Performance Analysis of a MIMO Optical Wireless link with Space Time Block Code (STBC)

By

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Contents

Chapter 1

Chapter 2

Chapter 3

Chapter 4

System Analysis

Content

Chapter 5

RESULT AND DISCUSSION

Declaration

It is hereby declared my partial thesis.

Signature of the candidate

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Md. Zahirul Islam

Abstract

Performance analysis will be carried out for a space time block coded multiple input multiple output (MIMO) optical wireless link considering Nakagami-m fading model. The diversity reception in the receiving will be carried out by multiple receiving antenna with maximal ratio combining (MRC) technique. The expression of the receiver output will be derived for several sets of space time block codes considering the above fading model. The Probability density function (PDF) of the output of the MRC combiner will be developed and will be used to find the unconditional average bit error rate (BER). The Performance results will be evaluated numerically in terms of BER for several code and system parameters. The optimum system design parameters will be determined at a given BER.

List of Abbreviations

SNR	Signal to noise ratio
SI	Scintillation
FSO	Free-Space Optical
BER	Bit error rate
SEP	Symbol error probability
BPSK	Binary phase shift keying
SISO	Single input single output
SIMO	Single input multiple output
MISO	Multiple input single output
MIMO	Multiple –input multiple-output
PPM	Pulse position modulation
FOV	Field of view
IEC	International Electro technical Commission
ANSI	American National Standards Institute
AEL	Allowable Exposure Limit
OOK	On Off keying
IM/DD	Intensity modulation/direct detection
PDF	Probability density function
MRC	Maximal ratio combining

List of Figure

List of Table

Chapter 1

Introduction

1.1 General Perspective

In recent Years, there has been a migration of computing power from the desktop to portable, mobile formats. Devices such as digital still and video cameras, portable digital assistants and laptop computers offer users the ability to process and capture vast quantities of data. Although convenient, the interchange of data between such devices remains a challenge due to their small size, portability and low cost. High performance links are necessary to allow data exchange from these portable device to established computing infrastructure such as backbone networks data storage device and user interface peripherals [1]. For this purpose, some parts of communication links need to be constructed wireless. During the last decade, therefore, the wireless communication technology has grown rapidly [2]–[5]. The Technology base for implementing this concept does not yet exist, however. Radio technology although well suited for moderate –speed applications such as voice, may not be sufficient to support many high-speed applications.

Table 1.1: Comparison of wireless optical and communication channel

Serial No	Property	Wireless Optical	Radio
1	RF Circuit design	No	Yes
2	Bandwidth regulated	No	Yes
3	Data rate	100’s Mbps	10’s Mbps
4	Security	High	Low

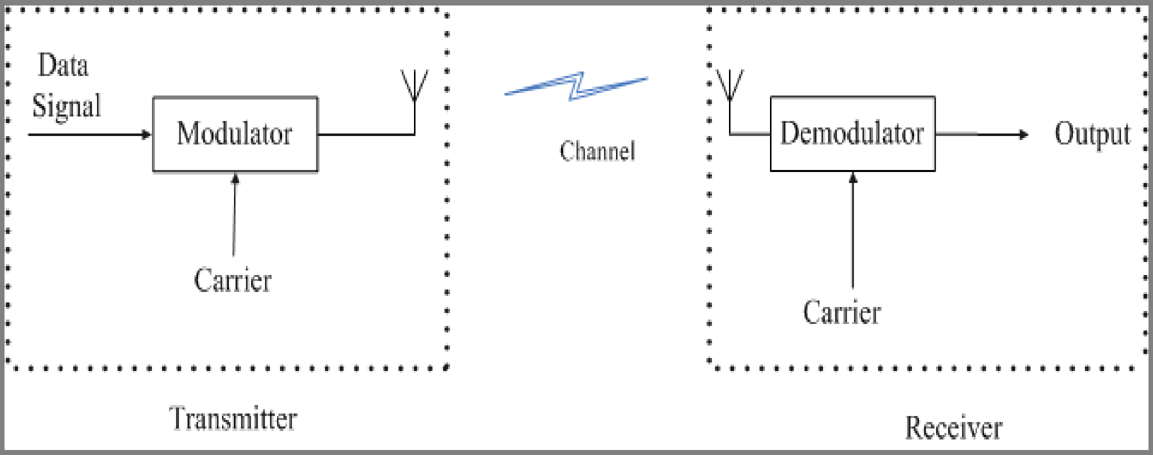

Fig.1.1: Block diagram of a wireless communication system System

1.2 Brief History of optical wireless communication

In early claude chappe invented the optical telegraph which was able to send message over distances by changing the orientation of signaling arms on a large tower. A code book of orientation of the signaling arms was developed to encode letters of the alphabet, numerals, common works and control signals. Message could be sent over distances of hundreds of kilometers in a matter of minutes [06]. One of the earliest wireless optical communication devices using electronic detectors was the photo phone invented by A.G. Bell and C.S trainer an patented on December 14, 1880. The System is design to transmit a operator s voice over a distance by modulating reflected light from the sun on a foil diaphragm. The receiver consisted of a selenium crystal which converted the optical signal into an electrical current. With this setup, they were able to transmit an audible signal a distance of 213 [07]. Optical transmission came to be available for the communication system after the laser as a light source was invented. As a coherent light source being not in a nature, ruby laser was invented by Dr. T. Mainman in 1960, H- Ne laser oscillated in Bel Labs next year , and GaAs semiconductor laser oscillated in1962. The continuous oscillation of GaAlAs laser was realized in Japan, the United States and the Soviet Union in 1970 and the small semiconductor laser which could be high- speed modulated advanced optical transmission technology greatly. Around from 1965, the beam guide system which arranged the lens in a pipe, and the space propagation system which emits light to free space were beginning to be studied so as to use laser for free space optical communication . In 1979, indoor Bapst [08]. In their system, diffuse optical radiation in the near-infrared region was utilized as signal carrier to interconnect a cluster of terminal located in the same room to a common cluster controller. However the reduction in loss of the fiber and invention of continuous semiconductor laser has moved the mainstream of the research to optical transmission system was accelerated from 1970 to 1980.

1.3 Objectives

i) To carry out performance analysis for a SISO and MIMO optical wireless link considering nakagami-m fading model without spatial diversity over turbulence channel.

ii) To evaluate the Performance result diversity reception in the receiver with maximal ratio combining (MRC) Technique.

iii) To derive the expression of the receiver output for several sets of space time block codes considering the above fading model .

iv) To find the expression of the conditional bit error rate (BER) and the PDF of the output of the MRC combiner.

v) To find the unconditional average bit error rate (BER).

vi) To evaluate the performance the result numerically in terms of BER for several code and system parameters

vii) To determine the optimum system design parameters at a given BER.

Chapter 2

Basic Knowledge of optical wireless communication systems

2.1 Introduction

This chapter introduces some basic concepts used in the following chapters which are required for the understanding of this work. We begin with the importance of free space optical communication in section 2.2. A review of the brief description of major components of a optical wireless link comes next in section 2.3. Section 2.3.Section 2.4 describes the characteristics of difference channel topologies and their relative advantage and disadvantage.

2.2 Importance of free-space optical communication in communication system

Communication systems transmit information from a transmitter to a receiver through the construction of a time- varying physical quantity or a signal. A familiar example of such a system is a wired electronic communication in which information is conveyed from the transmitter by sending an electrical current or voltage signal through a conductor to a receiver circuit. Another example is wireless radio frequency (RF) Communications in which a transmitter varies the amplitude, phase and frequency of an electromagnetic carrier which is detected by a receive antenna and electronics. In each of this communication system’s the transmitted signal is corrupted by deterministic and random distortions due to the environment. For example wired electrical communication systems are often corrupted by random thermal as well as shot noise and often frequency selective. These distortions due to external factors are together referred to as the response of a communications channel between the transmitter and receiver. For the purpose of system design, the communications channel between is often represented by a mathematical model which is realistic to the physical channel. The goal of communication system design is to develop signaling techniques which are able to transmit data reliable and at high

Rates over these distorting channels.As a medium for wireless communication Light wave radiation offers several significant advantage over radio. Light wave emitters and detectors capable of high speed operation are available at low cost. The light wave spectral region offers a virtually unlimited bandwidth that is unregulated worldwide. Infrared and visible light are close together in wavelength, and they exhibit qualitatively similar behavior. Both are absorbed by dark objects, diffusely reflected by light colored objects, and directionally reflected from shiny surfaces. Both types of light penetrate through glass, but not through walls or opaque barriers, so that optical wireless communications are confirmed to the room in which they originate. This signal confinement makes it easy to secure transmissions against casual eavesdropping, and it prevents interference between links operating in. different rooms. Thus, Optical wireless networks can potentially achieve a very high aggregate, capacity, and their design may be simplified, since transmissions in different rooms need not be coordinated. When an optical wireless link employs intensity modulation with direct detection (IM/DD), the short carrier wavelength and large-area square-law detector lead to efficient spatial diversity that prevents multi-path fading. By contrast, radio links are typically subject to large fluctuation in received signal magnitude and phase. Freedom from multi-path fading greatly simplifies the design of the optical wireless link. The light wave is not drawbacks however. Because light wave cannot penetrate walls, communication from one room to another requires the installation of optical wireless access points that are interconnected via a wired backbone. In many applications, there exists intense ambient light noise, arising from sun-light incandescent lighting and fluorescent lighting, which induce noise in an optical wireless receiver. In virtually al short-range, indoor applications IM/DD is the only practical transmission technique. The signal-to-noise (SNR) of a direct detection receiver is proportional to the square of the received optical power, implying that IM/DD links can tolerate only a comparatively limited path loss. Often optical wireless link must employ relatively high transmit power levels and operate over a relatively limited range. While the transmit power level can usually be increased without fear of interfering with other users, transmitter power may be limited by concern of power consumption and eye safety, particularly in portable transmitters[09].

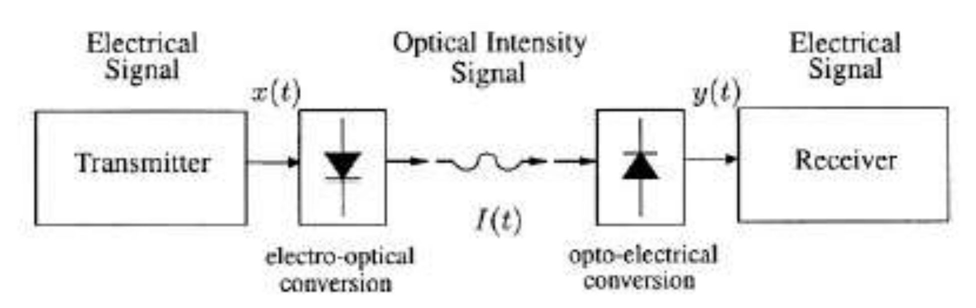

Fig:2.2: Block diagram of optical intensity, direct detection communication channel

2.3 Brief Description of Major Components of an Optical Wireless Link

An optical wireless links consists of a transmitter, wireless communication channels and a receiver as shown in figure 2

2.3.1 Optical Sources

In most optical communication systems, semiconductor light sources are used to convert electrical signals into light. Optical sources for wireless transmission must be compatible to overcome the atmospheric effects and they should be such that one can easily modulate the light directly at high data rates. Generally either Lasers or LEDs are used in optical communication systems[09].

LED

Light emitting diodes (LEDs) used in optical communication system are the same as visual display LEDs expect that they operate in the infra-red region and with many times higher intensity of emission. When the p-n junction is forward biased, photon emission takes place due to recombination of electron-hole pair. The wavelength of emission will depend on the energy gap[09].

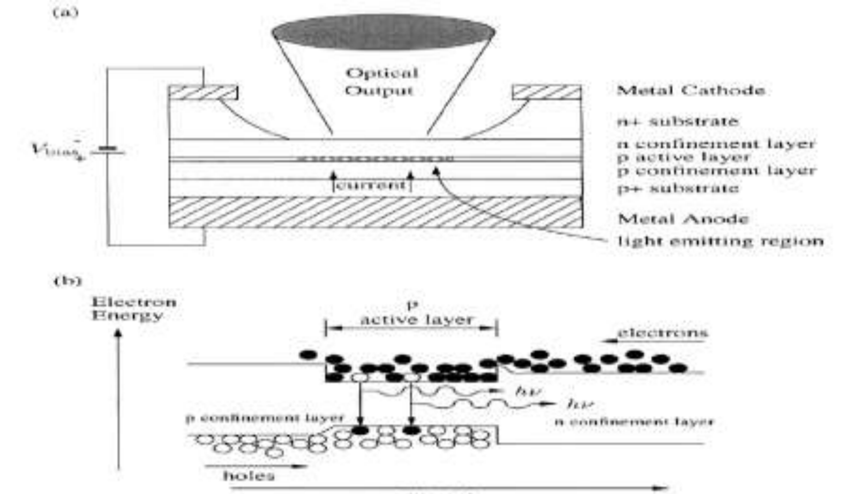

Fig: 2.3.1 An example of a double heterostructure LED (a) construction and (b) band diagram under forward bias

LASER

Laser stands for “Light amplification by stimulating emission of radiation”. Compared to LED, a laser has wider bandwidth, higher power output, higher modulation efficiency, narrower spectral line-width and narrower emission pattern. Laser sources are much brighter than LEDs [09].

2.3.2 Optical Detectors

An optical detector is a photon to electron converter. Avalanche photo-diode (APD) And positive intrinsic negative (PIN) diode is the most commonly used detectors. The most important thing of the optical communication system is that the spectral response of both the source and the detector must be same, otherwise efficiency will suffer [09].

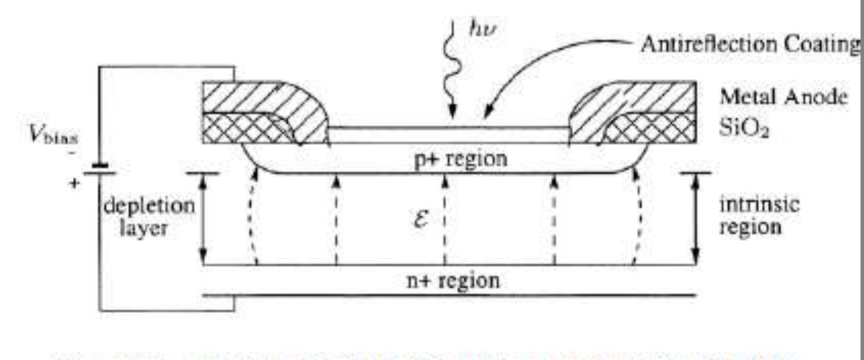

Fig:2.3.2 Structure a simple silicon p-i-n photodiode

PIN Photo detector

PIN photo detector is the simplest optical detector. It is composed of an n^+ substrate, a lightly doped intrinsic region and a thin p zone. Operated with a reverse bias, mobile carriers leave the p-n junction producing a zone of moderate electric field on both sides of the junction into the intrinsic region. As it only lightly doped, this field extends deeply. Incident light power is mainly absorbed in the intrinsic region, causing electron hole pairs to be generated. These carriers are separated by the influence of the electric field in the intrinsic and represent a reverse diode current can be amplified [09].

APD Photo detector

It is the second popular type of photo detector and has the advantage of internally multiplying the primary detected photo current by avalanche process, thus increasing the signal detection sensitively. But some noise is also generated here. The frequency response of both PIN and APD are similar, making them both suitable up to 1 GHz. The main advantage of APD over PIN diode is greater gain bandwidth product due to the inbuilt gain. Silica is the material used at short wavelength (< 1 nm), GE, InGaAsP and AlGaAsP becoming popular at the longer wavelength around 1.3 m [09].

2.4 Channel Topologies

The characteristics of the wireless optical channel can vary significantly depending on the topology of the link considered. This section presents three popular wireless optical channel topologies and discusses the channel characteristics of each [09].

2.4.1 Point -to-Point Links

Point-to-Point wireless optical links operate when there is a direct unobstructed path between a transmitter and a receiver. Figure 2 present a diagram of a typical point-to-point wireless optical link. A link is established when the transmitter is oriented toward the receiver. In narrow field –of-view applications this oriented configuration allows the receiver to reject ambient light and achieve high data rates and low path loss. The main disadvantage of this link topology is that it requires pointing and sensitive to blocking and shadowing. The frequency response of these links is limited primarily by front-end photodiode capacitance. Since inexpensive large-area photodiodes are typically used with limited reverse bias the depletion capacitance significantly limits the link bandwidth [10].

A typical example of these links is the standard infrared Data Association (IrDa) Fast IR 4 Mbps link. These links offer communication over 1 m of separation and are used primarily for data interchange between portable devices. The achievable bandwidth in this inexpensive system is on the order of 10-12 MHz which is approximately three orders of magnitude smaller than in wired fiber–optic systems. New IrDA point-to-point links operating at 16 Mbps have also been standardized and may begin appearing in a wider range of application. Another

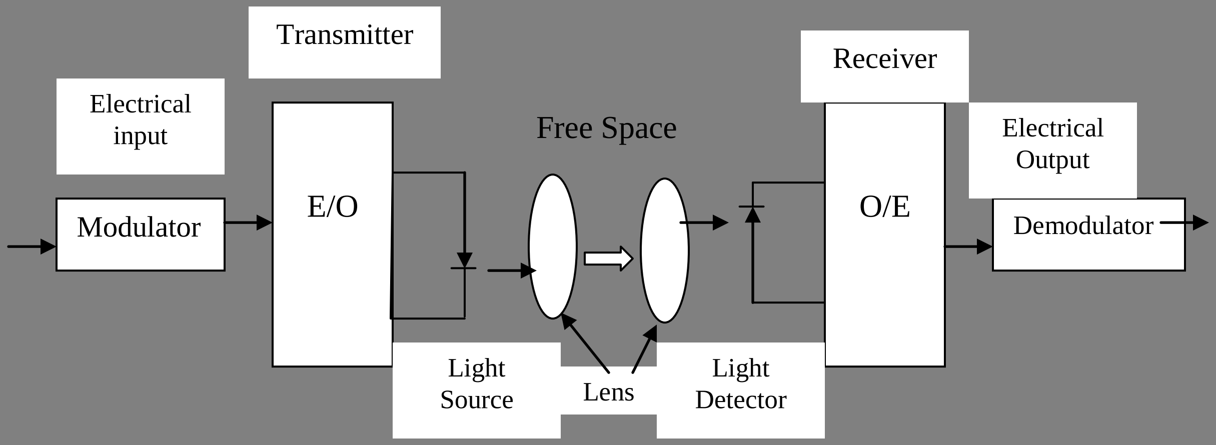

Fig:2.4.1: Block Diagram of point to point Optical link

Channel topology which uses a number of parallel point-to-point links is the space division multiplexing architecture. Space division multiplexing is a technique by which a transmitter outputs different data in different spatial directions to allow for the simultaneous use of one wavelength by multiple users. In one such system a ceiling-mounted base station has a number of narrow beams establishing point-to-point links in a variety of direction in a room. A fixed receiver once aligned to within 1 of a transmitter beam establishes a high speed link at up to 50 Mbps. Another means of implementing a space division multiplexing system the transmitter beams are steer able under the control of a tracking subsystem. Tracking is typically accomplished by a beacon LED or FM transmitter on the mobile terminal. These systems are proposed to provide 155 Mb/s ATM access to mobile terminals in a room. Electronic tracking systems have also been proposed which exploit a diffuse optical channel to aid acquisition. The advantage of this topology is that it is extremely power efficient and supports a large aggregate bandwidth inside of a room at the expense of system complexity. Point-to-point wireless optical links have been implemented in a wide variety of short and long range applications. Short range infrared band links are being designed to allow for the transfer of financial data between a PDA or cell phone and a point-of-sale terminal. Wireless optical links are chosen as the transmission medium due to the low cost of the transceiver and security available by confining optical radiation. The IrDA has specified a standard for this financial application under the title IrDA FM (Financial message). Medium range indoor links have also been eloped to extend the range of Ethernet networks in an office environment. A 10 Mbps point-to-point wireless infrared links to extend Ethernet networks has been deployed over a range of at most 10 m. Higher rate 100 Mbps point-to-point wireless infrared links have also been designed to extended Ethernet networks in indoor.

Chapter 3

Description the Limitation of Optical Signal With respect to MIMO Technology

3.1 Introduction to MIMO Technology

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. MIMO is one of several forms of smart antenna technology, the others being MISO (multiple input, single output) and SIMO (single input, multiple output).

In conventional wireless communications, a single antenna is used at the source, and another single antenna is used at the destination. In some cases, this gives rise to problems with multipath effects. When an electromagnetic field (EM field) is met with obstructions such as hills, canyons, buildings, and utility wires, the wavefronts are scattered, and thus they take many paths to reach the destination. The late arrival of scattered portions of the signal causes problems such as fading, cut-out (cliff effect), and intermittent reception (picket fencing). In digital communications systems such as wireless Internet, it can cause a reduction in data speed and an increase in the number of errors. The use of two or more antennas, along with the transmission of multiple signals (one for each antenna) at the source and the destination, eliminates the trouble caused by multipath wave propagation, and can even take advantage of this effect.

MIMO technology has aroused interest because of its possible applications in digital television (DTV), wireless local area networks (WLANs), metropolitan area networks (MANs), and mobile communications. Generic Spatial-diversity transmitter-receiver considering of MIMO and block diagram of MIMO technology.

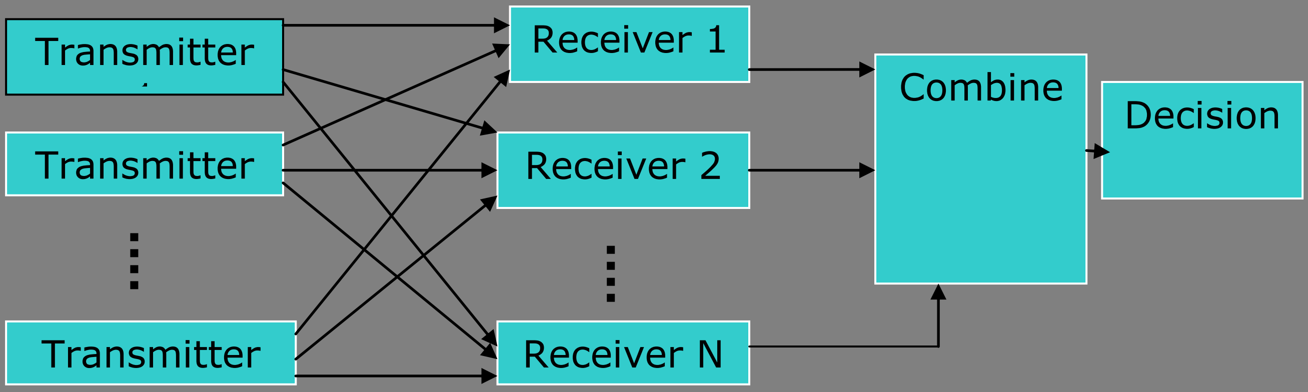

Fig. 3.1: Generic Spatial-diversity transmitter-receiver considering of MIMO[11]

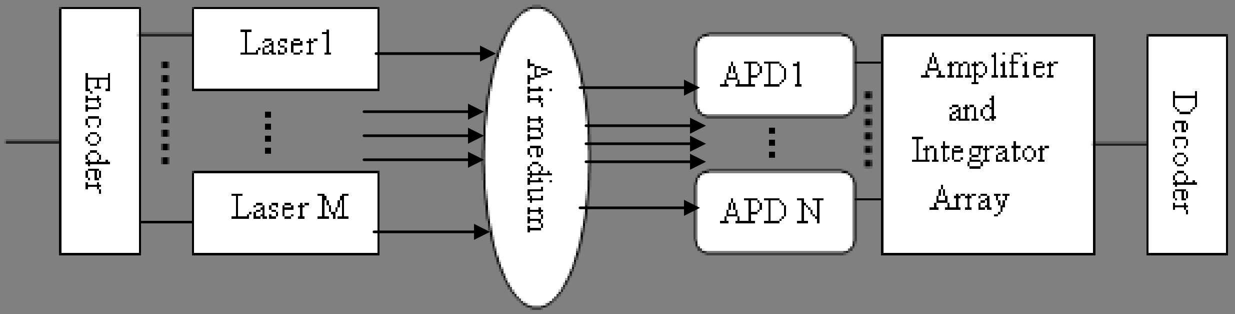

fig: 3.1 Block diagram of MIMO technology[12].

3.2 Nakagami fading

Unfortunately, mobile radio links are subject to severe multipath fading due to the combination of randomly delayed, reflected, scattered, and diffracted signal components. Fading leads to serious degradation in the link carrier to noise ratio(CNR), leading to higher Bit Error Rate (BER).[13] Rayleigh and Rician fading models have been widely used to simulate small scale fading environments. M Nakagami observed this fact and then formulated a parametric gamma function to describe his large scale experiments on rapid fading in high frequency long distance propagation.

The Model: The Nakagami fading model was initially proposed because it matched empirical results for short ionospheric propagation. The Nakagami distribution or the Nakagami –m distribution is a probability distribution related to the gamma distribution. This more general fading distribution was developed whose parameters can be adjusted to fit a variety of empirical measurements. The Nakagami Distribution described the magnitude of the received envelope by the probability density function:

$$P(z) = 2m^m z^{(2m-1)}/\Gamma(m)\ \Omega^m \exp[-mz^2/\Omega],\ z\geq 0,\ \Omega \geq 0,\ m\geq .5$$

$\Omega = E(z^2)$is the average received power or average CNR

$\Gamma(.)$ is the Gamma function.

$m = E(z^2)/\mathrm{var}(z^2)$ is the fading figure or the shape factor.

The probability density function (PDF) are primarily known as first order characteristics and mainly used to obtain static metrics associated with the channel, i.e. Bit Error Rate (BER).

When does Nakagami Fading occur?

Nakagami Fading occurs for multipath scattering with relatively larger time-delay spreads, with different clusters of reflected waves. Within any one cluster, the phases of individual reflected waves are random, but the time delays are approximately equal for all the waves. As a result the envelope of each cluster signal is Rayleigh Distributed. The average time delay is assumed to differ between the clusters. If the delay times significantly exceed the bit period of the digital link, the different clusters produce serious inter symbol interference.

3.3 Limitations of Optical wireless Signal

3.3.1 Scattering

a) Multiple Scattering:

Multiple scattering of waves induces bulk effects such as attenuation and anisotropy that are important in seismology, optics, medical imaging, and other fields involving propagation in disordered media.

b) Homogenous

Homogenous scattering means scattering produced more than once the same kind of scattering

c) Mie Scattering

Dielectric spheres are known to scatter electromagnetic radiation if the wavelength of the light is similar to the size of the dielectric sphere. This scattering process was first described theoretically by Mie in 1908. In FTIR spectroscopy, Mie scattering causes a broad sinusoidal oscillation that appears in the baseline of the spectra, which can cause a misrepresentation in the position and intensity of absorption bands .This Scattering created by such in homogeneities is mainly in the forward direction and called Mie scattering. Mie scattering depending upon the air medium.

d) Scattering Angle:

Scattering Angle means angle between more than one scattering[14].

e) Precise Scattering:

The precise Scattering mechanism of light propagating in a medium is dependent on the ratio of the particle radius and the radiation wavelength. When the scattering particles are of the order of magnitude of the radiation wavelength, as is the case for optical wireless communication through fogs and haze at visible and near infrared wavelength [14].

g) Aerosol Scattering:

Aerosol Scattering effects caused by rain, snow and fog can also degrade the performance of free space optical communication systems[14].

h) Rayleigh Scattering:

Rayleigh scattering occurs when atmospheric particles are much smaller than the wavelength. Rayleigh occurs primarily off of the gaseous molecules in the atmosphere. Blue light is scattering much more than red light. Rayleigh scattering is responsible for the blueness of the Sky. The effect of rayleigh scattering on the total attenuation coefficient is very small.[15]

3.3.2. Turbulence

a) Atmospheric effect:

Atmospheric turbulence has been studied extensively and various theoretical models have been proposed to describe turbulence induced image degradation and intensity fluctuations. Turbulence induced fading can be reduced substantially by aperture averaging [14]

3.3.3 Attenuation

Free-space laser communication is very similar to fiber optic communication, except that instead of the light being contained within a glass fiber, the light is transmitted through the atmosphere. Since similar optical transmitters and detectors are used for free-space and fiber, similar bandwidth capabilities are achievable. It has also been demonstrated that WDM fiber technologies will also work in free-space, which further increases the bandwidth potential of wireless optical links.6-8,10,11 However, a significant difference between free-space and fiber optic laser transmission is the predictability of the attenuation of laser power in the atmosphere compared to fiber. Fiber optic cables attenuate at a constant predictable rate. Current multimode fiber optic cables attenuate at 2 to 3 dB/km, and single mode fibers attenuate at .5 to .2 dB/km. On the other hand, the atmosphere’s attenuation of laser power is quite variable and difficult to predict. Atmospheric attenuation can vary from .2 dB/km in exceptionally clear weather, to 310 dB/km in a very dense UK fog.14,15 These large attenuation values in heavy fog are important because they can reduce the uptime or availability of laser com systems.16 If proposed free-space laser com systems, such as shown in Figure 2, are to be used in telecommunication applications, there will be requirements for very high availability. If the system link margin for atmospheric attenuation is 30 dB, then the maximum link range will have to be 100 m or less to always overcome the heaviest 300 dB/km fogs. This is the worst case scenario. In many cases, it will be very difficult to set up lasercom grids between buildings with all them links being less than 100 m in distance. By trading off more link margin and typically less extreme weather, the laser link range requirement can be extended

slightly. But to satisfy telecom requirements for availability, the laser links ranges will still have to very short – on the order of less then 500 m, or be backed up by lower data rate microwave or millimeter wave
links.

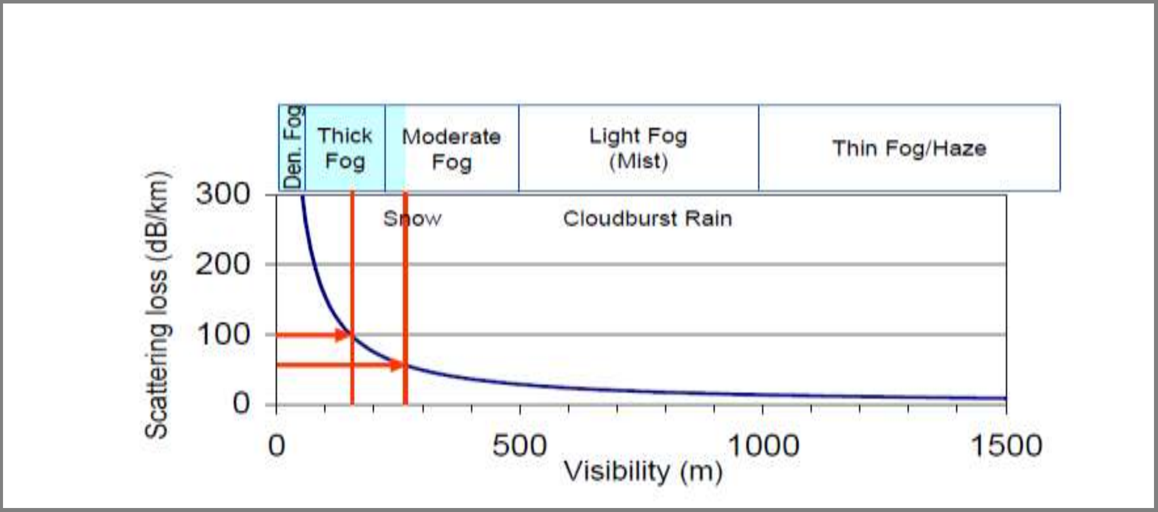

Figure 3.3.3: The bottom graph shows amount of atmospheric attenuation as a function of visibility. The top shows the weather conditions that correspond to the visibility. Typical laser com systems have 30 to 50 dB of margin at 500 m range which corresponds to handling attenuation up to 60 to 100 dB/km. The primary weather that can cause problems for these short (< 500 m) link ranges is fog and heavy snow.

For these short (<500 m) laser com links, fog and heavy snow are the primary weather conditions which can cause link outages. This is demonstrated in Figure 3. The bottom of Figure 3 shows a plot of the atmospheric attenuation as a function of the visibility. The technical definition of visibility or visual range is the distance that light decreases to 2% of the original power, or qualitatively, visibility is the distance at which it is just possible to distinguish a dark object against the horizon.17 The attenuation-visibility curve was calculated for 785 nm light from Equation 6. There is an obvious inverse relationship between visibility and the amount of attenuation. Also shown above the graph in Figure 3 are the descriptive weather conditions that are defined by the corresponding visibilities.14 For example, thick fog is defined as the weather condition where the visibility is between 50 m and 250 m. Typical link margins for atmospheric attenuation can run from 30 dB to 50 dB at 500 m link range for high-end laser com systems. 50 dB of link margin at 500 m corresponds to 100 dB/km of allowable atmospheric attenuation (see arrow at 100 dB/km on the scattering loss axis). This corresponds to weather with a visibility of 150 m (thick fog). Only weather that attenuates worst than 100 dB/km (visibility less than 150 m) will potentially take down the laser link. A system with 30 dB of atmospheric link margin at 500 m range will start to fade in weather which attenuates worse than 60 dB/km or weather with a visibility less then 270 m. In either case, it is fog (dense, thick or moderate) which is the type of weather of primary concern for these short (< 500 m) telecom laser com links. There are also conditions of heavy snow and extreme rain that can attenuate at these high 60 to 100 dB/km levels. In this hypothetical example, losses due to scintillation fades are ignored. But for ranges of 500 m, typical scintillation fade margins are 2 to 5 dB, which is much less than the margins for atmospheric attenuation[15].

3.3.4. Interference

a) Coherence :

A coherent light sources radiation with a continuous succession of Waves propagating in phase. This results in a distinct wave front, which is most tangibly discernible when the radiation from two or more A coherent source mixes causing constructive and destructive interference. Coherence interference occurs more than one signal to be place same Phase [16].

b) Incoherence :

Incoherence interference occurs more than one signal to be place different Phase.[17].

3.4 Block diagram of Free-Space optical wireless communication System

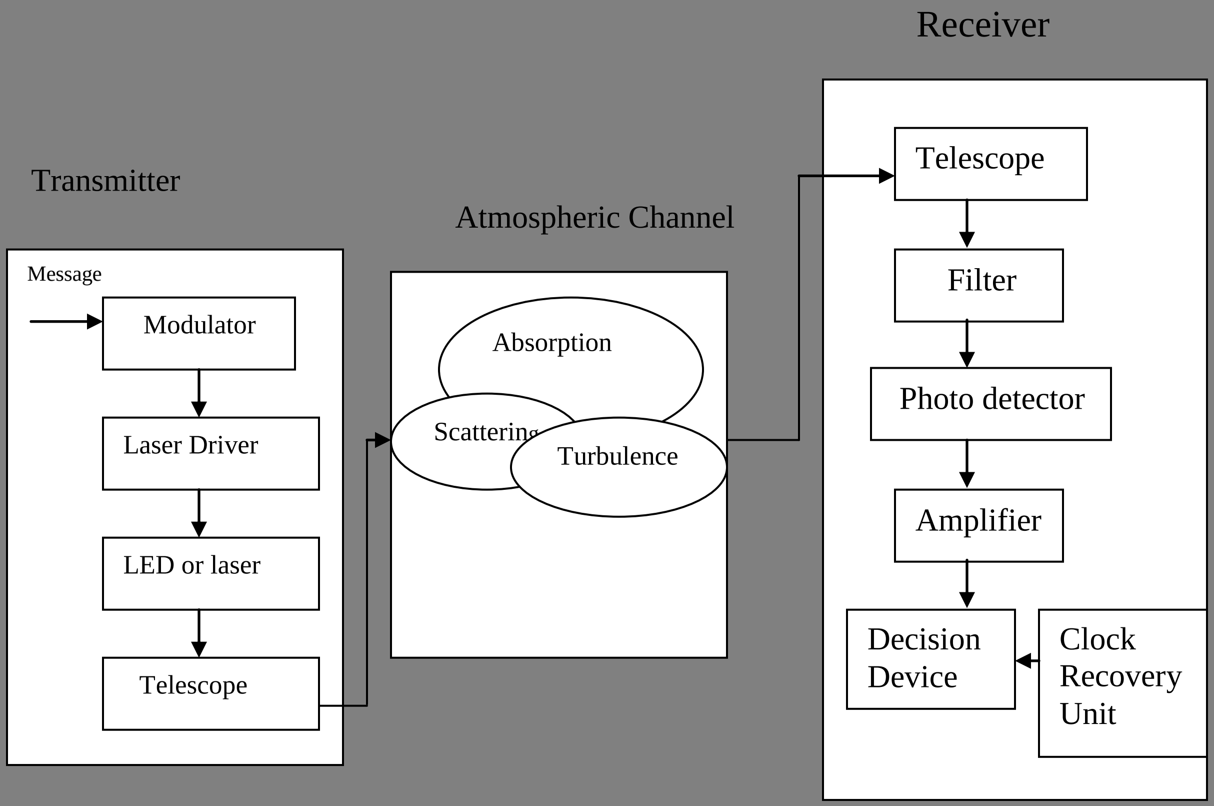

Fig 3.4: Block diagram of an OWC System

There are three key functional elements of free-space system OWC System (See fig 1:) the transmitter, the atmospheric channel and the receiver. The transmitter converts the electrical signal into light. The light propagates through the atmosphere to the receiver, which converts the light back into an electrical signal. The transmitter includes a modulator, a laser driver, a LED or laser, and a telescope. The modulator converts bits of information into signals in accordance with the chosen modulation method. The driver provides the power for the laser and stabilizes its performance; it also neutralizes such effects as temperature and aging of the laser or LED. The light sources convert the electrical signal into optic radiation. The telescope aligns the laser LED radiation to a collimated beam and directs it to the receiver. In the atmospheric channel, the signal is attenuated and blurred a as results of absorption, scattering and turbulence. This channel may be the traversed distance between a ground station and a satellite or a path of a few kilometers through the atmosphere between two terrestrial transceivers.

The receiver includes a telescope, filter, photo detector, an amplifier, a decision device, and a clock recovery unit. The telescope collects the incoming radiation and focus it onto filter. The filter removes background radiation and allows only the wavelength of the signal to pass through it. The photo detector converts the optic radiation into electrical signal, and the amplifier amplifies the electronic signal. The decision unit determines the nature of the bits of information based on the time of arrival and the amplitude of the pulse. The clock recovery unit and synchronizes the data sampling to the decision- making process [17].

Chapter 4

Systems Analysis

4.1 We investigate a MIMO FSO system affected by pointing errors without and with atmospheric turbulence. We assume intensity modulation / direct- detection (IM/DD) with On-off keying (OOK). We obtain the BER performance of the system considering the beamwidth, detector size, and pointing error variance. The results demonstrate that the use of diversity results in system performance improvement.

We consider a FSO link with M transmitter and N receivers, using IM/DD with OOK. The transmitter signal at the mth transmit and receiver signal at the nth receive aperture is given by

$$S(t) = \sum_{-\infty}^{\infty} a_k p(t-kt) * \sqrt{2p_T}\, e^{j\omega_c t}$$

a_k = Data Signal (0,1), p(t) = Pulse Shape, P_T= Transmitter Power

, $e^{j\omega}$ct = Carrier frequency

$$r_n = R_d X \sum_{m=1}^{M} h_{mn} + \upsilon_n$$ ①

Where x is the transmitted signal intensity, R_d is the detector reponsivity and u_n is the additive Gaussian noise with variance σ_m , h_{mn} is the normalized fading channel coefficient which models the channel from the nth receive aperture. The transmitted signal X is either 0 or 2p_t, where p_t is the average transmitted optical power. The channel state h_{mn} is the attenuation due to geometric spread and pointing errors. By considering a Gaussian beam and a circular detection aperture of the radius r, the probability density function (PDF) of h for a single input single output channel (SISO) is derived in[18] as

$$f_h(h) = \frac{\gamma^2}{A_o \gamma^2} h^{\gamma^2 - 1}$$ ②

Where $\gamma = w_{zeq} / 2\sigma_s$ is the ratio between the equivalent beam radius at the receiver and the pointing error displacement standard deviation at the receiver . The equivalent beamwidth at the receiver calculated using the relation :

$$\upsilon = \frac{\sqrt{\pi} r}{\sqrt{2}\omega_z}, \omega_{zeq}^2 = \omega_z^2 \frac{\sqrt{\pi} erf(\upsilon)}{2\upsilon \exp(-\upsilon^2)}, A_o = [erf(v)]^2$$ ③

Here ω_z is the beam waist (radius calculated at e^{-2}) at a distance z from the transmitter . The pointing error is defined as a radial displacement between the detector and the receiver light beam on the detector plane.

4.2 Average Bit-error Rate

4.2.1 SISO FSO Link

The BER of IM/DD System with OOK in the presence of AWGN is given by

$$p_b(e) = p(1)(e/1) + p(0)p(e/0)$$ ④

Where (p1) and p(0) are probabilities of sending a ‘1’ and ‘0’ respectively, and p(e/1) and p(e/0) are the conditional error probabilities when the transmitted bit is ‘1’ and ‘0’ respectively. Due to symmetry, p(1)= p(0) 0.5 and p (e\1) =p(e/0). It is easy to show that conditional on the fading coefficient h, We have [18],

$$p_b(e/h) = p(e/h,1) = p(e/h,0) = Q(\frac{\sqrt{2} R_d P_t h}{\sigma_n})$$ ⑤

Where Q(.) is the Gaussian Q function which is related to the complementary error function erfc (.) by erfc(x) = 2Q(√2 X). By averaging over the pdf of h, We obtain

$$BER = \int_0^{A_0} f_h(h) p_b(e/h) dh$$ ⑥

After substituting $h_h(h)$ from (2), we obtain the BER of a SISO FSO using numerical techniques

4.3 MIMO FSO Link

For the system with spatial diversity at both the transmitter and receiver, the optimum decision metric for on- off keying is given [18]

$$p(r/1, h_{mn}) \overset{1}{\underset{0}{\gtrless}} p(r/0, h_{mn})$$ ⑦

Where r =(r_1, r_2…. r_N) is the received signal vector. By finding the conditional probabilities and following a similar analysis as in [18], we the of a MIMO systems as

$$BER = \int_{h_{mn}} f_{h_{mn}}(h_{mn}) Q[\frac{\sqrt{2}}{\sigma_n MN} \sqrt{\sum_{n=1}^{N} (\sum_{m=1}^{M} R_d p_t h_{mn})^2}] dh_{mn}$$

⑧

Where $f_{h_{mn}}(h_{mn})$ is the joint pdf of vector $h = (h_{11}, h_{12}......, h_{MN})$ of length MN. The scaling factor MN is induced in the above equation to fairly compare a MIMO system with a SISO system. We considered transmit diversity and receive diversity separately to have a better understanding of the system performance.

When receive diversity is applied i.e for the single-input-multiple output (SIMO) system, the variance of the noise in each aperture is N times smaller. Therefore, for M=1 and OC Implementation at the receiver with perfect CSI (8) is written as

$$BER_{,SIMO} = \int_h f_n(h) Q[\frac{\sqrt{2} R_d p_t}{\sigma_n \sqrt{N}} \sum_{n=1}^{N} h_n^2] dh_n$$ ⑨

Equal Gain Combining (EGC): for the case where the receiver adds the signals at the receiver branches the expression for the BER can be expressed as

$$BER_{,SIMO} = \int_h f_n(h) Q[\frac{\sqrt{2} R_d p_t}{\sigma_n N} \sum_{n=1}^{N} h_n] dh_n$$ ⑩

4.4 LOGNORMAL TURBULENCE MODEL

The atmospheric turbulence impairs the performance of an FSO link by causing the received optical signal to vary randomly thus giving rise to signal fading. The fading strength depends on the link length, the wavelength of the optical radiation and the refractive index structure parameter

c_n^2 of the channel. The log-normal distribution is generally used to model the fading associated with the weak atmospheric turbulence regime [19]. This model is mathematically tractable and it is characterized by the Ryotov variance σ_1^2 The turbulence induced fading is termed weak when $\sigma_1^2 < 1.2$ and this defines the limit of validity of the log-normal model [19]. Beyond the weak turbulence regime, other models such as the gamma-gamma [19] and the negative exponential [19] will have to be considered. The Ryotov variance σ_1^2 can be calculated as [19]:

$\sigma_1^2 = 1.23 c_n^2 (\sqrt[6]{k^7 L^{11}})$

where L is the propagation distance and k is the wave number

The log-normal models assumes the log intensity of the laser light traversing the turbulent atmosphere to be normally distributed with a mean value of $\sigma_1^2/2$ Thus, the probability density function of the received irradiance is given by [19]:

$$p_I = \frac{1}{\sqrt{2\pi}\sigma_l}\frac{1}{I}\exp\left\{-\frac{(\ln(I/I_0)+\sigma_l^2/2)^2}{2\sigma_l^2}\right\} \qquad I \geq 0\,;$$

where I represents the irradiance at the receiver and I_0 is the signal irradiance without scintillation.

In order to show the effect of scintillation and noise on the system performance, we will be looking at the BER metric and fading penalty under different channel conditions. It should however be mentioned that since both subcarrier channels are BPSK modulated, their error performance will be similar and we will therefore be presenting results for one of them only. By adopting the approach given in [19], the theoretical unconditional BER per subcarrier channel is obtained as:

$$\begin{aligned} P_e &= \int_0^{\infty} P_{ec}\,p(I)\,dI \\ &= \int_0^{\infty} Q\left(\sqrt{\gamma(I)}\right)\frac{1}{I\sqrt{2\pi\sigma_l^2}}\exp\left\{-\frac{\left[\ln I/I_0+\sigma_l^2/2\right]^2}{2\sigma_l^2}\right\}dI \end{aligned} \;;$$

where $\gamma\,(I)$ represents the SNR at the input of the coheren demodulator.

Chapter 5

RESULT AND DISCUSSION

5.1 Introduction

This chapter represents the results obtained from computation on the model of FSO Wireless communication system considering the SISO, SIMO, MISO, MIMO system described (only SISO) in chapter-4. Results has been evaluated numerically and degradation of system performance due to channel impairments has been determined in terms of power penalty at a given BER with respect without and with turbulence .

5.2 Without and with turbulence

5.2.1 BER versus Ps(dBm) Without and with turbulence

With Following Parameters:

a. B= 1*10^9
b. Power= -26 to -6 dBm

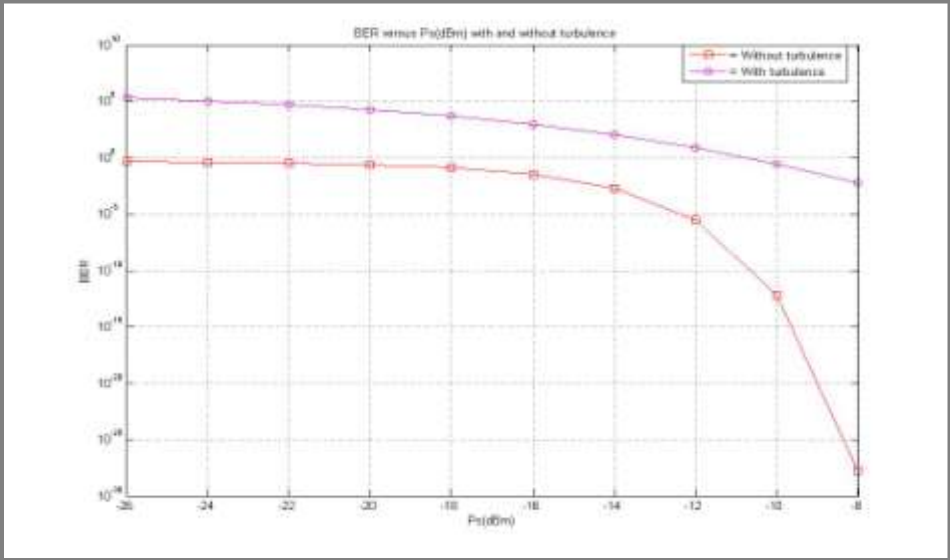

fig.5.2: Bit-error rate versus transmitted power at for the single input and single output without turbulence and with turbulence

The plots of bit error rate (BER) versus Ps (dBm) considering without turbulence and with turbulence are shown in Fig. 5.2. Let particular power level -12dBm in this figure we compare BER level, we get the Minimum BER without considering turbulence (BER=10^{0}) and we get the Maximum BER with considering turbulence (BER=$10^{3)}$.

5.3 Without turbulence considering different value of Bandwidth

5.3.1 BER versus Ps(dBm) Without turbulence

With Following Parameters:

a. B= $1*10^9$ to $8*10^9$
b. Power= -32 to -14 dBm

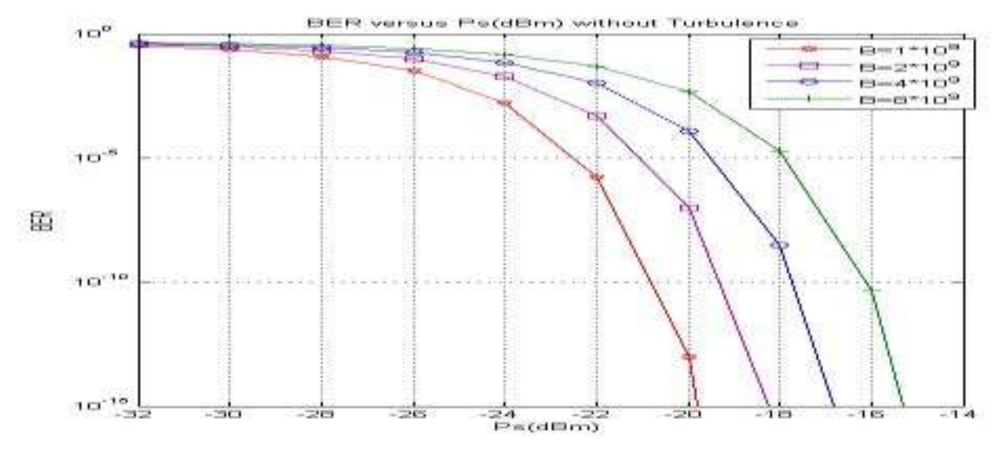

fig.5.3: Bit-error rate versus transmitted power at for the single input and single output with turbulence variation of bandwidth

The plots of bit error rate (BER) versus Ps (dBm) considering without turbulence is dependent on different value of Bandwidth are shown in Fig. 5.3. Let particular power level -22dBm in this figure we compare BER level, when B= $1*10^9$ and $2*10^9$ we get the Minimum BER(10^{-7}) for B= $1*10^9$ and we get the maximum BER (10^{-7}) for B= $2*10^9$ without considering turbulence . Because we know that if we increase the bandwidth SNR is decreased but by this time BER is increased.

5.4 With turbulence considering the different value of Bandwidth and lognormal variance

5.4.1 BER versus Ps(dBm) With turbulence

With Following Parameters:

a. B = $1*10^9$ to $8*10^9$
b. Power = -32 to -14 dBm
c. Lognormal variance $\sigma_{l=}$ .125 to .825

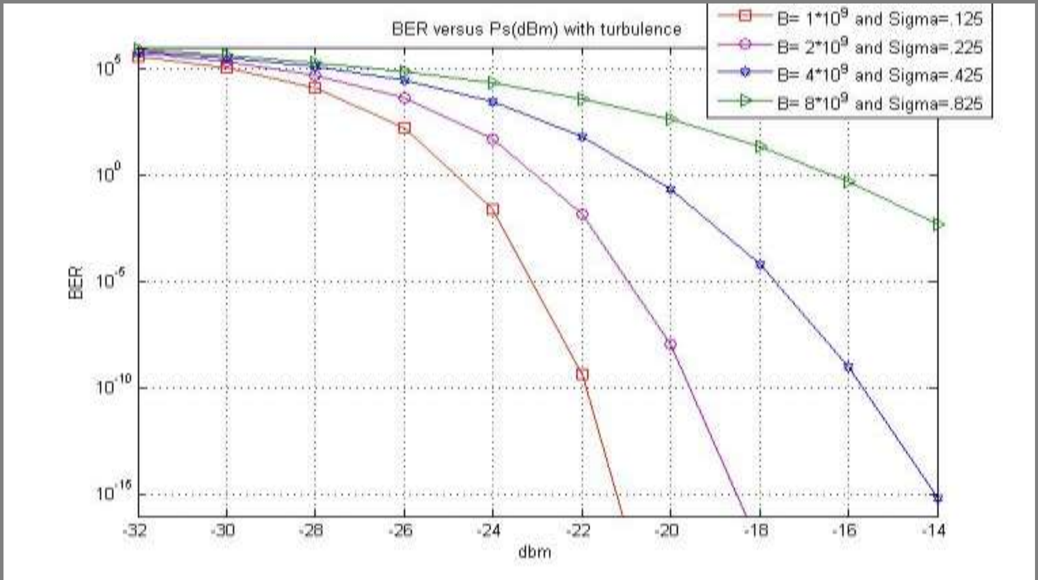

fig. 5.4: Bit-error rate versus transmitted power at for the single input and single output and with turbulence variation of bandwidth and $\sigma_{l.}$

The plots of bit error rate (BER) versus Ps (dBm) considering with turbulence dependent on different value of Bandwidth and log normal variance are shown in Fig. 5.4. Let particular power level -24dBm in this figure we compare BER level, when B= $1*10^9$ and σ_l= .125 we get the Minimum BER(10^{-3}) and we get the maximum BER (10^2) for B= $2*10^9$ σ_l= .225 with considering turbulence . Because we know that If we increase the log normal variance and Bandwidth by this time BER is increased.

5.5 Further work to be done duration of my thesis as bellow. To

1. The diversity reception in the receiver

1. To carry out performance analysis for MIMO optical wireless link considering atmospheric turbulence and Nakagami_m fading model.

2. The diversity reception in the receiver will be carried with maximal ratio combining (MRC) technique.

3. To derive the expression of the receiver output for several sets of space time block codes considering the above fading model.

4. To find the expression of the conditional bit error rate (BER) and the PDF of the output of the MRC combiner.

Hopefully to be completed of my thesis above 6 months

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