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Analysis on the performance of pointing error effects for RIS-aided FSO link over gamma-gamma channels

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ABSTRACT

In this study, we analysis on the performance of pointing error effects for reconfigurable intelligent surfeces (RISs) aided free-space optical (FSO) communication link over moderate to strong atmospheric turbulence channels. Among these solutions, RISs are considered as hardware technology to improve performance of optical wireless communication systems. Performance evaluation of systems is affected by atmospheric attenuation, pointing errors and moderate to strong atmospheric turbulence channels for quadrature amplitude modulation (QAM) technique. Atmospheric turbulence channel from moderate to strong is modeled using gamma-gamma distribution. Several numerical results obtained the average symbol error rate (ASER) performance versus beam waist radius and signal to noise ratio for three value of pointing error displacement standard deviation. From the results, it is show that with RIS assisted can effectively improve the performance and link distance of the wireless communication systems.

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1. INTRODUCTION

With advantages of free-space optical (FSO) communication compared to other wireless communication link, FSO is used to support the high-speed link requirements and specialized environments of the fifth-generation and sixth-generation wireless communication networks [1]. These advantages of FSO communication include highly secured, larger bandwidth, higher channel capacity, cost-effective, unlicensed spectrum and simplicity of system setup and design [1]-[5]. We perform to solve peformance’s problem in FSO systems affected by ponting errors and moderate to strong atmospheric turbulence by using reconfigurable intelligent surfaces (RISs) technique. RISs is considered a technique with many advantages and has been studied a lot of in recent years.

In recent years, there are studies that have used RIS technique, the results show the superiority of this technique. However, the transmission parameters have not been fully evaluated (atmospheric attenuation, atmospheric turbulence and pointing errors), quadrature amplitude modulation (QAM) technique and average symbol error rate (ASER) not used yet [6]-[15]. RISs offers wireless communication link several advantages over technologies such as optical relay systems. These advantages of RISs have recently studied and triggered intensive investigations of the technology [16]-[28].

This study introduces a theoretical analysis on the performance of pointing error effects for RIS aided FSO link over moderate to strong atmospheric turbulence channels. We theoretically analysis the ASER of signal-to-noise ratio (SNR) with gamma-gamma turbulence channels. The remainder of the paper is organized as: section 2 describes the system and channel models, section 3 presents the ASER, section 4 presents the numerical results and discussions, and we conclude the study in section 5.

2. SYSTEM AND CHANNEL MODELS
2.1. System model
The FSO link with RIS aided under study is shown in Figure 1, where the signal from the source node (S) transmitted to the destination node (D) after reflection on a RISs element. There is no direct link between source node and destination node because of obstructions. We assume that both reflected and transmitted channels, exhibit moderate to strong turbulenve levels.

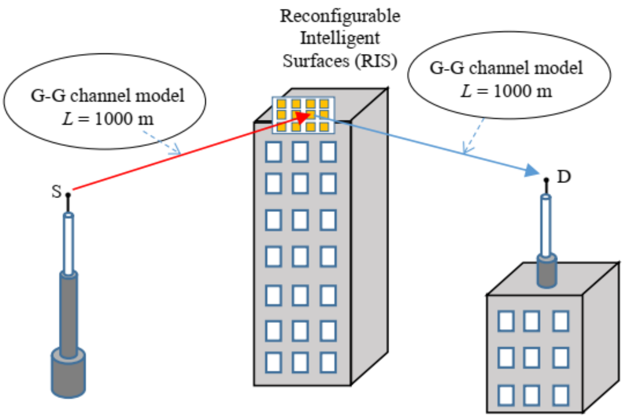

Figure 1. A diagram of FSO link with RIS aided

General model of FSO channel including pointing errors, atmospheric turbulence and link loss. That is subject to three main signal impairment factors: pointing errors h_p, atmospheric turbulence channel h_a, and attenuation h_l.

$$h = h_l \times h_a \times h_p \tag{1}$$

For moderate to strong atmospheric turbulence condition, h_a is a random process with gamma-gamma channel model. The probability density function (PDF) is given by [18].

$$f_{h_a}(h_a) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} h_a^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta h_a}\right), \tag{2}$$

In which:
- $\Gamma(\alpha),\ \Gamma(\beta)$: gamma function
- $K_{\alpha-\beta}(.)$: modified Bessel function
- α: the effective number of large-scale cells
- β: the effective number of small-scale cells

$$\alpha = \left[exp\left(\frac{0.49\sigma_2^2}{\left(1+0.18d^2+0.56\sigma_2^{12/5}\right)^{7/6}}\right) - 1\right]^{-1} \tag{3}$$

$$\beta = \left[exp\left(\frac{0.51\sigma_2^2\left(1+0.69\sigma_2^{12/5}\right)^{-5/6}}{1+0.9d^2+0.62\sigma_2^{12/5}}\right) - 1\right]^{-1} \tag{4}$$

In which:
- $\sigma_2^2 = 0.492C_n^2 k^{7/6} L^{11/6}$
- $d = \sqrt{kD^2/4L}$
- $k = 2\pi/\lambda$: the wave number
- λ: the wavelength
- D: the receiver aperture diameter of the photodiode
- The parameter σ_2^2 is the Rytov variance, it expressed by [2]
- C_n^2: the refractive-index structure parameter

The atmospheric attenuation be described by the exponential Beer-Lambert's law as:

$$h_l = exp(-\sigma_l L_a) \tag{5}$$

In which, σ_l is the attenuation coefficient, with the value of σ_l (dB) [dB/km] can be given by:

$$\sigma_l = \frac{3{,}91}{V[\text{km}]}\left(\frac{\lambda[\text{nm}]}{550}\right)^{-q} \tag{6}$$

Where λ is the optical wavelength, V is the visibility, q can be determined by using Kim model.

$$q = \begin{cases} 1{,}6 & V > 50 \\ 1{,}3 & 6 < V < 50 \\ 0{,}16V + 0{,}34 & 1 < V < 6 \\ V - 0{,}5 & 0{,}5 < V < 1 \\ 0 & V < 0{,}5 \end{cases} \tag{7}$$

The pointing error model is determined in [15], in which the PDF is given by:

$$f_{h_p}(h_p) = \frac{\xi^2}{A_0^{\xi^2}} h_p^{\xi^2 - 1}, 0 \leq h_p \leq A_0 \tag{8}$$

In which:
- $A_0 = [\text{erf}(v)]^2$: the fraction of the collected power at radial distance 0
- $v = \sqrt{\pi} r/(\sqrt{2}\omega_z)$
- r: the aperture radius
- ω_z: the beam waist at the distance z
- $\xi = \omega_{zeq}/2\sigma_s$
- $\omega_{zeq} = \omega_z(\sqrt{\pi}\, erf(v)/2v \times exp(-v^2))^{1/2}$
- $\omega_z = \omega_0[1 + \varepsilon(\lambda L/\pi\omega_0^2)^2]^{1/2}$
- ω_0: the transmitter beam waist radius at $z = 0$
- $\varepsilon = (1 + 2\omega_0^2)/\rho_0^2$ and $\rho_0 = (0.55C_n^2 k^2 L)^{-3/5}$: the coherence length.

2.2. End-to-end signal-to-noise ratio

In this section, we determine the SNR expression of the signal, and assume that the signal is completely reflected when it reaches RIS module. The detected signal at destination node can be expressed as [23].

$$y = \sqrt{E_s}(h\mu e^{j\theta} g)x + n \tag{9}$$

In which:
- h: the S-RIS complex channel vector
- g: the RIS-D complex channel vector
- E_s: the symbol energy

$$\gamma = \bar{\gamma}\left|h\mu e^{j\theta} g\right|^2 \tag{10}$$

In which:
- $\bar{\gamma} = \frac{E_s}{N_0}$: The average SNR
- N_0= the noise power spectral density

2.3. PDF of the end-to-end SNR

The PDF of SNR's system, $f_\gamma(\gamma)$ can be determined from the SNRs, γ_h and γ_g. The gain of system is given by $h\mu e^{j\theta}g$, in which the quantity $\mu e^{j\theta}$ is deterministic in contrast to h and g. The PDF of SNR's system, $f_\gamma(\gamma)$, can be evaluated as [28].

$$f_\gamma(\gamma) = \int_0^\infty f_{\gamma_h}(t) f_{\gamma_g}\left(\frac{\gamma}{t}\right)\frac{1}{t}dt \tag{11}$$

In which:
- $f_{\gamma_h}(\cdot)$ and $f_{\gamma_g}(\cdot)$: the PDFs of the S-RIS and RIS-D sub-channel's
- γ_h and γ_g: the weather condition over both parts of the channel

The PDF, $f_{\gamma_i}(\gamma_i)$ of system under gamma-gamma channel is given by:

$$f_{\gamma_i}(\gamma_i) = \frac{\xi^2}{(A_0X_l)^{\xi^2}\Gamma(\alpha)\Gamma(\beta)} \times G_{1,3}^{2,1}\left[\alpha\beta\frac{\gamma_i}{A_0X_l\bar{\gamma}}\middle|\begin{matrix}1+\xi^2\\ \alpha,\ \beta,\ \xi^2\end{matrix}\right] \tag{12}$$

We sequentially substitute γ_i by t and $\frac{\gamma}{t}$ and obtain $f_{\gamma_h}(t)$ and $f_{\gamma_g}(\frac{\gamma}{t})$ respectively as:

$$f_{\gamma_h}(t) = \frac{\xi^2}{(A_0X_l)^{\xi^2}\Gamma(\alpha)\Gamma(\beta)} \times G_{1,3}^{2,1}\left[\alpha\beta\frac{t}{A_0X_l\bar{\gamma}_h}\middle|\begin{matrix}1+\xi^2\\ \alpha,\ \beta,\ \xi^2\end{matrix}\right] \tag{13}$$

$$f_{\gamma_g}(\frac{\gamma}{t}) = \frac{\xi^2}{(A_0X_l)^{\xi^2}\Gamma(\alpha)\Gamma(\beta)} \times G_{1,3}^{2,1}\left[\alpha\beta\frac{\gamma}{A_0X_l\bar{\gamma}_g t}\middle|\begin{matrix}1+\xi^2\\ \alpha,\ \beta,\ \xi^2\end{matrix}\right] \tag{14}$$

In which $\bar{\gamma}_h$ and $\bar{\gamma}_g$ are respectively the average values of the SNRs γ_h and γ_g. We substitute (13) and (14) in to (11), the PDF of SNR, $f_\gamma(\gamma)$, can be evaluated as:

$$f_\gamma(\gamma) = \frac{\xi^4}{(X_lA_0)^{\xi^4}(\Gamma(\alpha)\Gamma(\beta))^2} \times \int_0^\infty G_{1,3}^{2,1}\left[\alpha\beta\frac{t}{A_0X_l\bar{\gamma}_h}\middle|\begin{matrix}1+\xi^2\\ \alpha,\ \beta,\ \xi^2\end{matrix}\right] \times G_{1,3}^{2,1}\left[\alpha\beta\frac{\gamma}{A_0X_l\bar{\gamma}_g t}\middle|\begin{matrix}1+\xi^2\\ \alpha,\ \beta,\ \xi^2\end{matrix}\right]\frac{1}{t}dt \tag{15}$$

With the help of integral of two functions Meijer, we solve the integral in (15). The PDF of SNR's system can be given by:

$$f_\gamma(\gamma) = \frac{\xi^4}{(X_lA_0)^{\xi^4}(\Gamma(\alpha)\Gamma(\beta))^2} \times H_{2,6}^{4,2}\left(\frac{(\alpha\beta)^2\gamma}{(A_0X_l)^2\bar{\gamma}_h\bar{\gamma}_g}\middle|\begin{matrix}(1+\xi^2,1),(1-\alpha,-1),(1-\beta,-1),(1-\xi^2,-1)\\ (\alpha,1),\ (\beta,1),(-\xi^2,-1),(\xi^2,1)\end{matrix}\right) \tag{16}$$

3. ANALYSIS ON THE PERFORMANCE

The end-to-end system, the ASER with using QAM scheme can be given by [18].

$$P_{se} = \int_0^{+\infty} P_e(\gamma) f_\gamma(\gamma) d\gamma \tag{17}$$

In which $P_e(\gamma)$ is the conditional error probability (CEP). With using QAM scheme, the CEP presented as:

$$P_e(\gamma) = 1 - [1 - 2q(M_I)Q(A_I)\sqrt{\gamma}]\left[1 - 2q(M_Q)Q(A_Q\sqrt{\gamma})\right] \tag{18}$$

In which:
- $A_I = \left(6/\left[(M_I^2-1) + r^2(M_Q^2-1)\right]\right)^{1/2}$
- $A_Q = \left(6r^2/\left[(M_I^2-1) + r^2(M_Q^2-1)\right]\right)^{1/2}$
- $q(x) = 1 - x^{-1}$
- $Q(x) = 0.5\, erfc(x/\sqrt{2})$: the Gaussian Q-function
- $r = d_Q/d_I$: the quadrature to in-phase decision distance ratio

M_I and M_Q are respectively the in-phase and quadrature signal amplitudes. The (17) and formula contact between probability density function, the PDF of end-to-end SNR, $f_\gamma(\gamma)$. For the case moderate to strong turbulence channels can be given by:

$$P_{se}(\gamma) = 2q(M_I)\int_0^\infty Q(A_I\sqrt{\gamma})f(\gamma)d\gamma + 2q(M_Q)\int_0^\infty Q(A_Q\sqrt{\gamma})f(\gamma)d\gamma - 4q(M_I)q(M_Q)\int_0^\infty Q(A_I\sqrt{\gamma})Q(A_Q\sqrt{\gamma})f(\gamma)d\gamma \tag{19}$$

4. NUMERICAL RESULTS AND DISCUSSIONS

Using (16) and (19), we analysis numerical results for ASER of the RIS aided FSO link over moderate to strong turbulence channels with index of refraction structure, $C_n^2 = 3 \times 10^{-14} m^{-2/3}$ and link distance, L = 1000 m. Parameters and constants considered in our analysis are provided in Table 1. First, we analyse the ASER against transmitter beam waist radius, ω_0 for three value of pointing error displacement standard deviation, σ_s. The results are show in Figure 2, in this figure it is clearly depicted that for a given condition and with aided of RIS, the minimum of ASER can be reached to a specific value of transmitter beam waist radius ($\omega_0 \approx 0.022\, m$). The ASER is significantly reduced when the system is supported by RIS.

Table 1. System constants and parameters

Parameter	Symbol	Value
Laser wavelength	λ	1550 nm
Photodetector responsivity	$\Re$	1 A/W
Modulation index	κ	1
Total noise variance	N_0	10^{-7} A/Hz
Quadrature amplitude modulation	$M_I \times M_Q$	8×4
Receiver apertude diameter	D	0.06 m
Index of refraction structure	C_n^2	$3 \times 10^{-14}\, m^{-2/3}$

Figure 3, illustrates the ASER performance against the signal-to-noise ratio under three value of pointing errors, in case without RIS and with RIS. As it is clearly shown, the system's ASER is improved significantly with the RIS aided FSO link. The impact of the RIS, the ASER improves significantly as pointing error increase.

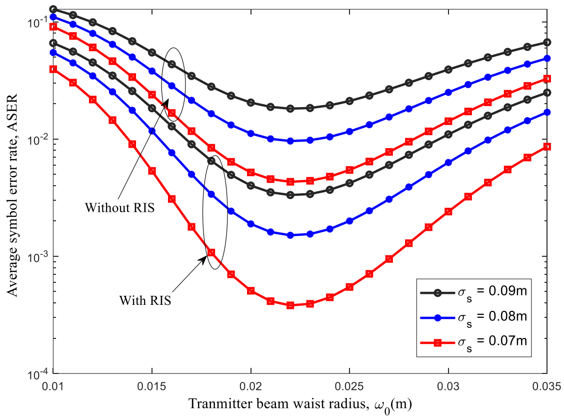

Figure 2. ASER performance versus transmitter beam waist radius

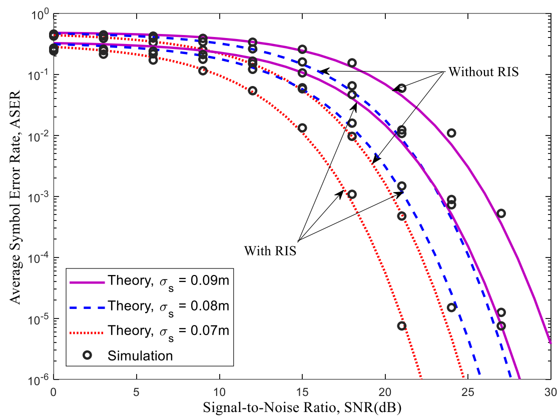

Figure 3. ASER performance versus the signal-to-noise ratio

5. CONCLUSION

In this study, we have presented unified and closed-form expression for the ASER of a RIS-aided FSO link over moderate to strong atmospheric turbulence channels and pointing errors. The system performance has been evaluated through ASER with RIS aided and pointing error effects. We have derived theoretical expressions performance of ASER systems taking into account the signal-to-noise ratio and transmitter beam waist radius with three value of pointing error displacement standard deviation. The numerical results showed the impact of RIS aided on the performance of systems. It has been shown, the ASER decreases with RIS aided.

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