Research on Smart Antenna System Based on Beamforming Algorithm

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Abstract. As the most important element of mobile communication, antenna is the component that radiates and receives electromagnetic waves. The performance of the antenna plays a very important role in the overall performance of mobile communications. Due to the increase in user demand, mobile communication systems are increasingly demanding antennas. In this paper, the composition and principle of the smart antenna system are analyzed. The smart antenna system is composed of an antenna array, a group of beam forming networks and algorithms. Compared with the antenna of the traditional antenna, it has no interference between signals and reduces the characteristics of external interference and noise, and improved signal coverage. The research results show that smart antenna technology will provide the best service for future mobile communications.

1. Introduction
The development of communication technology has greatly affected the progress of human society. Efficient, convenient and accurate communication technology is of great significance for speeding up the operation and facilitating people's lives. The rapid growth of the mobile communication market has strongly promoted the development of mobile communication technology. At the same time, it also puts forward higher requirements for communication technology. On the one hand, the communication blind zone is continuously reduced. In the process of electromagnetic wave propagation, the channel is degraded due to various reasons such as terrain complexity, such as path loss and shadow fading, which are seriously affected by communication quality. On the other hand, communication quality and communication coverage are required to increase significantly. The spectrum resources available for mobile communication are very limited, but the demand for mobile communication services is increasing day by day. More and more new communication technologies are beginning to be applied to mobile applications on a large scale. In communication. In this respect, smart antennas can effectively solve this problem. It is our top priority to study the performance of smart antennas and the realization of smart antenna systems. At the same time, smart antennas are also a new technology that constantly adds new technologies over time.

2. Smart Antenna System

2.1. Antenna Function
Smart antenna is an intelligent form of antenna. Its intelligence is embodied in the adaptation. This adaptive antenna array consists of multiple antenna elements. Each antenna is followed by a weighting
device. The true meaning of intelligence means that these weighting coefficients can be appropriately changed and adaptively adjusted. The smart antenna is an adaptive antenna array, which is processed by digital signals to generate a spatially oriented beam, so that the main beam of the antenna, that is, the main lobe, is aligned with the direction of the desired user, so that the side lobes are aligned with the direction of the interference signal; By fully utilizing the mobile user signal, it is also possible to delete or suppress the interference signal.

The smart antenna can automatically measure the direction of the user, so that the main beam, that is, the main lobe, is directed to the user, thereby realizing that the beam moves following the movement of the desired user. In this way, the gain of the antenna can be improved, and the power of the signal transmission can be reduced, thereby greatly improving the coverage of the base station. Therefore, the smart antenna is an antenna and the surrounding propagation environment and the user's best space matching communication. A typical smart antenna receiving system mainly includes an antenna array for realizing spatial signal sampling, a beamforming network for weight combining the respective array elements, and a control portion for updating the combined weights. In summary, a smart antenna system consists of three parts, an antenna array, a beamforming network, and a beamforming algorithm.

2.2. Antenna Array

The smart antenna array is an antenna array in which a plurality of antenna elements are arranged in a certain shape, and antenna elements having the same polarization characteristics, isotropy and gain are arranged in a certain manner. The array pattern of the antenna array is various. The typical array shape can be divided into: line array, area array, circular array, etc., but in practical applications, triangle arrays, irregular arrays, etc. can also be formed according to different needs. Linear arrays and planar arrays are easy to achieve directional coverage of base stations, and base station location is more flexible. Linear arrays and planar arrays can be easily placed on the side of a building or on a pole-like building. The array elements constituting the array may be arranged in any manner, and the spacing of the antenna elements of each antenna generally takes half a wavelength and the orientation is the same; because the spacing of the array elements is excessive, the correlation between the received signals is reduced, and the size is unnecessary on the pattern. Side lobes. Then the array mode of the array is selected according to user requirements.

Due to the electromagnetic waves coming from a distant place (which can be regarded as plane waves), the distances traveled to each array element are different, resulting in different phase differences. A signal having a different phase difference from the reference point is formed on each of the array elements. In order to be able to adjust the antenna pattern to meet the needs of the work, it is necessary to add a weight factor controller at the output of each antenna array element, because it can adjust the amplitude and phase of the output signal of each array element, so it can be modified. The purpose of the pattern of the antenna array.

The antenna array of the smart antenna system can simultaneously identify or track signals from all directions according to different needs. The combination of the antenna array signals can also emphasize the signals in certain specific directions, but the direction of the focus of the array is independent of the orientation of the antenna array. Different data methods can be used to obtain various weighted sums of the antenna array signals. Signals expected by users in many directions are simultaneously extracted. Then, the smart antenna array can enable different signals to be used in different directions at the same time, thereby increasing the capacity of the antenna system.

3. Smart Antenna Principle

As shown in Figure 1, a weighting factor controller is added to the output of each antenna element on the smart antenna to generate weighting coefficients, and all the obtained weighting coefficients are combined to form an array weight vector. Where the weight vector is $W = (W_1, W_2, ..., W_{n-1})$, the array weight vector is a vector related to the direction of arrival of the signal. The signal of each array element of the antenna array is weighted to achieve the purpose of adjusting the receiving pattern of
the antenna. Thus, it can be known that the array weight vector is a function of the position of the entire mobile station. Therefore, designing and controlling and adjusting the weight vector of the antenna array is the core of the adaptive antenna array.

![Figure 1. Principle of smart antenna receiving signals](image)

Can be obtained by principle $n$ the main lobe of the antenna element is pointed at the maximum value $f_0$ time, the first $n$ is the phase of the receiving current of the array elements is:

$$a_m = ka \sin \theta_0 \cos (f_0 - f_n), n = 0, 1, 2, \ldots, n - 1;$$

Among them, $k = \frac{2\pi}{\lambda}$, $k$ take $\frac{\lambda}{2}$, $\theta_0 = \frac{\pi}{2}$, $f_n = \frac{2\pi n}{N} = \pi n$.

Then there are:

$$a_m = \pi \cos (f_0 - f_n)$$

When $a_m$ indicates that the smart antenna is received at the base station $f_0$, When the mobile station in the direction signals, $n$ is the intrinsic or intrinsic phase of the current of the array element. When there are received signals in multiple directions, there are multiple $a_m$.

Change the external phase shifter group $W_0^*, W_1^*, W_2^*, \ldots, W_{n-1}^*$ value when $W_n^*$ value is equal to $-a_m$ in time, the received signal carriers of each channel can be added in phase at m, which can be defined as the in-phase diversity reception of the expected carrier phase of the received signal, and the diversity receiving gain of the smart antenna can be obtained at this time. $G_{RD} = 10\log n$ smart antennas can achieve the goal of obtaining the best antenna pattern by adjusting the weights. It has high gain for signals incident in a specific direction and attenuation for signals incident in other directions.

### 3.1. Beamforming Network

Whether the smart antenna can be realized is determined by the beamforming technology. Beamforming is to change the signal received by the antenna array to the baseband, and then perform corresponding spatial spectrum processing to obtain the spatial feature vector and matrix of the signal and the power estimation and DOA estimation of the signal.

The smart antenna mainly uses the relationship between the received signals of each array element and the spatial characteristics of the incoming signal to receive or transmit the signal. Therefore, one of the important processes is to use the received signals of each array element to obtain the wave direction estimation, that is, to suppress the angle of the incoming wave signal. For a far-field signal, there will be a wave path difference when the signal arrives at different array elements, which will
cause a phase difference between the received signals of each receiving array element. This phase difference can be used to determine the azimuth angle of the incident signal and other parameters.

Wireless positioning by the arrival angle estimation is one of the characteristics of a mobile communication system with a smart antenna. For a general mobile communication system, the wireless positioning scheme is mainly cell positioning, and the positioning is performed by different base stations to observe the time difference, and this method can be used in combination with the smart antenna method. The DOA estimation method includes a Bartlett spectrum estimation method that is easy to implement.

Assume $a(\varphi)$, $\varphi$ is the corresponding vector of the array of directions, $R_{xx}^k$ is the terminal $k$ spatial covariance matrix, $[\varphi_{\min}, \varphi_{\max}]$ is the range of angle estimates:

$$
\phi_k = \arg \max \left[ a(\varphi)R_{xx}^k a(\varphi) \right], \varphi \in [\varphi_{\min}, \varphi_{\max}]
$$

This method is simple and effective, and the calculation amount is not large. Although the music algorithm is a relatively high algorithm, it is not necessary for the communication system. The spatial spectrum of the mobile communication system is complicated due to the influence of the multipath channel. DOA estimates that only the direction of the main path or the direction of the main paths. For systems with different delay components that can be estimated, DOA of different delay components can be estimated. After obtaining the estimation of the direction of arrival, beamforming is an important part of the work of smart antennas. As long as the phase difference between the spatial elements is known, parameters such as the azimuth and elevation of the incident signal can be obtained. The task of beamforming is to create as high a gain as possible in the direction in which the received signal arrives; to minimize interference signals.

### 3.2. Beamforming Algorithm

Beam adaptive signal processing is an important aspect of smart antennas. It is based on adaptive algorithms and is mainly embodied in algorithm controllers. Its function is to select or calculate array weight vector according to signal environment and according to certain criteria and algorithms. The adaptive algorithm determines the instantaneous response rate and the complexity of the circuit implementation. Therefore, the most important thing is to choose a better algorithm to achieve intelligent control of the beam. At present, many adaptive algorithms for adaptive array antennas are used, depending on whether The algorithm needs to be used to classify the algorithm into two categories: unblinded algorithm and blind algorithm. For an adaptive algorithm, we must first measure the performance of its various aspects. There are several aspects to measuring the various adaptive algorithms:

1. Convergence rate. Refers to the number of iterations that the algorithm converges to the optimal solution in a static environment.
2. Tracking performance. Refers to the ability to adaptively track channels under conditions where the channel changes.
3. Robustness. Whether the algorithm works normally when the input is ill, or under which conditions the algorithm can converge.
4. Computational complexity. This is a very practical measure, referring to the number of multiply- and accumulate operations required by the algorithm. The performance in this area determines the implementation cost and hardware performance requirements of the algorithm.

Both non-blind and blind algorithms have their own advantages and disadvantages. Blind algorithms make more use of the required signals, while non-algorithms have better performance than blind algorithms, including better convergence speed, simpler computational complexity, etc. However, the unblinded algorithm also has its obvious limitations, that is, it needs to send some
training sequences, and the training sequence occupies valuable channel resources. Therefore, it is more practical to study blind algorithms that do not require training sequences.

This paper adopts an optimal algorithm in the blind algorithm, the least squares method. Define all data blocks as $X=(x(1), x(2), \ldots, x(N))$, where $N$ is the size of the data block; $k$ The weight generated by the iteration $W_k$, the corresponding output sequence is $y_k^*$:

$$y_k = W_k^H X = \left(W_k^H x(1), W_k^H x(2), \ldots, W_k^H x(N)\right) = (y(1), y(2), \ldots, y(N))$$

Then $k + 1$ is the weight of the generation of the iteration, then minimize its function:

$$J = \sum_{n=1}^{N} \left| W_{k+1}^{H} x(n) - d_k(n) \right|^2$$

Among them $d_k(n)$ for the training sequence, the above formula $W_{k+1}$ find the derivative and make it zero, we can get:

$$W_{k+1} = \hat{R}_x^{-1} \hat{r}_d$$

Among them $\hat{R}_x = \frac{1}{N} XX^H$, $\hat{r}_d = \frac{1}{N} \sum_{n=1}^{N} x(n) d_k(n)$.

Then the above formula constitutes an iterative formula of the least squares constant modulus algorithm. From the formula, the mechanism of updating the weights and the training sequences alternately can be obtained. That is to say, each time a new iteration is performed, the data block is updated once, which embodies the advantage of fast convergence.

4. Smart Antenna Application

In the development of mobile communication technology, smart antennas represented by adaptive array antennas have become one of the most active fields. The advantages brought by smart antenna technology to mobile communication systems are difficult to replace by any technology at present.

At present, countries all over the world attach great importance to this, and have invested a lot of manpower and resources for research and development work, and various products have been successfully developed and put into use, such as Array Comm’s application of smart antenna technology to WLL (wireless local loop) system. And adopt a variable array configuration, which has 12- and 4-member loop shape adaptive arrays for different environments. In its field experiments in Japan, experiments have shown that this technology can be used in PHS base stations. The capacity is increased by 3 times.

British researchers have recently invented a smart antenna that looks like an umbrella and can change shape. It consists of an aluminum foil attached to a flexible metal frame and 16 fixed Nitinol. The shape of the antenna is changed by controlling the energization to achieve an optimum state of receiving a particular radio signal. At the same time, with the development of software radio technology, smart antennas can also be implemented on software radio platforms. The quality of software radio equipment now provides support for smart antenna technology.

With the rapid development of modern technology, the widespread use of powerful portable computers, personal digital assistants and multimedia terminals, wireless LAN has emerged. In order to solve the lack of frequency resources, it is necessary to rely on smart antennas to improve system capacity and communication quality. Smart antenna technology has a great effect on the performance
improvement and cost reduction of cdma mobile communication systems. However, when smart antennas are applied to cdma systems, they also bring corresponding new problems. Such as: smart antenna calibration, beam shaping speed issues, equipment complexity considerations. However, the influencing factors in the implementation of the adaptive process are complex. So far, the smart antenna technology has not been fully realized in product design, and further efforts are needed.

5. Conclusion
With the rapid development of mobile communications and the development of communication services from narrowband voice communications to broadband high-speed data communications, antennas need to be considered in future 3G network construction. You can't just rely on adding base stations, which is not the best choice in terms of cost and performance. Smart antenna technology has received much attention in recent years. The research of smart antennas also involves many fields, such as antenna array, radio wave transmission, digital signal processing and so on. The introduction of smart antenna technology has improved the utilization of wireless spectrum at a higher level, and has become one of the hotspots of current research and application.

Smart antennas can transmit multiple signals, and in most cases assume that the signal is a narrowband signal that can follow the user's movement, both to reduce the radiation and to make the mobile communication terminal use longer. Under the action of the smart antenna, the accuracy of communication can be greatly improved, and the phenomenon of serial frequency and string line is greatly reduced. At the same time, the introduction of smart antennas provides a new solution for wireless positioning. It can also be used for help telephone services, stolen car tracking systems, mobile e-commerce and many other aspects, and has broad application prospects.

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