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Impacts of Transceiver Configuration on Ultraviolet Communication

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Abstract

In the channel estimation for ultraviolet communication, the single scattering power is usually used to approximate the received total power. This approximation error is affected by the transceiver configuration. Here, we employ the proportion of received single scattering power in received total power to indicate the approximation error of the single scattering model in different configurations. This is useful for reducing the approximation error by selecting a more appropriate transceiver configuration.

Keywords

Ultraviolet Communication, Single Scattering, Non-Line-of-Sight

1. Introduction

With the recent advances of ultraviolet (UV) source and detectors in the solar blind wavelength regime, UV communication system has attracted increasing attention. The non-line-of-sight (NLOS) channel modeling of UV communication has gradually become the core issue [1]. One valid way for channel modeling is to establish the single scattering channel model by assuming that ultraviolet photons traveling in the medium between the source and the detector are scattered only once in short-range cases [2] [3] [4]. Another way is to establish the multiple scattering channel model based on the Monte-Carlo method [5] [6]. As the communication range increases, single scattering model was modified by applying the atmospheric turbulence theory for the increasing atmospheric effect on the communication performance [7]. Unfortunately, the increase of communication range also decreases the proportion of single scattering power in received total power. This proportion reflects the approximation error of single scattering model itself. Since the proportion is affected by system geometry, the impacts of transceiver configuration on this proportion need to be analyzed in UV communication.

In this work, the proportion of the received single scattering power in the received total power is employed as an indicator to evaluate the approximation error and the effectiveness of the single scattering model under different transceiver configurations. The simulation results demonstrate that this proportion decreases with the increase of elevation angle, field-of-view (FOV) angle and the communication range. Thus, the effective range of single scattering model is limited by the transceiver configuration. We also find that the approximation error of the single scattering model in UV communication can be reduced by selecting a more appropriate configuration.

2. Methodology

Figure 1 shows a typical NLOS UV communication geometry. The configuration parameters are defined as follows: r is the baseline separation between transmitter (T) and receiver (R). (θ_T, β_T) and (θ_R, β_R) are the elevation angle and the divergence angle of beam and FOV, respectively. $\theta_S = \theta_T + \theta_R$ is the scattering angle between the photon forward direction and the observation direction. In the NLOS communication as shown in **Figure 1**, single scattering model is widely used to estimate channel performance. However, the power received at R is a combination of the scattering power of all scattering orders, and the received scattering power for each order changes as the transceiver configuration changes. Thus, the proportion of received single scattering power P_1 in received total power P_{all} can be an indicator to describe the approximation error and show the validity of single scattering model in different configurations. Higher proportion indicates the single scattering model in certain transceiver configuration is more accurate and more effective. The relationship between proportion and approximation error is $error = 10\log_{10}(P_{all}/P_1)$. 80% in proportion indicates that the error of approximating multiple scattering power with single scattering power is 1 dB.

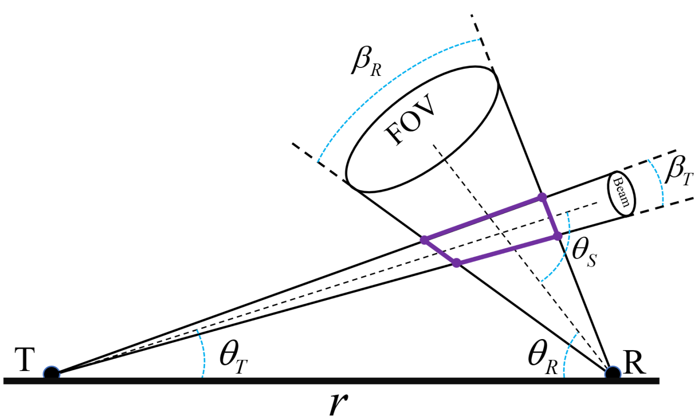

Figure 1. NLOS UV communication geometry.

3. Simulation Analysis

We take multiple scattering model [6] to simulate the proportion and assume the received total power is equal to the summation of the scattering powers of the first four scattering orders. The model parameters are selected as: $(k_e, k_s) = (0.802, 0.550)\ \text{km}^{-1}$, $A_r = 1.77\ \text{cm}^2$, $\lambda = 260\ \text{nm}$, $\gamma = 0.017$, $g = 0.72$, $f = 0.5$, $P_e = 30\ \text{mW}$ [3].

First, the proportion under different communication ranges r and transmitter elevation angles θ_T are simulated by multiple scattering model [6], as shown in **Figure 2** $(\beta_T = 1^\circ, \theta_R = 65^\circ, \beta_R = 30^\circ)$. We can find that the proportion decreases when r or θ_T increases. That is because the longer communication range and larger elevation angle both result in longer transmitting paths, thus the higher probability of photon extinction. In addition, the larger transmitter elevation angle also causes the larger scattering angle θ_S, which means fewer photons can arrive at the receiver by single scattering. In **Figure 2**, as the θ_T is equal to 5˚, the decline in the proportion from 100 m to 1500 m is 11%. And this decline in the proportion is rising as θ_T increases: the decline in the proportion from 100 m to 1500 m is 49% when θ_T is 40˚. As shown in **Figure 2**, even the communication range is 1500 m, the proportion still reach 80% as long as θ_T is less than 10˚. However, when the θ_T is 35˚, the proportion drops to 77% (*i.e.*, the proportion is smaller than 80%) as the communication range reaches 500 m. In 1500 m, the proportion drops to 49% corresponding to 3.1 dB in approximation error. Therefore, in system design, we can select a lower transmitter elevation angle to increase the proportion and to reduce approximation error in single scattering model. When maximum tolerable error is determined, we can enlarge effective range of single scattering model by reducing the elevation angles.

Second, **Figure 3** shows the relationships between the proportion with the receiver elevation angle and the communication range $(\beta_T = 1^\circ, \theta_T = 25^\circ, \beta_R = 30^\circ)$. Similar to the impacts that transmitter elevation angle exerts on the proportion, the rise of receive elevation angle also causes the increase of it.

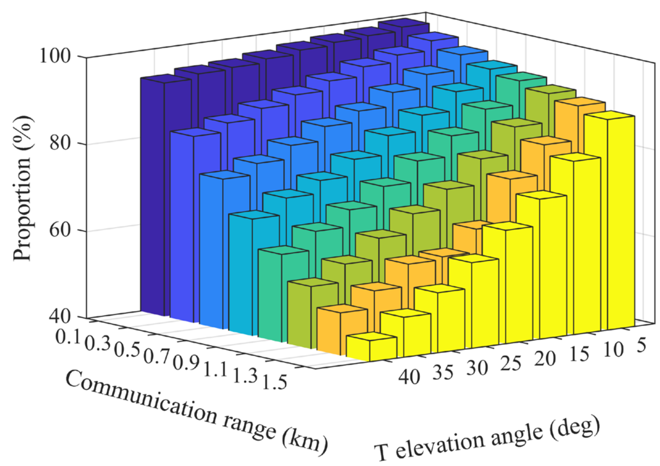

Figure 2. Proportion versus communication range and transmitter elevation angle.

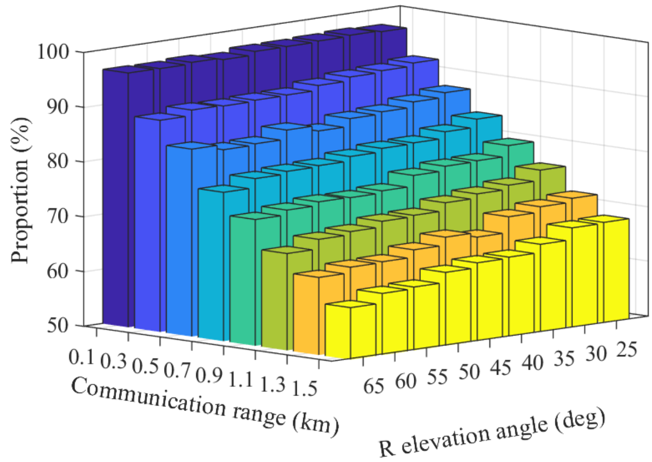

Figure 3. Proportion versus communication range and receiver elevation angle.

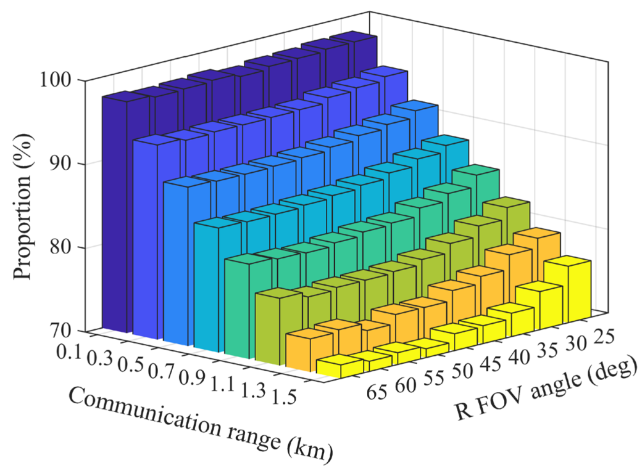

Figure 4. Proportion versus communication range and receiver FOV angle.

Third, in addition to two elevation angles and communication range, the changes in receiver FOV (*i.e.*, β_R) also affect the proportion, as shown in **Figure 4** $(\beta_T = 1^\circ, \theta_T = 15^\circ, \theta_R = 40^\circ)$. With β_R increasing from 25˚ to 70˚, the proportion first decreases to the minimum and then increases slightly. The maximal proportion appears when β_R is at the a minimum (*i.e.*, β_R is equal to 25˚). When we select a larger FOV angle to receive more optical power [8], the proportion decreases and single scattering model causes more absolute error. Thus, smaller FOV angle is needed to improve the effectiveness of single scattering model.

Based on the preceding analysis, the proportion of received single scattering power in received total power increases with the decrease of elevation angles and FOV angle. Three kinds of NLOS transceiver configuration in small elevation angle and small FOV case are shown in **Figure 5**: (i) Both elevation angles are small $(\beta_T = 1^\circ, \beta_R = 25^\circ, \theta_T = 15^\circ, \theta_R = 15^\circ)$; (ii) Only transmitter elevation is small $(\beta_T = 1^\circ, \beta_R = 25^\circ, \theta_T = 15^\circ, \theta_R = 65^\circ)$; (iii) Only receiver elevation is small

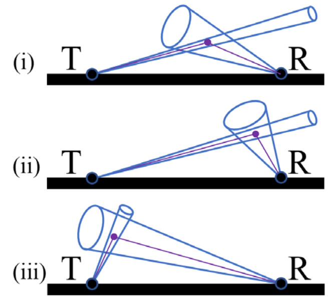

Figure 5. Three NLOS transceiver configurations in small elevation angle: (i) Both θ_T and θ_R are small; (ii) Only θ_T is small; (iii) Only θ_R is small.

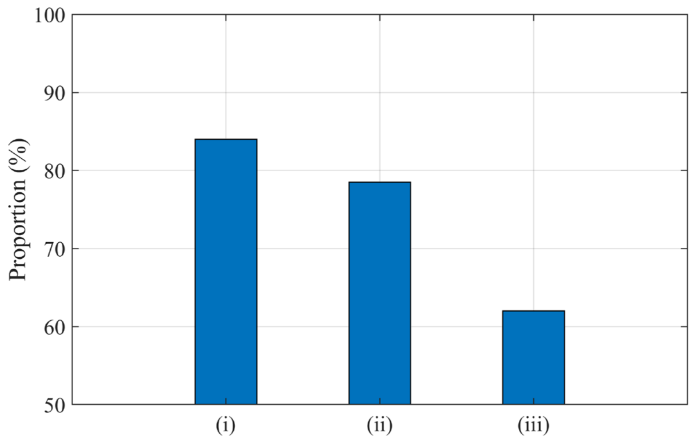

Figure 6. Proportion and path loss in three configurations of small elevation angle.

$(\beta_T = 1^{\circ}, \beta_R = 25^{\circ}, \theta_T = 65^{\circ}, \theta_R = 15^{\circ})$. **Figure 6** depicts the proportion in these configurations when the communication range is 1250 m. The configuration (i) has the highest proportion because of the shortest effective path. The proportion in this configuration is 84% corresponding to 0.7 dB in approximation error, which is negligible when communication range is 1250 m. In addition, the performance in the configuration (ii) is much better than that in the configuration (iii), even though the length of central paths in both configurations is equal. Thus, in the system design, the priority order of these three NLOS transceiver configuration in small elevation angle is (i) > (ii) > (iii).

4. Conclusions

The proportion of the received single scattering power in the received total power is employed to indicate the impacts of transceiver configuration. We use the proportion to analyze the approximation error and the effective range of single scattering model. The results show that the effective range of single scattering model is limited by the transceiver configuration. Furthermore, the approximation error of single scattering model can be negligible in the case of small elevation angles and small FOV, even in long range communication system.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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