CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Communication takes part, a significant role in the human evolution. Wireless communication is the fastest-growing segment of the communication history. Wireless system enhances the transmission capacity, when contrasted with the wired situation. The vision of wireless communication will support information exchange between people and devices more efficiently and this vision will enable multimedia communication anywhere in the world using small handheld devices like palmtop, laptop, etc. These devices have created a great demand for mobile connectivity. This in turn, has led to the development of wireless technologies such as Local Area Network (LAN) and the standard for wireless LAN is IEEE 802.11.

A wireless LAN utilizes electromagnetic waves to impart data starting with one point then onto the next without depending on any physical association. Wireless LAN offers a user with mobility and flexibility when compared with the traditional wired LAN system.
In last decade, there was a sudden build in the amount of Wireless communication systems. With more and more users around the world switching on to mobile devices, it is a need to research in this area for better wireless communication techniques. Optical Wireless (OW) is a cost efficient and high-data transfer capacity access method.

Wireless optical link is a solution that can be used in both short range and long range communications and is used since antiquity. Hany et al (2011) suggest that in today’s technologically developing world, the wireless optical link can transmit data at a speed of greater than 4Mbps with minimal cost. OW technology can be considered because of the array of profits, including un-regulated enormous (TeraHertz) transmission capacity, license free operation and minimal effort front-ends.

The legacy of an Optical Code Division Multiple Access (OCDMA) system follows the wireless and mobile connectivity for its wide applications. CDMA is a multiplexing technique, which is most widely the famous spectral spreading technique, which has been tremendously successful in the wireless domain.

In CDMA, all clients transmit the information at the same time on the same carrier frequency. To recognize the signals of the different clients, every data bit is coded by a code sequence, which has pseudo noise character and the same temporal length as the data bit.
Every client has an alternate 0, 1-code pair which is known by both the transmitter and the receiver. The receiver recognizes data bits of the client by associating the signal received with the client's 0 and 1 sequences. While in a wireless environment, along with radio, the term wireless is also applicable to systems, which utilize other regions of the electromagnetic spectrum, such as infrared.

Indoor wireless optical communication system can be envisioned as complementary rather than a replacement of Radio Frequency (RF) technologies. Wireless OCDMA systems have newly established significant interest due to its cost-effective nature and flexibility in implementation. Because the portable information needed wireless links, and infrared links have advantages with radio links.

1.2 OPTICAL COMMUNICATION SYSTEMS

In a communication system, the information is transmitted from a transmitter to a receiver through a channel. The information is interchanged between mobile devices to host through the electrical link. The cable and connectors are used for electrical connection. The small size connectors are costly and difficult to fabricate. These connectors break with the frequent age. Wireless communication techniques mitigate a large portion of the burdens of an altered electrical transmission.

Optical wireless systems permit indoor and short distance connections to be secured without any physical association (Steve 2005).
Optical communication techniques are extremely imperative to different sorts of telecommunications and systems. Optical communications include all the methods that use light to communicate. It comprises of a transmitter that encodes a message into an optical sign, a channel that conveys the indicator to its end of the line and a recipient that imitates the message from the gained optical signal.

As discussed by Jayasri et al (2007), Free Space Optics (FSO) frameworks are commonly used for 'last mile' communications and can work over separations of a few kilometers, as long as there is a clear line of sight between the source and the destination.

1.3 WIRELESS OPTICAL COMMUNICATION SYSTEMS

The optical wireless communication has risen as a reasonable innovation for cutting edge indoor and open-air broadband wireless requisitions. Provisions range from short-range wireless communication connections giving system access to portable workstations, to last-mile connections spanning crevices between end clients and existing fiber-optic correspondence bones and significantly laser correspondences in space joins.

Gfeller & Bapst (1979) proposed wireless Optical Communication as an alternate broadband innovation for wireless information transmission applications. The idea of wireless optical communication uses optical beams to help information through the climate or vacuum. Wireless optical architecture is likewise fundamentally the same to RF Wireless. Unlike radio
waves, the optical communication is done using light with free-space optical transceivers. Wireless optical framework is very much alike to optical fiber communication point-to-point joins, with the special case that no optical fibers are implemented as a transmission medium.

It is very effective in emergencies, to backup damaged wire line infrastructure for mobile ad-hoc network like military operations on the battlefield.

1.4 WIRELESS OPTICAL SYSTEM DESIGN

Figure 1.1 showcases a schematic illustration of a wireless optical communication system. Here, light waves are propagated in free space to transmit data. The data signal modulates the field created by the optical source. The modulated optical field then propagates through a free-space before reaching at the receiver. The electrical signals are re-generated from the optical signals using photo detector and then the communication takes place as in legacy systems.

![Figure 1.1 Schematic Diagram of Wireless Optical Communication System](image)

1.4.1 Transmitter Model
The drive circuit of the transmitter converts the electrical signal to an optical signal by differing the current flow through the light source. The optical transmitter front end comprises of a driver circuit alongside a light source. This optical light source could be of two sorts, in particular a Light-Emitting-Diode (LED) or a Laser-Diode (LD). One of the most critical limitations to optical wireless transmitters is the optical power level emitted by the source, which when surpassing particular levels is conceivably hazardous to the human eye. This circumstance must be considered especially for indoor free-space optic requisitions where lasers represent a specific security peril to unconscious onlookers, which may stroll through the way of a wireless Infra-Red (IR) link (Okuno et al 1998).

1.4.2 Wireless Optical Links

The aspects of the wireless optical channel can vary essentially relying upon the channel that is utilized. The three kinds of the optical links are as follows:

- Point-to-Point Links
- Diffuse Links
- Quasi-Diffuse Links

Point-to-Point Links
Figure 1.2 Point-to-Point Wireless Optical Communication System

Point-to-point connections work when there is an immediate, unobstructed way between a transmitter and a receiver. A connection, is secured when the transmitter is situated towards the receiver. In the narrow field-of-view applications, this oriented configuration allows the receiver to reject ambient light and achieve high data rates and low path loss. Figure 1.2 represents the typical point-to-point wireless optical link.

Diffuse Links

Diffuse transmitters emanate optical power over a wide robust plot so as to straightforwardness the indicating and shadowing issues. The transmitter does not have to be pointed at the beneficiary since the radiant optical force is thought to be reflected from the surfaces of the room. This bears client terminals a wide level of portability at the expenditure of high path loss. Figure 1.3 is the outlines of diffuse links communication systems as described by Kahn & Barry (1997).
Figure 1.3 A Diffuse Wireless Optical Communication System

Quasi-Diffuse Links

Quasi-diffuse connections inherit both point-to-indicate and diffuse connections upgrade join throughput. The transmitter enlightens the roof with an arrangement of gradually wandering pillar sources, which enlighten a lattice of spots on the roof. The transmit beams are made utilizing singular light sources. The information transmitted on all beams is indistinguishable. The connection is more delicate to shadowing with respect to diffuse connections. Figure 1.4 shows schematic representation of a simple quasi-diffuse wireless optical system.
1.4.3 Receiver Models

Different receiver structures are proposed for fiber-optic CDMA that could be utilized as a part of a regular indoor wireless optical system, for example, chip-level recipient and association + hard-limiter with daylight, fluorescent lights, and photo detector dark current as the foundation noise as pl

![Diagram of receiver model]

**Figure 1.5 The basic correlator structure.**

Correlation receiver is the most propounded structure for wireless optical networks. This basic receiver includes a matched channel, comparing
to its code design, and an integrator emulated by a sampler. In optical fiber
frameworks, fiber tapped-delay lines at the receivers could establish the
matched channel. A buffer after the Analog to Digital operation spares the
outcomes of expansion at each one testing time moment and resets at the end
of the bit time. At the end of the bit duration, the gathered value that is spared
in the buffer, i.e., correlation quality is contrasted and an ideal edge (Ghaffari
et al 2009).

1.5 COMPARISON BETWEEN WIRELESS OPTICAL AND RF

The wireless optical has alluring aspects when contrasted with RF. Wireless optical connections are naturally broadband and optical frequencies
in the infrared and spectrum are not directed or authorized. Optical segments
are less expensive and consume less electrical power than rapid RF
components (Deva et al 2012). FSO connections do not experience the
multiparty fading and have significantly less potential for interference when
contrasted with RF-sensitive electronic networks. The application of wireless
optical systems is restricted with respect to area coverage and client
portability, where as RF systems prove to be priceless. Wireless Optical
networks work under strict eye security regulations. Receivers provide lower
sensitivity than the RF systems, due to their photoelectric conversion
mechanisms and the effect of ambient light noise sources. Comparison of the
characteristics of wireless optical and RF communication systems is
tabulated in Table 1.1

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Wireless Optical</th>
<th>RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multipath fading</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>License free</td>
<td>Licensed</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td>----------</td>
</tr>
<tr>
<td>Detection type</td>
<td>Incoherent</td>
<td>Coherent/Incoherent</td>
</tr>
<tr>
<td>Multipath distortion</td>
<td>Only in diffuse indoor systems</td>
<td>Yes</td>
</tr>
<tr>
<td>Receiver sensitivity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Eye safety</td>
<td>Required</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>SNR (Signal to Noise Ratio)</td>
<td>Relies on upon optical signal power</td>
<td>Relies on upon RF signal amplitude</td>
</tr>
</tbody>
</table>

1.6 STANDARDS AND EYE SAFETY IN OPTICAL COMMUNICATION

The safety requirements must be considered while developing wireless optical connections. Since the vitality is proliferated in a free space channel, the effect of monochromatic high-energy light radiation on humans must be considered. There are a number of several standards, which are being followed for the wireless optical links. Furthermore, there are many international standards, which give rules on LED and laser outflow in particular: the International Electrochemical Commission (IEC), American National Standard organizations (ANSI) are probably the most renowned bodies. Wireless Optical connections follows Infrared Data Association (IrDA) norms coating an extensive variety of bit rates from 9.6Kb/s to 4Mb/s.

The average transmitted optical power limit for the IEC classes is of four different wavelengths as discussed by Steve (2005). Wavelengths in the 650nm range are visible red-light emitter. These visible bands are hardly ever used in FSO application because of the high background ambient light
noise present in the channel. Infrared wavelength is typically used in an optical network. The wavelength $\lambda = 880$nm, 1310nm and 1550nm are most commercially used frequencies for the optoelectronic applications (Ghaffari et al 2008). The 1550 nm source emits 20 times more optical power than 880nm source. The IR physical layer specifies optical signals in the 780-950nm wavelength range and bit rates of 1Mbps or 2Mbps using diffuse propagation is stated as ANSI/IEEE standard 2009.

1.7 MODULATION TECHNIQUES

The modulation schemes that are used in optical wireless system are;

- On-Off keying (OOK)
- Pulse –Position Modulation (PPM)

ON-OFF Keying

Around the different modulation techniques utilized for Intensity Modulation with Direct Detection (IM/DD), OOK is the least complex, in which a zero and one is transmitted as zero intensities and some positive power. OOK can utilize either Non-Return-to-Zero (NRZ) or Return-to-Zero (RZ) pulses. OOK is a binary level modulation scheme consisting of two symbols. In every symbol, one of the two symbols is picked with equivalent likelihood. The signal could be implemented to as basis function shown in Equation (1.1) for OOK.ie,

$$q_{OOK}(t) = \frac{2}{T} \text{rect}(t/T)$$  (1.1)
Using the above Equation, the time-varying optical intensity expressions is

\[ x(t) = \sum_{k=-\infty}^{\infty} 2P\sqrt{T} A[k] \phi_{\text{OOK}}(t - kT) \]  \hspace{1cm} (1.2)

Where \( A[k] \in [0, 1] \) and chosen uniformly. Since the basis, function is non-negative in the symbol period, and non-negative multipliers are used, \( x(t) \) satisfies the non-negativity constraint. The probability of a bit error can be determined using the previously defined framework as stated by Paul (2005) and is defined in Equation (1.3), as

\[ P_e = Q\left(\frac{P}{\sqrt{E_{\text{sr}}}}\right) \]  \hspace{1cm} (1.3)

OOK has its application in business IR frameworks, for example, IrDA links working beneath 4Mbps. In the links, Return-to-Zero–Inverted (RZI) signal is utilized, in which a pulse represents to a zero instead of one.

**Pulse Position Modulation**

OOK modulation is unable to deliver the power efficiency needed by numerous optical wireless systems. Hence, pulse code modulation is used to provide better efficiency. It offers an improvement in power efficiency sacrificing bandwidth efficiency. One such a method is known as PPM, in which M information bits are mapped to one of L possible symbols, where \( L = 2^M \).
M-ary PPM symbol can additionally be seen as a block coded adaptation of OOK, characterized over MT seconds in which the intensity output is zero. In the T interval, a fixed non-zero value is assumed. One possible basis set for M-PPM, $O_m(t)$ for $m \in M$, takes the form as shown in Equation (1.4) as

$$O_m(t) = \sqrt{\frac{E}{T}} \text{rect} \left( \frac{t - (T'j)/M}{T'} \right)$$

(1.4)

The signal space of M-PPM is a M dimensional Euclidean space with a single constellation point on each of the M axes is stated by Ghassemblooy & Hayes (2003). Figure 1.6 depicts PPM, OOK and Digital Pulse Interval modulation (DPIM)
1.8 FEATURES INFLUENCING WIRELESS OPTICAL COMMUNICATION SYSTEM

Since distinctive wavelengths are utilized as a part of optical wireless communication, many issues emerge (Osche 2002). Scattering, Absorption and refractive index variations are the prime factors influencing the propagation of optical signals in environment (Andrews 2004). As specified by Willebrand & Ghuman (2001), the absorption because of water vapor and dispersion brought on by little particles or fog decreases the optical power of the data signal intruding on the receiver. Disturbances influencing the optical signal propagation through the environment are shown in Figure 1.7 (Mutamed 2011).

Figure 1.7 Propagation of FSO
Fog

Fog is the climate sensation that has the more damaging impact over OWC networks. Since the measure of droplets is similar that of optical wavelengths utilized it causes signal interference. Scattering is termed as the most prevailing loss factor for the fog as discussed by Hemmati (2006).

Rain

Another weather phenomenon that affects the optical communication is the rain (Willebrand & Ghuman 2001). Unlike fog, the impact of rain on the optical signal is minimum (200\textmu m - 2000\textmu m).

Dispersion and absorption due to atmospheric gases

Willebrand & Ghuman (2001) also explained that the scattering is the re-directing or redistribution of light, which essentially diminishes the signal intensity received at the other end. The absorption of particles to the particle density is termed as absorption coefficient.

The output of optical networks will be influenced in light, since the environment is a dynamic and blemished media. Environmental turbulence impacts incorporate vacillations in the amplitude and period of the optical signal. As described by Zhu & Kahn (2002), the fading influenced by turbulence is equivalent to fading because of multi paths experienced by radio frequency communication links (Tomoaki 2003).

1.9 OUTDOOR WIRELESS OPTICAL COMMUNICATION
Figure 1.8  Application of Outdoor Optical Wireless Communication System

Protected and economic information up to a few kilometers with high bit-rates (Gbit/s-extent) might be empowered by free space optical transmission. Here the role of the transmitter to convert electrical signal into optical signal and transmit using the free space. On the other side, the receiver turns the optical one into electrical signal. In addition, the quality of this communication is characterized by the BER (Hansel et al 2001).

The standards of free space optical transmissions were set in the 60s after the advancement of first laser diodes and other optical parts. Today, the use of this transmission is extremely prominent once more, e.g. to overcome short separations in metropolitan ranges (see Figure 1.8). The ability to simulate the design and implementation of the FSO systems has minimized the efforts to experiment those systems. However, the estimation of BER should be accurate to measure the performance of the system.
1.10 CDMA TECHNOLOGY

Figure 1.9 CDMA Techniques

A various access technique permits a few users to interface with the same multi-point transmission medium and transmit over it. Also, it shares a capacity of the transmission medium. Three multiple accessing methods are available, namely Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and CDMA. Figure 1.11 describes the working of CDMA modulation technique.

CDMA utilizes exceptional spreading codes to spread the baseband information before transmission. The signal is transmitted in a channel, which is underneath a noise level. The receiver then utilizes a correlator to de-spread the needed signal, which is passed through an alternate filter. The filter will not allow the unwanted signals to pass through. Codes take the type of a
deliberately planned one/zero grouping processed at a much higher rate than that of the baseband information. The rate of a spreading code is alluded to as chip rate instead of bit rate.

1.11 CDMA IMPLEMENTATION IN FIBER OPTIC NETWORK

With a specific goal to make full utilization of the accessible data transfer capacity in optical fibers it is necessary to multiplex low rate data streams onto optical fiber to increase the total throughput. OCDMA, which can be described as a “next-generation CDMA” technology, which uses fiber-optic technology, helps to achieve this goal. OCDMA utilizes multiplexing transmission and multiple access with the help of coding in the optical space, which upholds numerous synchronous transmissions in the same time using same frequency.

The spread frequency is accomplished by encoding the light spectrum into pseudo random binary phase and afterward by deciphering the range stage encoded to recover the first pulse. In OCDMA, every bit of information is encoded and spread across several time slots or hop across several wavelengths.

On the receiving side, a key is used to decode the message, and the original information is recreated. However, with the development of OCDMA devices, it is possible to connect to the network backbone with secure and fast
link (John 2004). OCDMA can transmit data asynchronously without packet collisions. Since an OCDMA system uses the existing fiber-optic backbones, the implementation is relatively simpler than other technologies. OCDMA facilitates the simultaneous access to multiple users in the network asynchronously. It has gained a lot of popularity in recent times due to the fact that it is almost delay-free, and it necessitates very fewer optical signal processing. OCDMA uses asynchronous data transmission, which can make network control and management quite simple.

1.12 THESIS MOTIVATION

Optical CDMA communication systems incorporates huge advantages such as high-speed transmission, support to large number of users when compared with TDMA and Wavelength Division Multiple Access (WDMA), flexibility in networking and soft capacity. The various channel coding techniques in OCDMA such as OOC, Prime Code (PC) and Extended Prime Code (EPC) have their own benefits in different communication scenarios.

Also, the 2D OCMDA codes exhibits unique advantages like increase in number of users, improved Bit Error Rate (BER) parameter and is secure in nature. However, the wireless OCDMA systems which is under-explored possesses additional benefits such as reduced Multiple Access Interference (MAI), availability of license free communication channel, high speed transmission with increased bit rate, no multipath fading,
electromagnetic compatibility and limited multipath distortion. On the other hand, RF use is limited in sensible environments where high data security and high immunity against interference with other existing RF and electronic devices are required (Eg. Healthcare environments).

Given the observation in the communication systems especially in FSO communication, this research work is motivated and focused towards exploring the benefits of OCDMA systems under various coding schemes and 2D environments. Also, the optimization of transmission power remains a challenge in the free space system due to the eye safety requirements and efficiency of the transmission system. To address this issue, a power optimization algorithm is also devised in this work.

The main aim of the research is as follows:

- To examine the performance of the wireless OCDMA systems under OOC, PC and EPC environment.
- To observe wireless OCDMA systems under various channel parameters, including attenuation, wavelength, bit rate and beam divergence angle.
- To design the 2Dimensional PC/PC, PC/EPC and EPC/ EPC codes in wireless OCDMA system.
- To analysis PC/PC, PC/EPC and EPC/ EPC coding techniques is carried out with respect to BER, Q factor and eye diagram.
- To examine OCDMA systems with and without power control algorithms.

1.13 OUTLINE OF THE THESIS
The thesis is organized into seven chapters, including this chapter. The contents of each chapter are summarized as follows;

In Chapter 2, the existing OCDMA systems are presented initially. Detailed discussion is done on the Prime code implementation in OCDMA network, some of the milestone research works published in various reputed journals, and publications are reviewed and used as a reference for this thesis.

Following this, in Chapter 3, the construction of Prime code, extended prime code and their properties is discussed. The implementation of OOC code, prime code and extended prime code in wireless OCDMA environment is also presented.

In chapter 4, a detailed analysis is done on the performance of the wireless OCDMA systems under OOC, prime and extended prime code environment. The key parameters analyzed here are BER, Q factor and eye diagram. These observations are done by varying various channel parameters including attenuation, wavelength, bit rate and beam divergence angle.

The 2Dimensional Prime codes and its constructions are discussed in Chapter 5. Specifically, PC/PC, PC/EPC and EPC/ EPC codes are presented. Further, detailed performance analysis of the above-mentioned coding techniques is carried out with respect to BER, Q factor and eye diagram.

The issues related to optimizing the transmission power in the OCDMA systems is addressed in chapter 6. OCDMA systems with and without power control algorithms are analyzed and presented. The thesis is concluded in Chapter 7, in which the overall depiction of the thesis is detailed and the areas that can be explored for, through the research are mentioned explaining the need for each.