Computers, Materials & Continua CMC, vol.60, no.2, pp.527-544, 2019

Directional Antenna Intelligent Coverage Method Based on Traversal Optimization Algorithm

Jialuan He[1, 2], Zirui Xing[2], Rong Hu[2], Jing Qiu[3, *], Shen Su[3, *], Yuhan Chai[3] and Yue Wu[4]

Abstract: Wireless broadband communication is widely used in maneuver command communications systems in many fields, such as military operations, counter-terrorism and disaster relief. How to reasonably formulate the directional antenna coverage strategy according to the mobile terminal dynamic distribution and guide the directional antenna dynamic coverage becomes a practical research topic. In many applications, a temporary wireless boardband base station is required to support wireless signal communications between many terminals from nearby vehicles and staffs. It is therefore important to efficiently set directional antenna while ensuring large enough coverage over dynamically distributed terminals. The wireless broadband base station mostly uses two rotatable conical-polarized directional antennas with a coverage angle of 80 degrees. In this paper, we study this directional antenna coverage problem and propose a new solution by using three-dimensional coordinate transformation, provides wireless signal coverage schemes for point-to-point and point-to-region, determined the required horizontal rotation angle and pitch rotation angle of the directional antenna intelligent coverage, which lays the foundation for the performance of the wireless broadband communication in the maneuver command communication system.

Keywords: Wireless broadband communication, directional antenna intelligent coverage, three-dimensional coordinate transformation.

1 Introduction

With the development of wireless sensor networks [Wang, Gu and Yan (2018); Wang, Gu and Zhou (2017); Wang, Gu, Ma et al. (2017); Wang, Ju, Gao et al. (2018)], attacks can be effectively reduced by considering security [Yu, Tian, Qiu et al. (2018); Wang, Tian, Zhang et al. (2018); Tian, Cui, An et al. (2018); Tan, Gao, Shi et al. (2018)] and trustiness [Chen, Tian, Cui et al. (2018)] in wireless sensor networks. Wireless broadband

[1] School of Mechanical Electronic & Information Engineering, China University of Mining & Technology, Beijing, 100083, China.

[2] R&D and Application Center of Command Automation Technology, the 4th Institute of CASIC, Beijing, 102308, China.

[3] Cyberspace Institute of Advanced Technology, Guangzhou University, Guangzhou, 510006, China.

[4] USC Information Sciences Institute, Marina del Rey, CA 90292, USA.

[*] Corresponding Authors: Jing Qiu. Email: qiujing@gzhu.edu.cn;
Shen Su. Email: johnsuhit@gmail.com.

communication is an important basis for the rapid and flexible construction of a communications network and the implementation of command tasks for maneuver command communications systems. It is widely used in many scenarios where no civilian mobile communication service facilities are available, for example, military operations, counter-terrorism, and disaster relief, etc. The wireless broadband communication base stations need to be temporarily erected through maneuver vehicles to vehiclery out missions to vehicles within a certain range. The communication terminals used by personnel are covered by wireless signals to ensure that personnel and vehicles that perform military, counter-terrorism, and disaster relief tasks are always under the command and control of higher-level command systems.

Most wireless broadband base stations use directional antennas to implement signal coverage. Ramanathan et al. [Ramanathan, Redi, Santivanez et al. (2005)] proposed the use of directional antennas for ad hoc networking was presented, which was an interacting suite of modular network and medium access control (MAC)-layer mechanisms for adaptive control of steered or switched antenna systems in an ad hoc network. In contrast to previous studies in which the barrier coverage problem was solved under the assumption of an omni-directional sensing model, Ssu et al. [Ssu, Wang, Wu et al. (2009)] presented a scheme for constructing k-barrier coverage using randomly deployed sensors with directional sensing model. A new MAC protocol for full exploitation of directional antennas was proposed in wireless networks, which introduced a circular directional transmission of the Request to Send (RTS) control packet, spreading around station information about the intended communication [Korakis, Jakllari and Tassiulas (2008)]. A new MAC protocol that incorporates circular RTS and CTS transmissions was proposed [Jakllari, Broustis, Korakis et al. (2005)]. The concept of the exclusive region (ER) was introduced to allow concurrent transmissions to explore the spatial multiplexing gain of wireless networks [Cai, Cai, Shen et al. (2010)]. The use of directional antennas and beam steering techniques were investigated to improve the performance of 802.11 links in the context of communication between a moving vehicle and roadside Aps [Navda, Subramanian, Dhanasekaran et al. (2007)]. Methods and systems for packet-by-packet directional mobile wireless transmission utilizing the plurality of directional antenna sectors, such that, the transmission of each packet is performed by at least one selected antenna sector. The direction of transmission is selected responsive to the direction in which the best electromagnetic signal reception was received [Ofek and Gavish (2011)]. A method of operating a wireless access point having a configurable antenna system was proposed [Salo, Moore, Clark et al. (2011)].

An antenna apparatus comprises selectable antenna elements including a plurality of dipoles and/or a plurality of slot antennas (“slot”). Each dipole and/or each slot provides gain with respect to isotropic [Kish and Shtrom (2008)]. The dipoles may generate vertically polarized radiation and the slots may generate horizontally polarized radiation [Kish and Shtrom (2015)]. Mechanisms for wireless local area network coverage enhancement using dynamic antennas were provided [Kish (2014, 2016)]. A directional antenna-based leader–follower robotic relay system capable of building end-to-end communication was presented in complicated and dynamically changing environments [Min, Parasuraman, Lee et al. (2018)]. The basic characteristics of communication systems based on HAP were considered [Alsamhi and Rajput (2015)], which outlined alternative network architecture scenarios for provision of wireless access to broadband communication services. With unsupervised self-organizing map (SOM) learning, an intelligent solution for both coverage planning and performance optimization was proposed [Gazda, Šlapak, Bugár et al. (2018)]. Genetic algorithm, differential evolution (DE), immune algorithm and particle swarm optimization were tested and compared to find the optimal coverage [Zhu and Gao (2017)].

According to the effective signals 3dB attenuation principle, the coverage angle of conical-polarized directional antennas used in maneuver command communication systems is generally 80 degrees. For better coverage, the vehicles usually elevate the directional antenna up to 8 m to 15 m by using the antenna rod. Limited by the weight of the antenna rod, generally, no more than 2 directional antennas are installed on the high antenna rod. Wireless signal coverage for mobile terminals is realized through the rotation of the antenna using two axial servo mechanisms. Therefore, how to reasonably formulate the directional antenna coverage strategy according to the mobile terminal dynamic distribution and guide the directional antenna dynamic coverage becomes a practical research topic.

In this paper, we make two major contributions: 1) a directional antenna intelligent coverage method of point-to-point wireless coverage is proposed to overcome the problem of optimal coverage communication between points, and 2) To guarantee the effectiveness of optimal coverage communication between point-to-region, a directional antenna intelligent coverage method of point-to-point wireless coverage is given based on traversal optimization algorithm. The rest of the paper is organized as follows: Section 2 introduces typical application scenarios; Section 3 details directional antenna intelligent coverage method of point-to-point wireless coverage; Section 4 introduces the directional antenna intelligent coverage method of point-to-region wireless coverage based on traversal optimization algorithm; Section 5 presents simulation results; and we conclude the paper in Section 6.

2 Typical application scenarios

Maneuver command vehicle wireless broadband base station equipment with two plate-shaped directional antennas, the initial state of the two directional antennas is parallel to the vehicle and the direction is perpendicular downward to vehicle, the directional antenna can be horizontal rotated $\pm 90^{\circ}$ (180°), pitch rotated $\pm 30^{\circ}$ (60°), where the rotation is relative to the vehicle. The signal range of the directional antenna is horizontal $\pm 40^{\circ}$ (80°). When one or more terminals around the command vehicle, the rotation scheme of the directional antenna needs to be designed so that the comprehensive reception effect of each point is the best.

Known conditions: longitude and latitude ($B1$, $L1$) and ($B2$, $L2$) of the vehicle and receiving points, and elevation $H1$ and $H2$, azimuth angle θ and pitch angle ρ of the vehicle in the initial state. We do not care about the roll angle of the vehicle, which is 0. Find the horizontal rotation angle α and pitch rotation angle β.

Coordinate system:

Gauss-kruger plane rectangular coordinate system: take the equator and central meridian point as the origin of coordinate O, central meridian direction for the X-axis, south of the equator is negative, positive, north of north direction is positive. The equator is the Y-axis, the central meridian is positive to the east, negative to the west, and positive to the east. You can convert the geodetic coordinate to the plane rectangular coordinate, which are $(B1, L1) \rightarrow (X1, Y1)$ and $(B2, L2) \rightarrow (X2, Y2)$.

Vehicle coordinate system: plane xoy is parallel to the earth surface, that is, gaussian plane rectangular coordinate system, the initial plate position is the origin o, The forward direction of the car is X-axis forward, X-axis clockwise 90° is Y-axis forward, vertical plane xoy upward positive. The clockwise direction is E (East)-S (South)-W (West)-N (North)-E (East), which represents negative. The counter clockwise direction is E (East)-N (North)-W (West)-S (South)-E (East), which represents positive.

3 Point-to-point wireless coverage application scenario and design scheme

In this section, when the coordinate system is transformed, it does not need to change the difference between horizontal and vertical coordinate, but only changes some angles. And horizontal rotation and pitch rotation are independent and unaffected each other. We design the scheme in three steps:

Step 1: X-axis of the vehicle coordinate system points north, and the Y-axis points east, which is the azimuth angle θ=0 and pitch angle ρ=0 of the vehicle.

Step 2: azimuth angle $\theta \in [0, 360^\circ)$ and pitch angle ρ=0 (azimuth within plane xoy) of the vehicle.

Step 3: azimuth angle $\theta \in [0, 360^\circ)$ and pitch angle $\rho \in [-30^\circ, 30^\circ]$ of the vehicle (Here positive up and negative down).

3.1 The first step of the scheme

The azimuth angle θ=0 and pitch angle ρ=0 of the vehicle. As shown in Fig. 1.

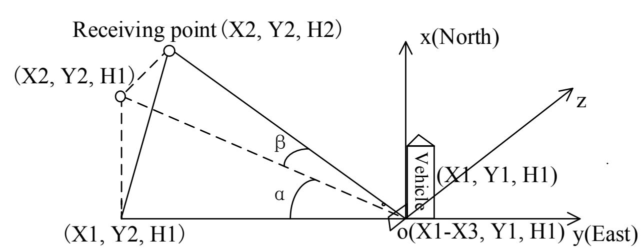

Figure 1: Coordinate System Diagram when azimuth θ=0 and pitch angle ρ=0

Coordinate $(X1, Y1, H1)$ of vehicle in gauss plane, distance between vehicle coordinate and plate $X3$, the coordinate of the plate $(X1 - X3, Y1, H1)$, receiving point

$(X2, Y2, H2)$, the coordinate of the receiving point projection $(X2, Y2, H1)$, plate need to rise $H3$ at work, plate coordinate $(X1 - X3, Y1, H1 + H3)$ at work.

Because the height difference and the distance between two points do not change, so：

$$\beta = \arctan \frac{H_2 - H_1 - H_3}{\sqrt{(X_2 - X_1 + X_3)^2 + (Y_2 - Y_1)^2}} \in [-30^\circ, 30^\circ] \tag{1}$$

Facing vehicle forward, the left plate directional antenna is plate 1, the right plate directional antenna is plate 2.

(1) When $Y_2 - Y_1 < 0$, plate 1 rotates.

$$\alpha = \arctan \frac{X_2 - X_1 + X_3}{Y_2 - Y_1} \in (-90^\circ, 90^\circ) \tag{2}$$

Negative sign means clockwise rotation, positive sign means counterclockwise rotation.

(2) When $Y_2 - Y_1 > 0$, plate 2 rotates.

$$\alpha = \arctan \frac{X_2 - X_1 + X_3}{Y_2 - Y_1} \in (-90^\circ, 90^\circ) \tag{3}$$

(3) When $Y_2 - Y_1 = 0$, plate 1 or plate 2 can rotate, and then let plate 1 rotate.

When $Y_2 - Y_1 = 0$ and $X_2 - X_1 + X_3 > 0$, plate 1 rotates $\alpha = -90^\circ$.

When $Y_2 - Y_1 = 0$ and $X_2 - X_1 + X_3 < 0$, plate 1 rotates $\alpha = 90^\circ$.

Taking into account the above three aspects:

When $Y_2 - Y_1 \le 0$, plate 1 rotates $\alpha = \begin{cases} -90^\circ, & \text{when } Y_2 = Y_1, X_2 > X_1 - X_3 \\ \arctan \dfrac{X_2 - X_1 + X_3}{Y_2 - Y_1} \in (-90^\circ, 90^\circ) & \\ 90^\circ, & \text{when } Y_2 = Y_1, X_2 < X_1 - X_3 \end{cases}$.

When $Y_2 - Y_1 > 0$, plate 2 rotates $\alpha = \arctan \dfrac{X_2 - X_1 + X_3}{Y_2 - Y_1} \in (-90^\circ, 90^\circ)$.

3.2 The second step of the scheme

The azimuth angle $\theta \in [0, 360^\circ)$ and pitch angle ρ=0 of the vehicle. As shown in Fig. 2.

Coordinate (X1, Y1, H1) of vehicle in gauss plane, distance between vehicle coordinate and plate X3, the coordinate of the plate(X1-X3 cosθ, Y1+X3 sinθ, H1), receiving point coordinate (X2, Y2, H2), the coordinate of the receiving point projection (X2, Y2, H1), plate need to raise H3 at work, the plate coordinate (X1-X3 cosθ, Y1+X3 sinθ, H1+H3) at work.

Because the height difference and the distance between two points do not change, it is given the following:

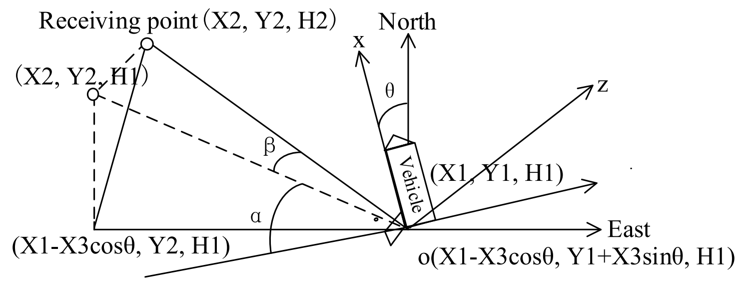

Figure 2: Coordinate System Diagram when of azimuth angle $\theta \in [0,360^{\circ})$ and pitch angle ρ=0

$$\beta = \arctan\frac{H_2 - H_1 - H_3}{\sqrt{(X_2 - X_1 + X_3\cos\theta)^2 + (Y_2 - Y_1 - X_3\sin\theta)^2}} \in [-30^{\circ}, 30^{\circ}] \tag{4}$$

Facing vehicle forward, the left plate is plate 1, the right plate is plate 2.

$$\alpha = \arctan\frac{X_2 - X_1 + X_3\cos\theta}{Y_2 - Y_1 - X_3\sin\theta} - \theta \in (-450^{\circ}, 90^{\circ}] \tag{5}$$

When $Y_2 - Y_1 - X_3\sin\theta = 0$ and $X_2 - X_1 + X_3\cos\theta > 0$, $\arctan\frac{X_2 - X_1 + X_3\cos\theta}{Y_2 - Y_1 - X_3\sin\theta} = -90^{\circ}$.

When $Y_2 - Y_1 - X_3\sin\theta = 0$ and $X_2 - X_1 + X_3\cos\theta < 0$, $\arctan\frac{X_2 - X_1 + X_3\cos\theta}{Y_2 - Y_1 - X_3\sin\theta} = 90^{\circ}$.

(1) When $\alpha + k\pi \in [-90^{\circ}, 90^{\circ}]$, k=0 or 2, if $Y_2 - Y_1 - X_3\sin\theta \le 0$, plate 1 rotates $\alpha + k\pi$; if $Y_2 - Y_1 - X_3\sin\theta > 0$, plate 2 rotates $\alpha + k\pi$. Negative sign means clockwise rotation, positive sign means counterclockwise rotation.

(2) When $\alpha + k\pi \in [-90^{\circ}, 90^{\circ}]$, k=1, if $Y_2 - Y_1 - X_3\sin\theta < 0$, plate 2 rotates $\alpha + k\pi$; if $Y_2 - Y_1 - X_3\sin\theta \ge 0$, plate 1 rotates $\alpha + k\pi$.

3.3 The third step of the scheme

The azimuth angle $\theta \in [0,360^{\circ})$ and pitch angle $\rho \in [-30^{\circ}, 30^{\circ}]$ of the vehicle. As shown in Fig. 3.

Coordinate (X1, Y1, H1) of vehicle in gauss plane, distance between vehicle coordinate and plate X3, the coordinate of the plate (X1-X3 $\cos\rho\cos\theta$, Y1+X3 $\cos\rho\sin\theta$, H1-X3 $\sin\rho$), receiving point coordinate (X2, Y2, H2), the coordinate of the receiving point projection (X2, Y2, H1-X3 $\sin\rho$), plate need to rise H3 at work, the plate coordinate (X1-X3 $\cos\rho\cos\theta$, Y1+X3 $\cos\rho\sin\theta$, H1-X3 $\sin\rho$ +H3) at word. Here we can see that a simple geometric transformation cannot solve the design scheme, only the three-dimensional coordinate transformation.

The vehicle attitude angles are known here: azimuth angle $\theta \in [0,360^{\circ})$, pitch angle

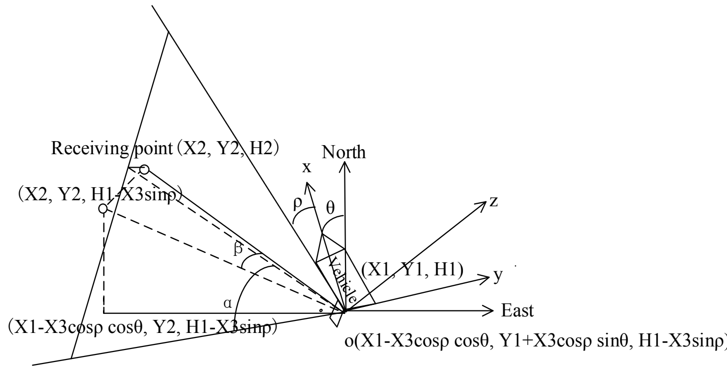

Figure 3: Coordinate System Diagram, when azimuth angle $\theta \in [0,360^{\circ})$ and elevation angle $\rho \in [-30^{\circ},30^{\circ}]$

$\rho \in [-30^{\circ},30^{\circ}]$ and roll angle $\gamma = 0$. The coordinate of plate in vehicle coordinate system is set as (x_1, y_1, h_1), and the coordinate of receiving point is (x_2, y_2, h_2). According to the three-dimensional coordinate transformation matrix formula, we obtain:

$$\begin{bmatrix} x_1 \\ y_1 \\ h_1 \end{bmatrix} = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\rho & \sin\rho \\ 0 & -\sin\rho & \cos\rho \end{bmatrix} \times \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_1 - X_3\cos\rho\cos\theta \\ Y_1 + X_3\cos\rho\sin\theta \\ H_1 - X_3\sin\rho + H_3 \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} x_2 \\ y_2 \\ h_2 \end{bmatrix} = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\rho & \sin\rho \\ 0 & -\sin\rho & \cos\rho \end{bmatrix} \times \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_2 \\ Y_2 \\ H_2 \end{bmatrix} \tag{7}$$

Because the height difference and the distance between two points do not change in the vehicle coordinate system, we get the following:

$$\beta = \arctan\frac{h_2 - h_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \in [-30^{\circ},30^{\circ}] \tag{8}$$

Facing vehicle forward, the left plate is plate 1, the right plate is plate 2.

(1) When $y_2 - y_1 < 0$, plate 1 rotates.

$$\alpha = \arctan\frac{x_2 - x_1}{y_2 - y_1} \in (-90^\circ, 90^\circ) \quad (9)$$

Negative sign means clockwise rotation, positive sign means counterclockwise rotation.

(2) When $y_2 - y_1 > 0$, plate 2 rotates.

$$\alpha = \arctan\frac{x_2 - x_1}{y_2 - y_1} \in (-90^\circ, 90^\circ) \quad (10)$$

(3) When $y_2 - y_1 = 0$, plate 1 or plate 2 can rotate, and then let plate1 rotate.

When $y_2 - y_1 = 0$ and $x_2 - x_1 > 0$, plate 1 rotates $\alpha = -90^\circ$.

When $y_2 - y_1 = 0$ and $x_2 - x_1 < 0$, plate 1 rotates $\alpha = 90^\circ$.

Taking into account the above three aspects:

When $y_2 - y_1 \le 0$, plate 1 rotates $\alpha = \begin{cases} -90^\circ, \quad \text{when } y_2 = y_1, x_2 > x_1 \\ \arctan\dfrac{x_2 - x_1}{y_2 - y_1} \in (-90^\circ, 90^\circ) \\ 90^\circ, \text{ when } y_2 = y_1, x_2 < x_1 \end{cases}$.

When $y_2 - y_1 > 0$, plate 2 rotates $\alpha = \arctan\dfrac{x_2 - x_1}{y_2 - y_1} \in (-90^\circ, 90^\circ)$.

It can be seen that the first and second step of design scheme are the special cases of the third step of design scheme, so the third step of design scheme is our general design scheme.

4 Point-to-region wireless coverage application scenario and design scheme

First, convert the coordinates of all receiving points and plates in the coverage region into the coordinates in the vehicle coordinate system, and figure out the angles between the connection line of all receiving points in the vehicle coordinate system from the projection point to the origin point o in the xoy plane and the forward direction of the Y-axis. Then, within $[0, 360^\circ)$ scope of horizontal sector region, using optimization algorithm with angle bisector of 5 degrees step length, based on traversal methods, find out two horizontal sector regions with the most optimal coverage (maybe be one). According to the position of the two horizontal sectors, consider whether vehicle head is needed to move. Finally, aiming at all of the receiving points in two sectors (maybe one) found, figure out the projection angles of pitch angles of all receiving points in the vertical sector plane, and within the $[-30^\circ, 30^\circ]$ scope, for vertical sector angle bisectors, using optimization algorithm with 1 degree step length, based on traversal methods, find out a vertical sector region with the most optimal coverage. In particular, it is pointed out that the above statements are based on the vehicle coordinate system. We followed the following steps to design the scheme:

(1) The coordinate of the vehicle (X_0, Y_0, H_0) in the gauss plane, the distance from the vehicle coordinate to plate is X_h, then the coordinate of the plate ($X_0 - X_h\cos\rho\cos\theta, Y_0 + X_h\cos\rho\sin\theta, H_0 - X_h\sin\rho$), the plate need to rise H_h at work, and the plate coordinate ($X_0 - X_h\cos\rho\cos\theta, Y_0 + X_h\cos\rho\sin\theta, H_0 - X_h\sin\rho + H_h$) at work. The coordinates of all receiving points are (X_1, Y_1, H_1), (X_2, Y_2, H_2), …, (X_N, Y_N, H_N) ($N \ge 2$).

Known vehicle attitude Angle: azimuth angle $\theta \in [0, 360^\circ)$, pitch angle $\rho \in [-30^\circ, 30^\circ]$ and roll angle $\gamma = 0$. The coordinate of plate in vehicle coordinate system is set as (x_0, y_0, h_0), and the coordinate of the nth receiving point is set as (x_n, y_n, h_n) ($1 \le n \le N$), so:

$$\begin{bmatrix} x_0 \\ y_0 \\ h_0 \end{bmatrix} = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\rho & \sin\rho \\ 0 & -\sin\rho & \cos\rho \end{bmatrix} \times \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_0 - X_h\cos\rho\cos\theta \\ Y_0 + X_h\cos\rho\sin\theta \\ H_0 - X_h\sin\rho + H_h \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} x_n \\ y_n \\ h_n \end{bmatrix} = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\rho & \sin\rho \\ 0 & -\sin\rho & \cos\rho \end{bmatrix} \times \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_n \\ Y_n \\ H_n \end{bmatrix} \tag{12}$$

Figure out the counterclockwise angle α_n ($1 \le n \le N, \alpha_n \in [0, 360^\circ)$) between the connection line of all receiving points in the vehicle coordinate system from the projection point to the origin point o in the xoy plane and the forward direction of the Y-axis:

$$\alpha_n = \begin{cases} \arctan\dfrac{x_n - x_0}{y_n - y_0} \in [0, 90^\circ), & \text{when } x_n \ge x_0, y_n > y_0 \\ 90^\circ, & \text{when } x_n > x_0, y_n = y_0 \\ \pi + \arctan\dfrac{x_n - x_0}{y_n - y_0} \in (90^\circ, 270^\circ), & \text{when } y_n < y_0 \\ 270^\circ, & \text{when } x_n < x_0, y_n = y_0 \\ 2\pi + \arctan\dfrac{x_n - x_0}{y_n - y_0} \in (270^\circ, 360^\circ), & \text{when } x_n < x_0, y_n > y_0 \end{cases} \tag{13}$$

(2) Within $[0,360^{\circ})$ scope of horizontal sector region, using optimization algorithm with angle bisector of 5 degrees step length, based on traversal methods, find out two horizontal sector regions with the most optimal coverage (maybe be one).

Algorithm process:

Step 1: First select the first horizontal sector, which has 72 possibilities. It is known when the ith case of the first horizontal sector, the degree of the counterclockwise angle ($\theta_i = (i-1)5^{\circ}$) between the angular bisector and the forward direction of Y-axis ($1 \le i \le 72$). In the ith case of the first horizontal sector Ω_i , if $2k\pi + \theta_i - 40^{\circ} \le \alpha_n < 2k\pi + \theta_i + 40^{\circ}$, $(k = 0 \text{ or } 1)$, it belongs to the region Ω_i, it can be seen that the region Ω_i covers the number of receiving points σ_i .

Step 2: Then select the second horizontal sector. The first horizontal sector is defined as the region Ω_i , which has 72-i possibilities. If $2k\pi + \theta_i - 40^{\circ} \le \alpha_n < 2k\pi + \theta_j + 40^{\circ}$ $(k = 0 \text{ or } 1)$ ($i+1 \le j \le 72$) and $2k\pi + \theta_i + 40^{\circ} \le \alpha_n < 2k\pi + \theta_i - 40^{\circ}, (k = 0 \text{ or } 1)$ $(1 \le i \le 72)$, then it belongs to the jth case of the second horizontal sector Θ_j , it can be seen that the region Θ_j covers the number of receiving points τ_j .

Step 3: Find out two horizontal sectors Ω_i and Θ_j with most optimal coverage, i.e. select $\max\{\sigma_i + \tau_j\}(1 \le i \le 72 \text{ and } i+1 \le j \le 72)$. Now the degrees of counterclockwise angle between selected two horizontal sector angular bisector and the positive Y-axis are respectively θ_i and $\theta_j (1 \le i \le 72 \text{ and } i+1 \le j \le 72)$.

There are three cases of the maximum combination selected:

(1) If i is fixed, and j is any selected value greater than i, now only one region needs to be covered. If $90^{\circ} \le \theta_i \le 270^{\circ}$, plate 1 rotates $\alpha = \theta_i - 180^{\circ}$. If $0 \le \theta_i < 90^{\circ}$, plate 2 rotates $\alpha = \theta_i$. If $270^{\circ} < \theta_i < 360^{\circ}$, plate 2 rotates $\alpha = \theta_i - 360^{\circ}$.

(2) If j is fixed, and i is any selected value less than j, now only one region needs to be covered. If $90^{\circ} \le \theta_j \le 270^{\circ}$, plate 1 rotates $\alpha = \theta_j - 180^{\circ}$. If $0 \le \theta_j < 90^{\circ}$, plate 2 rotates $\alpha = \theta_j$. If $270^{\circ} < \theta_j < 360^{\circ}$, plate 2 rotates $\alpha = \theta_j - 360^{\circ}$.

(3) In addition to the above two cases, the several maximum combinations (including one) are selected. At this time, take any one of the maximum combinations, then there are two regions need to be covered. Then according to the value of the two angles to determine whether the vehicle head is moving, and here is known $\theta_i < \theta_j$. Negative sign means clockwise rotation, positive sign means counterclockwise rotation.

(a) If $0 \le \theta_i < 90^{\circ}$, there are three possible cases of θ_j .

First, $0 \le \theta_i < 90^\circ$，the vehicle head needs to rotate at an angle of $-(90^\circ - \frac{\theta_i + \theta_j}{2})$, and then plate 1 rotates $\alpha = -(90^\circ - \frac{\theta_j - \theta_i}{2})$ and plate 2 rotates $\alpha = 90^\circ - \frac{\theta_j - \theta_i}{2}$.

Second, $90^\circ \le \theta_j \le 270^\circ$，the vehicle head does not need to rotate, then plate 1 rotates $\alpha = \theta_j - 180^\circ$, plate 2 rotates $\alpha = \theta_i$.

Third, $270^\circ < \theta_j < 360^\circ$，the vehicle head needs to rotate at an angle of $-(270^\circ - \frac{\theta_i + \theta_j}{2})$, and then plate 1 rotates $\alpha = 90^\circ - \frac{\theta_j - \theta_i}{2}$ and plate 2 rotates $\alpha = \frac{\theta_j - \theta_i}{2} - 90^\circ$。.

(b) If $90^\circ \le \theta_j \le 270^\circ$, there are two possible cases of θ_j.

First, $90^\circ \le \theta_j \le 270^\circ$, the vehicle head needs to rotate at an angle of $\frac{\theta_i + \theta_j}{2} - 90^\circ$, and then plate 1 rotates $\alpha = -(90^\circ - \frac{\theta_j - \theta_i}{2})$ and plate 2 rotates $\alpha = 90^\circ - \frac{\theta_j - \theta_i}{2}$。.

Second, $270^\circ < \theta_j < 360^\circ$, the vehicle head does not need to rotate, then plate 1 rotates $\alpha = \theta_i - 180^\circ$, plate 2 rotates $\alpha = \theta_j - 360^\circ$.

(c) If $270^\circ < \theta_j < 360^\circ$, there is only one case of θ_j.

First, $270^\circ < \theta_j < 360^\circ$, the vehicle head needs to rotate at an angle of $\frac{\theta_i + \theta_j}{2} - 270^\circ$, and then plate 1 rotates $\alpha = 90^\circ - \frac{\theta_j - \theta_i}{2}$ and plate 2 rotates $\alpha = -(90^\circ - \frac{\theta_j - \theta_i}{2})$.

(3) For the two found horizontal sectors with most optimal coverage (maybe one), Ω_i and Θ_j set as region A and B respectively. In region A, the coordinates of all receiving points in the vehicle coordinate system are (x_{A1}, y_{A1}, h_{A1}), (x_{A2}, y_{A2}, h_{A2})… (x_{An}, y_{An}, h_{An}), ($An \ge 0$). In region A, the coordinates of all receiving points in the vehicle coordinate system are (x_{B1}, y_{B1}, h_{B1}), (x_{B2}, y_{B2}, h_{B2})... (x_{Bn}, y_{Bn}, h_{Bn}), ($Bn \ge 0, An + Bn \le N$). Then the projection angles $\{\beta_{An}\}$ and $\{\beta_{Bn}\}$ of pitch angles of all receiving points in the vertical sector plane are calculated.

$$\beta_{An} = \arctan \frac{h_{An} - h_0}{\sqrt{(x_{An} - x_0)^2 + (y_{An} - y_0)^2} \cos(\alpha_{An} - \theta_i)} \tag{14}$$

$$\beta_{Bn} = \arctan \frac{h_{Bn} - h_0}{\sqrt{(x_{Bn} - x_0)^2 + (y_{Bn} - y_0)^2} \cos(\alpha_{Bn} - \theta_j)} \tag{15}$$

Within $[-30^\circ, 30^\circ]$ scope of vertical sector generated by bisector of region A and region B, using optimization algorithm with angle bisector of 1-degree step length, based on traversal methods, find out a vertical sector region with the most optimal coverage.

Algorithm process:

First step: for region A, the angle $\rho_{Al} = (Al-31)1^\circ (1 \le Al \le 61)$ between the bisector of the vertical sector Δ_{Al} $(1 \le Al \le 61)$ and the angle bisector $\theta_i = (i-1)5^\circ$ $(1 \le i \le 72)$ of the horizontal sector A, if $\rho_{Al} - 40^\circ \le \beta_{An} \le \rho_{Al} + 40^\circ$, it belongs to region Δ_{Al}. We can see that region Δ_{Al} covers the number of receiving points ε_{Al}. Find out a vertical sector Δ_{Al} with the most optimal coverage, i.e., select $\max\{\varepsilon_{Al}\}(1 \le Al \le 61)$. At this time, the pitch rotation angle of the plate in region A is $\beta = \rho_{Al}$.

Second step: in the same way in region B, the angle $\rho_{Bl} = \pm(Bl-31)1^\circ$ $(1 \le Bl \le 61)$ between the bisector of the vertical sector Δ_{Bl} ($1 \le Bl \le 61$) and the angle bisector $\theta_j = (j-1)5^\circ$ ($i+1 \le j \le 72$) of the horizontal sector B, if $\rho_{Bl} - 40^\circ \le \beta_{Bn} \le \rho_{Bl} + 40^\circ$, it belongs to the region Δ_{Bl}. We can see that the region Δ_{Bl} covers the number of receiving points ε_{Bl}. Find out a vertical sector Δ_{Bl} with the most optimal coverage, i.e., select $\max\{\varepsilon_{Bl}\}(1 \le Bl \le 61)$. At this time, the pitch rotation angle of the plate in the region B is $\beta = \rho_{Bl}$.

5 Numerical example

In this section, we use two examples to demonstrate the performance of the proposed methods.

5.1 Example of point-to-point wireless coverage application scenario

The effectiveness of the proposed directional antenna intelligent coverage method of point-to-point wireless coverage is validated in this section. The initial conditions are listed in Tab. 1, and other parameters of the vehicle, such as X3=2.5 m and H3=8 m. According to the information in Tab. 1, the position information and status information of the vehicle are changed successively. The location information of the overwritten target point is fixed, as shown in Tab. 2. The simulation results are obtained by software simulation, that is, the horizontal rotation angle α and pitch rotation angle β of the directional antenna on both sides of the vehicle to cover the target point, as shown in Tab. 3.

Table 1: The initial conditions of the vehicle

Number	Longitude			Latitude			Height	azimuth angle	pitch angle	roll angle
	degree	minute	second	degree	minute	second				
1	116	0	0	40	0	0	20	0	0	0
2	116	0	4	40	0	0	20	0	0	0
3	116	0	4	40	0	0	12	0	0	0
4	116	0	4	40	0	0	4	0	0	0
5	116	0	0	40	0	4	20	0	0	0
6	116	0	4	40	0	4	20	0	0	0
7	116	0	0	40	0	4	12	0	0	0
8	116	0	4	40	0	4	12	0	0	0
9	116	0	0	40	0	4	4	0	0	0
10	116	0	0	40	0	4	4	0	0	0
11	116	0	0	40	0	4	20	1	0	0
12	116	0	0	40	0	4	20	4	0	0
13	116	0	0	40	0	4	20	7	0	0
14	116	0	0	40	0	4	20	10	0	0
15	116	0	0	40	0	4	20	30	0	0
16	116	0	0	40	0	4	20	60	0	0
17	116	0	0	40	0	4	20	90	0	0
18	116	0	0	40	0	4	20	91	0	0
19	116	0	0	40	0	4	20	94	0	0
20	116	0	0	40	0	4	20	100	0	0
21	116	0	0	40	0	4	20	150	0	0
22	116	0	0	40	0	4	20	200	0	0
23	116	0	0	40	0	4	20	270	0	0
24	116	0	0	40	0	4	20	271	0	0
25	116	0	0	40	0	4	20	272	0	0
26	116	0	0	40	0	4	20	300	0	0
27	116	0	0	40	0	4	20	360	0	0
28	116	0	0	40	0	4	20	0	5	0
29	116	0	0	40	0	4	20	0	10	0
30	116	0	0	40	0	4	20	0	-10	0
31	116	0	0	40	0	4	20	0	-5	0
32	116	0	0	40	0	4	20	0	0	5
33	116	0	0	40	0	4	20	0	0	10
34	116	0	0	40	0	4	20	0	0	-10
35	116	0	0	40	0	4	20	0	0	-5
36	116	0	4	40	0	0	20	5	0	0
37	116	0	4	40	0	0	20	10	0	0
38	116	0	4	40	0	0	20	-10	0	0
39	116	0	4	40	0	0	20	-5	0	0

40	116	0	4	40	0	0	20	0	5	0
41	116	0	4	40	0	0	20	0	10	0
42	116	0	4	40	0	0	20	0	-10	0
43	116	0	4	40	0	0	20	0	-5	0
44	116	0	4	40	0	0	20	0	0	5
45	116	0	4	40	0	0	20	0	0	10
46	116	0	4	40	0	0	20	0	0	-10
47	116	0	4	40	0	0	20	0	0	-5

Table 2: The location information of the target point

Longitude			Latitude			Height
degree	minute	second	degree	minute	second	
116	0	0	40	0	0	20

Table 3: The horizontal rotation angle α and pitch rotation angle β of plate 1 and plate 2

Number	plate 1		plate 2	
	β	α	β	α
1	—	—	—	—
2	-3	0	—	—
3	0	0	—	—
4	3	0	—	—
5	-3	90	—	—
6	-3	45	—	—
7	0	90	—	—
8	0	45	—	—
9	3	90	—	—
10	3	45	—	—
11	-3	89	—	—
12	-3	86	—	—
13	-3	83	—	—
14	-3	80	—	—
15	-3	60	—	—
16	-3	30	—	—
17	-3	0	—	—
18	—	—	-3	-1
19	—	—	-3	-4
20	—	—	-3	-10
21	—	—	-3	-60
22	—	—	-3	70
23	—	—	-3	0
24	-3	-1	—	—
25	-3	-2	—	—

26	-3	-30	—	—
27	-3	90	—	—
28	-7	90	—	—
29	-13	90	—	—
30	7	90	—	—
31	2	90	—	—
32	-7	90	—	—
33	-13	90	—	—
34	7	90	—	—
35	2	90	—	—
36	-3	-5	—	—
37	-3	-10	—	—
38	-3	10	—	—
39	-3	5	—	—
40	-7	0	—	—
41	-13	0	—	—
42	7	0	—	—
43	2	0	—	—
44	-7	0	—	—
45	-13	0	—	—
46	7	0	—	—
47	2	0	—	—

5.2 Example of point-to-region wireless coverage application scenario

The effectiveness of the proposed directional antenna intelligent coverage method of point-to-point wireless coverage based on traversal optimization algorithm is validated in this section. The initial conditions are listed in Tab. 4, and other parameters of the vehicle, such as X3=2.5 m and H3=8 m. According to the information in Tab. 4, the position information and status information of the vehicle are changed successively. The location information of the overwritten target points is fixed, as shown in Tab. 5. The simulation results are obtained by software simulation, that is, the rotation angle of the vehicle and the horizontal rotation angle α and pitch rotation angle β of the directional antenna on both sides of the vehicle to cover the target points, as shown in Tab. 6.

Table 4: The initial conditions of the vehicle

Number	longitude			latitude			height	azimuth angle	pitch angle	roll angle
	degree	minute	second	degree	minute	second				
1	116	0	0	40	0	0	20	0	0	0
2	116	0	0	40	0	0	12	0	0	0
3	116	0	0	40	0	0	4	0	0	0
4	116	0	0	40	0	0	12	10	0	0
5	116	0	0	40	0	0	12	0	10	0
6	116	0	0	40	0	0	12	0	0	10

Table 5: The location information of the target points

Point number	longitude			latitude			height
	degree	minute	second	degree	minute	second	
1	116	0	4	40	0	0	20
2	116	0	3	40	0	1	25
3	116	0	2	40	0	2	15
4	116	0	3	39	59	59	20
5	115	59	57	40	0	1	24
6	115	59	56	40	0	0	20
7	115	59	57	39	59	59	20
8	115	59	58	39	59	58	16

Table 6: The rotation angle of the vehicle and the horizontal rotation angle α and pitch rotation angle β of plate 1 and plate 2

Number	rotation angle of the vehicle	plate 1		plate 2	
		β	α	β	α
1	0	-3	11	-3	-11
2	0	0	11	0	-11
3	0	3	11	3	-11
4	0	0	1	0	-21
5	0	-10	11	-10	-11
6	0	-10	11	-10	-11

6 Conclusion

This paper proposed a directional antenna intelligent coverage method based on traversal optimization algorithm, by using three-dimensional coordinate transformation, based on the actual demand of maneuver command system, provided the wireless signal coverage schemes for point-to-point and point-to-region, determined the required horizontal rotation angle and pitch rotation angle of the directional antenna intelligent coverage, and laid the foundation for the performance of wireless broadband communication in the maneuver command communication system.

Acknowledgement: This research was funded in part by the National Natural Science Foundation of China (61871140, 61872100, 61572153, U1636215, 61572492, 61672020), the National Key research and Development Plan (Grant No. 2018YFB0803504), and Open Fund of Beijing Key Laboratory of IOT Information Security Technology (J6V0011104).

References

Alsamhi, S. H.; Rajput, N. S. (2015): An intelligent HAP for broadband wireless communications: developments, QoS and applications. *International Journal of Electronics and Electrical Engineering*, vol. 3, no. 2, pp. 134-143.

Cai, L. X.; Cai, L.; Shen, X. M.; Mark, J. W. (2010): REX: a randomized exclusive region based scheduling scheme for mmWave WPANs with directional antenna. *IEEE Transactions on Wireless Communications*, vol. 9, no. 1, pp. 113-121.

Chen, J.; Tian, Z. H.; Cui, X.; Yin, L. H.; Wang, X. Z. (2018): Trust architecture and reputation evaluation for internet of things. *Journal of Ambient Intelligence & Humanized Computing*, pp. 1-9.

Gazda, J.; Šlapak, E.; Bugár, G.; Horváth, D.; Maksymyuk, T. et al. (2018): Unsupervised learning algorithm for intelligent coverage planning and performance optimization of multitier heterogeneous network. *IEEE Access*, vol. 6, no. 2, pp. 39807-39819.

Jakllari, G.; Broustis, I.; Korakis, T.; Krishnamurthy, S. V.; Tassiulas, L. (2005): Handling asymmetry in gain in directional antenna equipped ad hoc networks. *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1284-1288.

Kish, W. (2014): Coverage enhancement using dynamic antennas. U.S. Patent 8,792,414.

Kish, W. (2016): Coverage enhancement using dynamic antennas and virtual access points. U.S. Patent 9,344,161.

Kish, W.; Shtrom, V. (2008): Coverage antenna apparatus with selectable horizontal and vertical polarization elements. U.S. Patent 7,358,912.

Kish, W.; Shtrom, V. (2015): Coverage antenna apparatus with selectable horizontal and vertical polarization elements. U.S. Patent 9,093,758.

Korakis, T.; Jakllari, G.; Tassiulas, L. (2008): CDR-MAC: a protocol for full exploitation of directional antennas in ad hoc wireless networks. *IEEE Transactions on Mobile Computing*, vol. 7, no. 2, pp. 145-155.

Min, B. C.; Parasuraman, R.; Lee, S.; Jung, J. W.; Matson, E. T. (2018): A directional antenna based leader-follower relay system for end-to-end robot communications. *Robotics and Autonomous Systems*, vol. 101, pp. 57-73.

Navda, V.; Subramanian, A. P.; Dhanasekaran, K.; Timm-Giel, A.; Das, S. (2007): MobiSteer: using steerable beam directional antenna for vehicular network access. *Proceedings of the 5th International Conference on Mobile Systems, Applications and Services*, pp. 192-205.

Ofek, Y.; Gavish, B. (2011): Directional antenna sectoring system and methodology. U.S. Patent 7,953,372.

Ramanathan, R.; Redi, J.; Santivanez, C.; Wiggins, D.; Polit, S. (2005): Ad hoc networking with directional antennas: a complete system solution. *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 3, pp. 496-506.

Salo, R. W.; Moore, B. G.; Clark, R. H.; Abramov, O. Y.; Kirdin, A. N. et al. (2011): Optimized directional antenna system. U.S. Patent 7,907,971.

Ssu, K. F.; Wang, W. T.; Wu, F. K.; Wu, T. T. (2009): K-barrier coverage with a directional sensing model. *International Journal on Smart Sensing and Intelligent Systems*, vol. 2, no. 1, pp. 75-93.

Tan, Q. F.; Gao, F.; Shi, J. Q.; Wang, X. B.; Fang, B. X. et al. (2018): Towards a comprehensive insight into the eclipse attacks of tor hidden services. *IEEE Internet of Things Journal*, pp. 1.

Tian, Z. H.; Cui, Y.; An, L.; Su, S.; Yin, X. X. et al. (2018): A real-time correlation of host-level events in cyber range service for smart campus. *IEEE Access*, vol. 6, pp. 35355-35364.

Wang, B. W.; Gu, X. D.; Ma, L.; Yan, S. S. (2017): Temperature error correction based on BP neural network in meteorological WSN. *International Journal of Sensor Networks*, vol. 23, no. 4, pp. 265-278.

Wang, B. W.; Gu, X. D.; Yan, S. S. (2018): STCS: a practical solar radiation based temperature correction scheme in meteorological WSN. *International Journal of Sensor Networks*, vol. 28, no. 1, pp. 22-33.

Wang, B. W.; Gu, X. D.; Zhou, A. (2017): E2S2: a code dissemination approach to energy efficiency and status surveillance for wireless sensor networks. *Journal of Internet Technology*, vol. 8, no. 4, pp. 877-885.

Wang, J.; Ju, C. W.; Gao, Y.; Sangaiah, A. K.; Kim, G. J. (2018): A PSO based energy efficient coverage control algorithm for wireless sensor networks. *Computers, Materials & Continua*, vol. 56, no. 3, pp. 433-446.

Wang, Y. H.; Tian, Z. H.; Zhang, H. L.; Su, S.; Shi, W. (2018): A privacy preserving scheme for nearest neighbor query. *Sensors*, vol. 18, no. 8, pp. 2440.

Yu, X.; Tian, Z. H.; Qiu, J.; Jiang, F. (2018): A data leakage prevention method based on the reduction of confidential and context terms for smart mobile devices. *Wireless Communications and Mobile Computing*, pp. 1-11.

Zhu, X.; Gao, Y. (2017): Comparison of intelligent algorithms to design satellite constellations for enhanced coverage capability. *10th International Symposium on Computational Intelligence and Design*, vol. 2, pp. 223-226.