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System Performance Analysis and Enhancement of Optical Wireless Networks

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Abstract— For the last few years, we have seen a growing demand by the end users for bandwidth in mobile communications to support broadband wireless services such as, high-definition TV, mobile videophones, video conferencing and high-speed internet access. With the increasing demand for high-quality multimedia services, the quest for higher bandwidth is expected to grow higher in the next decade. As the global demand for bandwidth continues to accelerate, it is becoming exceedingly clear that copper or coaxial cables and RF cellular or microwave technologies with such limitations as limited bandwidth, congested spectrum, security issues, expensive licensing and high cost of installation cannot meet the upcoming needs. Optical Wireless Communication (OWC) is an innovative technology that has been around for the last three decades and is gaining more attention as the demand for capacity continues to increase. OWC is one of the most promising alternative technologies for indoor and outdoor applications. It offers flexible networking solutions that provide cost-effective, highly secure high-speed license-free wireless broadband connectivity for a number of applications, including voice and data, video and entertainment, enterprise connectivity, disaster recovery, illumination and data communications, surveillance and many others. Due to the unique properties of the optical signal, one can precisely define a footprint and hence can accommodate a number of devices within a small periphery; thus offering a perfect OWC system. OWCs, also referred to as free-space optical (FSO) communication systems for outdoor applications, will play a significant role as a complementary technology to the RF systems in wireless communication.

I. INTRODUCTION

The proliferation of wireless communications stands out as one of the most significant phenomena in the history of technology. Wireless devices and technologies have become pervasive much more rapidly than anyone could have imagined thirty years ago and they will continue to be a key element of modern society for the foreseeable future. Today, the term “wireless” is used almost synonymously with radio-frequency (RF) technologies as a result of the wide-scale deployment and utilization of wireless RF devices and systems. The RF band of the electromagnetic spectrum is however fundamentally limited in capacity and costly since most sub-bands are exclusively licensed. With the ever-growing popularity of data-heavy wireless communications, the demand for RF spectrum is outstripping supply and the time has come to seriously consider other viable options for wireless communication using the upper parts of the electromagnetic spectrum.

Mobile phones, laptops, and global positioning systems are all devices that implement certain forms of wireless communication to send information to another location. However, the availability of current forms of wireless is very limited, and it is not necessarily safe to implement wireless radio, making it necessary to explore other alternatives to wireless communication to allow continued expansion upon communication systems and to ensure safe use. The radio spectrum is highly congested and the demand for wireless data communication is increasing day-by-day. Bandwidth required for the radio frequency communication is rapidly getting exhausted. Introduction of multiple nodes and cell splitting can be done to overcome this, but it is expensive. Also, two nodes do not provide double the capacity of one due to the interference issue. Moreover, doubling the infrastructure will not double the revenue. Recent studies on hazards of radio frequency have found that extreme radio frequency radiation causes adverse effect on environment.

II. OPTICAL COMMUNICATION AND LINK CONFIGURATION

Optical wireless communication systems operating in the visible band (390 nm to 750 nm) are commonly referred to as visible light communication (VLC). VLC systems take advantage of light emitting diodes (LEDs) which can be pulsed at very high speeds without noticeable effect on the lighting output and human eye. VLC can be possibly used in a wide range of applications including wireless local area networks, wireless personal area networks and vehicular networks among others. On the other hand, terrestrial point-to-point OWC systems, also known as the free space optical (FSO) systems, operate at the near IR frequencies (750 nm to 1600 nm). These systems typically use laser transmitters and offer a cost-effective protocol-transparent link with high data rates, that is, 10 Gbit/s per wavelength and provide a potential solution for the backhaul bottleneck. There has also been a growing interest on ultraviolet communication (UVC) as a result of recent progress in solid state optical sources/detectors operating within solar-blind UV spectrum (200nm to 280 nm).

In this so-called deep UV band, solar radiation is negligible at the ground level and this makes possible the design of photon-counting detectors with wide field-of-view receivers that increase the received energy with little additional background noise. Such designs are particularly useful for outdoor non-line-of-sight configurations to support low power short-range UVC such as in wireless sensor and ad-hoc networks.

Over the decades, the interest in OWC remained mainly limited to covert military applications and space applications including inter-satellite and deep-space links. OWCs mass market penetration has been so far limited with the exception of IrDA which became a highly successful wireless short-range transmission solution. Development of novel and efficient wireless technologies for a range of transmission links is essential for building future heterogeneous communication networks to support a wide range of service types with various traffic patterns and to meet the ever-increasing demands for higher data rates. Variations of OWC can be potentially employed in a diverse range of communication applications ranging from optical interconnects within integrated circuits through outdoor inter-building links to satellite communications.

The most common link configurations for indoor OWC systems are the line-of-sight (LOS) and the diffuse or a hybrid LOS-diffuse. Normally, the diffuse system provides a larger coverage area and an excellent mobility, but at the cost of lower data rates, higher path losses and multipath induced intersymbol interference (ISI) caused by the signal reflections from walls and other objects within the room. On the other hand, LOS links, where the beam is confined within a narrow field-of-view (FOV), offer a much higher channel capacity and a longer range. However, LOS links offer a limited coverage area as well as requiring alignment and tracking to maintain link availability. In order to protect the data integrity during transmission the input data should be framed, so as to detect lost signals and to ensure correct transmission and reception of the data. Computer network protocols like stop and wait algorithms are employed to solve this problem.

III. OPTICAL SOURCES AND DETECTORS

There are a number of light sources and photodetectors that could be used for OWC systems. The most commonly used light sources used are the incoherent sources – Light Emitting Diodes (LEDs) and coherent sources LASER Diodes (LD). LEDs are mainly used for indoor applications. However, for short link (e.g., up to a kilometer) and moderate data rates, it is also possible to use LEDs in place of LDs. LASERs, because of their highly directional beam profile, are mostly employed for outdoor applications. Particularly for long transmission links, it is crucial to direct the energy of the information to be transmitted precisely in the form of a well-collimated LASER beam. This is to limit the often still very large channel power loss between the transmitter and the receiver. In order to limit the beam divergence, ideally, one should use a diffraction-limited light source together with a relatively large high-quality optical telescope. At the receiving end, it is also advantageous to use a high-directionality telescope not only to collect as much of the transmitted power as possible but also to reduce the background ambient light, which introduces noise and thus reduces the performance of the link. As for detectors, both PIN and APD photodetectors could readily be used.

A. Light Sources

For optical communication systems, light sources adopted must have the appropriate wavelength, linewidth, numerical aperture, high radiance with a small emitting surface area, a long life, a high reliability and a high modulation bandwidth. There are a number of light sources available but the most commonly used source in optical communications are LEDs and LDs, both of which rely on the electronic excitation of semiconductor materials for their operation. The optical radiation of these luminescent devices excludes any thermal radiation due to the temperature of the material as is the case in incandescent devices. Both LD and LED light sources offer small size, low forward voltage and drive current, excellent brightness in the visible wavelengths and with the option of emission at a single wavelength or range of wavelengths. Which light source to choose mainly depends on the particular applications and their key features, including optical power versus current characteristics, speed and the beam profile. Both devices supply similar power between 10mW and 50 mW.

Light Emitting Diode

The LED is a semiconductor p-n junction device that gives off spontaneous optical radiation when subjected to electronic excitation. The electronic excitation is achieved by applying a forward bias voltage across the p-n junction. This excitation energizes electrons within the material into an excited state which is unstable. When the energized electrons return to the stable state, they release energy in the process and this energy is given off in the form of photons. The radiated photons could be in the UV, visible or IR part of the electromagnetic spectrum depending on the energy band-gap of the semiconductor material. In LEDs, the conversion process is fairly efficient, thus resulting in very little heat compared to incandescent lights. In the working of an LED, the electronic excitation causes electron(s) in the conduction band to spontaneously return to the valence band. This process is often referred to as the radiative recombination. It is so called because the electron returning to the valence band gives off its energy as photon. In effect, the energy of the emitted photon is equal to the energy difference between the conduction and the valence bands, that is, the band-gap energy. Non-radiative recombination occurs when the falling electron only gives out phonons (heat) and not photons.

LASER

LASER is the acronym for Light Amplification by Stimulated Emission of Radiation, is a device that amplifies (generated) light. LASERs are used mainly as an optical oscillator with light bouncing back and forth in an optical cavity. One end of the cavity is made to have almost 100 percent reaction while the other is significantly less to allow the emission of monochromatic light (not exactly single wavelength but a very narrow band of wavelengths, typically 0.15 nm). In the operation of a LASER, certain vital conditions are required to be met before lasing can take place. In LASER, the conversion process is fairly efficient compared to LEDs and it has a high output power. In comparison, for an LED to radiate 1 mW of output power, up to 150 mA of forward current is required, whereas for a laser diode to radiate the same power only 10 mA or less of current is needed.

B. Photodetectors

The photodetector is a square-law optoelectronic transducer that generates an electrical signal which is proportional to the square of the instantaneous optical field impinging on its surface. Thus, the signal generated by a photodetector is always proportional to the instantaneous (received) optical power. Since the optical signal is generally weak, having travelled through the communication channel, the photodetector must therefore meet stringent performance requirements such as high sensitivity within its operational range of wavelengths, a low noise level and an adequate bandwidth to accommodate the desired data rate. The effect of temperature fluctuations on the response of the photodetector is required to be minimal and the device must equally have a long operating life. The wavelengths at which the detector responds to light depend on the detectors material composition.The speed of response and the bandwidth of a photodetector depend on the transit time of the photon-generated carriers through the depletion region, the electrical frequency response determined by the RC time constant and the slow diffusion of carriers generated outside the depletion region.

There are four types of photodetectors that could be used in optical receivers – PIN photodiodes (with no internal gain, which is compensated by a larger bandwidth), APDs, photoconductors and metal-semiconductor-metal photodiodes. Both PIN and APD are the most popular and widely used detectors for OWC systems.

PIN Photodetector

The PIN photodetector consists of p and n type semiconductor materials separated by a very lightly n-doped intrinsic region. In normal operating conditions, a sufficiently large reverse bias voltage is applied across the device. The reverse bias ensures that the intrinsic region is depleted of any charge carriers. For the device to convert an incident photon into an electron (electric current), the energy of the incoming photon must not be less than the band-gap energy of the semiconductor material. The incident photon uses its energy to excite an electron from the valence band to the conduction band, thereby generating a free electron hole pair in the process. Normally, the incident light is concentrated on the depleted intrinsic region. The high electric field present in this depleted region causes the generated charge carriers to separate and be collected across the reverse biased junction. This gives rise to a current flow in an external circuit.

APD Photodetector

The APD (Avalanche Photodiode) is different from the PIN photodetector in that it provides an inherent current gain through the process called repeated electron ionization. This culminates in increased sensitivity since the photocurrent is now multiplied before encountering the thermal noise associated with the receiver circuit. Typical gain values lie in between 50 and 300. Thus, the responsivity value of an APD can be greater than unity. The APD offers a higher sensitivity than the PIN detector. But the statistical nature of the ionization or avalanche process means that there is always a multiplication noise associated with the APD. The avalanche process is also very temperature sensitive. These factors are very important and must always be taken into account whenever an APD is used in an optical communication system.

IV. SYSTEM DESCRIPTION

In an optical wireless communication system, a source produces information waveforms which are then modulated onto an optical carrier. The generated optical field is radiated through the atmosphere towards a remote destination. At the receiver, the field is optically collected and a photo-detector transforms the optical field to an electrical current. The receiver processes the detected electrical current to recover the original transmitted information.

Transmitter

As illustrated in the figure, the transmitter consists of an optical source, a modulator, an optical amplifier (if required), and beam forming optics. Channel coding can be optionally used before modulation. Data bits from the information source are first encoded, and then modulated. The modulated LASER beam (modulated light from LED in case of visible light) is then passed through the optical amplifier to boost the optical intensity. The light beam is collected and refocused by means of beam forming optics before being transmitted.

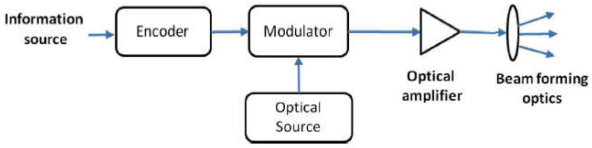

Fig. 1. Block diagram representation of OWC transmitter

An important factor for LASER transmitters is the safety issues. The primary safety concern is the potential exposure of the eye to the LASER beam. Several standards have been developed to limit the transmitted optical power, which rely on parameters such as the laser wavelength and the average and peak transmission power. In fact, only certain wavelengths in the near-IR wavelength range can penetrate the eye with enough intensity to damage the retina. Other wavelengths tend to be absorbed by the front part of the eye before the energy is focused on the retina. In fact, the absorption coefficient at the front part of the eye is much higher for longer wavelengths (greater than 1400 nm). For this reason, the allowable transmission power for LASERs operating at 1550 nm is higher, and hence, they are considered for longer distance transmissions.

Receiver

OWC systems can be broadly categorized into two classes based on the detection type - Non-coherent and coherent. In coherent systems, amplitude, frequency, or phase modulation can be used. At the receiver side, the received field is optically mixed before photo-detection with a locally generated optical field. In non-coherent systems, the intensity of the emitted light is employed to convey the information.

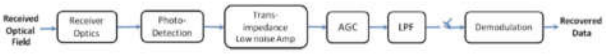

Fig. 2. Block diagram representation of OWC receiver

At the receiver side, the photo-detector directly detects changes in the light intensity without the need for a local oscillator. These systems are also known as intensity- modulation direct-detection (IM/DD) systems. Although coherent systems offer superior performance in terms of background noise rejection, mitigating turbulence-induced fading, and higher receiver sensitivity, IM/DD systems are commonly used in the terrestrial OWC links due to their simplicity and low cost.

The receiver front-end in an IM/DD FSO system consists of optical filters and a lens which has the role of collecting and focusing the received beam onto the photodiode (PD). The PD output current is next converted to a voltage by means of a trans-impedance circuit, usually a low-noise Op-Amp with a load resistor. This latter is determined based on the transmission rate, the dynamic range of the converted electrical signal, the generated receiver thermal noise, and impedance matching with the other receiver parts.

The solid state PD can be a PIN diode or an avalanche photodiode (APD). PIN diodes are usually used for FSO systems working at ranges up to a few kilometers. The main drawback of PIN diodes is that the receiver performance becomes very limited by the thermal noise. For long distance links, APDs are mostly used which provide a current gain thanks to the process of impact ionization. The drawback of APDs is the excess noise at their output, which models the random phenomenon behind the generation of secondary photo-electrons. Due to this reason, the APD gain is usually optimized with respect to the received signal power in order to maximize the received SNR. The advantage of APD comes at the expense of increased implementation complexity. In particular, we require a relatively high voltage for APD reverse biasing that necessitates the use of special electronic circuits. This also results in an increase in the receiver power consumption. The optical pre-amplifiers can be used in long range OWC links to improve the performance. In the 1550 nm wavelength, an Erbium-doped fiber amplifier (EDFA) is a good choice. Semiconductor optical amplifiers (SOAs) can also be used in a variety of wavelengths (including 1550 nm).

V. MODULATION TECHNIQUES

The eye safety introduces a limitation on the amount of optical power being transmitted. For indoor applications, the eye safety limit on transmit optical power is even more stringent. The optical channel differs significantly from the RF channels. Unlike RF systems where the amplitude, frequency and phase of the carrier signal are modulated, in optical systems, it is the intensity of the optical carrier that is modulated in most systems operating below 2.5 Gbps data rates. For data rates greater than 2.5 Gbps, external modulation is normally adopted. Additionally, the use of photodetectors with a surface area many times larger than the optical wavelength facilitates the averaging of thousands of wavelength of the incident wave.

On-Off Keying (OOK)

Among all modulation techniques based on intensity modulation with direct detection, on-off keying (OOK) is the most used scheme for digital optical transmission due to its simplicity. A bit one is simply represented by an optical pulse that occupies the entire or part of the bit duration while a bit zero is represented by the absence of an optical pulse. Both return-to-zero and non-return-to-zero schemes can be applied. In the NRZ scheme, a pulse with duration equal to the bit duration is transmitted to represent 1 while in the RZ scheme, the pulse occupies only the partial duration of bit.

The electrical power spectral densities of OOK-NRZ and OOK-RZ (Duty cycle = 0.5) assuming independently and identically distributed (IID) ones and zeros are given by

$$s_{OOK-NRZ}(f) = (P_r R)^2 T_b \quad \left(\frac{(\sin \pi f T_b)}{(\pi f T_b)}\right)^2 \left(1 + \frac{\delta(f)}{T_b}\right) \ (1)$$

$$s_{OOK-RZ(DUTY\ CYCLE=0.5)}(f) = (P_r R)^2 T_b \quad \left(\frac{(\sin \pi f T_b/2)}{(\pi f T_b/2)}\right)^2 \left(1 + \sum_{n=-\infty}^{\infty} \frac{\delta(f \quad \frac{n}{T_b})}{T_b}\right)$$

(2)

where, $\delta(f)$ is the Dirac delta function, f = Frequency, Tb = Bit duration, Rb = Bit rate, Pr = Average optical power, R = Responsivity

Pulse Position Modulation (PPM)

In PPM, each symbol interval of duration *T = log2 L/Rb* is partitioned into L subintervals, or chips, each of duration *T/L*, and the transmitter sends an optical pulse during one and only one of these chips. For any *L* greater than 2, PPM requires less optical power than OOK. In principle, the optical power requirement can be made arbitrarily small by making *L* suitably large, at the expense of increased bandwidth. The bandwidth required by PPM to achieve a bit rate of *R*b is approximately the inverse of one chip duration, *B = L/T*. In addition to the increased bandwidth requirement, PPM needs (compared to OOK) more transmitter peak power and both chip- and symbol-level synchronization.

$$s_{PPM}(f) = |\mathrm{P(f)}|^2 + [s_{C,PPM}(f) + \ s_{D,PPM}(f)] \ \ (3)$$

$$s_{C,PPM}(f) = \frac{1}{\mathrm{T_{sym}}} + \left[1 \quad \frac{1}{L}\right] + \frac{2}{L}\sum_{k=1}^{L-1}\left(\left(\frac{\mathrm{k}}{\mathrm{L}} \quad 1\right)\cos\frac{k2\pi f \mathrm{T_{sym}}}{L}\right) \ (4)$$

$$s_{D,PPM}(f) = \frac{2\pi}{\mathrm{T_{sym}}^2}\sum_{k=-\infty}^{\infty}\delta\left(\mathrm{f} \quad \frac{\mathrm{kL}}{\mathrm{T_{sym}}}\right) \ \ (5)$$

f = Frequency, L = Symbol length, Tsym = Symbol duration, Sc = Continuous component, Sd = Discrete component, P(f) = Fourier transform of pulse shape

Digital Pulse Interval Modulation

In DPIM, the information is encoded by inserting empty slots between two pulses. The DPIM offers a reduced complexity compared to PPM due to its built-in symbol synchronization. Guard slots can also be inserted.

$$s_{DPIM}(f) = \frac{1}{T_{sym\_DPIM}}|\mathrm{P(f)}|^2 + [s_{C,DPIM}(f) + \ s_{D,DPIM}(f)] \ (6)$$

$$s_{C,DPIM}(f) = \sum_{k=-5L}^{5L}\left(\mathrm{R_k} \quad \frac{1}{\mathrm{L}^2}\right)\mathrm{e}^{-\mathrm{j}2\pi k f T_{sym\_DPIM}} \ \ (7)$$

$$s_{D,DPIM}(f) = \frac{2\pi}{{T_{sym\_DPIM}}^2\mathrm{L}^2}\sum_{k=-\infty}^{\infty}\delta\left(\mathrm{f} \quad \frac{2\pi\mathrm{k}}{T_{sym\_DPIM}}\right) \ (8)$$

f = Frequency, L = Symbol length, Tsym_DPIM = Symbol duration, Sc = Continuous component, Sd = Discrete component, P(f) = Fourier transform of pulse shape

Dual Header - Pulse Interval Modulation

In PIM-DH, for an M bit input word, the maximum number of time slots in each sampling period is n = 2^M. Depending on the most significant bit (MSB) of the frame generated, different header and information time slots are provided. For MSB = 0 each frame consist of a header of g_1T_s time duration displaced from the previous header by a number of time slots proportional to the decimal value of the input data. For MSB = 1 each frame starts with a header of g_2T_s time duration pulse, where the duty cycle $0 < g_1 < g_2 \leq 1$, followed by a number of time slots corresponding to the decimal value input data after taking its 2's complements.

VI. IMPLEMENTATION AND SIMULATION RESULTS

The simulation is done using *MATLAB* software. *MATLAB* (*MAT*rix *LAB*oratory) is a numerical computing environment and fourth-generation programming language. The software is developed by MathWorks Incorporated. The matrix manipulations, plotting of functions and data and implementation of algorithms can be done using this platform. These are often used in physical and mathematical problems and are most useful when it is difficult or impossible to obtain a closed-form expression, or infeasible to apply a deterministic algorithm. The goal of conducting simulations is to verify and validate the selection of parameters as well as to visualize the intermediate results not obtainable from experimental results.

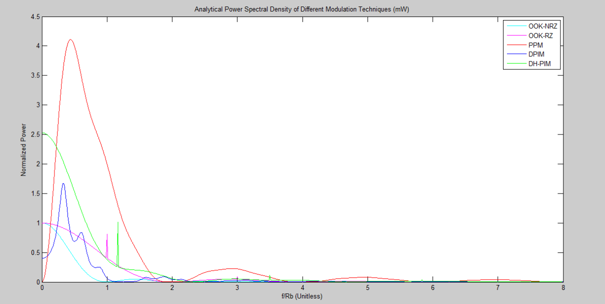

Fig. 3. Comparison of various modulation techniques for optical communication

The four digital modulation schemes popular in optical wireless communication systems (OOK, PPM, DPIM and DH - PIM) are compared based on bandwidth requirement, power efficiency and transmission capacity. In OOK, the bandwidth requirement is roughly equivalent to the data rate. PPM achieves higher average power efficiency than OOK at the expense of an increased bandwidth compared to OOK. Besides, the use of PPM imposes more system complexity compared to OOK at the receiver.

Unlike PPM, DPIM does not require symbol synchronization since each symbol is initiated with a pulse. Furthermore, DPIM displays a higher transmission capacity by eliminating all the unused time slots from within each symbol. DH - PIM requires marginally higher optical power compared to PPM and DPIM techniques. It supports the same bit rate with much lower bandwidth requirement. The header pulse plays a dual role of symbol initiation and time reference for the preceding and succeeding symbols, thus resulting in a built-in symbol synchronization in DH-PIM.

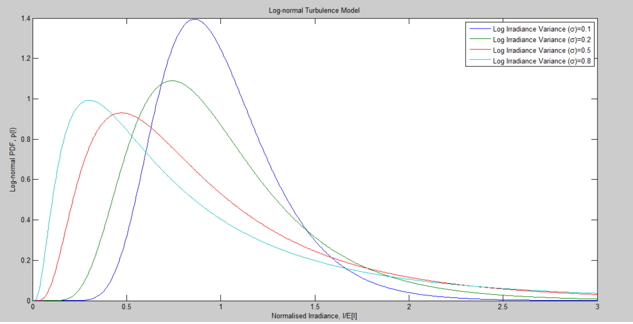

Fig. 4. Log-normal turbulence model

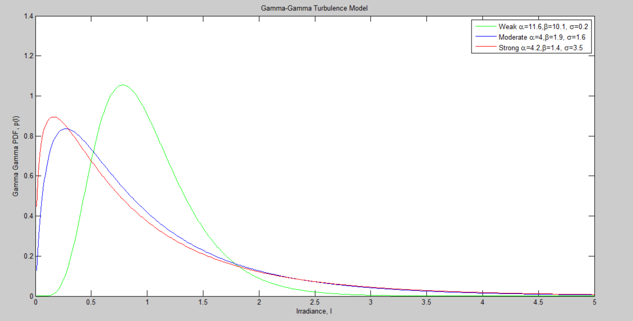

Fig. 5. Gamma-gamma turbulence model

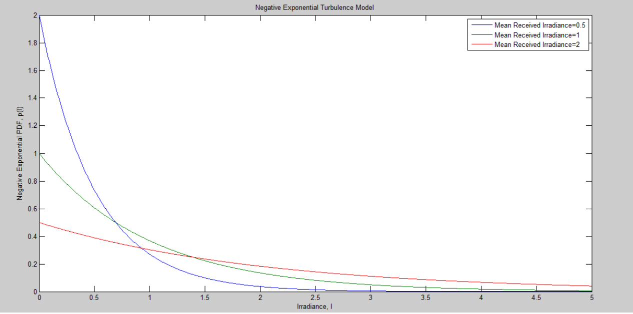

Fig. 6. Negative exponential turbulence model

The solar radiation absorbed by the Earth causes air around its surface to be warmer than that at higher altitude. Layer of warmer air becomes less dense and rises to mix turbulently with the surrounding cooler air. This inhomogeneity produces eddies of different temperature which acts as refractive prisms. The interaction between LASER beam and the turbulent medium results in random phase and amplitude variations of optical beam. It results in fading of the received optical power, leading to the system performance degradation.

The major atmospheric turbulence models used for optical wireless channel modelling are Log-normal turbulence model, Gamma-gamma turbulence model and Negative exponential turbulence model. Log-normal turbulence model is used to denote the extent of fluctuation of irradiance as channel inhomogeneity increases. The log-normal distribution function to obtain the irradiance PDF is given by

$$p(I) = \frac{1}{\sqrt{2\pi\sigma^2}} \frac{1}{I} \exp\left(\frac{-\ln\left(\frac{I}{I_0}\right) + \frac{\sigma^2}{2}}{2\sigma^2} \right) \qquad (9)$$

p(I)=Log-normal Distribution Function, σ^2=Log Irradiance Variance, I= Irradiance, I =Mean Irradiance

The fluctuation of light radiation traversing a turbulent atmosphere is assumed to consist of small-scale (scattering) and large-scale (refraction) effects in gamma-gamma turbulence model. Small-scale effects include contributions due to eddies or cells smaller than the Fresnel zone. Large-scale are generated by the turbulent eddies larger than that of the first Fresnel zone. As turbulence increases from weak to strong regime, distribution spreads out more, with an increase in irradiance. The gamma-gamma distribution function to obtain the irradiance PDF is given by

$$p(I) = \frac{2(\alpha\beta)^{\left(\frac{\alpha+\beta}{2}\right)}}{\Gamma(\alpha)\Gamma(\beta)} I^{\left(\frac{\alpha+\beta}{2}-1\right)} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right) \qquad (10)$$

p(I)=Gamma-Gamma Distribution Function, α=Effective number of large-scale eddies, β= Effective number of large-scale eddies, Γ(.)=Gamma Function, I= Irradiance, Kn(.)=Bessel Function

In saturation regime and beyond, the link length spans several kilometres, the number of independent scatterings becomes large. The amplitude fluctuation of the field traversing the turbulent medium in this situation is generally believed and experimentally verified to obey the Rayleigh distribution implying negative exponential statistics for the irradiance, that is,

$$p(I) = \frac{1}{I_0} \exp\left(\frac{-I}{I_0} \right) \qquad (11)$$

As turbulence increases from weak to strong regime, distribution spreads out more, with an increase in irradiance. This is explained in the three various turbulence models.

VII. CONCLUSION

The development of novel and efficient wireless technologies for a range of transmission links is essential for building future heterogeneous communication networks to support a wide range of service types with various traffic patterns and to meet the ever-increasing demands for higher data rates. Optical wireless communication (OWC) enables wireless connectivity using infrared, visible or ultraviolet bands. With its powerful features such as high bandwidth, low cost and operation in an unregulated spectrum, OWC can be, in some applications, a powerful alternative to and, in others, complementary to the existing wireless technologies. Optical wireless communication should be considered as an essential component of such heterogeneous networks. With their large optical bandwidth, OWC systems can be used, in some applications, as a powerful alternative to and, in others, as complementary to the existing RF wireless systems. OWC system provides advantages including ubiquitous computing, highly secure data transmission, very high data, low cost of maintenance, low power consumption, safety and reliability.

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