Modeling and Analyzing of UV Channels Characteristics in Various Configuration of Transmitters and Receivers for Building Manet

Igor S. Konstantinov, G. S. Vasyliev, Oleg R. Kyzichkin, D. I. Surzhik, I. A. Kyrilov, Sergey A. Lazarev

Abstract:** Mobile Ad-Hoc Networks (MANET) provide operation in the absence of traditional telecommunications infrastructure, which makes such networks indispensable in the context of military operations, search and rescue operations, the elimination of emergency situations and other responsible and dangerous objects. The high value of ultraviolet (UV) communication networks and systems in the UV-C range of 200-280 nm is determined by a number of key features. They are nonsusceptible to electronic warfare, solar radiation, and the ability to secure data transmission in a non-line-of-sight mode (NLOS). These advantages determine the perspectivity use of MANET networks with a UV channel. For reliable operation of such networks, it is necessary to ensure reliable communication in all possible directions, which is caused by the constant movement of subscribers in a wide area. The solution is to use grids of emitters and receivers with various configurations. Based on the modified Monte Carlo algorithm, the characteristics of the UV channels were simulated using flat and sector grids of transmitters and receivers. It has been established that increasing the opening angle of the transmitters and receivers grids in azimuth to 20 or 40 degrees makes it possible to significantly smooth the loss dependence on the network nodes azimuths, which is necessary for reliable communication with subscribers in all possible directions. In this case, when changing the range and other angular parameters of the channel the loss values do not increase much (less than 10 dB). Indicated promising areas of development studies to optimize the antenna array configurations for specific conditions and operation of MANET routing protocol parameters for transmitting data through intermediate nodes when the requested node is unavailable because of the large UV channel attenuation.

***Keywords:** wireless UV connection; Mobile Ad-Hoc Network (MANET); Monte Carlo method.*

INTRODUCTION

Progress in the development and production of electronic components, such as sources and receivers of ultraviolet (UV) radiation, has attracted considerable interest in UV communications, especially in the non-line-of-sight (NLOS) mode [1-3]. The high value of UV communication systems in the UV-C range, which is not exposed to solar radiation (wavelength 200-280 nm), is determined by the possibility of reliable data transmission in the NLOS mode. This advantage makes such systems irreplaceable in the conditions of difficult terrain and obstacles between the transmitter and receiver (buildings or natural irregularities). In addition, UV communication is not subject to electronic warfare. These aspects determine the usage relevance of UV communication systems in the context of military operations, search and rescue operations, the elimination of emergency situations, etc. Communication networks at responsible and hazardous facilities should function in the absence (inappropriate use) of traditional telecommunications infrastructure, which is typical to mobile self-organizing networks (Mobile Ad-Hoc Network, MANET) [4, 5].The classic solution for building MANET networks is radio frequency use. Individual works [6–9] are devoted to the problems of modeling and analyzing MANET networks with a UV communication channel.

For reliable operation of MANET networks with a UV channel, it is necessary to ensure reliable communication in all possible directions, which is caused by the constant movement of subscribers in a wide area. The problem is aggravated by the fact that the propagation of UV radiation in the atmosphere is accompanied by strong attenuation — more than 100 dB in the NLOS mode [10–12]. It is necessary to use highly directional emitters to ensure an acceptable signal level at the receiving side. To increase the bit rate of data transmission, narrowly targeted receivers are also needed, which further increases the channel loss.

A large number of works are devoted to modeling and experimental study of attenuation in the NLOS UV channel with variations in the communication range and transmitter and receiver elevation angles [13-16]. The question of the influence of the transmitting and receiving nodes azimuths have been studied to a much lesser extent [6, 17, 18]. The obtained results show a significant (on the order of 25 ... 40 dB) increase in losses with varying azimuths over a wide range (200 or more), using a single transmitter and a single receiver. To ensure acceptable attenuation over the entire azimuth range from –1800 to 1800, it is necessary to use grids of emitters and receivers directed in different directions.

The main target of the work is to simulate and analyze the characteristics of ultraviolet channels when using the gratings of transmitters and receivers of various configurations for building MANET networks.

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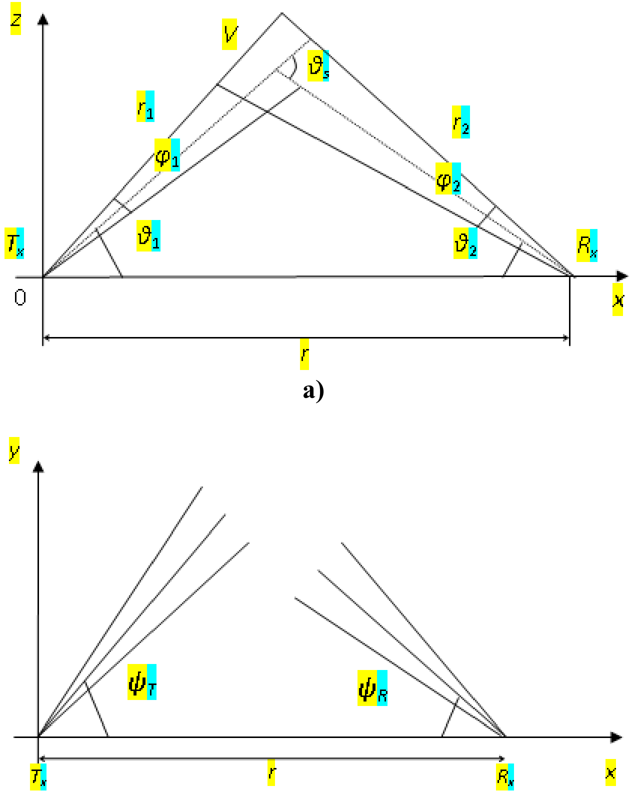
MODELS OF UV NLOS CHANNELS WITH DIFFERENT CONFIGURATION OF TRANSMITTERS AND RECEIVERS

The UV NLOS channel geometry with one transmitter and one receiver is shown in Fig. 1. In the figure it is indicated: Tx – transmitter, Rx – reciever, r – the distance between Tx and Rx, $\theta_{1,2}$ and $\varphi_{1,2}$ – angle and the width of the DP, index 1 refers to the transmitter, index 2 to the receiver, θ_s – the scattering angle, V – is the total amount of Tx and Rx radiation patterns, $r_{1,2}$ – the distance from Tx and Rx to the center of the region V, $\psi_{T,R}$ – the transmitter and receiver azimuths.



a)

b)

Fig. 1 – The UV NLOS channel geometry with one transmitter and one receiver:
a) channel vertical projection; b) channel horizontal projection

The scattering model, which characterizes the probability of photon scattering in a given direction, is described by the phase scattering function. The phase function is a weighted sum of the Rayleigh molecular scattering and Mie aerosol phase scattering functions [15, 19, 20],

$$p^R(\mu)=\frac{3\left[1+3\gamma+(1-\gamma)\mu^2\right]}{16\pi(1+2\gamma)}, \qquad (1)$$

$$p^M(\mu)=\frac{1-g^2}{4\pi}\left[\frac{1}{\left(1+g^2-2g\mu\right)^{3/2}}+f\,\frac{0.5\left(3\mu^2-1\right)}{\left(1+g^2\right)^{3/2}}\right] \qquad (2)$$

where $\mu=\cos\theta_s$ – the cosine of the scattering angle, γ, g, f – the parameters of the scattering model. In difficult weather conditions, the Mie model additionally includes terms describing the contribution of certain types of aerosol particles with different radius and concentrations [21, 22].

Varying the azimuthal characteristics of emitters and detectors in a wide angle range makes it difficult to use analytical models. Most of the known analytical models are focused on studying the characteristics of a channel with a coplanar geometry (in the absence of azimuthal deviation, when the central rays of the transmitter and receiver patterns in the same plane) are located in the same plane [23] or with a small azimuthal deviation, when the total volume of the transmitter and receiver DP is saved and the model of single scattering of photons may be applied [24].

Thus, for reliable modeling of UV channels in a wide range of azimuths in the absence of a total volume of DP transmitter and receiver, it is necessary to use the Monte Carlo statistical test method [25-27].

The key differences of the proposed algorithm based on the Monte Carlo method in comparison with the known implementations of this method are as follows:

- geometric parameters of the beam pattern are given by vector quantities to simulate the communication mode with many transmitters and many receivers;
- an additional discrete random variable with an equal distribution sets the number of the transmitter that emits each specific photon when the number of transmitters is more than one. The coordinate transformation is performed, described by the product of two rotation matrices in three-dimensional space to simulate the initial trajectories of photons emitted by transmitters with different elevation angles θ_T and azimuths ψ_T;
- for each transmitter and receiver cosine DP is used, which is more adequate for real DP components then commonly used rectangular;
- the product of two rotation matrices in three-dimensional space are describing coordinate transformation for receivers with different elevation angles θ_R and azimuths ψ_R is described. Summing the field of view (FOV) values calculated for the individual receivers are calculating the resulting FOV for many receivers.

The configurations of emitters and receivers grids are defined by the following parameters: the number of components, the span in azimuth, the span in elevation. Practically implemented by the authors an example of a specific configuration is shown in Fig. 2.

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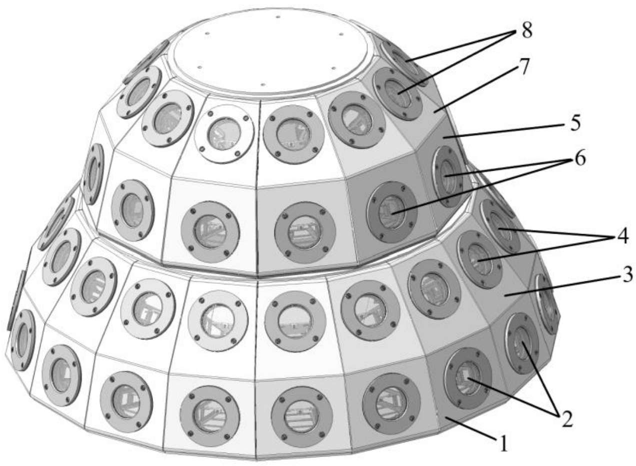

Fig. 2 – An example of a specific configuration of transmitter and receiver grids

The presence of several channels of transmission and reception of ultraviolet radiation with a circular arrangement of optical transmitters and receivers allows to provide reliable communication in the absence of direct visibility between network clients during movements and turns of mobile communication nodes, as well as to increase the receiving channels range and sensitivity due to the narrowing of optical radiation angles transmitters and angles of view of optical receivers.

The two lower tiers of the structure (1 and 3) have 18 faces at the base, located at different angles to the horizontal and containing cells (2 and 4) to accommodate 18 optical transmitters in each, providing a circular pattern for the propagation of transmitted light rays.

The first row of optical transmitters with a low elevation angle is used to create a communication channel with minimal loss of radiation propagation in the mode of direct visibility between the transmitter and the receiver, the second row with a large elevation angle is necessary to create a communication channel with large losses in the NLOS mode due to difficult terrain conditions (presence of obstacles).

The two upper tiers of the structure (5 and 7) each have 12 faces at the base, also located at different angles to the horizontal and containing cells (6 and 8) to accommodate 12 optical receivers each, providing reliable omnidirectional reception of transmitted light rays, as in the presence or absence of a direct line of sight between the transmitter and the receiver.

The described circular configuration (Fig. 2) provides reliable communication in all possible directions, but requires large hardware costs. The actual transmitter and receiver grids configuration uses fewer components and modeling of UV channels when using such arrays.

RESULTS OF MODELING

As a result of modeling, the dependences of losses on the parameters of the channel geometry were obtained (Fig. 3). Were taken the following values of the UV channel parameters: communication range r = 100m, the elevation angles of transmitters and receivers grids centers θ_1 =30^0 and θ_2 =50^0, width of DP transmitter and receiver φ_1 =17^0 and φ_2 =30^0, radiation wavelength λ=260 nm, clear weather scattering and absorption coefficients, the receiver aperture area A_r=1,77 cm^2. The location of the transmitters and receivers in the grids is two-row, the number of transmitters and receivers of the grids N_T=3 and N_R=3.

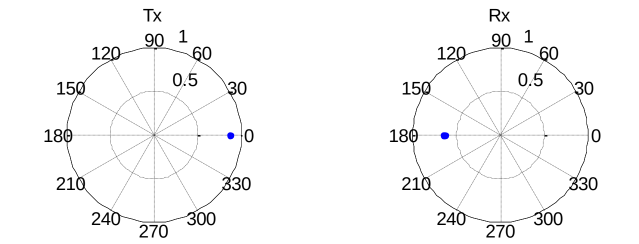

Fig. 3 - Transmitters and receivers layout (flat grids)

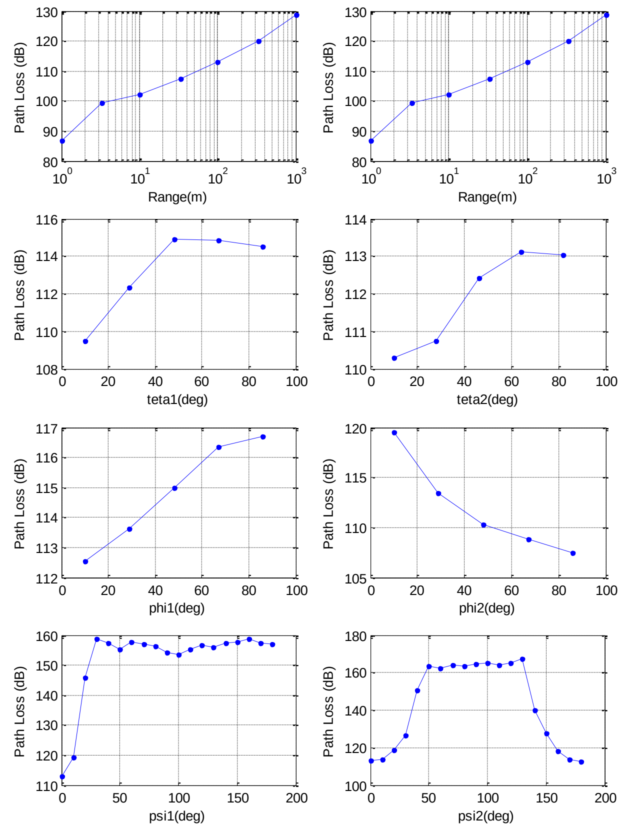

Fig. 4 – Channel loss using flat grids of transmitters and receivers

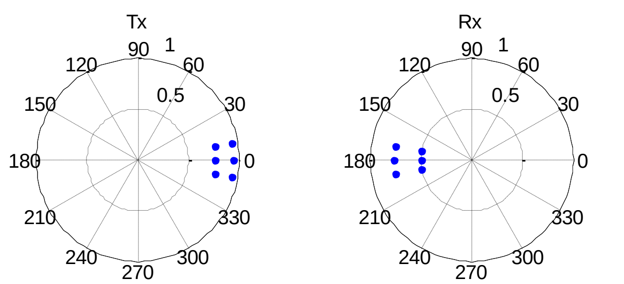

Fig. 5 - Layout of transmitters and receivers (sector grids with aperture azimuth angles and elevation angle of 20 degrees)

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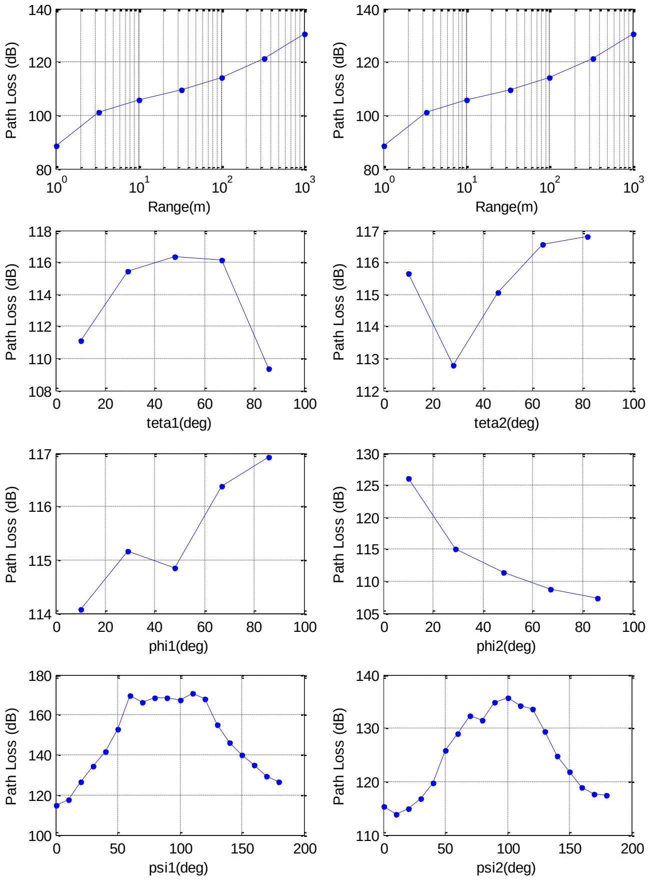

Fig. 6 - Channel losses using sector grids of transmitters and receivers (grids azimuth opening and elevation angles of 20 degrees)

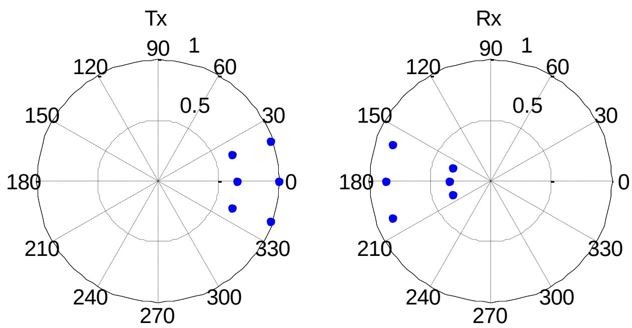

Fig. 7 - Layout of transmitters and receivers (sector grids with aperture azimuth angles and elevation angle of 40 degrees)

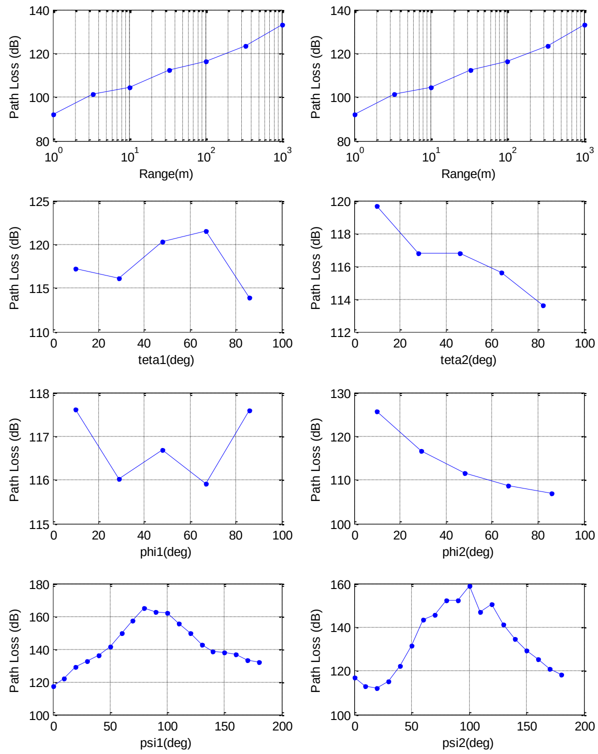

Fig. 8 - Channel losses using sector grids of transmitters and receivers (grids azimuth opening angle of 40 degrees and elevation angle of 20 degrees)

As a result of the simulation, was established that the dependence of the attenuation value on the transmitter azimuths $\psi_1=\psi_T$ and receiver $\psi_2=\psi_R$ is the strongest. When using flat grids of transmitters and receivers (Fig. 3, 4), the attenuation from ψ_1 varies from the minimum value of 112 dB at $\psi_1=0^0$ to 160 dB already at $\psi_1=30^0$. The variation range of loss with variation ψ_2 is from 117 to 165 dB. In this case, the loss dependence on ψ_2 is much less sharp than on ψ_2: with an increase of ψ_1 by 25^0 and ψ_2 by 50^0 occurs increase in losses by 45 dB. This fact, as well as the attenuation decay at $\psi_2>130^0$ is caused by the greater width of the receiver's DP ($\varphi_2=30^0$) compared with the width of the transmitter's DP ($\varphi_1=17^0$).

The use of sector grids of transmitters and receivers with angles of opening in azimuth and elevation angle of 20 degrees (Fig. 5, 6) smooths the dependence of losses on azimuths, but leads to an increase in losses in the range of ψ_1 from 60^0 to 120^0 (from 160 to 170 dB) compared to with the option of using flat arrays (less 160 dB). Increasing the aperture angle of the transmitter and receiver arrays in azimuth to 40^0 with the same aperture in elevation angle 20^0 (Fig. 7, 8) makes it possible to even more smooth out the dependence of losses on ψ_1 and ψ_2, while the values of losses in the transmitter and receiver pointing perfectly at each other in the horizontal plane (118 dB with $\psi_1 = \psi_2 = 0^0$), as well as changing the range and other angular parameters (θ_1, θ_2, φ_1, φ_2), increase not too significantly (by less than 10 dB).

The results show the promising application of sector grids with a small number of optical transmitters and receivers for building a MANET network with a UV channel. The grids geometry and the number of their elements should be selected based on the allowable costs, the required data transmission distance and the sensitivity of the existing receivers, as well as the risks of unavailability of individual nodes. The task of communicating with nodes that are directly inaccessible due to the high attenuation in the UV channel (for example, more than 150 dB in the range $\psi_1 = 45^0...130^0$, Fig. 6) can be solved by transferring data through intermediate nodes by routing protocols at the network level.

CONCLUSIONS

Based on the modified Monte Carlo algorithm, the characteristics of the UV channels are simulated using transmitter and receiver grids of various configurations for building MANET networks. In the models under study were used flat and sector gratings with a two-row arrangement of elements and three elements in each row. The results showed a promising application of sector-type arrays with a small number of optical transmitters and receivers for building a MANET network with a UV channel. Was established that increasing the opening angle of the transmitters and receivers gratings in azimuth to 20 or 40 degrees makes it possible to significantly smooth the loss dependence on the azimuths of the network nodes, which is necessary for reliable communication with subscribers in all possible directions. In this case, the loss values when changing the range and other angular parameters of the channel do not increase much (by less than 10 dB). The obtained results will further allow choosing the grid geometry and the number of their elements based on the allowable costs, the required data transmission distance and sensitivity of the existing receivers, as well as the risks of unavailability of individual nodes. Another direction in the development of the conducted research is the development and adjustment of routing protocols parameters at the network level for data transmission through intermediate nodes when the required node is unavailable due to the high attenuation in the UV channel.

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