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Review

Performance comparison of diversity techniques with Addictive White Gaussian Channel (AWGC) in free space optical communication (FSO) under atmospheric turbulence scenario

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The spatial diversity techniques are broken down and explained systematically along with its combination which includes Maximum Ratio Combining (MRC), Equal Gain Combining (EGC) and Simple Selection Combining (SC) under the influence of atmospheric-induced turbulence fading in Free Space Optical (FSO) communication. Diversity is a technique used to prevent or reduce multipath. Multipath is a phenomenon describing propagation that results in the signals reaching the antenna by two or more paths. There is an extreme difficulty for a transmitted signal to be detected by a receiver in a case of increased turbulence. This research provides a forum for the receiver with some forms of diversity. The validation of the recommended simulation is through Additive White Gaussian Channel without combiner of the same process. The results display that Maximum Ratio Combining (MRC) has the greatest mitigation level of fading in comparison with others. Consequently, where fading is more dominant like on a terrestrial FSO link, Maximum Ratio Combining (MRC) can be used. Overall, the findings suggest the capability of the model in mitigating atmospheric turbulence especially for the 5G wireless networks in the terrestrial link.

***Key words*:** Free Space Optical Communication (FSO), Atmospheric Turbulence, Additive White Gaussian Channel (AWGC), Maximum Ratio Combining (MRC), Equal Gain Combining (EGC), Selection Combining (SC) and Additive White Gaussian Noise (AWGN).

INTRODUCTION

In the modern world, the most significant tool for technological advancement is wireless communications. Achieving wireless communications involves the use of electromagnetic wireless technologies, namely: light, electric or magnetic field, or the use of sound (Kedar and Arnon, 2004; Popoola et al., 2012). There are also several

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modes of wireless communications, which includes Radio-frequency, Free Space Optical (FSO) communication, Sonic communication, and Electromagnetic Induction communication (Kedar and Arnon, 2004). As a promising technology to combat bandwidth shortage of a continuously crowded wireless place, the scholars draw their attention to the Free Space Optical (FSO) communication (Kedar and Arnon, 2004; Ricardo and Federico, 2013). As the demand for high bandwidth data increases, Radio-frequency (RF) technology, and other communication systems could not meet up over recent years.

The inability to change the optical wave as it transmits through the turbulent area in the channel (the atmosphere) posed a major challenge when installing wireless links based on FSO technology. The presence of aerosols and suspended water particles provide a medium through which light is dispersed, deflected, and eventually, attenuation of optical pulse takes place in the atmosphere (Sheikh et al., 2008; Popoola et al., 2012). The most difficult challenge, however, was the atmospheric turbulence-induced irradiance fluctuation, even though FSO communication is stalled in a clear atmosphere by a very low attenuation (Hamzeh and Kavehrad, 2002). The combination and aggregation of a broad range of communication services like video, high-speed data, multimedia traffic in addition to voice signals were the target for the next generation of the wireless communication system. In this case, a method is used to balance for fading channel destruction, in which two or more receiving antennas are used (Kumar and Ali, 2014).

Merging several copies of the transmitted signal, which undergo fading solely and to augment the overall power received is the idea behind this method called Diversity. For each different type of diversity, there are different combining methods. Diversity combining devotes the entire resources of the array to service a single user (Godara, 2002). Diversity can be used to reduce channel fluctuations due to fading, which subsequently, increases the reliability of the channel.

Different versions of the same signal are received by the different antenna and within diversity combiner (or diversity reception), there are three common techniques, which are Selection Combining (SC), Maximal Ratio Combining (MRC) and Equal Gain Combining (EGC). To improve the 3G network, combining diversities was used in Multiple Input and Multiple Output (MIMO) Wireless Communication over the recent years (Kumar and Ali, 2014). In SC scheme, the link that receives the signal with the strongest Signal-to-Noise Ratio is selected at any time from a collection of antennas and connected to the demodulator (Sarita et al., 2013). The receiver monitors the Signal-to-Noise Ratio (SNR) of all links and connects the branch with largest SNR to the demodulator at any instant in time. In order to prevent phase discontinuities when the receiver switches between both branches, which occurs when one signal falls below the other and receiver switches to the strongest branch, the signals in both channels are constantly co-phased. In MRC, all the branches are used simultaneously. Each of the branch signals is weighted with a gain factor which is proportional to its own SNR. Then co-phasing and summing is done for adding up the weighted branch signals in phase. Both branches are weighted by their respective Signal-to-Noise Ratios. The branches are then co-phased prior to summing in order to ensure that all branches are added in phase for maximum diversity gain. The summed signals are then used as the received signal and connected to the demodulator (Kumar and Ali, 2014; Sarita et al., 2013).

In EGC, the outputs of different diversity branches are first co-phased and weighted equally before being summed to give the resultant output. After that the resultant output signal is connected to the demodulator (Sarita et al., 2013). The weights are all set to one with the requirement that the link gains are approximately constant and this is usually achieved by using an Automatic Gain Controller (AGC) in the system. Some practical applications of EGC include the use of regenerative circuits to co-phase the received carriers. However, the implementation of EGC diversity is complex due to the additional circuitry required in order to co-phase the signal in each branch (Sarita et al., 2013).

The critical comparison of the performance of combining diversities in FSO Communication under atmosphere turbulence is considered in this paper to improve deficient power and fight against fading caused by turbulence. The main purpose is to meet the next era of 5G wireless networks. The link performances of the scheme using EGC, MRC, and SC are investigated using efficient computer simulation as well as an application with the gamma-gamma atmospheric channels performed outdoors. This is then validated with AWGN without combiners.

THEORETICAL CONCEPT

Gamma-gamma turbulence channel

The basis of the Gamma-gamma turbulence model is the modulation process in which the fluctuation of light radiation traversing the turbulent atmosphere is assumed to consist of small-scale (scattering) and large-scale (refraction) effects, assuming the small-scale eddies are to be modulated by the large-scale eddies. Consequently, the received radiance (I) is defined as the product of two statistically independent random processes Ix and Iy, that is (Al-Habash et al., 2001; Andrews et al., 2001):

$$I = I_x I_y \tag{1}$$

Ix and *Iy* arise from the large scale and small-scale turbulent eddies respectively. The gamma radiation controls the large and small-scale effects; the gamma-

gamma model for the probability density function (PDF) of receiving irradiance fluctuation is given by

$$P(I)=\frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)}I^{\left(\alpha+\beta/2\right)-1}K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right)$$
$$I>0 \tag{2}$$

where α and β is the effective number of large and small-scale eddies of the scattering process respectively. $Kn(\cdot)$ represents modified Bessel function of the 2nd kind of order n, and $\Gamma(\cdot)$ is the gamma function. The optical radiation at the receiver is considered a plane wave (Popoola et al., 2007), whereas α and β, which are the large and small scale eddies for the plane determines the PDF of the model and is given by:

$$\sigma_l^2=1.23C_n^2k^{7/6}L_p^{11/6} \tag{3}$$

where C_n^2 is the refractive index structure parameter of the wave, σ_l^2, L and k represent the log irradiance variances, the link range and wave number respectively. $k = 2\pi/\lambda$ and λ is the wavelength of the wave which is 850 nm (Popoola et al., 2007).

All turbulence scenarios can be validated by the PDF of irradiance fluctuation of the gamma turbulence model given in (2), but the values of α and β, which is large and small eddies determine the given regime that can be obtained. They are given as (Al-Habash et al., 2001);

$$\alpha=\left[\exp\left(\frac{0.49\sigma_l^2}{\left(1+1.11\sigma_l^{12/5}\right)^{5/6}}\right)-1\right]^{-1} \tag{4}$$

and

$$\beta=\left[\exp\left(\frac{0.5\sigma_l^2}{\left(1+0.69\sigma_l^{12/5}\right)^{5/6}}\right)-1\right]^{-1} \tag{5}$$

The Signal to Noise Ratio with N receivers for each combining diversity

In the MATLAB simulation, a Single Input (Single Transmitter antenna) and Multiple Output (SIMO) FSO system with number of receive antennas (Multiple receiver antenna) was created. Free space channel characterized by turbulence was the channel used. There is a variation in time which receive antenna due to the channel experience by each receive antennas and a randomly varying complex number h_i multiplied each transmitted symbol (http://www.dsplog.com/2008/09/06/receiver-diversity-selection-diversity/; http://www.dsplog.com/2008/09/28/maximal-ratio-combining/; http://www.dsplog.com/2008/09/19/equal-gain-combining/). The channel considered was gamma-gamma turbulent channel and the real and imaginary parts of h_i are Gaussian distributed having mean $\mu h_i = 0$ and variance $\sigma^2_{h_i} = \frac{1}{2}$.

The channel experience by each receive antenna is different and independent from other receive antennas. On each receive antenna, the noise n has the Gaussian probability density function with

$$p(n)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{\frac{-(n-\mu)}{2\sigma^2}} \text{ with } \mu=0 \text{ and } \sigma^2=\frac{N_O}{2} \tag{6}$$

The noise on each receive antenna is also independent of the noise on the other receive antennas. At each receive antenna, the channel h_i is known at the receiver (http://www.dsplog.com/2008/09/06/receiver-diversity-selection-diversity/; http://www.dsplog.com/2008/09/28/maximal-ratio-combining/; http://www.dsplog.com/2008/09/19/equal-gain-combining/). In the presence of channel, h_i the instantaneous bit energy to noise ratio at i^{th} receive antenna is given as

$$\gamma_i==\frac{|h_i|^2E_b}{N_o} \tag{7}$$

Maximal Ratio Combining (MRC)

The instantaneous bit energy to noise ratio at i^{th} receive antenna in the presence of channel $|h_i|$ is

$$\gamma_i=\frac{|h_i|^2E_b}{N_o} \tag{8}$$

Given that the channel is being equalized with h^H, with the N receive antenna case, the effective bit energy to noise ratio is (http://www.dsplog.com/2008/09/28/maximal-ratio-combining/),

$$\gamma=\sum_{i=1}^{N}\frac{|h_i|^2E_b}{N_o} \tag{9}$$

$$=N\gamma_i \tag{10}$$

Equal Gain Combining (EGC)

The effective Eb/N0 with equal gain combining is the channel power gathered over all receive chains, that is,

$$E(\gamma_i) = \frac{E_b}{N_O}\frac{1}{N}\left(\sum_{i=1}^{N}|h_i|^2\right) \quad (11)$$

$$= \frac{E_b}{N_O}\frac{1}{N}\left(\sum_{i=1}^{N}\sum_{k=1}^{N}|h_i||h_k|\right) \quad (12)$$

$$= \frac{E_b}{N_O}\frac{1}{N}\left(\sum_{i=1}^{N}|h_i|^2 + \sum_{i=1}^{N}\sum_{\substack{k=1\\k\neq n}}^{N}|h_i||h_K|\right) \quad (13)$$

The first term is chi-square random variable with $2N$ degrees of freedom having mean value of $2N\sigma^2_{h_i}$. Hence, the first term reduces to,

$$\sum_{I=1}^{N}|h_i|^2 = N\ . \quad (14)$$

A product of two gamma-gamma random variables is the second term. The mean of gamma-gamma random variable with variance $\sigma^2_{h_i}$ is $\sigma^2_{h_i}\sqrt{\frac{\pi}{2}}$. Hence the second term is (http://www.dsplog.com/2008/09/19/equal-gain-combining/),

$$\sum_{I=1}^{N}\sum_{\substack{k=1\\k\neq n}}^{N}|h_i||h_k| = N\sqrt{\frac{\pi}{4}}(N-1)\sqrt{\frac{\pi}{4}} = N(N-1)\frac{\pi}{4} \quad (15)$$

Simplifying, the effective Eb/N0 with equal gain combining is**,**

$$E(\gamma_i) = \frac{E_b}{N_o}\frac{1}{N}\left[N + N(N-1)\right]\frac{\pi}{4} \quad (16)$$

$$= \frac{E_b}{N_o}\frac{1}{N}\left[1 + (N-1)\frac{\pi}{4}\right]$$

Selective Combining (SC)

On the i^{th} receive antenna, the probability that the bit energy to noise ratio falls below a threshold is the outage probability. The probability of outage on i^{th} receive antenna is,

$$p_{out,\gamma_i} = p[\gamma_i < \gamma_s] \quad (17)$$

$$= \int_0^s \frac{1}{(E_b/N_0)} e^{\frac{-\gamma_i}{(E_b/N_O)}} d\gamma_i \quad (18)$$

$$= 1 - e^{-\frac{\gamma_i}{(E_b/N_O)}} \quad (19)$$

γ_s is the defined threshold for bit energy to noise ratio.

In N receiver antenna case, the probability that all bit energy to noise ratio on all the receive antenna are below the threshold γ_s is,

$$P_{out} = P[\gamma_1, \gamma_2 ..., \gamma_N < \gamma_s] \quad (20)$$

Where $\gamma_1, \gamma_2 ..., \gamma_N$ are the bit energy to noise ratio of the 1st, 2nd and so on until the Nth receive antenna. Since the channel on each antenna is presumed to be independent, the joint probability is the product of individual probabilities (http://www.dsplog.com/2008/09/06/receiver-diversity-selection-diversity/).

$$p_{out} = P[\gamma_1 < \gamma_s]P[\gamma_2 < \gamma_s]...P[\gamma_N < \gamma_s] \quad (21)$$

$$= \prod_{i=1}^{N} P[\gamma_i < \gamma_s] \quad (22)$$

$$= \left[1 - e^{-\frac{\gamma_i}{(Eb/N_O)}}\right]^N \quad (23)$$

Note that the equation above defines the probability that the effective bit energy to noise ratio with N receive antennas is lower than the threshold γ_s. This is actually the Cumulative Distribution Function (CDF) of γ. The Probability Density Function (PDF) is then the derivatives of the CDF (http://www.dsplog.com/2008/09/06/receiver-diversity-selection-diversity/).

$$P(\gamma) = \frac{d\,P_{out}}{d\gamma} \quad (24)$$

$$= \frac{N}{(E_b/N_o)} e^{-\frac{\gamma}{(E_b/N_o)}} \left[1 - e^{-\frac{\gamma}{(Eb/N_O)}}\right]^{N-1} \quad (25)$$

Given that we are aware of the PDF of γ, the average

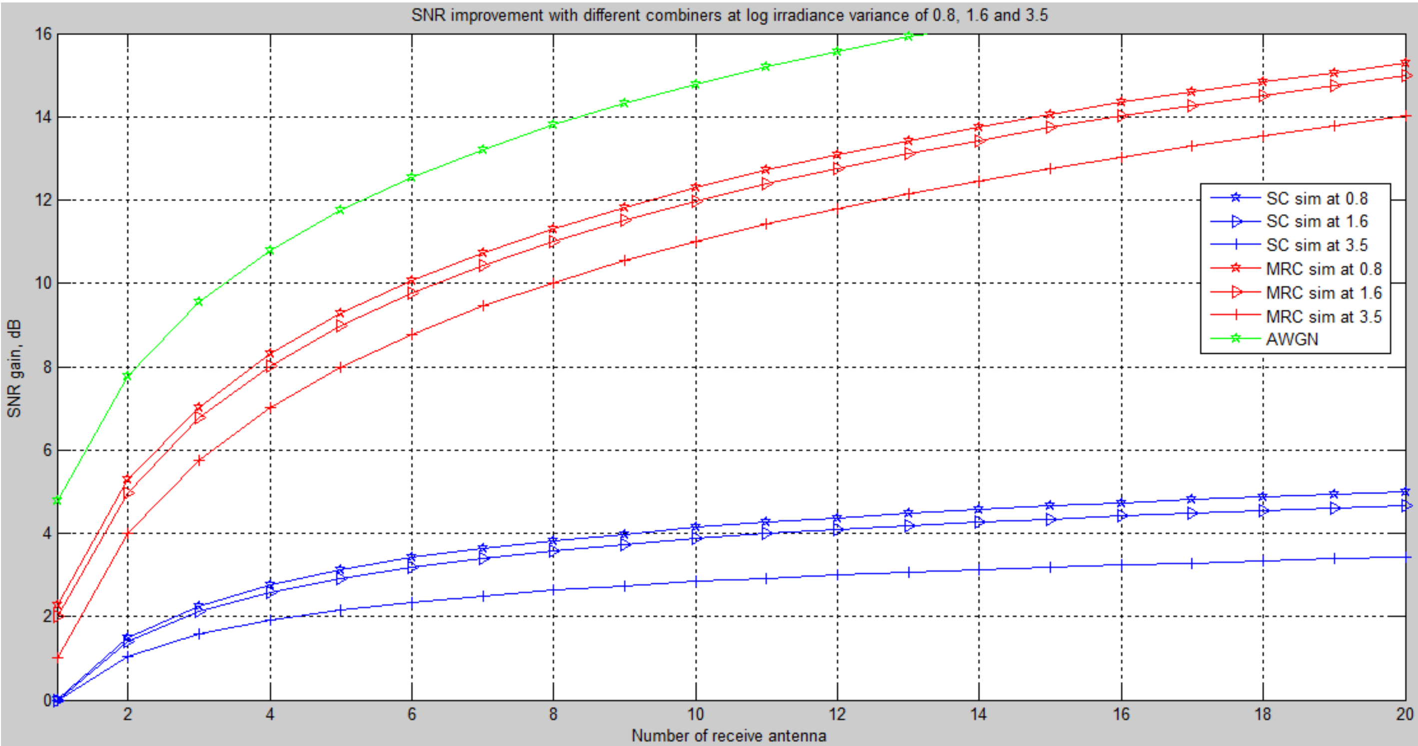

Figure 1. SNR versus N receivers for SC and MRC at log irradiance variance of 0.8, 1.6, and 3.5 with AWGN without combiners.

output bit energy to noise ratio is,

$$\cdot E(\gamma) = \int_0^{\infty} \gamma P(\gamma) d\gamma \tag{26}$$

$$= \int_0^{\infty} \gamma \frac{N}{(E_b/N_o)} e^{-\frac{\gamma}{(E_b/N_o)}} \left[1 - e^{-\frac{\gamma}{(E_b/N_o)}}\right]^{N-1} \tag{27}$$

$$= \frac{E_b}{N_O} \sum_{i=1}^{N} \frac{1}{i} \tag{28}$$

SIMULATION RESULTS

Under different log irradiance variance (gamma-gamma turbulence), the performance of the proposed combining diversities was investigated and validated with AWGC without combiner. Figure 1 compares the performance of SC and MRC when 12 receivers at log irradiance variance 0.8 are put into consideration. SC, MRC, and AGWC without combiner have a SNR of 4.2, 13.2, and 15.8 dB respectively. At log irradiance variance 1.6, SC, MRC, and AGWC without distribution have a SNR of 4.0, 12.9 and 15.8 dB respectively; similarly, at log irradiance variance 3.5, SC, MRC, and AGWN without combiners have a SNR of 3.0, 11.9 and 15.8 dB respectively.

Figure 2 compares the performance of EGC and MRC when 12 receivers at log irradiance variance 0.8 are considered; EGC, MRC, and AGWC without combiners have a SNR of 10.4, 13.2 and 15.8 dB respectively; at log irradiance variance 1.6, EGC, MRC and AGWC without distribution have SNR of 10.8, 12.9 and 15.8 dB respectively; and, at log irradiance variance 3.5, EGC, MRC and AGWC without combiner have a SNR of 11.0, 11.9 and 15.8 dB respectively.

In addition, Figures 1 and 2 show the performance of each diversity at constant log irradiance variance are considered. For MRC at 3.5 log irradiance, 8 and 12 receive antennas have 10 and 11.8 dB SNR gain respectively; for SC at 3.5 log irradiance, 8 and 12 receive antennas have 2.7 and 3.0 dB in SNR gain; whereas for EGC at 3.5 log irradiance, 8 and 12 receive antennas have 8.5 and 10.3 dB SNR.

Also, for MRC at 1.6 log irradiance, 8 and 12 receive antennas have 11 and 12.5 dB respectively; for SC at 1.6 log irradiance, 8 and 12 receive antenna have 3.2 and 4.4 dB; for EGC at 1.6 log irradiance, 8 and 12 receive antenna have 9.0 and 10.8 dB. For MRC at 0.8 log irradiance, 8 and 12 receive antenna have 11.4 and 13.0 dB SNR gain respectively; for SC at 0.8 log irradiance, 8 and 12 receive antenna have 3.9 and 4.1 dB in SNR gain; for EGC at 0.8 log irradiance, 8 and 12 receive antenna have 9.3 and 11 dB SNR again.

The kind of diversity (SC, MRC, EGC) employed with the log irradiance variance, as well as the number of

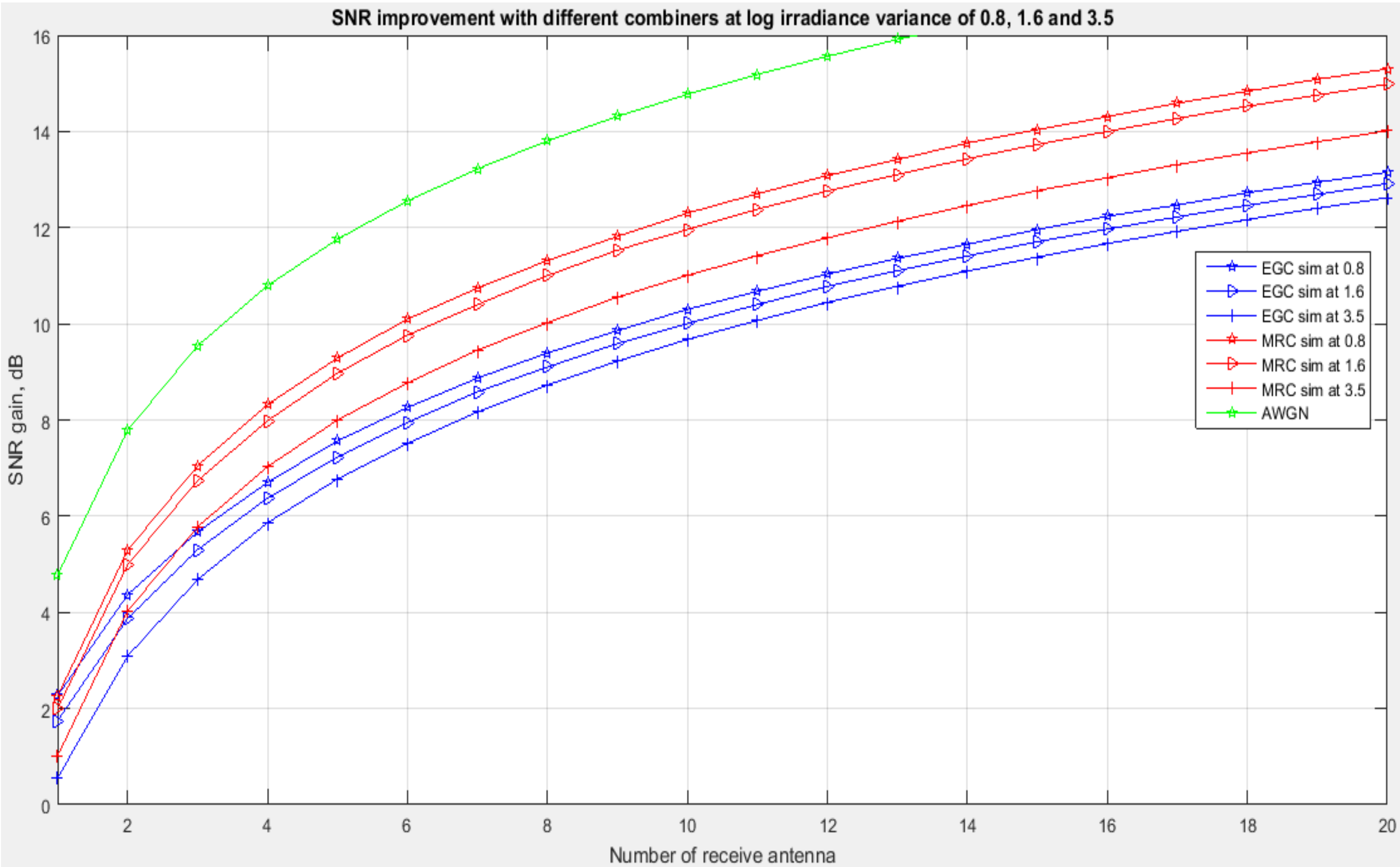

Figure 2. SNR versus N receivers for EGC and MRC at log irradiance variance of 0.8, 1.6, and 3.5 with AWGN without combiners.

receivers used play a significant role in the improvement of SNR again. Increase in the log irradiance, decrease the SNR gain. At the constant log irradiance, increase in the number of receive antenna also increase the SNR again at each diversity.

CONCLUSION

It has been observed that the SNR gain increases with increase in the number of receive antennas as turbulence increases irrespective of the nature of diversity employed to combat or reduce the effect of turbulence. Hence, to combat against fading in FSO terrestrial links where turbulence is pronounced, the use of combining diversity is very important. Therefore, for the same number of receive antennas where diversity is employed, the value of SNR for Maximal Ratio Combiner (MRC) is maximized over EGC and SC. Overall, MRC diversity combats any degree of turbulence than other diversities in comparison with AWGC without combiner. Also, the results suggest a model that is capable of mitigating atmospheric turbulence especially for the 5G wireless networks in the terrestrial link.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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