rH} S_r(\lambda) R_f(\lambda) d(\lambda) \quad (7)$$

Where λ_{rH} and λ_{rL} are the upper and lower wavelength bounds of optical filter at the receiver,S_r is the source radiant power spectrum density.

2. *Line coding channel model*

The channel model with line coding depends on the transmitter and receiver [4, 34].The radiation intensity pattern is given by eq. (8)

$$R(\phi) = \frac{n+1}{2\pi} p_s \cos^n(\phi) \quad \phi \varepsilon \left[\frac{-\pi}{2}, \frac{\pi}{2}\right] \quad (8)$$

$$s = \left\{ r_s \cdot \hat{n_s}, n \right\} \quad (9)$$

Where R (ϕ) is the radiation intensity pattern, n is the number of radiation pattern,r_s is the position of impulse response of optical intensity, n_s is the orientation and n is the number of mode in eq.(9)

The multisource impulse response of LOS condition is calculated by eq. (10)

$$(t;S,R) = \sum_{k=0}^{\infty} h^{(k)} h \ (t;S,R) \quad (10)$$

Where $h^{(k)}$ is the response of light undergoing k reflections.

The received signal is given by eq. (11)

$$y(t) = \hat{x}(t) \otimes h(t) + n(t) \quad (11)$$

Where y (t) is the received signal, $\hat{x}(t)$ is the line coded input, h (t) is the channel impulse response and n (t) is the additive white Gaussian noise.

3. *Reflection based channel model*

The channel model based on reflection is called Lambert-Phong pattern which relates the characteristics of the reflector (walls, ceiling, etc) [35].

The well approximated intensity pattern is given by eq. (12)

$$p(\theta, \phi, m) = \frac{P_{Tx}(m+1)}{2\pi} \cos^m(\theta) \quad (12)$$

Where m is the Lambert exponent defining the width of the beam, P_{Tx} is the optical transmitted power, is the angle between the initial direction of ray and direction of maximum power,ϕ is the azimuth angle.

The incident optical power is given by eq. (13)

$$P_p = \frac{A_R}{d^2} p(\theta, \phi, m) \cos\varphi \, rect \frac{\varphi}{FOV} \quad (13)$$

Where A_R is the detecting surface area of photodiode, d is the distance between transmitter and receiver, FOV is the field of view and φ is the incident angle of incident light. In Lambert-Phong pattern the new reflection is identified in two steps.

Firstly specular reflection vector R_S is calculated and is given by eq. (14)

$$R_S = (2N.\mathrm{L})\,\mathrm{N} - \mathrm{L} \quad (14)$$

Where L is the incident light vector and N is the unit normal vector.

Secondly a random variable is calculated which is the angle between new reflection vector and specular reflection vector. The reflection intensity distribution is given by eq. (15)

$$P_f(\sigma, \phi, \eta_S) = \rho \frac{P_i(m_S+1)}{2\pi} \cos^{m_S}\sigma \quad (15)$$

Where P_f is the reflected light power, P_i is the incident light power, reflectivity of obstacles and m_s is the directionality of reflection light.

The VLC channel impulse response is given by eq. (16)

$$h_{VLC} = h_{LOS}(t) + h_{diffuse}(t) \quad (16)$$

Where $h_{LOS}(t)$ is the impulse response of the LOS signal.

Thus in Lambert-Phong pattern computational complexity is reduced and the calculations are linear to the number of reflections.

3. *VLC receiver*

From channel, the optical signal enters the VLC receiver which converts it into electrical signal. VLC receiver uses two different kinds of photodiodes, Avalanche photodiode (APDs) and positive-intrinsic-negative (PIN) photodiode. PIN photodiodes are used in most applications due to low cost, linear response characteristics over the wide ranges, low power operation and tolerance to high temperature fluctuations to improve the receiver performance [5]. Optical concentrator or lens is used to focus the radiation on to the photodiode. The photodiode Responsivity (R) is given by given by eq. (17)

$$R = \frac{I_P}{P_P} \quad (17)$$

III. VLC DESIGN CHALLENGES

The biggest problem faced by the designer of the VLC is to achieve high signal to noise ratio (SNR). It implies, the designer must design the system in such a way to provide eye safety, high data rate, minimize multipath dispersion, provision of uplink and to mitigate the sources of noise to achieve better system performance.

A. *High data rate*

There are different methods to increase the data rate using transmitter/receiver side equalization, complex modulation and parallel communication. The limited modulation bandwidth of LED is increased by pre- equalization technique which is modulated by resonant driving technique, hence overall bandwidth of 25MHz and low error rate transmission up to 40 Mb/s is achieved [6]. Post equalization technique includes a combination of blue filter to detect the phosphorescence components and equalizer at the receiver side, hence data rate of 100 Mb/s and bandwidth of 50 MHz is achieved [7]. Multiple Input Multiple Output (MIMO) uses white LEDs, each transmitting 250 Mb/s and using Orthogonal Frequency Division Multiplexing modulation, hence data rate of 1 Gb/s is achieved [8]. Challenges in OFDM technique includes low spectral efficiency and high peak to average power ratio (PAPR) which can be overcome with the Expurgated pulse position modulation which provides more bandwidth and supports data rate up to Gb/s [9].

B. *Multipath dispersion*

The optical signals coming from the transmitter side of LED undergoes reflections from the ceiling walls and other objects are also collected by the photodiode. Multipath dispersion occurs due to time spreading of the received optical signal.

Power Delay Profile (PDP) is used to calculate the multipath dispersion between the transmitter and receiver [10].

C. Lights off

Dimming and control is an important feature in VLC because communications is integrated with illumination. During day time, artificial lighting is not used always, hence the power required for VLC is not free, and it needs to be sufficiently powered by the suitable lights to transmit the information [28].

D. Duplex transmission

Provision of uplink in visible light communication always remains as a challenging problem. VLC downlink combined with RF uplink provides full connectivity and it reduces the load shared on RF channel and hence it improves the network performance [11]. A bidirectional VLC system achieving a data rate of 225 Mb/s upstream and 575Mb/s downstream transmissions using SCM, WDM and QAM OFDM is achieved. The capacity of downlink and uplink depends on the bandwidth and modulation formats of the sub channel [12].

E. Noise at the receiver

There are different sources of noise which degrades the performance of the optical wireless communication system [36]. Fig.2.shows different sources of noise in optical wireless communication link.

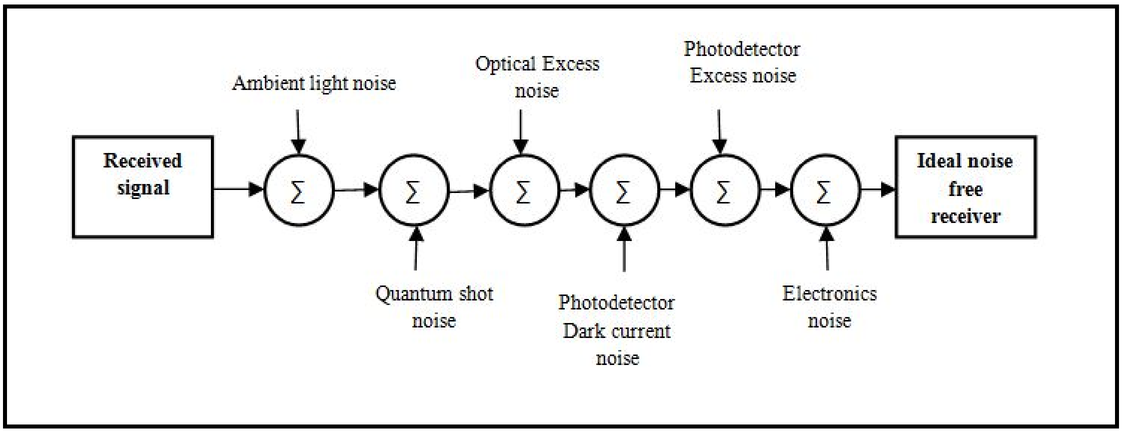

Fig.2.Different sources of noise in optical wireless communication link [36]

1. Optical excess noise

When laser is used in transmitter side, any noise that combines with the received signal other than the quantum shot noise is called optical excess noise.

2. *Photo detector excess noise*

Photodetector excess noise occurs due to gain multiplication process internal to the photodetector.This kind of noise is present only in Photodetector with internal gain like avalanche Photodiode or Photomultiplier tube (PMT).

Both the above mentioned kinds of noise can be eliminated in Visible Light Communication using LEDs and PIN photodiodes. The noise sources that are considered in the VLC system using white LEDs and the photodiode as receiver are ambient light noise, quantum shot noise, electronics noise and Photodetector dark current noise.

3. *Dark current noise*

Dark current noise occurs in the photo detector due to random emission of electrons due to absorption of thermal energy at a fixed average rate when no field is being detected. It depends on the temperature and area of the photo detector. The dark current I_d is modeled as a DC current with noise PSD is given by eq. (18)

$$S_d(f) = I_d^{\,2}\,\delta(f) \tag{18}$$

4. *Ambient light noise*

Different light sources such as natural and artificial background light contribute to the ambient light noise. Source of natural ambient light noise is sunlight. The artificial ambient light comes from many light sources such as incandescent lamps, and fluorescent lamps driven by conventional and electronic ballasts.Fig.3 shows the optical spectra of different ambient light noise sources. The unmodulated noise spectral density (A^2/Hz) can be represented by eq. (19)

$$S_{ds}(f) = \left[\frac{e}{hc}\int_{\lambda rL}^{\lambda rH} \eta(\lambda)\lambda S_b(\lambda) R_f(\lambda)\,\mathrm{d}\lambda\right]^2 \delta(f) \tag{19}$$

Where η (λ) is the quantum efficiency of the detector, Sb (λ) is the power spectrum density of the background e is the electron

Charge, h is the Planck's constant and c is the speed of light.R_D (λ) = eη (λ) λ in the above equation is the detector responsivity (A/W) at wavelength λ.

5. *Quantum shot noise*

The mean of photocurrent includes contribution from sunlight, ambient light interference and dark current contains the desired signal of interest that varies with the received optical power, where the variance acts as distortion to the desired signal received and it represents how much amount of noise power is present in the photodetector's output. Quantum shot noise occurs due to quantum mechanical nature of light. The PSD of quantum shot noise due to unmodulated ambient and dark current is given by eq. (19)

$$S_{ds}(f) = 2e\left[\frac{e}{hc}\int_{\lambda rL}^{\lambda rH} \eta(\lambda)\lambda S_b(\lambda) R_f(\lambda)\,\mathrm{d}\lambda + I_d\right] \tag{19}$$

Where S_b (λ) represents the ambient light noise power spectral density.

6. *Electronics noise*

The electronics noise occurs at the pre-amplifier front end. Four kinds of front end amplifier designs are used in optical receivers mainly consist of resistor termination with a low-impedance voltage amplifier, high impedance amplifier, transimpedance amplifier and noise matched or resonant amplifier. Among all these four types of amplifiers, transimpedance amplifiers are widely used in VLC because of the capacity to achieve high bandwidth and low noise at the same time. Fig.5 shows the Transimpedance amplifier circuit with the feedback impedance Zfb(ω) and open loop gain $A_v(\omega)$.

The equivalent input current noise PSD of Transimpedance amplifier is given by

$$s_a(f) = i_n^2 + \frac{4kT}{R_{fb}} + \frac{v_n^2}{R_t^2}\left[1 + (2\pi R_{fb} c_t f)^2\right] \qquad (20)$$

Where $R_t = Rf_b A_0 R_d \,/\, [(A_0 + 1)R_d + Rf_b]$, $c_t = c_{fb} + c_d$, Rf_b is the feedback resistance,A_0 is the core amplifier DC gain $A_v(0)$, c_{fb} is the feedback capacitance,$c_{d,Rd}$ are the resistive and capacitive parts of the combined impedance. The noise performance of the core amplifier is characterized by spectral densities v_n^2 and i_n^2 of the internal voltage and current random sources. The electronics noise can be treated as zero-mean additive Gaussian random process with variance as the noise power.

If the field effect transistor (FET) is used for the transimpedance amplifier, the equivalent noise power spectral density is given by

$$s_{aFET}(f) = \left[\frac{4kT}{R_{fb}} + 2eI_L + \frac{4kT\Gamma}{g_m}(2\pi c_t)^2 f_c f + \frac{4kT\Gamma}{g_m}(2\pi c_t)^2 f^2\right] \qquad (21)$$

Where I_L is the leakage current, g_m is the FET transconductance, c_t the total input capacitance, f_c is the 1/f noise corner frequency of the FET, $\Gamma$is the numerical constant (0.7 for Si JFETs, 1.03 for Si MOSFETs and GaAs MESFETs).In the above equation, first noise term and second is due to feedback resistance thermal noise and leakage current. The third and the fourth noise term corresponding to channel thermal and induced gate noise [36].

IV. OPTICAL BACKGROUND NOISE INTERFERENCE

Among all the above VLC challenges, optical background noise has a major concern which affects the performance of the communication system. In the Visible light communication system there will be thermal noise from electronics devices and shot noise due to mean received signal power and the ambient noise. Thermal noise is modeled as Gaussian noise and can be easily handled. The ambient induced shot noise has power from 20 to 40 dB greater than the signal shot noise [15].Therefore the ambient induced shot noise is considered to be dominant source of noise which is Gaussian and nearly white [38].In our work we mainly focus on the natural and artificial ambient light background noise which is a dominant source of degradation in the visible light communication. Moreira et. al has performed lot of measurements considering the natural and ambient light interference sources. Sunlight is the source of natural ambient light. Incandescent lamps, fluorescent lamps driven by conventional and electronic ballasts are the sources artificial ambient light. The differential optical receiver is used to measure the interference signal [14, 15]. Boucouvalas also performed similar measurements considering the optical background noise [16].

The interference model must be modelled along with the channel model.At the receiver side, the irradiance produced by the background light is given by eq. (22) [15]

$$H(t) = H_B + H_{interf}(t) \qquad (22)$$

Where H_B is the average background irradiance and $H_{inter}(f)$ is the time varying component.

The optical power is converted into current in the receiver side of the photodiode. So the background irradiance produced by the light sources produces shot noise and there will be variations in the optical power due to the interference.

The output current at the photodiode is given by eq. (23) [15]

$$i_d(t) = I_B + i_{interf}(t) + i_{noise}(t) \qquad (23)$$

Where $I_B = A_r R_a H_B$ (23a)

Where $i_{interf}(t) = A_r R_i H_{interf}(t)$ (23b)

A_r is the photo detector active area and R_a and R_b are the responsivity of the photo detector for the average and interference irradiance.

The double sided power spectral density (PSD) of shot noise for natural light is given by eq. (24) [15]

$$N_0 = qI_B \qquad (24)$$

Where I_B is the average DC photocurrent generated by the shot noise, and q is the charge of an electron.

A. Characteristics of natural ambient light-sunlight

The sunlight is a strong source of shot noise because of the slow variations in the intensity of light coming from the sun. In a shiny day, the sunlight spreads over the entire responsivity curve of the Photodetector. Hence it leads to steady background noise current of order of order of mA which is stronger than a room illuminated with artificial lights. Depending on the position of the sun during the normal day, the SNR at the receiver vary drastically due to temporal variation and change in nature of both the signal and noise. The shot noise produced by sunlight is stationary and the power is proportional to D.C current on the photodiode [15].

B. Characteristics of artificial ambient light-Incandescent lamps

A differential receiver is used to measure the interference signal produced by incandescent lamp [38].Six different types of incandescent lamps and halogen lamps are tested and their characteristic features are analyzed. The interference signal produced by incandescent lamp is a perfect sinusoidal signal with frequency of 100 Hz. Only for the first harmonics up to 2 KHz, the amount of energy carried is significant and for frequencies greater than 800 Hz all the components are more than 60 dB below the fundamental.

High pass filters are used to reduce the narrow band interference produced by incandescent lamps [14, 15].

C. Characteristics of artificial ambient light-Fluorescent lamps driven by conventional ballast

Seven different types of fluorescent lamps driven by conventional ballast are tested and their characteristic features are analyzed. The interference signal cannot be analyzed easily for few hours which are dependent on lamp temperature, type of ballast and starter used. The interference signal produced by the fluorescent lamp is a distorted sinusoidal signal with frequency up to 20 kHz. The Power Spectral Density (PSD) is more than 50 dB below 100 Hz for the frequency above 5 kHz. Optical filters are used to reduce the strong interference caused due to fluorescent lamps driven by conventional ballast [14, 15].

Optical filters are used to reduce the strong interference caused due to fluorescent lamps driven by conventional ballast [14, 15].

D. Characteristics of artificial ambient light-Fluorescent lamps driven by electronic ballast

Five different types of fluorescent lamps driven by electronic ballast are tested and their characteristic features are analyzed. The interference signal produced by the fluorescent light is very broad, extending up to 1 MHz and is considered to be one of the main source of degradation in the optical wireless system [14,15].Optical filters and high pass filters filters cannot be used to reduce the artificial ambient light interference. Signal denoising or adaptive noise cancellation can be used.

Different approaches are proposed in addition to the conventional filters to mitigate the optical background noise interference and to increase the data rate [10][17][18][19].

V. PERFORMANCE OF WHITE LEDS UNDER THE DESIGN CHALLENGES

The performance two different types of white LEDs under the design challenges such as data rate, multipath propagation, provision of uplink, noise sources is analysed and explained in TABLE.1. It infers, Phosphor based white LED is cost effective when compared to RGB LED but it limits the data rate.RGB LEDs offers more data rate. Thus by overcoming the drawbacks of Phosphor based white LEDs, it is mostly preferred to be used in many applications of VLC.

Table 1: Performance of two different types of white LEDs under various design challenges

VLC Optical source (White LEDs)	Data rate	Uplink and downlink provision	Noise sources	Multipath dispersion
Phosphor based white LED	• The modulation bandwidth of LED is limited to about 2-3 MHz due to slow response of the phosphor • The limited bandwidth is overcome by using blue filter is used at the receiver front end to suppress the slow phosphorescence components. It increases the bandwidth up to 20 MHz • The data rate can be increased by spectrally efficient complex modulation, equalization and filtering techniques • For example using phosphor based white LED and DMT modulation data rate of 1 Gb/s is achieved [30].	Phosphor based LEDs provide upstream up to225Mb/s [29].	Sunlight, other artificial ambient light sources [4].	• Wide band of phosphor topped white LEDs results in multipath dispersion • Data rate is limited due to inter-symbol interference (ISI) caused by multipath dispersion.

RGB based white LED	• RGB LED consists of three different wavelength colours which is used to carry multiple data stream and it is multiplexed over wireless channel, hence high data rates are achieved. • For example using RGB LEDs and DMT modulation data rate of 3.4 3.4Gb/s is achieved [31]. .	RGB LEDs are used to provide downstream up to 575 Mb/s [29].	Sunlight, other artificial ambient light sources [4].	• Multipath dispersion occurs due to characteristic changes of RGB colour in RGB LED. The junctions that produce and green light are not as efficient as the junction that produces blue light. Efficiency of blue light is about 80% whereas it is only it is only about 60% and 30% for red and green light respectively[4].

VI. VLC APPLICATIONS

Visible light communication has potential applications in many areas ranging from military purposes, hospitals, aircrafts, toy applications, under water communications, vehicular communications and many more.

A. Under water communications

Visible light communication is more useful for the sea divers to communicate when they are in need of emergency. It provides long data transmission of about 50 cm distance and higher bandwidth [20]. Non destructive nuclear reactor is inspected using mobile underwater robots for safety measure in order to avoid disaster like Fukushima, which performs both communication and localization [21].

B. Road to vehicular communications

Intelligent Transport System (ITS) is used to overcome many problems such as congestion problem and accidents etc, hence it provides more safety and ecological to our environment. Some of the applications include, on vehicle high speed camera is used to recognize the traffic lights, used to detect the obstacles and pedestrians [22]. Vehicular visible light communication based on LED headlamp is used in road safety applications. This system provides data rate of 10 kbps and covers distance of 20 cm [23].

C. Hospitals and healthcare

Visible light communications is best suited for the hospitals and healthcare applications especially near MRI scanners and operation theatres where RF radiations are undesirable. The biomedical data such as the patient monitoring medical details are transmitted using visible light which achieves data rate of 56 kbps [24]. Automatic mobile robots are used in the hospitals, the safety of the robots is important to prevent it from damage. LED lights are used in the building communicates to robot about staircase and other obstacles, so that an in house GPS system is created and robots are prevented from damage [25].

D. Mobile applications

Visible light communications are used in mobile applications such as Games, toys, location services, and augmented reality. Exchange of messages when the cars are face to face and the cars are behind one another up to distance of 1m and data rate of 1kbps is achieved. [26].

E. Location based communication

Indoor navigation system is very useful for visually impaired persons. With the use of visible light LEDs the location based information is communicated to the visually impaired person using the smart phone connected to the head phones of the person [27].

VII. CONCLUSION

The revolution in future green lightning by replacing conventional light sources with the LEDs formed an opening for visible light spectrum for optical wireless communications.VLC finds it applications in many areas such as hospitals, road to vehicular communications, underwater communications etc.Background ambient light noise is one of the main factor which affects the performance of the communication system in all the VLC applications. Hence in this paper we have presented the review of impact on main challenges such as significance of ambient light noise sources and application related to the VLC system. Noise sources such as fluorescent light lamps driven by electronic ballasts and sunlight proves to main factor of ambient light noise source compared to incandescent lamps and fluorescent lamps driven by conventional ballasts. Different methods are used to reduce the ambient light noise apart from the conventional filtering schemes. Regardless of these challenges, for short range applications still VLC proves to be a promising next generation technology which acts as an added supplement to existing radio communication. It is highly expected that visible light communication will reach the market soon and benefit the users with both illumination and data communication overcoming the challenges.

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