Original research article

A networking strategy for three-dimensional wireless ultraviolet communication network

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\textbf{A B S T R A C T}

Wireless ultraviolet (UV) non-line-of-sight (NLOS) communication network is increasingly being used in three-dimensional (3D) space, such as formation flying and holding, underwater communication networks and ground-to-air communications. In this article, a networking strategy for three-dimensional wireless ultraviolet communication network (UVNNS) is proposed to optimize the coverage, connectivity and the survivability of the UV network. The performance of UVNNS with different communication parameters (apex angle, transmitted power, data rate, error probability and node density), modulation and noise model is simulated and analyzed in the 3D UV network. The simulation results show that the approach of UVNNS can improve the coverage ratio, connectivity and the survivability. Compared with the random deployment approach, the performance metrics of UVNNS are better than that of random deployment approach (RDA) in the same UV network. Therefore, the deployment of the 3D UV network can be accomplished efficiently with a minor impact of obstacles.

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1. \textbf{Introduction}

With the continuous development of wireless optical communication, wireless ultraviolet (UV) scattering communications are followed closely by more and more people. The background noise in the band (200–280 nm, called solar-blind band) caused by solar radiation is blocked by the earth’s atmosphere effectively, so wireless UV communication system can work all the day \cite{1}. Wireless UV scattering communications is based on the non-line-of-sight (NLOS), so it can make up for shortcomings of other wireless optical communications that operate in the line-of-sight (LOS) mode \cite{2}. Compared with other wireless communication, wireless UV communications have the following advantages \cite{2}: outstanding ability to secure communication, excellent anti-interference ability and for special occasion communication. However, there is a serious attenuation in UV scattering communication and the signal transmission power has some certain restrictions. The scattering communications can give full play to its advantages only that scattering communications’ effective communication range be expanded through the method of wireless multi-hop networking. In a wireless UV scattering communication system, the transmitting and receiving apex angle, divergence angle and field-of-view (FoV) of receivers are the main factors affecting the communication link performance. Roughly speaking, UV communications can apply in commercial and military applications. Commercial applications contain public building surveillance, aircraft landing aid under low visibility conditions, environmental monitoring around chemical industries and so on. Ground-to-air communications, UV guidance

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and UV warning are some common military applications. Owing to the continuous evolution of this new communication technology, more and more applications will emerge in the near future [3].

Most of the published work considered two-dimensional (2D) regions, and numerous issues are not tackled in the three-dimensional (3D) space. Three-dimensional space is our human world, in addition to long and wide, including a high degree of concept. For example, the trilateration position algorithm in UV mesh network [4], the single-scatter path loss model for NLOS ultraviolet channels [5] and the area coverage algorithm for NLOS UV communication network [6] are studied. The full coverage that each target in the network is monitored at any time by at least one sensor is important in many detections and tracking applications. In order to make sure that detected information can be transmitted to the sink or a command center, the connectivity of network must be maintained [7]. The coverage and connectivity issues in 3D wireless sensor networks (WSN) was be discussed in Ref. [8] for the purpose of meeting the needs of the applications for underwater surveillance and oceanic studies. Besides, how to avoid dynamic obstacles and successfully guide unmanned aerial vehicles (UAVs) to the target is another widely researched key topic [9].

In fact, the tanks can achieve covert communication and go ahead with specified formation through the 3D UV communication networks on the battlefield. Using 3D UV communication networks, the UAVs and helicopters also can realize formation flying and holding with a secret way. However, many existing coverage analysis and placement strategies developed for 2D but not applied in 3D space [10]. Although practical wide-scale deployment of 3D networks is still relatively limited, there has been a lot of work in progress, which promises to make 3D networks more universal in the not-so-far future.

In this article, we mainly focus on the problem of coverage control in the 3D UV communication network. A Networking Strategy for three-dimensional wireless ultraviolet communication network (UVNNS) is put forward. Considering the influence of communication parameters (apex angle, transmitted power, data rate, error probability and node density), modulation and noise model on the coverage and connectivity in the process of network communication, suitable communication parameters are selected by the relative position of neighbor nodes to enhance the coverage ratio and the connectivity. We investigate the deployment cost of network when nodes are in different positions and regions of interest (ROI) with obstacles. Finally, we give an optimum deployment scheme taking coverage ratio, connectivity and deployment cost into consideration.

The rest of the article is organized as follows. Section 2 outlines the necessary UV theory for our analysis and gives a description of the network. In Section 3, a short description of the coverage control problem in the 3D UV communication network is presented. Expressions for the effective coverage radius for OOK (On-Off Keying) and PPM (Pulse Position Modulation) are given considering both Poisson and Gaussian noise models, as well. In addition, performance metrics of the algorithm are introduced. In Section 4, the steps of the UVNNS are described in general. Numerical results are shown and discussed in Section 5. Finally, some concluding remarks are summarized in Section 6.

2. Three-dimensional ultraviolet network model

2.1. Three-dimensional UV NLOS communication model

A multi-hop network consisting of several nodes using UV NLOS communication is considered. The typical UV communication link between a transmitter (Tx) and a receiver (Rx) is shown in Fig. 1. Tx transmits a signal upwards with a beam divergence angle $\phi_1$. The cone beam produced by the Tx has a $\theta$ intersection angle with the cone beam of Rx. The distance between Tx and Rx is $d$, while the distance from the common volume V to Tx and Rx are $r_1$ and $r_2$, respectively.

![Fig. 1. The UV NLOS link model.](https://example.com/fig1.png)
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