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Comparison of Free Space Optical Communication System With And Without Pointing Errors

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Abstract: From several years Free Space Optical (FSO) Communication system has become more and more interesting and also which can be used as an exchange or alternative to radio frequency (RF) communication system. In this paper the effect of atmospheric turbulence mainly called pointing error on Free Space Optical communication system is investigated. The end to end capacity of dual hop Free Space Optical communication system assuming that the channel state information is only known at the receiver part. The performance of the considered system is mainly affected by misalignment fading, atmospheric turbulence induced fading, pointing errors. Numerically evaluated and computer simulation results are further provided to demonstrate the comparison of Free Space Optical communication system with and without pointing errors in dual amplify and forward relayed system over turbulence channel.

Keywords: Amplify and Forward, Atmospheric turbulence, Dual-hop system, Free Space Optics, Pointing errors

I. INTRODUCTION

For high speed and fast proof communication, Free Space Optical communication has introduced. The research community have attracted to their ability to attain high data rates (multiple gigabits) under unlicensed spectrum along with low installation and operational cost. FSO can also be used as a backup link, also can be used as a backhaul traffic between the base stations and main switching centres and HDTV transmission. FSO mainly needs a direct Line Of Sight (LOS) technology that utilizes the light to transfer the data between source and receiver. Free Space Optical system which is mainly affected by several atmospheric conditions such as scattering, absorption and turbulence.

The decrease in overall performance and the increase in error rate is mainly due to the fluctuation that is caused by the signal that propagates through the point to point wireless optical channel. Fluctuations are mainly caused by the aerosol scattering caused by rain, fog, snow. The major issue of a FSO system is that it is highly depended on pointing performance. The misalignment between source and destination of free space optical communication is caused due to the vibrations that occur in the propagating beams through the tall buildings and resulting to the pointing errors.

The employment of multiple transmit and receive aperture will mitigate the effects of atmospheric turbulence. By using spatial diversity, that is by using multiple input multiple output FSO system offers significant enhancement in the performance. Although the performance of FSO relaying system over fading channel evaluated in terms of outage probability and error rate, the capacity of FSO system is also evaluated. Analytical expression for the ergodic capacity of dual hop FSO operation is analysed. By evaluating the probability density function of end to end signal to noise ratio, where the parameters are calculated from the moments of end to end SNR. Upper bounds for the end to end capacity are analyzed by Jensen's inequality as well as gain relaying system.

II. SYSTEM MODEL

Energy efficient dual hop optical wireless communication system using intensity modulation with direct detection and On-Off keying modulation. The performance of the considered modulation is limited by background radiation and thermal noise. For the good approximation of poison photon counting detection, consider additive white Gaussian noise model. The modulated light source S, propagates to the destination node D, through an optical transceiver which can be named as relay node. It is assumed that the channel state information is known only at the receiving terminal. Total transmission time are allocated equally to each transmitting terminal along the dual-hop path. It is assumed that only one transmitting node transmits in each time slot.

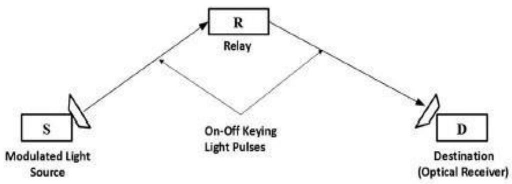

Figure 1:Dual-Hop optical wireless communication system

The signal at the r[th]receive aperture is defined by:

$$y_r = R_r h_r x_{r-1} + n_r \qquad (1)$$

where y_r is the signal at the r^{th} receiver aperture; $R_r$is the detector responsivity at the r^{th} node; h_r is the channel state

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from the r^{th}hop $x_{k-1} \in \{0,2P_{t,r-1}\}$, represents the OOK modulated information bits from the($r-1)^{th}$ terminal, where $P_{t,r-1}$ is the average transmit optical power at the r^{th} node; and n_r is the AWGN at the r^{th} terminal with zero mean and variance $\sigma_{n,r}^2 = \frac{N_0}{2}$.

The channel state h_r models the random fluctuations of the propagation channel resulting from atmospheric loss, turbulence and misalignment induced fading, which can be described as

$$h_r = h_{r,l} h_{r,s} h_{r,p} \quad (2)$$

where$h_{r,l}$, $h_{r,s}$, $h_{r,p}$ describes attenuation due to the beam extinction arising from both scattering and absorption, turbulence effects and misalignment fading effects. The values of $h_{r,}$ and $h_{r,}$ randomly vary with time and $h_{r,}$ is deterministic parameter which shows the variations in fading channel on the order of milliseconds. Moreover time scales of these fading processes are far larger than the bit interval ($\equiv 10^{-9}$s), is considered to be constant over a large number of transmitted bits. In a dualhop transmission system employing AF relaying, the end-to-end received instantaneous electrical SNR at the destination for the relaying transmission is given by

$$\omega = \frac{\omega_1 \omega_2}{C_2 + C_1\omega_1 + \omega_2} \quad (3)$$

whereω_r, is the instantaneous electrical SNR of the r^{th}hop defined as

$$\omega_r = \frac{2P_{t,r}^2 R_r^2 h_k^2}{\sigma_{n,r}^2} \quad (4)$$

whereω is tightly upper bounded at high SNRs for $C_1 = 1$ and $C_2 = 0$ for CSI assisted relays. An ideal relay that can amplify the incoming signal with the inverse of the channel gain of the first hop, although it is regardless of AWGN at that hop.

III. CHANNEL MODEL

The atmospheric loss is defined as

$$h_{r,l}(z) = \exp(-S_z) \quad (5)$$

where$h_{r,l}(z)$ is the loss over a propagation path of length z, and S denotes a wavelength and weather-dependent attenuation coefficient. In clear weather conditions, assume that the attenuation coefficient can be determined from the visibility data as:

$$S = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-q} \quad (6)$$

whereV is the visibility (in kilometres), λ is the wavelength (in nanometres), and q is a parameter related to the particle size distribution and visibility.

Atmospheric turbulence affects the propagation of beam of light within the channel in mainly three ways. Initially, the wavefront is distorted by the variation due to scintillation index then the beam wandering takes place due to the diffraction of laser beam when the diameter of beam is equal to or smaller than the size of eddies that occur due to the turbulent effects. Next, the atmospheric turbulence makes the laser beam to spread beyond the diffraction limit. In order to provide a realistic performance of FSO systems in the presence of atmospheric turbulence, there is a great importance in modelling for the distribution of the turbulence-induced fading. The small-scale irradiance fluctuations are modulated by large scale irradiance fluctuations of the propagating wave, both governed by independent gamma distributions. It provides an excellent fit with measurement data for a wide range of turbulence conditions (weak to strong). The PDF of the gamma-gamma distributed signal irradiance $h_{r,s}$($h_{r,s} \geq 0$) is in form

$$f_{h_{r,s}} = \frac{2(\alpha_r\beta_r)^{\frac{\alpha_r+\beta_r}{2}}}{\Gamma(\alpha_r)\Gamma(\beta_r)} x^{\frac{\alpha_r+\beta_r}{2}-1} K_{\alpha_r-\beta_r}[2\sqrt{\alpha_r\beta_r x}] \quad (6)$$

whereα_r and β_r are the effective number of small-scale and large-scale eddies of the scattering environment

$$\alpha_r = \{ \exp[\frac{0.49\Sigma_r^2}{(1+0.18d_r^2+0.56\Sigma_r^{\frac{12}{5}})^{\frac{7}{6}}}] \text{ -1}\}\text{\^{}-1} \quad (7)$$

$$\beta_r = \{ \exp[\frac{0.51\Sigma_r^2(1+0.69\Sigma_r^{\frac{12}{5}})^{-\frac{5}{6}}}{\left(1+0.9d_r^2+0.62d_r^2\Sigma_r^{\frac{12}{5}}\right)^{\frac{5}{6}}}] \text{ -1}\}\text{\^{}-1} \quad (8)$$

where$\Sigma_k$is the Rytov variance defined as

$$\Sigma_r^2 = 0.49C_n^2 K^{\frac{7}{6}} z_r^{\frac{11}{6}} \quad (9)$$

where$z_r$is the distance of the r^{th}link,$K = 2\frac{\pi}{\lambda}$ is the optical wave number with λ being the operational wavelength, $d_k = \sqrt{\frac{KD_r^2}{4z_r}}$ is the aperture diameter of the receiver, and C_n^2 is the strength of the atmospheric turbulence.

In Line of Sight technology of FSO communication systems, pointing performance is an important problem in determining link performance and reliability. Due to building sways, wind loads and thermal expansion occurs which result in signal fading and pointing errors at the receiver. Due to geometric spread attenuation occurs with pointing errors which can be represented as α, of Gaussian spatial intensity profile of beam waist $W_{z,r}$ on the destination plane at a distance z_r from the r^{th}, $h_{r,p}$ can be approximated as the Gaussian form

$$h_{r,p}(\alpha{:}\, z) \equiv A_{0,r}\exp\left(-\frac{2\alpha^2}{W_{z,r_{eq}}^2}\right) \quad (10)$$

where$W_{z,r_{eq}}^2$ is the equivalent beam width with

$$W_{z,r_{eq}}^2 = W_{z,r}^2\sqrt{\pi}\,\frac{\mathrm{erf}(v_r)}{2v_r\exp(-v_r^2)}$$

$$v_r = \frac{\sqrt{\pi}r_r}{\sqrt{2}\,W_{z,h}}.$$

and$A_{0,r} = [\mathrm{erf}(\ v_r)]^2$.

The PDF of $h_{r,p}$ can be written as

$$f_{h_{r,p}} = \frac{\xi^2}{A_{0,r}^{\xi^2}} x^{\xi^2-1} \text{ ,} 0 \leq x \leq A_{0,r} \quad (11)$$

where$\xi = \frac{W_{z,r,eq}}{2\sigma}$ is the ratio between the equivalent beam radius at the receiver and the pointing errors displacement standard deviation at the receiver.

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IV. CHANNEL CAPACITY ANALYSIS

The average capacity of the proposed system is determined by the expected value of the instantaneous mutual information, C, between the source and receiver nodes. It can be mathematically formulated as

$$C_{erg} \triangleq \mathbb{E}\langle C\rangle = \frac{1}{2}\int_0^\infty log(1+\omega) f_\omega(\omega)\, d\omega \qquad (12)$$

where the factor 1/2 in equation (12) is because the relay is operated in half duplex mode. The upper bounds on the ergodic capacity of dual-hop AF transmission systems is analysed, and applying the Jensen's inequality in equation (12), it is upper bounded as

$$C_{erg} \le \frac{1}{2} log_2(1+\mathbb{E}<w>) \qquad (13)$$

For CSI assisted relaying systems, by applying harmonic geometric means inequality, the ergodic capacity of the considered system is upper bounded as

$$C_{erg} \le \frac{1}{2} log_2(1+\mathbb{E}<w>) = \frac{1}{2ln2}\int_0^\infty \ln(1+x)\, f_{w_{eq}}(x)dx \qquad (14)$$

Throughout the analysis, it is assumed that the available transmit power,P_t, is allocated to the source and relay such that $P_{t,1} = \rho P_t$and $P_{t,1} = (1-\rho)P_t$with $0 < \rho < 1$.

V. SIMULATION RESULT

In this section, the simulation result demonstrates the mathematical analysis of average channel capacity. The noise standard deviation for both links $\sigma_{n,1} = \sigma_{n,2} = 10^{-7}$A/Hz is taken. Here the value of wavelength, λ is 1550 nm. According to clear weather condition,$C_n^2 = 5*10^{-14} m^{\frac{2}{3}}$, and path loss factor is $h_{l,1} = h_{l,2} = 0.9$ for a propagation path equal to 1km. The aperture diameter for receiver, $d_r = 0$ is considered, where no aperture averaging is possible. The responsivity, $R_r$at both the relay and destination nodes is assumed equal to be 0.5. In fixed gain case, a semi blind relayis assumed, where the fixed gainequal to the average of channel state information assisted gain found as $G^2 = (1/(\omega_1 + 1))$.

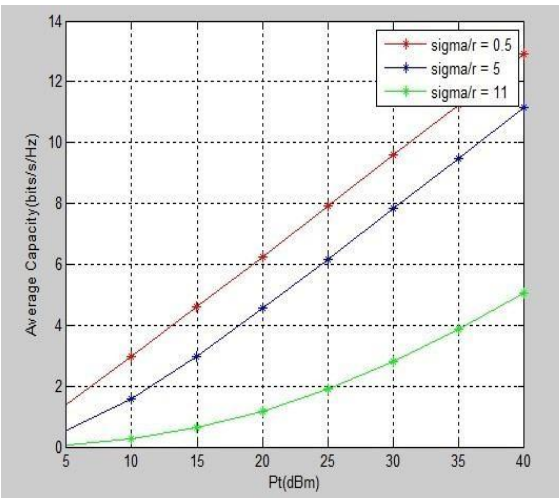

Figure 1: Average channel capacity of a dual-hop CSI assisted optical wireless system as a function of the transmitted optical power, $P_t$with pointing errors.

In figure 1, the average channel capacity of CSI assisted gain dual-hop systems under clear weather conditions, as a function of the transmitted optical power, P_t, assuming $\sigma_{s,1} = s_{s,2} = \sigma_s$and with a fixed value of = 10 and various values of $\sigma_s$are considered. I have taken the values of are 0.5, 5, 11. The distances between the r links are $z_1 = 2000$m, $z_2 = 3000$m respectively. The transmitted optical power is allocated at the hops as $P_{t,1} = 0.6P_t$, $P_{t,2} = 0.4P_t$. The presence of pointing errors that degrade the performance of the dual hop system is also depicted in figure 1.For comparison purposes, the ergodic capacity of this system in the absence of pointing error is considered.

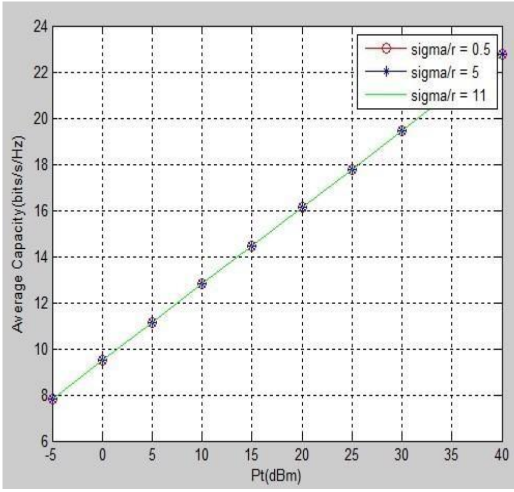

Figure 2: Average channel capacity of a dual-hop CSI-assisted optical wireless system as a function of the transmitted optical power, P_t without pointing error.

From figure 2, in the absence of pointing error the system is having good performance when compared to that of system having pointing errors. Here I considered the average channel capacity of CSI assisted gain dual-hop systems under clear weather conditions, as a function of the transmitted optical power, P_t, assuming $\sigma_{s,1} = s_{s,2} = \sigma_s$and with a fixed value of = 10 and various values of $\frac{\sigma_s}{r}$ are considered. I have taken the values of $\frac{\sigma_s}{r}$ are 0.5, 5, 11. The distances between the links are $z_1 = 2000$m, $z_2 = 3000$m respectively. The transmitted optical power is allocated at the hops as $P_{t,1} = 0.6P_t$, $P_{t,2} = 0.4P_t$.

VI. CONCLUSION

The presented system was assumed to operate in the presence of atmospheric turbulence and pointing errors. The ergodic capacity of an AF dual-hop optical wireless relaying system was studied, assuming CSI is only known at the receiving terminals. Upper bounds were derived for evaluation of the ergodic capacity of the considered system. Simple asymptotic capacity expressions, valid at high SNR values, were also derived that provided useful insights regarding the parameters that affect the system performance. By the comparison of free space optical communication system in turbulence conditions, shows higher efficiency when there is no pointing errors that the system which is affecting from pointing errors.

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BIOGRAPHIES

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