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Led-Based Visible Light Communication System: A Brief Survey and Investigation

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Abstract: The study investigates on Light Emitting Diode (LED) based Visible Light Communication (VLC) systems. Starting with a short review on High Brightness (HB) LEDs and their recent performances reaching up to 100 Lm W^{-1}, the researchers examine the processes and techniques of using light emitted by LEDs as a medium for carrying data. The technology exploits the inherent high rate switching characteristic of these devices. In addition, investigation on different modulation techniques is explained. Recent developments in VLC and its potential application areas are discussed. A prognosis for future trend, functional requirements and challenges are also discussed.

Key words: Light Emitting Diode (LED), optical wireless, Visible Light Communication (VLC), exploits, potential application, prognosis

INTRODUCTION

A special, relatively new area of research is communication via visible light also known as VLC. This technology uses LEDs emitting light in the wavelength interval of 380-700 nm. VLC is a novel kind of optical wireless communication with a promising future. Due to inherently diffuse optical source, the safety issue is minimized. As an extra benefit, there is potential for simultaneously using the LEDs for lighting and communication. The idea of bringing these two words together was recently re-invigorated through the emergence of white and colored LEDs (Tanaka *et al*., 2000; Kim *et al*., 2006; Nakamura, 1997) which offer a considerable modulation bandwidth of about 20 MHz.

It is believed that high speed data transmission will play an important role in the daily life. Multimedia information is envisaged to be available at any place and at any time and wireless access networks constitute a key element for achieving these goals. However, Radio Frequency (RF) bandwidth at frequency ranges which allow reasonable spatial coverage is a limiting factor. Therefore, alternative wireless transmission means as supplementary technology have to be explored. VLC using LEDs offers the potential for such supplementary system. The main reasons are:

- White or colored HB-LEDs are currently penetrating many areas of the everyday life. They are envisaged to replace high energy consuming light bulbs in private and business homes and even in street lamps. Also, they are widely used in specific lighting scenarios such as museums or even in more power demanding applications such as exterior lighting in cars, trains or airplanes
- Bandwidth is virtually unlimited
- Existing local power line infrastructure can potentially be used as a backbone
- Transmitters and receivers devices are cheap and there is no need for expensive radio frequency units
- As light waves do not penetrate opaque objects they cannot be eavesdropped. It is very difficult for an intruder to (covertly) pick up the signal from outside the room
- Visible light radiations with limited intensity are free of any health concerns. Therefore, these systems will receive acceptance for use in sensitive scenarios, such as hospitals, private homes. Furthermore, no interference with RF based systems exists, so that the use in airplanes is uncritical

All these benefits have started to attract attentions for HB-LEDs in their usage as data communication devices (Komine and Nakagawa, 2003). Also and unlike infrared (IR) transmission, current health regulations restrict the transmitted power only in terms of lighting levels and when compared with IR indoor communication, VLC is still able to use much higher radiation power, thus enabling higher quality of service given that the light is within the visible range. The optical medium can be

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viewed as complementary to the radio medium rather than competitive. For example, if a Wireless Local Area Network (WLAN) is required to cover a large area where users can roam freely inside and outside a building and remain connected to the network at all times then radio transmission is the best choice to achieve this. If however, a WLAN is required to cover a relatively small area and the service is provided locally inside a room but high transmission rates are required such as for video conference, digital TV (television) or video on demand then the optical transmission with almost unlimited bandwidth can be used. At the same time, this would free radio frequency spectrum for other purposes as described before.

Light emitting diodes: The recent emerging developments in LED technologies have produced significant improvements in the performance of LEDs in terms of power efficiency and switching capabilities (Krames *et al*., 2002). In addition, they present a long lifetime and resistance to adverse conditions such as humidity. As a result it is now common to see large-area full-color outdoor displays visible at long distances even with shiny skies or to have automobile lighting (rear lights as well as headlights) or control traffic lights assembled with HB-LEDs for instance. Visible-range HB-LEDs are used to produce large levels of optical power since their main objective is to illuminate large areas or to be visible at long distances. Therefore, LEDs are being considered the next generation lighting system and ultimate lamp for the future (Holonyak, 2000). In addition, being a semiconductor device with inherent feature of switching at high speed the idea of concurrent use in data communication with lighting has been instigated.

High brightness LEDs and lighting: LEDs have changed, the concept of lighting not only in expectation of the ultimate efficiency but also in tremendous opportunities for versatile and smart lighting applications. LED-based lighting technology, Solid State Lighting (SSL) (Zukauskas *et al*., 2002) allows for unprecedented versatility in control over the radiation spectrum which can be tailored for specific needs from general to medical and agricultural lighting, lighting for space flights, lighting for the elderly, lighting for people with special color needs, lighting for animals, lighting for museums and for illuminating art objects and lights for theatrical productions (Nylander, 2005).

A low driving voltage, fast switching and compatibility with networked computer controls enable intelligent lighting systems with software-controlled stability, operating function, adaptation and energy saving. Such systems are expected to emerge and become a disruptive and revolutionary technology in the near future. In case of automotive, the use of LEDs in forward lighting not only allows a more compact auto headlamp design but offers other benefits such as integrated high/low-beam functionality.

Precisely defined emitting area creates the potential for sharper far-field radiation patterns which improves visibility while reducing glare for incoming traffic. Finally, selective use of down-converting phosphors offers flexible tailoring of the spectral content of the LED headlamp beam.

The development of aluminium gallium arsenide (AlGaAs) LEDs grown on Gallium arsenide (GaAs) substrates and employing fully lattice-matched direct bandgap systems and hetero-structure active regions allowed these early red LEDs to exceed the luminous efficiency of a red-filtered incandescent bulb (Steigerwald *et al*., 2002). Efficiency was further doubled by the use of transparent substrate devices (AlGaAs grown on AlGaAs) (Ishiguro *et al*., 1983). Also, the introduction of aluminum indium gallium phosphide (AlInGaP) devices has revolutionized this LED technology. The entire visible spectrum is occupied with these LEDs which have luminous efficacy peaks much higher than those of incandescent lamps. Figure 1 shows the progress in luminous efficiency over the years, as declared by different manufactures over time.

The core areas of improvement which promise the greatest gain in efficiency are the LED chip and phosphor (Kim and Schubert, 2008).

For the LED chip, the internal quantum efficiency provides potential for improvement, particularly in the green spectral range where the LED efficiency has been lower than for other colors. Yet even in the blue color range, there is potential for significant improvement, particularly at high injection currents for example through a migration from conventional gallium indium nitride/gallium nitride (GaInN/GaN) i.e., ternary/binary active regions to ternary/ternary and ternary/quaternary active regions.

These advanced active regions hold great promise due to their polarization-matching characteristics (Kim *et al*., 2007; Schubert *et al*., 2008).

LED as data communication: The availability of HB-LEDs makes the visible-light medium even more realistic for communications. The novel idea to modulate light waves from visible range LEDs for communication purposes was presented by Pang *et al*. (1998, 2001). This concurrent use of visible LEDs for simultaneous signaling and communication, called iLight, leads to many new and

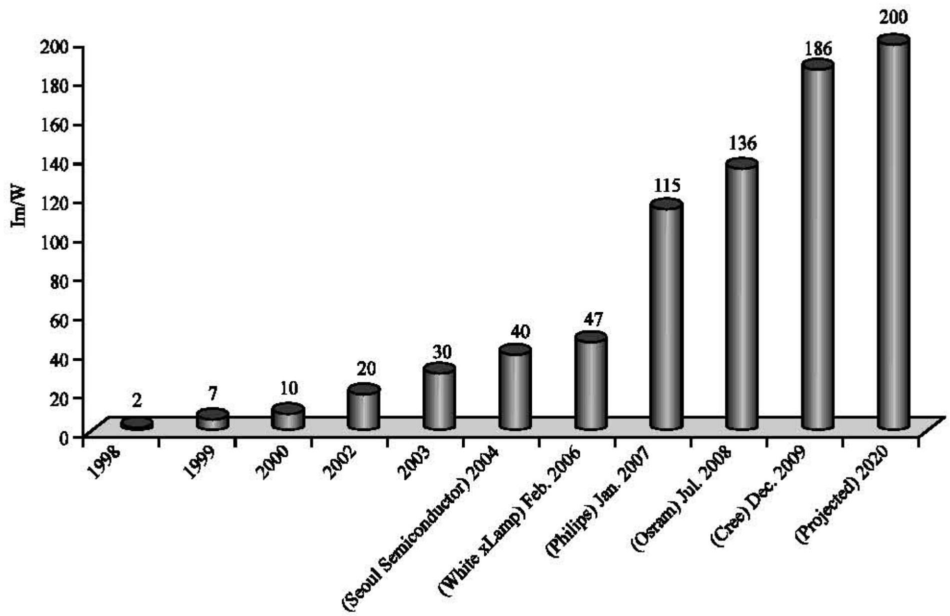

Fig.1: Progress in luminous efficacy of LED over the year

interesting applications and is based on the idea of fast switching of LEDs and the modulation of the visible-light waves for free-space communications. All products with visible-LED components can be turned into an information beacon.

That is the visible light emitted by LEDs can be modulated and encoded for example with audio information for broadcasting, thus making LEDs a part of wireless optical communication systems. For communication LEDs, the combination of a high achievable bit rate and high external quantum efficiency is essential.

This iLight technology has many characteristics that are different from IR. The iLight transceivers make use of the direct Line of Sight (LOS) property of visible light which is ideal in applications for providing directional guidance to persons with visual impairments.

On the other hand, IR has the property of bouncing back and forth in a confined environment. Another advantage of iLight is that the transmitter provides easy targets for LOS reception by the receiver. Data rate transmission in VLC is mostly limited by the switching speed and light output of visible range LEDs. In particular, light output will determine the range and reliability of data transmission with acceptable Signal to Noise Ratio (SNR) and Bit Error Rate (BER). For indoor application, data transmission rates of few tens of Megabits/s has been described (Komine and Nakagawa, 2003) however, in outdoor applications it would be difficult to realize data communication at high speeds mostly due to many kinds of optical noise sources from both natural and artificial lights.

Basic architecture and working principle

General system architecture: In this study, we introduce a basic VLC transceiver system using LEDs and Photodiodes (PD). The block diagram representation of overall system architecture is shown in Fig. 2. Devices such as laptop and mobile phones can be used for transmitting and receiving information signal. The transmitter part consists of a modulator and a pulse shaper to switch the LEDs at the rate of data transmission. Normally, multiple LEDs housed in a container form an emitter. Choice of multiple LEDs also justifies the necessary effective light output and brightness level.

These LEDs are most commonly switched from a single optical driver. As the rate of switching is faster, it goes undetectable to human eyes. For optical wireless links, the most viable modulation is Intensity Modulation (IM) (Kahn and Barry, 1997) in which the desired waveform is modulated onto the instantaneous power of the carrier. However, different modulation schemes are being experimented for enhanced performance. The optical driver is necessary to drive the emitter with adequate power to obtain long distance communication. The optical signal is then detected by the VLC receiving system generally composed by a photodiode and a front-end amplifier. The gain of the front-end is continuously adapted in order to reduce the effect of ambient and other background light sources.

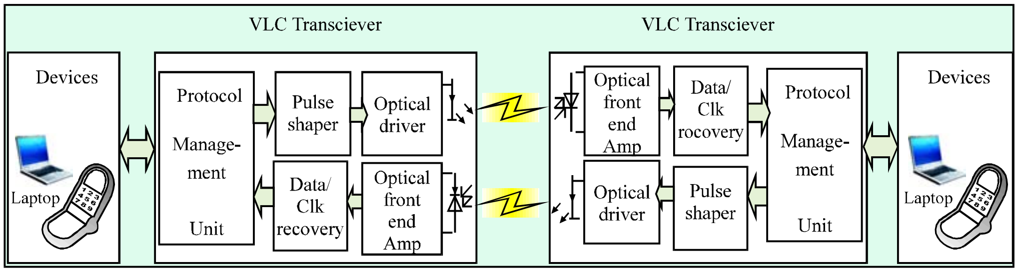

Fig. 2: General architecture for a full duplex VLC system

The most practical down-conversion technique is Direct Detection (DD). The detector is characterized by the parameter, Field of View (FOV). For a larger service area, a receiver with a wider FOV is preferable.

However, a wider FOV leads to performance degradation because all received signals including undesired signals are processed simultaneously. In addition, the system will also need the protocol management unit and data/clock recovery circuit for the synchronization of received packets corresponding to the received power level.

Functional requirements: Optical wireless communication using both visible light and infrared communication can become a viable option for last mile access and ubiquitous availability.

Nevertheless, atmospheric attenuation of optical signals and unpredictability of weather conditions limit the distance and affect link availability. In addition, high background ambient light creates challenging issues towards increasing Signal to Noise (SNR) Ratio in VLC. Thus, in these scenarios where channel behaviour keeps changing, a reliable data transmission would be difficult especially for long range. It would require several measurements in real time to approximate and guarantee data transfer.

For instance, in road traffic information transmission, failure of LOS is very common either from traffic light/road light to vehicle or between vehicle to vehicle. In this case, critical data information may be lost. To overcome this, the car in front can retransmit the received information from traffic light to the car behind.

It is also possible to maintain the LOS link by placing additional traffic light towards the right side of the road which will also be centrally controlled. This arrangement will equally support reliable information transmission to the receiver in both the lanes by improving signal strength. In VLC system, the received power is another key factor affecting performance. Using LED lights, especially in the outdoor environments, requires assuring safe and reliable usage of information transmission.

With the limitation of brightness, power and luminous efficiency of LEDs constrains on the collection area of the detector and the varying channel conditions mentioned above, it is difficult to realize a VLC system for long range information transmission. A communication system should support BER $<10^{-6}$ for reliable data transmission. Achieving such requirements in outdoor scenario is challenging.

The optical wireless channel: For VLC systems using intensity modulation, the desired channel model depends on the intensity of the background light. In low background light, the received signal can be modeled as a Poisson process with rate $\lambda_r(t) = \lambda_s(t)+\lambda_n(t)$ where λ_s and λ_n are proportional to the instantaneous optical power of the received signal and the power of the background light, respectively.

However, this assumption is not valid in outdoor environment in the presence of high ambient light level emanating from both natural and artificial sources. λ_n is usually very high and therefore, the photodiode shot noise can be modeled as additive white gaussian noise. However, for more accuracy the noise need to be modeled approximately considering different major sources of light. Considering VLC as an extension of IR, the channel DC gain is given as (Kahn and Barry, 1997):

$$H(O)=\begin{cases} \frac{m+1}{2\pi d^2} A\cos^m(\varnothing) T_S(\psi) g(\psi) \cos\psi, & 0 \le \psi \le \psi_C \\ 0, & 0 \ge \psi_C \end{cases} \quad (1)$$

Where:

A	=	The physical area of the detector in a PD
d	=	The direct distance between a transmitter and a receiver
Ψ	=	The angle of incidence
ø	=	The angle of irradiance

$T_s(\Psi)$ = The gain of an optical filter
$g(\Psi)$ = Gain of an optical concentrator
Ψc = Denotes the width of the FOV at the receiver

The m is the directivity of the LED given as:

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

Where, hpa is the half power angle of the LED. The optical concentrator $g(\Psi)$ can be given as:

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

where η represents the refractive index.

Modulation: One of the major problems with VLC is offsetting the impact of background lights, such as fluorescent lamps or day time sunlight on communications. It is important that stable data transmission is provided even if the background light is strong. The modulation method used must offer high robustness to background light. The Pulse Position Modulation (PPM) or its variants (L-PPM) are effective techniques for IR supporting high average-power efficiency and minimal power consumption.

Since, VLC systems are integrated with illumination functions, some methods should be employed whereby high brightness and illumination are achieved. A modulation technique called Inverted-LPPM (I-LPPM) can be used. In the case of conventional PPM, we set only one pulse among L sub intervals. Average transmitted power i.e., LED brightness, falls to 1/L when the peak amplitude is not changed. Of course, LED brightness can be made to equal with other modulation methods if we increase the amplitude L times (practically limitation with power constraint).

I-LPPM yields higher brightness than conventional PPM. Inverting the pulse position of conventional PPM, we obtain I-LPPM. The optical intensity is off during the L-th sub-interval and on everywhere else. For example, in case of 4-PPM light is on equivalent to 3-chip duration, making the LED three times as bright as conventional 4PPM.

When amplitude of the transmitted waveform is A, average transmitted power of I-4PPM is 3A/4. That is, the average transmitted power of I-L-PPM is (L-1)A/L. This modulation technique is particularly suitable in the indoor environment given that it provides better illumination. However, for VLC system sub-carrier PPM (SC-PPM) may find an edge over conventional PPM. Since the fluorescent lamp noise spectrum has the DC and low-frequency component which in principle can be made immune by setting the sub-carrier frequency high enough (Alves and Aguiar, 2003).

In SC-PPM, we replace the rectangular pulses with the sub-carrier which shifts the power spectrum of the signal to higher frequency band minimizing the effect of fluorescent light and low frequency background effect. The signal component can be separated from the background light component by placing a suitable filter at the receiver side.

Bit Error Rate (BER) and required power: BER of $<10^{-6}$ is necessary for reliable transmission and therefore, the receiver should receive correspondingly minimum signal power. The performance of VLC system also depends on type of modulation used. In order to calculate and determine the BER and power efficiency of different modulation schemes, we need to generalize error probability for an L-ary modulation in the presence of additive white gaussian noise, assuming Maximum Likelihood (ML) detection and neglecting inter symbol interference.

The transmitter conveys information at a rate of R_b bits/sec by transmitting one of L non-negative signals $\{x_1(t), x_2(t), \ldots, x_L(t)\}$ every $T = \log_2 L/R_b$ sec and the channel adds white gaussian noise with power spectrum N_0. For example, an On Off Keying (OOK) transmitter emits a rectangular pulse of duration $1/R_b$ and of intensity 2P to signify a one bit and no pulse to signify a zero bit. The average signal power is given as $P_{av} = \sum_i (x_i(t))/L$. The band-width required by OOK is roughly R_b, the inverse of the pulse width. The Bit Error Rate (BER) is given in terms of minimum distance as:

$$BER = Q\left(\frac{d_{min}}{2\sqrt{N_O}}\right) \quad (4)$$

Where d_{min} is the minimum euclidean distance given as:

$$d_{min}^2 = \min \int_{1 \ne j} \left[x_i(t) - x_j(t)\right]^2 dt \quad (5)$$

Then, BER for OOK modulation is:

$$BER_{OOK} = Q\left(\frac{RP_{avg}}{\sqrt{N_o R_b}}\right) \quad (6)$$

In the case of L-PPM, the minimum distance is:

$$d_{min} = \sqrt{\frac{2R^2 LP_{av}^2 \log_2 L}{R_b}} \tag{7}$$

So that the Symbol Error Rate (SER) is given by:

$$SER_{L-PPM} = Q\left(\sqrt{\frac{R^2 LP_{av}^2 \log_2 L}{2N_o R_b}}\right) \tag{8}$$

and BER is therefore;

$$BER_{L-PPM} = \frac{L/2}{L-1} Q\left(\sqrt{\frac{R^2 LP_{av}^2 \log_2 L}{2N_o R_b}}\right) \tag{9}$$

However, in the case of I-LPPM, the BER is given as:

$$BER_{I-LPPM} = \frac{L/2}{L-1} Q\left(\sqrt{\frac{R^2 LP_{av}^2 \log_2 L}{2(L-1)^2 N_o R_b}}\right) \tag{10}$$

Where, N_0 is the Power Spectral Density (PSD) of Additive White Gaussian Noise (AWGN). Similarly, the BER for SC-LPPM is given by:

$$BER_{SC-LPPM} = \frac{L/2}{L-1} Q\left(\frac{1}{2}\sqrt{\frac{3R^2 LP_{av}^2 \log_2 L}{N_o R_b}}\right) \tag{11}$$

Figure 3 a-c shows the power requirements to achieve BER of 10^{-6}. It also shows the necessary power to achieve different data rate maintaining necessary BER. Signal to noise ratio for various BER is also presented.

When L = 4 and 8. It is seen that more power becomes necessary for I-LPPM as compared to L-PPM which is power efficient techniques. Therefore, there is a trade-off between brightness and power requirement. Of course, this will depend on the distance and environment either in indoor or outdoor.

When we increase L, the power efficient scheme L-PPM can be used for high data rate. However, SC-LPPM seems to be more reliable than any other especially providing very good SNR characteristics. In this analysis, we have considered AWGN case for all the modulation schemes.

It is obvious that the BER will decrease with increase in power (or luminance) transmitted by the LED. In other words, brighter the light is the smaller the BER. However over the distance, the brightness of light falls. In addition,

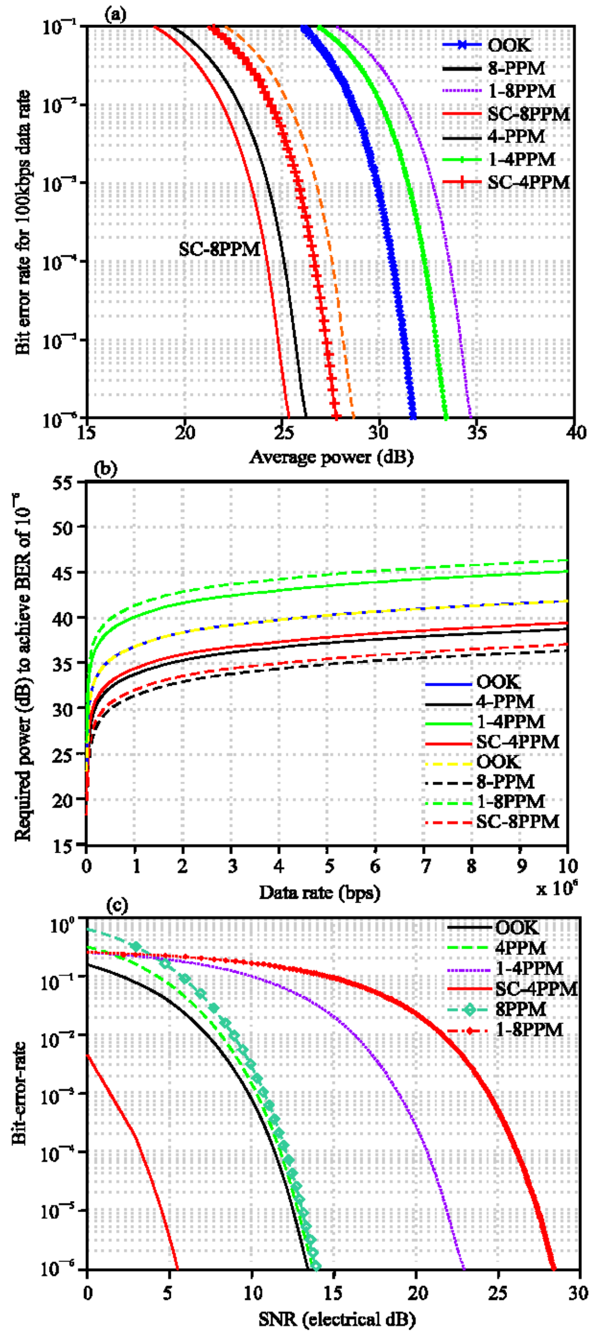

Fig. 3: a) BER vs average power (dB) for different modulation for m = 4 and 8; b) Necessary power to achieve BER of 10^{-6} for various data rate when m = 4 and 8; c) BER vs signal to noise ratio (dB) for different modulation schemes when m = 4 and 8

light from many other sources interfere making detection of actual tiny signal very difficult. Under these circumstances, the BER will increase (Pang *et al*., 2001).

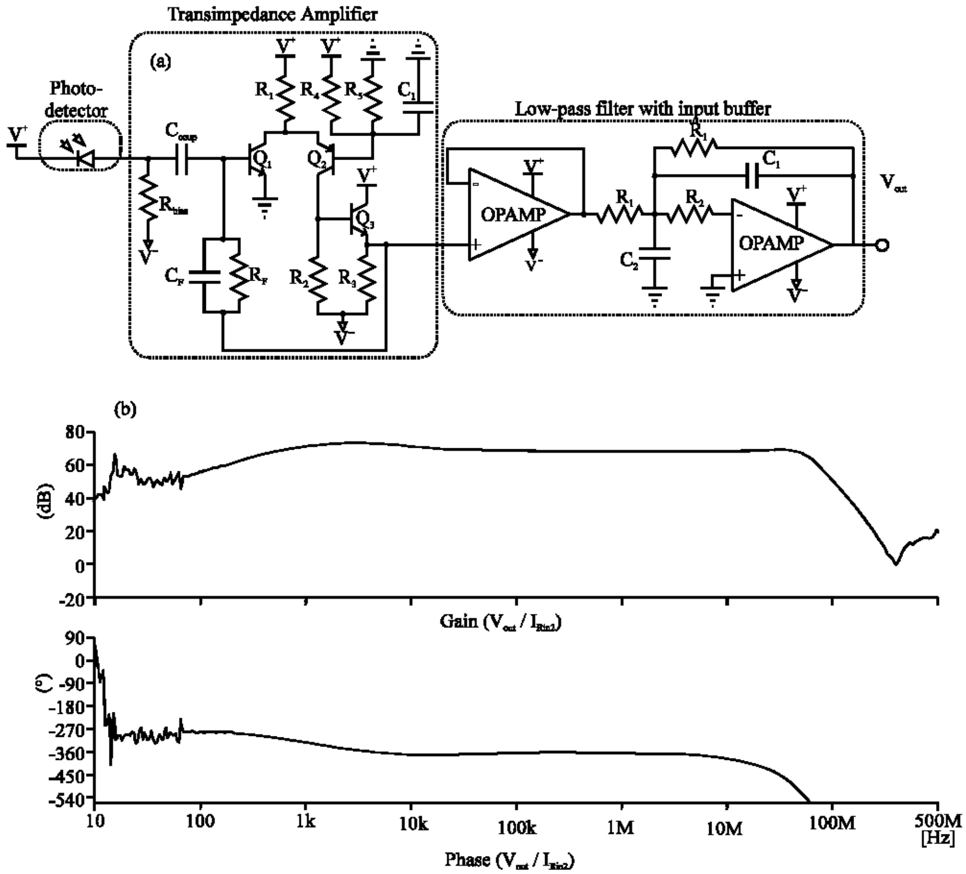

Fig. 4: a) Simple receiver's diagram; b) Gain/phase plot

The detector and front end amplifier: Usually PIN photodiodes are used for better performance in the presence of ambient noise. In LOS, the influence of the directed light is a determinant factor of the system performance.

The generated photocurrent consists of desired signal current (proportional to the incident optical power) and a noise component mostly dominated by shot noise current. However, outdoor environments have many light noise sources.

Therefore, obtaining an approximate model of the noise sources may help improve the performance and reliability of receiving system. With such information the dynamic input range and gain of front-end can be appropriately adjusted.

There are two quantities which bound the dynamic input range of an optical front-end amplifier: the front end sensitivity the minimum signal that can be recognized considering the presence of noise and the maximum output signal for which the front end still exhibits an approximately linear response. In a first practical approach, a simple receiver consisting on a PD detector followed by a transimpedance amplifier and an output low-pass filter was built and tested.

Figure 4a shows the electrical circuit of the implemented prototype while Fig. 4b shows the gain/phase measurements.

This practical approach results in a robust configuration with an approximate cut-off frequency of 30 MHz at a gain of 68 dB. However, it is limited in terms of dynamic input range and easily saturates for high background light noise levels.

To achieve both high sensitivity and high input dynamic range the transimpedance gain should not be fixed and should be adapted to the input signal. This necessity is naturally justified by the need to operate in different environmental situations, such as: day and night, different weather conditions (with or without fog), proximity between transmitter and receiver. Two strategies (Alves and Aguiar, 2003) have been implemented to produce this required gain control capability: a switching feedback scheme (Fig. 5a) and a controlled feedback scheme (Fig. 5b). The number and magnitude of the different gains are set to meet the required sensitivity and

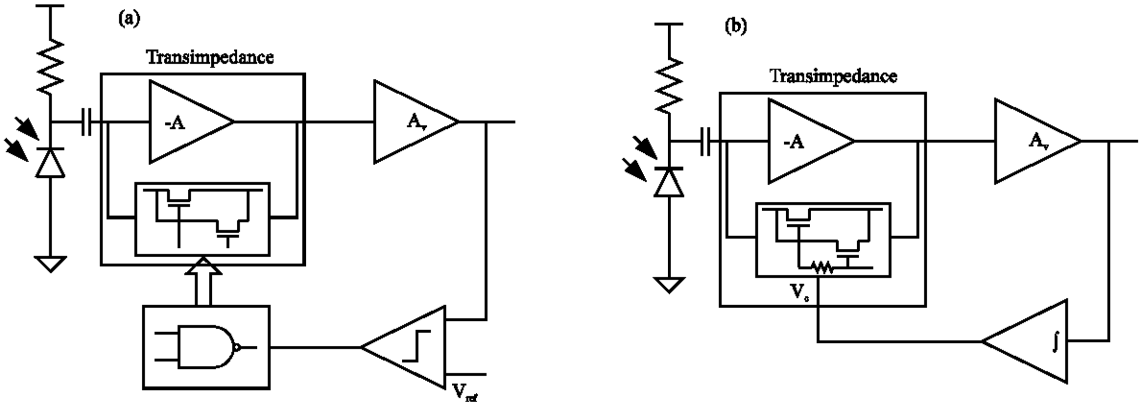

Fig. 5: a) Switching feedback scheme; b) Controlled feedback scheme

the required input dynamic range. However, for any implemented configuration, the overall performance is mostly limited by the design of the front end.

MATERIALS AND METHODS

All the new applications for HB-LED's have made possible to implement VLC systems in different scenarios. This means that it can play a vital role in the future 4G wireless access networks.

For example, by taking advantage on using the existing infrastructure around us, the transmission of positional information can be entered into individual indoor LED lighting devices and sent to a cellular telephone or similar device, thus enabling position detection that is accurate to within several meters.

Theoretically, precision is possible to within several millimetres and it is at this level that the true power of VLCs will be realized, such as in controlling robots). VLC systems allow us to receive on-off positioning information where you are and others easily from illumination and emergency lights everywhere.

In another example, musicians each play a different instrument under red, green and blue lights. When visitors wearing headphones turn in the direction of one of these lights, they will be able to hear only the sound of the instrument receiving that particular colored light. By making the most of the visibility of this light, visitors will be able to instinctively choose the information they want to receive.

There are many promising indoor applications including the transmission of television and multimedia signals using the ceiling lamp or the desk lamp, the use of LED light spots in cars, trains, buses and airplanes as Internet access points and the realization of local information points in shops, airports, train stations and museums. Beside the indoor applications, there are many possible outdoor applications including car to car communication via the front and back lights, traffic lights providing the drivers with traffic related information and street lamps providing the pedestrians with local information.

All of these are examples of the advantages that VLC can present in a future ubiquitous communication world.

Indoor applications: With visible-light wireles systems, it would be possible to broadcast broadband information in various environments such as offices (Fig. 6a) that are lighted anyway.

In such scenario, a Power Line Communication (PLC) system can be used as feeder. Data arriving in an office or home flow into the network and are taken out from optical access points composed of LEDs in each room and have a function of lighting simultaneously.

White LEDs at access points do not only illuminate a room but also modulate electric signals into visible light wave signal and these signals are emitted into the air.

Shadowing also can be avoided by using distributed light source. Normally, all LEDs transmit same data signal however, it is possible to use different color LEDs and different information signal can be transmitted as shown in Fig. 6b.

Transmitted optical pulses from LED lights are received at a user terminal which is composed of photo diodes and can convert optical pulses into electrical signals. The optical receiver at the user terminal employs band pass optical filter to attenuate ambient light. There For example, researchers (Komine and Nakagawa, 2003) have analyzed and demonstrated VLC integrated with power line communication at data rate of 1 Mbps with BER of 10^{-6}.

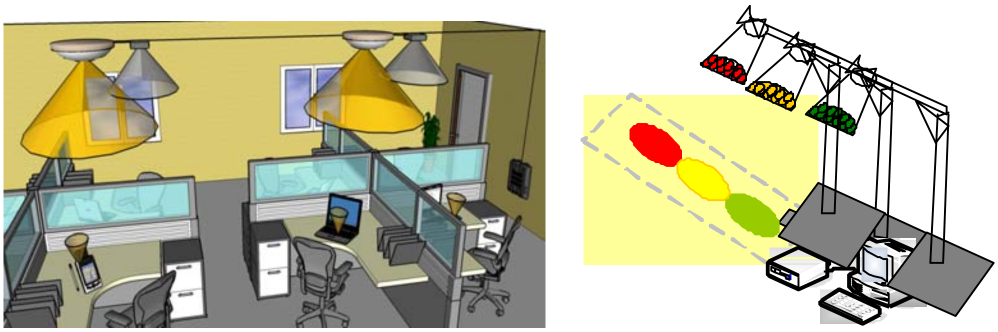

Fig. 6: a) Indoor broadcasting via VLC; b) VLC parallel data communication

PLC makes it possible to use ubiquitous electricity power-lines for the medium of communications. In a house, already installed power-lines and outlets behave as data-networks and ports. Since, many data equipments and electric appliances are already connected to outlets, there is no necessity to introduce tangled cables for data communications. Using plural white LEDs, researchers (Yuichi *et al.*, 2003) discussed and proposed the VLC system.

They performed the numerical analysis of LED lighting as illuminance, SNR and RMS delay spread during use as an optical transmitter. VLC can be considered as a candidate for Wireless Home Link (WHL) (Tanaka *et al.*, 2000).

The optical wireless link is suitable for a non-public network or a consumer communication network such as, WHL because it does not require any license for use. Moreover, light waves are obstructed only by physical obstacles and it is easy to prevent interference from adjacent rooms.

The VLC can be used where radio electromagnetic interference is strictly prohibited (hospitals and airplanes). Therefore, transmission by light waves is more suitable for indoor wireless network than by the radio wave.

Outdoor applications: VLC system is equally important and useful in outdoor application such as Intelligent Transport System (ITS) and road safety application etc. Transmitting different traffic information (Fig. 7) from LEDs traffic light to approaching vehicle integrated with VLC receiving system may minimize road accidents. In addition, such information will help regulating the traffic flow smoothly. Traffic light signal can broadcast audible traffic information which will help the pedestrian and physical handicap people to receive the status of the traffic and follow them.

It will not be a surprise when we see cars communicating among themselves using rear, front or side lights as well as to road side units or parking lights to obtain important information (Fig. 7).

In parking area LEDs based parking light can transmit vacant slot for parking at each entry gate and even to car arriving in parking zone. VLC system can find its importance in airplanes where hundreds of kilometers of physical wire are currently used and could be replaced. However, few experiments have been performed in outdoor environment as well. Researchers (Akanegawa *et al.*, 2001) carried out basic study on traffic light information system using white LEDs.

They analyzed the system for basic modulation techniques and evaluated the required SNR as well as design a service area for successful transmission. Kitano *et al.* (2004) discussed road illumination communication system based on LEDs. researchers proposed the shape of LED road illumination which fulfills the standard specification of road illuminations in Japan. Through, numerical analysis they justified the possibilities of communication on road. Using 2-dimensional image sensor a VLC system was analyzed and proposed in (Wook *et al.*, 2006). Arai *et al.* (2007) proposed hierarchical coding scheme based on 2D fast Haar wavelet transform.

The proposed hierarchical transmission schemes outperform the conventional on-off keying and the reception of high priority data is guaranteed even LED-camera distance is further. Iwasaki *et al.* (2007) took a step forward proposing a parallel communication in VLC. They proposed a road to vehicle communication system using a high speed camera. In this system, they receive data by capturing the ransmitter with the high speed camera, making it possible to recognize each LED

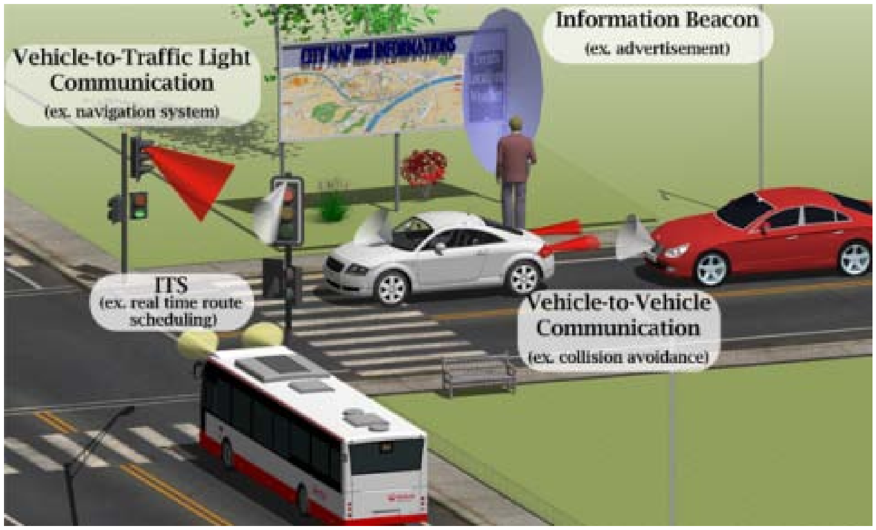

Fig. 7: VLC outdoor applications scenario

separately. They have examined communication speed and conducted experiment of parallel data transmission under laboratory condition.

Short range wireless access: For future short range applications, optical wireless communications, especially VLC, present a viable and promising supplemental technology to radio wireless systems. This technology can act as a standard light, doing what standard lights do but stand underneath it with a suitably equipped gadget such as a PDA, mobile phone or MP3 player and we can transfer data straight to the gadget at speeds approaching that of fiber instantly.

At exhibitions, we can stand underneath a VLC lamp and download information from the display. In electronic advertising signs, letting us download data about the product being advertised. In the office with a VLC equipped desk lamp being used as a modem for the laptop pretty much anywhere we currently use Wi-Fi.

As a medium for wireless short range communication, visible light has both advantages and disadvantages when compared with IR, microwave and radio media (Yuichi *et al*., 2003). On one hand, LEDs and photo detectors capable of high-speed operation are available at low cost.

Like the IR, the visible spectral region is unregulated worldwide and licenses are not necessary, as the commission does not regulate the visible light frequencies. Both IR and visible light penetrate through glass but not through walls. For transmission to be possible there must be no obstructions standing in the way of the visible LED light beam as it requires a clear LOS between the sending side (LED) and receiving side, whereas IR also allows non-directed and non-LOS link design.

Like microwaves, visible LED light beams follow a straight line path and are well suited for the wireless delivery of large quantities of voice and data information. In practical use, one should take advantage of this highly directional feature of LEDs. On the other hand, LEDs also have many drawbacks. They are suitable for short range only, as the photo detector current is proportional to the received power. Intensity modulation with direct detection seems the only practical transmission method. The SNR of a direct detection receiver is proportional to the square of the received optical power. It should also be mentioned that the relationship between the radiant intensity and distance from the receiver follows the inverse square law. Hence, as a communication medium, it has limited range and is subject to noise arising from sunlight, incandescent lighting and fluorescent lighting. It is not suitable for broadcasting signals over a wide coverage area or over long ranges.

RESULTS AND DISCUSSION

Indoor broadband wireless access: Although, a few tens of Mega bits per second data transmission has been successfully demonstrated in the indoor application of VLC, high data rate of 100 Mbps is yet to be realized. Improvement in data rate is possible with the use of equalizer as proposed by Zeng *et al*. (2008). They use equalization at the receiver to improve the data rate.

Simulation shows a highly reliable communication channel with an SNR of up to 81 dB. Moreover, the data rate can be improved from 16-32Mb/s NRZ-OOK at a BER of 10^{-6}.

Use of multiple resonant equalizers is proposed (Minh *et al*., 2008) to further enhance the data rate. In this letter they have described a link that uses 16 LEDs which are modulated using a resonant driving technique, creating an overall BW of 25 MHz. This is used to implement a 40 Mb/s nonreturn to zero ON–OFF keying link which operates at low error rates and also provides illumination at levels sufficient for a standard office environment.

Thus, it can be seen that it is possible to access broadband data using VLC especially in indoor environment. But the major problems being encountered are: The switching limit of LED, switching limit of photo detector and the background ambient noise.

Specialized low rate short range transmission: VLC system can play an interesting role where high data rate transfer and long range is not an issue. For example, interesting and important advertised information displayed on electronics sign board can be downloaded by placing a handheld mobile device or PDA equipped with VLC receiver in the front. Similarly, news broadcast can be downloaded or read-in on e-paper while sitting in cafeteria.

From exhibition or museum important information about any particular object can be downloaded and saved for future references. A wireless USB port, interface and device based on VLC for very high data rate is likely to get popularity. The basic function and descriptions are available (Kumar *et al*., 2008). VLC because of its important characteristic of non interference to electromagnetic waves has high potential to be used in airplane where 100 km of physical cable are wired. Similarly, this technology will find a room for safe use in the hospital.

Countering noise effect: Apart from the limitation imposed by the optoelectronic devices (such as LED and PD), the performance of VLC system is greatly affected and influenced by several sources of light noise; natural (such as sun light, shining moon light) and or artificial (street and road lights, vehicles light etc).

Natural and artificial light sources produce a certain amount of background optical power density or irradiance that impairs the optical receiver's performance. The effects of this background irradiance manifests in two distinct forms: as shot noise induced on the receiver photodiode by the steady background irradiance and as interference induced by the variations in time of the same irradiance. The noise is directly proportional to the amount of light incident on the photo-detector therefore is a function of average optical power.

The shot noise is due to the mean received desired signal power and ambient light. Natural ambient light noise caused by sunlight can be considered steady with slow intensity variations in time. Artificial ambient light comes from several light sources: incandescent lamps, fluorescent lamps driven by conventional ballasts and fluorescent lamps geared by electronic ballasts. Normally, they are referred to as shot noise and can be considered Gaussian and nearly white. The use of fixed optical filters reduces out of band ambient light noise. The steady background irradiance produced by natural and artificial light sources is usually characterized by a direct current induced at the receiver photodiode that is directly proportional to that current.

This current is referred as the background noise current. The interfering signal produced by incandescent lamps is almost perfect sinusoid with a frequency of 100 Hz. In addition, only the first harmonics (up to 2 KHz) carry a significant amount of energy and for frequencies >800 Hz, all components are 60 dB below the fundamental. So using electrical high pass filter this interference can be eliminated without much signal degradation.

For fluorescent lamps equipped with conventional ballasts driven at a power-line of 50 or 60 Hz, they induce interference at harmonics up to 50 KHz. This also can be eliminated by careful choice of modulation scheme to ensure there are no low frequency components and through electrical high pass filtering. For fluorescent lamps equipped with electronic ballasts, the ballast modulation frequency itself is 35 KHz. Therefore, interference harmonics extending up to 1 MHz are introduced. This cannot be easily filtered. In case of interference overlapping the signal spectrum, sophisticated digital signal processing algorithms need to be developed.

Although, it seems in principle that the effect of artificial and natural light be minimized using suitable electrical or color filters, modulation techniques but practically they are difficult and unable to reduce the effect to the expectation.

CONCLUSION

The status of visible light communication has been presented. Due to recent developments on LED illumination technology, VLC can be exploited for simultaneous function as illumination and data transmission in both indoor and outdoor environments. For future short range applications, VLC present a viable and promising supplemental technology to radio wireless systems. Though, there are many challenging issues such as overcoming heavy ambient noise and thereby increasing SNR, however we believe that VLCs will be one of the most promising technologies in the future. The system is challenging however interesting area of research.

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