Performance enhancement of FSO link with RIS-aided over Weibull distribution for 5G/6G and IoT applications

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Article Info

Article history:

Received Jul 16, 2023
Revised Sep 3, 2023
Accepted Sep 17, 2023

Keywords:

Average channel capacity
Free-space optical communication
IoT applications
Reconfigurable intelligent surface
Weibull distribution

ABSTRACT

With continuous development of wireless communication and internet of things (IoT) technology enables many terminals to be interconnected with each other through the external environment by wireless communication. Along with that, 5G/6G technology provides services with enhanced quality and high data transmission speeds, requiring the implementation of IoT in the 5G/6G architecture. Free space optical (FSO) communication is considered as a promising technique that can connect IoT devices by high-speed communication link, so for wireless networks to fully realize the potential of 5G/6G technology providing speeds of 100 Gb/s or more, FSO is the optimal choice. By implementing FSO features in IoT, the performance and convegare of IoT will be improved and enhanced by using techniquaes for FSO systems. Therefore, this paper proposed and investigated the FSO communication system using reconfigurable intelligent surfaces (RISs) over Weibull distribution. The performance of system is evaluated according to the average channel capacity (ACC) parameters in the case with and without RIS, while the the different of the model is changed. The average spectral efficiency (ASE) parameters can also be represented ACC.

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1. INTRODUCTION

The free space optical (FSO) communication link are where near terrestrial acts as a communication channel between source and destination that are line-of-sight (LOS), that not obscured by obstacles for optical signals is transmitted successfully. The benefits of FSO systems are larger bandwidth, highter channel, highly secured and unlicensed [1]. Besides, the FSO system has disadvantages caused by the transmission channel, such as the atmospheric propagation factors, the negative effects of scattering and absorption, turbulence and misalignment fading. Recent works have proposed solutions and evaluated performance of FSO systems with pointing errors and turbulence [2]–[7].

In recent years, there are studies on wireless communication systems using reconfigurable intelligent surfaces (RIS) technique, and the research results show its superiority [8]–[16]. Performance of RIS for FSO communication [9]. Design of a power with RIS assisted for FSO communication [13]. Analysis of principles, challenges, and opportunities with RIS assisted for wireless communication [15]. Although there are many studies on RIS assisted for wireless systems, however, the transmission paremeters have not been fully evaluated, quadrature amplitude modulation (QAM) technique and parameters average channel capacity (ACC) with Weibull distribution have not been mentioned or researched. With RIS assisted, the wireless communication systems have several advantages over relay technologies [17]–[27].

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 channels models are present in section 2. Section 3 presents the closed form statistical analysis. Section 4 shows ACC analysis. The numerical results and discussions are presents in section 5. The study is included in section 6.

2. SYSTEM AND CHANNEL MODELS

2.1. System model

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

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 extinct the coming signal. We assume that, both transmitted and reflected links exhibit both transmitted and reflected channels represents atmospheric turbulence conditions, the intensity of signal over them have the same attenuation level.

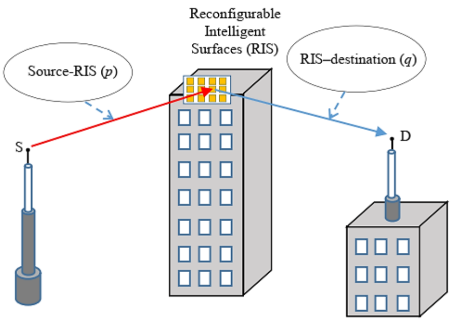

Figure 1. A diagram of RIS-assisted FSO channels

2.2. Weibull distribution

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

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

Where $\eta>0$ is a scale parameter, $\beta>0$ is a shape parameter. The $n-th$ irradiance moment is given by:

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

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

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

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. End-to-end signal to noise ratio

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

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

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 signal-to-noise ratio is computed by [3].

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

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 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:

- $f_{\gamma_p}(\cdot)$: PDF of the source-RIS
- $f_{\gamma_q}(\cdot)$: 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):

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

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

We substitute (9) and (10) in to (7), the PDF 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:

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

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 (14).

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

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

4. AVERAGE CHANNEL CAPACITYSER ANALYSIS

The parameter used to evaluate performance of system is average channel capacity, is a random variable, $\langle\overline{C}\rangle$. As mentioned in the abstract, the average spectral efficiency (ASE) can also be represented by ACC, the ASE of systems can be given by [6].

$$\langle\bar{C}\rangle = \int_0^\infty Blog_2(1+\gamma) \times f(\gamma)d\gamma, \text{ [bit/s/Hz]} \quad (15)$$

Where, B is the bandwidth of channel, $f_\gamma(\gamma)$ is the PDF of SNR. We substitute (14) in to (15), the ASE can be given by:

$$\left\langle\frac{\bar{C}}{B}\right\rangle = \int_0^\infty \frac{ln(1+\gamma)}{ln(2)} \left(\frac{\beta}{\eta}\right)^2 \left(\frac{\gamma}{\eta^2}\right)^{\beta-1} \lim_{n\to\infty} \sum_{k=1}^{n} exp\left[-\left(\frac{e^{\gamma_k}}{\eta}\right)^\beta - \left(\frac{\gamma_k}{\eta e^{\gamma_k}}\right)^\beta\right](z_k - z_{k-1})d\gamma \text{ [bit/s/Hz]} \quad (16)$$

5. NUMERICAL RESULTS AND DISCUSSION

Using the (16), we discuss and show numerical results, performance enhancement of FSO systems with RIS assisted over Weibull distribution for 5G/6G and IoT applications. In this analysis, the parameters and constants are presented in Table 1. Figures 2 and 3, illustrates the ASE versus SNR in the case without and with RIS, while changing the different parameters of the model, with link distances *L*=2,000 m (Figure 2) and *L*=2,000 m (Figure 3). The ASE is showed as a function of SNR, it can be also seen that the ASE strongly relies on the FSO link with RIS assisted, in Figure 3, ASE increased about 3 (bit/s/Hz) when using RIS. The longer link distance is the stronger effects of shape parameter, and scale parameter becomes. Obviously, the ASE strongly depends on RIS assisted and different parameters of the model in the high regions of signal-to-noise, ASE does not change much in the low regions. As it is clearly shown, with the RIS assisted for FSO channels, the ASE is improved significantly.

Table 1. System constants and parameters

Parameter	Symbol	Value
Laser wavelength	λ	1,550 nm
Modulation index	κ	1
Photodetector responsivity	$\Re$	1 A/W
Total noise variance	N_0	10^{-7}A/Hz
Quadrature amplitude modulation	$M_I \times M_Q$	8×4
Receiver aperture diameter	D	0.06 m

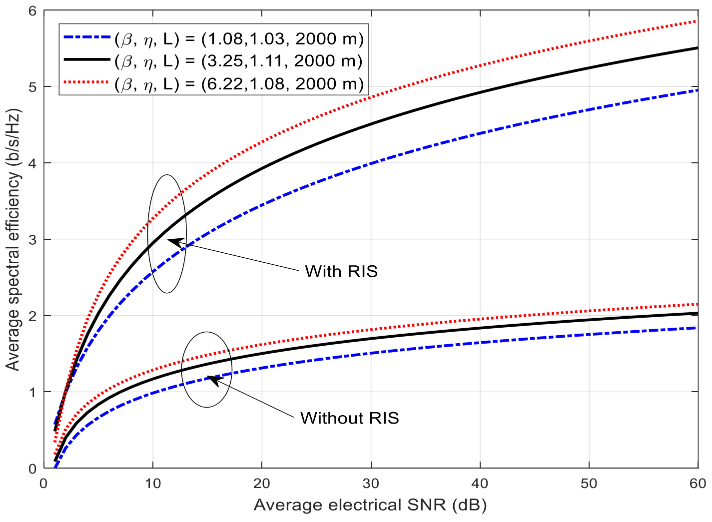

Figure 2. ASE illustrates versus SNR without RIS and with RIS

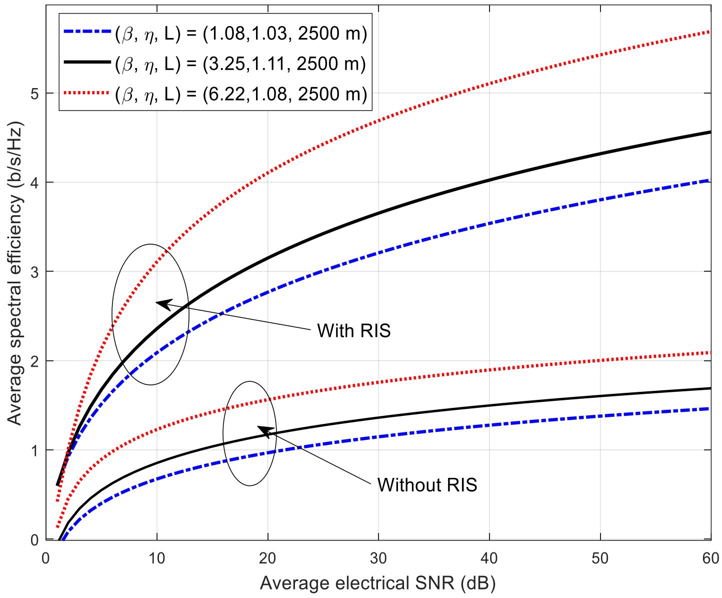

Figure 3. ASE illustrates versus SNR without RIS and RIS

6. CONCLUSION

This study, we have presented unified and closed form expression for the ASE of a FSO link with RISs assisted over Weibull distribution channels for 5G/6G and IoT applications. The system performance has been evaluated through ASE with RIS assisted, considering link distance, shape parameter, and scale parameter, and SNR. We have derived theoretical expressions performance of ASE systems taking into account the SNR for value of shape parameter, scale parameter and link distance. The results showed the impact of RIS assisted on the performance of systems. It has been shown, the ASE decreases without RIS assisted.

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