International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 3, March - 2014

Optical Wireless Communications Through Visible Light Leds: An Overview

Iskandar Slaiman, Nor Hisham B. Hamid, Tang Tong Boon
Electrical and Electronics Engineering department
University Technology Petronas
Tronoh, Malaysia

***Abstract*—Communications through visible light LEDs have obtained great interest for indoor and outdoor short range applications in last few years. LED based transmitters will replace RF systems in near future with higher data rates and wider bandwidths. Although LED transceivers have good advantages, their performance restricted by some critical issues like LED junction capacitance, driver switching speed and noise from different light sources. In this paper we introduce an overview on the optical wireless communication technology through visible light LEDs including basic concepts, challenges and major works have done in this field.**

Keywords— visible light communications, indoor optical wireless, LED based systems.

I. INTRODUCTION

Short range communication systems through LED which basically a type of free space optical communications (FSO) is promising future technique that will substitute most RF technologies. The vision for (4G) wireless communications sets the target download speed at few hundred of Mbps for mobile systems and few Gbps for fixed systems. Also, fourth generation systems will encompass a number of multiple complementary access technologies rather than using single access technology. Essentially, it is agreed that optical communications through LEDs (also known as optical wireless) is expected to be common technology for indoor and short-range communications. LED based communication systems can be considered the most suitable techniques for these applications because of several issues including unregulated wide bandwidth, typically few GHz, license-free operations, and efficient-cost equipment [1]. Compared to RF systems LED transmitters offer higher data transmission at rate comparable to fiber optics with fraction of its deployment cost, in addition other functions can be provided such as lighting or signaling. For indoor applications using LEDs as transmitters considered to be safe, emitted visible and infer-red waves don't hurt human eyes, also optical signals do not interfere with other RF systems making it safe to use in environments where using RF devices are prohibited like airplanes and hospitals [2]. A comparison between RF and wireless LED based systems shows the advantages of LED transmission over conventional RF systems especially in terms of security, data rates and cost. Table.1 1illustrates some of these advantages:

TABLE.1 RF VERSUS OPTICAL WIRELESS

specification	***RF Systems***	***Optical Wireless Systems***
Security	Penetrate Walls/weak	Doesn't penetrate/strong
Cost of spectrum	Expensive when available	None
Interference	Other systems on same frequency	Ambient and artificial light
Multiple fading	Destructive when RF waves out of phase	Non-destructive, appears as noise
Path Redundancy	Achieved with multiple AP's	Achieved with multiple LED's
Data Rates	Few 100 Mbps	Few Gbps

LED based transmission systems can be used not only for indoor applications but also in some outdoor systems. LED systems provide reliability and low cost data links for many applications some of which are video broadcasting, road information exchanging through traffic lights and vehicle to vehicle communications [3].

II. BACKGROUND

Recently, due to development of laser diodes (LD) and light emitting diodes (LED), researchers believed that wireless optical transmission presents a viable and promising technology to substitute RF systems by enabling their use for indoor- short range applications and some outdoor long range cases [4]. Energy-efficient LED materials and devices have witnessed great progress last few years, undoubtedly, replacing the old incandescent and fluorescent lamps with white LED lamps will happen in the near future. These cheap and power-efficient devices will give rise to many interesting applications for both indoor and outdoor communication scenarios. Although laser diode has many advantages over LED such as higher data rates and modulation bandwidth, using these diodes for indoor and short range communications considered to be prohibitive because it's harmful effects on human eyes and skin. Infrared and visible light LEDs are common used for indoor and short range systems. While infra-red LEDs can reach about few MHz bandwidth, using visible light LEDs can achieve up to 800 Mbps and few hundred MHz while providing both communication and illumination tasks [5]. Narrow radiation beam of infra-red systems makes their performance ideal for point to point connections. On the other hand, wide beam of visible light LEDs make point to multi point communications "broadcasting" as effective as point to point. In this case some restrictions on energy consumption will appear.

III. LED BASED COMMUNICATION SYSTEM

Basically, any communication system using LED transmitters consists of two parts which are: Modulator-Demodulator circuit and front-end electronics, fig. 1 Illustrates the block diagram of simple LED transmitter- receiver. Front-end electronics usually contain LED driver circuit at the transmitter and trans-impedance amplifier with clock and data recovery circuit at the receiver.

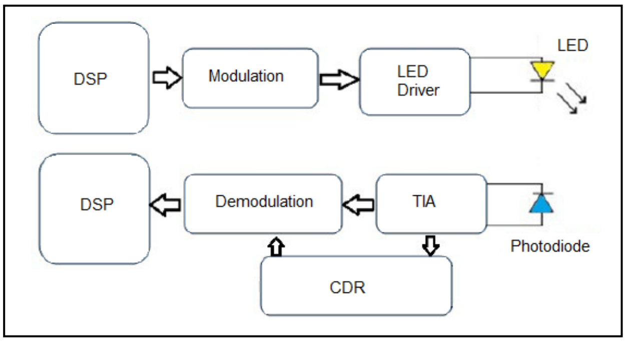

Fig .1 block diagram of LED based communications system (optical wireless)

A. *Transmitter*

Consists of LED device and LED driver circuitry. Optical carrier emitted by LED can be modulated in amplitude, frequency, or polarization. For short range applications the most commonly schemes used are carrier amplitude modulation due to its relatively simple implementation. OOK [6] is a type of amplitude modulation scheme where the LED is turned off to transmit a logic "zero" and turned on to transmit a logic "one". In this case optical pulse occupies whole bit duration during "one" and totally disappears during "zero". This modulation scheme is called non-return-to-zero on off keying (NRZ–OOK) [7]. Simplicity in implementation, low Bandwidth requirements and data rates achieved made NRZ OOK the best modulation scheme when compared to other existing schemes like RZ and Manchester [6]. LED driver circuit can be simple TTL or CMOS current switch. Achieving high data rates depend on drivers switching speed as well as LEDs characteristics.

B. *Receiver*

Basically consists of photo-detector which can be either photodiode or phototransistor, this detector is followed by trans-impedance amplifier to convert photodiode current to corresponding voltage signal. After that the signal is amplified, filtered and data is recovered for demodulation process.

C. *Communication link*

Like all free space optical communication systems, LED based systems use free space as communication medium. Attenuation in free space (for outdoor links) is caused basically by weather conditions (fog, smog, and rain ….etc.)[8], also transmitted power goes down as the distance increases. For indoor and short range systems, optical signal attenuation is lower due to absence of previous factors. Indeed, there is much important issues that must be taken in consideration which are optical noise sources that include ambient, sun light and artificial light sources [9].

IV. MULTIPURPOSE OPTICAL WIRELESS SYSTEMS

As it is mentioned earlier, the significant feature of LED systems is its possibility to achieve multiple tasks. White-light LEDs can be used for both communication and illumination purposes [10]. Researchers are trying to minimize communication hardware in order to integrate them into light sources for providing both communication and illumination functions [11, 12]. Two types of LED are suitable for this kind of operation:

- LEDs that use separate red–green–blue emitters.
- LEDs that use a blue emitter in combination with a phosphor that emits yellow light. This latter approach is attractive for general illumination due to its lower complexity when compared with the three-emitter device [13].

Besides illumination, LED transmitters can provide some signaling tasks. Traffic light devices use monochromatic LEDs to regulate road traffic, in addition to signaling function these LEDs could be used to broadcast traffic status information to receivers mounted on cars [14, 15] or for broadcasting some commercial advertisements [16].

V. RELATED WORKS

Several works have been reported on indoor and short range communications using LED systems. G. Pang introduced a system using visible light LEDs for traffic light-based communications [4]. The system was set up with 441 red ultra-bright LEDs achieving transmission distance over 20 meters in lab conditions at 128 Kbps data rate. Another prototype was developed by T. Douseki in [11] which is an indoor application for short range communications providing 40 cm transmission distance as a desktop lamp without batteries. Supplying Power is derived from small solar cell which also acts as a photo detector for receiving data. The prototype can support 100 Kbps under illumination at 40 cm distance. A prototype described by Wada et al. is an extension of a pixilated system for short range outdoor application [17]. The system uses a LED array traffic light as a transmitter and a high speed camera as a receiver. The authors claimed that it can achieve data rate of 2.78 Kbps within distance up to 4 m under laboratory conditions. Minh et al. at the University of Oxford have developed a prototype that can operate at 100 Mbps [10]. However, it can be used only for a very short distance (10 cm). Little et al. demonstrated a duplex point-to-point short range (almost 3 m) white- LED based system with 56 Kbps data rate [12]. The system was developed with available electronic parts demonstrating the simplicity, viability, and low cost solution. Lately, the same group created a system that can deliver in excess of 1 Mbps providing both communication and illumination at several meters. The prototype was demonstrated as an array consists of seven luminaries have the form of overhead spot lighting. In [18, 19] data rates of 50Mbps were achieved by using extra CMOS circuit for faster discharging of LED junction capacitance which limits the operating bandwidth and so the data rate. Using optical filters to filter out slow LED light component and post equalization allowed authors in [20] to reach 80Mbps data rate and 25MHz bandwidth, anyway only 10 cm of transmission distance could be reached. Minh et al. [21] introduced multiple resonant equalization technique. The prototype uses 16 white LEDs that are modulated with a resonant driving technique; the system could achieve 25 MHz bandwidth and 40 Mbps data rate. Enabling higher data rates was done using multiplexing schemes and complex modulation techniques. Discrete multi-tone modulation with Quadrature-amplitude modulation scheme can increase transmission rate to 500 Mbps as it was showed by Jelena et al. [22], point to point communication link was designed based on a commercial white phosphorescent LED within the BER of less than 0.002 for an illumination level of 1000 lux. Finally, 1 Gbps LED based optical link was reported in [23] using an optimized discrete multi-tone modulation technique with adaptive bit and power loading algorithms. Using these techniques authors achieved BER of 0.0015 even under very low illumination conditions (10 lux).

VI. LED BASED COMMUNICATIONS CHALLENGES

a. *Achieving high data rates*

Limited bandwidth and data rates are the essential characteristics of simple LED based transmitters. Due to its intrinsic capacitance effect, LEDs are limited in their modulation speed. A number of approaches were proposed to improve the modulation bandwidth, including using a blue-filters at receiver side to filter out the slow components of LED emission [24]. Equalization of the driving circuitry also can increase the bandwidth [20, 21]. Using pre-equalized LED driver enabled authors in [20] to achieve 80 Mbps data rate, this rate was extended to 100 Mbps using post-equalization at receiver side. In both approaches, LED modulation bandwidth that was achieved is approximately 50 MHz. Another important factor degrading data rates is capacitive characteristics of the LED. These characteristics must be determined accurately as they significantly impact the function of the semiconductor device and the whole system performance [18]. Switch on/off time of the LED limited by its junction/diffusion capacitances which affect charging and discharging times of the LED and thus its switching speed. Therefore, shorting the LED during logic “zero” time will drawing out the carrier that remains in the LEDs capacity faster and hence increasing its switching speed [18, 19]. LED driving electronics play another role in determining data rates. Fast switching driver allow faster rates to be implemented, thus improving transfer characteristics of drivers can add great improvement on LED transmission rates [25]. Finally, the highest switching speed of the transmitter is determined by smallest switching time of both LED and its driver circuit.

b. *Providing Uplink*

LED based communication systems basically are suited to broadcast applications, so providing an uplink to the transmitter unit can be problematic. Many approaches have been proposed for providing uplink connection. An infra-red link was used to connect to the transmitter with the visible light source [26, 27]. In [28] a retro-reflecting transmitter-receiver was proposed to provide the uplink by reflecting a proportion of the incident light back to the transmitter, and this reflected beam is modulated to provide data link from user terminal to the infrastructure. Although data-rates achieved by this technique are low, it could be very attractive for future developments. Using co-operation between LED based systems and RF wireless standards can allow required connectivity between equipments [29]. A LED based downlink can be combined with an RF uplink, and this can reduce the overall load on shared RF channel enhancing network performance.

c. *Regulation*

Short range communications through LEDs are subject to regulation [30] by different standards such as an eye-safety, automotive (in case of traffic light signals), or illumination regulation standards. Therefore standardization must encompass communications and other associated issues. This is unlike most other communication standards, which raises challenges of coordination across regulatory concepts and frameworks. Recently a lot of activities have been done for standardization of LED based communications, especially visible light communications through LEDs. In Japan, several national standards were developed by VLCC [2], also the IEEE 802.15c Study Group on visible light communications is currently trying to become a working group. Perhaps the biggest challenge for LED based communications is to achieve compatibility with other existing structures and developing links with relevant regulatory frames.

d. *Interference from light sources*

The major noise source in LED based communication systems is the ambient light [31]. Also a combination of sunlight, fluorescent and incandescent light introduces high value noise to the system receiver. The performance of the optical receiver also limited by optical interference [32, 33]. Natural and artificial light sources produce an amount of background irradiance that affect the receiver’s performance. The effects of this irradiance appear in two distinct forms:

- Shot noise that induced on the receiver photodiode by the steady irradiance
- Interference induced by variations in time of the same irradiance.

Shot noise is characterized by the direct current (DC) it induces on the receiver photodiode. The resulting noise power is directly proportional to this current and has a sufficient impact on bias conditions. Interference which is produced by artificial light sources such as fluorescent and Incandescent lamps affect receiver performance in different ways depending on its source, however using low pass filters can eliminate most interference because of their low frequencies (typically few KHz). In [32] interference sources taken into consideration when design and modeling LED based communication system. Higher levels of attenuation on interference origin current can be achieved using optical filters. Anyway, the current high costs of these devices make their use on low-cost systems impractical.

e. Signal propagation

Optical communications through LED are basically point to point type of communications. Providing point to multi point connection seems to be a difficult challenge [34]. Using LEDs with wide emission pattern would solve the problem of transmitter – receiver alignment, but in this case a high penalty will be imposed to transmitted power and so the transmission distance. For indoor applications, multiple reflections and diffusive signal propagation causes jitter and inter symbol interference (ISI) due to optical pulse dispersion at receiver side [35]. Some approaches were introduced in order to enhance propagation patterns enabling point to multi point efficient connection. In [36-38] Employment of diffuse optics has led to solve the problem of "line of sight", anyway this proposal has been challenged because of limited source power which being diffused in many directions. Using multiple transceivers introduced another solution for propagation issue [39]. In spite of providing efficient propagation module, these techniques considered to be cost inefficient due to large amount of equipment it requires. More work was concentrated on omni-directional optical antennas [40] which promise to provide great improvement in near future.

VII. CONCLUDING REMARKS

Future expansion of wireless optical communications into indoor applications replacing conventional RF systems will create many challenges in optical transceivers design field. Researcher's primary work has been focused on speed and sensitivity of these systems which arise new requirements on transceivers designs. LED based transceivers implementing multiple LEDs, complex electronics and high power consumption requirements are not suitable for portable devices, also using optical components like optical filters will clearly increase the cost. More efforts must be done for developing transceivers with simple and cheap technologies to fit the requirements of existing devices, achieving high data rates using single LED which in turn can reduce cost, size, and power as well as system complexity. For indoor and short range applications, efforts must be concentrated on achieving higher data rates and wider bandwidths keeping the cost in its lowest limits.

General overview on LED based communication systems through visible light was introduced. Many works were done so far to improve performance of these systems making them the best solution for future wireless communications, providing cheap high bandwidth and fast data transmission for huge number of applications for indoor and outdoor short range communications.

REFERENCES

1. H. Elgala, R. Mesleh, and H. Haas, "Indoor broadcasting via white LEDs and OFDM," Consumer Electronics, IEEE Transactions on, vol. 55, pp. 1127-1134, 2009.
2. H. Elgala, R. Mesleh, and H. Haas, "Indoor optical wireless communication: potential and state-of-the-art," Communications Magazine, IEEE, vol. 49, pp. 56-62, 2011.
3. S. Haruyama, "Visible light communications: Recent activities in Japan," Smart Spaces: A Smart Lighting ERC Industry—Academia Day at BU Photonics Center, Boston University (Feb. 8, 2011)(49 pages), 2011.
4. G. Pang, "Information technology based on visible LEDs for optical wireless communications," in TENCON 2004. 2004 IEEE Region 10 Conference, 2004, pp. 395-398.
5. S. Haruyama, "Visible light communication," Journal of Japan Society of Mechanical Engineers, vol. 107, pp. 710-711, 2004.
6. L. Zeng, D. O'Brien, H. Le-Minh, K. Lee, D. Jung, and Y. Oh, "Improvement of date rate by using equalization in an indoor visible light communication system," in Circuits and Systems for Communications, 2008. ICCSC 2008. 4th IEEE International Conference on, 2008, pp. 678-682.
7. Z. Wang, W.-D. Zhong, S. Zhang, C. Yu, and Y. Ding, "Performance evaluation of OOK free-space optical transmission system with dynamic decision threshold and coherent detection," in Photonics Global Conference (PGC), 2010, 2010, pp. 1-5.
8. M. Ijaz, Z. Ghassemlooy, H. Le Minh, S. Rajbhandari, and J. Perez, "Analysis of fog and smoke attenuation in a free space optical communication link under controlled laboratory conditions," in Optical Wireless Communications (IWOW), 2012 International Workshop on, 2012, pp. 1-3.
9. J. Graeme, Photodiode amplifiers: op amp solutions: McGraw-Hill, Inc., 1995.
10. H. Le Minh, D. O'Brien, G. Faulkner, L. Zeng, K. Lee, D. Jung, et al., "100-Mb/s NRZ visible light communications using a postequalized white LED," Photonics Technology Letters, IEEE, vol. 21, pp. 1063-1065, 2009.
11. T. Douseki, "A batteryless optical-wireless system with white-LED illumination," in Personal, Indoor and Mobile Radio Communications, 2004. PIMRC 2004. 15th IEEE International Symposium on, 2004, pp. 2529-2533.
12. T. D. Little, P. Dib, K. Shah, N. Barraford, and B. Gallagher, "Using LED lighting for ubiquitous indoor wireless networking," in Networking and Communications, 2008. WIMOB'08. IEEE International Conference on Wireless and Mobile Computing, 2008, pp. 373-378.
13. Y. Tanaka, T. Komine, S. Haruyama, and M. Nakagawa, "Indoor visible light data transmission system utilizing white LED lights," IEICE transactions on communications, vol. 86, pp. 2440-2454, 2003.
14. H. B. C. Wook, S. Haruyama, and M. Nakagawa, "Visible light communication with LED traffic lights using 2-dimensional image sensor," IEICE transactions on fundamentals of electronics, communications and computer sciences, vol. 89, pp. 654-659, 2006.
15. M. Wada, T. Yendo, T. Fujii, and M. Tanimoto, "Road-to-vehicle communication using LED traffic light," in Intelligent Vehicles Symposium, 2005. Proceedings. IEEE, 2005, pp. 601-606.
16. J. Grubor, S. Randel, K.-D. Langer, and J. W. Walewski, "Broadband information broadcasting using LED-based interior lighting," Journal of Lightwave technology, vol. 26, pp. 3883-3892, 2008.
17. S. Hranilovic and F. R. Kschischang, "A pixelated MIMO wireless optical communication system," Selected Topics in Quantum Electronics, IEEE Journal of, vol. 12, pp. 859-874, 2006.
18. H. Tanaka, Y. Umeda, and O. Takyu, "High-speed LED driver for visible light communications with drawing-out of remaining carrier," in Radio and Wireless Symposium (RWS), 2011 IEEE, 2011, pp. 295-298.
19. T. Kishi, H. Tanaka, and Y. Umeda, "A high speed LED driver for visible light communications with drawing out remaining carriers by a CMOS inverter," in Microwave Conference Proceedings (APMC), 2011 Asia-Pacific, 2011, pp. 1234-1237.
20. H. Le Minh, D. O'Brien, G. Faulkner, L. Zeng, K. Lee, D. Jung, et al., "80 Mbit/s visible light communications using pre-equalized white LED," in Optical Communication, 2008. ECOC 2008. 34th European Conference on, 2008, pp. 1-2.
21. H. Le Minh, D. O'Brien, G. Faulkner, L. Zeng, K. Lee, D. Jung, et al., "High-speed visible light communications using multiple-resonant equalization," Photonics Technology Letters, IEEE, vol. 20, pp. 1243-1245, 2008.
22. J. Vučić, C. Kottke, S. Nerreter, K.-D. Langer, and J. W. Walewski, "513 Mbit/s visible light communications link based on DMT-modulation of a white LED," Journal of Lightwave Technology, vol. 28, pp. 3512-3518, 2010.
23. A. Khalid, G. Cossu, R. Corsini, P. Choudhury, and E. Ciaramella, "1-Gb/s transmission over a phosphorescent white LED by using rate-adaptive discrete multitone modulation," Photonics Journal, IEEE, vol. 4, pp. 1465-1473, 2012.

24. V. G. Yánez, J. R. Torres, J. B. Alonso, J. A. R. Borges, C. Q. Sánchez, C. T. González, et al., "Illumination interference reduction system for VLC communications," in WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering, 2009.
25. J. Rose, S. Bradbury, I. Bond, P. Ogden, A. Price, R. Oliver, et al., "Driving LED in a Nanosecond Regime by a Fast Operational Amplifier," arXiv preprint arXiv:1011.1954, 2010.
26. M. Noshad and M. Brandt-Pearce, "Can Visible Light Communications Provide Gb/s Service?," arXiv preprint arXiv:1308.3217, 2013.
27. K.-D. Langer and J. Grubor, "Recent developments in optical wireless communications using infrared and visible light," in Transparent Optical Networks, 2007. ICTON'07. 9th International Conference on, 2007, pp. 146-151.
28. T. Komine, S. Haruyama, and M. Nakagawa, "Bidirectional visible-light communication using corner cube modulator," IEIC Tech. Report102, pp. 41-46, 2003.
29. D. O'Brien, "Cooperation in optical wireless communications," in Cognitive Wireless Networks, ed: Springer, 2007, pp. 623-634.
30. D. O'Brien, H. Le Minh, L. Zeng, G. Faulkner, K. Lee, D. Jung, et al., "Indoor visible light communications: challenges and prospects," in Optical Engineering+ Applications, 2008, pp. 709106-709106-9.
31. A. Boucouvalas, "Indoor ambient light noise and its effect on wireless optical links," IEE Proceedings-Optoelectronics, vol. 143, pp. 334-338, 1996.
32. A. J. Moreira, R. T. Valadas, and A. de Oliveira Duarte, "Characterisation and modelling of artificial light interference in optical wireless communication systems," in Personal, Indoor and Mobile Radio Communications, 1995. PIMRC'95.'Wireless: Merging onto the Information Superhighway'., Sixth IEEE International Symposium on, 1995, pp. 326-331.
33. A. Moreira, R. Valadas, and A. de Oliveira Duarte, "Performance of infrared transmission systems under ambient light interference," in Optoelectronics, IEE Proceedings-, 1996, pp. 339-346.
34. M. Bilgi and M. Yuksel, "Multi-transceiver simulation modules for free-space optical mobile ad hoc networks," in Proc. of SPIE Vol, 2010, pp. 77050B-1.
35. G. Ren, S. He, and Y. Yang, "Light Communication Systems," Information Technology Journal, vol. 12, pp. 1245-1250, 2013.
36. D. C. O'Brien, G. E. Faulkner, K. Jim, E. B. Zyambo, D. J. Edwards, M. Whitehead, et al., "High-speed integrated transceivers for optical wireless," Communications Magazine, IEEE, vol. 41, pp. 58-62, 2003.
37. D. J. Heatley, D. R. Wisely, I. Neild, and P. Cochrane, "Optical wireless: The story so far," Communications Magazine, IEEE, vol. 36, pp. 72-74, 79-82, 1998.
38. J. Derenick, C. Thorne, and J. Spletzer, "On the deployment of a hybrid free-space optic/radio frequency (FSO/RF) mobile ad-hoc network," in Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on, 2005, pp. 3990-3996.
39. A. Sevincer, M. Bilgi, M. Yuksel, and N. Pala, "Prototyping Multi-Transceiver Free-Space Optical Communication Structures," in Communications (ICC), 2010 IEEE International Conference on, 2010, pp. 1-5.
40. B. Nakhkoob, M. Bilgi, M. Yuksel, and M. Hella, "Multi-transceiver optical wireless spherical structures for MANETs," Selected Areas in Communications, IEEE Journal on, vol. 27, pp. 1612-1622, 2009.