Performance Analysis on Free space MIMO Optical Wireless link over strong Atmospheric Turbulences

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Declaration

We hereby declare that, our thesis is based on the results found by ourselves. Material of work found other researchers are mention by references. This thesis neither in whole nor in part has been previously submitted for any degree.

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(Signature of supervisor)

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Abstract:

Performance analysis will be carried out for optical wireless link with multiple transmitters & multiple receivers over a strong atmospheric turbulence channel. The receiver will be consisted of direct detection receiver with equal gain combining technique. The analysis will be carried out for the MIMO FSO system to find the expression for the output signal & photo detector currents in presence of strong atmospheric turbulence. The signal to noise ratio (SNR) and the unconditional BER will be evaluated numerically for different system parameters. The degradation in system performance due to the channel effect and improvement in receiver sensitivity will be determined numerically. Optimum system parameters will be determined for a given system BER.

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Chapter 1

Introduction to FSO

&

The Effect of Atmospheric Turbulence on FSO

1.1 Introduction:

Free space Optical wireless link also known as “Free space optical communication “(FSO). Free Space Optics (FSO) communications, also called Free Space Photonics (FSP) or Optical Wireless, refers to the transmission of modulated visible or infrared (IR) beams through the atmosphere to obtain optical communications. Like fiber, Free Space Optics (FSO) uses lasers to transmit data, but instead of enclosing the data stream in a glass fiber, it is transmitted through the air. Free Space Optics (FSO) works on the same basic principle as Infrared television remote controls, wireless keyboards or wireless Palm devices

1.2 How Free Space Optics (FSO) Works:

Free Space Optics (FSO) transmits invisible, eye-safe light beams from one "telescope" to another using low power infrared lasers in the tera Hertz spectrum. The beams of light in Free Space Optics (FSO) systems are transmitted by laser light focused on highly sensitive photon detector receivers. These receivers are telescopic lenses able to collect the photon stream and transmit digital data containing a mix of Internet messages, video images, radio signals or computer files. Commercially available systems offer capacities in the range of 100 Mbps to 2.5 Gbps, and demonstration systems report data rates as high as 160 Gbps.

Free Space Optics (FSO) systems can function over distances of several kilometers. As long as there is a clear line of sight between the source and the destination, and enough transmitter power, Free Space Optics (FSO) communication is possible.

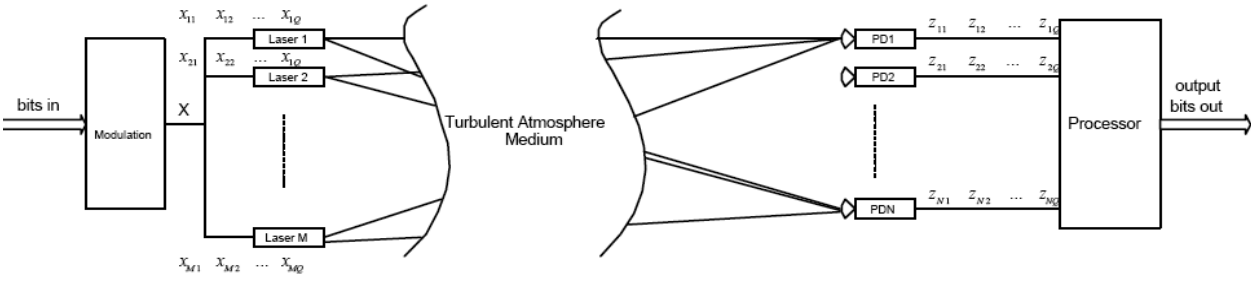


Figure : System block diagram of free space optical communications.

1.3 FSO at the Speed of Light:

Unlike radio and microwave systems, Free Space Optics (FSO) is an optical technology and no spectrum licensing or frequency coordination with other users is required, interference from or to other systems or equipment is not a concern, and the point-to-point laser signal is extremely difficult to intercept, and therefore secure. Data rates comparable to optical fiber transmission can be carried by Free Space Optics (FSO) systems with very low error rates, while the extremely narrow laser beam widths ensure that there is almost no practical limit to the number of separate Free Space Optics (FSO) links that can be installed in a given location.

Free Space Optics (FSO) Advantages:

Free space optical (FSO) systems offers a flexible networking solution that delivers on the promise of broadband. Only free space optics or Free Space Optics (FSO) provides the essential combination of qualities required to bring the traffic to the optical fiber backbone – virtually unlimited bandwidth, low cost, ease and speed of deployment. Freedom from licensing and regulation translates into ease, speed and low cost of deployment. Since Free Space Optics (FSO) optical wireless transceivers can transmit and receive through windows, it is possible to mount Free Space Optics (FSO) systems inside buildings, reducing the need to compete for roof space, simplifying wiring and cabling, and permitting the equipment to operate in a very favorable environment. The only essential for Free Space Optics (FSO) is line of sight between the two ends of the link. No tariffs are required for its utilization.

It has low power consumption. Cannot be intercepted easily. Cannot be interpreted with spectrum analyzers or RF meters.

1.4 Free Space Optics (FSO) Security:

The common perception of wireless is that it offers less security than wireline connections. In fact, Free Space Optics (FSO) is far more secure than RF or other wireless-based transmission technologies for several reasons: Free Space Optics (FSO) laser beams cannot be detected with spectrum analyzers or RF meters

Free Space Optics (FSO) laser transmissions are optical and travel along a line of sight path that cannot be intercepted easily. It requires a matching Free Space Optics (FSO) transceiver carefully aligned to complete the transmission. Interception is very difficult and extremely unlikely

The laser beams generated by Free Space Optics (FSO) systems are narrow and invisible, making them harder to find and even harder to intercept and crack Data can be transmitted over an encrypted connection adding to the degree of security available in Free Space Optics (FSO) network transmissions.

1.5 Free Space Optics (FSO) Challenges due to the Atmospheric Turbulence

The advantages of free space optical wireless or Free Space Optics (FSO) do not come without some cost. When light is transmitted through optical fiber, transmission integrity is quite predictable – barring unforeseen events such as backhoes or animal interference. When light is transmitted through the air, as with Free Space Optics (FSO) optical wireless systems, it must contend with a complex and not always quantifiable subject - the atmosphere.

1.5.1Fog

Fog substantially attenuates visible radiation, and it has a similar affect on the near-infrared wavelengths that are employed in Free Space Optics (FSO) systems. Note that the effect of fog on Free Space Optics (FSO) optical wireless radiation is entirely analogous to the attenuation – and fades – suffered by RF wireless systems due to rainfall. Similar to the case of rain attenuation with RF wireless, fog attenuation is not a “show-stopper” for Free Space Optics (FSO) optical wireless, because the optical link can be engineered such that, for a large fraction of the time, an acceptable power will be received even in the presence of heavy fog. Free Space Optics (FSO) optical wireless-based communication systems can be enhanced to yield even greater availabilities.

1.5.2 Scintillation

Heated air rising from the earth or man-made devices such as heating ducts create temperature variations among different air pockets. This can cause fluctuations in signal amplitude which leads to "image dancing" at the FSO-based receiver end. Light Pointe's unique multi-beam system is designed to address the effects of this scintillation. Called "Refractive turbulence," this causes two primary effects on optical beams.

1.5.3 Solar Interference:

Solar interference in Free Space Optics (FSO) free space optical systems operating at 1550 nm can be combated in two ways. The first is a long-pass optical filter window used to block all optical wavelengths below 850 nm from entering the system; the second is an optical narrowband filter proceeding the receive detector used to filter all but the wavelength actually used for intersystem communications. To handle off-axis solar energy, two spatial filters have been implemented in SONA beam systems, allowing them to operate unaffected by solar interference that is more than 1.5 degrees off-axis.

1.5.4 Scattering:

Scattering is caused when the wavelength collides with the scatterer. The physical size of the scatterer determines the type of scattering. When the scatterer is smaller than the wavelength, this is known as Rayleigh scattering. When the scatterer is of comparable size to the wavelength, this is known as Mie scattering. When the scatterer is much larger than the wavelength, this is known as non-selective scattering. In scattering â€� unlike absorption â€� there is no loss of energy, only a directional redistribution of energy that may have significant reduction in beam intensity for longer distances.

1.5.5 Beam Wander:

Beam wander is caused by turbulent eddies that are larger than the beam.

Beam Spreading:

Beam spreading is long-term and short-term and it is the spread of an optical beam as it propagates through the atmosphere.

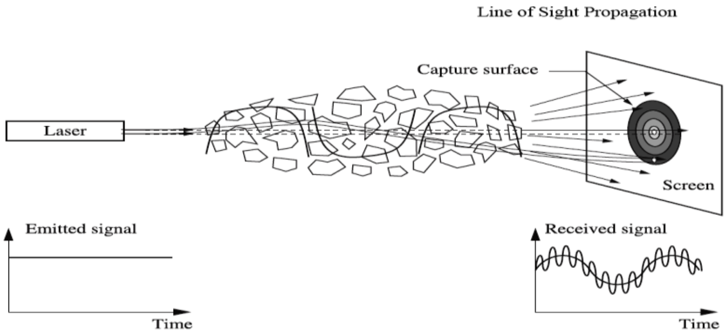


Figure: Effect of atmospheric turbulence

Chapter 2

Received Photo Detector Current at the Presence of Atmospheric Turbulences

2.1 The Received photo detector current at the presence of Atmospheric Turbulences :

The received optical signal level is highly dependable on the FSO channel parameters.

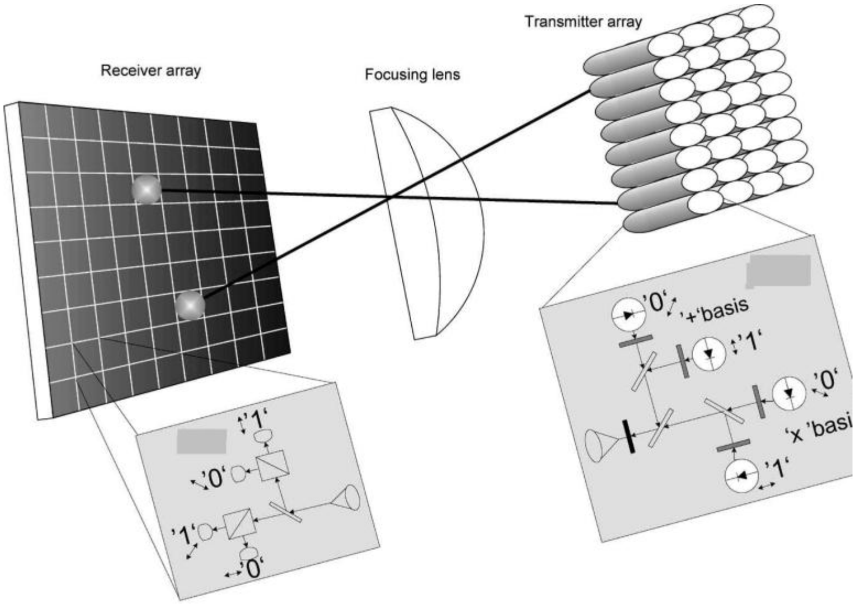


Figure: photo detector

For a ***PIN diode, a photo detector current I_p,*** will be generated based o

$$I_p = \Re P_{rx} = \Re P_{tx} L_{tx} G_{tx} L_p L_R G_{rx} L_{rx}$$

… … …. …**(1)Equn**

Where, ***R*** is responsivity of PIN diode, ***P_{rx}*** is received power, ***P_{tx}*** is transmit power, ***L_{tx}*** is transmit optics efficiency, ***G_{tx}*** is transmit gain, ***L_p*** is pointing loss, ***L_R*** is range loss, ***G_{rx}*** is receive gain and ***L_{rx}*** is receive optics efficiency. Assuming accurate beam pointing, values of these parameters are fixed except the range loss, which depends on the distance.

Considering signal shot noise, dark current shot noise and thermal noise in the detection Process, noise current ***i_{noise}***, is given by

$$i_{noise} = \sqrt{\left[2q\left(i_p + i_{dark}\right)B\right] + \left[\frac{4kTB}{R_{eq}}\right]}$$ ……………..**(2)Equn**

Where ***idark*** is dark current*,* ***ishot*** is shot noise current; ***ithermal*** is thermal noise current,

B is signal bandwidth or data rate, ***k*** is Boltzmann constant, ***T*** is temperature and ***Req*** is the equivalent resistance.

$$\Delta f = \frac{1}{2\pi C_t R_{eq}}$$ ………………**(3) Equn**

Equn(3) gives the frequency response, **Δ*f***, of a PIN diode ***Ct*** is the terminal capacitance of the PIN. Thus, for any wideband operating PIN, the required low ***Req*** will cause high thermal noise and therefore thermal noise is the dominating noise source

And for, AWGN calculation we use; $AWGN = \sigma^2_{thermal} + \sigma^2_{shot}$ **……….(4)Equn**

$\sigma^2_{thermal} = \frac{4KTB}{Rl}$; $\sigma^2_{shot} = 2eBIs$

Chapter 3

Theoretical Unconditional Bit Error Rate

&

Signal to Noise Ratio Analysis

3.1 Theoretical Unconditional Bit Error Rate (BER) & Signal to Noise Ratio(SNR).

We calculate Theoretical unconditional Bit error rate (BER).so first we calculate BER for different Condition and then we multiply it to the probability function as we need to find out -unconditional bit error rate(BER). So I took lognormal distribution function to find out the probability.

The lognormal amplitude can be statistically described by a Gaussian distribution or lognormal distribution.

Before that we background theoretical explanation on BER and SNR

3.2 Bit Error Rate (BER)

Standard transmission-error rate of a media such as copper wire, coaxial cable, or fiber-optic cable. Used as a measure of transmission quality, it is the ratio of error-bits received to the total bits sent. BER is expressed usually as a negative power of ten.

In telecommunication transmission, the bit error rate (BER) is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power. The BER is an indication of how often a packet or other data unit has to be retransmitted because of an error. Too high a BER may indicate that a slower data rate would actually improve overall transmission time for a given amount of transmitted data since the BER might be reduced, lowering the number of packets that had to be resent.

Bit Error Rates in FSO links

Bit-Error-Rate (BER) depends on average received power, the scintillation over the aperture, and the receiver noise .It also depends strongly on the decision level setting in the receiver. The atmosphere fluctuates relatively slowly; in fact, there is not much fluctuation on time scales below about 1ms. Consequently, at high data rates, large numbers of bits are transmitted through a channel that is in a frozen state, but for successive groups of bits the characteristics of the channel slowly change. Consequently, the BER is constantly changing due to such fluctuations caused by atmospheric turbulence.

In the absence of turbulence, the BER can be calculated by assuming the errors result from receiver noise. This can be determined from the shot and Thermal noise originating in the receiver. In the presence of turbulence, there is an additional dominating factor that needs to be added to the noise in the BER calculations originating from the intensity fluctuations caused by turbulence. Such fluctuations are only apparent for a received “one”, since a received “zero” Implies no received signal. By averaging over the appropriate intensity distribution function, and using the function describing the probability of making an error in detecting a “one”, an average BER can be calculated for different log intensity variances. There are several techniques for detecting the signal, which ordinarily rely on a threshold device of some kind. Only when the output of the detector exceeds the set threshold value do we say a signal is present. False alarms occur when the noise alone exceeds the threshold value and is interpreted as the presence of a signal. On the other hand, if the signal plus noise does not exceed the threshold, it is called missed detection. Threshold detection concepts are illustrated in Figure 2.5 [7]

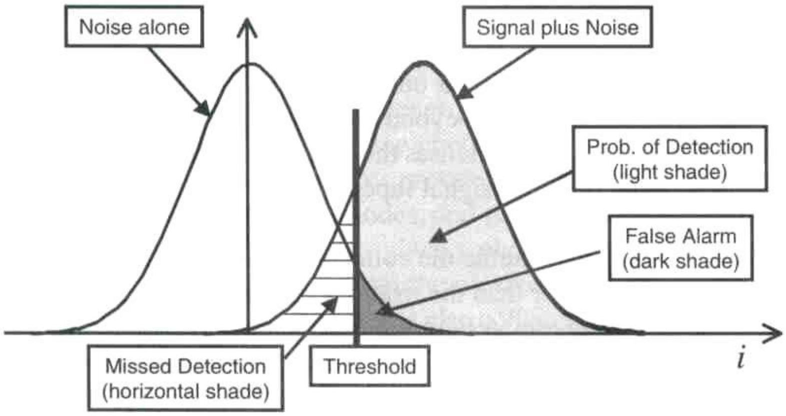


Figure: Probability of detection and false alarm.

In on-off keyed (OOK) systems, the probability distributions of either noise alone or signal plus noise is assumed to be Gaussian. Thus, if the threshold level is set at half the average signal level *.l/2.*, then a “one” error results if the signal *l/2l*plus detector noise is less than (2^I/2I+iN <I which means iN <-I/2)

A “zero” error results if the detector noise is greater than (2). Hence, the overall probability of error is,

$$BER = \frac{1}{2}\left(p_{one} + p_{zero}\right)$$
$$= \frac{1}{2}\left[P\left(i_N < -I/2\right) + P\left(i_N > I/2\right)\right].$$

………….(**5)Equn**

The BER can be written as,

$$BER = \frac{1}{2\sigma\sqrt{2\pi}}\left(\int_{-\infty}^{-I/2} e^{-x^2/2\sigma^2}\,dx + \int_{I/2}^{\infty} e^{-x^2/2\sigma^2}\,dx\right)$$
$$= \frac{1}{2}\left[\frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{S}{N}}\right) + \frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{S}{N}}\right)\right]$$
$$= \frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{S}{N}}\right).$$

…………………**(6)Equn**

3.3.1 Signal to Noise Ratio (SNR)

SNR is short for signal-to-noise ratio, the ratio of the amplitude of a desired analog or digital data signal to the amplitude of noise in a transmission channel at a specific point in time. SNR is typically expressed in logarithmic decibel (db).

SNR measures the quality of a transmission channel or an audio signal over a network channel. A SNR of zero indicates that the desired signal is virtually indistinguishable from the unwanted noise.

The ratio of the power or volume (amplitude) of a signal to the amount of disturbance (the noise) mixed in with it. Measured in decibels, signal-to-noise ratio (SNR or S/N) measures the clarity of the signal in a circuit or a wired or wireless transmission channel. The greater the ratio, evidenced by a larger number, the less noise and the more easily it can be filtered out. The lowest number is an SNR of 0, which means that noise and signal levels are the same. Although signals contain non-random intelligence and can be isolated and separated, with a 0 SNR, it would be extremely difficult to isolate the signal in real time. It would be more easily accomplished offline. The quantity that measures the relationship between the strength of an information-carrying signal in an electrical communications system and the random fluctuations in amplitude, phase, and frequency superimposed on that signal and collectively referred to as noise. For analog signals, the ratio, denoted S/N, is usually stated in terms of the relative amounts of electrical power contained in the signal and noise. For digital signals the ratio is defined as the amount of energy in the signal per bit of information carried by the signal, relative to the amount of noise power per hertz of signal bandwidth (the noise power spectral density), and is denoted E_b/N_0. Since both signal and noise fluctuate randomly with time, S/N and E_b/N_0 are specified in terms of statistical or time averages of these quantities. The magnitude of the signal-to-noise ratio in a communications systems is an important factor in how well a receiver can recover the information-carrying signal from its corrupted version and hence how reliably information can be communicated. Generally speaking, for a given value of S/N the performance depends on how the information quantities are encoded into the signal parameters and on the method of recovering them from the received signal. The more complex encoding methods such as phase-shift keying or quadrature amplitude-shift keying usually result in better performance than simpler schemes such as amplitude- or frequency-shift keying.

3.3.2 Signal-to-Noise Ratio(SNR) in Direct Detection Receiver

The simplest implementation of an optical receiver is a power-detecting receiver, also called a non-coherent or direct detection receiver. Because it responds only to the instantaneous power of the collected field, a direct detection receiver does not use the transverse spatial coherence of the transmitted optical field. In a typical model of a direct detecting FSO system, the information is intensity modulated onto an optical source and transmitted through an atmospheric channel to the receiver. The receiving lens collects a portion of the received optical field and focuses it onto a photo detector.

The optical field is always photo detected in the presence of various noise sources present in the optical detection process. In FSO systems, background radiation such as natural light, is also collected along with the transmitted optical field and is usually treated as an additive noise to the desired signal field. Another source of noise is the shot noise originating in the photo detection process and dark current at the photo detector itself. Lastly, the Johnson noise is also present in the electronic circuitry following the photo detection process. Fig **** shows the typical model for a direct detection system.

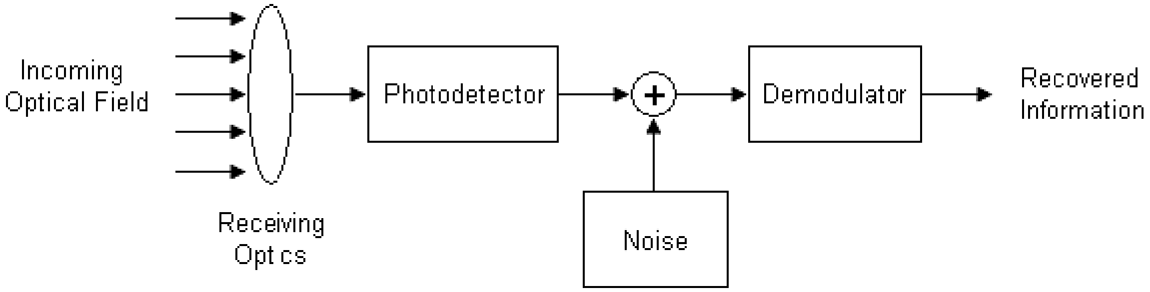


Figure: Block diagram of direct detection optical receiver**.**

Recall that free space propagation of a laser beam can be modeled using a Gaussian beam with intensity profile described in Eq. (7) If the receiver has an aperture diameter ***D*** then received signal power ***P_R*** at the photo detector is

$$P_R = \int_0^{2\pi}\int_0^{\infty} I(r,L)\,r\,dr\,d\theta \cong \frac{\pi D^2}{8} I(0,L)$$

............(7)Equen

PIN photo detector is used, the output signal current induced by the incident optical wave is

$$i_S = \Re P_R$$

…………………(8)Euen

Where ***R*** is the photo detectors responsivity, Let the detector be followed by a filter of bandwidth **Δ*f*** , where the bandwidth is chosen to match the frequency spread of the incoming signal envelope. If all noise sources have zero mean and are statistically independent of each other, then the total noise power in the detector current $\boldsymbol{\sigma^2_N}$ is defined by

$$\sigma^2{}_N = 2q(i_S + i_D + i_B)\Delta f + \frac{4kT\Delta f}{R}$$

………….**(9)Equen**

Where $\boldsymbol{i_D}$ and $\boldsymbol{i_B}$ are the photo detector dark current and background illumination induced currents.

To quantify the performance of a direct detection receiver, the output signal-to-noise ratio (SNR) is defined as the ratio of the detector signal power to the total noise power. In practice, the received power is typically large enough such that the signal current dominates over the dark current and background illumination noise. Therefore, the remaining noise terms are typically caused by shot noise and Johnson noise,

Which gives a **SNR expression for direct detection as** $\boldsymbol{\Gamma_{0,DD}}$

$$\Gamma_{0,DD} = \frac{i^2{}_S}{\sigma^2{}_N} = \frac{i^2{}_S}{2qi_s\Delta f + 4kT\Delta f / R}$$

………………….**(10)Equen**

If the shot noise dominates over the Johnson noise, then the resulting

Shot noise limited SNR $\boldsymbol{\Gamma_{0,DD-SNL}}$ is given by

$$\Gamma_{0,DD-SNL} = \frac{i_S}{2q\Delta f} = \frac{\eta P_R}{2hv\Delta f}$$

……………………….**(11)Equen**

3.4.1 Definition lognormal probability density function

The lognormal probability density function (pdf) is

$$y = f(x \mid \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{-(\ln x - \mu)^2}{2\sigma^2}}$$

……………………**(12)Equen**

The normal and lognormal distributions are closely related. If *X* is distributed lognormally with parameters *μ* and *σ*, then log(*X*) is distributed normally with mean *μ* and standard deviation *σ*. The mean *m* and variance *v* of a lognormal random variable are functions of *μ* and *σ* that can be calculated with the lognstat function. They are:

$$m = \exp\left(\mu + \sigma^2 / 2\right)$$

$$v = \exp\left(2\mu + \sigma^2\right)\left(\exp\left(\sigma^2\right) - 1\right)$$

A lognormal distribution with mean *m* and variance *v* has parameters

$$\mu = \log\left(m^2 / \sqrt{v + m^2}\right)$$

$$\sigma = \sqrt{\log\left(v / m^2 + 1\right)}$$

The lognormal distribution is applicable when the quantity of interest must be positive, since log(*X*) exists only when *X* is positive.

As a result of the Rytov method, for weak turbulence of the irradiance, fluctuation of a propagating beam can be described by a lognormal distribution. Therefore, one can derive that the irradiance probability density function (PDF) is given by the following equation ………*(1)*

$$p_{\mathrm{I}}(I) = \frac{1}{\sqrt{2\pi} I \sigma_{\mathrm{I}}} \exp\left\{ -\frac{\left[\ln\left(I/\langle I\rangle\right) + \frac{1}{2}\sigma_{\mathrm{I}}^2\right]^2}{2\sigma_{\mathrm{I}}^2} \right\},$$

…………………………**(13)Equen**

Where *(I)* is the average irradiance

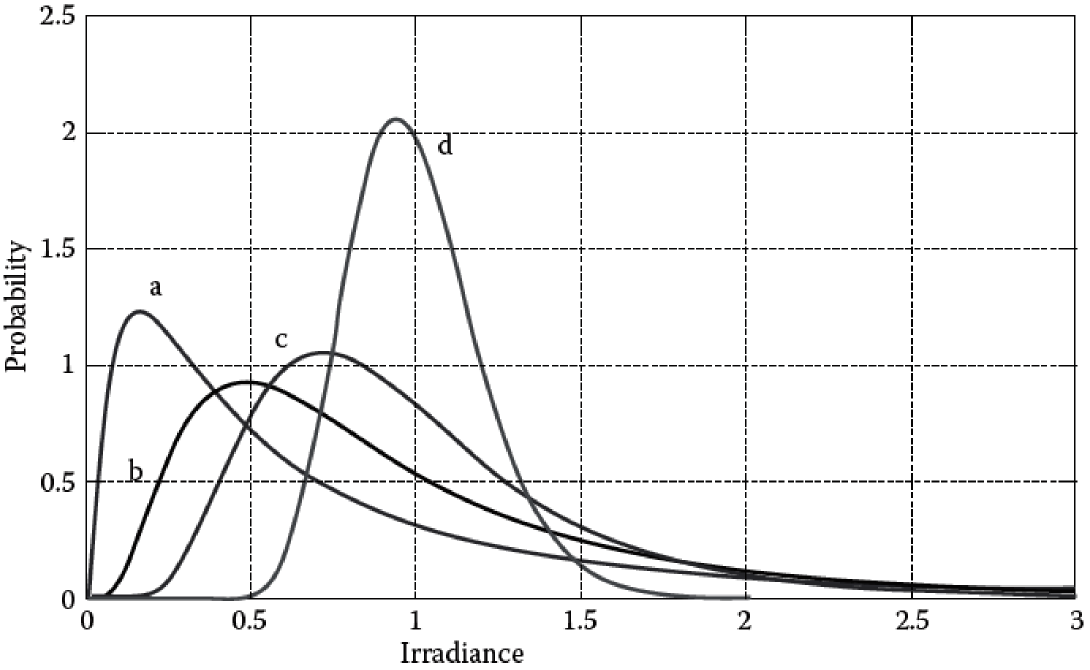


FIGURE Irradiance PDF for a weak turbulence for different values of variance of the lognormal field amplitude: (a) $\sigma_\chi^2 = 0.2$; (b) $\sigma_\chi^2 = 0.1$; (c) $\sigma_\chi^2 = 0.05$; and (d) $\sigma_\chi^2 = 0.025$. The average irradiance here is $\langle I \rangle = 1$ in arbitrary unit.

3.4.2 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 *Cn²* of the channel. The log-normal distribution is generally used to model the fading associated with the weak atmospheric turbulence regime .This model is mathematically tractable and it is characterized by the Ryotov variance *σl²* The turbulence induced fading is termed weak when 2 . 1 2 ⍰*σl²* and this defines the limit of validity of the log-normal model. Beyond the weak turbulence regime, other models such as the gamma-gamma and the negative exponential will have to be considered. The Ryotov variance *σl²* can be calculated as

$$\sigma_l^2 = 1.23 C_n^2 \left(\sqrt[6]{k^7 L^{11}}\right);$$ ……………..**(14)Equen**

We use the value of *.1<σl² <.9w*

Cn² ≤ 10^-14 weak turbulence

$Cn^2 \geq$ 10^-14 strong turbulence

K=2Π/λ

L=Distance between Tx & Rx

The log-normal models assumes the log intensity *I* of the laser light traversing the turbulent atmosphere to be normally distributed with a mean value of – *$\sigma l^2/2$.*Thus, the probability density function of the received irradiance is given by following equation

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

………………**(15)Equen**

Where *I* represents the irradiance at the receiver and *Io* 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. Their error performance will be similar and we will therefore be presenting results for one of them only.

3.4.3 The theoretical unconditional BER is obtained as:

$$P_e = \int_0^\infty P_{ec}\,p(I)\,dI$$

$$= \int_0^\infty Q\left(\sqrt{\gamma(I)}\right)\frac{1}{I\sqrt{2\pi\sigma_l^2}}\exp\left\{-\frac{\left[\ln I/I_0+\sigma_l^2/2\right]^2}{2\sigma_l^2}\right\}dI$$

…………………….(**16)Equen**

We use the value of $.1<\sigma l^2<.9$

$Q(\sqrt{\gamma(I)})$=0.5erfc {$\sqrt{SNR}$ /2}*I

We use PIN photo detector

We also calculate BER, SNR for different condition using these formula and parameters and we plot it under different condition.

SNR=$(Rd*Ps)^2$/{2eBIs + (4KTB)/R*l*} for PIN photo detector……………(17)Equen

BER= .5*erfc [Is/2√2*σn*]=.05erfc{$\sqrt{SNR}$ /2√2}………………………(18)Equen

Received average signal current =$(Rd*Ps)^2$

Shot noise= 2eBIs

Thermal noise =(4KTB)/R*l*

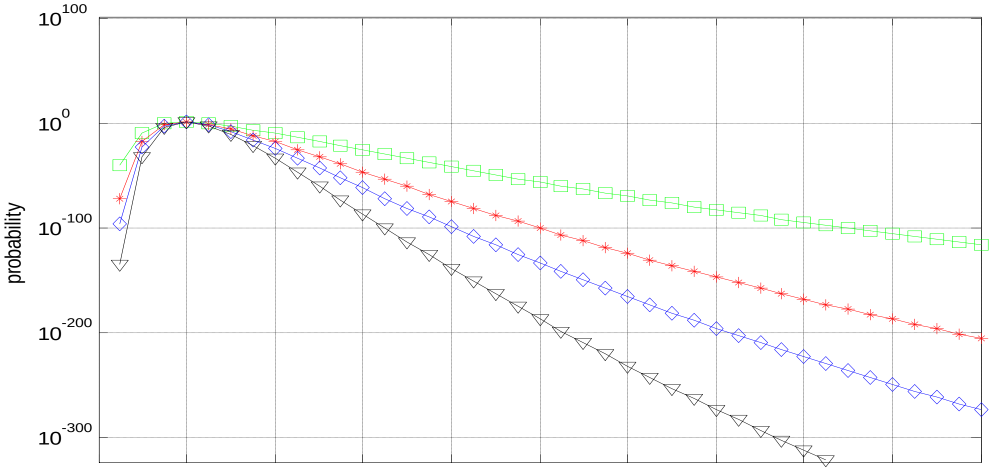
Rd=Responsivity of photo detector

Ps= signal power

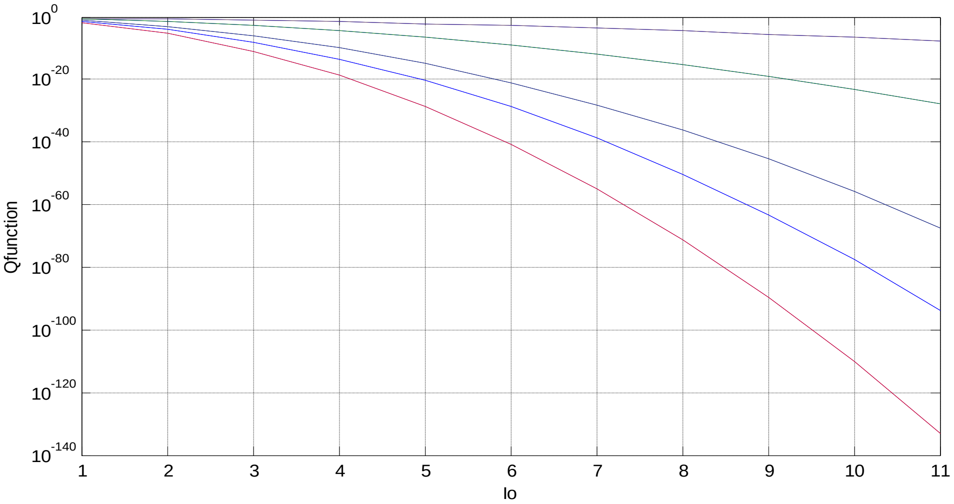
B=band width

T=temperature (◦k)

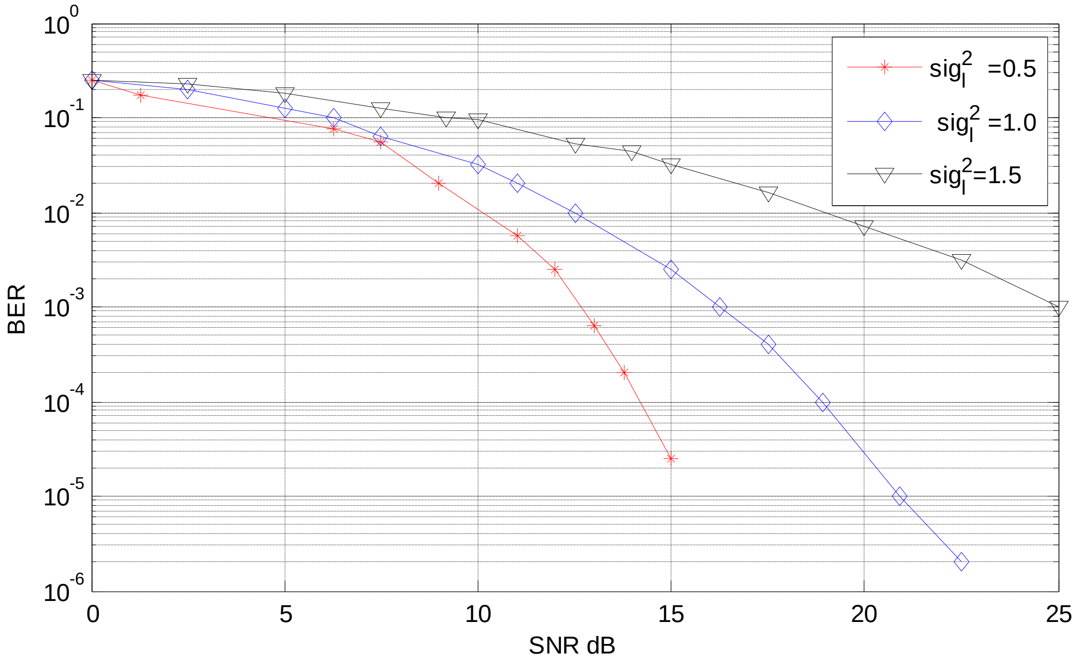
R*l*= load resistance



Graph (1): Irradiance vs probability

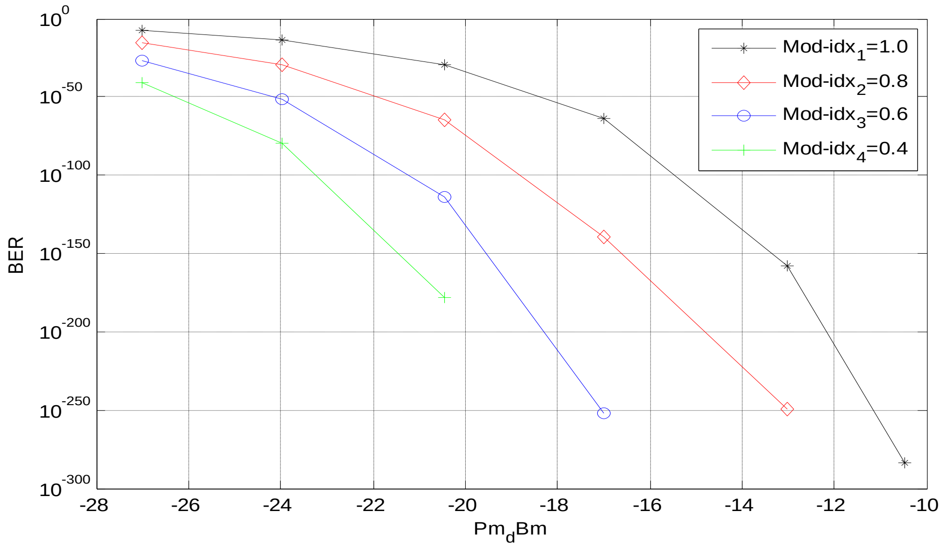


Graph (2): Irradiance (Io) vs Q_function



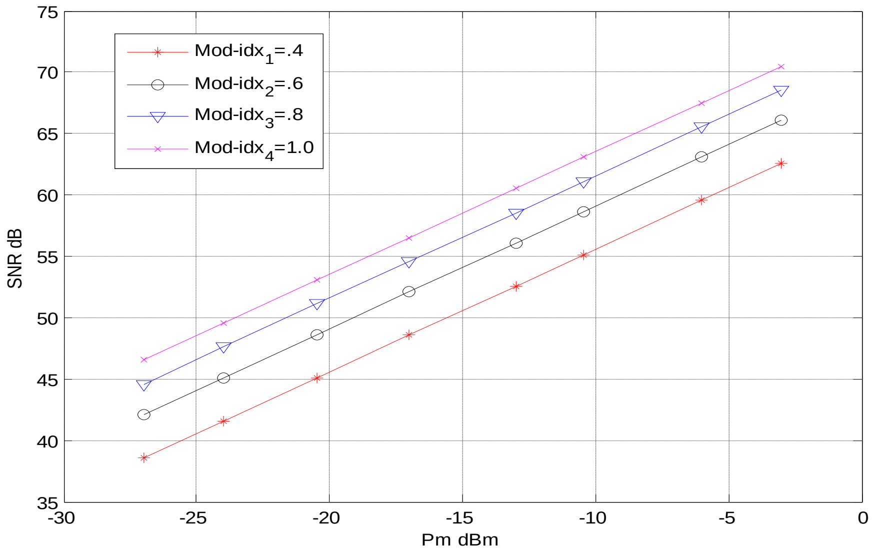
Graph (3): SNR dB vs BER when $\sigma l^2=0.5$; $\sigma l^2=1.0$;$\sigma l^2=1.5$

Now we Subtract $\boldsymbol{\gamma(l)} = \frac{(Rd*Ps)^2\ \xi^2*Pm}{\sigma^2 n}$ into (16)Equen Where $\boldsymbol{\xi}$ = Modulation Index ; P_m=subcarrier power. Then we plot Subcarrier vs Bit error rate



Graph (4): Subcarrier (Pm_dBm) Vs Bit error rate (BER)

For different modulation index the curves are shifted where we vary Subcarrier power.



Graph (5): Subcarrier power (Pm_dBm) Vs SNR (dB)

Here we also vary the modulation index and subcarrier power. These two experimental curve shows if modulation index has been changed, then to obtain proper SNR or BER we have to vary (Increase) the subcarrier power.

Chapter 4

Degradation in System Performance Due to Channel Effect
&
Improvement in Receiver Sensitivity

4.1 Degradation in System Performance and due to Channel effect and Improvement in Receiver Sensitivity

4.1.1 Fading:

When the delay differences among various distinct propagation paths are very small compared with the symbol interval in digital transmission, the multipath components are almost indistinguishable at the receiver. Those multipath components can add constructively or destructively, depending on the carrier frequency and delay differences. As the mobile station moves, the position of each scattered with respect to the transmitter and receiver may change. The overall effect is that the received signal level fluctuates with time, a phenomenon called fading.

4.1.2 Rayleigh Fading: (NLOS Propagation)

Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver.
Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables. It is the specialized model for fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalized concept of Rician fading. In probability theory and statistics, the Raleigh Distribution is a continuous probability distribution. It usually arises when a two –dimensional vector has its two orthogonal components normally and independently distributed the absolute value will then have a Rayleigh Distribution. The Rayleigh Distribution also may arise in the case of random complex numbers whose real and imaginary components are normally and independently distributed. The absolute value of these numbers will then be Rayleigh Distributed.
In this case,

$E[Z_c(t)] = E[Z_s(t)] = 0$ Assume, at any time t, for n=1,2,….,n

The values of $\theta_n(t)$ are statistically independent, each being uniformly distributed over $[0,2\pi]$

The values of $\alpha_n(t)$ are identically distributed random variables , independent of each other and of the $\theta_n(t)$'s.

As K approaches to infinity (∞), the Rayleigh distribution approaches to Rician distribution. i.e.

NLOS → LOS (no fading)

As a result, wireless channel approaches an AWGN (Additive White Gaussian Noise) channel

4.2.1Diversity in Wireless Communication:

To combat multipath fading diversity is an efficient way.

4.2.2 Why Diversity

Diversity improves transmission performance by making use of more than one independently faded version of the transmitted signal. If several replicas of the signal, carrying the same information, are received over multiple channels the chances that all the independently faded signal components experience deep fading simultaneously are greatly reduced. That will significantly improve transmission accuracy as transmission errors are most likely to happen when SNR (signal to noise ratio) is low during deep fading period. So diversity is a common used technique in wireless system to combat channel fading.

4.2.3Types of Diversity:

The following sections describe the various ways of obtaining independently faded signals:

4.2.3.1 Frequency Diversity:

The desired message is transmitted simultaneously over several frequency slots. The separation between adjacent frequency slots should be larger than the channel coherence bandwidth such that channel fading over each slot is independent of that in any other slot. By using redundant signal transmission, this diversity improves link transmission quality at the cost of extra frequency bandwidth.

4.2.3.2Time Diversity:

The desired message is transmitted repeatedly over several time periods. The time separation between adjacent transmissions should be larger than the channel coherence time such that the channel fading experienced by each transmission is independent of the channel fading experienced by all of the other transmission. In addition to extra system capacity (in terms of transmission time) due to the redundant transmission, this diversity introduces a significant signal processing delay, especially when the channel coherence time is large. In practice, time diversity is more frequently exploited through interleaving, forward-error correction, and automatic retransmission request (ARQ).

4.2.3.3 Space diversity:

The desired message is transmitted by using multiple transmitting antennas and receiving antennas. The space separation between adjacent antennas should be large enough to ensure that the signals from different antennas are independently faded. In a Rayleigh fading environment, it can be shown that, if two antennas are separated by half of the carrier wavelength, the corresponding two signals experience independent fading. Taking into account the shadowing effect, usually a separation of at least 10 carrier wavelengths is required between two adjacent antennas. This diversity does not require extra system capacity; however, the cost is the extra antennas needed.

4.2.3.4 Angle Diversity:

The desired message is received simultaneously bt several directive antennas pointing in widely different directions. The received signals consist of waves coming from all directions. It has been observed that the scattered signals associated with the different (non overlapping) directions are uncorrelated. Angle diversity can be viewed as a special case of space diversity since it also requires multiple antennas.

4.2.3.5 Path Diversity:

In CDMA cellular networks, the use of direct sequence spread spectrum modulation techniques permits the desired signal to be transmitted over a frequency bandwidth much larger than the channel coherence bandwidth. The spread spectrum signal can resolve multipath signal components as long as the path delays are separated by at least one cheap period. A rake receiver can separate the received signal components from different propagation paths by using code correlation and can then combine the signal components constructively. In CDMA, exploiting the path diversity reduces the transmitted power needed and increases the system capacity.

4.2.3.6 Polarization Diversity:

The horizontal and vertical polarization components transmitted by two polarized antennas at the base station and received by two polarized antennas at the mobile station can provide two uncorrelated fading signals. Polarization diversity results in 3dB power reduction at the transmitting site since the power must be split into two different polarized antennas.

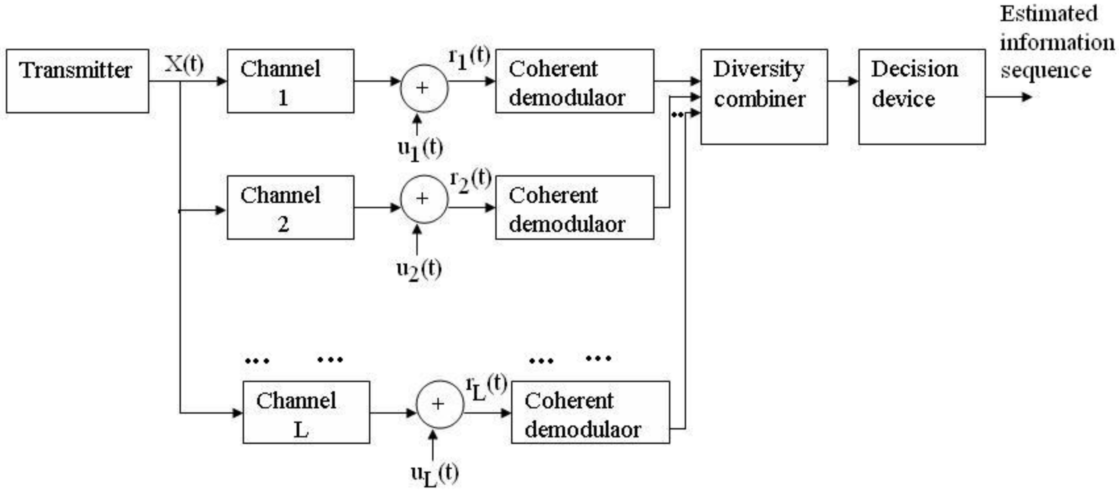


Figure: Illustration of diversity with coherent demodulator

Figure: diversity with coherent demodulator

4.3. Different types of Linear Combining:

4.3.1 Maximal ratio combining:

In this combining technique the receiver is able to accurately estimate the amplitude fading and carrier phase distortion for each diversity channel .with the complex channel gains ,the receiver coherently demodulates the received signal from each branch .The phase distortion is removed from the L-th branch by multiplying the signal component with complex term. The coherently detected signal is then weighted by the corresponding amplitude gain .The weighted received signals from all the L branches are then summed together and applied to the decision device .Maximal ratio combining achieves the best performance.

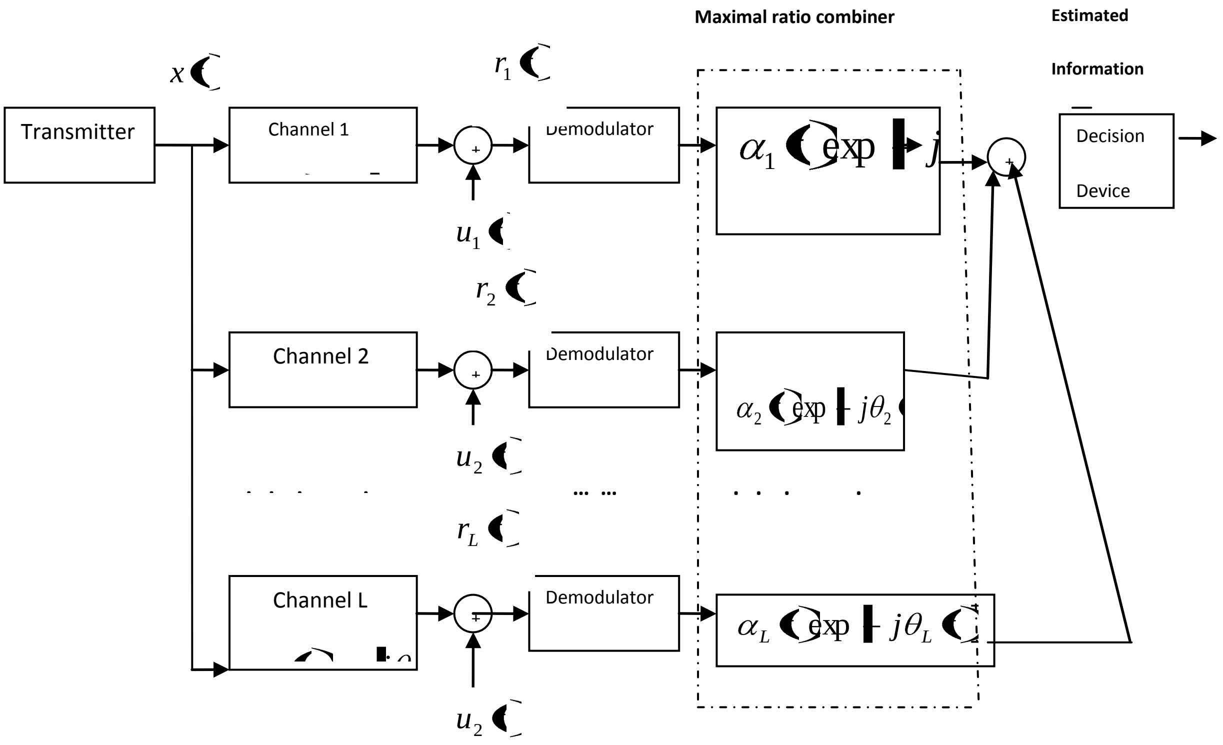


Figure: Diversity reception with Maximal Ratio Combining

4.3.2 Equal-Gain Combining:

The maximal ratio combining approach an accurate estimate of the channel amplitude gain .Which increases the receiver complexity .An alternative approach is to weight all the signals equally after coherent detection ,which removes the phase distortion .the coherently detected signals from all the L branches are simply added and applied to the decision device .As the receiver does not need to estimate the amplitude fading ,its complexity is reduced as compared with that of maximal ratio combining.

4.3.3 Selective Combining:

In this scheme, the receiver monitors the SNR value of each diversity channel and chooses the one with the maximum SNR value for signal detection .Compared with the preceding two schemes, selective diversity is much easier to implement without much performance degradation, especially located in different base stations, which would make it difficult to use maximal ratio combining or equal gain combining.

4.3.4 Why we used Maximal Ratio Combining?

Among the three combining schemes, selective combining is easier to implement without much performance degradation. But Maximal Ratio Combining achieves the best performance.

4.4 Antenna diversity

- Antenna diversity techniques are commonly utilized at the base stations due to less constraint on both antenna space and power. In addition, it is more economical to add more complex equipment to the base stations rather than at the remote units.
- To increase the quality of the transmission and reduce multipath fading at the remote unit, it would be beneficial if space diversity also could be utilized at the remote units.
- In 1998, S. M. Alamouti published a paper entitled “A simple transmit diversity technique for wireless communications”. This paper showed that it was possible to generate the same diversity order traditionally obtained with SIMO system with a Multiple-Input Single-Output (MISO) system.

4.4.1 Diversity and Combining Techniques of System:

A system is characterized by how it responds to input signals. In general, a system has one or more input signals and one or more output signals. Therefore, one natural characterization of systems is by how many inputs and outputs they have:

- SISO (Single Input, Single Output)
- SIMO (Single Input, Multiple Outputs)
- MISO (Multiple Inputs, Single Output)
- MIMO (Multiple Inputs, Multiple Outputs)

It is often useful (or necessary) to break up a system into smaller pieces for analysis. Therefore, we can regard a SIMO system as multiple SISO systems (one for each output), and similarly for a MIMO system. By far, the greatest amount of work in system analysis has been with SISO systems, although many parts inside SISO systems have multiple inputs (such as adders).

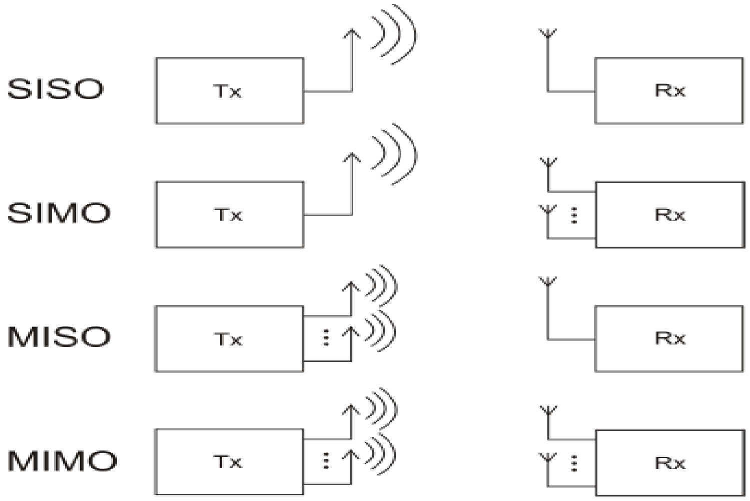


Figure: Diversity and Combining Techniques of System

4.4.2 SISO (Single Input & Single Output) :

SISO is an acronym for single-input and single-output system. Single Input Single Output is a form of antenna technology for wireless communications in which a single antenna at both the transmitter and at the destination(receiver) are used.

4.4.3 SIMO: Single Input Multiple Output

Single Input Multiple Output (SIMO) is a form of smart antenna technology for wireless communications in which a single antenna at the transmitter and multiple antennas are used at the destination (receiver). An early form of SIMO, known as diversity reception, has been used by military, commercial, amateur, and shortwave radio operators at frequencies below 30 MHz since the First World War.

4.4.4 MISO: Multiple Input Single Outputs

Multiple Input & Single Output (MISO) is a smart antenna technology that uses multiple transmitters and a single receiver on a wireless device to improve the transmission distance. MISO technology can be applied in areas such as Digital TeleVision (DTV), Wireless Local Area Networks (WLANs), Metropolitan Area Networks (MANs), and mobile communications. The implementation of MISO would include multiple antennas at the source, or transmitter, and the destination, or receiver, has only one antenna -- the antennas are combined to minimize errors and optimize data speed

4.4.5 MIMO (multiple-input and multiple-output):

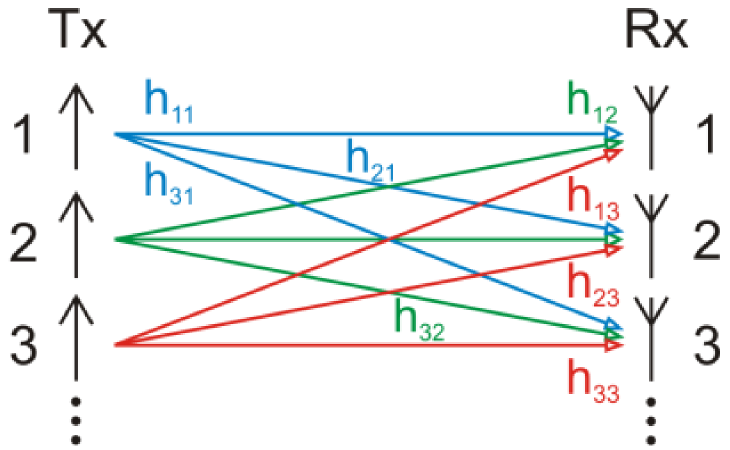


Figure: MIMO

A technique for increasing wireless bandwidth by spatial antenna diversity, MIMO is incorporated into IEEE 802.11n specifications for wireless LAN (WLAN) and 802.16 specifications for broadband wireless access (BWA), more commonly known as WiMAX. As radio signals travel from transmitter to receiver in an enclosed space, they propagate along multiple paths. The signal elements traveling a direct path along a line of sight (LOS) arrive first and strongest. Those that travel the least direct paths, having reflected off walls, floors, ceiling, potted plants, people, and other obstructions, not only arrive last, but also suffer the greatest attenuation due to absorption, diffusion, and other contributing factors. MIMO technology employs multiple spatially diverse transmit antennas to actually encourage the signals to traverse multiple paths and multiple receive antennas to extract additional information from the signals that do so. MIMO algorithms in the receive device correlate and recombine the signals, realizing diversity gain, i.e., an increase in signal strength, in the process. MIMO technology doubles the spectral efficiency. The 802.11n MIMO technology, for example, is expected to yield a theoretical maximum signaling rate of 108 Mbps, compared to the 54 Mbps yielded by the earlier 802.11g technology.

From the fig.** MIMO we can see that, In MIMO systems, a transmitter sends multiple streams by multiple transmit antennas. The transmit streams go through a matrix channel which consists of multiple paths between multiple transmit antennas at the transmitter and multiple receive antennas at the receiver. Then, the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information.

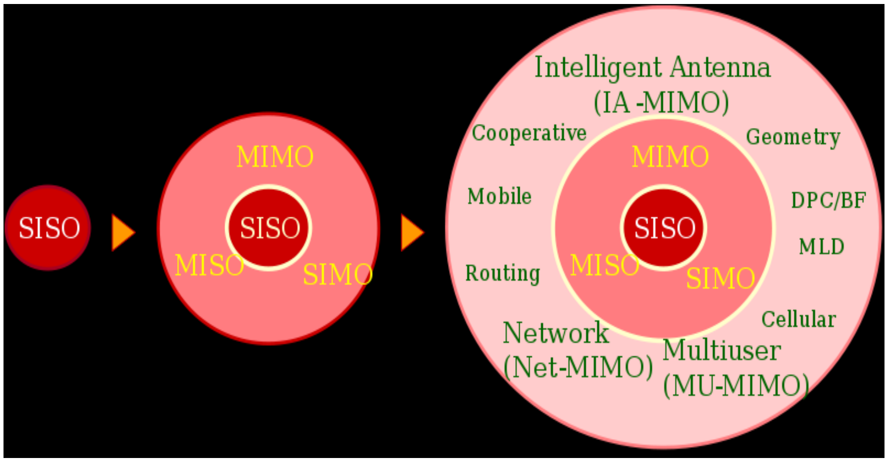


Figure: from SISO to advanced MIMO system

4.5.1 Performance improvement using maximum ratio combining:

Consider the transmission of a digital modulated signal x(t) over flat slow Rayleigh fading channel using coherent demodulation with the L order diversity.

The receiving signal component from the L th diversity channel is

$$\mathbf{r_L(t)= \alpha_L(t)} e^{[j\theta L(t)]x(t)} \mathbf{+u_L(t) \quad L=1,2,3.....} \quad \text{..........................(19)Equen}$$

It is assumed that

(a) The channel fading process is mutually statically independent

(b) The AWGN process is mutually statically independent

(c) The channel fading process and additive noise process are independent of each other.

For a slow fading channel, the complex channel gain can be assumed to be a complex constant over each symbol interval. The demodulator of each channel is optimum for an AWGN channel. There for the output of the demodulator of the Lth branch at the end of the Kth symbol interval is $\boldsymbol{\alpha_{Lk}\exp(j\theta Lk)xk + n_{Lk}}$ **......................................(20)Equen**

Where, $\boldsymbol{\alpha_{Lk}\exp(j\theta_{Lk})}$ is the complex channel gain of the Lth channel over the Kth symbol interval. Xk is the vector representation of the transmitted signal over the Kth symbol interval in the N dimensional signal space and is also the demodulator output for an AWGN channel;

And n_{Lk}=($n_{Lk}1$, $n_{Lk}2$, $n_{Lk}3$...........)

Is the corresponding vector representation of the noise component at the demodulator output due to the $U_{Lk}(t)$.

It can be easily shown that **ll Xk ll²=Es** (Es is the symbol of energy). And the each component in n_{Lk} is a Gaussian random variable with zero mean and the variance $N_0/2$ that is independent of any other noise component in the same diversity channel or different channel diversity.

Consider maximum ratio combining (MRC).

The decision variable for the Kth transmitted symbol be represented by

$$\mathbf{r_k}=\sum_{l=1}^{L}[\boldsymbol{\alpha lk\ exp-(-j\theta k)}][\boldsymbol{\alpha lkexp(j\theta lk)\vec{X}k+\vec{n}lk}]$$

$$=[\sum_{l=1}^{L}[\boldsymbol{\alpha^2 lk}]\boldsymbol{\vec{X}k}] + \quad [\sum_{l=1}^{L}\boldsymbol{\alpha lkexp(-j\theta k)\vec{n}lk}]$$

$$=\vec{\mathbf{g}}_{\mathbf{k}}\ \mathbf{Xk} + \vec{\mathbf{n}}_{\mathbf{k}} \quad \text{.......................................(21)Equen}$$

Where **$\vec{g}k = \sum_{l=1}^{L}[\alpha^2 lk]$**

$\vec{n}k = \sum_{l=1}^{L} \alpha lk exp(-j\theta k)\vec{n}lk$

For noise vector **$\vec{n}k$ = [n_{k1}, $n_{k}2$, $n_{k}3$, $n_{k}4$ ………… $n_{k}n$] ;………………(22)Equen**

$nk.n = \sum_{l=1}^{L} \alpha lk\ exp(-j\theta k)\ nlk.n$ n=1,2,3……..N ;………………(23)Equen

Therefore, gives the weighting gain **α_{Lk}(-jθlk); L=1,2,3……l ;………………(24)Equen**

Each noise component nk.n is Gaussian random variable with zero mean variance

$\sigma^2_{k.n} = N0/2\sum_{l=1}^{L} \alpha^2 lk$; ……………………..(25)Equen

For BPSK N=1, the vector $\vec{r}k$, $\vec{x}k$ and $\vec{n}k$ can represented by the corresponding scalar variable rk, Xk and nk, respectively.

The decision variable for the kth transmitted symbol is

$r_k = gkXk + nk$ ……………..……………(26)Equen

Where X_k = **√Eb** for symbol "**1**" & **Xk = -√Eb** for symbol "**0**"

The SNR bit at output of the combiner for the Kth symbol is then

$$\gamma_k = \frac{[gkXk]^2}{2\sigma^2 k.n} = \frac{[\sum_{l=1}^{L}\alpha lk^2 Xk]^2}{No\sum_{l=1}^{L}\alpha^2 lk} = \frac{Eb}{No}\sum_{l=1}^{L}\alpha^2 lk \quad \text{………………(27)Equen}$$

Where E_b/N_o is the SNR value of the AWGN channel with αLk=1 and L=1. In the Rayleigh fading environment, the αLk are Rayleigh random variable with parameter $\sigma^2\alpha$.

Therefore **γ** follows a chi square distribution with 2L degree of the freedom. Its **pdf** is given by

$$f_\gamma(x) = \frac{X^{L-1}\exp(-x/\gamma c)}{(L-1)!\,\gamma_c^L}, \quad X\geq 0 \quad \text{………………(28)Equen}$$

Where **$\gamma c = 2\sigma^2\alpha Eb/No$** is the average SNR per bit in each diversity channel. From (27)Equn the mean SNR per bit after the combining is

$\gamma b = E[\gamma k] = L\gamma_c$

Which is increasing linearly with L.

The analysis of the *probability of bit error over a Rayleigh fading channel* can extended to the case with diversity, so that

$Pb = \int_0^\infty pe\gamma(x)\ f\gamma(x)dx$ ………………(29)Equen

Where $pe\gamma(x)$ is the conditional probability of bit error given that the received SNR per bit is **γ=x.** for coherent BPSK we know,

$pe\gamma(x)$=∫ $Q\sqrt{2x}$ ……………………. (30)Equen

Subtracting (28)Equen & (30)Equen into (29)Equen we will find

P_b = [0.5(1-μ)^L] $\sum_{l=0}^{L-1}$ $(L-l+1_{C\,l})$ **[0.5(1+μ)]^*l*** ……………………(31)Equen

Where, ***μ= √{γc/(1+γc)}*** ………………(32)Equen

and **$\gamma_c = 2\sigma^2\alpha E_b/N_o$**

Now we use **P_b** = **P_{ee}= Q{√(γ(I)}………………(33)Equen**

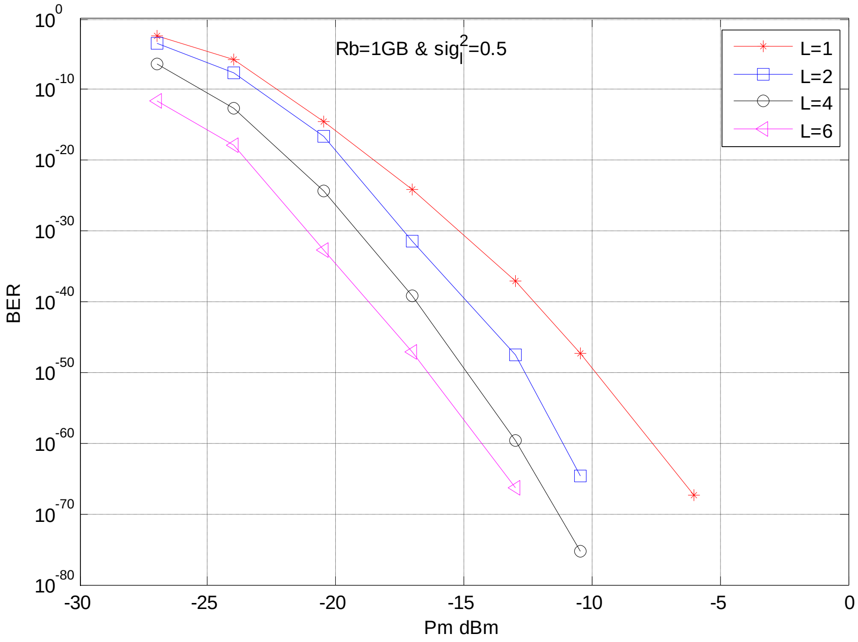
$$P_e = \int_0^\infty P_{ec}\,p(I)\,dI$$

$$= \int_0^\infty Q\left(\sqrt{\gamma(I)}\right)\frac{1}{I\sqrt{2\pi\sigma_l^2}}\exp\left\{-\frac{\left[\ln I/I_0+\sigma_l^2/2\right]^2}{2\sigma_l^2}\right\}dI$$

Then we will get BER as

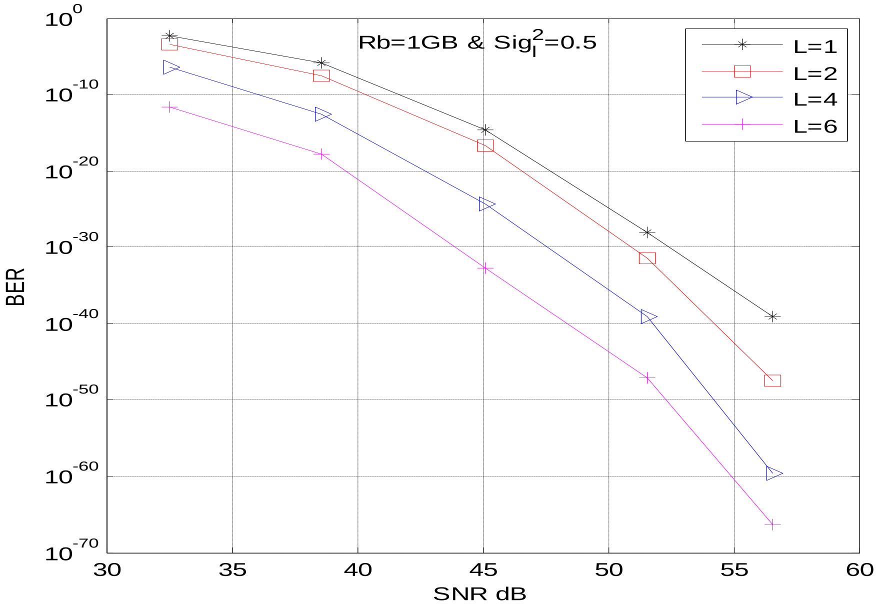
$\int_0^\infty$**[0.5(1 − μ)^L]** $\sum_{l=0}^{L-1}$ $(L-l+1_{C\,l})$ **[0.5(1 + μ)]^l** $\frac{1}{I\sqrt{2\Pi\sigma^2 l}}$ **exp {-**$\frac{[\ln\frac{I}{I_o}+\frac{\sigma^2 l}{2}]^2}{2\sigma^2 2}$**} dl** .

………………(34)Equen

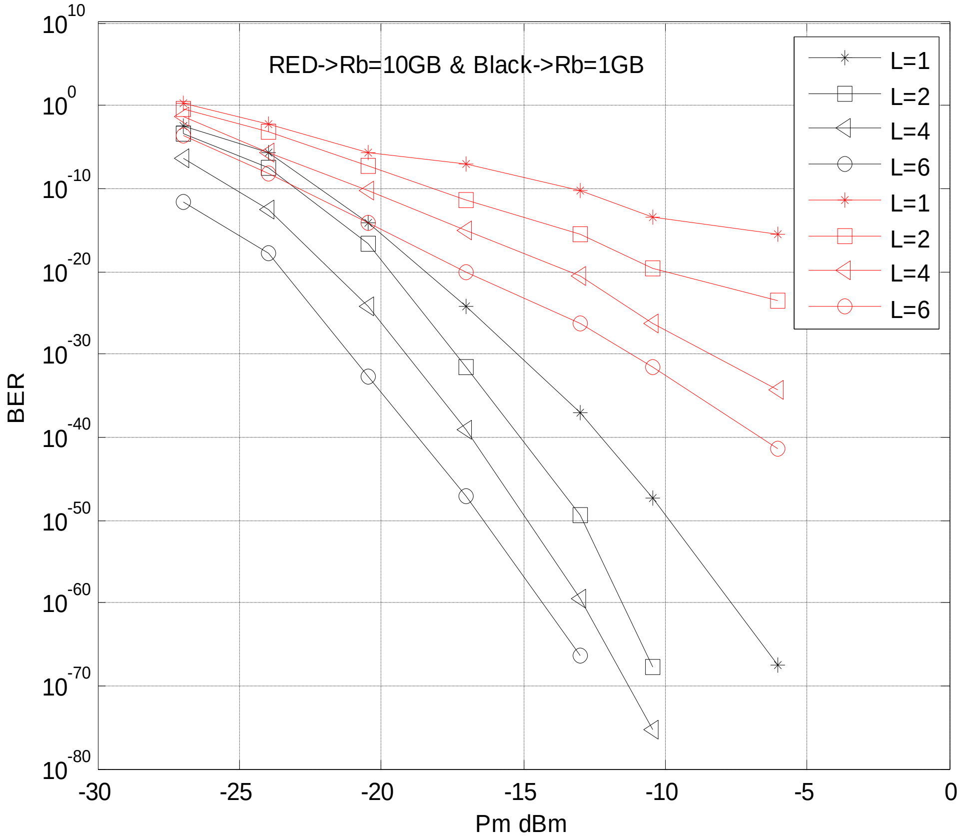


Graph (6): Pm_dBm Vs Ber for different number of antenna (L) when, Rb=1Gb & σl^2=.05

From (34)Equen we use number of antenna 1 to 6 and consecutive other values and we obtain this curve.



Graph (7): SNR_dB vs BER when, Rb=1 GB & σl^2=.05



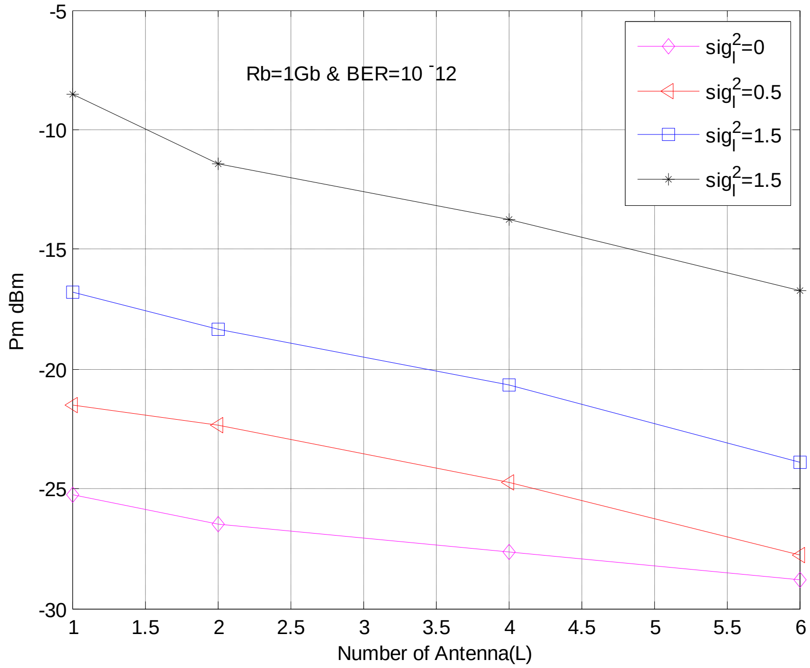
Graph (8): Pm_dBm Vs BER when Rb=1Gb & 10Gb

We got the curve from equation (32).

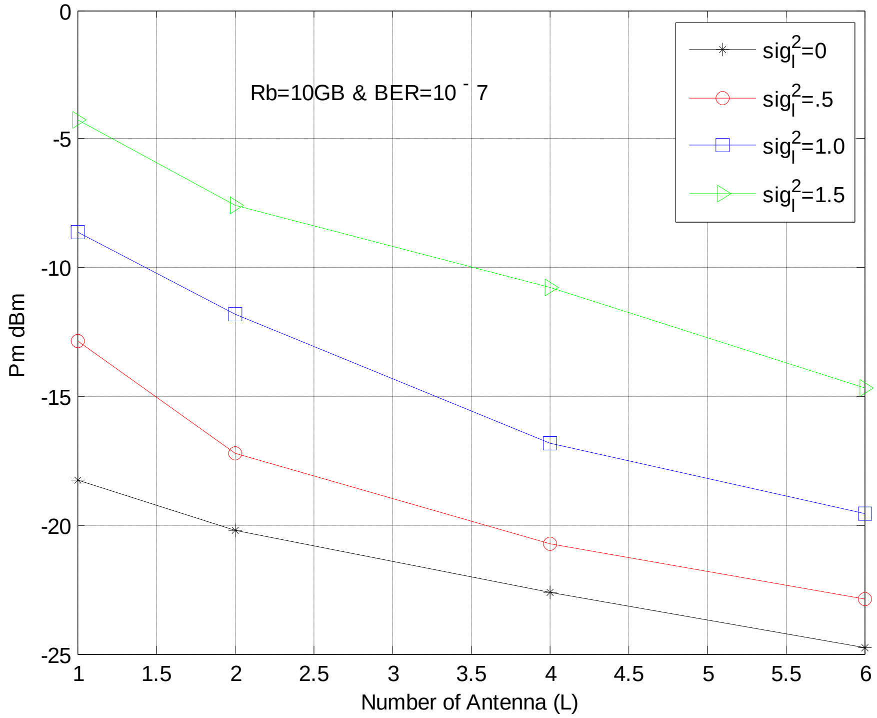
Only we vary the parameters. From this curve we can say that, When number of antenna has been increased the performance will be better in turbulenced atmosphere.

But for higher bit rate the noise effect and BER as well as Subcarrier power is high. So we suggest operating low bit rate as far as possible with higher number of antenna shown in figure.

From this curve we set BER=10^-12 and 10^-7 for 1Gb and 10Gb Rb respectively. Then we got those curve number of antenna Vs Pm_dBm



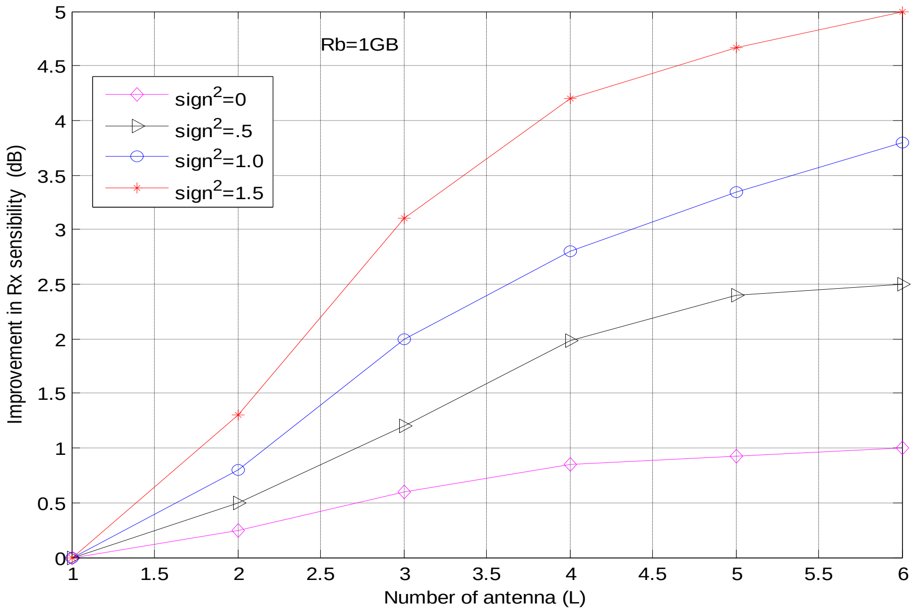
Graph (9): Number of antenna (L) VS Pm_dBm when Rb=1Gb &BER=10^-12



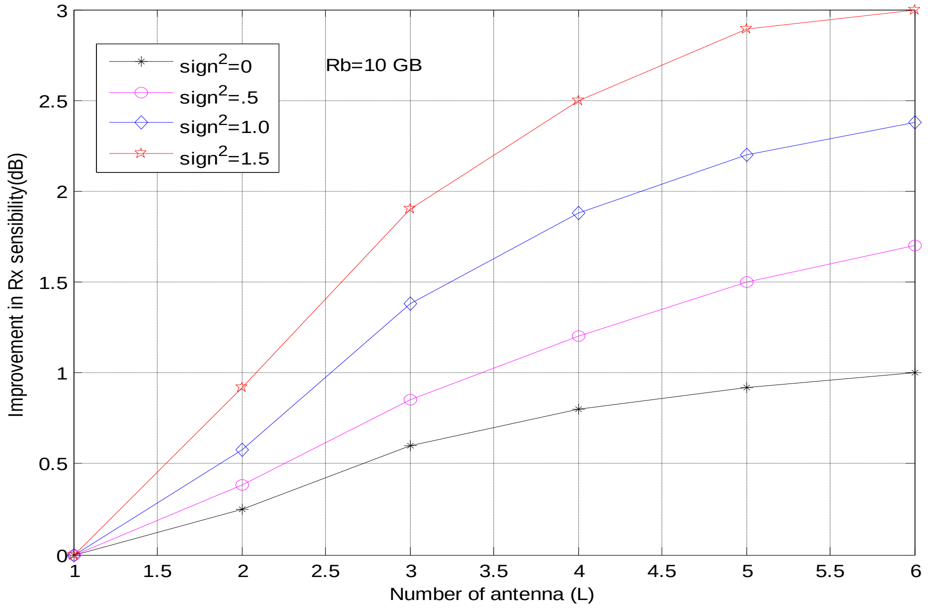
Graph (10): Number of antenna (L) VS Pm_dBm when Rb=10Gb &BER=10^-7

From the graph (9) &(10) we got these following (11) & (12) and additional (13)

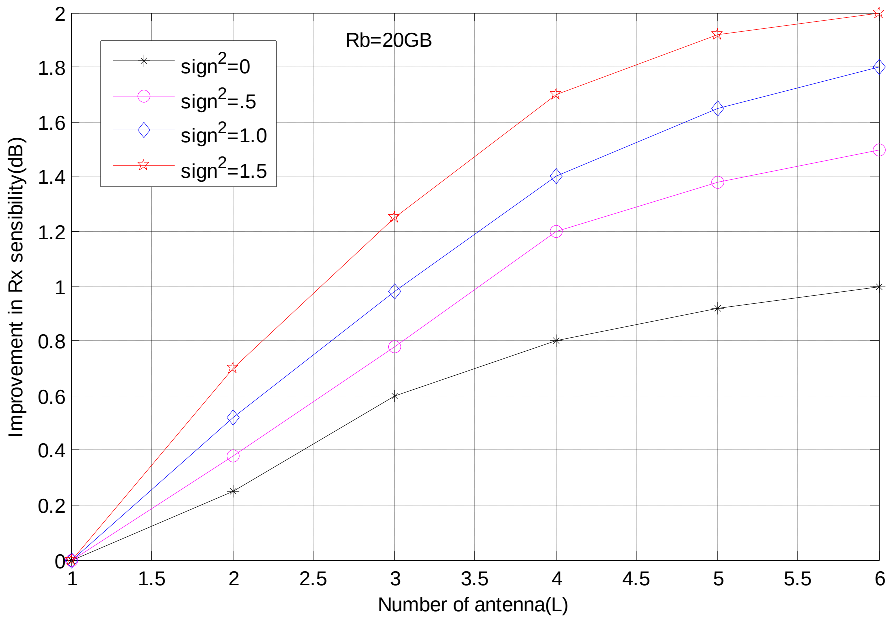
Where, we got improvement in receiver antenna sensibility. More we use the antenna then the sensibility has increased. But at higher Bit rate Rb this improvement is very low. So we suggest operating Rb as low,it is good to operate (1GB-5Gb)



Graph (11): Number of antenna (L) vs Improvement in Rx Sensibility(dB);when Rb=1Gb



Graph (12): Number of antenna (L) vs Improvement in Rx Sensibility (dB); when Rb=10Gb



Graph (13): Number of antenna (L) vs Improvement in Rx Sensibility (dB); when Rb=20Gb

Chapter 5

Optimum System Parameter

For

Given Bit Error Rate

5.1 Optimum system parameter

From our analysis we found few eligible values of the system parameters to perform better on Free Space Optical communication. From there we suggest optimum system parameters for a given BRE.

5.2 Optimum system parameters will be determined for a given system BER (10^-7)

Parameter	Values
Data rate ,R_b	(1 -5) Gb
Laser wavelength ,λ	850nm (used in simulation) 1360nm
PIN photo detector Reponsivity, R	0.8 or 1**
Receiver Sensitivity	-45 dBm
Lognormal variance ,σl^2	$0.1< \sigma l^2<0.9$ ** $1< \sigma l^2<2$
Number of antenna ,**L**	6-8
Number of sub-carrier	6
Used modulation scheme	**BPSK-SIM** **OOK**
Used Sub carrier power for desire communication	(22-25) dBm week turbulence & (10-12) dBm strong turbulence
Used photo detector	InGaAs PIN (used in simulation) **InGaAs APD
Tx to Rx distance	1-1.5 Km
Optical modulation index ,ξ	$I\xi I \leq 1$
Transmit Lens diameter, **Dtx**	2.5 cm each
Receiver Lens diameter, **Drx**	8 cm each

Conclusion

We try to do Performance analysis for optical wireless link with multiple transmitters & multiple receivers over a strong atmospheric turbulence channel. The receiver was consisted of direct detection receiver with equal gain combining technique; but for better performance we used maximum ratio combination technique. We try to analysis to find out the expression of the signal & photo detector currents in presence of strong atmospheric turbulence for the MIMO FSO system as far as possible considering all the parameters which are efficiently practical to the system. The signal to noise ratio (SNR) and the unconditional BER were evaluated numerically for different system parameters. The degradation in system performance due to the channel effect and improvement in receiver sensitivity were determined numerically.
And then we try to plot in graph and determine the performance for different turbulenced condition. Optimum system parameters were determined for a given system BER, and we assume BER 10^{-7}.

Future work

What we have done in our thesis all about in theoretically through a software simulation and tried to create a practical environment using different theory and the equations.
In future,
We analysis all our experiment by using the real life analyzed data.
We also try to analysis with receiving aperture area, and distance between Tx and Rx
And different modulation scheme and so on.

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