CHAPTER 1

Introduction

1.1. Introduction.

Recently, optical wireless (OW) communication has gained increasing attention as a potential technology for indoor wireless communication. The use of the optical medium as a means for indoor wireless communication was proposed al- most three decades ago. Gfeller and Bapst first proposed and investigated indoor OW using IR radiation [1]. IR communications refer to the use of free space propagation of light waves in the near infrared band as a transmission medium for communications. One of the prime motivators for reconsidering the use of IR radiation in the wireless context is the demand for greater transmission bandwidths. Thus optical wireless communication (OWC) has drawn considerable attention to the researchers. In number of applications where higher data throughputs is more of requirement than the mobility, transmission link based on OW would be one of the best options as outlined in [2-5]. The performance of OW systems depends on the propagation and type of system used.

Because of the nature of the light OWC offers several advantages over traditional RF systems, these are: an abundant free spectrum, extremely high communication speed is possible by all network, does not interfere with the over congested RF spectrum, a degree of privacy at the physical layer as optical signals are confined to the room in which they originate (hence the possibility of frequency reuse). Despite these advantages, there are some limitations including: a beam is short ranged; eye safety considerations which restrict the maximum transmit power, multipath propagation which leads to an increased delay spread and directive noise sources (background noise) which reduce the signal-to-noise ratio (SNR).

OW transmission links can be classified into two categories; diffuse or line of sight (LOS) systems. In LOS systems, high data rates in the order of Gbit/s can be achieved [6], but the system is vulnerable to blockage/shadowing because of its directionality. In a diffuse OW system, several paths from source to receiver exist, which makes the system robust to blockage/shadowing. However, the path losses are high and multipath creates inter-symbol interference (ISI) which limits the achievable data rate. Many researchers have considered diffuse systems for indoor applications as it offers robust link and overcomes the problem of shadowing [7], does not require transmitter-receiver alignment and uses the wall or ceiling for multipath reflection [8]. The multipath reflections increases delay spread or ISI. Ambient light such as florescent, incandescent light and Compact Florescent Lamp (CFLs) produces channel noise which reduces signal-to-noise plus interference ratio (SNIR).

In order to improve the system performance several spot diffusion configuration using multibeam transmitter have been proposed [9]. Multi beam transmitter is place in center of the room and pointed upward. A multi-spot pattern have been generated, illuminated multiple small areas in the ceiling and then reflected multiple spot have been received by receivers. In [10], to improve the bandwidth, reduce the effect of ISI, and increase the SNR when the transmitter operates at a higher data rate under the impact of multipath dispersion, background noise, and mobility in conjunction with an imaging receiver. It proposed different line streaming multi-beam spot diffusion (LSMS) model to gain about 32.3 dB SNR at worst communication path. But the multi path dispersion reduces the performances due to transmitter power and can be improve using power adaptive system by [9]. User mobility is very important aspect of wireless communication especially with today’s hand hold devices. As the user device can mobilize with the room then power adaptation will be a great solution to get higher SNR. In this aspect [12] propose a genetic algorithm for multi spot diffuse system in indoor wireless communication. But it is noted from different research that if the diffuse system has a predefined spot for a room and use an adaptive power allocation for beam using calculation of delay spread then it can improve the performance of the OWC. Neural network and Adaptive Linear Equalizers can be a solution in this case for adaptive power distribution. [12] Presents a comparative study of two equalizers, the adaptive linear and the neural equalizer for indoor OW links using OOK modulation technique to reduce ISI effect.

1.2 Objectives.

The main objective of this work is to evaluate the performance of a indoor OWC system. The specific objectives are:

- To study the different methods of OWC system for indoor applications.
- To formulate Bit Error Rate (BER) and delay spread analysis for OWC system.
- To proposed Neuro-Fuzzy (NF) based multi-beam transmission for OWC system where transmitted located at the center of a room.
- Finally, to evaluate the BER performance of the proposed system using MATLAB.

1.3 Assumptions and Limitations.

The assumptions are:

- Only download data transmission is considered.
- Channel state information is known to the receiver.
- The effects of ambient light interferences are ignored.
- It is also considered that the position of the receiver is known to the transmitter.
- The ceiling is painted by a reflecting coating to increase the intensity of the reflected beam.

1.4 **Thesis Layout**.

The paper is organized as follows: Chapter 1 introduces with the goal and an overview of the thesis paper. Chapter 2 gives a Literature Review on the related topics of the thesis subject. In Chapter 3 proposed system model is discussed. Chapter 4 presents numerical analysis and results. The concluding remarks and future work are included in chapter 5.

CHAPTER 2

Literature Review

2.1 Introduction.

Before going into performance evaluation of OWC for indoor application a brief description about wireless communication, OWC, reasons for choosing OWC, comparison between OW and Radio frequency, Indoor OW system, Orthogonal Frequency Division Multiplexing system model is given.

2.2 Wireless Communication.

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. Wireless operations permit services, such as long-range communications, that are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g. radio transmitters and receivers, remote controls etc.) which use some form of energy (e.g. radio waves, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances.

The most common wireless technologies use radio. With radio waves distances can be short, such as a few meters for television or as far as thousands or even millions of kilometers for deep-space radio communications. It encompasses various types of fixed, mobile, and portable applications, including two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of applications of radio wireless technology include GPS units, garage door openers, wireless computer mice, keyboards and headsets, headphones, radio receivers, satellite television, broadcast television and cordless telephones.

2.2.1 <u>History Of Wireless Communication</u>.

The world's first wireless telephone conversation occurred in 1880, when Alexander Graham Bell and Charles Sumner Tainter invented and patented the photophone, a telephone that conducted audio conversations wirelessly over modulated light beams (which are narrow projections of electromagnetic waves). Similar to free-space optical communication, the photophone also required a clear line of sight between its transmitter and its receiver.

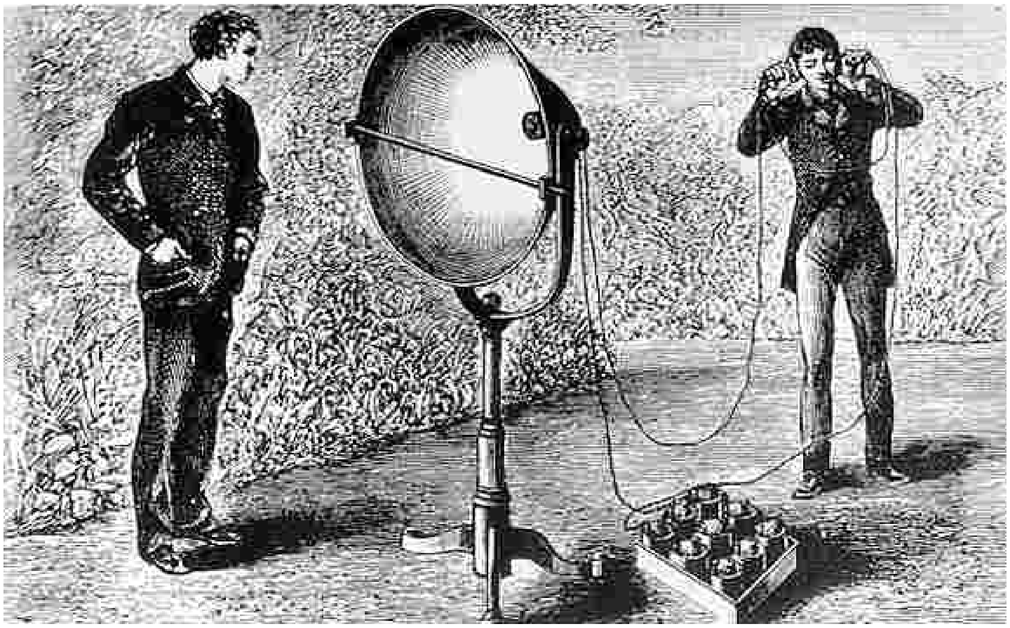


Figure 2.1: World's First Wireless Telephone Conversation using Photophone [14]

In 1888, Heinrich Hertz demonstrated the existence of electromagnetic waves, the underlying basis of most wireless technology. The theory of electromagnetic waves was predicted from the research of James Clerk Maxwell and Michael Faraday. Hertz demonstrated that electromagnetic waves traveled through space in straight lines, could be transmitted, and could be received by an experimental apparatus. Hertz did not follow up on the experiments. Jagadish Chandra Bose around this time developed an early wireless detection device and helped increase the knowledge of millimeter-length electromagnetic waves. Practical applications of wireless radio communication and radio remote control technology were implemented by later inventors, such as Nikola Tesla.

The term "wireless" came into public use to refer to a radio receiver or transceiver (a dual purpose receiver and transmitter device), establishing its usage in the field of wireless telegraphy early on; now the term is used to describe modern wireless connections such as in cellular networks and wireless broadband Internet. It is also used in a general sense to refer to any type of operation that is implemented without the use of wires, such as "wireless remote control" or "wireless energy transfer", regardless of the specific technology (e.g. radio, infrared, ultrasonic) used. Guglielmo Marconi and Karl Ferdinand Braun were awarded the 1909 Nobel Prize for Physics for their contribution to wireless telegraphy.

2.2.2 Application of Wireless Technology.

(a) Mobile telephones.

One of the best-known examples of wireless technology is the mobile phone, also known as a cellular phone, with more than 4.6 billion mobile cellular subscriptions worldwide as of the end of 2010. These wireless phones use radio waves to enable their users to make phone calls from many locations worldwide. They can be used within range of the mobile telephone site used to house the equipment required to transmit and receive the radio signals from these instruments.

(b) Wireless data communications.

Wireless data communications are an essential component of mobile computing. The various available technologies differ in local availability, coverage range and performance, and in some circumstances, users must be able to employ multiple connection types and switch between them. To simplify the experience for the user, connection manager software can be used, or a mobile VPN deployed to handle the multiple connections as a secure, single virtual network. **Supporting technologies includes:**

- Wi-Fi is a wireless local area network that enables portable computing devices to connect easily to the Internet. Standardized as IEEE 802.11 a,b,g,n, Wi-Fi approaches speeds of some types of wired Ethernet. Wi-Fi has become the de facto standard for access in private homes, within offices, and at public hotspots. Some businesses charge customers a monthly fee for service, while others have begun offering it for free in an effort to increase the sales of their goods.

- Cellular data service offers coverage within a range of 10-15 miles from the nearest cell site. Speeds have increased as technologies have evolved, from earlier technologies such as GSM, CDMA and GPRS, to 3G networks such as W-CDMA, EDGE or CDMA2000.

- Mobile Satellite Communications may be used where other wireless connections are unavailable, such as in largely rural areas or remote locations. Satellite communications are especially important for transportation, aviation, maritime and military use.

- Wireless Sensor Networks are responsible for sensing noise, interference, and activity in data collection networks. This allows us to detect relevant quantities, monitor and collect data, formulate meaningful user displays, and to perform decision-making functions.

Wireless networking is used to meet many needs. Perhaps the most common use is to connect laptop users who travel from location to location. Another common use is for mobile networks that connect via satellite. A wireless transmission method is a logical choice to network a LAN segment that must frequently change locations. The following situations justify the use of wireless technology:

- To provide a backup communications link in case of normal network failure

- To link portable or temporary workstations
- To overcome situations where normal cabling is difficult or financially impractical
- To span a distance beyond the capabilities of typical cabling
- To remotely connect mobile users or networks.

(c) Wireless Services

Common examples of wireless equipment include:

- Telemetry control and traffic control systems
- Infrared and ultrasonic remote control devices
- Professional LMR (Land Mobile Radio) and SMR (Specialized Mobile Radio) typically used by business, industrial and Public Safety entities.
- Consumer Two way radio including FRS Family Radio Service, GMRS (General Mobile Radio Service) and Citizens band ("CB") radios.
- The Amateur Radio Service (Ham radio).
- Consumer and professional Marine VHF radios.
- Air band and radio navigation equipment used by aviators and air traffic control
- Cellular telephones and pagers: provide connectivity for portable and mobile applications, both personal and business.
- Global Positioning System (GPS): allows drivers of cars and trucks, captains of boats and ships, and pilots of aircraft to ascertain their location anywhere on earth.
- Cordless computer peripherals: the cordless mouse is a common example; keyboards and printers can also be linked to a computer via wireless using technology such as Wireless USB or Bluetooth

- Cordless telephone sets: these are limited-range devices, not to be confused with cell phones.
- Satellite television: Is broadcast from satellites in geostationary orbit. Typical services use direct broadcast satellite to provide multiple television channels to viewers.

2.3 Optical Wireless communication.

OW is the combined use of "optical" (optical fiber) and "wireless"(radio frequency) communication to provide telecommunication to clusters of end points which are geographically distant. The high capacity optical fiber is used to span the longest distances, and a lower cost wireless link carries the signal for the last mile to nearby users. Another way to define this is Free-space optical communication (FSO) is an optical communication technology that uses light propagating in free space to wirelessly transmit data for telecommunications or computer networking. "Free space" means air, outer space, vacuum, or something similar. This contrasts with using solids such as optical fiber cable or an optical transmission line. The technology is useful where the physical connections are impractical due to high costs or other considerations.

2.3.1 History.

Optical communications, in various forms, have been used for thousands of years. The Ancient Greeks polished their shields to send signals during battle. In the modern era, semaphores and wireless solar telegraphs called heliographs were developed, using coded signals to communicate with their recipients.

In 1880 Alexander Graham Bell and his assistant Charles Sumner Tainter created the Photophone, at Bell's newly established Volta Laboratory in Washington, DC. Bell considered it his most important invention. The device allowed for the transmission of sound on a beam of light. German colonial troops used Heliograph telegraphy transmitters during the 1904/05. During the trench warfare in World War I when wire communications were often cut German signals used three types of optical Morse transmitters called Blinkgerät, the intermediate type for distances of up to 4 km at daylight and of up to 8 km at night, using red filters for undetected communications. Optical telephone communications were tested at the end of the war, but not introduced at troop level. In addition, special blinkgeräts were used for communication with airplanes, balloons, and tanks, with varying success.

A major technological step was to replace the Morse code by modulating optical waves in speech transmission. The invention of lasers in the 1960s revolutionized free space optics.

2.3.2 Usages & Technologies.

An OW communication system relies on optical radiations to convey information in free space, with wave lengths ranging from infrared (IR) to ultraviolet (UV) including the visible light spectrum. The transmitter/source converts the electrical signal to an optical signal, and the receiver/detector converts the optical power into electrical current. Light emitting diodes (LEDs) or laser diodes (LDs) can be used as optical sources and photodiodes (PDs) as detectors.

Wavelengths from 780 nm to 950 nm are currently the best choice for IR indoor OW systems. In this range, low-cost optical sources are readily available. Also, this band coincides with the peak sensitivity of inexpensive PDs. The first IR system was based on a diffuse link operating at about 950 nm and 1 Mb/s proposed by Gfeller and Bapst in 1979. A faster system proposed by March and Khan in 1996 achieves a data rate of 50 Mb/s. In quasi-diffuse systems, a data rate of 70 Mb/s was demonstrated by Carruther and Kahn in 2000.

Recently, Visible Light Communication (VLC) technology using white LEDs is gaining attention in academia and industry, driven by progress in white LED (WLED) technology for solid state lighting and the potential of simultaneously using such LEDs for wireless data transmission.

The maximum measured data rate for a VLC system using blue chip LEDs where a modified version of the classical orthogonal frequency- division multiplexing (OFDM) modulation technique is considered to achieve data rates higher than 500 Mb/s. in October 2008, the VLCC started cooperation with the Infrared Data Association (IrDA) and the Infrared Communication Systems Association (ICSA). In March 2009, a VLCC specification standard adopting and expanding the IrDA physical layer was announced. A standard for VLC local area network (LAN) based on full duplex by the aid of wavelength-division multiplexing (WDM) (IR and visible) is being pursued by the ICSA. In early 2009, the task group IEEE 802.15.7 was working on a VLC standard encompassing both new physical and medium access control (MAC) layers based on a clean- slate approach. In November 2010 the P802.15.7 IEEE draft standard was published.

2.3.3 Potential of Indoor Optical Wireless Communication System.

The vision for the fourth-generation (4G) wireless communication systems sets the peak download speed at 100 Mb/s for high-mobility communication and 1 Gb/s for low-mobility communication. Moreover, 4G systems will not be based on a single access technology; rather, these systems will encompass a number of different complementary access technologies. It is commonly agreed that OW is expected to be essential for short-range communication links (i.e., low-mobility indoor applications) with high throughputs. Clearly, OW technology can be considered for this scenario because of several benefits, including unregulated huge (terahertz) bandwidth, license-free operation, and low-cost front-ends.

2.4. Reasons To Choose Optical Wireless Communication (OWC).

2.4.1 State-Of-The Art Commercial RF and OW Technologies.

To better understand the place of OW systems in the wireless world, Figure 2.2 summarizes state-of-the art commercial RF and OW technologies, as well as technologies under standardization by major bodies including IEEE, 3GPP, Bluetooth and IrDA. Technologies are presented with respect to their area of coverage, ranging from a few centimeters in personal communications to over 1 km in outdoor communications, and the data rates they attain, including low rate legacy links under 1 Mb/s (Bluetooth and older IrDA systems). Clearly, contemporary OW links provide channel rates up to 10 Gb/s, which directly compare to the ones of optical fibers. At the same time, commercial OW links operate at link distances that are challenging to attain in RF (3G/4G) and millimeter-wave (60 GHz) broadband communications.

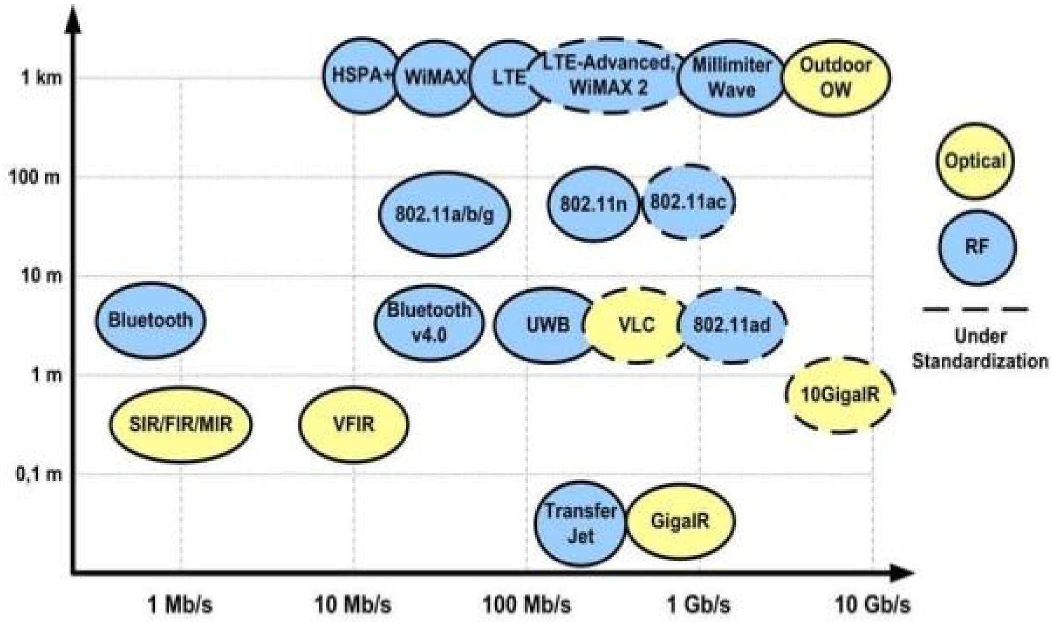


Figure 2.2: State-Of-The Art Commercial RF and OW Technologies [15]

2.4.2 <u>Alternative Technology</u>.

OW is a unique technology that provides an attractive alternative in niche application areas, complementing fiber-optic and RF wireless solutions when they are either too costly to deploy, create undesirable interference, or are not feasible at all. Figure 2.3 illustrates some of the application areas in which OW has been successfully applied. Two mainstream application areas of OW are last-mile broadband access and office interconnection; both are the business objectives of a number of component and system manufacturers. In such applications, state-of-the-art OW systems support 10 Gb/s Ethernet, which equals the bandwidth provided by metro fiber optic systems and is significantly higher than the

1.25 Gb/s Ethernet provided by competing RF wireless systems that operate in the 60 GHz frequency range.

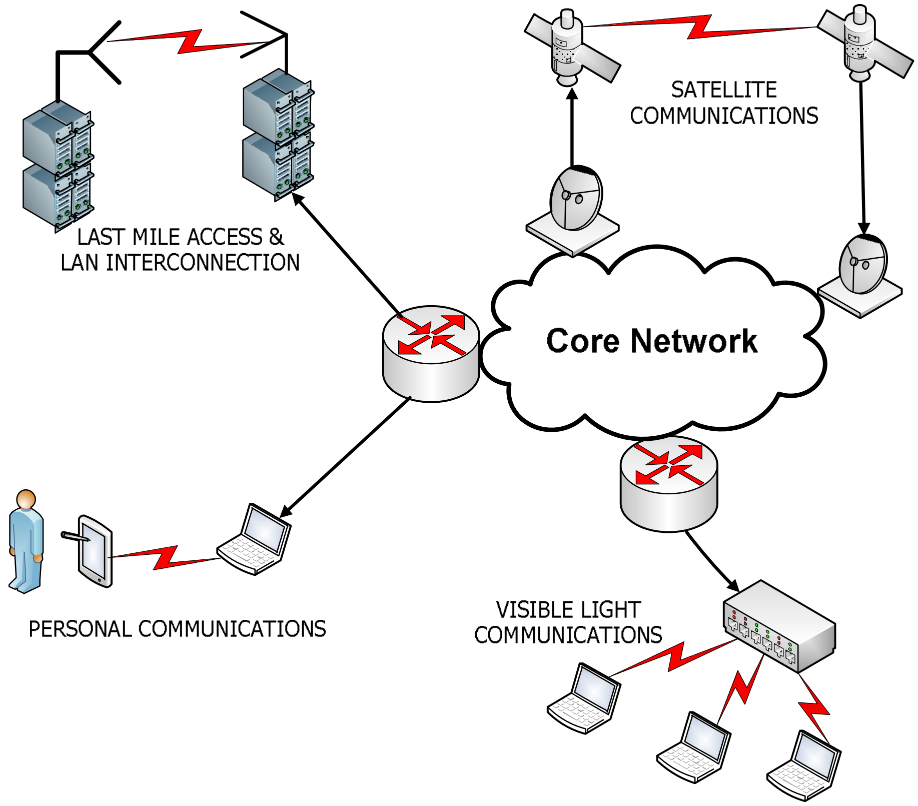


Figure 2.3: Application areas of optical wireless systems [16]

2.4.3 <u>Low Bit Error Rate & High Data Rate</u>.

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The BER is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage. The bit error probability (ρe) is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors. OW system provides low bit error rate which is negligible in count. This system also provide High data rate in comparison to RF system.

2.4.4 Enormous Bandwidth.

OWC has enormous Bandwidth in comparison to traditional RF, As the demand for ultra broadband wireless access home networks constantly increases, the RF spectrum is becoming extremely congested and thus, attention is drawn towards alternative technologies. Indoor infrared wireless communications were first proposed by Gfeller and Bapst and are since attracting growing interest due to the abundance of unregulated bandwidth, which renders them an attractive candidate for high speed data communications.

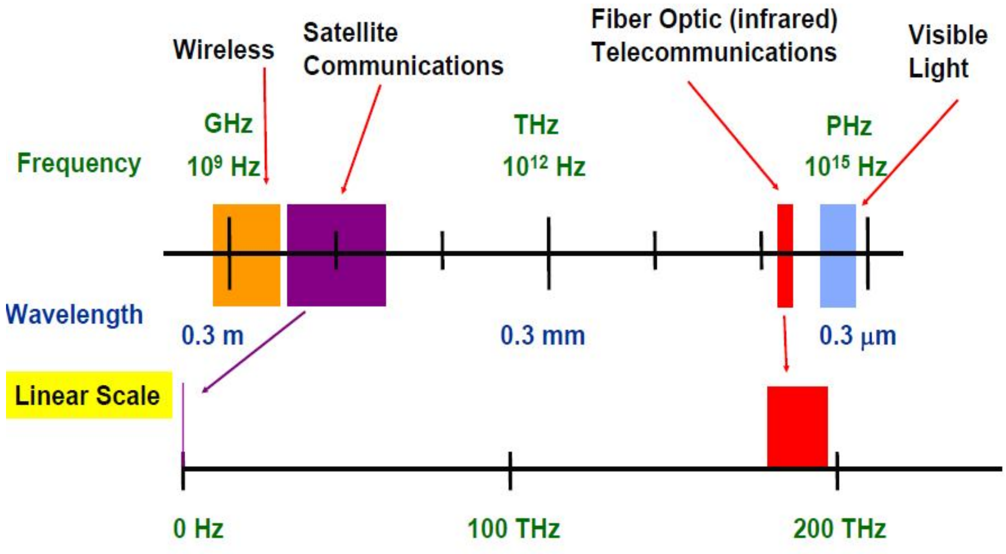


Figure 2.4: OWC Enormous Bandwidth [17]

2.4.5 Immunity from Interference.

In many indoor environments, it is not easy to achieve a high SNR ratio, since there may be intense ambient infrared noise. This noise is due to the infrared spectrum components arising from the radiation of tungsten or fluorescent lamps and sunlight. In addition, artificial light introduces significant in band components for systems operating at bit rates up to several Mb/s and thus induces interference. However, in comparison to traditional RF system, the OWC provides less interference and immune from noise.

2.5 Comparison Between RF and OW Systems.

It has been more than 30 years since OW was proposed as an alternative broadband technology for wireless data transmission applications. The underlying concept of OW is very simple: utilize optical beams to carry data through the atmosphere or vacuum. As a result, OW link architectures are very similar to optical fiber communication point-to-point links, with the exception that no optical fibers are deployed as a transmission medium. OW is also very similar to RF wireless, but radio waves are replaced with light and antennas with free-space optical transceivers. Despite this superficial resemblance between OW and RF links, OW exhibits several appealing attributes when compared to RF. OW links are inherently broadband and optical frequencies in the infrared and visible spectrum are neither regulated nor licensed. Optical components are also cheaper and consume less electrical power than high-speed RF components. Finally, OW links do not suffer from multipath fading and have much less potential for interference with RF-sensitive electronic systems. These advantages do not, however, imply that OW is a universal replacement for RF communications. The application of OW systems is limited when considering area coverage and user mobility, where RF technologies prove invaluable.

Table-1 summarizes the main differences between OW and RF systems.

Table-1 **Comparison Between RF and OW Systems**

Subject	OW	RF
Bandwidth	Not regulated	Licensed
Available line rates	<10 Gb/s	<1.25 Gb/s
Path losses	High	High
Multipath fading	No(large collector area)	Yes
Multipath distortion	Only in diffuse indoor systems	Yes
Noise sources	Ambient light	Interference from other users, electrical noise
Detection type	Incoherent	Coherent/Incoherent
SNR	Depends on optical signal power	Depends on RF signal amplitude
Receiver sensitivity	Low	High
Eye safety	Required	N/A
Electromagnetic compatibility	Yes	Conditional

In addition, OW systems operate under strict eye safety regulations while at the same time incoherent OW receivers present lower sensitivity than their RF counterparts because of their photo-electric conversion mechanisms and the impact of ambient light noise sources. OW links operate at link distances that are challenging to attain in RF (3G/4G) and millimeter-wave (60 GHz) broadband communications OW is a unique technology that provides an attractive alternative in niche application areas, complementing fiber-optic and RF wireless solutions when they are either too costly to deploy, create undesirable interference, or are not feasible at all.

2.6 Indoor OW systems.

OW has been extensively studied as a broadband, low cost and power efficient technology for indoor communication systems. Similar to the case of personal communications, OW indoor systems provide considerable cost savings to device manufacturers and end users due to the existence of unlicensed available spectrum, are perceived as safer than competing RF technologies to humans and do not suffer from RF interference. Indoor OW link architectures, however, are quite different from their personal communication counter- parts due to the fact that a key requirement here is user mobility. In real-world indoor systems the user is allowed to move within a limited area of coverage, which typically equals the size of a room or an aircraft cabin.

Providing OW access to a moving user can be challenging, since the optical beams are blocked by objects inside the room. A possible solution is to deploy a roof-mounted and narrow-beam transmitter that is controlled by a tracking mechanism. The tracking mechanism rotates the transmitter and directs the narrow optical beam from the transmitter to the mobile receiver. This approach leads to a point-to-point OW link whose architecture is very similar to that of personal communication systems (Figure 2.5a). An alternative approach is to design the transmitter with a broad-angle emission pattern and allow multiple reflections from the walls and objects inside the room. In such a case, the OW system is categorized as diffuse (Figure 2.5b). If the emission pattern is properly engineered, the multiple reflections result in uniform illumination inside the area boundaries, even at places that are out of line-of-sight of the transmitter, and therefore enhance user mobility.

However, the multipath propagation in diffuse channels leads to time-dispersion of any pulse transmitted on the channel. Multipath dispersion is a critical impairment, since it drastically reduces the system bandwidth, and attainable data rate, and increases the link losses. As a result, point-to-point and diffuse topologies present a tradeoff between mobility and bandwidth. More advanced topologies, for instance multispot diffusing (Figure 2.5c), combine the best of both worlds and allow for significant user mobility while at the same time achieve two orders of magnitude higher bandwidth than purely diffuse ones.

2.6.1. Point-to-Point Links.

Point-to-point links require a LOS between the transmitter and the receiver, as shown in Figure 2.5a. Such a link topology permits the use of highly directional transmitters with low beam divergence and narrow field-of-view (FOV) receivers. Thus, point-to- point links are able to reject the majority of ambient light that interferes with communications. In addition, the directionality of the link removes the impact of multipath dispersion since any reflected transmitter energy is essentially rejected by the receiver. Still, a disadvantage of this link topology is the fact that precise alignment and pointing are required, making the realization of mobile links difficult.

Very high data rates can be achieved in point-to-point indoor OW links by means of spatial division multiplexing, a technique that has been considered for some time. In hundreds of parallel links, each operating at 50Mb/s, were shown feasible in large areas using a ceiling-mounted transmitter. The transmitter was capable of creating a large number of narrow beams pointed to a variety of locations. Although such systems are ideal for high-speed data distribution, they are of high complexity and do not permit motion of terminals.

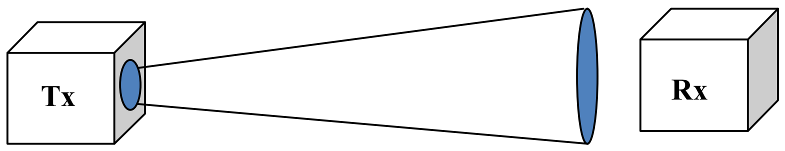
Table-2 summarizes the Comparison of OW link topologies (Point-to-pointlinks, diffuse indoor OW links and multispot diffusing links).

Table-2 **Comparison of OW Link Topologies For Indoor Systems**

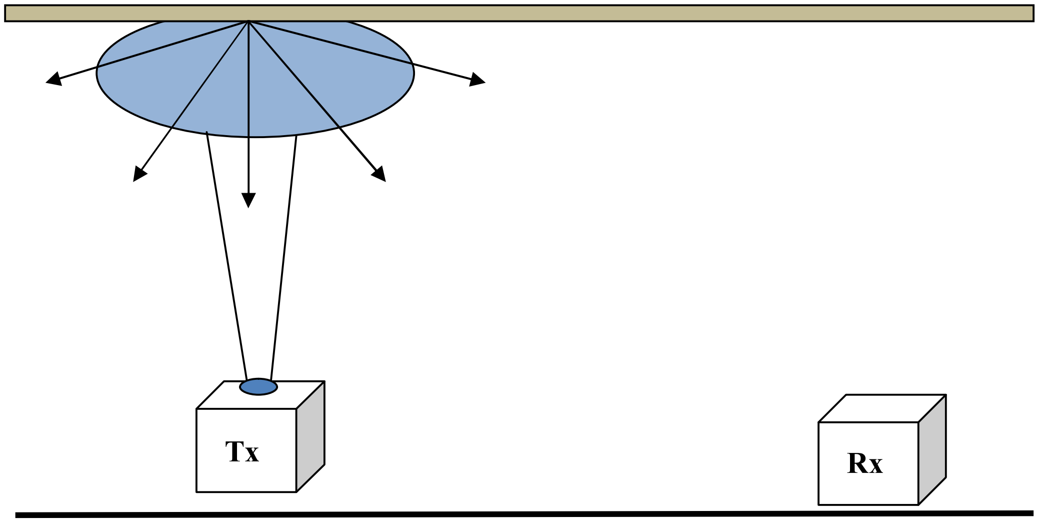
Subject	**Link type**		
	Point-to-point	**Diffuse**	**Multispot Diffusing**
Link rate	High	Moderate	Moderate
Implementation complexity	Low	Low	High
Beam pointing	Required (exact)	Not-required	Required (partial)
Beam blocking	Yes	No	No
User mobility	Limited	High	High
Dispersion	None	High	Low
Path loss	Low	High	Moderate
Impact of ambient noise	Low	High	Low

High-speed electronic tracking was reported into support mobility at a rate of 155 Mb/s over ranges of nearly 2 m. Tracking was accomplished by using a transmitter that had an array of laser diodes combined with optics and a receiver with a wide FOV and detection array. Tracking involved the selection and switching of paths onto the appropriate receive element. Point-to-point OW links have also found a great deal of popularity in a variety of shorter-range applications.

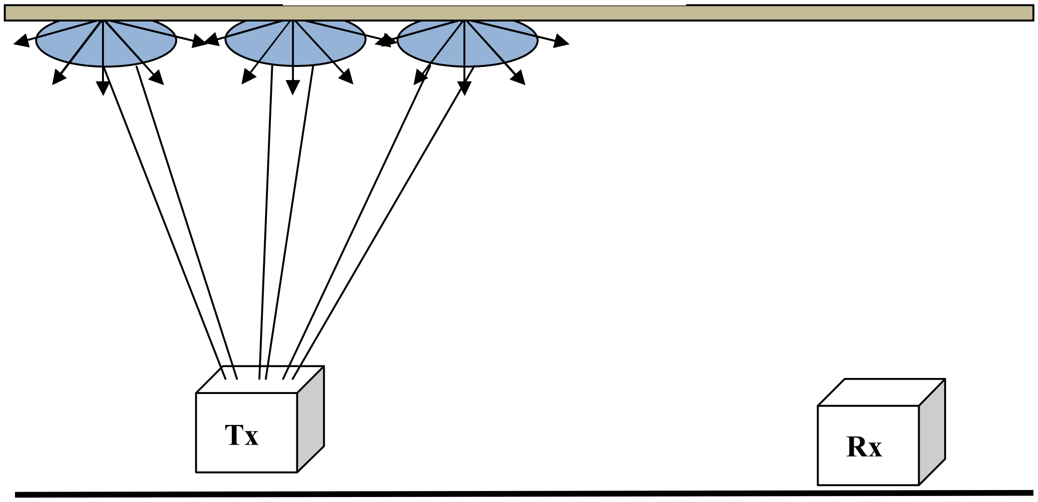
The majority of indoor point-to-point OW links have single element transmitters and receivers. However, great gains can be attained by using multiple-transmitters and receivers in a coordinated fashion. The implementation of such Multiple-Input-Multiple-Output (MIMO) links involves the use of laser and photodiode arrays, optical interconnects or a spatial-light modulator (SLM) as a transmitter and an image as a receiver. Incoming data is either parallelized and trans- mitted over multiple beams, while when a SLM is employed, data is sent by creating a series of two- dimensional (2D) optical intensity images. OW MIMO links require tight spatial alignment between the transmitter and receiver arrays to avoid interference between the channels.



(a) Point to Point



(b) Diffuse



(c) Multispot Diffusing

Figure 2.5: Topologies For Indoor OW Systems.[26,27,28]

(a) Point-to-point (b) Diffuse (c) Multispot diffusing.

2.6.2 Diffuse Indoor OW links.

Initial studies into diffuse OW links were presented in 1979 and diffuse links are robust, immune to shadowing and allowed for terminal mobility. Unlike point-to-point OW links, a diffuse OW link does not require the existence of a LOS to establish communications. Rather, as illustrated in Figure 2.5b, it employs wide beam transmitters and large FOV receivers to exploit diffuse reflections from the walls and objects inside the room and establish a communication link. As a result, there is inherent path diversity and diffuse links are relatively immune to blockage and pointing errors and permit a great degree of mobility for the receivers. However, the received signal is corrupted by multipath dispersion due to the large number of collected reflections at the receiver. The temporal spread of reflections results in ISI at high data rates and limits the system bandwidth. Notice that although diffuse OW links suffer from multipath dispersion, they do not exhibit multipath fading as in RF links.

The indoor diffuse OW channel is well modeled as a linear, time-dispersive channel with a time-invariant impulse response **h(t)**. The impulse response is calculated from the individual reflections of walls and objects inside the room and there is an array of methods in the literature to compute the impulse response in optical intensity domain for a typical room layout. While specular reflections are possible, the vast majority of reflections are diffuse since the dimensions of the surface roughness is on the order of the wavelength of light used in the link. As a result, the optical power is reflected nearly independently of the angle of incidence of the optical wave.

The impact of multipath dispersion on diffuse indoor OW links is quantified by the path loss and normalized delay spread. The path loss is calculated from the channel impulse response h (t) and ranges from 10^{-7} to 10^{-5}. The temporal dispersion due to multipath can be measured by the root-mean square (RMS) delay spread of the impulse response and ranges from 2 to 10 ns. A popular and convenient model that correlates the temporal dispersion with the channel band- width is the exponential-decay model. In this model, the 3-dB bandwidth of the channel impulse response is calculated from the channel temporal dispersion D using the following simple analytical relation.

$$f_{3dB} = \frac{1}{4\pi D}$$

A range in temporal dispersion D from 2 to 10 ns implies that the 3-dB channel bandwidth approximately ranges from 10 to 40 MHz. The impulse response, delay spread and path loss depend on the particular composition and arrangement of the room and are considered fixed once the room characteristics are fixed. Diffuse OW links have been standardized by both IrDA and IEEE. The standardization of diffuse OW links from IrDA resulted in the Advanced Infrared (AIr) physical layer interface.

2.6.3. Multispot Diffusing Links.

Spatial diversity techniques have been successfully applied to indoor OW links in a topology that is termed multispot diffusing (MSD) and shown in Figure 2.5c. The MSD architecture aims to combine the advantages of point-to-point links with the mobility of diffuse links.The MSD transmitter modulates data onto a series of beams that are projected onto the ceiling above the communications floor. The MSD receiver ideally images one or perhaps several spots and decodes data from the diffusely reflected energy. The same data is modulated for all spots and the arrangement and number of spots is optimized so that at least one spot is in the imager for every receiver position.

Even though both diffuse OW and MSD links rely on diffuse reflections on surfaces inside the room, there are large differences in the underlying channel models of both topologies. The first main difference lies in the intensity distribution of the optical transmitter. Whereas diffuse OW links emit light over a large divergence angle, the MSD transmitter uses a series of narrow divergence beams directed to the ceiling. This more efficient organization of the optical intensity leads to a far smaller path loss in MSD systems than in diffuse systems. The second major difference lies in the construction of the receiver. The MSD receiver consists of a series of narrow FOV elements directed to the ceiling. These narrow FOV receivers reject a large portion of ambient light. In addition, the narrow FOV receivers are able to reject any stray multipath signals and this effect significantly improves the bandwidth of the channel. It has been shown that in a typical room setting the channel bandwidth of an MSD system is in excess of 2 GHz, which is in stark contrast to the tens of MHz available in diffuse systems.

One of the challenges in implementing an MSD link is the creation of an array of spots on the ceiling. Although using arrays of emitters with their own optics is bulky and expensive. A less expensive and compact method is to use a laser diode and a computer generated hologram. In a hologram which produces an array of 8 × 8 beams is presented, while holographic diffusers with fewer lobes were considered earlier. Holograms have also been considered to create arrays as large as 10 × 10 spots. Other work has considered different geometries for MSD spots including a line strip and a diamond in an effort to reduce transmitter complexity.

MSD links maintain the high bandwidth and low path losses of point-to-point links and at the same time achieve mobility that is comparable with those in diffuse links at the expense of slightly more complicated transmitters and receivers. As a result, the MSD architecture is an excellent topology for future indoor high- speed content distribution systems.

2.7 Components of Indoor Optical Wireless system.

A basic OW system consists of a transmitter (using LEDs or LDs), free space as the propagation medium and the receiver (using APDs or PIN diodes). Information, typically in the form of digital data, is input to electronic circuitry that modulates the transmitting light source (LEDs/LDs). The source output passes through an optical system (typically has telescope and optical diplexer) into the free space (propagation medium). The received signal also comes through the optical system and passes along the optical signal detectors (PIN diodes/APDs) and thereafter to signal processing electronics. The wavelength band from 780nm to 950nm is the best choice for indoor OW systems. In this range, low cost LEDs and LDs are readily available. Also, this band coincides with the peak responsivity of inexpensive, low-capacitance silicon photodiodes. The OW system uses IR technology in which links are based on intensity modulation and direct detection (IM/DD) of the optical carrier. Intensity modulation is performed by varying the drive current of LED or LD (direct modulation). Direct detection is performed by PIN photo-diodes or APDs which produce an electric current proportional to the incident optical power.

2.7.1 <u>Transmitter</u>.

For indoor OW transmitter, LDs are preferable over LEDs because they have higher optical power outputs, broader modulation bandwidths and linear electrical to optical signal conversion characteristics. Linearity in signal conversion is particularly important when sophisticated modulation schemes such as multi-subcarrier modulation or multilevel signaling are used. But due to safety reasons (eye safety) laser diode cannot be used directly for the indoor IR systems, where radiation can enter a human eye quite easily. LDs are highly directional radiation sources and can deliver very high power within a small area on the retina thereby resulting in permanent blindness. On the other hand, LEDs are large-area emitters and thus can be operated safely at relatively higher powers. They are also less expensive and more reliable. Consequently, LEDs are the preferred light source for most indoor applications. To compensate for the lower powers, array of LEDs can be used. However, LEDs cannot be used beyond 100 Mbps due to the limitations imposed by the mechanism by which they emit light, whereas LDs can be used for transmission at bit rates of the order of a few Gbps.

2.7.2 <u>Receiver</u>.

As mentioned earlier, there are two basic detectors; the PIN diodes and the APDs. PIN receivers are commonly used due to their lower cost, tolerance to wide temperature fluctuations and operation with an inexpensive low-bias voltage power supply. PIN receivers are about 10 to 15 dB less sensitive than APD receivers. Increasing the transmitter power and using larger receiver lens diameter can compensate the reduced sensitivity of these receivers. On the other hand, the increased power margin afforded by the APDs provides a more robust communication link, which reduces the criticality of accurate aiming of lenses. This allows in reduction of transmitter power. In addition to this, the better internal gain of APDs increases the SNR. However, the APD receivers are costly and need high operating voltages.

2.8 Orthogonal Frequency Division Multiplexing (OFDM) System Model.

OFDM for OW systems using non-coherent light. In particular, light emitting diodes (LEDs) and photodiodes (PDs) are considered. The current WLAN standards IEEE 802.1 la and IEEE 802.1 lg are based on OFDM.

2.8.1 Background and Principle of OFDM.

OFDM is an example of a multi-carrier technique that operates with specific orthogonality constraints between the subcarriers. Due to these constraints, it achieves a very high spectral efficiency. For adequate transmission quality, however, it is important to preserve the subcarrier orthogonality that is inherent to the OFDM concept. Although the OFDM principle has been around for many years, only the current technology level makes satisfactory implementation feasible. As a result, more and more systems that operate in the Gigahertz bands are based on OFDM.

Figure 2.6 shows the general structure of a multi-carrier system. The data stream $s(\mathrm{i})$ is converted to parallel data streams, which are modulated onto separate sub channels. The resulting signals are summed and transmitted. At the receiver, the different sub channels are down converted to parallel baseband signals, demodulated, and then concatenated to a serial data stream.

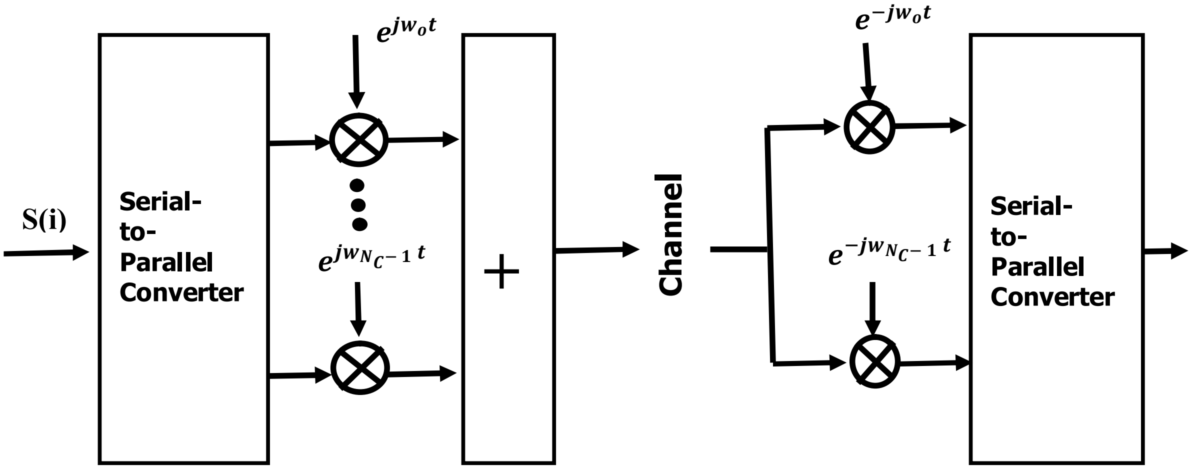


Figure 2.6: Basic Structure of a Multi-Carrier System

2.8.2 Main Advantages of OFDM.

One significant advantage to use OFDM is its low complexity compared to an equivalent single carrier system designed to work with the same amount of delay spread. The other advantage of OFDM over single-carrier systems with equalizers is that for the latter systems, the performance degrades abruptly if the delay spread exceeds the value for which the equalizers are designed. Because of error propagation, the raw bit error probability increases so quickly that introducing lower rate coding or a lower constellation size does not significantly improve the delay-spread robustness. For OFDM, however, such non-linear effects as error propagation do not occur, and coding and lower constellation sizes can be employed to provide fall-back rates that are significantly more robust against delay spread. This is an important consideration, as it enhances the coverage area and avoids the situation that users in bad spots cannot get any connection at all.

2.8.3 OFDM Symbol With Cyclic Prefix.

A cyclic prefix (CP) is needed in wireless OFDM systems due to multipath propagation. The CP acts as a guard interval to avoid ISI. To realize the CP, the last G samples of the OFDM symbol in eqn. (1) are repeated at the beginning so that N + G samples are transmitted. The minimum length for G is the channel impulse response duration. However, the measured channel delay spread in OW systems is significantly less than that of RF based systems. Hence, the effect of the CP length on the bandwidth efficiency and SNR is insignificant in optical systems.

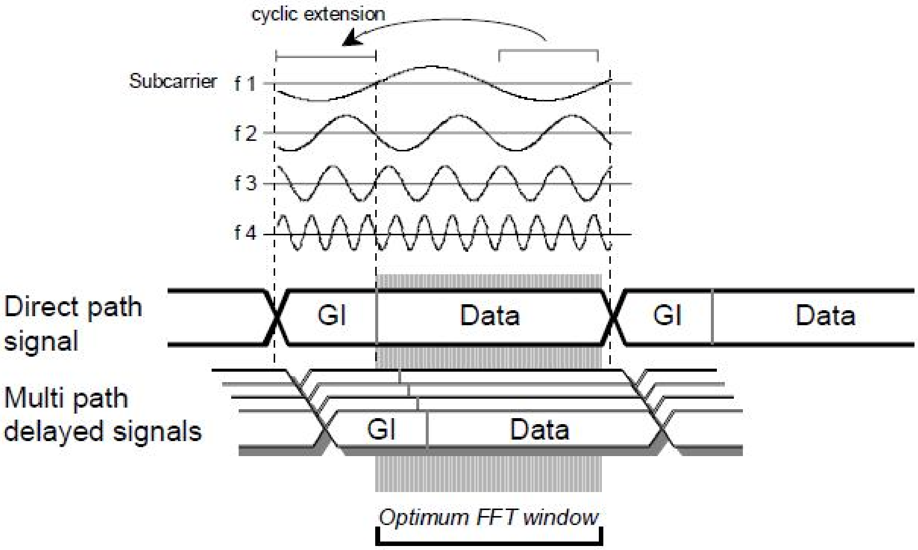


Figure 2.7: OFDM Symbol With Cyclic Prefix.

The SNR loss due to CP can be calculated as follows:

$$SNR_{loss} = -10log_{10}\left(1-\frac{\boldsymbol{T_{CP}}}{(\boldsymbol{N}\ \boldsymbol{X}\ \boldsymbol{T_S})+\boldsymbol{T_{CP}}}\right) \qquad (1)$$

Where, TCP is the CP period. Assuming 2048 sub-carriers, the SNR loss is calculated to be 0.0174dB.

CHAPTER 3

Proposed System Model

3.1 Proposed System Model.

Consider an empty room with floor dimensions of 8x4 m and ceiling height of 3m as shown in Figure 3.1. The reflection coefficient of the ceiling is considered to be 0.8. There are eight spot lights on the ceiling. In the Figure, δ is the elevation angle, α is the azimuth angle, d =8, w =4 and h =3, x_0 and x are the position of the imaging receiver and v is the velocity. Neuro-Fuzzy (NF) adaptive multibeam transmitter is located at the center of the room whereas an imaging receiver is placed at x_0 = (1, 1, 0.5). The transmitter generates multi spot beam matrix on the ceiling where beam power and beam angle (α,δ) are adapted and the reflected beams are received by the imaging receiver. The transmitter learns receiver position, mobility through the low rate diffuse channel. At low data rate, the beam maintains the fixed power.

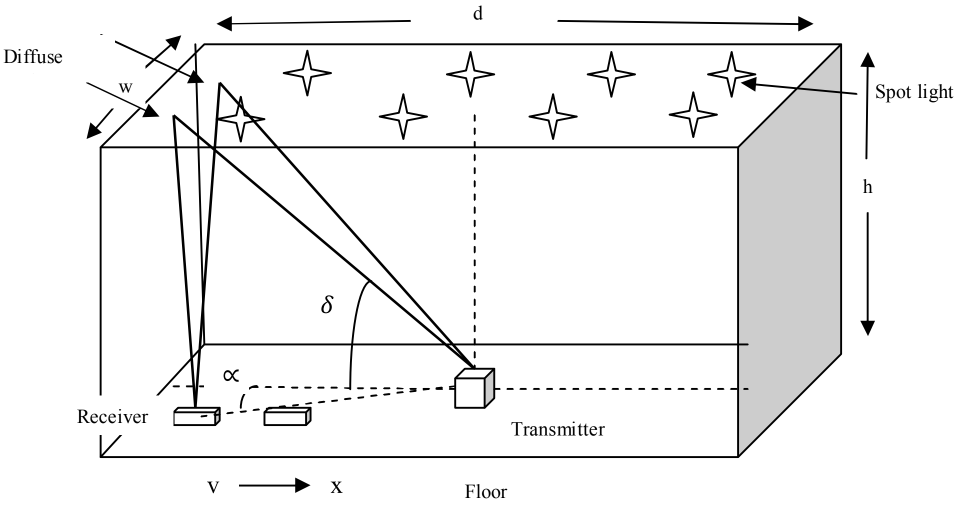


Figure 3.1: System Model for OWC Based on Spot-Diffusing Technique.

Here δ is the elevation angle, α is the azimuth angle, d =8, w =4 and h =3

3.2 Signal to Noise Plus Interference Ratio (SNIR).

In indoor OWC, the ambient light affects SNIR at the receiver. Many researchers have considered intensity modulation with direct detection (IM/DD) as most viable approximation. The received signal, denoted by y(t), can be expressed as

$$y(t)=\sum R\,x(t) * h(t, \alpha , \delta) +\sum n(t, \alpha, \delta)) + \sum I(t, \alpha, \delta) \tag{1}$$

where R is the receiver responsivity , $x(t)$ is the instantaneous optical transmitted power, $h(t, \alpha , \delta)$ is the impulse response of the OW channel, $n(t, \alpha , \delta)$ is the ambient light noise, $I(t, \alpha , \delta)$ is the instantaneous interference power.

The SNIR, denoted by γ, of the received signal can be calculated by [9]

$$\gamma = \frac{R^2(P_{s1}-P_{s0})h^2}{(\sigma_{s1}-\sigma_{s0})^2} \tag{2}$$

Where P_{s1} and P_{s0} are the optical power associated with the binary 1 and binary 0 respectively, σ_{s1} are σ_{s0} are the shot noise variation component with P_{s1} and P_{s0} respectively.

3.3 Adaptive Power Allocation.

The achievable data transmission rate, denoted by b, of the OWC system is given by

$$\mathbf{b} = \frac{1}{M}\sum_{i=1}^{M} \log_2 \left(\frac{1+R^2(P_{s1i}-P_{s0i})hi^2}{(\sigma_{1i-}\ \sigma_{0i})^2}\right) \tag{3}$$

The optimization problem and constraint of the power allocation can be written as

$$\text{Maximize} \quad \mathbf{b} \tag{4}$$

$$\text{Subject to} \quad \sum_{j=1}^{J} \boldsymbol{P_i} \ \leq \boldsymbol{\overline{P}} \tag{5}$$

Where $\overline{P}$ is the average power. Lagrange multiplier method can be utilized to analyze the above optimization problem and the Lagrangian function is defined as

$$\mathbf{L = b +} \mu_j \ \left(\sum_{j=1}^{J} \mathrm{P}_{\mathrm{j}} - \overline{P} \right) \tag{6}$$

Where μ_j is the Lagrange multiplier. After solving the Eqn. (6), it can be written as

$$\boldsymbol{P_j} \ = \left[\frac{\left(\boldsymbol{P}+\sum_{j=1}^{J}\frac{1}{h_i}\right)}{\boldsymbol{C}} - \frac{1}{\boldsymbol{h_i}}\right] \tag{7}$$

$$= \max\left[\boldsymbol{\lambda}(\boldsymbol{C}) - \frac{1}{\boldsymbol{h_i}}, \mathbf{0}\ \right] \tag{8}$$

3.4 Delay Spread.

The delay spread of an impulse is expressed as rms value by,

$$D = \sqrt{\frac{\sum(t_i - \mu)^2 P_r^2}{P_r^2}} \qquad (9)$$

Where $\mu = \frac{t_i \;\; P_r^2}{P_r^2}$ and t_i is the delay time and P_τ is the received power.

3.5 Doppler Shift.

Light waves require no medium and being able to travel even through vacuum. Let $\bar{\vartheta}$ is the relative velocity between transmitter and receiver, the proper frequency of the transmitted information signal from the optical transmitter is f_0. Let f is the frequency of the received signal accepted by the moving receiver with a velocity $\bar{\vartheta}$, then

$$\mathbf{f} = f_0 \,\mathrm{x} \sqrt{\frac{1 \pm \beta}{1 \mp \beta}} \qquad (10)$$

Where $\beta = \frac{\vartheta}{C}$, c is the speed of light. For low speed, i.e., β << 1, and in this case the above eqn. (10) is reduced to

$$\mathbf{f} = f_n (1 - \beta)^{-½}$$

$$= f_0 (1 + \beta + \tfrac{1}{2}\beta^2) \qquad (11)$$

3.6 Adaptive Neuro-Fuzzy Interference System (ANFIS) Model.

Neuro-fuzzy inference system is considered if learning capabilities are required. ANFIS can be considered for the implementation of the spot beam matrix selection. Based on the SNR, i.e. $\boldsymbol{\gamma}$ and link delay, i.e. Δ_{τ}, ANFIS decides a spot is eligible for selection or not. The ANFIS is trained iteratively to achieve the desired output for the input parameters and their membership functions. This can be done by back propagation gradient descendent which evaluates the error signals recursively from the output layer backward to the input nodes. In this way, ANFIS learns the behavior of the system. Sugeno ANFIS model contains if and then rules, e.g., If x is $\boldsymbol{A}_{i}$and y is $\boldsymbol{B}_{i}$then $\mathbf{f} = \boldsymbol{p}_i\mathbf{x} + \boldsymbol{q}_i\mathbf{y} + \boldsymbol{r}_i$, where $\{\boldsymbol{p}_i, \boldsymbol{q}_i, \boldsymbol{r}_i\}$ is the consequent parameter set. Fig. 3.2 shows ANFIS model for spot beam matrix selection. It consists of five layer: input layer, output layer and three hidden layers.

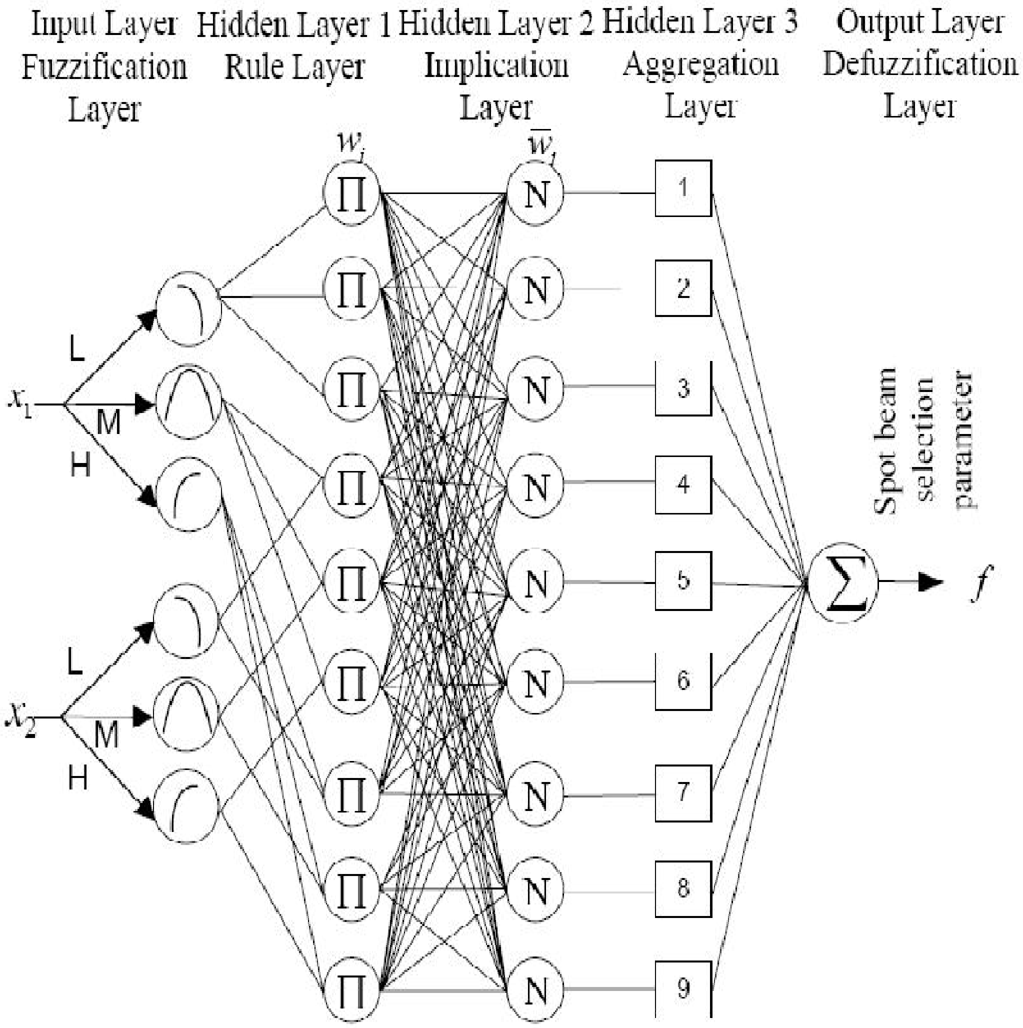


Figure 3.2 ANFIS Model For Spot Beam Selection

Each adaptive node in the input layer generates membership grades. If bell shape membership functions are considered, output of this node, denoted by O_i^1 can be written as

$$O_i^1 = \mu_{\alpha i}(x) = \frac{1}{\left[1+\left|\frac{x-c_i}{\alpha_i}\right|^{2b_i}\right]}$$

Where $\boldsymbol{\alpha_i} \in \{\boldsymbol{A_i}, \boldsymbol{B_i}\}$ is the input vector, $\{\boldsymbol{a_i}, \boldsymbol{b_i}, \boldsymbol{c_i}\}$ are the premise parameters.

Nodes in the first hidden layer calculate the firing strength of a rule via multiplication. The output of the each node, denoted by $\boldsymbol{O_i^2}$, can be written as

$$\boldsymbol{O_i^2 = \omega_i = \mu_{A_i} . \mu_{B_i}(x)}$$

Where i=1, 2, 3. ANFIS performs AND operation in this layer.

Nodes in the second hidden layer compute the normalized value of the firing strength. The output of the each node, denoted by $\boldsymbol{O_i^3}$, can be written as

$$\boldsymbol{O_i^3 = \bar{\omega}_i = \omega_i / \sum \omega_i}$$

Nodes in the third hidden layer compute the contribution of i-th rule towards the overall output. The output of the each node, denoted by O_i^4, can be written as

$$\boldsymbol{O_i^4 = \bar{\omega}_i\ f_i = \bar{\omega}_i(p_i \mathrm{x} + q_i \mathrm{y} + r_i)}$$

A single node in the output layer computes the overall output, denoted by O_i^5, can be written as

$$\boldsymbol{O_i^5} = \textstyle\sum_i \boldsymbol{\bar{\omega}_i f_i}$$

3.7 Adaptive Spot-Beam Selection Algorithm.

Figure 3.3 shows the block diagram of the adaptive spot-beam selection algorithm. In the first step the beam hologram or matrix generates 40 × 20 equal powered spot-beams in the ceiling. The SNIR and delay spread for each beam have been calculated by the image receiver. The receiver periodically evaluates the SNIR after 1 second interval whereas the delay spread for each beam is same if the receive is not moving. In the second step, the receiver sends the spot-beam information which contains SNIR and delay spread to the transmitter. Based on the minimum SNIR and maximum delay spread, transmitter select the spot-beam matrix by NF based algorithm in the third step. The transmitter allocates the power for each selected beam adaptively using eqn. (8) in the forth step. Finally based on the velocity of movement of the receiver, transmitter moves spot-beam matrix for the receiver.

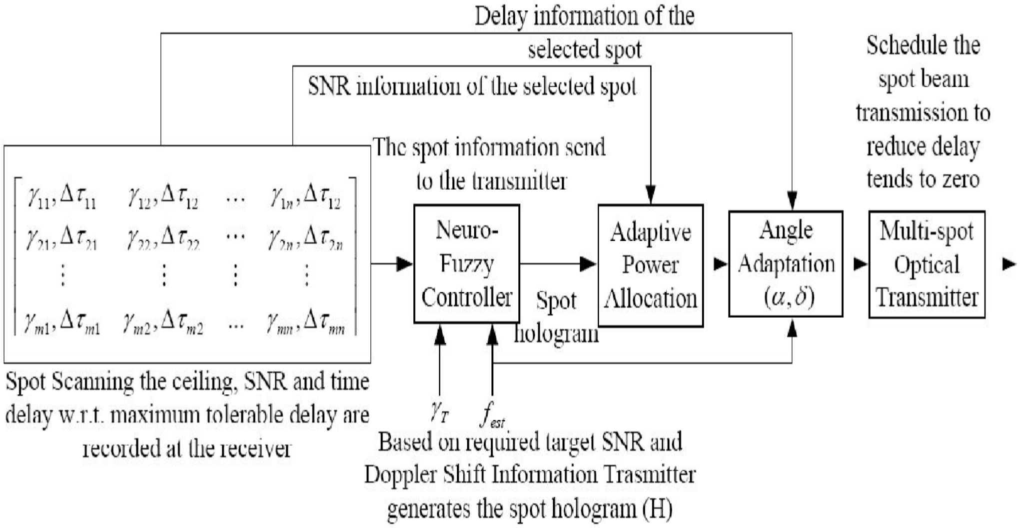


Figure 3.3 Spot Beam Selection Algorithms In The Presence Of Doppler Shift Due To Receiver Movement

The algorithm is summarized as follows:

The following algorithm will find the spot beam with an equal power allocation over 40x20 beam hologram or matrix, H.

Step 1 A spot beam scans the ceiling, SNIR, γ and delay spread, Δ_{τ} for each beam have been calculated by the image receiver using Eqns (2) and (9).

Step 2 Based on the required minimum SNIR, i.e. $\boldsymbol{\gamma_{min}}$ and maximum delay spread, i.e. $\Delta_{\boldsymbol{\tau\, max}}$ transmitter selects the spot-beam matrix (H) by NF controller.

Step 3 The transmitter allocates the power for each selected beam adaptively using Eqn (7)

Step 4 Based on Doppler shift, the transmitter adapts the beam angles α and δ.

Step 5 Multi-spot optical transmitter further reduce the Δ_{τ} by scheduling.

Step 6 Finally, Multi-spot optical transmitter transmits the spot beam matrix to receiver via ceiling.

Step 7 Go to Step 1 if transmitter gets receiver’s position update.

3.8 Numerical Analysis.

Neuro-Fuzzy based multibeam system (NFMS) is investigated with diversity receiver configuration. The ANFIS model, adaptive power allocation and multi-spot diffuse pattern formation are implemented in MATLAB/SIMULINK. ANFIS consider two input such as SNR & delay. Here according to the logic parameter shown in the table ANFIS has been done to achieve the desired output.

3.8.1 Parameters Used In Neuro-Fuzzy ANFIS Model (Real Time).

Ser	SNR (γ)	Delay Time (Δ_τ)	Traffic (Real Time)
1	H	L	Y
		M	C
		H	N
2	M	L	S
		M	N
		H	N
3	L	L	N
		M	N
		H	N

3.8.2 Meaning Of Parameters Used In Neuro-Fuzzy ANFIS Model

Serial	Legend	Meaning
1	H	HIGH
2	M	MEDIUM
3	L	LOW
4	Y	YES
5	C	CONSIDERED
6	N	NO

3.8.3 ANFIS Model Input (Real Time).

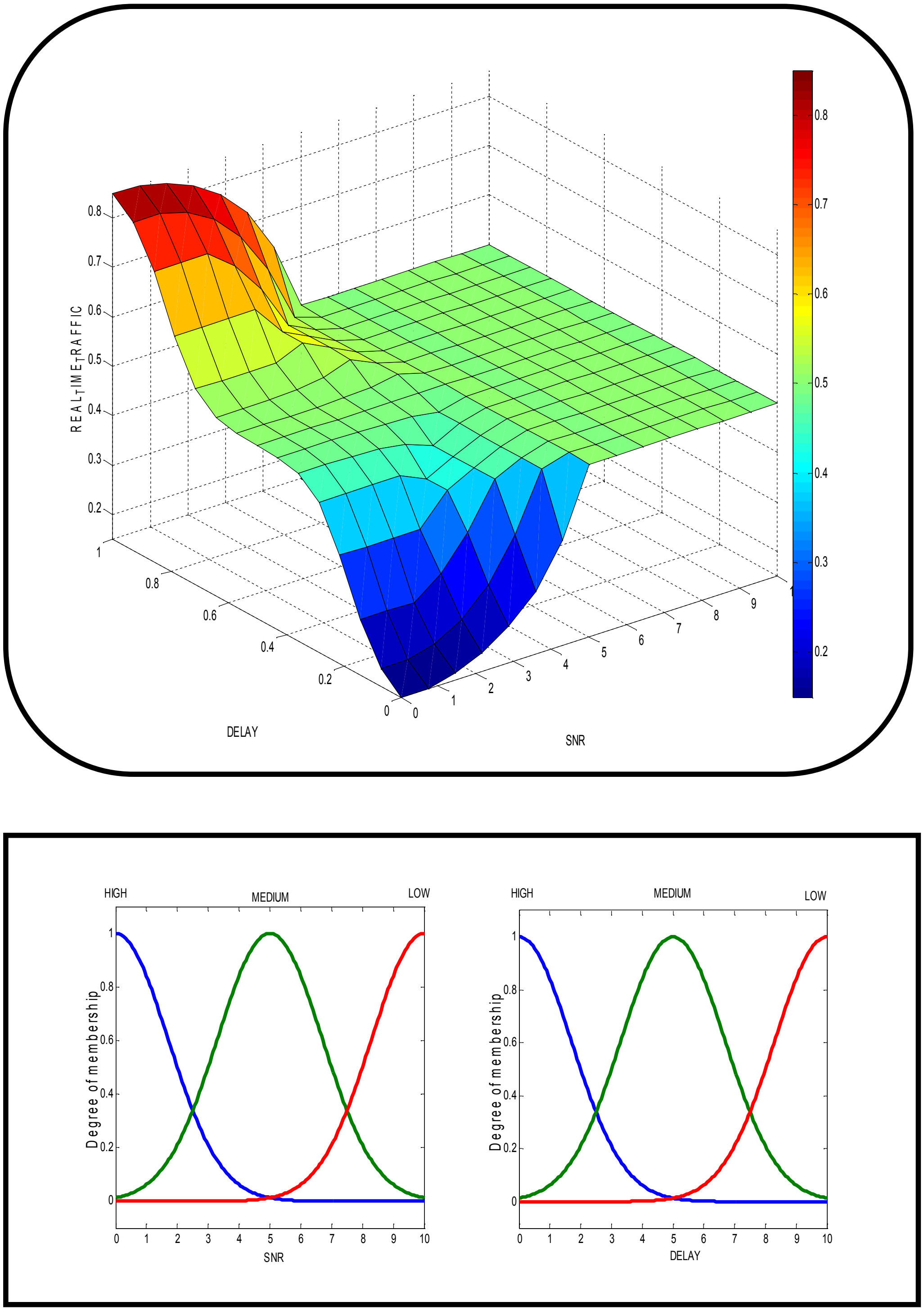
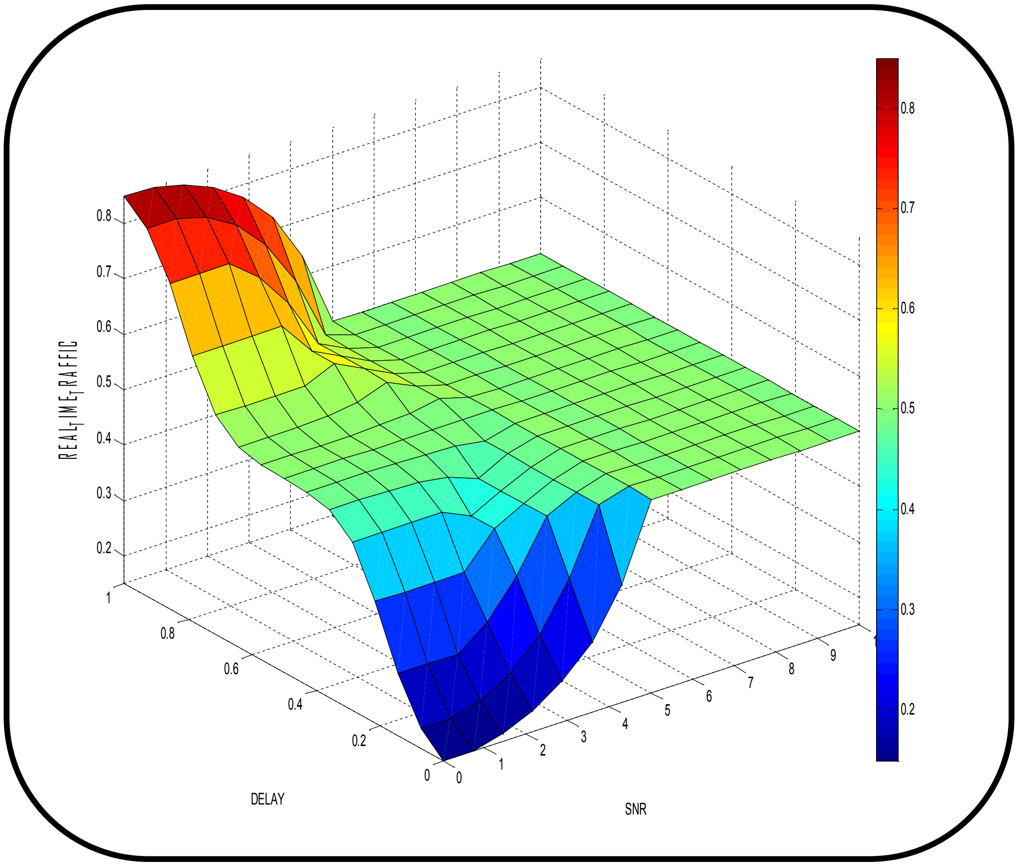


Figure 3.4: ANFIS Model Input (Real Time)

3.8.4 ANFIS Model Output (Real Time).



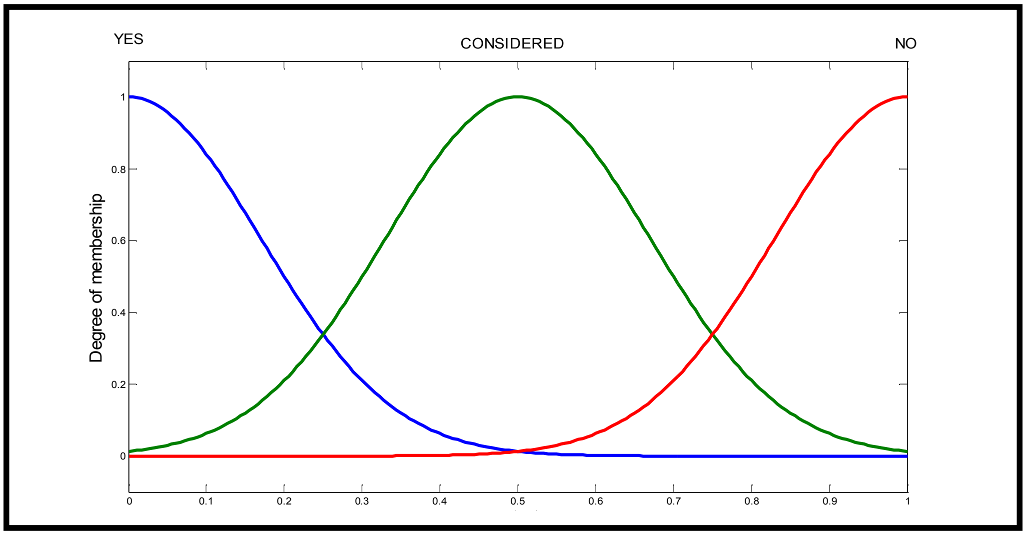


Figure 3.5: ANFIS Model Output (Real Time)

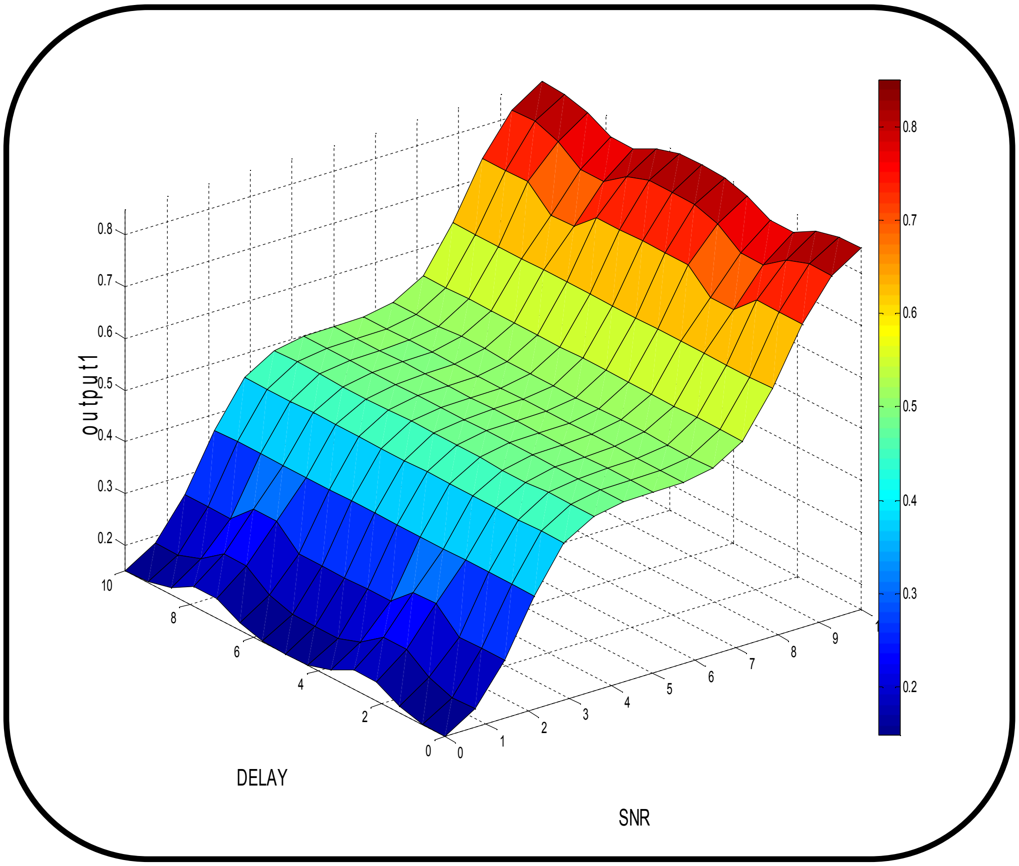
3.8.5 Parameters Used In Neuro-Fuzzy ANFIS Model (Non Real Time).

Ser	SNR (γ)	Delay Time (Δ_τ)	Traffic (non real time)
1	H	L	Y
		M	Y
		H	Y
2	M	L	C
		M	C
		H	C
3	L	L	N
		M	N
		H	N

3.8.6 Meaning Of Parameters Used In Neuro-Fuzzy ANFIS Model

Serial	Legend	Meaning
1	H	HIGH
2	M	MEDIUM
3	L	LOW
4	Y	YES
5	C	CONSIDERED
6	N	NO

3.8.7 ANFIS Model Input (Non Real Time).



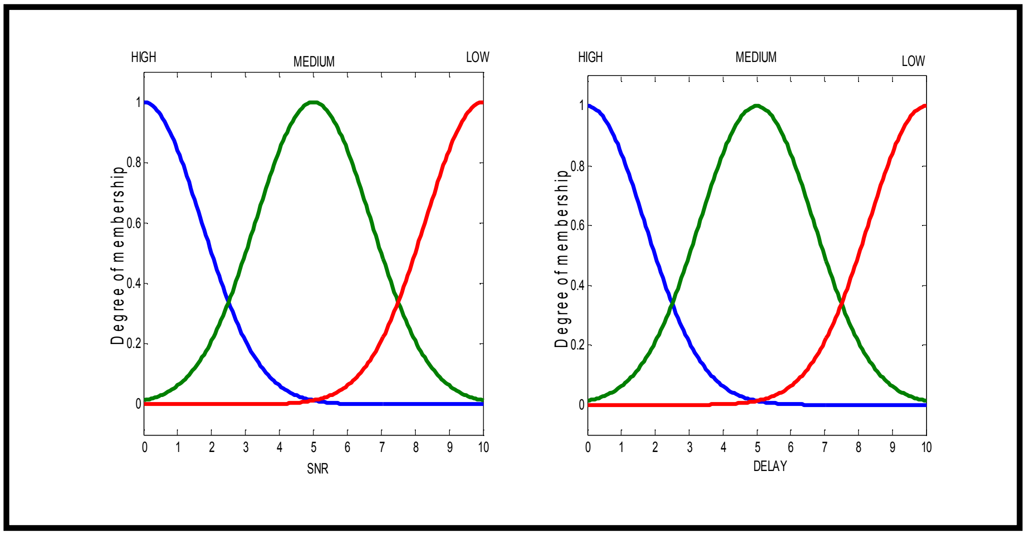


Figure 3.6: ANFIS Model Input (Non Real Time)

3.8.8 ANFIS Model Output (Non Real Time).

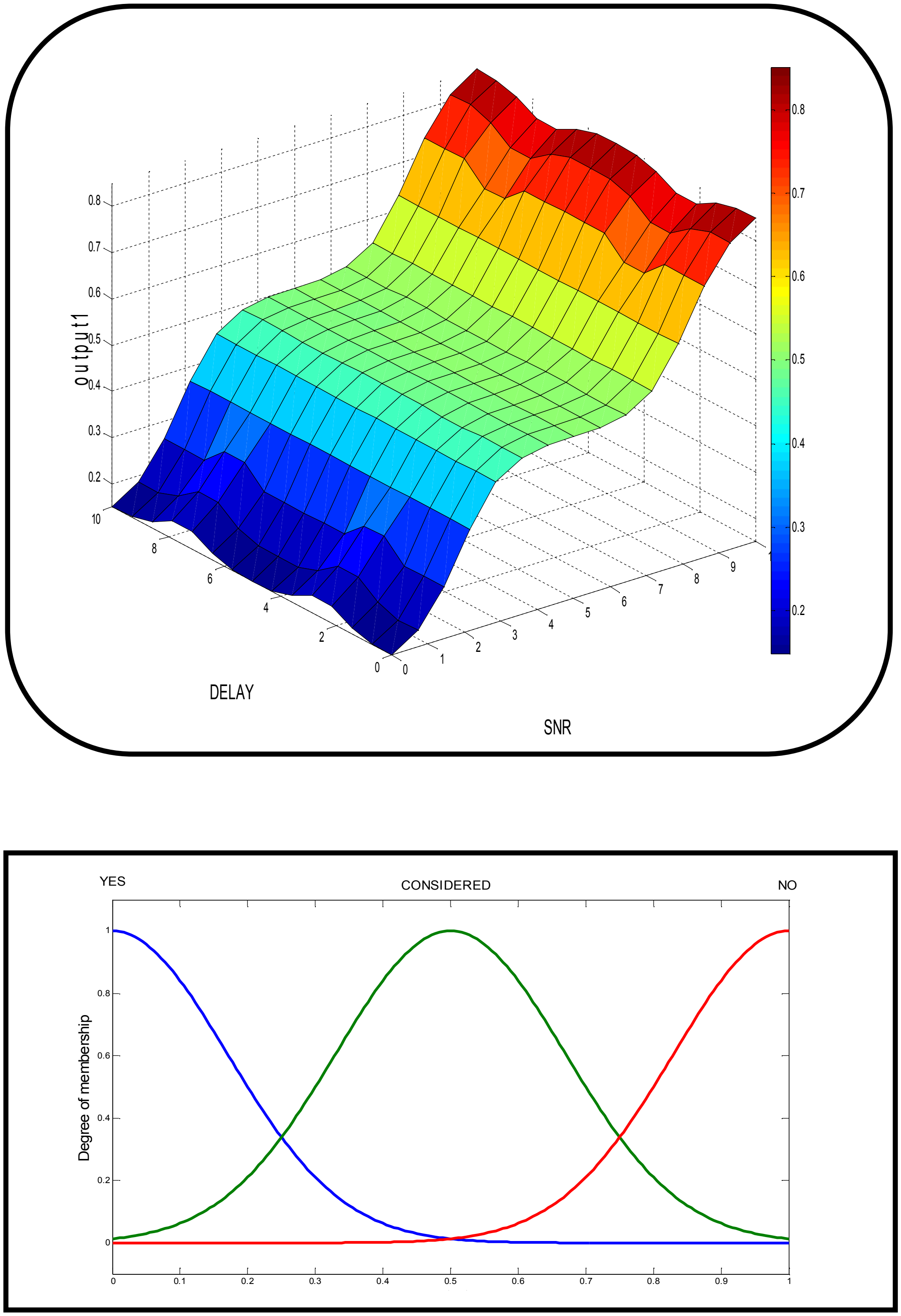


Figure 3.7: ANFIS Model Output (Non Real Time)

CHAPTER 4

Numerical Analysis and Result

4.1 Numerical Analysis.

Simulation parameters considered for the analysis are: length, width and height of the room are 8m, 4m and 3 m; the reflection coefficient of the ceiling is ρ =0:8; there is one transmitter which is located at (2, 4, 1) location; there is also one receiver; the area, acceptance semi-angle of the each photo-diode are $2cm^2$and 65^0 respectively. The number of pixel at the receiver is 200 (with area of $0:01cm^2$) Pedestrians move typically at the speed of 1 m/s. If the SNIR is computed after 10 s; there are 8 spot lamp in the room which are located at (1, 1, 1), (1, 3, 1), (1, 5, 1),(1, 7, 1),(3, 1, 1), (3, 3, 1), (3, 5, 1), and (3, 7, 1); and the wavelength of the light is 850nm

The 80 ms adaptation time will give overhead of 8%. Adaptation time depends on environment. Receiver computes the SNIR and delay spread and sends these information via a low rate channel to the transmitter.

ANFIS consider two inputs. Iterative training of the ANFIS has been done to achieve the desired output. After a predefined simulation time to obtain the simulation result and use them to train.

4.2 Mean Delay Time Calculation.

Assuming the Floor plane and Ceiling plane always same in volume, a (10x8) matrix is formed and assuming the Transmitter (2,5) and receiver (1,1) positions at the floor plane and geometrically assume two variable (x,y). Delay time can be calculated after simulating in MATLAB and from these delay times the mean delay time can be found out.

4.2.1 Delay Time (10x 8 Matrix).

Table 3 Delay Time of (10x8) Matrix

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8
2.70E-08	2.51E-08	2.45E-08	2.52E-08	2.72E-08	3.05E-08	3.48E-08	3.99E-08
2.72E-08	2.52E-08	2.45E-08	2.51E-08	2.70E-08	3.03E-08	3.46E-08	3.97E-08
2.90E-08	2.70E-08	2.62E-08	2.67E-08	2.85E-08	3.16E-08	3.58E-08	4.08E-08
3.21E-08	3.02E-08	2.94E-08	2.98E-08	3.15E-08	3.43E-08	3.82E-08	4.29E-08
3.61E-08	3.43E-08	3.36E-08	3.40E-08	3.55E-08	3.81E-08	4.17E-08	4.60E-08
4.08E-08	3.92E-08	3.85E-08	3.89E-08	4.02E-08	4.26E-08	4.58E-08	4.98E-08
4.59E-08	4.45E-08	4.39E-08	4.42E-08	4.55E-08	4.76E-08	5.05E-08	5.42E-08
5.14E-08	5.01E-08	4.96E-08	4.99E-08	5.10E-08	5.30E-08	5.57E-08	5.90E-08
5.72E-08	5.60E-08	5.55E-08	5.58E-08	5.68E-08	5.86E-08	6.10E-08	6.41E-08
6.31E-08	6.20E-08	6.16E-08	6.18E-08	6.28E-08	6.44E-08	6.67E-08	6.95E-08

Mean Delay Time: 4.2369e-008

4.2.2 3D View of the Mean Delay Time.

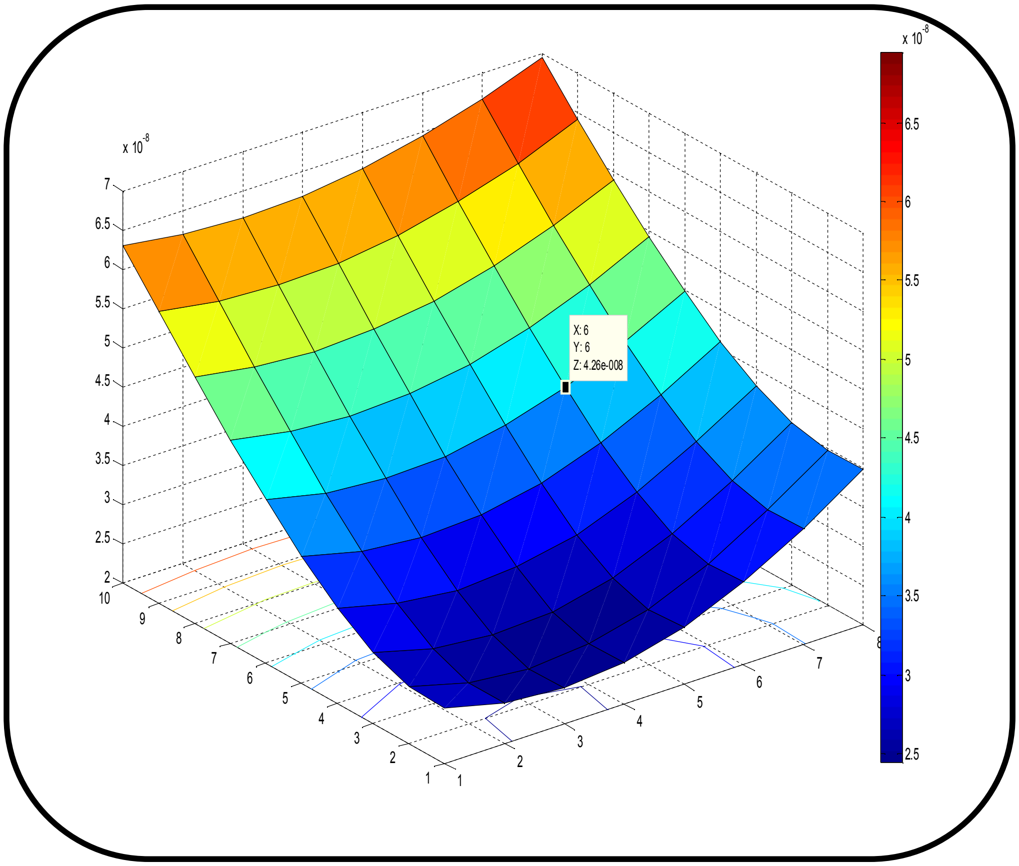


Figure 4.1: 3D View of MATRIX Showing the Mean Delay Time

Multi-beams are reflected by the ceiling and received at the different time. It constitutes delay spread as discussed in the previous chapter. Figure 4.1 shows the surface view of effect of delay for the different possition in the room. It is found that the delay spread is maximum 6.95E-08 for the beam possion (10,8) whereas it is minimum 2.70E-08 for beam position (1,1).

4.2.3 <u>3D View of the Delay Spread</u>.

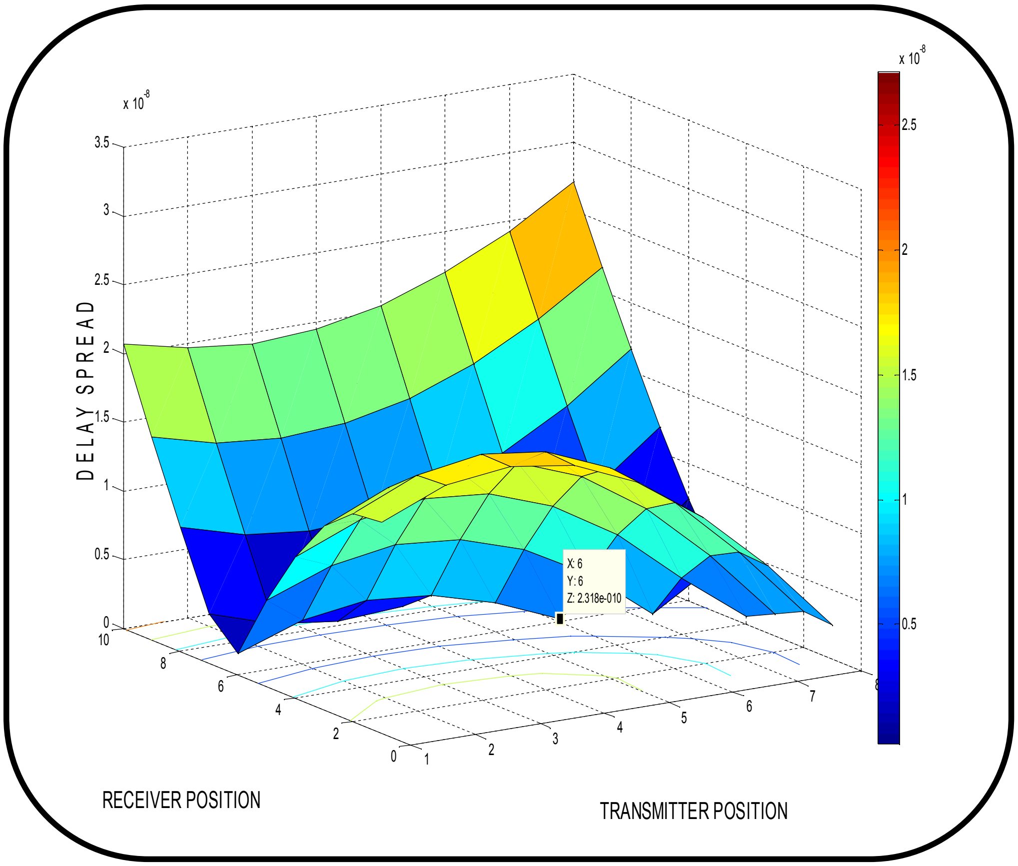


Figure 4.2: 3D View of MATRIX Showing the Delay Spread Time

4.2.4 Effect Of Receiver Position On BER.

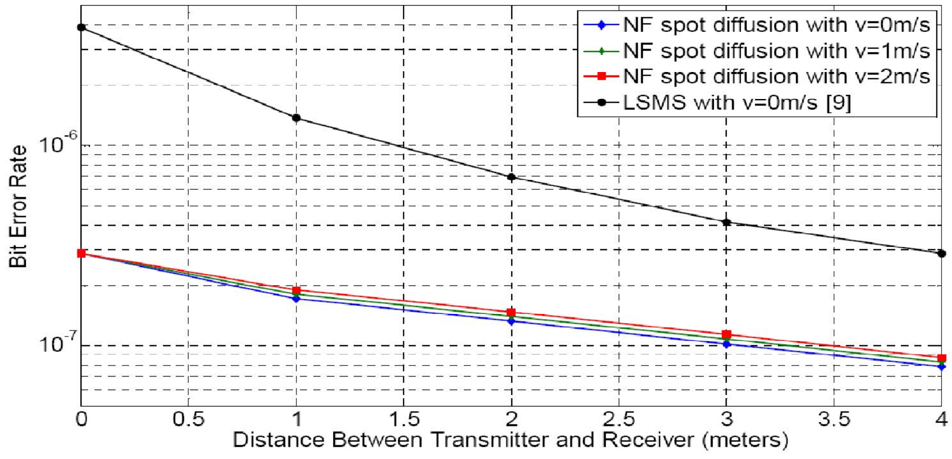


Figure 4.3: Effect of receiver position on BER and LSMS Here the beam pattern is shifted with Doppler shift

4.2.5 Effect Of Receiver Position On Delay Spread.

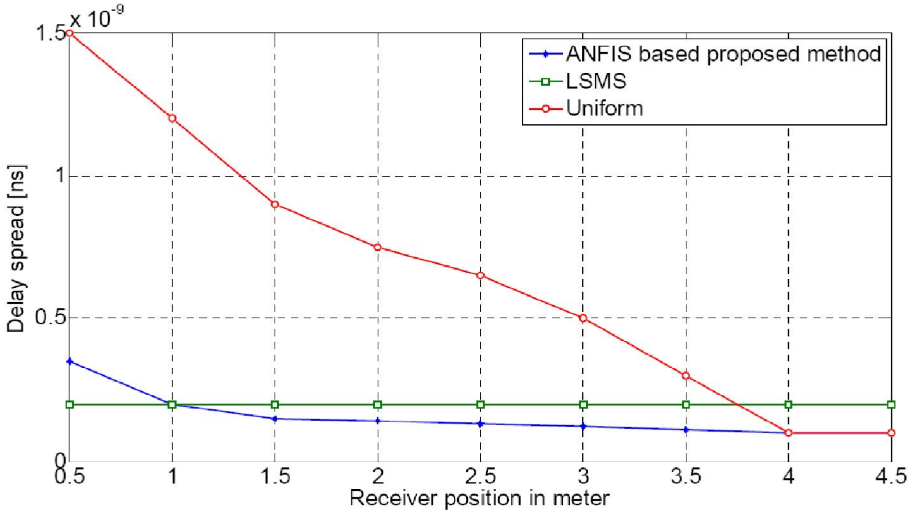


Figure 4.4: Effect of Receiver Position on Delay Spread for proposed model and LSMS.

CHAPTER 5

Conclusion

5.1 Conclusion

In this work, the performance of an OWC system has been evaluated using MATLAB. As a performance metric, BER and delay spread have been considered. It has been found from the literature, OWC system can provide data rate of few tera bit per second, but it can cover only few meters that is the range is short. Moreover the light beams are absorbed by the wall and ceiling. Thus we have improved the BER performance of the system by proposing the multi-beam transmitter where beam and angle of the each beam is adapted based on the channel state information.

Here, we have proposed a new method of real-time beam and angle adaptation technique for OWC system using ANFIS. This NF controller has five layers and is trained with back-propagation gradient decent algorithm. The controller is trained with data obtained by simulations. Simulation results show that the proposed NF based OW spot-diffusing communication system outperforms other spot-beam diffusion method in terms of SNIR and delay spread. ANFIS model distributes power allocation by calculating delay spread in considering Doppler shift effect of the mobile devices.

5.2 Recommendation and Future Works

- In this work, we have considered receiver can move within the room, that is hand-off is ignored. We will extend this work by considering multi-beam multi optical-wireless transmitters are coving all rooms and receiver is moving from one room to another.
- Since there is one user in the room, the interferences created by other users are ignored. We will consider multi-user system.
- Finally, we will design a prototype OWC system.

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Appendix A
Numerical Analysis –Matlab Code

1 Matlab Code:

```
clc
clear all;
close all;

c = 3e8;    % speed of light

A = [1,1; 1,2; 1,3; 1,4; 1,5; 1,6; 1,7; 1,8;
    2,1; 2,2; 2,3; 2,4; 2,5; 2,6; 2,7; 2,8;
    3,1; 3,2; 3,3; 3,4; 3,5; 3,6; 3,7; 3,8;
    4,1; 4,2; 4,3; 4,4; 4,5; 4,6; 4,7; 4,8;
    5,1; 5,2; 5,3; 5,4; 5,5; 5,6; 5,7; 5,8;
    6,1; 6,2; 6,3; 6,4; 6,5; 6,6; 6,7; 6,8;
    7,1; 7,2; 7,3; 7,4; 7,5; 7,6; 7,7; 7,8;
    8,1; 8,2; 8,3; 8,4; 8,5; 8,6; 8,7; 8,8;
    9,1; 9,2; 9,3; 9,4; 9,5; 9,6; 9,7; 9,8;
    10,1; 10,2; 10,3; 10,4; 10,5; 10,6; 10,7; 10,8];
% height of room
h=3;

% position of receiver
x1 = 1;
y1 = 1;

% position of transmitter
x2 = 2;
y2 = 5;
%
for j = 1:10
for i = 1:8

    xu(j,i) = A((j-1)*8+i,1);
    yu(j,i) = A((j-1)*8+i,2);

    d1(j,i) = sqrt((x1-xu(j,i))^2 + (y1-yu(j,i))^2);
    d2(j,i) = sqrt((x2-xu(j,i))^2 + (y2-yu(j,i))^2);

    p1(j,i) = sqrt(h^2+d1(j,i)^2);
    p2(j,i) = sqrt(h^2+d2(j,i)^2);

    pf(j,i) = p1(j,i)+p2(j,i);
```

```
    % delay time for certain point
    delay(j,i) = pf(j,i)/c;

end
end
% mean delay time of the room
mean_delay1 = mean(delay)
mean_delay_final = mean(mean_delay1)
for i = 1:10
    for j = 1:8

    diff_delay(i,j) = delay(i,j)-mean_delay_final;
    diff_delay1(i,j) = abs(delay(i,j)-mean_delay_final);

    end
end

figure(1)
surfc(delay)

figure(2)
surfc(diff_delay)
```