BER Analysis of FSO System with Airy Beam as Carrier Over Exponentiated Weibull Channel Model

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BER analysis of FSO system with Airy beam as carrier over Exponentiated Weibull channel model

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Abstract: Average Bit Error Rate (BER) expression of free-space optical (FSO) communication links with Airy beam as signal carrier under weak atmospheric turbulence and on-off keying (OOK) modulation scheme is derived based on scintillation index of Airy beam and Exponentiated Weibull (EW) channel model. The average BER has been evaluated at different transverse scale factors and exponential decay factors of Airy beam and link distances. And comparison of the average BER of FSO links with Airy beam and Gaussian beam as signal carrier has been carried out. The simulation results show that the average BER of FSO links with Airy beam as carrier decreases with the increase of mean signal to noise ratio (SNR) and increases with the increase of transmission distance. When the transverse scale factor is about 1.5cm, a lower average BER can be obtained. And the smaller the exponential decay factor is, the lower the average BER is. Under the same atmospheric turbulence condition, the average BER of FSO links with Airy beam as carrier is obviously better than that of FSO links with Gaussian beam as carrier. The results of this research have some significance for the application of Airy beam in FSO system.

Keywords: free-space optical communication, Airy beam, Exponentiated Weibull channel model, bit error rate

1. Introduction

Free-space optical (FSO) communication is a promising communication technology for high-data-rate information transmission that is available at optical frequencies[1][2]. For FSO links using Gaussian beam as signal carrier, beam spreading and atmospheric turbulence are two mainly factors that deteriorate their performances , particularly over link distance of 1km or longer[3][4]. For this reason, it is a natural thought to replace conventional Gaussian beam with non-diffracting Airy beam for improving the properties of FSO links[5].

As a new type of non-diffracting beam, Airy beam is solution of the Helmholtz wave equation and has unique non-diffracting, self-accelerating and self-healing properties [6-9]. Compared with the traditional Gaussian beam, Airy beam can keep its transverse intensity distribution invariant over a longer propagation distance and has a smaller scintillation index[10][11]. These features make Airy beam has potential applications in optical communication and optical design to reduce diffractive spreading and the effects of atmospheric turbulence. Therefore, properties of Airy beam travelling in atmospheric turbulence have been widely investigated from several aspects such as propagating evolution[12-15], far-field divergence[16][17], scintillation behavior[18-20] and beam wander[21-23]etc. And applications of Airy beam in optical route[24], image signal transmission[25], label-free imaging[26] and obstacle evasion in FSO links[27] have been reported. However, to the best of our knowledge, no one has yet discussed the link performance, such as BER, channel capacity and interrupt probability etc, of FSO links with Airy beams as optical carrier in the published literatures.

In this paper, we explored the average BER performance of FSO links with Airy beam as signal carrier under weak atmospheric turbulence. Firstly, we derived the average BER expression based on scintillation index of Airy beam, Exponentiated Weibull channel model and on-off keying(OOK) modulation scheme. Secondly, we evaluated the average BER at different transverse scale factors and exponential decay factors of Airy beam and link distances, and compared it with that of FSO links with Gaussian beam as carrier under the same condition. Simulation results show that the average BER of FSO links with Airy beam as carrier decreases with the increase of mean signal to noise ratio (SNR) and increases with the increase of transmission distance. When the value of transverse scale factor of Airy beams is selected to be 1.5cm, a minimum average BER can be obtained. And the smaller the exponential decay factor is, the lower the average BER is. Under the same atmospheric turbulence condition, the average BER of FSO links with Airy beam as carrier is significantly lower than that of FSO links with Gaussian beam as carrier. This research has certain significance for extending the application of Airy light to FSO communication field.

2. Scintilation index of Airy beam

Scintillations (intensity fluctuations due to turbulence) are one of the fundamental limitations in the development of free-space optical communication systems. The fluctuations increase the Bit Error Rate(BER) of the communications system. Scintillation index σ_I^2 of Airy beam based on first order Rytov approximation deduced by Eyyuboğlu at 2013 is represented by[18][19]

$$\sigma_I^2 = 0.4147 k^2 C_n^2 \int_0^L dp \int_0^{2\pi} d\phi_\kappa \int_0^\infty d\kappa \frac{\kappa \exp\left[-\kappa^2 \left(l_0/5.92\right)^2\right]}{\left[\kappa^2 + \left(2\pi/L_0\right)^2\right]^{11/6}}$$
$$\times \left\{ \exp\left[-\frac{2(L-p)}{kw_x} a_x \kappa \cos\phi_\kappa\right] \frac{|Ai_{x1}|^2 |Ai_{y1}|^2}{|Ai_x|^2 |Ai_y|^2} - \mathrm{Re}\left\{ \exp\left[-\frac{j(L-p)}{k}\kappa^2 \cos^2\phi_\kappa\right] \frac{Ai_{x1} Ai_{x2} Ai_{y1} Ai_{y2}}{Ai_x^2 Ai_y^2} \right\} \right\} \quad (1)$$

with

$$Ai_x = Ai\left\{ \frac{r_x}{w_x} + \frac{ja_x L}{kw_x^2} - \frac{L^2}{4k^2 w_x^4} \right\} \quad (2)$$

$$Ai_{x1} = Ai\left\{ \frac{r_x}{w_x} + \frac{1}{kw_x^2}\left[ja_x L - \kappa w_x (L-p)\cos\phi_\kappa\right] - \frac{L^2}{4k^2 w_x^4} \right\} \quad (3)$$

Ai_y is simply the y equivalent of Eq.(2). Ai_{x2} is simply Ai_{x1} with sign of k inverted. Ai_{y1} and Ai_{y2} are the y counterparts of Ai_{x1} and Ai_{y2}, additionally with cosine changed to sine.

where $Ai(\cdot)$ is the Airy function, w_x, w_y and a_x, a_y are the coordinate dependent transverse scale factors and exponential decay factors, r_x and r_y are the transverse coordinates on receiver plane, L is the distance of the receiver plane away from the source plane, κ is the magnitude of spatial wave number and ϕ_κ indicates its angular orientation, $k = 2\pi/\lambda$ is the wave number being related to the wavelength λ, p is the axial propagation distance, C_n^2 is the atmospheric refractive index structure constant, l_0 and L_0 are the inner and outer scales of turbulence respectively.

The scintillation index of Airy beam at the position coincide with the peak of the beam on the receiver plane can be calculated by Eq. (1). While the scintillation index of Gaussian beam has been widely discussed in literatures and its formulation can refer to Eq.(23) in chapter 8 of reference [28].

3. System and channel model

3.1 System model

On-off-keying (OOK) modulation scheme is commonly used in FSO system because of its simplicity and low cost[29][30]. The OOK based communication system is assumed to have an Airy beam generator and an amplitude modulator. Airy beam is launched from the Airy beam generator and then modulated by the modulator. Received optical signal is guided into an optical amplifier, and then the amplified amplitude modulated optical signal is converted into electrical signal and passed on to the decision circuit. Block diagram of FSO link with Airy beam as optical carrier is shown in Fig.1.

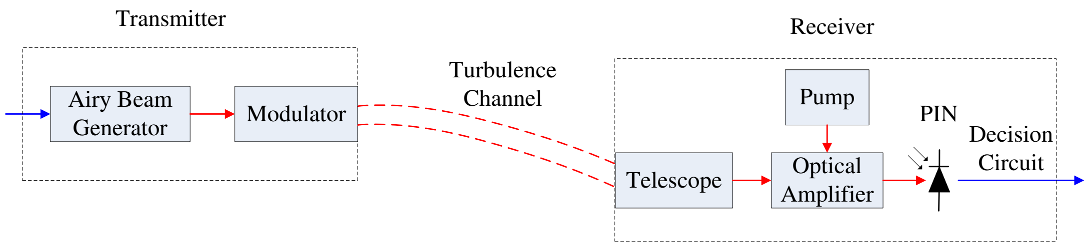

Fig.1 Block diagram of OOK modulation for FSO link with Airy beam as carrier

In the absence of atmospheric effects, signal to noise ratio (SNR) of a FSO link is defined by

$$SNR_0 = \frac{i_s}{\sigma_N} \tag{4}$$

where i_s is the detector signal current and σ_N is the root-mean-square noise power.

The mean signal current is represented by

$$\langle i_s \rangle = \frac{\eta e \langle P_s \rangle}{h\nu} \tag{5}$$

where $\langle P_s \rangle$ is the mean signal power in watts, η is the detector quantum efficiency in electrons/photon, e is the electric charge in coulombs, h is Plank's constant, and ν is optical frequency in hertz.

The output current variance of the photodetector is defined by

$$\sigma_{SN}^2 = \langle i_S^2 \rangle - \langle i_S \rangle^2 + \langle i_N^2 \rangle = \left(\frac{\eta e}{h\nu}\right)^2 \langle \Delta P_S^2 \rangle + \frac{2\eta e^2 B \langle P_S \rangle}{h\nu} \tag{6}$$

where $\langle \Delta P_S^2 \rangle = \langle P_S^2 \rangle - \langle P_S \rangle^2$ represents power fluctuations in the signal that become a contributor to the detector shot noise.

Taking optical turbulence into account, the SNR above for a shot-noise limited is defined by the mean SNR[31]

$$\langle SNR \rangle = \frac{SNR_0}{\sqrt{\left(\frac{P_{s0}}{\langle P_s \rangle}\right) + \sigma_I^2 SNR_0^2}} \tag{7}$$

where P_{s0} is the signal power in the absence of atmospheric effects, P_s is the instantaneous input signal power on the photodetector.

The mean SNR can be rearranged as

$$\langle SNR \rangle = \frac{SNR_0}{\sqrt{\frac{1}{1+1.33\sigma_R^2 \Lambda^{5/6}} + \sigma_I^2 SNR_0^2}} \tag{8}$$

where $\sigma_R^2 = 1.23 C_n^2 k^{7/6} L^{11/6}$ is the Rytov variance, Λ denotes the nondimensional diffractive beam parameter at the receiver. Due to the non-diffracting feature of Airy beam in a certain propagation distance, Λ is assumed to 1 for Airy beam analyzed in next sections.

3.2 Exponentiated Weibull (EW) channel model

Many distributions have been proposed to model the probability density function of irradiance fluctuations in FSO channels. The most widespread models are the Lognormal(LN) and Gamma–Gamma(GG) distributions. Albeit these models comply with the actual PDF data most of the time, neither of them works in all scenarios. The LN model is only valid in weak turbulence regime for a point receiver. The GG model is accepted to be valid in all turbulence regimes for a point receiver, nevertheless, it does not hold when aperture averaging takes place. EW distribution was first proposed by Barrios to model the distribution of the irradiance in FSO links. And it is valid through the whole weak-to-strong turbulence regime in the presence of aperture averaging. The probability density function (PDF) of a random variable I described by the EW distribution is given by[32]

$$f(I) = \frac{\alpha\beta}{\eta}\left(\frac{I}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right]\left\{1-\exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right]\right\}^{\alpha-1} \tag{9}$$

where $\alpha > 0$ and $\beta > 0$ are shape parameters related to the scintillation index σ_I^2, $\eta > 0$ is a scale parameter and is related to the mean value of the irradiance. Using standard curve fitting techniques the parameters α, β and η are given by[32]

$$\alpha \cong \frac{7.220\sigma_I^{2/3}}{\Gamma\left(2.487\sigma_I^{2/6} - 0.104\right)} \tag{10}$$

$$\beta \cong 1.012\left(\alpha\sigma_I^2\right)^{-13/25} + 0.142 \tag{11}$$

$$\eta = \frac{1}{\alpha\Gamma\left(1+1/\beta\right) g_1\left(\alpha,\beta\right)} \tag{12}$$

where $g_n\left(\alpha,\beta\right)$ is defined by

$$g_n\left(\alpha,\beta\right) = \sum_{i=0}^{\infty} \frac{(-1)^i \Gamma\left(\alpha\right)}{i!\left(i+1\right)^{1+n/\beta} \Gamma\left(\alpha - i\right)} \tag{13}$$

Eq.(18) is easily computed numerically as the series converges rapidly, and usually as much as 10 terms or less are sufficient for the series to converge[32].

4. BER over the EW channel model

The average BER of IM/DD with OOK modulation scheme can be expressed by[33]

$$\langle \text{BER} \rangle_{\text{OOK}} = \Pr\left(E\right) = \frac{1}{2}\int_0^{\infty} f\left(I\right) \text{erfc}\left(\frac{\langle SNR\rangle I}{2}\right) dI \tag{14}$$

where $\text{erfc}\left(\cdot\right)$ is the complementary error function.

Using Eq. (9) in Eq. (14) gives

$$P_e = \frac{1}{2}\int_0^{\infty} \frac{\alpha\beta}{\eta}\left(\frac{I}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right] \left\{1-\exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right]\right\}^{\alpha-1} \times \text{erfc}\left(\frac{\langle SNR\rangle I}{2}\right) dI \tag{15}$$

The $\text{erfc}\left(\cdot\right)$ and $\exp\left(\cdot\right)$ functions can be represented by Meijer's G function as[34]

$$\text{erfc}\left(x\right) = \frac{1}{\sqrt{\pi}} G_{1,2}^{2,0}\left[x^2 \middle| \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix}\right] \tag{16}$$

$$\exp\left(x\right) = G_{0,1}^{1,0}\left[-x \middle| \begin{matrix} - \\ 0 \end{matrix}\right] \tag{17}$$

Using Eq. (16) in Eq.(15), the average BER can be given as

$$P_e = \frac{1}{2\sqrt{\pi}}\int_0^{\infty} G_{1,2}^{2,0}\left[\frac{\left(\langle SNR\rangle I\right)^2}{4} \middle| \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix}\right] \frac{\alpha\beta}{\eta}\left(\frac{I}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right] \left\{1-\exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right]\right\}^{\alpha-1} dI \tag{18}$$

The last item in Eq. (18) can be expanded using Newton's general binomial theorem as

$$\left\{1-\exp\left[-\left(\frac{I}{\eta}\right)^{\beta}\right]\right\}^{\alpha-1} = \sum_{j=0}^{\infty} \frac{(-1)^j \Gamma\left(\alpha\right)}{j!\Gamma\left(\alpha - j\right)} \exp\left[-j\left(\frac{I}{\eta}\right)^{\beta}\right] \tag{19}$$

Combining Eqs. (17, (18) and (19), the average BER represented by Meijer's function can be expressed by

$$P_e = \frac{\alpha\beta}{2\eta\sqrt{\pi}} \sum_{j=0}^{\infty} \frac{(-1)^j \Gamma(a)}{j!\Gamma(a-j)} \int_0^{\infty} \left(\frac{I}{\eta}\right)^{\beta-1} G_{1,2}^{2,0}\left[\frac{\left(\langle SNR\rangle I\right)^2}{4}\middle|\begin{matrix}1\\0,\frac{1}{2}\end{matrix}\right] \times G_{0,1}^{1,0}\left[(j+1)\left(\frac{I}{\eta}\right)^{\beta}\middle|\begin{matrix}-\\0\end{matrix}\right] dI \tag{20}$$

Setting $y = (I/\eta)^2$, yields

$$P_e = \frac{\alpha\beta\sqrt{m\pi}}{2\sigma(2\pi)^{\frac{l+m}{2}}}\left(\frac{l}{\sigma}\right)^{\frac{\beta}{2}-1} \sum_{j=0}^{\infty} \frac{(-1)^j \Gamma(\alpha)}{j!\Gamma(\alpha-j)} G_{2l,m+l}^{m,2l}\left[\left(\frac{\omega}{k}\right)^m \left(\frac{l}{\sigma}\right)^l \middle| \begin{matrix}\Delta\left(l,1-\frac{\beta}{2}\right),\Delta\left(l,\frac{1}{2}-\frac{\beta}{2}\right)\\ \Delta(m,0),\Delta\left(l,-\frac{\beta}{2}\right)\end{matrix}\right] \tag{21}$$

where $\omega = 1+j$, $\sigma = \left(\eta\langle SNR\rangle\right)^2/8$, $\Delta(K,A) = \frac{A}{K},\frac{A+1}{K},\ldots,\frac{A+K-1}{K}$, l and m are integer number that should meet $l/m = \beta/2$. Eq.(21) is in the form of an infinite series but converges rapidly, and usually as much as 30 terms or less are sufficient for the series to converge.

5. Numerical results and discussion

5.1 Average BER analysis for FSO link with Airy beam as carrier

In this section, the average BER of FSO link with Airy beam as carrier is numerically evaluated and compared with that of FSO link with Gaussian beam as carrier. In the following numerical evaluations, wavelength, structure constant, inner and outer scales of turbulence are set as λ=1550nm, $C_n^2 = 10^{-15}\mathrm{m}^{-2/3}$, $l_0 \to 0$, $L_0 \to \infty$. And x, y symmetry is assumed, hence only the x parameter settings are quoted. Additionally, the receiver plane position is selected to coincide with the peak of the Airy beam at the particular propagation distances because Airy beam experiences propagation distance and source parameters dependent bending[18].

Fig.2 shows the average BER versus the mean SNR at selected propagation distances and at a single setting of the transvers scale factor $w_x = 2\mathrm{cm}$ and the exponential decay factor $a_x = 0.5$. As seen from Fig.2, the average BER decreases with the increase of the mean SNR and increases with the increase of the transmission distance. When the average SNR is less than 8dB, the influence of different propagation distances on the average BER is very small, and the average BER is higher than 1.7×10^{-3}. With the increase of mean SNR, the influence of propagation distance on average BER becomes more and more obvious. For example, when the mean SNR is 20dB, the average BER is about 2.32×10^{-19} when the propagation distance is L=1000m. When the propagation distance increases to 2000m, the average BER increases by 3 orders of magnitude compared with L=1000m, which is about 5.13×10^{-16}. When the propagation distance increases to 3000m, the average BER increases by 4 orders of magnitude compared with L=1000m, which is about 8.86×10^-15^. When the propagation distance increases to 4000m, the average BER increases by 5 orders of magnitude compared with *L*=1000m, which is about 4.16×10^-14^.

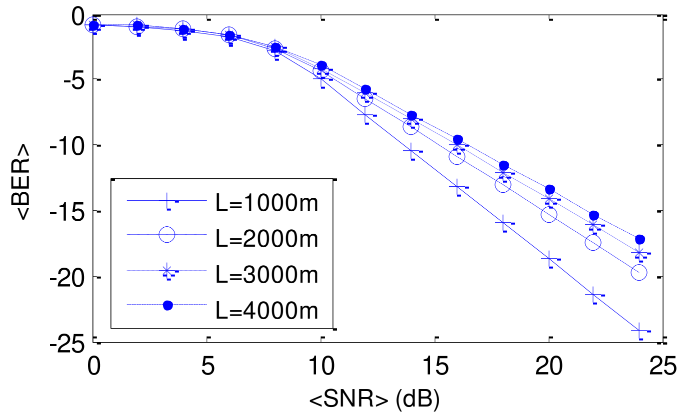

Fig. 2 Average BER versus mean SNR at selected propagation distances and constant transvers scale factor w_x=2cm and exponential decay factor a_x=0.5

Fig.3 shows the average BER versus the mean SNR at selected transvers scale factors and at a single setting of the propagation *L*=3000m and the exponential decay factor $a_x = 0.5$. As can be seen from the figure, when the transvers scale factor $w_x \le 1\text{cm}$, the average BER is higher than that when $w_x = 1.5\text{cm}$ and $w_x = 2\text{cm}$, but lower than that when $w_x = 3\text{cm}$. When $w_x > 1\text{cm}$, the average BER increases with the increase of w_x. For example, when the mean SNR is 20dB, the average BER is about 2.78×10^{-16} at the selected value of $w_x = 1.5\text{cm}$. When $w_x = 2\text{cm}$, the average BER increases by an order of magnitude, about 8.86×10^{-15}. When $w_x = 3\text{cm}$, the average BER increases by 4 orders of magnitude, about 1.29×10^{-12}. Therefore, when the transverse scale factor is 1.5cm or 2cm, FSO link with Airy beam as carrier can obtain a lower average BER.

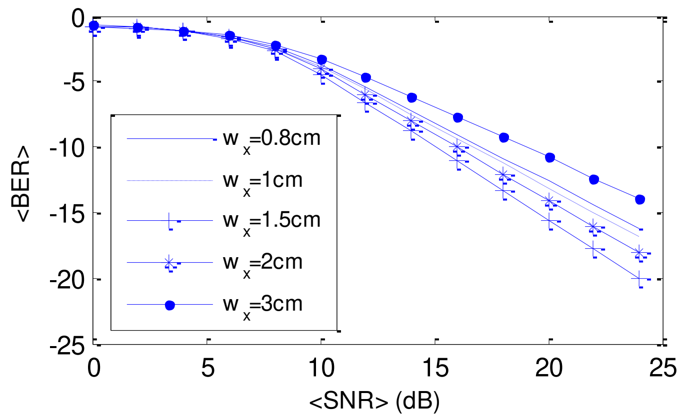

Fig. 3 Average BER versus mean SNR at selected transvers scale factors and constant propagation distance *L*=3000m and exponential decay factor a_x=0.5

In Fig.4, we fix the propagation distance *L*=3000m, the transverse scale factor $w_x = 2\text{cm}$ and take the selective values of the exponential decay factor a_x, then plot the average BER against mean SNR. Fig.4 reveals that the average BER increases with the exponential decay factor a_x. For example, when the average SNR is 20dB, the average BER is about 6.73×10^{-16} when

$a_x = 0.2$. When $a_x = 0.5$, the average BER increased by an order of magnitude, about 8.86×10^{-15}. When $a_x = 1$, the average BER increased by 4 orders of magnitude, about 1.01×10^{-12}. When $a_x = 1.5$, the average BER increased by 5 orders of magnitude, about 1.10×10^{-11}. When $a_x = 2$, the average BER increased by 5 orders of magnitude, about 4.08×10^{-11}. Therefore, when the exponential decay factor $a_x \le 1$, the change of a_x has a great influence on the average BER. This is due to the fact that when the exponential decay factor of Airy beam decreases, more side lobe is present and Airy beam would travel much farther without diffracting.

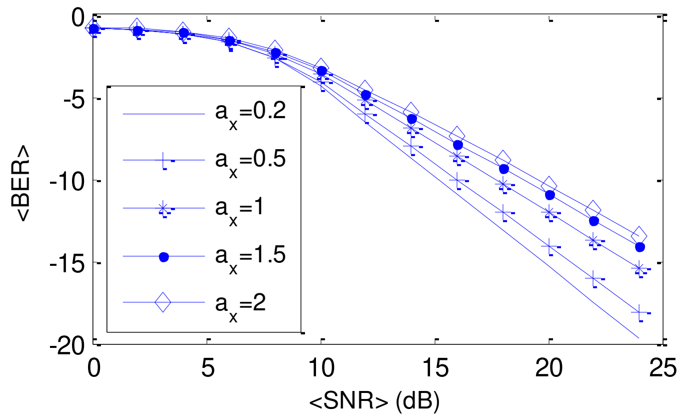

Fig. 4 Average BER versus mean SNR at selected exponential decay factors and constant propagation distance *L*=3000m and transvers scale factor w_x=2cm

5.2 Comparison of average BER of FSO links with Airy and Gaussian beams as carrier

In order to compare the average BER of FSO links with Airy and Gaussian beam as carrier, we assume the light sources are one dimensional Airy and Gaussian beams. And one dimensional Airy beam source power can be calculated as follow [9]

$$P_{AS} = \int_{-\infty}^{\infty} Ai^2\left(\frac{s_x}{w_x}\right)\exp\left(\frac{2a_x s_x}{w_x}\right)ds_x = \frac{w_x}{\sqrt{8\pi a_x}}\exp\left(\frac{2a_x^3}{3}\right) \tag{22}$$

While the source power of one dimensional Gaussian beam with waist radius ω_x can be expressed as [18]

$$P_{GS} = \int_{-\infty}^{\infty} \exp\left(-\frac{s_x^2}{\omega_x^2}\right)ds_x = \sqrt{\pi}\omega_x \tag{23}$$

Firstly, we consider the case that the source powers of Airy and Gaussian beam are the same. In this case, Eqs. (22) and (23) are equal, and we can obtain

$$\omega_x = \pi^{-0.5}P_{AS} = \frac{w_x}{2\pi\sqrt{2a_x}}\exp\left(\frac{2a_x^3}{3}\right) \tag{24}$$

Therefore, when the source parameters of Airy beam (the transverse scale factor w_x and the exponential decay factor a_x) are given, the source parameters of Gaussian beam (the waist radius ω_x) can be calculated by Formula (24), and then its scintillation index can be calculated by relevant theory.

Fig. 5 shows the average BER of FSO links with Airy and Gaussian beam as carriers against the mean SNR under the same source power condition. We fix the propagation distance L=3000m, the exponential decay factor a_x=0.5 and take the selective values of the transverse scale factor w_x, then calculate the waist radius of equipower Gaussian beams. We can see that within the given range of transverse scale factor, the average BER of Airy beam link increases with the increase of transverse scale factor, while that of equipower Gaussian beam link is basically unchanged. If the transverse scale factor w_x is less than 2.5cm, the average BER of Airy beam link is significantly lower than that of equipower Gaussian beam link. But when the transverse scale factor goes up to 3cm, the average BER of Airy beam link is higher than that of equipower Gaussian beam link. For example, when the mean SNR is 20dB, the average BER of Airy beam link with w_x=1.5cm is about 2.78×10^{-16}, and that of equipower Gaussian beam link is about 4.02×10^{-12}, which is 4 orders of magnitude higher. When $w_x = 2\text{cm}$, the average BER of Airy beam link is about 8.86×10^{-15}, and that of equipower Gaussian beam link is about 3.31×10^{-12}, which is 3 orders of magnitude higher. When $w_x = 2.5\text{cm}$, the average BER of Airy beam link is about 1.46×10^{-12}, and that of equipower Gaussian beam link is about the same of 2.69×10^{-12}. When $w_x = 3\text{cm}$, the average BER of Airy beam link is about 1.55×10^{-11}, and that of equipower Gaussian beam link is about 2.14×10^{-12}.

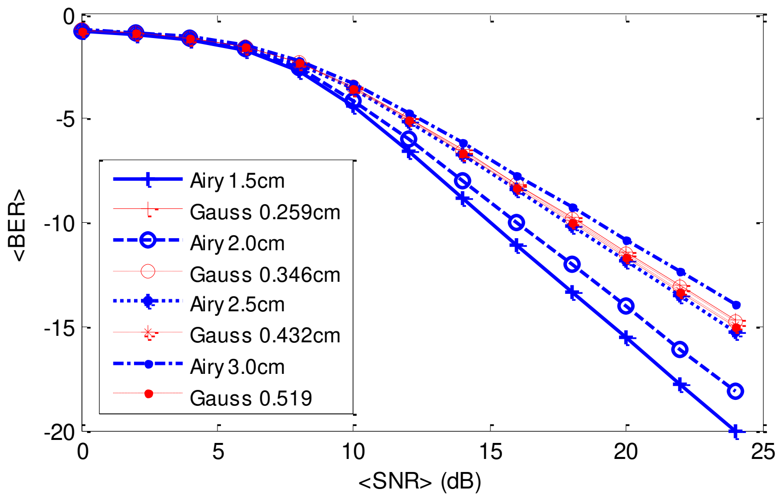

Fig. 5 Comparison of the average BER of FSO links with Airy and Gaussian beam as carrier under condition of the same source power and at constant propagation distance L=3000m and exponential decay factor a_x=0.5

Secondly, we consider the case that the transverse scale factor of Airy beam is the same as the waist radius of Gaussian beam and we call it source width. In this case, the source power can be calculated respectively according to Eqs. (22) and (23).

Fig.6 shows the average BER of FSO links with Airy and Gaussian beam as carriers against the mean SNR under the same source width of 1.5cm. The propagation distance is selected to L=3000m and take the selective values of the exponential decay factor a_x. It can be seen that the average BER of Gaussian beam link is higher than that of corresponding Airy beam links. For example, when the mean SNR is 20dB, the average BER of Gaussian beam link is about

1.47×10^{-13}. While that of Airy beam links are about 2.34×10^{-18} and 2.78×10^{-16} for the case of exponential decay factor value of 0.2 and 0.5 respectively.

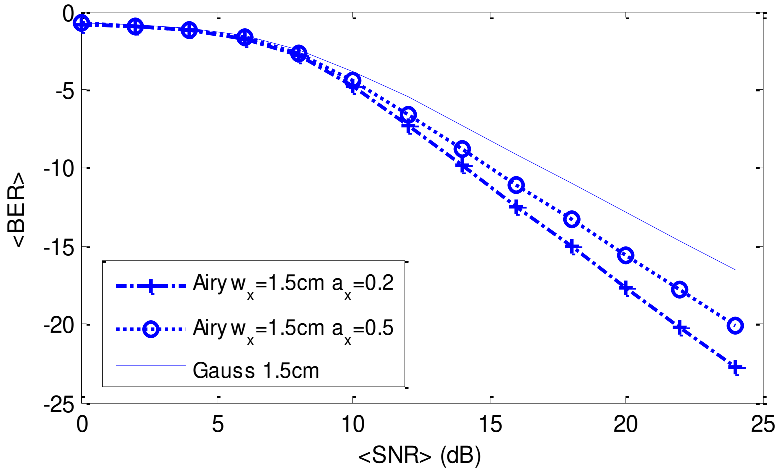

Fig. 6 The average BER of FSO link with Airy and Gaussian beam as carrier against the mean SNR under condition of the selected source width value of 1.5cm

Fig.7 gives comparison curve of the average BER between Airy and Gaussian beam links when the source width value is 2cm. And the results are similar to those in Fig.6. When the mean SNR is 20dB, the average BER of Gaussian beam link is about 6.26×10^{-14}, which is lower than that of Gaussian beam link with source width of 1.5cm. For Airy beam link with $a_x = 0.2$ and $w_x = 2\text{cm}$, the corresponding average BER is about 6.73×10^{-16}. And for Airy beam link with $a_x = 0.5$ and $w_x = 2\text{cm}$, the corresponding average BER is about 8.86×10^{-15}. Comparing the results of Figs. 6 and 7, we can see that the average BER of Gaussian beam link decreases with the increase of source width. While the average BER of Airy beam links with source width of 2cm is lower than that of Airy beam links with source width of 1.5cm.

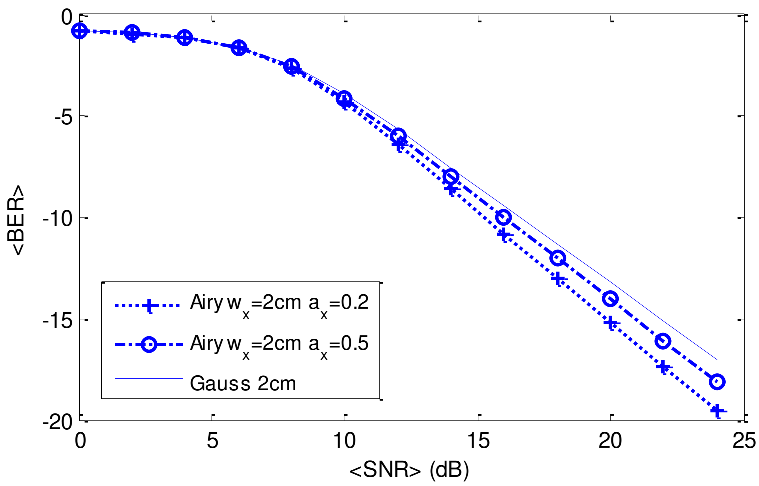

Fig. 7 The average BER of FSO link with Airy and Gaussian beam as carrier against the mean SNR under condition of the selected source width value of 2cm

6. Conclusion

The average BER performance of FSO ink with Airy beam as carrier under weak turbulence was analyzed. Based on scintillation index model of Airy beam and EW channel model, we derived the expression of the average BER of FSO link with Airy beam as carrier. The BER performance of FSO link with Airy beam as carrier was then numerically evaluated and compared with that of FSO link with Gaussian beam as carrier. The results show that the average BER of FSO with Airy beam as carrier decreases with the increase of mean SNR and increases with the increase of transmission distance. When the transverse scale factor of Airy beam is about 1.5cm, a relatively low average BER can be obtained. Decreasing the exponential decay factor of Airy beam, a better average BER of FSO link with Airy beam as carrier can be achieved. Under condition of the same source power, when the transverse scale factor of Airy beam is about 1.5cm, the average BER of FSO link with Airy beam as carrier is significantly lower than that of corresponding FSO link with Gaussian beam as carrier. When the source width of Airy and Gaussian beam are the same, if the transverse scale factor of Airy beam is less than 2cm and its exponential decay factor less than 1, the average BER of FSO link with Airy beam as carrier is still lower than that of corresponding FSO link with Gaussian beam as carrier. To sum up, FSO link with Airy beam as carrier has better average BER performance than FSO link with Gaussian beam as carrier. The results can be used as a reference for application of Airy beam in the design of FSO communication link.

Acknowledgments

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Figures

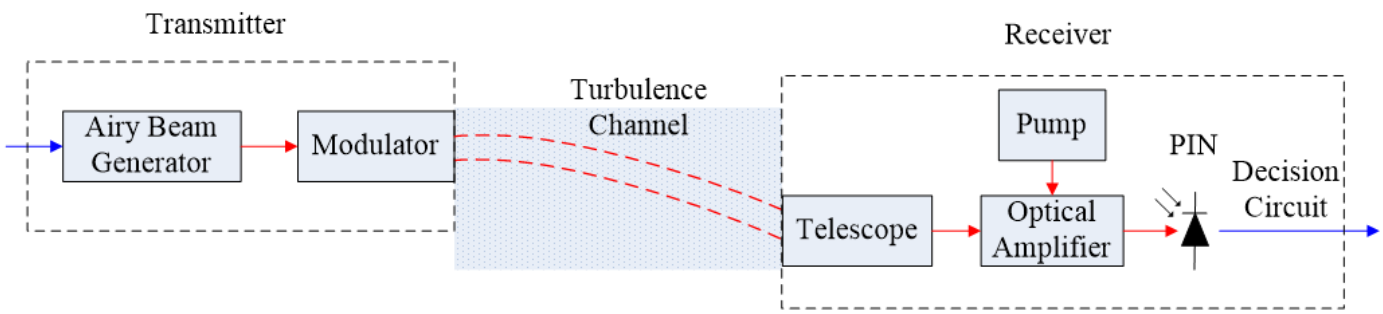

Figure 1

Block diagram of OOK modulation for FSO link with Airy beam as carrier

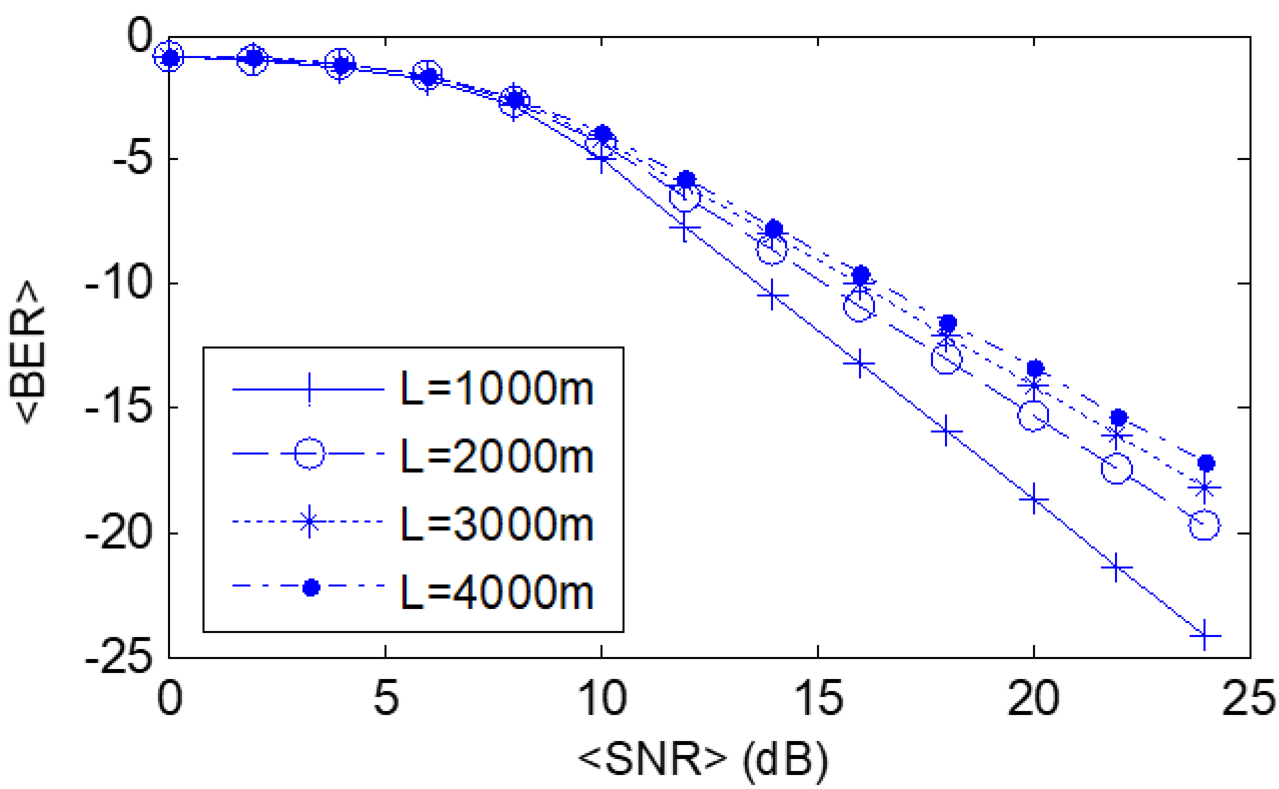

Figure 2

Average BER versus mean SNR at selected propagation distances and constant transvers scale factor wx=2cm and exponential decay factor ax=0.5

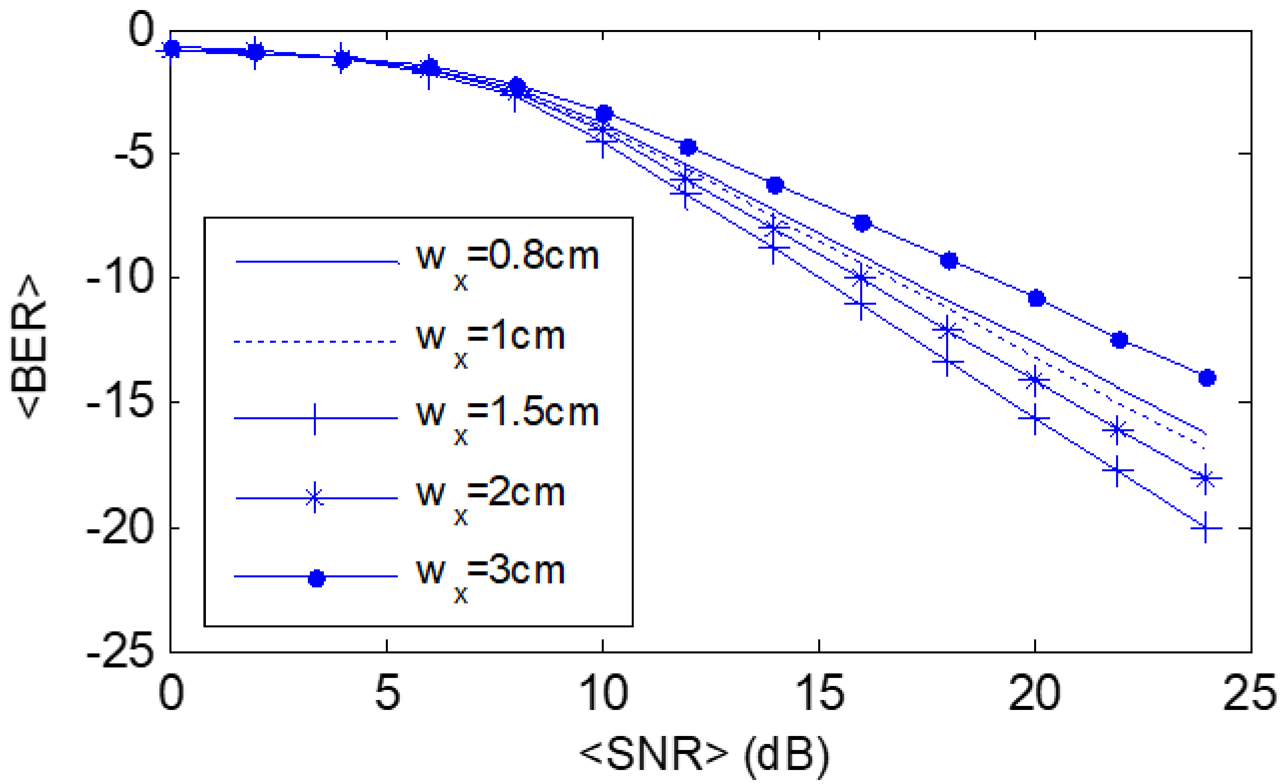

Figure 3

Average BER versus mean SNR at selected transvers scale factors and constant propagation distance L=3000m and exponential decay factor ax=0.5

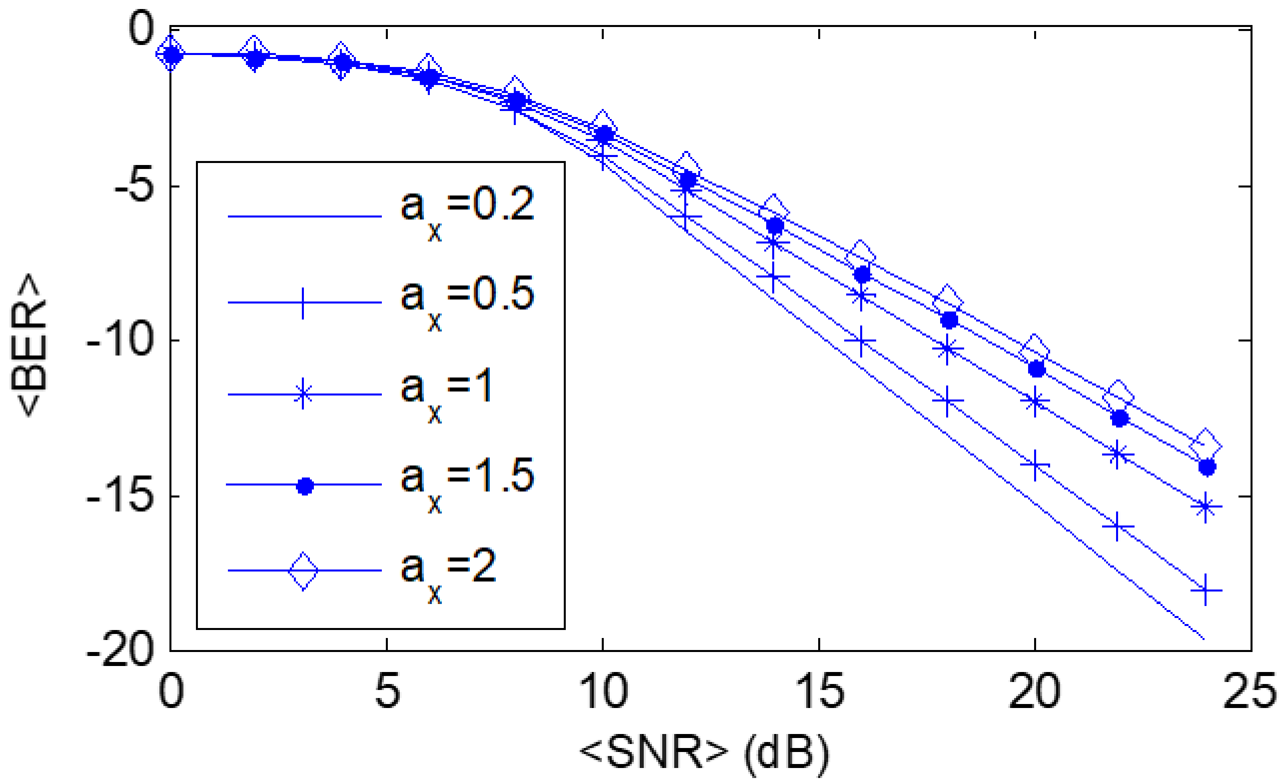

Figure 4

Average BER versus mean SNR at selected exponential decay factors and constant propagation distance L=3000m and transvers scale factor wx=2cm

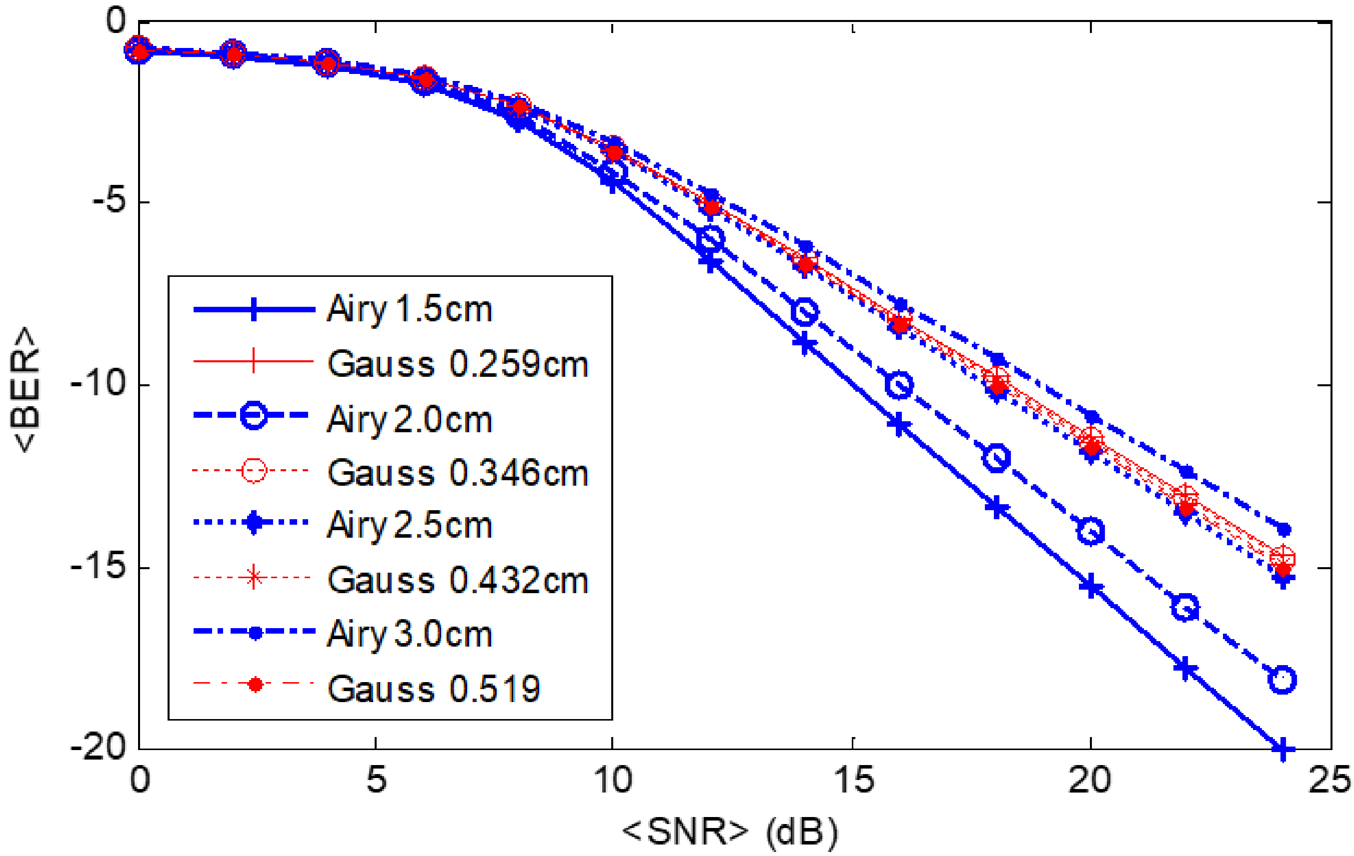

Figure 5

Comparison of the average BER of FSO links with Airy and Gaussian beam as carrier under condition of the same source power and at constant propagation distance L=3000m and exponential decay factor ax=0.5

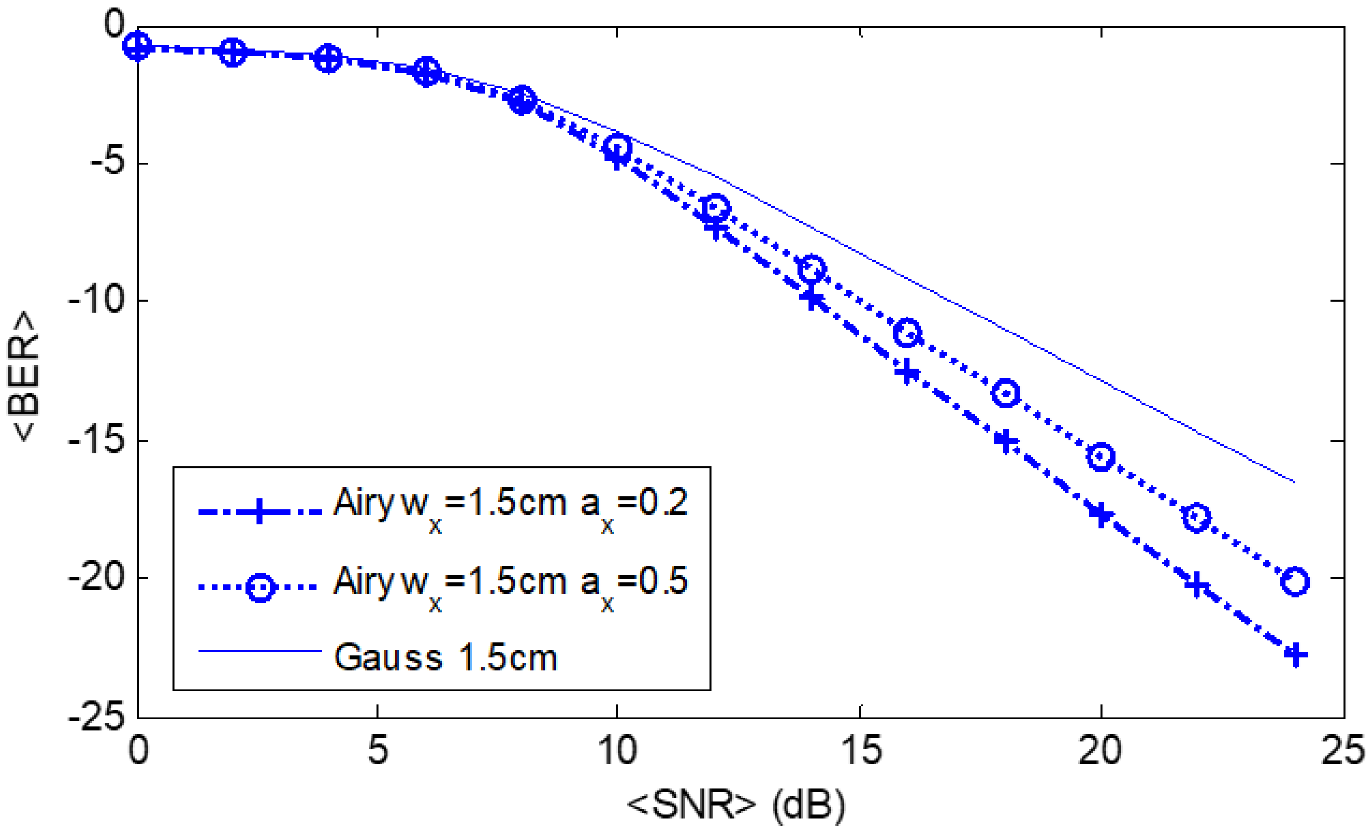

Figure 6

The average BER of FSO link with Airy and Gaussian beam as carrier against the mean SNR under condition of the selected source width value of 1.5cm

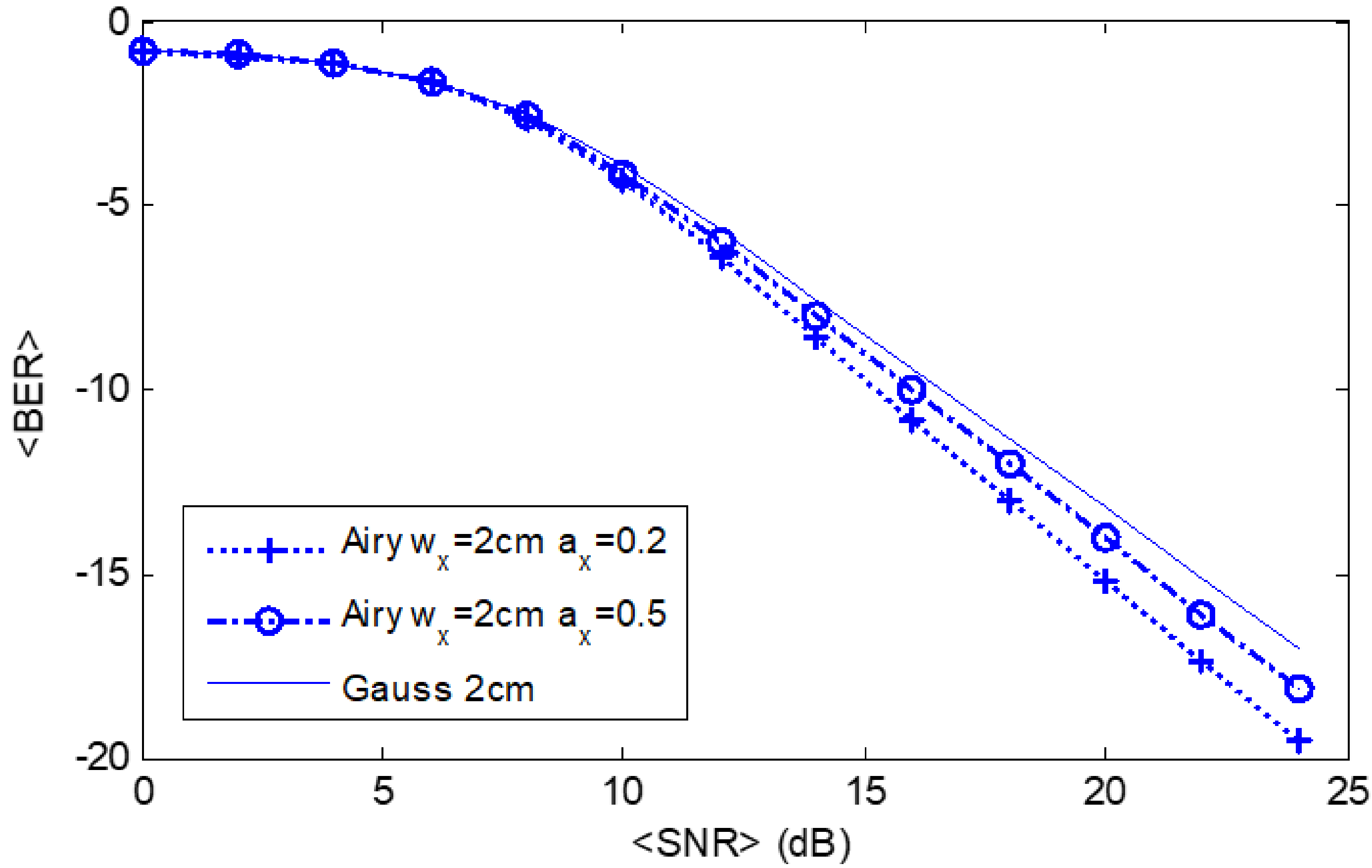

Figure 7

The average BER of FSO link with Airy and Gaussian beam as carrier against the mean SNR under condition of the selected source width value of 2cm