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Analysis of the Transmission Characteristics of Ultraviolet Communication in Non-Common-Scattering Volume

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Abstract: This paper uses multiple scattering model based on Monte Carlo simulation to study the transmission characteristics of uv communication in non common scattering volume And theoretically analyze the performance of the omnidirectional full-duplex UV optical communication system. In the model, the variation of the average scattering times of uv light in the atmosphere, the variation of the path loss, the change of the pulse response time delay and signal to noise ratio (SNR) along with the transmission distance. And the variation of signal to noise ratio of full duplex communication system based on WDM technology are analyzed in the omnidirectional directional scattering case. The results show that unlike the case of a common scattering volume at least twice atmospheric scattering are required to reach. the receiving end in non-common-scattering volume model, The path loss and impulse response time delay with the same transmission distance for the non public scattering transmission model is much higher than those the common scattering volume transmission model. The interference signal-to-noise ratio of full-duplex communication system based on theory of wavelength division multiplexing is much smaller than that of the common scatter transmission model. The full duplex UV communication can be realized by WDM technology. The results show that the theory of WDM technology can realize omnidirectional full-duplex UV communication. When the transmission power is increased and the detection efficiency is improved, the application requirements can be fully satisfied. The paper theoretically gives the ultraviolet transmission characteristics of the transmission model without common scatterers, and provides theoretical basis and favorable reference value for the study of omnidirectional communication of actual ultraviolet light.

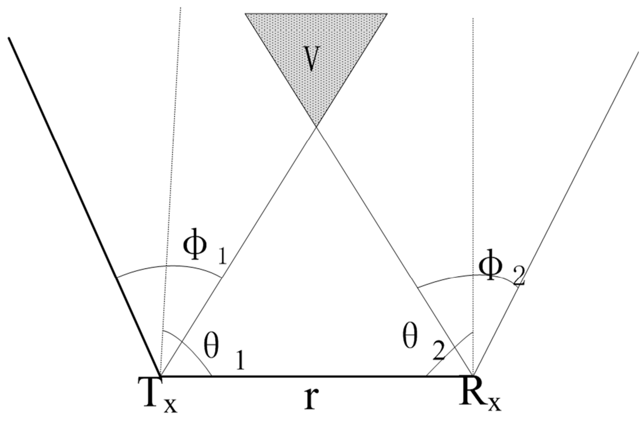
Keywords: Ultraviolet Communication, Non-Common-Scattering, Monte Carlo, Full Duplex

1. Introduction

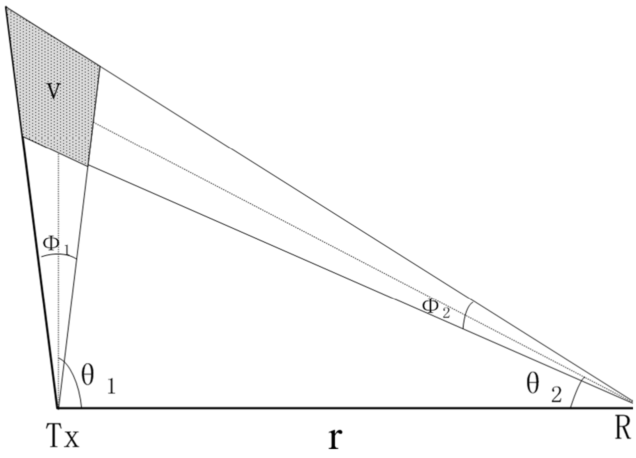
There are different requirements for different spiritual domains of information transmission, which promotes the diversification of communication modes. Solar Blind ultraviolet (UV) communication in Free atmosphere space has become the focus of research because it has the characteristics of flexibility, Strong secrecy, can be omnidirectional and all-weather work, and the link is stable and reliable, The transmission characteristics of UV in the atmospheric channel are one of the main research contents [1-5]. At present, the transmission characteristics of UV in the atmosphere are mainly studied for the UV communication model with common scatterers volume [6-8], But the non-sight-distance (NLOS) UV communication also contains another case, that is, non-common-scattering volume, but few studies on it. Generally speaking, the following 4 methods can be used to study the atmospheric transmission characteristics of UV communication. the single scattering analytical model in a Elliptical coordinate system, It can be applied to short distance and in common scattering volume [9]; the discrete coordinate method, for the complex environment, but it is difficult to solve the problem [10], Atmospheric transmission module simulators such as LOWTRAN or MODT-RAN T, It uses the mean atmospheric hypothesis, which Only suitable for atmospheric transmission under the sight distance [11]. The NLOS multi-scatter model based on the Monte Carlo method, Theoretically, it can deal with the radiation problem in arbitrary geometry state [12]. In order to have a comprehensive understanding of the atmospheric transmission characteristics of UV communication under different transceiver models. In this paper, using multi-scatter model based on the Monte Carlo method, The transmission characteristics of the UV communication model with common scatterers volume and in non-common-scattering volume are compared and analyzed. It provides an effective theoretical foundation for the realization of UV omnidirectional communication system.

2. Scattering Model of Ultraviolet NLOS Communication for Non-common Scattering Volume

Generally speaking, there are 4 forms of NLOS UV communication transmission model [13], as shown in Figure 1. The Tx is the transmitter, the divergence angle is φ_1, the Rx is the receiver, the receiving view angle is φ_2, the distance between the transmitter and the receiver is r, and θ_1 is the elevation angle, θ_2 is the receiving angle. The Figure 1. (a) is non-directional transmission and omni-directional receiver, requires the lowest for the position direction of transmitting and receiver; the Figure 1. (b) communication mode is non-directional transmission and oriented receiving, Only the direction and scattering angle of the transmitter are required; the Figure 1. (c) communication mode is directional transmitting and directional receiving, Both angles and directions of the transmitter and receiver are required, and its transmission distance is far away, and the coverage range is wide; for the Figure 1. (d), the communication transmission mode, the sum of the elevation angle and the elevation angle should be greater than 180°. The 4 models can transform each other by changing the elevation angle and receiving elevation angle.



(a)



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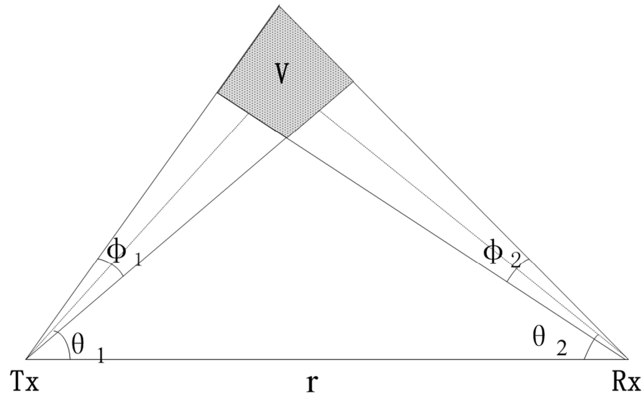

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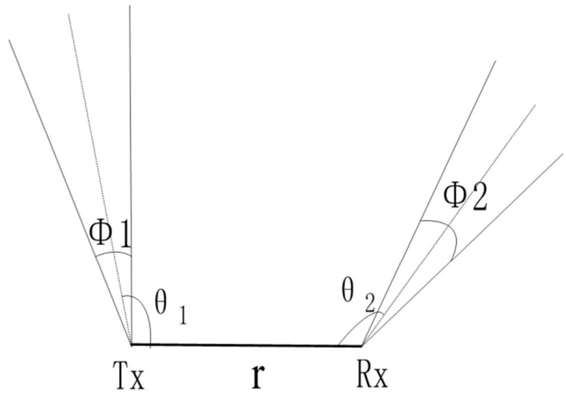

(d)

Figure 1. *Four transmission model of NLOS UV communication. (a) (b) (c) UV communication in common-scattering volume, (d) UV communication in non-common-scattering volume.*

The transceiver schematic diagram of NLOS UV communication in non-common-scattering volume is shown in Figure 2. The basic characteristic of the non-common-scattering volume model is that there is no overlap area between the transmitted light and the receiving field in the atmosphere. Angle $\theta_s = \theta_1 + \theta_2$ and $\theta_s > 180$ degrees. In this transmission model, UV usually needs more than 2nd scattering to reach the receiving field, and it is received by the receiver. Therefore, in this case, the single scattering model is no longer applicable, so the Monte Carlo UV multiple scattering method is used to simulate the atmospheric transmission characteristics.

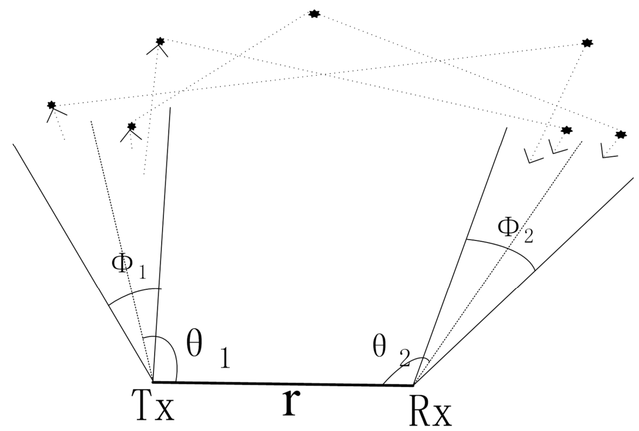

Figure 2. *A schematic diagram of the transceiver of the NLOS UV communication in non-common-scattering volume.*

3. Mathematical Description of Monte Carlo Method

Monte Carlo method is a calculation method based on probability and statistics theory [14, 15]. The flow chart of the pointing probability method based on Monte Carlo-based NLOS UV scattering modeling method is shown in Figure 3.

The UV source is regarded as a point source, Randomly emit a photon within a solid angle $2\pi(1-\cos\frac{\phi_1}{2})$ of a certain divergence angleφ1. The photon is initialized to sample the square angle and the deflection angle of the exit direction, after the photon is emitted, it is transmitted in the atmosphere, then sample the free path to the photon, make weight updates and judgments. Calculation of acceptance probability, transmission time update, judgment of reception conditions, and the final calculation of the total acceptance probability [16].

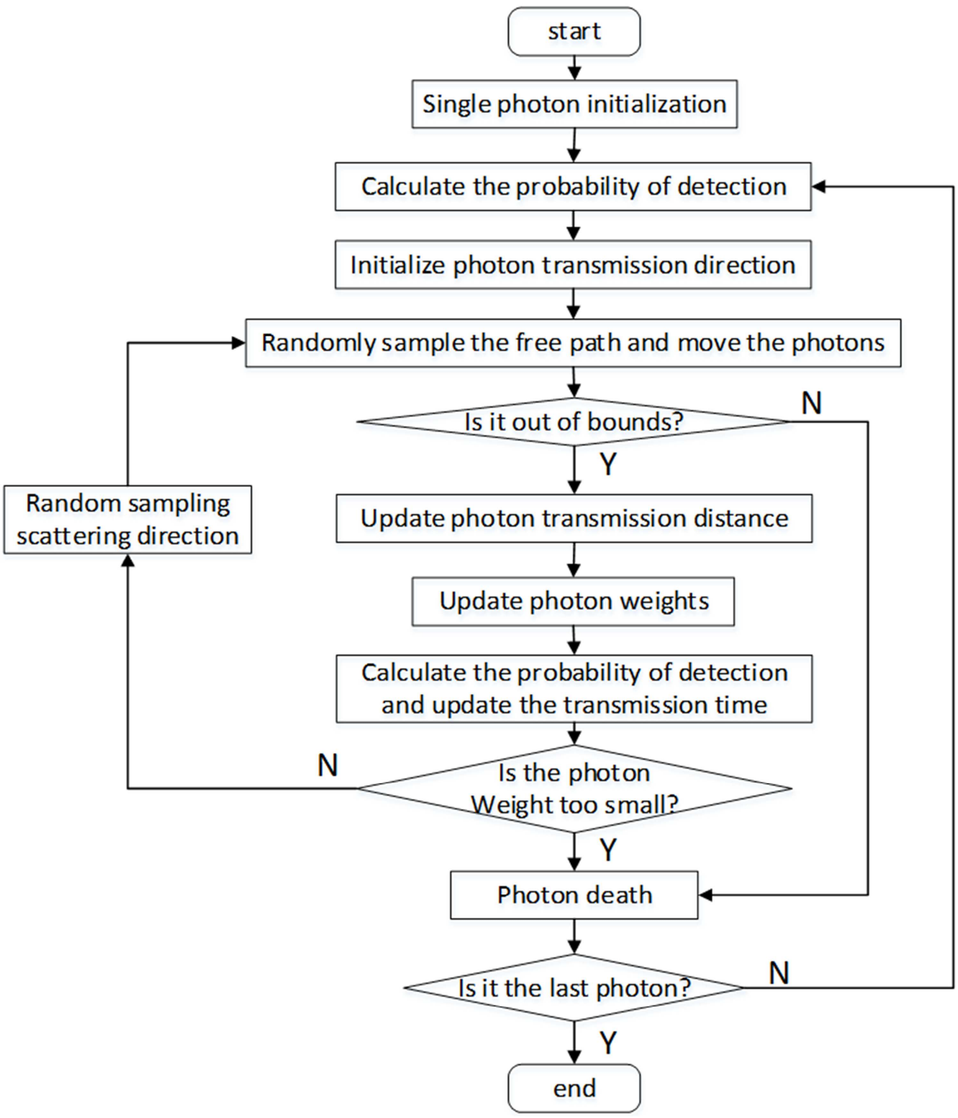

Figure 3. *Simulation flow chart of UV multiple scattering is based on Monte Carlo.*

In the atmosphere, the UV transmission is dominated by scattering [17], The scattering phase function is the addition of the Mie scattering phase function to the Ray scattering phase function [18]. That is:

$$p(\mu) = \frac{k_s^{Ray}}{k_s} p^{Ray}(\mu) + \frac{k_s^{Mie}}{k_s} p^{Mie}(\mu) \quad (1)$$

Where: $\mu = \cos\theta_s$ is defined by the scattering angle θ_s; k_s^{Ray} is the Rayleigh scattering coefficient; k_s^{Mie} is the Mie scattering coefficient, k_s is the atmospheric scattering coefficient; the Ray scattering phase function is [19]:

$$p^{Ray}(\mu) = \frac{3}{4}(1+\mu^2) \quad (2)$$

The Mie scattering phase function is:

$$p^{Mie}(\mu) = \frac{1-g^2}{(1+g^2-2g\mu)^{3/2}} \quad (3)$$

Where:g is the asymmetric factor of atmospheric aerosol.

After the nth scattering of photons, the probability that a photon will scatter into the receiver in the receiving field of view is:

$$p_{1n} = \int_{\Omega_n} p(\cos\theta)d\Omega \quad (4)$$

Where:the Ω is the solid angle at which Ar receives the photon along the scattering direction of the photon. In this article, Ar is $1cm^2$.

If a photon is scattered N times, the probability that it will be successfully received by the receiver is [20].

$$P = \sum_{n=1}^{N} P_n = \sum_{n=1}^{N} \omega_n p_{1n} p_{2n} \quad (5)$$

Where: $\omega_n = (1-p_{1n})e^{-k_s|r_n - r_{n-1}|}\omega_{n-1}$ is the survival probability of photons, the initial weight ω=1 in this paper; $p_{2n} = e^{-k_e|r_n - r'|}$ is the probability that a photon will reach the detector directly at the nth scattering point without extinction, Ke is the atmospheric extinction coefficient, the absorption coefficient of the atmosphere, and the R 'as the position vector of the receiver.

After simulating random scattering of a large number of photons, accumulate the probability of reaching the detector in different small time zones, after being converted into weight distribution, the impulse response function of the atmospheric system to the NLOS optical signal is obtained. At the same time, the path loss PL can be obtained.

$$P = 10\lg(1/p)dB \quad (6)$$

4. Simulation Results and Analysis

The simulation uses the MC method, and the basic parameters are set to: λ=254nm, k_a = 0.9 km^{-1}, k_s^{Ray} =0.21048 km^{-1}, k_s^{Mie} =0.3548 km^{-1}, g=0.72, φ1=30°, φ2=30°.

Based on the basic parameters, When the transmission distance is 100m, based on three typical transmission models, the ratio of the energy received after different scattering times to the total accepted energy is analyzed, as shown in Figure 4. It can be seen that the energy received by the single scattering of the NLOS (c) mode accounts for more than 80%, the proportion of other scattering times is relatively small, so in general, this mode can be used to analyze its scattering characteristics well using a single scattering model; Based on the NLOS (a) transmission mode, the proportion of single scattering and secondary scattering is basically the same, and the sum of single and secondary scattering is more than 80% of the total received energy, In this case, if the analysis is continued using the single scattering model, a large error will occur; For the NLOS (d) communication mode, the photon needs at least two scattering to reach the receiving end. when the transmission distance is 100m, the second scattering is dominant. In this case, the energy of the ultraviolet light reaching the receiving end after two times of scattering is more than 80%. Based on θ_1 =90°, θ_2 =135°, φ1=30°, φ2=30°, The variation of the average number of scattering times with distance in the NLOS (d) communication mode using the MC method is shown in Figure 5. The results show that as the transmission distance increases, the average number of scattering increases. At 1000 m, the third scattering is dominant.

Based on the basic parameters, When the transmission distance is from 0 to 100m, Compare the path loss under different transmission models with the distance. As shown in Figure 6, in 5 cases, path loss increases with distance; However, in the case of the same transmission distance, the path loss in non-common-scattering volume transmission model is much larger than that of the common scatterer transmission model. in non-common-scattering volume transmission model, The path loss of the directional transmit omnidirectional receive transmission model is significantly larger than the path loss of the omnidirectional transmit directional receive transmission model.

Based on the basic parameters, when the transmission distance is from 0 to 1000m, Compare the variation of the impulse response time with the distance in different transceiver modes, As shown in Figure. 7, In all four cases, the impulse response time delay increases with distance, it can be seen from the figure that the curve generally rises linearly, and the slope increases at 900 m; But when the transmission distance is the same, Compared with the two models with in non-common-scattering volume and common scattering volume, the impulse response time delay of the former is significantly larger; and the impulse response time delay varies with the transmission distance.

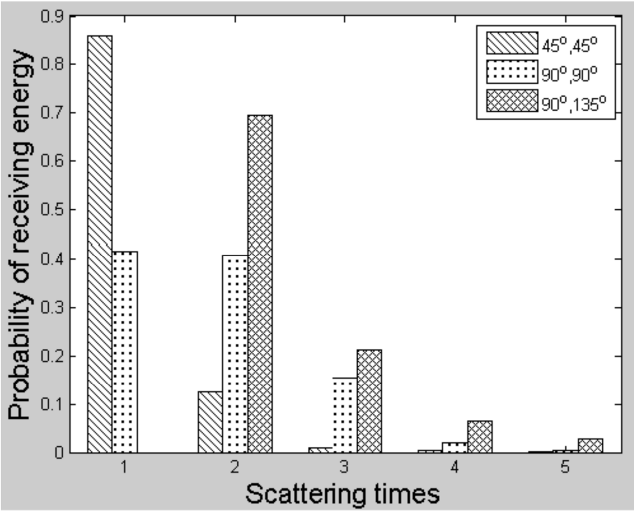

Figure 4. *The schematic diagram of the number of different scattering to receive the energy ratio.*

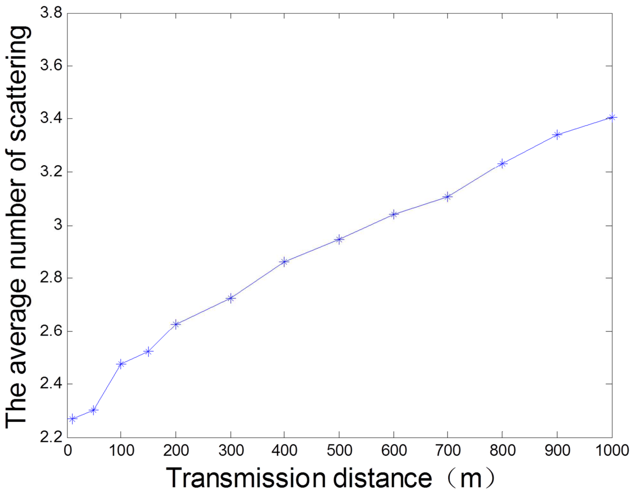

Figure 5. *The change curve of average scattering times with transmission distance in non-common-scattering volume.*

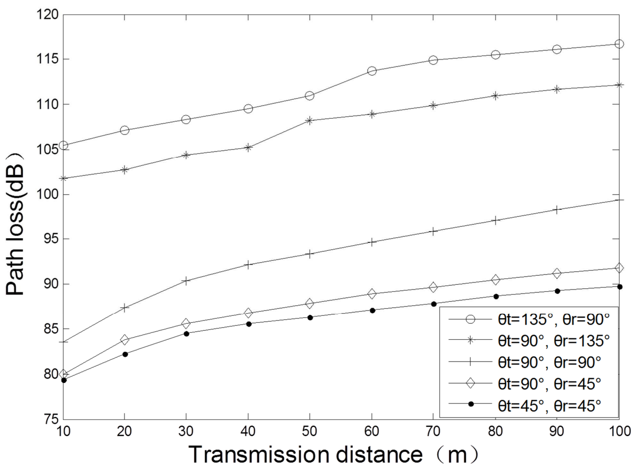

Figure 6. *The change curve of path loss with transmission distance.*

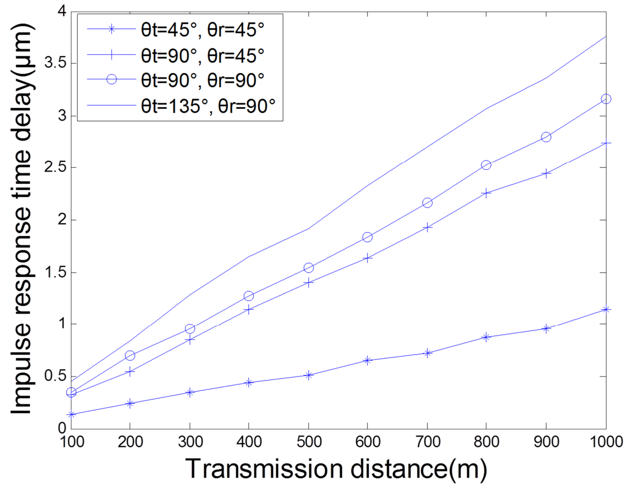

Figure 7. *Change curve of pulse response delay with transmission distance.*

Based on the basic parameters, when the transmission distance is from 0 to 100m, The signal-to-noise ratio changes with distance as shown in Figure 8. In 4 different modes, the signal-to-noise ratio decreases with increasing distance; in the case of 4 different modes, when the transmission distance is the same, Compared with the two models with in non-common-scattering volume and common scattering volume, The former has a much smaller signal-to-noise ratio.

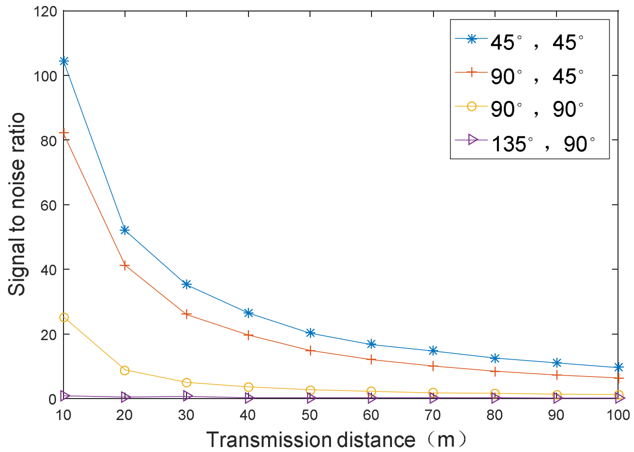

Figure 8. *The variation of signal to noise ratio with transmission distance under four different modes.*

UV light achieves full-duplex communication generally adopts space division multiplexing technology, it has the characteristics of simple implementation, but at the same time it has higher requirements on the angle of the transmitting and receiver; Therefore, in this paper, the full-duplex UV communication is realized by using the carrier wavelengths of the signals transmitted at both ends of A and B as different wavelengths of ultraviolet light. As shown in Figure 9.

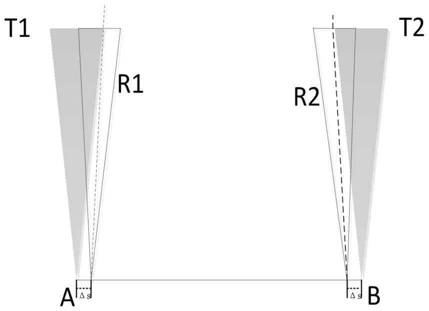

Figure 9. *A full duplex UV communication system model based on different transmitting wavelengths at A and B ends.*

For full-duplex systems based on different emission wavelengths, Both the receiving elevation angle and the emission elevation angle are selected to be 90˚. Moreover, the emission wavelength at the A end is 254 nm, and the emission wavelength at the B end is 270 nm. Δs=0.1m, The basic parameters are set to: When λ = 254 nm, the same as above; When λ = 270nm, k_a = 0.8 km-1, k_s^{Ray} =0.17 km^{-1}, k_s^{Mie} =0.32 km^{-1}, g=0.72, φ1=30˚, φ2=30˚, As shown in Figure 10, For the curve of path loss with transmission distance at two different wavelengths, it can be seen that the difference is not large.

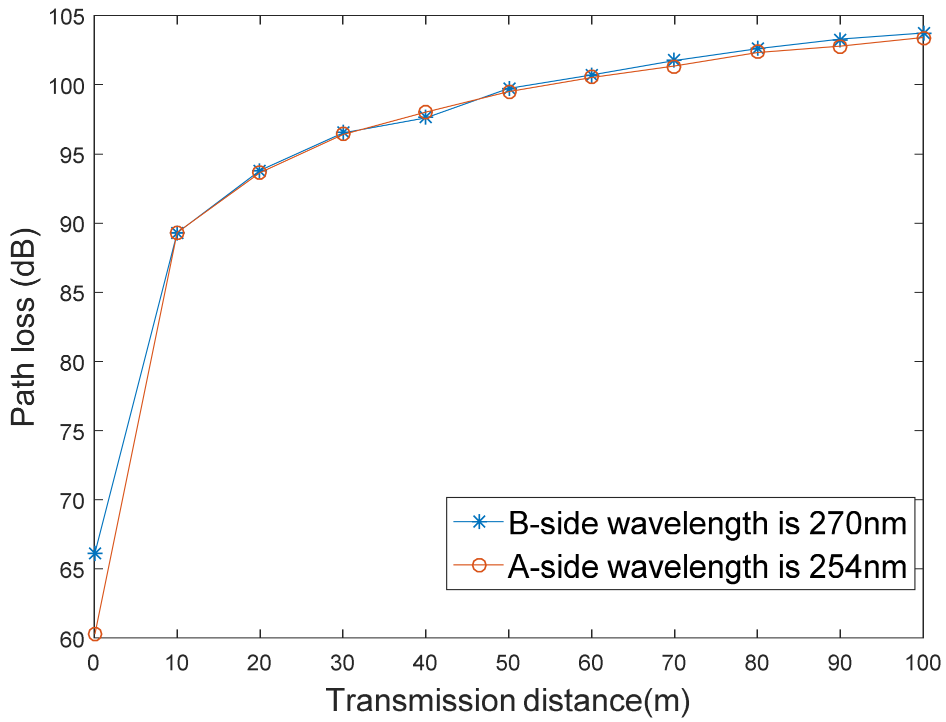

Figure 10. *Curves of path loss with transmission distance under two different wavelengths.*

Combined with changes in emission energy and path loss, Figure 11 shows the interference signal-to-noise ratio of both ends of A and B when receiving signals. It can be seen that the larger the transmission distance is, the smaller the signal-to-noise ratio is, and the signal-to-noise ratio of both ends is greater than 0 for the completion of duplex communication. The product characteristics based on the filter and the scattering and absorption of different wavelengths by the atmosphere are different. Under the influence of the selected transmission power of 1W, the performance of 270nm signal light and 254nm signal light is different. The transmission distance at 254nm is about 17m, and at 270nm is about 24m. In general, although the transmission distance of the system is very Small, the maximum is about 17m, but in the case of increasing the transmission power, the transmission distance can be greatly improved to meet the communication requirements.

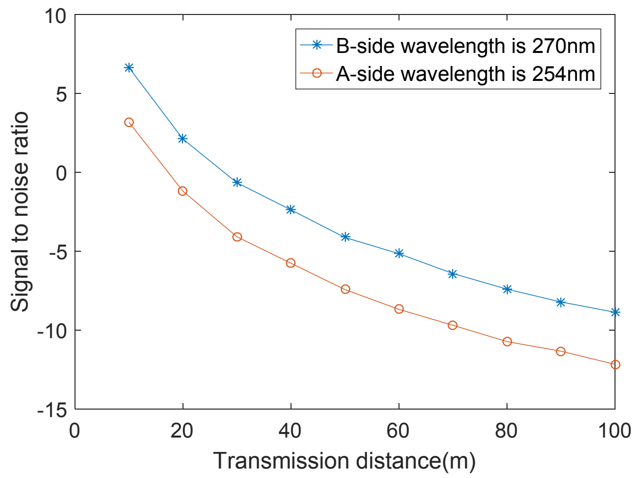

Figure 11. *The interference signal to noise ratio (SNR) of the received signals at the ends of A and B varies with the transmission distance.*

5. Conclusion

In this paper, four common NLOS UV communication transmission models are compared. The Monte Carlo UV communication channel multi-scattering model is used to study the UV atmospheric transmission characteristics under the non-common scatterer transmission model. The simulation results show that the transmission energy of the common scatterer transmission model is dominated by single scattering at a transmission distance of 100 m, while the non-common scatterer transmission model is dominated by two-time scattering. For the non-common scatterer transmission model, UV needs more than two atmospheric scattering to reach the receiving field of view; when the transmission distance is the same, there is non-common scatterer transmission model. The path loss is larger than that of the common scatterer transmission model, but the overall growth increases with the transmission distance. The time characteristics of UV transmission in different transmission models show that, under the same transmission distance, the impulse response time delay is also higher than that of the common scatterer transmission model, and the former has a much smaller signal-to-noise ratio. Using the theoretical basis of wavelength division multiplexing technology, the full-duplex UV optical communication system for omnidirectional communication is studied to meet the theoretical requirements for implementing duplex communication. The paper theoretically gives the ultraviolet transmission characteristics of the transmission model without common scatterers, and provides theoretical basis and favorable reference value for the study of omnidirectional communication of actual ultraviolet light.

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