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The optimization of antenna location based on channel capacity maximization

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ABSTRACT: In recent years,China's communication technology has developed very rapidly,among which information and communication infrastructure is a key element to enhance national strength,maintain national security and enrich people's lives.The location of base station is very important since it will impact the performance of the communication network. This paper starts from the perspective of channel capacity maximization, constructs different mathematical models in different scenarios,and uses corresponding theoretical research methods to reasonably analyze the base station location problem and find the scheme for the optimal base station location. Finally, simulation resultsare used to verify the feasibility of the theory and prove the rationality of the base sationlocation optimizationscheme.

KEYWORDS:antenna location;location optimization;channelcapacity;target optimization

I. INTRODUCTION

Communication,as an indispensable and important tool for people in information acquisition and communication, has been playing an increasingly important role in today's information era[1].Therefore, countries all over the world are devoted to the research of modern communication technologies.Among the information transmission technologies,mobile communication is one of the most active and rapidly developing fields in the field of communication today as it can provide fast,convenient and reliable communication[2].The goal of mobile communication development is to make the communication desire of human beings "to be able to exchange any information with anyone at anytime and anywhere" a reality[3].

In the early days,BTS site selection was often done by network engineers who manually determined the candidate solutions of BTS based on their previous working experience, and then the staffs conducted field surveys to determine whether the BTS was suitable for construction.This method is inaccurate in the first place because the selection of candidate base stations is based on the staff's experience,which can lead to a large error in the candidate base stations,and the actual selected solution may not achieve the network coverage optimization goal well in the end[4]. Later,digital maps emerged to help network engineers make auxiliary decisions,but their significance is more for prediction and coverage analysis,which ultimately depends on engineers' personal experience[5].Since only the layout of the antennas in the base station is considered, this paper will focus on describing the location optimization process of the distributed antennas.

According to previous studies, the fading damage suffered by radio signals passing through a wireless channel can be generally classified into three types: path loss, shadow fading, and small-scale fading[6].

1.Path loss, or propagation loss, refers to the loss generated by the propagation of radio waves in space, which is caused by the radiation spread of the transmit power and the propagation characteristics of the channel, reflecting the change in the mean value of the received signal power in the macro range. Theoretically, it is believed that for the same receiving and transmitting distance, the path loss is also the same. However, in practice, it is often found that the same transmission and reception distance of the received power at different reception points but there is a large change, and even the same reception point on the received power at different points in time also produces large fluctuations.

2.Shadow fading is caused by the obstacles between the transmitter and receiver, these obstacles attenuate the signal power by absorption, reflection, scattering and bypassing, etc.and will seriously block the signal, causing power changes on the scale distance of the obstacles (10m~100m outdoors, and even smaller indoors). In the mobile communication propagation environment, radio waves in the propagation path encounter undulating hills, buildings, woods and other obstacles to block the formation of radio waves of the shadow area, it will cause a slow change in the median signal field strength, causing fading. This phenomenon is usually referred to as the shadowing effect, and the resulting fading is also known as shadowing slow fading. In addition, due to changes in meteorological conditions, the refraction coefficient of the radio wave changes gently over time, making the median field strength of the signal received at the same location also changes slowly over time.

3.Small-scale fading is the most fundamental characteristic of a wireless channel due to multipath scattering and the rapid change in received signal power caused by the relative motion between the transmitter and receiver. It is mainly reflected in two aspects: multipath propagation and Doppler expansion. The specific manifestations of the small-scale fading effect are mainly:

(1) A sharp change in the amplitude of the signal after a short distance or a short time.

(2) In different path signals, there is a time-varying multispectral frequency shift caused by random frequency modulation.

(3) multipath propagation time delay caused by the expansion (echo).

The performance of wireless communication system is mainly constrained by the mobile wireless channel. Compared to other communication channels, the wireless communication channel is one of the most complex. The propagation path between transmitter and receiver ranges from simple line-of-sight propagation to encountering a variety of complex terrain such as buildings, mountains and foliage[7].

In contrast to wired channels, wireless channels are not fixed and predictable, but are highly random and time-varying. Modeling of wireless channels is usually performed using statistical methods and by channel measurements over specific frequency bands.

Antenna location optimization is a multi-objective combined optimization problem, and in a complex communication environment, a variety of factors need to be considered, such as system capacity, performance, coverage and propagation characteristics, and other factors[8]. Antenna location optimizationis to establish a wireless network with good service quality, and the main objectives of wireless base station distribution optimization include cost objectives, coverage objectives, quality objectives, etc.

In general,regarding the field of antennalocation,it has been transformed and upgraded from the early manual experience screening to the current mainstream intelligent algorithm optimization type.For this model,this paper mainly makes a breakthrough from two directions:on the one hand, the mathematical model established is improved to select different scenarios and optimization targets;on the other hand, the intelligent optimization algorithm is used to conduct reasonable multi-objective optimization analysis for different targets under the selected different scenarios[9].On the other hand,it is to use intelligent optimization algorithms to perform a reasonable multi-objective optimization analysis for different objectives in different scenarios.The improvement of the mathematical model can start from the types of independent variables and the specificity of the independent variables.Therefore,this direction is currently of great research interest.

II. CHANNEL CAPACITY-BASED MODELING IN LINEAR CELLS

A linear cell system model is shown in Figure 3.1

Figure 3.1A linear cell system model

In a narrow channel, such as subway, train, dormitory corridor and other scenarios, they can be approximated as a linear cell, let the length of this cell be 2a， x_1, x_2 are the locations of antennas $k = 1,2$ two transmitting antennas are distributed in different locations of this linear cell, and they are connected to a central base station by fiber or coaxial cable, and assume that the antenna function, performance, and setting parameters are the same.And the users are evenly distributed,Considering only the path fading, the antenna k free space path loss model is

$$L_k = \left(\frac{\lambda}{4\pi d_k}\right)^2$$

$d_k$is the distance from the receiving antenna to the transmitting antenna

$$d_1 = \sqrt{(x - x_1)^2 + (h - c)^2}$$
$$d_2 = \sqrt{(x - x_2)^2 + (h - c)^2}$$

Assume that the two antennas transmit at frequency P,and the noise is the same. Antenna heighth, user height c ,Then the signal-to-noise ratio of the antenna signal received by the user at position x is

$$\bar{\gamma} = \frac{L_1 P}{N_0} + \frac{L_2 P}{N_0} = \frac{P}{N_0}\left(\frac{\lambda}{4\pi}\right)^2 \left(\frac{1}{(x - x_1)^2 + (h - c)^2} + \frac{1}{(x - x_2)^2 + (h - c)^2}\right)$$

The channel capacity of the dual antenna system is

$$\mathrm{C} = \int_{-a}^{a} \mathrm{B}\log_2(1+\bar{\gamma})\mathrm{dx} \qquad (1)$$

$$= \int_{-a}^{a} \mathrm{B}\log_2\left(1 + \frac{\mathrm{P}}{\mathrm{N_0}}\left(\frac{\lambda}{4\pi}\right)^2\left(\frac{1}{(\mathrm{x}-\mathrm{x_1})^2+(\mathrm{h}-\mathrm{c})^2} + \frac{1}{(\mathrm{x}-\mathrm{x_2})^2+(\mathrm{h}-\mathrm{c})^2}\right)\right)\mathrm{dx} \qquad (2)$$

III. THE PROCESS OF SOLVING THE OPTIMIZATION PROBLEM

According to the model building and derivation in Chapter 2,The maximum channel capacitywill be

$$\begin{cases}\max & \mathrm{C}(\mathrm{x_1},\mathrm{x_2}) \\ \mathrm{s.t.} & -\mathrm{a} \le \mathrm{x_1},\mathrm{x_2} \le \mathrm{a}\end{cases}$$

The procedure for solving the channel capacity is as follows

$C(x_1,x_2) = \int_{-a}^{a} f\,(x_1,x_2)dx$;

Find the partial derivatives of $C(x_1,x_2)$ for x_1,x_2 respectively

$$\frac{\partial C(x_1,x_2)}{\partial x_1} = \int_{-a}^{a} \frac{\frac{2(x-x_1)}{(x-x_1)^2+(h-c)^2}}{f(x_1,x_2)}dx$$

$$\frac{\partial C(x_1,x_2)}{\partial x_2} = \int_{-a}^{a} \frac{\frac{2(x-x_2)}{(x-x_2)^2+(h-c)^2}}{f(x_1,x_2)}dx$$

Since the analytic formula is too complicated, we define $D(x_1,x_2)$as follows

$$D(x_1,x_2) = \frac{1}{(x-x_1)^2+(h-c)^2} + \frac{1}{(x-x_2)^2+(h-c)^2}$$

Let $x_2 = x_1 + 2d$,then $D(x_1,x_2) = D(x_1,x_1+2d)$Using the basic inequality property, we get

$$D(x_1,x_2) \le D(-d,d)$$

Solving for the maximum value of $C(x_1,x_2)$ is equivalent to solving for $C(-d,d) = C(d)$

Derivative for $C(d)$

$$C'(d) = \int_{-a}^{a} \frac{\frac{-2(x+d)}{(x+d)^2+(h-c)^2}}{f(d)} + \frac{\frac{2(x-d)}{(x-d)^2+(h-c)^2}}{f(d)}dx$$

Clearly $C'(d)$is an odd function; then $C'(0) = 0$,the first stationary point.

By the integral median theorem, wecanget

$$C'(d) = \frac{1}{2a}\left(\frac{\frac{-2(\xi+d)}{(\xi+d)^2+(h-c)^2}}{f(d)} + \frac{\frac{2(\xi-d)}{(\xi-d)^2+(h-c)^2}}{f(d)}\right) = 0$$

$\xi \in (-a,a)$, simplify to get

$$\frac{-2(\xi+d)}{(\xi+d)^2+(h-c)^2} + \frac{2(\xi-d)}{(\xi-d)^2+(h-c)^2} = 0$$

$$d = 0, \xi^2 + c^2 - 2ch + h^2 \ne 0$$

$$d = -\sqrt{(\xi^2 - c^2 + 2ch - h^2)}, \xi^2 - (c-h)^2 \ge 0$$

$$d = \sqrt{(\xi^2 - c^2 + 2ch - h^2)}, \xi^2 - (c-h)^2 \ge 0$$

$$C'(d) = 0 \qquad (3)$$

The necessary conditions for the existence of three solutions are

$\xi^2 - (c-h)^2 \ge 0$,equalsto

$$0 < h - c \le \xi < a \qquad (4)$$

Now further determine the range of values of ξ,

$$f'(d) = \frac{\frac{-2(x+d)}{(x+d)^2+(h-c)^2}}{f(d)} + \frac{\frac{2(x-d)}{(x-d)^2+(h-c)^2}}{f(d)}$$

$$f'(\xi) = \frac{\frac{-2(\xi+d)}{(\xi+d)^2+(h-c)^2}}{f(d)} + \frac{\frac{2(\xi-d)}{(\xi-d)^2+(h-c)^2}}{f(d)}$$

$$f'_{min} \le f'(\xi) \le f'_{max}$$

Now find the derivative of f′(d) with respect to x, and let it be equal to 0 : $\frac{\partial \mathrm{f}'(\mathrm{d})}{\partial \mathrm{x}} = 0$

Thesolutionis

$$x = \pm\sqrt{-2\sqrt{(C-h)^2(C^2-2Ch+d^2+h^2)} + C^2 - 2Ch + d^2 + h^2},$$
$$2\left(C^2 - C\sqrt{(C-h)^2(C^2-2Ch+d^2+h^2)} + h\sqrt{(C-h)^2(C^2-2Ch+d^2+h^2)} - 3C^2h + Cd^2 + 3Ch^2 - d^2h - h^3\right) \ne 0$$

apparently, $\mathrm{h} - \mathrm{c} < \xi \le \mathrm{x}$

we can get

$$\mathrm{d} > \sqrt{(\mathrm{h}-\mathrm{c})^2 + \sqrt{((\mathrm{h}-\mathrm{c})^2+2)^2+4}}$$

IV. SIMULATION ANALYSIS AND VALIDATION

In order to verify the correctness of the analysis results, a computer simulation was performed

First we give the basic simulation conditions: channel bandwidth B=1Mbps, whiteGaussian noise N0=0.1J , fading factor $\boldsymbol{\lambda = 4\pi}$, antenna height $\mathbf{h = 4m}$, user height $\mathbf{c = 1m}$, cell radius$\mathbf{a = 100m}$, modulation method is BPSK .

The simulation results are shown below:

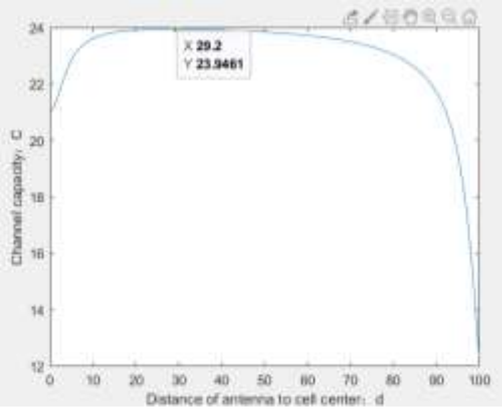

Figure 4.1simulation results

Since the previous derivation we have concluded that:ifwe want the channel capacity to reach the maximum, then the position of the two antennas must be symmetrical about the center of the cell. (Or they are bothset in the location of the center of the cell, but this will degenerate into a centralized antenna, so we do not consider this case) from the above figure we can see that, when the above simulation conditions are elected, the two antennas are located at 29.2m from the center of the cell symmetrically placed, and the channel capacity will reach the maximum, at this time the maximum value of the channel capacity is23.9461Mbps.

V. CONCLUSION

For the distributed transmit antenna system in one-dimensional linear cell environment, this paper firstly obtains the traversal channel capacity in this scenario based on the consideration of path loss, Gaussian noise, and uniform distribution of users, and then analyzes the theoretical derivation to maximize the channel capacity in this scenario, so as to obtain the optimal transmit antenna location placement scheme. The theoretical analysis shows that when the channel capacity is maximized, the single antenna is located at the location of the center point of the linear cell, at which time the distributed transmit antenna degenerates to a centralized transmit antenna, i.e.If there are two transmit antennas, then they are placed centrally at the center of the cell; or the two antennas are distributed on the roof in a symmetric relationship about the center point of the cell. The findings of this paper provide a feasible reference design solution for antenna location of distributed transmit antenna systems in a one-dimensional linear cell environment from the perspective of maximizing the system channel capacity.

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