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Study of Wireless Optical CDMA LAN in Indoor Environment

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ABSTRACT

In this paper we present a deeper view on the methods and the application considered in wireless Optical Code Division Multiple Access (OCDMA) systems. The high cost of reconfiguring and maintaining in wired networks makes wireless an economical and flexible alternative to wired system. The advantages of using infrared medium in LAN are noted. Properties of the wireless links are analyzed. Since system architecture plays an important role, the transmitter and receiver models are discussed and their limitations are presented. Modulation schemes are noted and the advantages of different wireless links are studied.

Keywords: Optical Code Division Multiple Access (OCDMA), wireless CDMA, Optical wireless communication.

1. INTRODUCTION

The concept of Wireless CDMA has emerged before 16 years. The CDMA systems are all about encoding the information signal with the pseudo sequence. The main advantage of CDMA systems is that same channel can be used for transmitting many messages. Because of this property network capacity gets increased. The next advantage would be that device integration becomes quite easier. The main application of CDMA is found in the field of LAN (Local Area Network). When the number of users gets increased, system performance needs to be improved without decreasing the bit rate. When coherent CDMA system is used, the required optical sources are likely to be mode-locked lasers producing transform limited pulses, rendering the system expensive and possibly not competitive when compared with those using other access schemes. If an incoherent CDMA system is considered, it might be difficult, at some point, to find lasers for which the coherence time is much shorter than the chip period, a necessary condition for these systems to behave as expected [1].

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More flexible and efficient spectral allocation, asynchronous and high-speed connectivity, no need of centralized control and simpler protocols are some issues that Optical CDMA networks claim as advantages over other multiple access techniques, especially for LANs [2]. Wireless infrared LAN can be used to cover a better area but provides good bandwidth efficiency. It can be used for multimedia networks where bandwidth efficiency is highly required.

Though Radio frequency covers a good area and the user is connected to the network all the times, it can't be used for high data rate services like video conferencing. In this scenario infrared medium is used. The advantages of infrared medium are [3]

- Abundance of unregulated bandwidth: *200 THz in the 700-1500 nm range*
- No multipath fading: *intensity modulation and direct detection*
- High security
- Higher capacity per unit volume (bps/m3): *due to neighboring cells sharing the same frequency*
- Cost effective at rates near 100 Mbps
- Small cell size
- At 800-890 nm and 1550 nm absorption effects are minimal

The optical wireless communication system has the following various advantages compared with radio systems.

- An optical carrier has wide bandwidth available, and is suitable for high speed communication networks.
- The device for an optical wireless transmission system are low in cost, thus the optical wireless communication system is suited for a consumer communication network.
- A light wave cannot penetrate the opaque objects such as walls. It is thought that the light wave is secured against eavesdropping; therefore cell planning in network is simple and easy.
- The optical wireless network occupies no radio frequency spectrum and it can be used where electro-magnetic interference is strictly prohibited, such as hospitals, airplanes, and so on.
- The light waves are worldwide unregulated by any law.

Section 2 deals about the system design of the wireless optical CDMA communication

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system. Section 3 describes the properties of indoor wireless optical CDMA link. Section 4 deal with the strength of wireless optical CDMA and section 5 describe the issues in wireless optical CDMA and section 5 deals the application of wireless optical CDMA.

II. WIRELESS OPTICAL CDMA SYSTEM DESIGN

The system can be designed by constructing the transmitter side. Suitable modulation schemes are chosen and receiver side is designed. Different types of optical wireless links are also discussed.

A. Transmitter Model: The drive circuit of the transmitter transforms the electrical signal to an optical signal by varying the current flow through the light source. This optical light source can be of two types a light emitting diode (LED) or a laser diode (LD). The information signal modulates the field generated by the optical source. The modulated optical field then propagates through a free-space path before arriving at the receiver. Here, a photo detector converts the optical signal back into an electrical form. The following figure illustrates the basic structure of the wireless optical communication system.

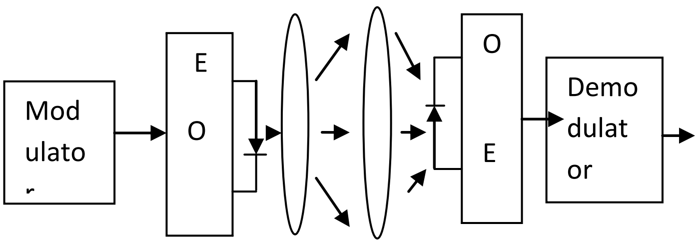

Figure 1 Basic Optical Wireless Communication Systems

One of the most important restrictions to optical wireless transmitters is precisely the optical power level emitted by the source, which, when exceeding specific levels, is potentially dangerous to the human eye. This situation must be taken into account, particularly for indoor free-space optic applications where lasers pose a particular safety hazard to unaware bystanders, which may walk through the path of a wireless IR link. The optical transmitter front end consists of a driver circuit along with a light source.

An Optical Source to transmit light in an optical wireless communication link, a suitable light source is needed at the end of the transmitter circuit. The appropriate light source, can be a light emitting diode (LED) or a laser diode (LD), is chosen depending on the specific application of the system. These optical sources are often considered the active component in an optical communication system. The output properties and the characteristics of the optical source used for the transmitter are important parameters to consider when designing and evaluating an optical wireless communication system [4].

It is important, that the light source launches its energy at angles that optimize the transmitted beam. It is also important that the frequency response of the light source exceeds the frequency of the input signal. Furthermore, the light source should have a long lifetime, present a sufficiently high intensity, and be reasonably monochromatic. Both LEDs and LDs provide good brightness, small size, low drive voltage, and are able to emit a signal at a desired wavelength or range of wavelengths. The selection of one over another depends on the characteristic of the particular application in which they are to be used. When deciding whether to choose an LED or an LD as the light source in a particular transmitter system, one of the main features to consider is their optical power versus current characteristics. This is particularly important because the characteristics of these devices differ considerably (as illustrated in Fig 1).

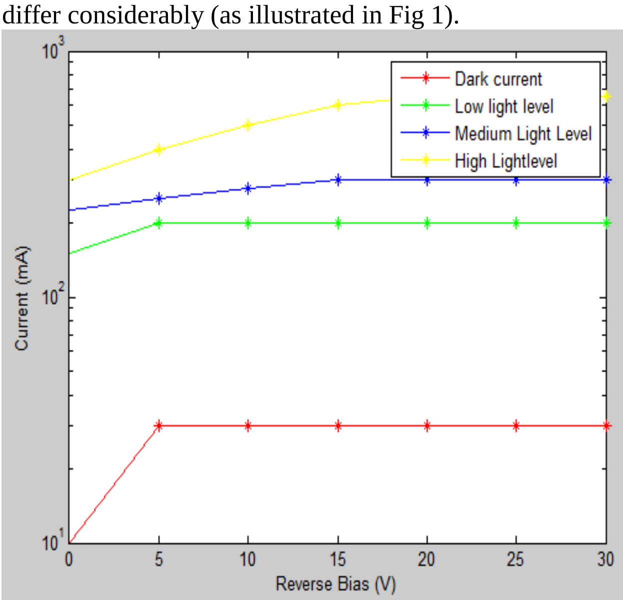

Figure 2: Current –voltage characteristics of a photodiode

It can be seen in the Fig 2. that, near the origin, the LED response is linear, although it becomes nonlinear for larger power values. The laser response, on the other hand, is linear above threshold. Sometimes, mode-hopping creates a slightly nonlinear response above the threshold in a multimode laser. Single-mode lasers exhibit a linear response above the threshold. The linearity of the source is particularly important for analog systems. The power supplied by both devices is similar (about 10 to 20 mW) , but LDs are much more sensitive to temperature variations than LEDs. This is illustrated in Fig, where it can be observed that, as the temperature increases, the laser diode's gain decreases (for example, a laser that at 30 °C requires 70 mA to output 2 mW of optical power may require in excess of 130 mA at 80 °C). This implies that more current is required before oscillation.

TABLE 1 Comparison of LEDs versus LDs for wireless optical links

CHARACTERSTICS	LED	LD
Optical Spectral Band Width	25-100 nm	0.1 to 5nm
Special Circuitry Required	None	Threshold and Temperature Compensation Circuitry
Eye Safety	Considered Eye Safe	Must be rendered eye safe
Reliability	High	Moderate
Cost	Low	Moderateto High
Modulation Bandwidth	Tens of kHz to Hundreds of MHz	Tens of GHz to Tens of GHz

B. Wireless Optical Links

The characteristics of the wireless optical channel can vary significantly depending on the channel that is used. The three kind of the optical links are

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

POINT-TO-POINT LINKS

They operate when there is a direct, unobstructed path between a transmitter and a receiver. A link is established when the transmitter is oriented towards the receiver. In the narrow field-of-view applications, this oriented configuration allows the receiver to reject ambient light and achieve high data rates and low path loss [5]. The below mentioned figure represents the typical point-to-point wireless optical link.

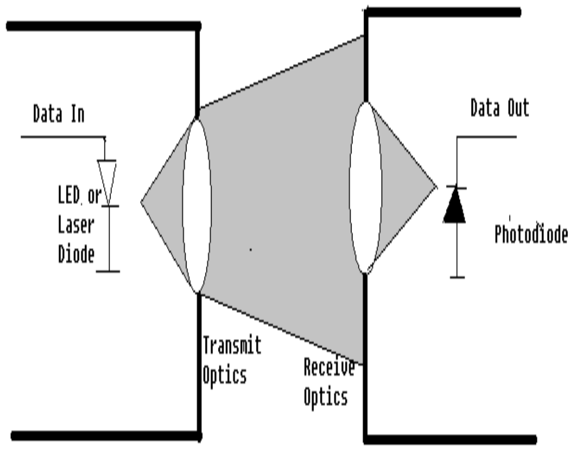

Fig 3 Point-to-Point wireless optical communication system

Following are the disadvantages of point-to-point links

- It requires pointing and is sensitive to blocking and shadowing.
- The frequency response of this link is limited primarily by front-end photodiode capacitance.
- Since inexpensive, large-area photodiodes are typically used with limited reverse bias, the depletion capacitance significantly limits the bandwidth.

Diffuse Links

Diffuse transmitters radiate optical power over a wide solid angle in order to ease the pointing and shadowing problems. The transmitter does not need to be aimed at the receiver since the radiant optical power is assumed to be reflected from the surfaces of the room. This affords user terminals a wide degree of mobility at the expense of high path loss. The following figure represents the block diagram of the diffuse wireless optical communication systems.

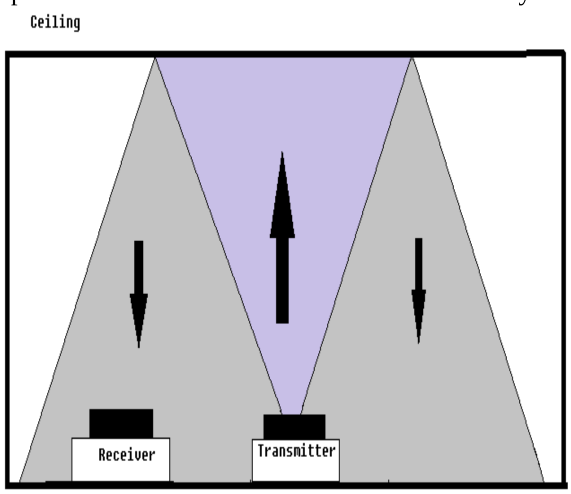

Fig 4 A diffuse wireless optical communication system

Following are the advantages of diffuse links

- Diffuse channels do not exhibit fading. This is due to the fact that the receive photodiodes integrates the optical intensity field over an area of millions of square wavelengths.
- Large size of the photodiode relative to the wavelength of light provides a degree of spatial diversity which eliminates multipath fading.

The disadvantage is that these links suffer not only from optoelectronic bandwidth constraints but also from low-pass multipath distortion.

Quasi-Diffuse Links

Quasi-diffuse links inherit both point-to-point and diffuse links to optimize link throughput. The transmitter illuminates the ceiling with a series of slowly diverging beam sources which illuminates a grid of spots on the ceiling. The transmit beams are created using individual light sources .The data transmitted on all beams are identical. The link is more sensitive to shadowing relative to diffuse links. The figure 5 shows the simple quasi-diffuse wireless optical system.

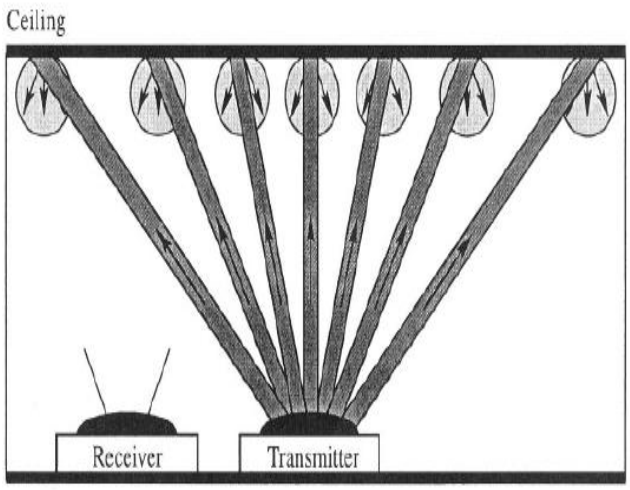

Fig 5 A quasi-diffuse wireless optical communication system.

Comparison Of Optical Wireless Links

TABLE 2.Comparison of diffuse, quasi-diffuse, point-to-point links

PARAMETERS	POINT-TO-POINT	DIFFUSE	QUASI-DIFFUSE
Rate	High	Low-Moderate	Moderate
Pointing Required	Yes	No	Somewhat
Immunity To Blocking	Low	High	Moderate -High
Mobility	Low	High	Moderate -High
Multipath Distortion	None	High	Low

C. Receiver Model:

Optical wireless links operate with limited transmitter power due to eye safety considerations; and in relatively high noise environments due to ambient illumination, the performance of the optical receiver has a significant impact on the overall system performance. To reduce the shot noise introduced in the detector by ambient light, an optical filter is required, while the preamplifier needs to allow for shot-noise limited operation. In addition, due to link budget considerations, the receiver must have a large collection area, can be achieved through the use of an optical concentrator (that offers effective noiseless gain). Furthermore, as indoor and outdoor optical transceivers are intended for mass computer and peripheral markets, the receiver design is extremely cost sensitive, which makes sophisticated optical systems unattractive. The design of an optical receiver depends on the modulation format used by the transmitter.

Optical wireless receiver systems are very similar to fiber-based receiver systems. They consist essentially of a photo detector and a preamplifier, with possibly additional signal processing circuitry [1].Figure 1 illustrates the basic optical receiver structure. Therefore, it is necessary to consider the properties of the photo detector in the context of the associated circuitry combined in the receiver because it is essential that the detector performs efficiently with the following amplifying and signal processing stages. This chapter discusses some of the key issues related to the specification and design of optical wireless receivers.

In the analysis, the sampled value of the detected photons is assumed to be a random variable with Poisson distribution. The effect of background noise such as sunlight and florescent lights and also the effect of photodetector dark current on the system performance is obtained. The main difference between a fiber-optic and a wireless OCDMA receiver is that in the former the detection process can be performed in the optical domain. For example, optical hard-limiter can be placed in the path of incident optical signal. Also fiber tapped-delay lines can be designed to act as a correlates before photo detection. But in our wireless optical system which is implemented on a digital platform all detection operations including hard limiting and correlation is performed after photo detection.

For this reason we study various receiver structures proposed for fiber-optic CDMA that can be used in a typical indoor wireless optical network such as chip-level receiver and correlation + hard-limiter with sunlight, florescent lights, and photo detector dark current as the background noise. Synchronization circuitry which plays an important role in a typical CDMA receiver consists of acquisition and tracking blocks. In the acquisition stage the CDMA receiver is synchronized with an accuracy which is within half of chip time with its corresponding code in the start-up phase.

The exact and dynamic synchronization is achieved during the tracking stage. In a digital system, tracking circuit precision depends on the rate of the fastest achievable clock. Consequently, tracking action in digital systems may not be performed exactly as in some analog systems. Thereby we evaluate the effect of sampling on tracking operation and obtain the power penalty needed to mitigate this undesired effect. The following figure gives the basic correlator structure.

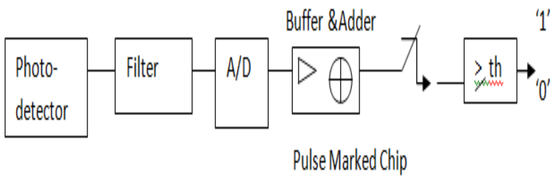

Figure 6 Digital structure of wireless OCDMA receiver-Correlator

Correlation receiver is the most propounded structure for OCDMA systems. This simple receiver involves a matched filter, corresponding to its code pattern, and an integrator followed by a sampler. In optical fiber CDMA systems the matched filter can be implemented by fiber tapped-delay lines at their receivers [6].However, in a typical wireless OCDMA LAN system where the speed of operation is not very high and the distances are relatively short correlation may take place after the photodetection at the receiver. In such a receiver the signal at the output of photodetector is sampled by an analog to-digital converter (A/D) at a rate which is *ns* times of the OOC chip rate. The correlation of the received signal with the desired users' code can be evaluated by the summation of w_{ns} samples of received signal in all marked pulse chips of one bit duration using a simple adder.

A buffer after the A/D operation saves the results of addition at each sampling time instant and resets at the end of the bit time. At the end of the bit duration, the accumulated value that is saved in the buffer, i.e., correlation value is compared with an optimum threshold.

III. PROPERTIES OF INDOOR OPTICAL CDMA WIRELESS LINKS

For low-cost optical wireless communication systems, intensity modulation with direct detection (IM/DD) is the only feasible method of communication .In this mode of operation, the intensity or power of the optical source $x(t)$ is directly modulated by varying the drive current. At the receiver, a photodetector is used to generate a photocurrent $y(t)$, which is proportional to the instantaneous optical power incident upon it. optical wireless system using IM/DD has an equivalent baseband model which hides the high-frequency nature of the optical carrier. This model is illustrated in the, below **Figure 7**, in which R is the photodetector responsivity and $h(t)$ is the linear baseband channel impulse response.

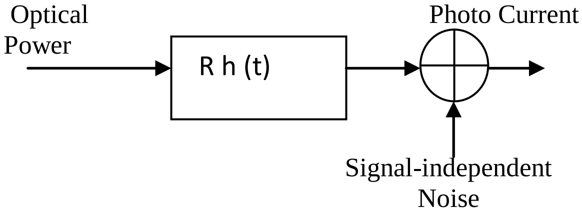

Fig 7 Equivalent baseband model of optical wireless system using IM/DD

As with radio systems, indoor optical wireless links are subject to multipath propagation, which is most pronounced in links using non-directional transmitters and receivers. For both systems, multipath propagation causes the received electric field to undergo severe amplitude fades on the scale of a wavelength, and consequently, a detector smaller than one wavelength would experience multipath fading.

However, infrared wireless receivers have detector areas which are typically millions of square wavelengths, and since the total photocurrent generated is proportional to the integral of the optical power over the entire photo detector surface, this provides an inherent spatial diversity, thus preventing multipath fading Whilst indoor infrared links are not susceptible to multipath fading, multipath propagation does lead to dispersion, which is modeled as a linear baseband channel impulse response $h(t)$.[15,16]

Linearity follows from the fact that the received signal is comprised of multiple spatial modes . The channel is fixed for a given position of the transmitter, receiver and intervening reflectors, and changes significantly only when any of these are moved by distances in the order of centimeters .Due to the high bit rates under consideration and the relatively slow movement of people and objects within a room, the channel will vary significantly only on the time scale of many bit periods, and therefore may be considered to be time invariant.

Infrared wireless transceivers will usually operate in environments containing an intense amount of ambient light, emanating from both natural (solar) and artificial sources. The average combined power of this background radiation generates a DC photocurrent I_B photoodetector, giving rise to shot noise *n*(*t*), which has a single-sided power spectral density *No*, given as

$$N_0 = 2qI_B \quad \_\_(1)$$

where *q* is the electron charge. Even when optical filtering is used to reject out of band light sources, the received signal power is much lower than the power from ambient light sources (typically 25 dB lower [7]). Consequently, I_B is much larger than the maximum photocurrent generated by the signal, and hence, the shot noise may be regarded as white, Gaussian and independent of the received signal [8].

In the presence of intense ambient light, which is usually the case, shot noise is the dominant noise source in a typical diffuse receiver [9]. Note that, if little or no ambient light is present, the dominant noise source is receiver preamplifier noise, which is also signal independent and Gaussian [10]. In addition to contributing to the generation of shot noise, artificial ambient light sources also generate a periodic interference signal, which must be added to *n*(*t*).

The equivalent baseband model of an optical wireless link, as illustrated in Fig.7 can be summarised by [10]:

$$y(t) = Rx(t) \otimes h(t) + n(t) \quad \_\_\_\_\_\_\_(2)$$

where *R* is the photo detector responsivity and the symbol "⊗" denotes convolution. Simply stated, the received photocurrent *y*(*t*) is the convolution of the transmitted optical power *x*(*t*) with the channel impulse response *h*(*t*), scaled by the photo detector responsivity, plus an additive noise *n*(*t*). Whilst (2.5.2) is simply a linear filter channel with additive noise, optical wireless systems differ from conventional electrical or radio systems since *x*(*t*) represents power rather than amplitude. This places two constraints on the transmitted signal. Firstly, *x*(*t*) must be non-negative, i.e.

$$x(t) \geq 0 \quad \_\_\_\_\_\_\_ \quad (3)$$

Secondly, eye safety requirements limits the maximum optical transmit power which may be employed. Generally, it is the average power requirement which is the most restrictive and hence, the average value of *x*(*t*) must not exceed a specified value P_{max}, i.e. [9]:

$$P_{\max} \geq \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} x(t)dt \quad \_\_\_\_\_\_\_\_\_ (4)$$

This is in contrast to the time averaged value of two times *x*(*t*) , which is the case on conventional channels when *x*(*t*) represents amplitude. These differences have a profound effect on system design. On conventional channels, the signal to noise ratio (SNR) is proportional to the average received power, whereas on optical wireless links, it is proportional to the square of the average received optical signal power; thus implying that relatively high optical transmit powers are required, and only a limited path loss can be tolerated.

The fact that the average optical transmit power is limited, suggests that modulation techniques possessing a high peak-to-mean power ratio are favorable. This is generally achieved by trading off power efficiency against bandwidth efficiency. When shot noise is dominant, the SNR is also proportional to the photodetector area. Thus, single element receivers favour the use of large area detectors [11]. However, as the detector area increases so does its capacitance, which has a limiting effect on receiver bandwidth. This is in direct conflict with the increased bandwidth requirement associated with power efficient modulation techniques.

IV. WIRELESS OPTICAL CDMA POTENTIAL STRENGTH An

Abundant Bandwidth : Infrared radiation appears to be a viable alternative to radio for wireless communications. This is because,for indoor short-range cccommunication applications,infrared presents certain advantages when compared with radio-frequency systems.Radio-frequency transmission is regulated by the FCC(Federal Communications Commission) in the USA,and the Radio Communications Agency in the UK and licenses are obtained with difficulty because of the increasing congestion of the frequency bands.The infrared region of the spectrum offers huge bandwidth that is spreaded all over the world [12].

No need for frequency and Time management: Optical CDMA does not need time and frequency management because all the users transmit using the whole BW at the same time. It can also operate asynchronously (as in wireless applications) without packet collisions.Slot allocation requirements are not needed here in contradiction to TDMA and WDMA

Simple communication Protocol

Security against interception: Infrared radiation, just like visible light, is confined to the room in which it is generated, so it cannot be detected outside, securing transmissions against eavesdropping. Also, infrared radiation does not interfere with systems of the same nature operating in neighbouring rooms and does not interfere with the radio frequency spectrum.

Accommodate additional users with less cost and complexity[13]. A new TDMA or WDMA user reduces free bandwidth irreversibly, thus requiring changes to bandwidth allocation. For instance, for every new user added in TDMA, the OLT may be required to run the admission control procedure to protect bandwidth previously guaranteed under ONU service-level agreements (SLA). In OCDMA, adding a user does not reduce the bandwidth of other users. By virtue of its inher- ent bandwidth and quality fairness, OCDMA avoids the complexity of measures such as admission control.

V. TECHNOLOGICAL CHALLENGES IN WIRELESS OPTICAL CDMA:

Unreliable Bandwidth availability : Variations in weather conditions like fog,mist , affect available bandwidth .

*Fog:*Wavelength dependence of fog attenuation change with density Between 0.5-4um attenuation by dense fog increases with wavelength

*Atmospheric Absorption:*Molecular absorption (gases),Aerosol absorption (dust, smoke, water drops).

*Scattering:*Rayleigh Scattering (gases),Mie scattering (aerosol, fog),Geometrical optics (snow, rain)

Requires Line of Sight link: One of the most attractive configurations is the nondirected-non-LOS, or diffuse.Sysyems working under this configuration do not require a direct line of line of sight,or alignment,between the optical transmitter and the receiver because the optical waves are spread as uniformly as possible in the room by making use of the reflective properties of the walls and the ceiling.This kind of link has the advantage that it can operate even when barriers are placed between the transmitter and the receiver.This makes it the most robust and flexible configuration.Inspite of the advantages of the diffuse configuration,this kind of system suffers from multipath distortion and higher optical losses than LOS.

VI. APPLICATION OF WIRELESS OPTICAL CDMA SYSTEM

Short Range Applications[14]

- Weather monitors; fog, snow, rain using light back-scatter
- Traffic counting and monitoring
- Optical Interconnects.

Long Range Applications

- Deep space probe communications; distances measured in light-years
- Building to building computer data links; very high data rates.
- Ship to ship communications; high data rates with complete security.
- Telemetry transmitters from remote monitors; weather, geophysical.
- Electronic distance measurements; hand held units out to 1000 ft.
- Optical radar; shape, speed, direction and range.
- Remote telephone links; cheaper than microwave

Wide Area Applications

- Campus wide computer networks
- City-wide information broadcasting
- Inter-office data links

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