INDOOR BROADCASTING USING VISIBLE FREE SPACE OPTIC OVER BROADBAND POWERLINE COMMUNICATION

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Dedicated to my beloved family especially my wife “Samira”, my lovely daughter “Nahal”, my parents and my supportive supervisor – Associate Prof Ir Dr Abu Sahmah Mohd Supa’at. Thank you very much for being supportive, helpful and understanding.

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ABSTRACT

Visible Free Space Optic (VFSO) is a new and attractive technology, which employs visible light generated by white light emitting diode (LED) for optical wireless communications. In addition, it is possible to use ubiquitous powerline cables as a communication medium among other fixed network equipments which is powerline communication (PLC) technology. An integrated system of VFSO and PLC uses existing powerline cables and white LEDs as a communication channel hence it has the advantage of low operating cost and provides easy data transmission. The current integrated system encounters some problems due to PLC multipath, noise, and no practical modeling for white LEDs, which degrades significantly the performance of the whole system. Therefore, this study presents the optimum orthogonal frequency division multiplexing (OFDM) modulating signal power, proper DC biasing point, and LED dynamic range to solve system degradation. Moreover, a practical LED model is also presented, and the performance of the integrated system in terms of OFDM signal power versus bit error rate in the presence of broadband PLC impulsive noise, multipath issue, and additive white Gaussian noise optical channel is studied. Based on indoor applications, the primary purpose for VFSO link is the general lighting designation with the standard brightness level and the secondary purpose is for data transmission. Therefore, to have a high quality VFSO link besides ensuring sufficient horizontal brightness of the place, high data rate of optical communication links with low bit error rate are also achieved. The radiometric parameters of white LEDs using simulation and experiment are reported. Optimum 15dBm OFDM signal power, (3.2V, 350mA) biasing point, and 1Vp-p dynamic range for white LED has the data rate more than 28Mbits/second with the bit error rates lower than 10^{-6}. Moreover, at least 400lx of indoor lighting was also fulfilled. So, the new integrated system is considered as a good alternative for other indoor wireless system counterparts.

ABSTRAK

Nyata Ruang Optik (VFSO), adalah satu teknologi baru dan menarik yang dijana menggunakan cahaya nampak dari Diod (LED) putih untuk komunikasi optik wayarles. Selain itu, mana-mana kabel elektrik boleh digunakan sebagai medium komunikasi dengan peralatan rangkaian tetap yang lain seperti teknologi Komunikasi Talian Kuasa (PLC). Sistem bersepadu VFSO dan PLC menggunakan kabel elektrik yang ada dan LED putih sebagai saluran komunikasi, jadi sistem ini mempunyai kelebihan dari segi kos operasi yang rendah dan penghantaran data yang mudah. Sistem bersepadu yang ada mengalami beberapa masalah berpunca dari PLC jalan berbilang, bunyi bising, dan tiada model yang praktikal untuk LED putih yang merosotkan lagi keseluruhan prestasi sistem. Oleh itu, kajian ini mengemukakan isyarat kuasa OFDM optimum modulasi, DC titik pincangan yang sesuai dan julat dinamik LED bagi membina sistem degradasi. Sebagai tambahan, model praktikal LED juga dibentangkan dan prestasi sistem bersepadu dari segi kuasa isyarat pemultipleksan pembahagian frekuensi ortogon (OFDM) melawan kadar ralat di hadapan bunyi impulsif jalurlebar PLC dan isu jalan berbilang dan saluran optik tambah putih gaussian bunyi bising dikaji. Berdasarkan kepada aplikasi tertutup, tujuan utama pautan VFSO ialah susunan pencahayaan umum dengan kecerahan piawai dan tujuan sekunder adalah penghantaran data. Oleh itu, untuk mandapatkan pautan VFSO berkualiti tinggi selain daripada memastikan kecerahan mendatar yang mencukupi pada tempat hubungan, kadar data komunikasi optik yang tinggi dengan kadar ralat bit rendah juga dicapai. Parameter radiometrik putih LED dengan menggunakan simulasi dan eksperimen adalah dilaporkan. Optimum 15dBm OFDM isyarat kuasa, (3.2V, 350mA) titik pincangan, dan 1 Vp-p julat dinamik untuk LED putih mempunyai kadar data lebih dari 28Mbit/saat dengan ralat bit yang lebih rendah daripada 10^{-6}. Selain itu, sekurang-kurangnya 400lx pencahayaan tertutup telah diselesaikan. Jadi, sistem bersepadu yang baru boleh dianggap sebagai alternatif yang baik untuk sistem wayarles tertutup di dalam bangunan yang lain.

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LIST OF ABBREVIATIONS

ACO-OFDM	-	Asymmetrically clipped optical OFDM
AWG	-	Additive white Gaussian
AWGN	-	Additive white Gaussian noise
BER	-	Bit Error Rate
BFSK	-	Binary frequency shift keying
BPF	-	Band pass filter
BPLC	-	Broadband Powerline Communication
CP	-	Cyclic prefix
DC	-	Direct current
DCO-OFDM	-	DC biased optical OFDM
DD	-	Direct Detection
DFT	-	Discrete Fourier Transform
DSP	-	Digital signal processing
FEC	-	Forward error correction
FSK	-	Frequency shift keying
GLE	-	General lighting design
HV	-	High voltage
IFFT/FFT	-	(Inverse) Fast Fourier transform
IM	-	Intensity Modulation
ISI	-	Intersymbol Interference
ITS	-	Intelligent transport system
JEITA	-	Japan Electronics and Information Technology Industries Association
LV	-	Low voltage
MCM	-	Multi-carrier modulation
MIMO	-	Multi input, multi output
M-QAM	-	Multi-level quadrature amplitude modulation
MV	-	Medium voltage
NRZ OOK	-	Non-Return to Zero On-Off Keying
OFDM	-	Orthogonal Frequency Division Multiplexing
PLC	-	Powerline Communication
OOK	-	On-Off Keying
PAPR	-	Peak-to-average power ratio
PDA	-	Personal digital assistance
PPM	-	Pulse position modulation
PSK	-	Phase shift keying

LIST OF ABBREVIATIONS

QAM	-	Quadrature amplitude modulation
QPSK	-	Quadrature phase shift keying
RONJA	-	Reasonable Object near Joint Access
SC-BPSK	-	Subcarrier Binary PSK
SC-PPM	-	Subcarrier pulse position modulation
SNR	-	Signal to Noise Ratio
TOV	-	Turn On Voltage
VA	-	Viterbi algorithm
VFSO	-	Visible Free Space Optic
VLC	-	Visible Light Communication
VLCC	-	Visible light communications consortium
WLED	-	White Light Emitting Diodes

CHAPTER 1

INTRODUCTION

1.1 Background of the study

White-LEDs are more advantageous than incandescent lamps in case of power efficiency, lifetime expectancy, and minimal heat generation and so on, therefore they could be a good alternative for existing lighting equipments (Steigerwald et al., 2002). Due to high switching rate of white LEDs, recently, visible light communication (VLC) a new and attractive technology which employs visible light generated by white LEDs for optical wireless communications, has gained considerable attention by researchers (Elgala et al., 2011; Grubor et al., 2008; Komine and Nakagawa, 2004; O'Brien et al., 2008; Tanaka et al., 2003). Therefore, beside aesthetically pleased illuminated area it is possible to have optical wireless communication simultaneously. Since VLC technology is used to transmit data over free space optic (FSO) utilizing visible light, in this context we use visible free space optic (VFSO) interchangeably with VLC. VFSO has much higher power levels than an infrared system and a large radiation pattern at the sources (transmitters) since they also function as lighting device (Moreno and Sun, 2008).

Apart from optical wireless communications, it is possible to use the ubiquitous powerline cables as a communication medium between other fixed network equipments which is powerline communication (PLC) technology. A frequency spectrum from 9 to 140 kHz for narrowband PLC makes possible data rates up to several thousand bits per second which are sufficient only for some metering functions, data transmission with very low bit rates and the realization of few numbers of transmission channels for voice connections. But for the realization of the higher data rates, PLC transmission systems have to operate in a wider frequency spectrum (from 1 MHz up to 30 MHz) which offers broadband PLC (BPLC) to realize the more sophisticated telecommunication services (Galli and Logvinov, 2008; Galli et al., 2011). According to telecommunication purposes it should be noted that, the PLC medium was at the beginning designed only for energy distribution, and for this reason several types of machines and appliances are connected to it, these activities on the power supply make this medium not adequate for information communications signals.

In modern fourth generation communication systems (4G), to overcome the problems in case of noise, data rate, attenuation, distortion, commercially reasonable designation, and implementation and so on, designers have used some hybridization techniques. Radio-over-Fiber (RoF) and Radio-over-VLC are some good examples which tried to integrate radio wireless system to optical communication system (Khalid et al., 2011; Neo, 2011). The integration of visible free space optic (VFSO) and broadband powerline communication (BPLC) could be defined as one of such 4G systems (Rajesh and Nakkeeran, 2008). This integrated system uses already installed powerline cables and white LEDs as a communication channel. However this system has the advantage of low cost and easy implementation for data transmission but, it suffers from performance degradation due to the issue of noise and interference exists on PLC mediums. Furthermore non-linear characteristics of white LED can degrade data transmission so it is another major problem that causes high bit error rate (BER) in this integrated system.

The idea of integrating these two systems (VFSO and PLC) for indoor networking was pioneered by Japanese researchers (Komine and Nakagawa, 2003). It was based on narrowband PLC and single carrier modulation. To improve the old system and to overcome the effects of powerline noises multi-carrier modulation methods were used (Komine et al., 2006). More recently this system has found some applications in particular military aircraft powerline network where researchers at Pennsylvania State University have shown that both systems (VFSO and PLC) could provide a relatively high data rate (Less than 100 Mbit/sec) communications access for on-board aircraft networking (Kavehrad et al., 2008).

1.2 Motivation

Compared with conventional lighting methods, the white LED has lower power consumption, lower voltage requirements, longer lifetime, smaller size, and cooler operation. In one survey the ministry of economy, trade and industry (METI) of Japan has estimated that if half of all incandescent and fluorescent lamps currently in use are replaced by LEDs, Japan could save the equivalent output of six mid size power plants, and reduce the production of greenhouse gases (Komine et al., 2006). The study, by the Institute of Energy Economics (IEE), a foundation supervised by the METI, estimated that 92.2 billion kWh of electricity – worth the output of 13 nuclear reactors – would be saved annually if the switch was made.

On the other hand, using the powerline as a communication medium could be a cost effective way compared to other systems because it uses an existing cabling infrastructure. Since lighting equipment (white-LED) is usually distributed over the ceiling, it is difficult to install new communication cables between other fixed networks (PC, Set Top Box, fiber networks, etc.) and LED lights or among the LED lights. This wiring problem is especially serious for existing offices and houses. As mentioned before, powerline communication (PLC) makes it possible to use ubiquitous electricity powerlines for the medium of communications, so there is no necessity to introduce tangled cables for data communication.

Therefore, the idea of using white LEDs as optical wireless communication source and integrating this technology with PLC could be a more cost efficient way than other existing methods. Also implementation of this system is very easy because there is no need to lay new cabling and installing any device.

Furthermore, comparing this system with other wireless counterparts such as WiFi systems, this integrated system could be considered as green technology since there is no source of pollution for human being.

1.3 Problem formulation

The currently available integrated system is based on narrow-band PLC (9 to 140 kHz) so the bandwidth is limited and suffers from accurate modeling of channel and noises both in wired powerline medium and wireless optical medium. Also this integrated system was not based on specific application.

Author in recent works, have proposed new broadband (1MHz up to 30 MHz) integrated system in which by considering all types of noises and multipath effects in the hostile PLC medium, a multi-carrier modulation (MCM) was selected to overcome channel impairments (Alavi et al., 2009). Actually, migrating from narrowband to broadband PLC needs an accurate modeling of impulsive noises and multipath distortions existing in powerline channel and also additive white Gaussian noise (AWGN) in optical wireless channel.

Orthogonal frequency division multiplexing (OFDM) is the most common form of MCM. Although, using OFDM will help to combat powerline channel impairments but in this new integrated system when OFDM signal which is passed through powerline channel is applied to modulate the intensity of white light emitting diodes (WLEDs) due to the nonlinearity characteristics of LED the modulating signal will be more degraded. The LED distorts the signal amplitude both in upper and lower peaks. Lower peaks below Turn–on-Voltage (TOV) of LED are forced to be clipped since LED does not conduct current in this voltage and assumes to be off. On the other hand, before modulating LED upper peaks (higher amplitudes which belong to the maximum permissible ac/pulsed current) are clipped to keep LED not overheated. On the other hand white LEDs are more used for lighting purposes and that is why in their datasheets only photometric parameters such as luminous intensity is reported so the need for radiometric parameters such radiated optical power for wireless communication is also required in this system.

In this work the integrated system is proposed to be used for specific application which is one conference room with defined dimensions and environmental conditions such as darkness or brightness of the room.

1.4 Objectives of the Study

From the formulated problem which is addressed in the past section, the objectives of this research work could be stated as follows:

1) To model the indoor broadband powerline communication (BPLC) and visible free space optic channels mathematically.

2) To model the white LED non-linear characteristics mathematically and experimentally and to report its radiometric parameters

3) To integrate modeled broadband powerline communication (BPLC) and visible free space optic (VFSO) inside a conference room so that:

    - In the BPLC part the impulsive noise and multipath effects are considered.

    - In the VFSO part, high quality communication link which fulfills both sufficient horizontal brightness and data transmission.

4) To develop a system with optimum values regarding to system performance based on achievable signal to noise ratio (SNR) and lowest bit error rate (BER).

1.5 Scope of study

The following scope of work has been carried out to achieve the objectives of project:

- A literature review on related topics which are broadband powerline communications (BPLC) and visible free space optic (VFSO).
- Modeling and simulation of equivalent channel including powerline channel with considering its noises and multipath distortions, visible free space optic, transmitter and receiver and white LED radiometric parameters.
- To choose a proper modulation scheme which is robust against the effects of impulsive noise and multipath issue that exist in powerline.
- To consider a conference room with actual dimensions and environmental characteristics as a test bed.
- To design a high quality VFSO link in this conference room both with one LED and multiple LED arrays so that it is capable of both proper lighting and data communication.
- To integrate VFSO and BPLC
- To optimize and refine the system

1.6 Methodology

The progress of this project is divided into certain phases. The phases involved are according to the background recognition of both broadband powerline communication (BPLC) and visible free space optic (VFSO) systems. Modeling, simulation and experiment measurements of white LED characteristics in integrated system of VFSO and BPLC are also other important phases which should be performed to complete the study. Figure 1.1 has illustrated the research flow diagram where all the tasks and functions to complete the project are prioritized. As it can be seen, the diagram involves four phases which in the following subsections they are discussed briefly.

1.6.1 Phase one: Background Recognition and Problem Formulation

In order to start the project a good understanding and recognition of the scope of study plays vital role in conducting research coherently. This recognition is gained through deeply studying of the related literature which was conducted during the first year of study.

In the literature study the related works are first classified and evaluated. The literature study was classified into two major fields which are VFSO and BPLC. The major challenging factors regarding to each field which affect the performance of the system were introduced and are applied to use in the next phase. Then, based on the factors which affect the system performance, the problems regarding to each previous work were clarified and the objectives of this research are concentrated to solve these problems.

1.6.2 Phase 2: Prerequisites to Integrate Two Systems via Modeling

Before integrating BPLC and VFSO accurate channel model for each system is required. In this regard an analytical formulation of powerline channel and VFSO link specifications must be performed. On the other hand in terms of appropriate design and operation of the integrated system theoretical and mathematical analysis on the factors which affect the performance of each system (BPLC and VFSO) such as multipath effects and noises are required. Using robust modulation method and practical modeling of white LEDs are also crucial issues which should be taken into account in this phase.

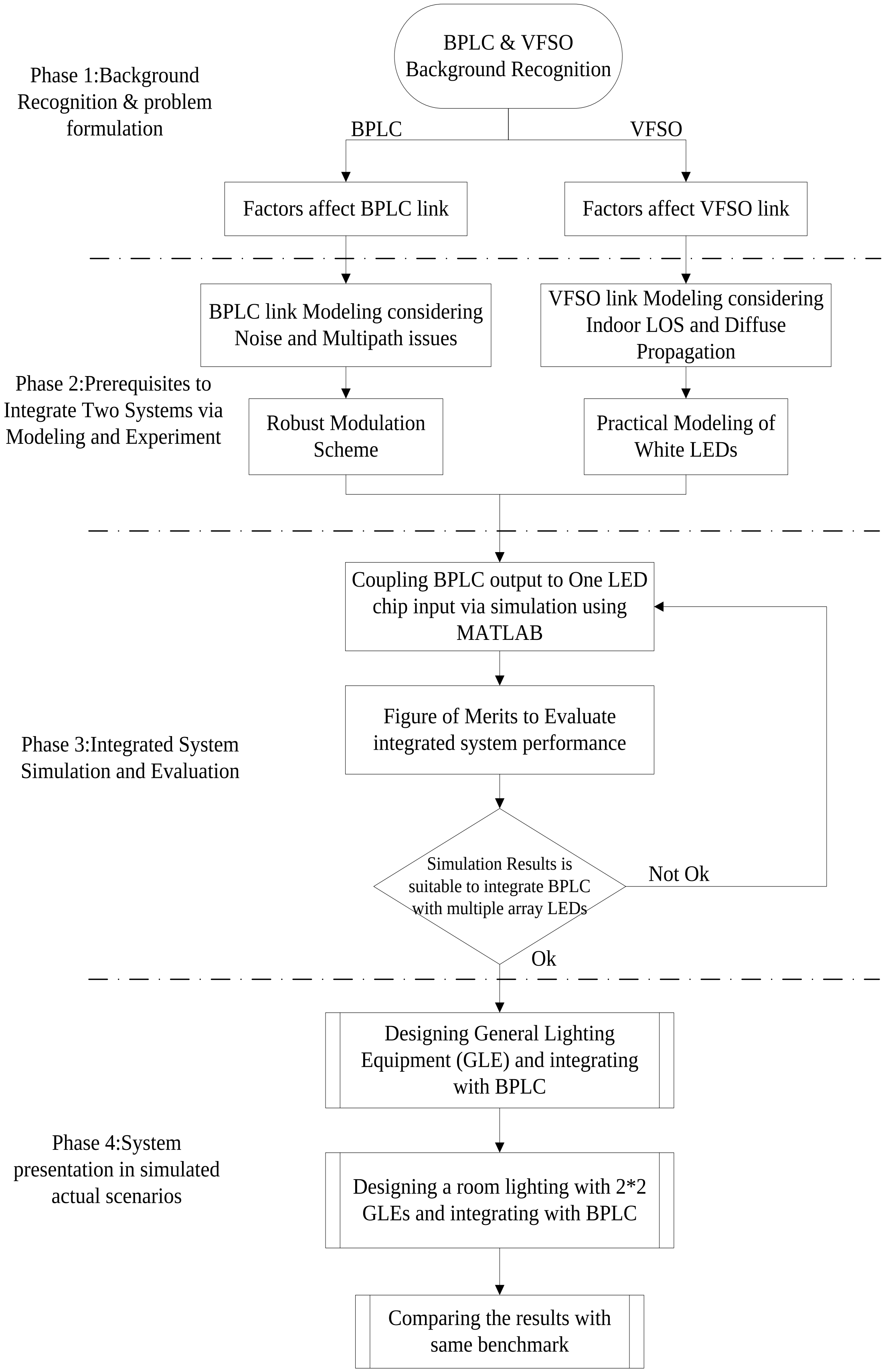

Figure 1.1 Research Flow Diagram

1.6.3 Phase 3: Integrated System Simulation and Evaluation

After appropriate modeling of both BPLC and VFSO links it is the moment to integrate these two systems via simulation. In phase 3 the architecture of this integrated system is presented and MATLAB is used to simulate the modeled system. In order to gain the optimum configuration of integrated system the figures of merit that are required were introduced (i.e satisfying horizontal illumination, acceptable BER vs SNR and so on). Based on the achieved results through simulation, if the system requirements are not satisfied, the integrated system should be modified to be ready for the next phase which is presentation of integrated system for multiple array lighting system for simulated actual scenarios.

1.6.4 Phase 4: System presentation in simulated actual scenarios

Based on the optimum system design which was derived from previous phase, in order to compensate optical power loss the number of LEDs is increased by forming a transmitter array (while considering eye safety requirements). In this phase, two LED array systems are considered. First a general lighting equipment (GLE) with (10x10) LEDs were designed and the integrated system performance is analyzed, then one room is assumed to be lightened via (2x2) GLEs such that both standard lighting requirements and data transmission utilizing white light from LEDs are achieved simultaneously. In both cases the integrated system performance is compared with previous works in this scope.

1.7 Organization of the thesis

The organization of thesis is structured based on the research flow diagram shown in Figure 1.1.

Chapter 2 presents the main principles of VFSO and BPLC. Starting with the literature review map chapter 2 tries to make sure that a clear understanding about terms that is used in this thesis is clarified. While, some most important fields of applications are presented, current standardization efforts for each medium are also discussed. Lists of recent challenges that are being worked on in the literature are presented as well. The recent studies in the field of integrated system of VFSO and BPLC are deeply scrutinized and the problems regarding to the currently exist system are elaborated.

Chapter 3 provides channel modeling methods for both BPLC and VFSO links and also robust modulation method and practical modeling of white LEDs are discussed in this chapter.

Chapter 4 emphasizes on describing the integrated system main components and its architecture. The analytical formulation of integrated system is presented in this chapter and the integrated system is ready to be simulated.

The results of thesis are thoroughly discussed in chapter 5. The results have shown the system performance and the comparison is made with other research works in this scope.

Finally, the research contributions, conclusions and future work and also project constraints and limitations are discussed and presented in chapter 6.

1.8 Summary

This chapter has discussed the background of the problem faced by integrated system of visible free space optic and broadband powerline communication. Besides, this chapter stated the objectives of this project and a brief description about the problems. Based on the formulated problem, it has been briefly stated that the integrated system of BPLC and VFSO can be improved by several ways. This chapter also states the scope of this study to make sure that the research work carried out will always be on track. The research flow and the thesis organization are also presented in this chapter.

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