Average symbol error rate analysis of reconfigurable intelligent surfaces based free-space optical link over Weibull distribution channels

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ABSTRACT

Optical wireless communication (OWC) enables wireless connectivity using ultraviolet bands, infrared or visible. With its advantages features as high bandwidth, low cost, and operation in an unregulated spectrum. Free-space optical (FSO) communication systems are near terrestrial as a communication link between transceivers, the link is line-of-sight and successfully transmitted optical signals. Nevertheless, the optical signals transmissions over the FSO channels bring challenges to the system. To overcome the challenges posed by the FSO channels, the most common technique is to use relay stations, the most recent is the reconfigurable intelligent surfaces (RISs) technique. This study introduces a Weibull distribution model for a free-space optical communication link with RISs assisted, the parameter used to evaluate the performance of the system is the average symbol error rate (ASER). The RISs effect is examined by considering the influence of the transmitter beam waist radius, shape parameter, aperture radius, scale parameter, and signal-to-noise ratio on the ASER.

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1. INTRODUCTION

With the advantages of free-space optical (FSO) communication compared to other wireless communication links, FSO communication offers a high data rate to meet the high-speed link and specialized environments of the sixth generation and beyond wireless communication networks [1]. These advantages of FSO communication include cost-effectiveness, larger bandwidth, higher channel capacity, unlicensed spectrum, highly secured, and simplicity of system setup and design [1]–[5]. We perform to solve performance problems in FSO communication systems affected by transmitter beam waist radius, aperture radius, shape parameter, scale parameter, and signal-to-noise by using the reconfigurable intelligent surfaces (RISs) technique. RISs is considered a technique with many advantages and has been studied a lot in recent years.

In recent years, there have been studies that have used the 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) have not been used yet [6]–[16]. RISs offer wireless communication link advantages and features over technologies such as optical relays of FSO systems [17]–[26]. These advantages of RISs have recently been studied and triggered intensive investigations of the technology [27], [28].

In this study, we theoretically analyze the performance of FSO systems with RISs assisted over Weibull distribution channels. The study is organized as follows. System and channel models are present in Section 2. Section 3 presents the closed-form statistical analysis. Section 4 shows the ASER analysis. The numerical results and discussions are presented in Section 5. The study is included in Section 6.

2. SYSTEM AND CHANNEL MODELS

2.1. System model

The FSO link with RISs assisted under study is shown in Figure 1, where the signal is transmitted to RISs from the source node (S), and then after reflection on a RISs element the signal is transmitted to the destination node (D). Assuming in this case, because of obstructions there is no direct signal between the source node and the destination. We assume that both Source-RISs and RISs-Destination channels have the same atmospheric turbulence conditions.

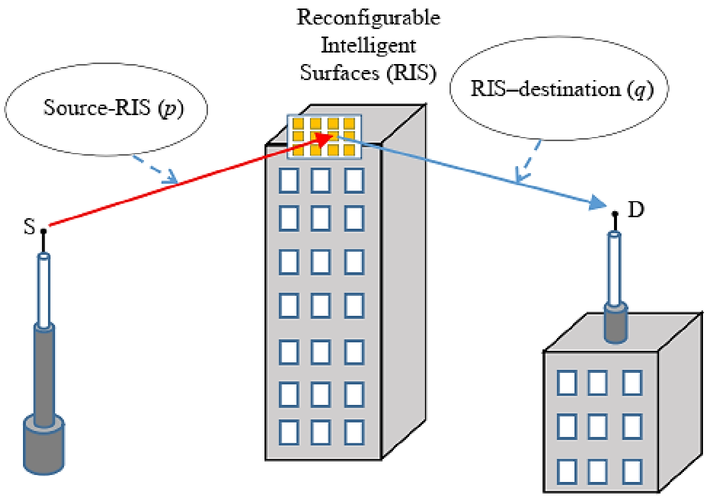

Figure 1. A diagram of RIS-assisted FSO channels

The RISs module is located at a convenient location in the buildings, it is not shielded by obstacles and reflects the signal coming from the source. RISs are electromagnetic devices, they can scatter, reflect, refract, or extinguish the coming signal. We assume that both reflected and transmitted links exhibit both transmitted and reflected channels representing atmospheric turbulence conditions, and the intensity of the signal over them has the same attenuation level.

2.2. Weibull distribution

Due to atmospheric turbulence conditions, a beam of optical wave is deformed and attenuated when it moves through atmospheric channels. Many models have been proposed to represent atmospheric channels. In this study, we perform FSO channels with RISs assisted over Weibull distribution. The irradiance intensity is modeled by the probability density function (PDF) given by (1) [2].

$$f_W(I;\beta,\eta) = \frac{\beta}{\eta}\left(\frac{I}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right] \quad (1)$$

where $\eta > 0$ is a scale parameter, $\beta > 0$ is a shape parameter. The n^{-th} irradiance moment is given by (2).

$$\langle I^n \rangle = \eta^n \Gamma\left(1+\frac{n}{\beta}\right) \quad (2)$$

where $\Gamma()$ is the gamma function, the brackets $\langle\ \rangle$ denote expectation. The scintillation index is given by (3).

$$\sigma_I^2 = \frac{\Gamma(1+2/\beta)}{\Gamma(1+2/\beta)^2} - 1 \approx \beta^{-11/6} \tag{3}$$

without loss generality, to take the derivative of the scale parameter, setting $n = 1$ and the irradiance data is normalized in the sense that $\langle I \rangle = 1$.

$$\eta = \frac{1}{\Gamma(1+1/\beta)} \tag{4}$$

3. CLOSED FORM STATISTICAL ANALYSIS

3.1. Signal-to-noise ratio

Firstly, assuming that the RISs module reflects light completely, no light is absorbed at the surface. Also, assume the channel stages are perfect knowledge at the RISs and destination. The signal at the destination node is given as (5) [3],

$$y = \sqrt{E_s}(p\mu e^{j\theta} q)x + n \tag{5}$$

where p and q are respectively the source-RISs and RISs-destination complex channel vectors, E_s is the symbol energy, $\eta e^{j\phi}$ characterizes the RISs element, η is amplitude reflection coefficient, ϕ is induced phase, n is additive white Gaussian noise. The value of the signal-to-noise ratio is computed by (6) [3].

$$\gamma = \bar{\gamma}\left|p\mu e^{j\theta} q\right|^2 \tag{6}$$

where $\bar{\gamma} = \frac{E_s}{N_0}$ is the average value of SNR in both source-RISs and RISs-destination channels, N_0 is the noise power spectral density.

3.2. PDF of the end-to-end SNR

Secondly, the overall gain of the system is $p\eta e^{j\phi} q$, where p and q are random variables. The quantity $\eta e^{j\phi}$ is deterministic. The pdf, $f_\gamma(\gamma)$, of the SNR is evaluated as [4],

$$f_\gamma(\gamma) = \int_0^\infty f_{\gamma_p}(t) f_{\gamma_q}\left(\frac{\gamma}{t}\right)\frac{1}{t}dt \tag{7}$$

where $f_{\gamma_p}(\cdot)$ is the pdf of the source-RISs and $f_{\gamma_q}(\cdot)$ is the pdf of the RIS-destination.

Thirdly, assuming that with stable weather conditions, the channel model is represented by Weibull distribution, $f_{\gamma_i}(\gamma_i)$ is expressed as (8).

$$f_W(\gamma_i;\beta,\eta) = \frac{\beta}{\eta}\left(\frac{\gamma_i}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{\gamma_i}{\eta}\right)^\beta\right] \tag{8}$$

where $i \in \{h, g\}$, perform variable change γ_i by t and $\frac{\gamma}{t}$ in (8), and pdf function of channels for $f_{\gamma_p}(t)$ and $f_{\gamma_q}(\frac{\gamma}{t})$ respectively as (9) and (10).

$$f_W(t;\beta,\eta) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{t}{\eta}\right)^\beta\right] \tag{9}$$

$$f_W(\tfrac{\gamma}{t};\beta,\eta) = \frac{\beta}{\eta}\left(\frac{\gamma}{\eta t}\right)^{\beta-1} exp\left[-\left(\frac{\gamma}{\eta t}\right)^\beta\right] \tag{10}$$

We substitute (9) and (10) into (7), and the probability density function of end-to-end SNR $f_\gamma(\gamma)$ can be evaluated as (11).

$$f_\gamma(\gamma) = \int_0^\infty \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{t}{\eta}\right)^\beta\right] \times \frac{\beta}{\eta}\left(\frac{\gamma}{\eta t}\right)^{\beta-1} exp\left[-\left(\frac{\gamma}{\eta t}\right)^\beta\right]\frac{1}{t}dt \tag{11}$$

Put $dz = \frac{1}{t}dt$, so that $t = e^z$, (11) can given by (12).

$$f_\gamma(\gamma) = \left(\frac{\beta}{\eta}\right)^2 \left(\frac{\gamma}{\eta^2}\right)^{\beta-1} \int_0^\infty exp\left[-\left(\frac{e^z}{\eta}\right)^\beta - \left(\frac{\gamma}{\eta e^z}\right)^\beta\right] dz \quad (12)$$

With the help of (13) and get the exact PDF of SNR. We analyze the integral in (12), the exact PDF of SNR, $f_\gamma(\gamma)$, as in (14).

$$\lim_{n\to\infty} \sum_{k=1}^{n} f(t_k)\,(z_k - z_{k-1}) = \int f(z)dz \quad (13)$$

$$f_\gamma(\gamma) = \left(\frac{\beta}{\eta}\right)^2 \left(\frac{\gamma}{\eta^2}\right)^{\beta-1} \lim_{n\to\infty} \sum_{k=1}^{n} exp\left[-\left(\frac{e^{\gamma_k}}{\eta}\right)^\beta - \left(\frac{\gamma_k}{\eta e^{\gamma_k}}\right)^\beta\right] (z_k - z_{k-1}) \quad (14)$$

4. AVERAGE SYMBOL ERROR RATE ANALYSIS

We consider the ASER with RISs assisted for FSO system that uses quadrature amplitude modulation (QAM) technique over atmospheric turbulence. It is counted as (15) [5],

$$\bar{P} = \int_0^{+\infty} P(\gamma) f_\gamma(\gamma) d\gamma \quad (15)$$

where $f_\gamma(\gamma)$ is the pdf of SNR, $P(\gamma)$ is the conditional error probability (CEP). With using the QAM scheme, the CEP is presented as (16),

$$P(\gamma) = 1 - [1 - 2q(M_I)Q(A_I)\sqrt{\gamma}]\left[1 - 2q(M_Q)Q(A_Q\sqrt{\gamma})\right] \quad (16)$$

where

$$A_I = \sqrt{6/\left[(M_I^2 - 1) + r^2(M_Q^2 - 1)\right]},$$
$$A_Q = \sqrt{6r^2/\left[(M_I^2 - 1) + r^2(M_Q^2 - 1)\right]},$$
$$q(x) = 1 - \frac{1}{x},$$
$Q(x) = \frac{1}{2} erfc(x/\sqrt{2})$: Gaussian Q-function

with the conditional error probability, $P(\gamma)$ determined by (16), (15) of average symbol error rate, $\bar{P}$ can be represented as (17).

$$\begin{aligned}\bar{P}(\gamma) = &\int_0^\infty 2q(M_I)Q(A_I\sqrt{\gamma}) f(\gamma)d\gamma + \int_0^\infty 2q(M_Q)Q(A_Q\sqrt{\gamma}) f(\gamma)d\gamma \\ &- \int_0^\infty 4q(M_I)q(M_Q)Q(A_I\sqrt{\gamma})Q(A_Q\sqrt{\gamma}) f(\gamma)d\gamma\end{aligned} \quad (17)$$

5. NUMERICAL RESULTS AND DISCUSSION

In this section, we present the results of ASER for FSO link with RISs assisted over Weibull distribution channels. ASER is computed as aperture radius, transmitter beam waist radius, and SNR. Many different effects conditions are investigated when the performance analysis: shape parameter and scale parameter in case RISs assisted and without RISs.

First, we analyze the ASER against transmitter beam waist radius, ω_0 with RISs and without RISs of FSO link for two values of shape parameter, scale parameter. The results are shown in Figure 2, in this figure it is clearly depicted that for a given condition and with aided of RIS, the minimum symbol error rate 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.

Figure 3 describes the ASER performance again the aperture radius for various link distance shape parameters, and scale parameters. As a result of the figure, ASER significantly decreases with the values of aperture radius increase and RIS assisted. It is clearly depicted that, in high-value regions when the aperture radius increases, ASER is much changed.

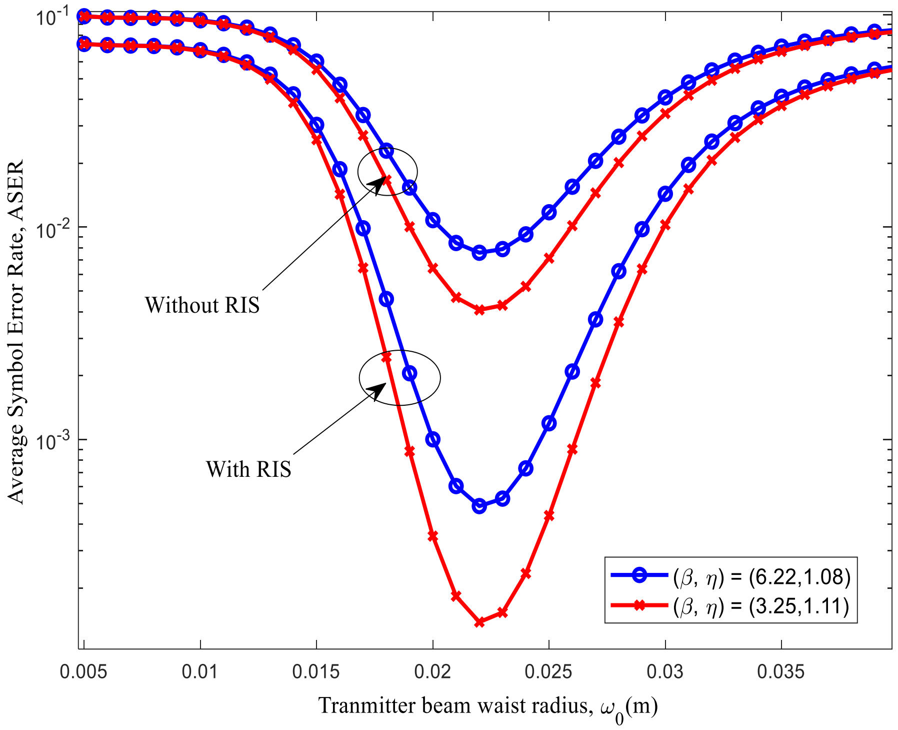

Figure 2. ASER performance versus transmitter beam waist radius

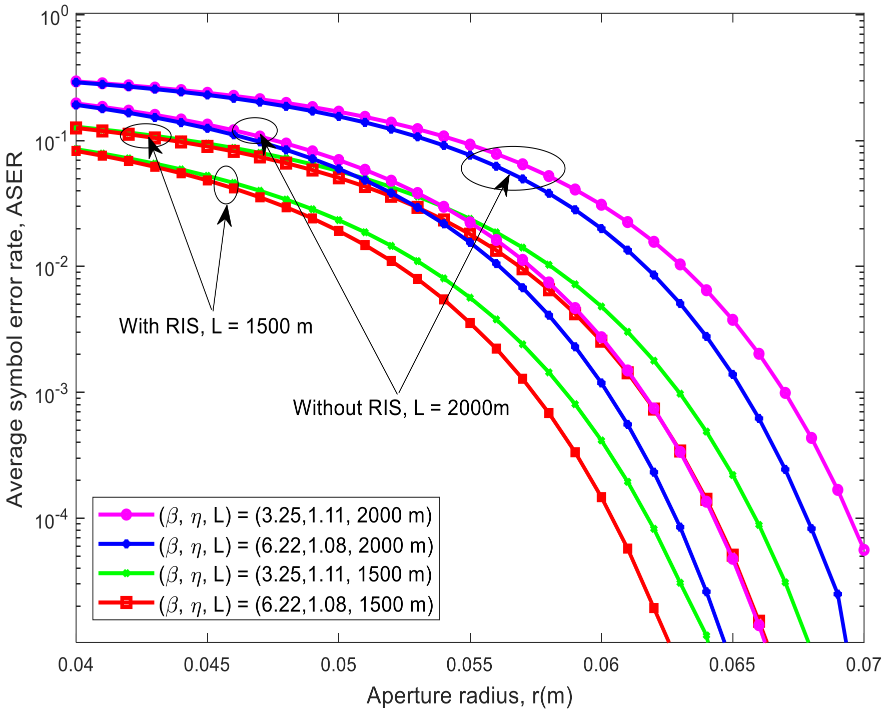

Figure 3. ASER performance versus the aperture radius

Figure 4 illustrates the ASER performance against the SNR under three value shape parameters and scale parameters, link distance, $L = 2{,}000\ m$, in the case without RISs and with RISs. As it is clearly shown, the ASER of the system is improved significantly with the RISs-assisted FSO channels. The impact of the RISs is that the ASER improves significantly as shape parameters increase.

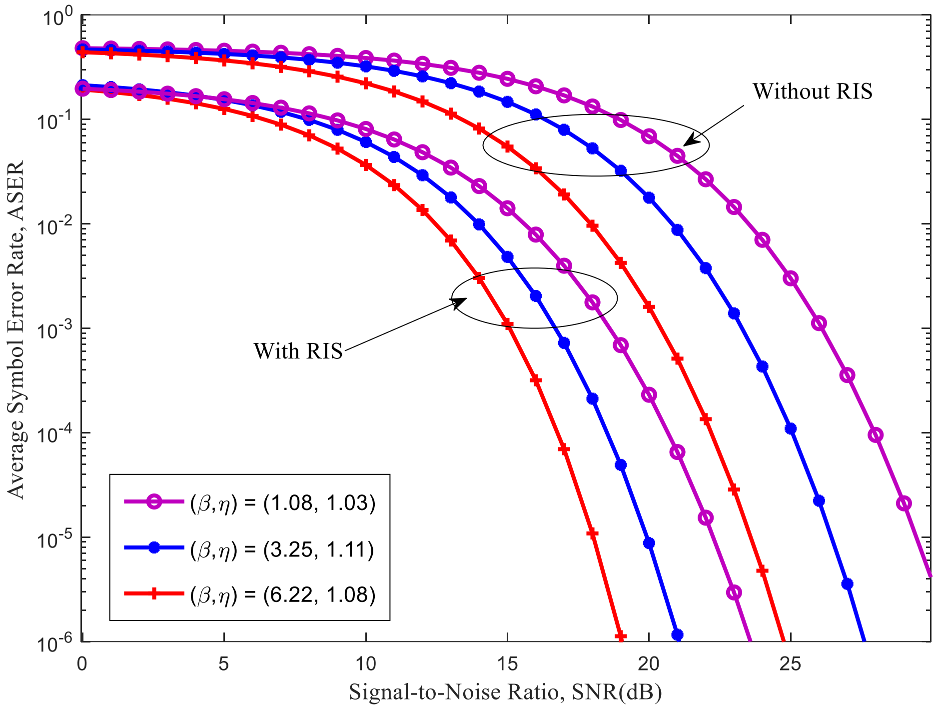

Figure 4. ASER performance versus the signal-to-noise ratio

6. CONCLUSION

This study presents unified and closed form expression for the ASER of an FSO link with RISs assisted over Weibull distribution channels. The system performance has been evaluated through ASER with RISs assisted, considering aperture radius, transmitter beam waist radius, and SNR. We have derived theoretical expressions performance of ASER systems taking into account the SNR and transmitter beam waist radius, aperture radius for the value of shape parameter, scale parameter, and link distance. The results showed the impact of RISs assisted on the performance of systems. It has been shown that the ASER decreases with RISs assisted.

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