



**DEVELOPMENT OF INDOOR WIRELESS
OPTICAL CDMA SYSTEM FOR LOCAL-AREA
NETWORKS (LANs) AND HEALTH-CARE
CONTINUOUS MONITORING**

055171

rb

FTK5103.452

A477

2016

by

EMAD AHMED MUBARAK ALYAN

(1530811620)

A thesis submitted

In fulfilment of the requirement for the degree of
Master of Science in Communication Engineering

**School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS (UniMAP)
MALAYSIA**

2016

ACKNOWLEDGEMENTS

In the name of Allah the Most Compassionate, the Most Merciful. Alhamdulillah. Thanks to the Almighty Allah S.W.T for His blessings and guidance for giving me the inspiration and strengths to complete this project with good health until the last day of the project report has been submitted. First and foremost, I would like to express my appreciation to my supervisor, Prof. Dr. Syed Alwee Aljunid Syed Junid who has helped me a lot in giving me ideas, opinions and valuable comments on the making of this project. I am deeply grateful to have him as my supervisor and also my mentor. His guidance and supervision will help me in the future life. I would also like to thank my co-supervisor Assoc. Prof. Anuar Bin Mat Safar for his kind support and suggestions. A special acknowledgment must be given to my brothers and sisters for their motivational help and support during my academic period at UniMAP. I am indebted to them and words will never express the gratitude I owe to them. I wish to thank my parents for their daily prayers, giving me the motivation and strength, and encouraging me to accomplish and achieve my goals. Last but not least, sincere thanks and gratitude to my lovely wife Ghalya and my son Manaf who inspired me by their courage, support and patience throughout the period of my study.

Emad Ahmed Mubarak Alyan

Universiti Malaysia Perlis (UniMAP)

*Specially dedicated
to my beloved Parents, wife, son, brothers, sisters
to others who encouraged and helped,
and who inspired me
throughout my journey of education*

©This item is protected by original copyright

TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iv
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xiv
ABSTRAK	xvi
ABSTRACT	xvii
CHAPTER 1 INTRODUCTION	1
1.1 Introduction	1
1.2 Optical Code Division Multiple Access (OCDMA)	4
1.3 Problem Statement	7
1.4 Thesis Objectives	9
1.5 Scope of Works	10
1.6 Research Contribution	12
1.7 Thesis Outline	13

CHAPTER 2 LITERATURE REVIEW	15
2.1 Introduction	15
2.2 Optical Wireless Communication Links	19
2.3 Indoor Optical Wireless Limitations	21
2.3.1 Background Noise (BN)	21
2.3.2 Multipath Dispersion	23
2.3.3 Photo-detector High Capacitance	25
2.3.4 Optical Safety	26
2.4 Reception of Optical Wireless Data	28
2.4.1 Optical Concentrator	29
2.4.2 Optical Filter	30
2.4.3 Photo-detector	30
2.5 Modulation Schemes	31
2.6 Multiple Access Techniques in Indoor OW Systems	35
2.6.1 Time Division Multiple Access (TDMA)	36
2.6.2 Frequency Division Multiple Access (FDMA)	37
2.6.3 Optical Code Division Multiple Access (OCDMA)	37
2.6.3.1 Zero Cross Correlation (ZCC) Code	38
2.6.3.2 Flexible Cross Correlation (FCC) Code	41
2.7 Optical wireless applied to healthcare monitoring system	44
2.8 Summary	45

CHAPTER 3 OPTICAL WIRELESS CHANNEL MODELLING	46
3.1 Introduction	46
3.2 Simulation Model	48
3.2.1 Transmitter and Receiver Model	50
3.2.2 Indoor Optical Wireless Communication Channel	52
3.3 Optimum divergence semi-angle (ODSA) of LEDs	57
3.4 Multiple cell configuration systems	60
3.5 Indoor Wireless Optical CDMA System	61
3.5.1 System design based on ZCC code	62
3.5.2 Performance Analysis of Indoor W-OCDMA System based on the ZCC code	63
3.6 Summary	68
CHAPTER 4 PERFORMANCE ANALYSIS OF THE INDOOR OPTICAL WIRELESS COMMUNICATION SYSTEM	69
4.1 Introduction	69
4.2 Theoretical Analysis	72
4.2.1 The Relationship between Minimum Received Power and the Optimum Divergence Semi-angle of LEDs for 1-cell, 4-cell and 16-cell configurations	73
4.2.2 Optical Received Power Distribution	75
4.2.3 Impulse Responses	77
4.2.4 RMS delay spread	81
4.2.5 Effect of Channel Attenuation Variation on APD and PIN Photo-detectors	83
4.2.6 Effect of Data Rate Variation on Noise Variance	85

4.2.7 The Effect of Received Power on System Performance under the Influence of Background Noise	86
4.2.8 SNR distribution of 1-cell and 4-cell Configurations	88
4.2.9 Variation of BER as a Function of Number of Users for different Receiver's Positions and Cell configurations	90
4.3 Simulation Results	92
4.3.1 Effect of Fluorescent Light Noise on Indoor W-OCDMA system	95
4.3.2 Bit Error Rate as a Function of Data Rate	96
4.3.3 Performance Comparison between 1-cell and 4-cell Configurations with Various Receiver's Positions	97
4.3.4 Effect of Channel Attenuation on BER Performance	98
4.4 Comparison of Theoretical and Simulation Results	99
4.5 Summary	102
CHAPTER 5 APPLICATION OF A MOBILE OPTICAL WIRELESS SYSTEM FOR CONTINUOUS HEALTHCARE MONITORING	103
5.1 Introduction	103
5.2 System Description	103
5.3 Channel Response and Distribution	107
5.4 Simulation Results	110
5.4.1 Effect of Transmitted Power on System Performance	110
5.4.2 Effect of Number of Medical Nodes on System Performance	114
5.5 Summary	116

CHAPTER 6 CONCLUSION AND FUTURE WORK	117
6.1 Conclusion	117
6.2 Future works	120
REFERENCES	121
LIST OF PUBLICATIONS	129

©This item is protected by original copyright

LIST OF TABLES

NO.		PAGE
1.1	A comparison between optical wireless (OW) and radio frequency (RF) systems (Alsaadi, 2011).	3
2.1	Safety Classification for A point Source Emitter	27
4.1	Typical Parameters used in Mathematical Analysis I	71
4.2	Comparison between FCC and ZCC codes	87
5.1	Simulation parameters used in the monitoring system	106

©This item is protected by original copyright

LIST OF FIGURES

NO.		PAGE
1.1	Encoded Optical signal waveforms of an OCDMA system.	5
1.2	Study Model of the Indoor W-OCDMA system.	11
2.1	Access points in a LAN for connecting optical wireless devices with wired backbone network systems (Alsaadi, 2011).	17
2.2	Configurations of optical wireless links	20
2.3	Optical power spectrum of main ambient infrared sources (Kahn & Barry, 1997)	22
2.4	Block diagram of a typical optical wireless receiver (Alsaadi, 2011).	28
2.5	Channel model Optical wireless link	32
2.6	Representation of bits '1 0' using (a) OOK-NRZ, and (b) OOK-RZ (50% duty cycle).	33
2.7	Time waveforms for OOK-NRZ and PPM.	35
2.8	Illustration of multiple access techniques	36
3.1	Flow chart for ray tracing model	49
3.2	Normalised radiation pattern of a generalised Lambertian source for several values of m .	51
3.3	Optical wireless channel propagation.	53
3.4	Indoor NLOS-OWC system for multi-cell configurations	58
3.5	Indoor W-OCDMA System Based on the ZCC code	63
4.1	Receiver Positions in the Proposed Indoor Environment	69
4.2	Transmitters' Positions on the ceiling for various cell configurations.	73
4.3	Minimum Received Power versus the Receiver's Height.	74
4.4	Optimum Divergence Semi-angle of LED versus the Receiver's Height.	75

4. 5	Received Power (dBm) with consideration of: (a) 1-cell configuration (b) 4-cell configuration. (Receiver's Height = 0.9 m).	76
4. 6	Channel Impulse Response at Position A	78
4. 7	Channel Impulse Response at Position B	79
4. 8	Channel Impulse Response at Position C	80
4. 9	Spatial distribution of RMS delay spread for 1-cell configuration.	81
4. 10	Spatial distribution of RMS delay spread for the 4-cell configuration.	82
4. 11	BER versus Channel Attenuation Using PIN and APD.	83
4. 12	BER versus Channel Attenuation for different transmission powers. Number of users is 5	84
4. 13	Effect of Data Rate on Noises.	86
4. 2	Comparison between FCC and ZCC codes	87
4. 14	BER versus Effective power for the ZCC and FCC codes.	88
4. 15	SNR Distribution versus Width and Length of the Room for 1-Cell and 4-Cell Configurations, the Receiving Plane's Height is 0.9 m.	89
4. 16	BER versus Number of Users for 1-cell and 4-cell configurations at Different Receiver's Positions of: A (2.5, 2.5, 0.9), B (2.5, 0.25, 1), C (0.5, 0.5, 1.5). The weight is 4	90
4. 17	BER versus Number of Users for 4-cell Configuration at Different Receiver's Positions at: A (2.5, 2.5, 0.9), B (2.5, 0.25, 1), C (0.5, 0.5, 1.5). The weight is 4	91
4. 18	Eye Diagram of the 1-cell configuration W-OCDMA system; a) Position A with BER of 4.8×10^{-60} ; b) Position B with BER of 1.6×10^{-15} ; c) Position C with BER of 5.2×10^{-8} .	93
4. 19	Eye Diagram of the 4-cell configuration W-OCDMA system; a) Position A with BER of 7.5×10^{-43} ; b) Position B with BER of 2.8×10^{-19} ; c) Position C with BER of 2.6×10^{-15} .	94
4. 20	BER versus Effective Power in the case of with and without Fluorescent Light Noise.	95

4. 21	Variation of BER as a Function of Data Rate for various Receiver's positions of the 1-cell and 4-cell configurations. A (2.5, 2.5, 0.9), B (2.5, 0.25, 1), C (0.5, 0.5, 1.5). Number of users is 5.	97
4. 22	Variation of BER versus Receiver's Position for 1-cell and 4-cell configurations. Receiver's Height is 0.9 m. Number of users is 5.	98
4. 23	Effect of Channel Attenuation on BER based on the ZCC and FCC codes for various Users.	99
4. 24	Comparison of Theoretical and Simulation Result of the ZCC code with various Effective Power, and under the Influence of Fluorescent Light Noise.	100
4. 25	Comparison between the Theoretical and Simulation Results of the ZCC code with Channel attenuation	101
5. 1	The architecture of an Infrared channel with OCDMA transmitter and receiver schemes for the proposed patient monitoring system.	104
5. 2	Network configuration of the Wireless Optical CDMA system for Patient's Bio-signal Monitoring	105
5. 3	Channel Impulse response of Scenario 1 and Scenario 2.	108
5. 4	PDF of Optical Channel Gain for Scenario 1.	109
5. 5	PDF of Optical Channel Gain for Scenario 2.	109
5. 6	System Performance (BER) versus Transmitted Power for LOS channel of Scenario 1 and Scenario 2.	111
5. 7	System Performance (BER) versus Transmitted Power for Diffuse channel of Scenario 1 and Scenario 2.	112
5. 8	Eye Diagram of Scenario 1 of Monitoring System; a) LOS Channel with BER of 2.63×10^{-51} , $P_t = 40$ mW; b) Diffuse Channel with BER of 2×10^{-75} , $P_t = 200$ mW.	113
5. 9	Eye Diagram of Scenario 2 of Monitoring System; a) LOS Channel with BER of 5.14×10^{-38} , $P_t = 40$ mW; b) Diffuse Channel with BER of 5.17×10^{-38} , $P_t = 200$ mW.	113

5. 10 Bit Error Rate (BER) versus Number of Medical Nodes for Scenario 1, Weight = 114
4.
5. 11 Bit Error Rate (BER) versus Number of Medical Nodes for Scenario 2, Weight = 115
4.

©This item is protected by original copyright

LIST OF ABBREVIATIONS

APD	Avalanche Photodiode
AWGN	Additive White Gaussian Noise
BER	Bit-Error-Rate
BN	Background Noise
FBG	Fiber Bragg Grating
FCC	Flexible Cross-Correlation
FDMA	Frequency Division Multiple Access
FOV	Field-of-View
FSO	Free Space Optics
Gbps	Giga Bit per Second
IM/DD	Intensity Modulation and Direct Detection
Ir	Infrared
ISI	Intersymbol Interference
LAN	Local Area Network
LD	Laser Diode
LED	Light Emitting Diode
LOS	Line-of-Sight
MAI	Multiple Access Interference
Mbps	Mega Bit per Second
NRZ-OOK	Non-Return-to-Zero OOK
OCDMA	Optical Code Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing

OOO	Optical Orthogonal Code
OOK	On-Off Keying
OW	Optical Wireless
W-OCDMA	Optical Wireless Code Division Multiple Access
PIN	Positive-Intrinsic Negative
PIIN	Phase Induced Intensity Noise
PPM	Pulse Position Modulation
PSD	Power Spectral Density
RF	Radio Frequency
SAC	Spectral Amplitude Coding
SNR	Signal-to-Noise Ratio
TDMA	Time Division Multiple Access
WDM	Wavelength Division Multiplexing
ZCC	Zero Cross-Correlation

©This item is protected by original copyright

Pembangunan Sistem Dalam CDMA Optik Tanpa Wayar untuk Rangkaian Kawasan Tempatan (RKT) dan Pemantauan Berterusan Penjagaan Kesihatan

ABSTRAK

Komunikasi optik tanpa wayar merupakan satu bidang kajian yang menawarkan beberapa manfaat berbanding sistem berasaskan frekuensi radio. Antara manfaatnya termasuk jalur lebar yang tinggi, jalur spektrum berlesen percuma, keselamatan yang tinggi, pemasangan mudah, keimunan kepada gangguan elektromagnet (GE) dan subsistem kos rendah. Tesis ini memfokus kepada saluran dan sistem KOW tertutup. Had-had utama sistem tertutup KOW termasuk Gangguan Inter-Symbol disebabkan oleh penyerakan berbilang Jaluan, hingar cahaya ambien, dan Gangguan Capaian Berbilang (GCB) serta Hingar Keamatan Fasa Teraruh (HKFT) berkaitan dengan sistem multipengguna serentak. GCB merendahkan nisbah isyarat-hingar (NIH) dan HKFT mengehadkan kadar data maksimum yang boleh dicapai. Tesis ini mengkaji penggunaan sudut capaian optimum sebuah pemancar dalam sebuah struktur bilik dengan konfigurasi 1 sel dan 4 sel untuk mencapai pemancaran jalur lebar yang lebih tinggi dan agihan kuasa optik yang lebih seragam, seterusnya menghasilkan GIS yang lebih rendah. Kajian ini turut menyiasat penggunaan Kod Optik Pembahagian Berbilang Capaian (KOPBC) berdasarkan kod Korelasi Silang Sifar (KSS) dalam rangkaian optik wayarles untuk mengurangkan gangguan seperti GCB dan HKFT yang wujud dalam sistem dan seterusnya meningkatkan prestasi sistem tersebut. Keputusan kajian dibandingkan dengan sistem berasaskan Korelasi Silang Fleksibel (KSF). Hasilnya, sistem tertutup wayarles KOPBC (W-KOPBC) berasaskan konfigurasi 4 sel dan menggunakan kod KSS mampu menampung jumlah pengguna yang banyak dengan kadar data tinggi walaupun dengan kuasa penghantaran yang rendah berbanding konfigurasi 1 sel atau menggunakan kod KSF. Sebagai contoh, sistem konfigurasi 4 sel berdasarkan kod KSS menawarkan 42% dan 150% kekardinalan yang lebih besar di tepi dan penjuru bilik masing-masing, berbanding konfigurasi 1 sel. Tambahan pula, konfigurasi ini turut menawarkan 55%, 47%, dan 51% kekardinalan yang lebih besar di tengah, tepi, dan penjuru bilik, masing-masing, berbeza dengan kod KSF. Di samping itu, kajian ini turut menilai penggunaan teknologi inframerah dalam pengawasan perkhidmatan penjagaan kesihatan untuk membangunkan sistem perubatan mudah alih. Hal ini kerana teknologi sedia ada umumnya berdasarkan sistem frekuensi radio (FR) yang mungkin mengalami gangguan elektromagnet (GE). Selain itu, kesan medan radiasi terhadap peralatan perubatan boleh menyebabkan diagnosis salah. Bagi menyelesaikan masalah ini, pautan optik wayarles antara sensor perubatan dan penerima di tengah siling bilik hospital telah dinilai. Berdasarkan keputusan, kecekapan kuasa sistem optik wayarles mudah alih ditubuhkan untuk memastikan berlakunya komunikasi antara sensor perubatan dan titik penerima. Kuasa pemancar minimum yang diperlukan turut dikenalpasti untuk mencapai kuasa autonomi lebih tinggi. Keputusan turut menunjukkan bahawa keperluan aplikasi pemantauan perkhidmatan penjagaan kesihatan untuk nod perubatan sehingga 10 nod, dengan mengambil kira kadar data kurang daripada 1 Mbps, boleh dicapai menggunakan teknologi inframerah. Hasil kajian mengesahkan kelebihan sistem teknologi optik wayarles berbanding rangkaian komunikasi berasaskan radio konvensional untuk sistem pemantauan perkhidmatan penjagaan kesihatan.

Development of Indoor Wireless Optical CDMA System for Local-Area Networks (LANs) and Health-care Continuous Monitoring

ABSTRACT

Optical wireless communication (OWC) is an important area of research that offers a number of advantages over radio frequency based systems. These advantages include high bandwidth, free licensed spectrum band, high security, ease of installation, immunity to induced electromagnetic interference (EMI), and low-cost subsystems. The focus of this thesis is on indoor OWC channels and systems. The main limitations of indoor OWC systems include Inter-Symbol Interference (ISI) due to multipath dispersion, background noise, and Multiple Access Interference (MAI) and Phase-Induced Intensity Noise (PIIN) associated with simultaneous multi-user systems. The former degrades the signal-to-noise ratio (SNR), while the latter limits the maximum achievable data rate. This thesis investigates the use of an optimised divergence angle of the transmitter in a room structure of 1-cell and 4-cell configurations to achieve a higher transmission bandwidth and a more uniform optical power distribution, resulting in lower ISI. This work also investigates the use of Optical Code Division Multiple Access (OCDMA) technology based on a Zero Cross Correlation (ZCC) code in optical wireless networks to reduce the impairments such as MAI and PIIN that exist in the system and thus improve the overall system performance. The obtained results are compared with a Flexible Cross Correlation (FCC) based system. As a result, the indoor wireless OCDMA (W-OCDMA) system based on 4-cell configuration and using the ZCC code can accommodate a large number of users with less transmission power and a higher data rate compared to the 1-cell configuration or using the FCC code. The 4-cell configuration system based on the ZCC code offered 42% and 150% larger cardinality at the edges, and the corners of the room respectively, compared to the 1-cell configuration. In addition, this system also offered 55%, 47%, 51% larger cardinality at the centre, the edges, and the corners of the room, respectively, in contrast to the FCC code. Furthermore, this research also investigates the use of infrared technology in healthcare monitoring to develop a mobile medical system. This is because existing technology is generally based on radio frequency (RF) systems, which might suffer from electromagnetic interference (EMI). Additionally, the effect of the radiation field on medical equipment may lead to misdiagnosis. In answer to these issues, optical wireless links between the medical sensors and the receiver in the middle of the ceiling in a hospital room was examined. From the results, the power efficiency of the mobile optical wireless system to ensure the communication between medical sensors and the receiving point was established. Furthermore, the minimum required transmitted power for the required performance was determined, so as to achieve a higher power autonomy. The results also show that the requirements of a healthcare monitoring application for medical nodes of up to 10 nodes, considering a data rate lower than 1 Mbps, can be achieved using infrared technology. The results prove the superiority of the optical wireless technology over the conventional radio-based communication network in healthcare monitoring systems.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Communication has played an important role in the development of human civilisation. It is the human's endless desires that have driven the evolution of communication technology. The history of communication dates back to the early days of human civilisation, in which natural phenomena were used to get messages across. For example, these messages were transmitted through the sounding of horns or the lighting of fires, in order to announce important events such as enemy invasions or royal births.

In 1837, Samuel Morse invented the wire-line telegraph, the first wired long-distance communication link. In 1876, Alexander Graham Bell invented the telephone, a device that could transmit the human voice, which became the most efficient form of telecommunication of that time. The telephone has since paved the way to the development of communications technology today. In 1896, Guillermo Marconi introduced a degree of flexibility to the telegraph when he made available wireless communication for voice transmission. Throughout the 20th century, there have been huge demands on technology that convey data following various inventions such as the computer, the television and video technology, newly introduced to the market.

During this time also, the number of personal digital assistants increased incredibly in indoor environments, resulting in the need for flexible intercommunication through a distributed or centralised data communication system. In a traditional manner, this

requirement can be facilitated using physical wire. However, these physical connections could cause troubles in installation, rewiring, maintenance, etc. Hence, wireless communication systems were introduced as an attractive and alternative method that could offer mobility and flexibility for users. These systems can be implemented using two methods, radio frequency (RF) and infrared (IR) radiation. RF is used in most current wireless communication systems, and because of this the RF spectrum has become crowded and its capacity is limited to accommodating new high bit rate services (Padgett, Gunther & Hattori, 1995). At the same time, the need for significant bandwidth, high speed links, and low-priced components, has led to the development of infrared wireless communication systems. Within the radio range, a limited bandwidth of up to tens of MHz can be provided by the carriers, whereas infrared signals can be extended to several orders of magnitude. Infrared light cannot penetrate through opaque objects such as walls and therefore, mutual interferences between adjacent rooms are eliminated. This is a major advantage for Optical Wireless Communication (OWC) systems, which allow numerous IR systems to operate in different rooms of a large building without any interference problems.

Furthermore, OWC devices are not susceptible to induced electromagnetic interference (EMI), and this makes them a preferable choice for environments that suffer from EMI such as healthcare centres and factories. Additionally, OW receivers are also immune to interference caused by devices that generate radio waves such as electrical devices and radio wave communication devices. In the growing area of indoor OWC, energy savings and low-cost solutions are the key items that must be considered. In constructing the indoor OW system, LED-based communication has attracted wide interest. Regardless of the advantages, non-directed line-of-sight (NLOS) infrared systems are subjected to multipath dispersion, which results in significant Inter-Symbol

Interference (ISI) (Ghassemlooy, & Hayes, 2003). Additionally, OW links, which are fed via a fibre distribution network, could be blocked by walls and opaque objects. Furthermore, eye and skin safety regulations constrain maximum allowable optical power (Ghassemlooy, Popoola & Rajbhandari, 2012). Table 1.1 shows the comparison between optical wireless (OW) and radio frequency (RF) systems.

Table 1.1: A comparison between optical wireless (OW) and radio frequency (RF) systems (Alsaadi, 2011).

	Advantages	Disadvantages
Optical wireless systems	<ul style="list-style-type: none"> ○ Unregulated large bandwidth. ○ Immunity to interference between links operating in different rooms. ○ Possibility of frequency reuse in different parts of the same building. ○ Security and freedom from spectrum regulation and licensing. ○ Freedom from fading. ○ Inexpensive components, which are small and consume little power. 	<ul style="list-style-type: none"> ○ Shot noise induced by intense ambient light. ○ Intersymbol interference due to multipath dispersion. ○ The need for a backbone network to interconnect OW access points in different rooms. ○ Transmission of optical power is restricted by eye safety regulations.
Radio frequency systems	<ul style="list-style-type: none"> ○ Possibility of transmission through walls. ○ High mobility. ○ The omni directional portable antenna is relatively insensitive to rotation. 	<ul style="list-style-type: none"> ○ Regulated bandwidth. ○ Multipath fading. ○ Interference from other users. ○ Expensive for the moment without guarantee of high bit rates. ○ Low security.

1.2 Optical Code Division Multiple Access (OCDMA)

Optical code division multiple access (OCDMA) has been an area of interest in the past few years, due to its fairness, flexibility, cost-effective nature, simplified network control and management, service differentiation, and increased inherent security. OCDMA also enables multiple users to access the same bandwidth simultaneously without requiring high-speed electronic data processing circuits that are necessary in optical TDMA and other multiple access networks (Lin, Wu, Tsao & Yang, 2005; Andrew & Edward, 2000). Pruncal et al. first proposed the OCDMA concept (Pruncal, Santro & Fan, 1986). The basic idea of OCDMA is that it works based on spread spectrum techniques that have been widely used in wireless communication systems (Dixon, 1994). OCDMA has been recognised as one of the most important technologies for simultaneously supporting many users in shared media by assigning a unique code to each user; to communicate with another node, users imprint their agreed-upon code onto the data (Maric, Moreno & Corrada, 1996). In other words, each user's optical signal is optically encoded in an optical encoder that maps each bit onto a very high-rate optical sequence, substantially increasing the bandwidth occupied by the transmitted signal. At the receiver end, the bit stream is decoded by looking into the same code sequence. This is how the security properties are preserved in optical systems, besides leading to additional support in electrical security.

Figure 1.1 shows the encoding of the data bit sequence '101' using an On-Off Keying (OOK) scheme via a unipolar CDMA sequence '100100' where the data bit '1' represents the presence of optical pulses, and the absence of the pulses is represented by '0'. These optical pulses are mapped according to the assigned optical sequence. The number of pulses in a code indicates the weight (w) of the code.

As illustrated in Figure 1.1, T_b donates the bit duration, and T_c is the chip duration. The bit duration over the chip duration gives the temporal length (ν), which is equal to the number of chips in a sequence. The entire number of users in an OCDMA system depends on the orthogonal codes where the limited availability of suitable orthogonal codes confines the total number of users.

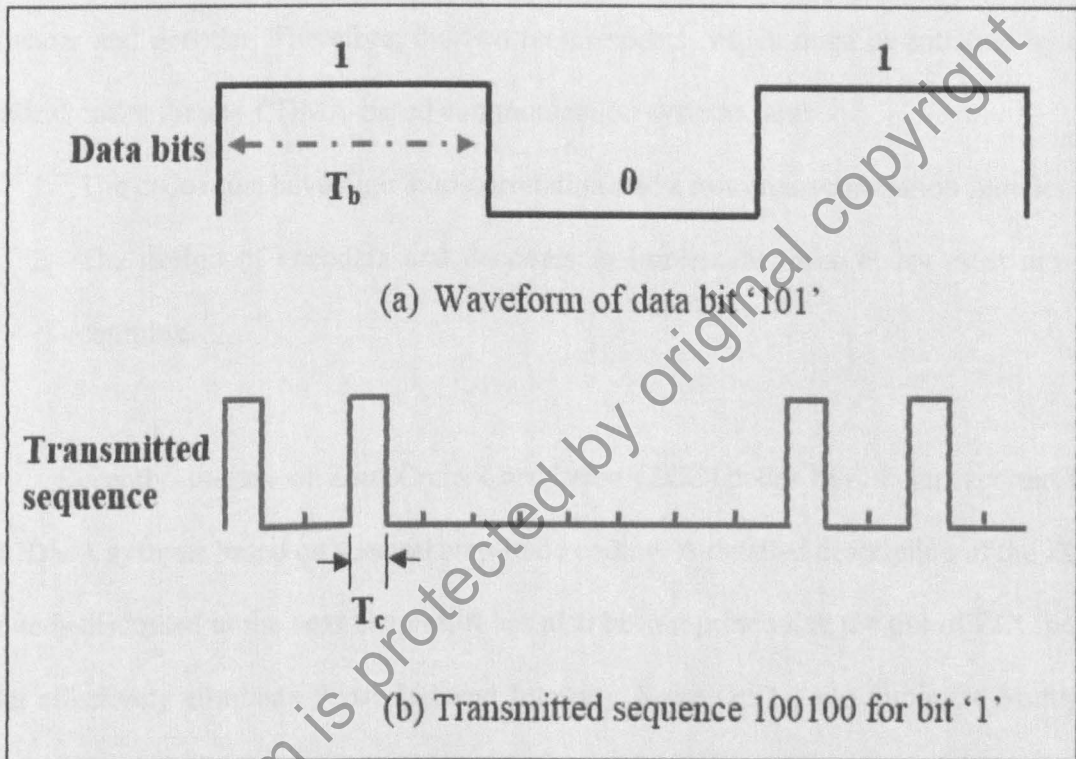


Figure 1.1: Encoded Optical signal waveforms of an OCDMA system.

Therefore, to support many subscribers, a large set of code sequences is needed, which implies that very narrow pulses have to be used. The encoded optical signals from all active users are broadcasted on the network using a star coupler. At the receiver, the optical decoder is matched to the transmitting node, giving a high auto-correlation peak and low cross-correlation function, only if the appropriate code is used. Hence, the desired

user's transmitted signal could then be detected by the photo-detector. All other received signals other than the desired users are termed Multiple Access Interferences (MAI).

The choice of spreading code is critical to any CDMA-based system. Without an appropriate spreading sequence, the successful recovery of data at the receiving end would be impossible. Furthermore, this factor also dictates the hardware design of the encoder and decoder. Therefore, the two requirements, which must be satisfied by the optical codes for any CDMA-based communication systems, are:

1. The code must have high auto-correlation and a low cross-correlation function.
2. The design of encoders and decoders to implement these codes must not be complex.

Recently, the use of Zero Cross Correlation (ZCC) codes have been reported for OCDMA systems based on spectral amplitude coding. A detailed description of the ZCC code is discussed in the next chapter. It has also been reported that the use of ZCC code can effectively eliminate Phase-Induced Intensity Noise (PIIN) and minimise Multiple Access Interferences (MAI), which exist in OWC systems due to its Zero Cross Correlation properties (Anuar, Aljunid, Saad & Hamzah, 2009). The signal is only dominated by shot noise and thermal noise; therefore, the use of ZCC code would contribute to better performance of the bit error rate (BER). So, the absence of overlapping bit '1' in the ZCC code will result in good performance, particularly in the results analysed according to the parameters imposed.

1.3 Problem Statement

Unlimited customer demands such as the need for higher data rates, higher security, and increased cost effectiveness, have led to the rapid development of optical wireless communication (OWC) systems over RF communication systems due to the former's high transmission bandwidth (Smitha, Sivabalan & John, 2008; Lucaciu, Mihăescu & Vladeanu, 2010). For the growing area of indoor OWC, energy savings and low-cost solutions are still considered. In this case, LED-based communication that has attracted wide interest, is looked at in constructing the indoor OW system. OWC systems operate at infrared frequencies (free licensed spectrum band) and can be classified into two main links when IR technology is considered. These two links are the Line-of-Sight (LOS) and diffuse links. LOS requires the transmitter and receiver to be aligned. Consequently, it also has better power efficiency and lower multipath dispersion due to the small divergence angle of the transmitter. Additionally, the receiver is made with quite a narrow field of view (FOV) and a photo detector (PD) with a small surface area, to ensure reduced background noise, and thus offering large bandwidth and improved sensitivity (Ghassemlooy, Wu, Khalighi, & Tang, 2013).

Nevertheless, LOS has certain drawbacks due to moving objects across its direct path, which causes shadowing. The diffuse link does not require any alignment between the transmitter and receiver, and instead, makes use of reflections from walls, ceilings, and other reflectors. However, diffuse transmission links are usually affected by multipath dispersion (which causes pulse spread and significant Inter-Symbol Interference (ISI)), poor power efficiency, and a high amount of collected ambient light noise at the receiver part (Green, Joshi, Higgins & Leeson, 2008; Jivkova & Kavehrad, 1999). Compared with LOS and diffuse links, the non-directed Line-of-Sight (NLOS)