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# Secure hybrid fiber optic and free optical space communication systems

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**ABSTRACT**

This work investigates the integration of electrical to optical (E/O) and optical to electrical (E/O) communication systems. Two ways of transition, namely, hybrid fiber optic (FO) and free space optical (FSO) transmission system have been proposed. This work aims to evaluate the performance of these two transition ways. FO has the optimum transmission due to its lower attenuation which can be reached to 350 km. However, for further assurance of reaching data to the receiver side a second way of transition has been investigated. FSO path has been employed under different weather conditions of clear, moderate dust, heavy dust and heavy fog. MATLAB and Optisystem7 software's have been used to simulate optical secure data transition (SDT). The results show that an optimum transmission could be obtained using FO with red, green, blue (RGB) image encryption where the mean square error (MSE) reach to $9.88\times10^{7}$ in read channel and it can reach to $4.93\times10^{9}$ using discrete wavelet transform (DWT).



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## 1. INTRODUCTION

The fiber optic is being increasingly employed in communication systems due to its several features in wide fields of applications such as high-capacity, long haul, and high-speed transmission [1], [2]. Data may be lost during bad environment situation. However, free space optics (FSO) is usually used to transmit securely the important data. FSO is a communication system where free space becomes intermediary between transmitters and receivers, since medium is space or air [3]. The main advantages of this system are absence of spectrum license and it has a high bandwidth. Based on economy reason, FSO can be used. However, the attenuation caused by medium e.g. scattering, fog , physical obstruction, rain, smoke, and atmospheric turbulence are the main external elements that disturb the performance of the system [4]. Transmission data with encryption and decryption is an important and essential issue due to security attacks [5].

Many previous studies addressed in this perspective to investigate how to reduce the impact of attenuation [6], [7]. Different techniques like orthogonal frequency division multiplexing-FSO and wavelength-division multiplexing-FSO based system are new approach to improve the system performance with high speed and longer distance [8]. Wireless optical communication system-FSO has been studied to evaluate the effect of different weather conditions on the performance of the system [9]. Two bi-directional FSOs are compared as case study in the middle east region [5]. The effect of visibility and operating wavelengths on atmospheric attenuation has been addressed [10]. Cipher algorithm has been developed to produce the ciphered image. An experimental optical link attenuation measurements has been studied under the visibilities ranging of 9-12 km to show relationship between atmospheric visibility and optical attenuation [11]. Free space optical transmitter and receiver link have been investigated to study the attenuation inherent in adverse weather conditions [12]. The performance of free space optical communication link has been studied under average and worst rain weather conditions of India [13]. The receiver sensitivity and maximum reached distance has been studied [14]. A survey on FSO communication systems has been presented [15]-[17].

Based on these previous works, we have proposed an approach for red, green, and blue (RGB) image encryption and decryption. Two stages of random matrix affine cipher associated with discrete wavelet transformation have been used to increase the mean square error. The rest of this paper is structured as follows. Methodology is described in section 2. Section 3 contains the findings and discussions. The conclusion of the study is provided in section4.

## 2. METHOD

This work proposes a hybrid fiber optic (FO)-FSO transmission system as shown in Figure 1. The system composes of two main stages electrical to optical (E/O) and E/O integrations using two software programs MATLAB and Optisystem7. Data is encrypted depend on RGB image encryption algorithm by MATLAB program. The secure data is introduced to the optical communication network via an optical controller with bits' generator in Optisystem program. Continuous wave (CW) laser diode acts as the optical carrier source at 1550 nm. CW laser diode has minimum attenuation, about 0.2 dB/km. As well, it has minimum outstanding amplification techniques by erbium-doped fiber amplifier (EDFA) and stimulated Raman scattering (SRS). The secure data transition (SDT) data transmit via control optical network unit (CONU) to select the best transmission path depending on environmental and security reasons. An avalanche photo diode (APD) with a low-pass Gaussian filter has been used in the receiving side. The reason behind that is to reduce signal jitter that yields by signal dispersion and induces data cluttering with low signal to noise ratio [18].

The proposed design is shown in Figure 1. It has been proposed depending on standard communication system components to transmitted 10 Gb/s at 1550 nm with -10 dBm and to transmit the SDT data (image), based on RGB encryption technique. The secure hybrid FO-FSO transmission links controlled by CONU will be discussed in section 3.

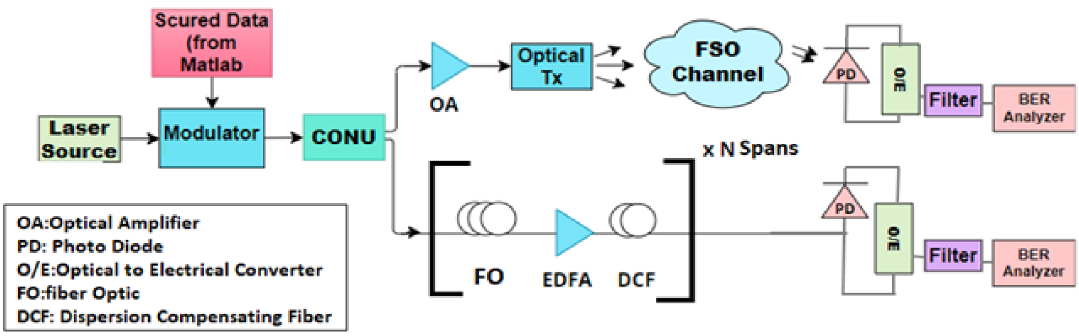



Figure 1. Hybrid FO/FSO system design

### 2.1. Design Issue

The system in Figure 1 proposes two links paths to transmit the SDT data. Each link performance is estimated in different distances. CONU controller is used to get an optimum transmission secured optical network system. The main focus of this work is to study the effect of transmission on a SDT data.

### 2.2. RGB image encryption

To obtain a high security with real image color, RGB image encryption technique has been used. This method is characterized by a constant bit values, based on rows and columns shifted in position as in [19]. The image has been split to its original components as three channels (Red (R), Green (G), Blue (B)). The three channels' components are considered to forms a partial encryption by each pixel. The encryption processes depicted in Figure 2 with the whole system flow chart. This method has a Mean Square Error (MSE) which can be measured by using the following [19], [20]:

$$MSE = \frac{1}{A}\left(\sum_{x=0}^{x-1}\sum_{y=0}^{y-1}(s[x,y] - \check{s}[x,y])^2\right) \quad (1)$$

where s $[x, y]$ is the original image of size $x, y$ and $\check{s}$ is the reconstructed image which has same size, and A=$x \times y$ is the image size. The encryption process is programmed by MATLAB2018b. This process has a special management with such a type of encryption. For farther improvement, discreet wavelet transform (DWT) has been applied in the encryption process. DWT is widely used in data transmission of optical network and data compression.

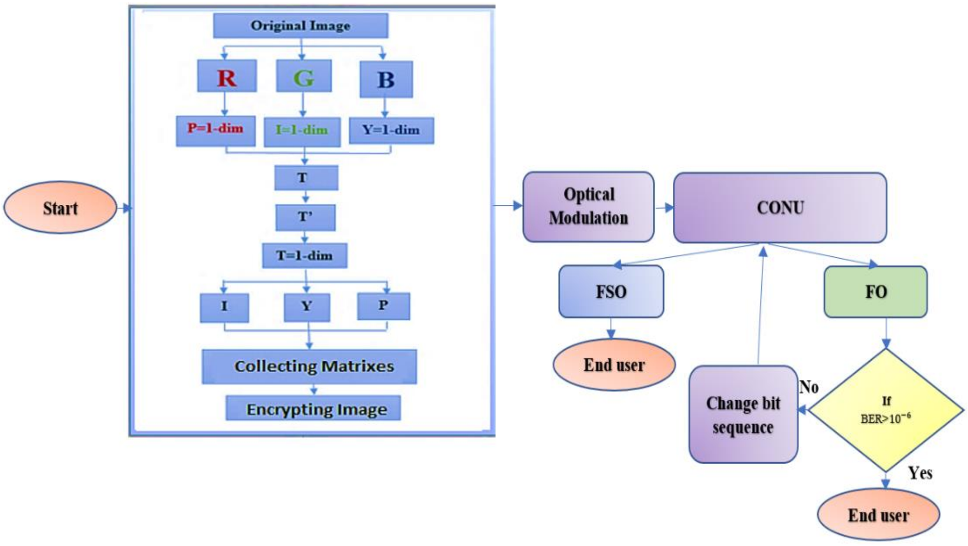



Figure 2. System flowchart

### 2.3. Controlled optical network unit (CONU)

CONU or control optical switch is an optical device that enhances the system performance by remove the required of E/O conversion and electrically processing which make it faster and higher transmission capacity [21]. The CONU is a function of bits' sequence to operate the hybrid FO-FSO system as in Figure 3. The components operate by two interfaced software; MATLAB and Optisystem7.

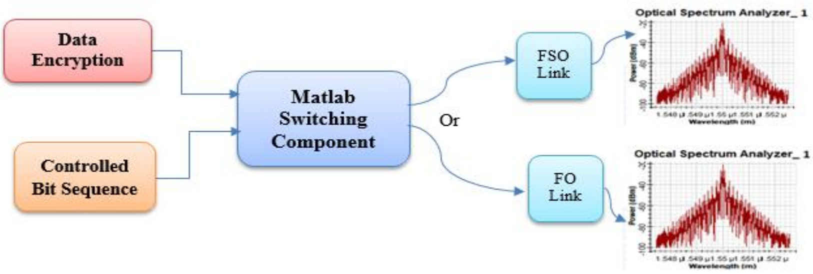



Figure 3. CONU components

### 2.4. Transmission links

Two types of communication links have been used. The transmission path has been selected by the CONU depend on the weather and security conditions. Both links performance has been measured by scaled its eye diagram as shown in Figure 4, depending on the Q-factor and the BER accordingly using the attenuation of SSMF at 1550 nm and other noise types as in [22].

$$\text{SNR}=\frac{i_{sig}^2}{i_n^2} \quad (2)$$

Where $i_{sig}$ is the signal current and $i_n$ is the noise current therefore at a constant source power (-10 dBm) the signal-to-noise ratio (SNR) will reduce with distance depending on the accumulated noise with distance. And the BER will affected accordingly by (3).

$$\text{BER}=\frac{1}{2}\text{erf}\left(\frac{\sqrt{S/N}}{2\sqrt{2}}\right) \quad (3)$$

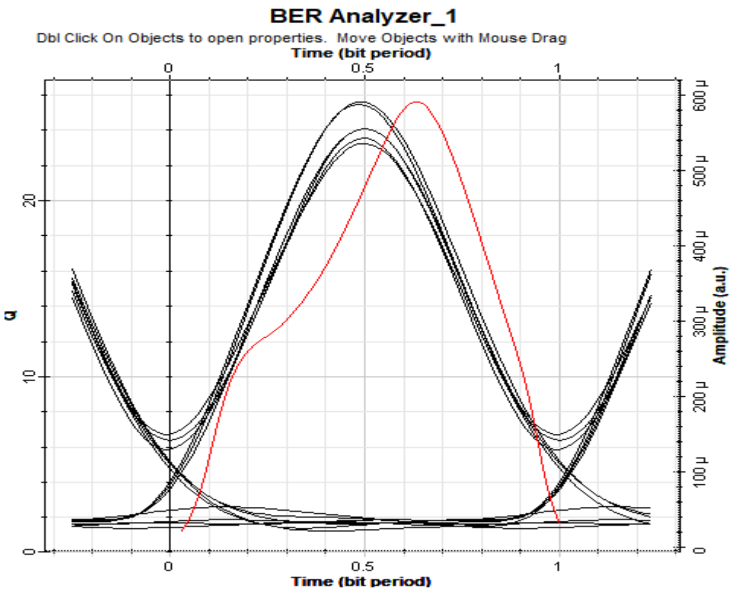



Figure 4. Eye diagram for measuring links performance

### 2.5. FO link

To verify the system performance and evaluate its operations, an FO transmission link was used in the central of C band 1550 nm to transmit the SDT data with -10 dBm at different distance from 250 to 350 km with an EDFA amplifier to compensate the 0.2 dB/km loss with the stander single mode fibre (SSMF) and dispersion compensate fibre (DCF) of -85 ps/nm.km. The link has been operated with a signal control loop to reach its maximum transmissions. The process has been taken only few seconds to operate and it can be modified to WDM system to increase its capacity performance as in [23].

### 2.6. FSO link

In case of signal switch to the free space due damages of the infrastructure links or other conditions effected. The SDT data then will face many challenges due to the effect of complex weather therefore the signal will be transmitted with maximum 5 km at a clear weather and reach to 125 m or 100 m in heavy dust and fog respectively. The FSO transmission part has been operated with 1mrad divergence angle and 20dB amplifier gain with different attenuation range from 0.4 dB/km (in clear weather) to 242 dB/km and 304 dB/km (in heavy dust and fog respectively). The attenuation is calculated by Kim model with a visibility of 70 m and 49 m respectively as in [6], [7]. Where the atmospheric attenuation coefficient according to Kim model equals to [5], [24].

$$\alpha=\frac{3.91}{V}\times\left(\frac{\lambda}{550nm}\right)^{-q} \quad (4)$$

q=1.6 for visibility (V > 50 km), q = 1.3 for visibility (6 km < V < 50 km), q = 0.16 V + 0.34 for visibility (1 km < V < 6 km), q = V − 0.5 for visibility (0.5 km < V < 1 km), and q = 0 for visibility (V < 0.5 km). Where V is the visibility or the distance where the luminance is propagated in atmosphere with a low divergence angle, q is the size of the particles dispersed coefficient, and λ is the wavelength. The Kim model is very handy to use at a specific wavelength due to its dependence on the visibility [5], [25].

## 3. RESULTS AND DISCUSSIONS

RGB image encryption is one of the best way and high security encryption method due its ability to obtain a real RGB colour. The RGB encryption technique is based on RGB pixel displacement, therefore the histogram before and after the encryption is same as shown in Figure 5. The MSE of each channel of the encryption image (R, G, B), as shown in Figure 5, is listed in Table 1.

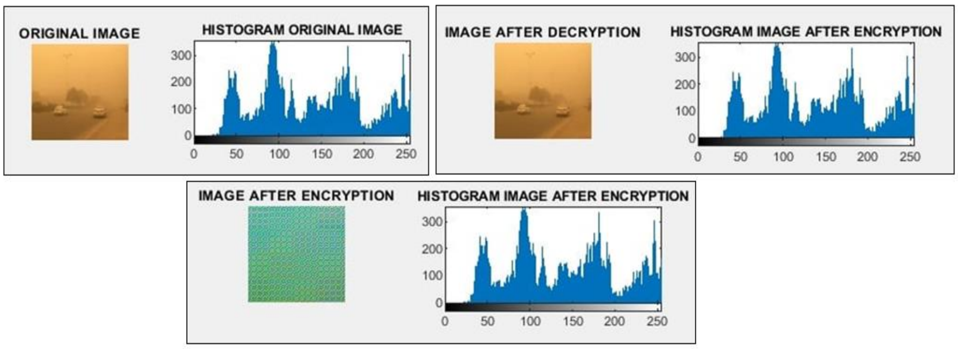



Figure 5. RGB image encryption and decryption with histogram

Table 1. MSE for R, G, and B channels

| Channel Component | MSE Value |
|---|---|
| R (Read Channel) | $9.88 \times 10^7$ |
| G (Green Channel) | $3.83 \times 10^7$ |
| B (Blue Channel) | $9.25 \times 10^6$ |

MSE results show large values, which indicate that it's too difficult to obtained information about the original image without knowing the values of shifted pixels. However, when use a DWT as shown in Figure 6 the results of MSE will be much higher as shown in Table 2, due to its ability of edge extraction and data compression. This approach will increase the image security and the original image can be easily obtained by using the inverse of the DWT.

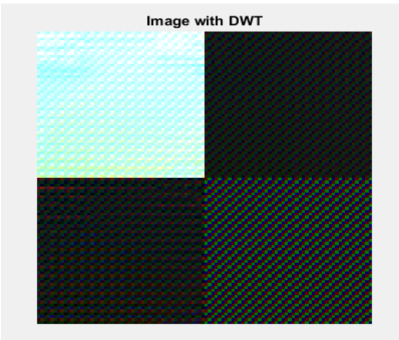



Figure 6. DWT of encrypted image

Table 2. MSE for R, G, and B channels with DWT

| Channel Component | MSE Value |
|---|---|
| R (Read Channel) | $4.93 \times 10^9$ |
| G (Green Channel) | $1.59 \times 10^9$ |
| B (Blue Channel) | $4.42 \times 10^9$ |

The result shows that the pixel's values and the histogram distribution do not change. Both depend on swapping in (R, G, B) pixels which provide difficult penetration and high security. Figure 6 shows the results of using DWT on the encrypted image. It composes of four parts of the harr transformation wavelets, LL, HL, LH and HH [23]. The characteristics and the performance of FO link have been presented as a function of Q-factor and BER based on Figure 1. The FO link has been modelled by using different length design with compensated dispersion fibre. Figure 7 shows the system's Q-Factor while Figure 8 shows the BER performance among the transmission link.

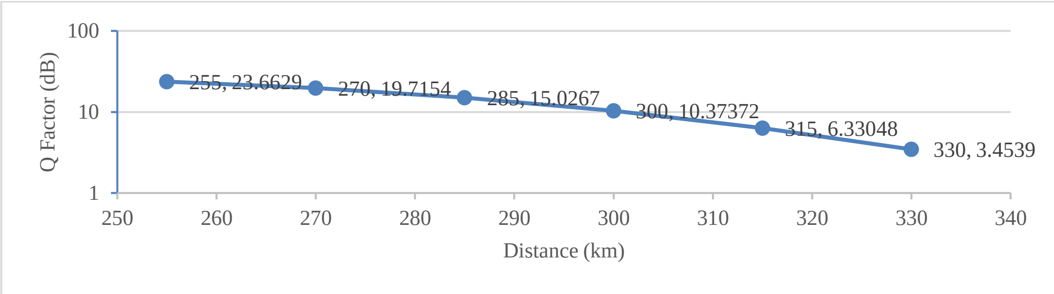



Figure 5. Q-factor of FO link in different distance

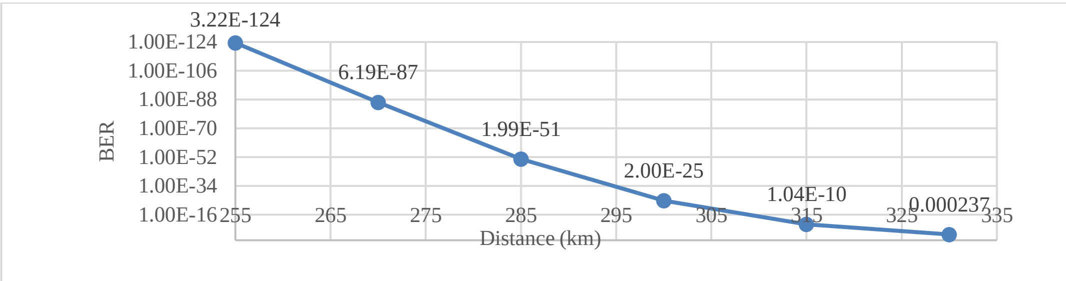


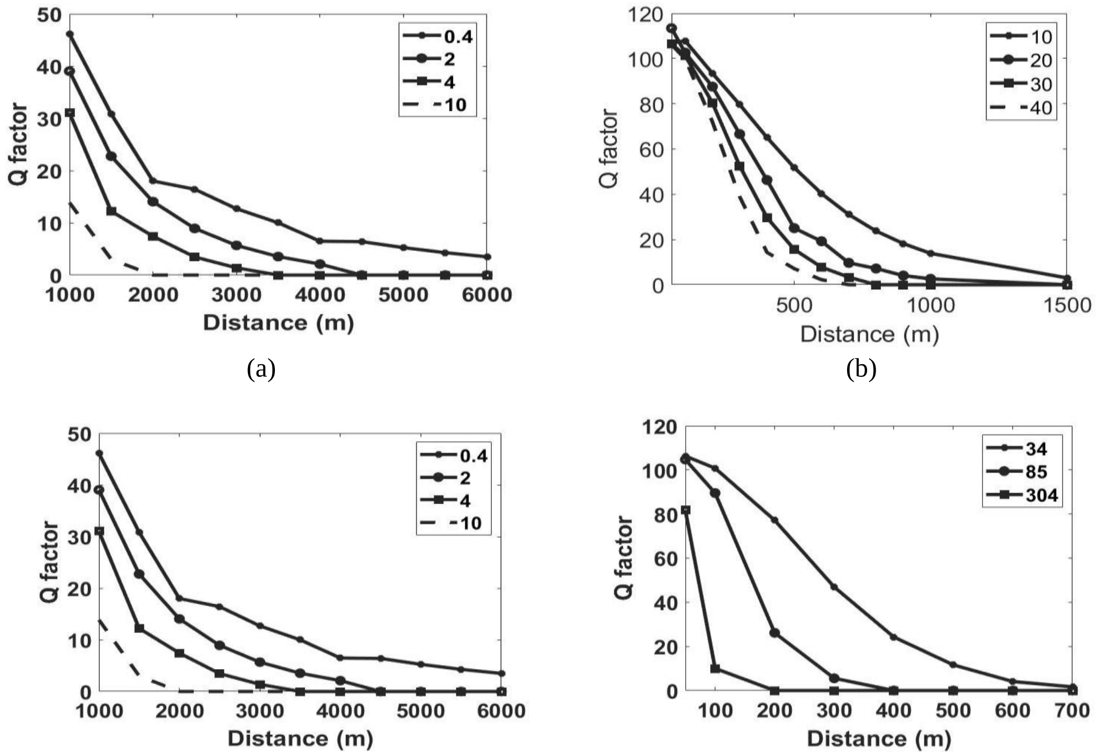

Figure 6. BER performance of FO link in different distance

The maximum distance can be reached using FO is 350 km at BER $1.04\times 10^{-10}$ and 6 dB Q-factor. The signal has been measured based on attenuation of 1550 nm in SSMF and using (1) and (2). While in FSO, the performance depends on weather conditions. Attenuation measured deepens on Kim model and it has been implemented to measure the maximum distance can be reached as clarifies in Table 3. The results of different weather conditions in Figure 9 and see Figures 9 (a)-(d) shows that using system in Figure 1 can be reach to 5 Km in clear weather comparing with 2 Km in [14] with same data rate. However, this system is based on using only one channel at 1550 nm.

Table 3. Different attenuation with various distance measurement

| Weather condition | Attenuation (dB/km) | Maximum distance range (m) |
|---|---|---|
| Clear | 0.4-2 | 5000-3000 |
| Light Dust | 4-10 | 2500-1250 |
| Moderate Dust | 10-40 | 1000-500 |
| Heavy Dust | 40-242 | 650-125 |
| Heavy Fog | 34-304 | 700-100 |

The results show that heavy dust storms or heavy fogs are considered as a design's challenge since its attenuation has a higher value as shown in Table 3. The visibility versus attenuation has been measured at 1550 nm at different weather conditions as shown in Figure 10. This figure shows the effect of attenuation on the visibility, where higher attenuation has the lower visibility reach to 1 Km at about 6 dB/km in moderate dust case. While in light dust case, the visibility can be reached higher than 70 Km. This work was based on Iraq weather, dry and dusty in summer and wet with high fog range in winter which is the must challenges in FSO link transitions due its high attenuation per km. the results shows that FSO has a poor performance therefore it preferred to transmitted over the FO link.




(a) (b) (c) (d)

Figure 9. Q- factor with different weather condition, (a) clear and light dust, (b) moderate dust, (c) heavy dust and (d) heavy fog

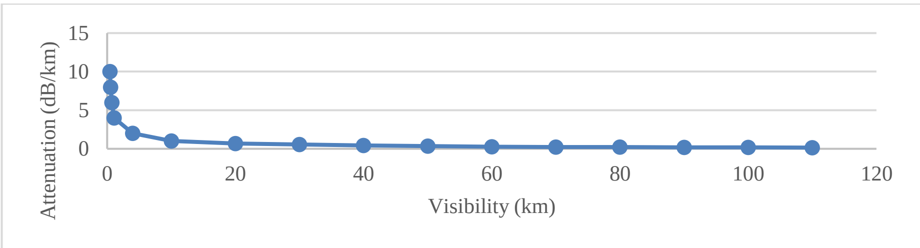



Figure 10. Atmospheric attenuation versus visibility

## 4. CONCLUSION

This study investigates the processing of signals in the optical and electrical domain of secure hybrid FO-FSO system and study the weather effect on the performance of the FSO links. The results of data encryption show that the pixel values and the histogram do not change. Since this method depends on swapping in (R, G, and B) pixels which provides difficult penetration and high security. However, to improve data security, DWT has been applied due to its ability of edge extraction and data compression. Transmitted SDT data rate decreases with increasing divergence angle and link distance for the parameters under study. It is observed that the clear and haze weather has low attenuation compared with the fog attenuation.

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