TD-LTE Antenna Array Smart Cover Study

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Abstract— This paper integrated the antenna array analysis with differential evolution algorithm to optimize weights of antenna ports efficiently based on the customers' expected pattern, which could form the special broadcast beam to cover weak coverage cell. The broadcast beams were optimized by this method coincide with expected pattern through antenna anechoic chamber test. The LTE network experiment shows that the RSRP (Reference Signal Receiving Power) of communication network are improved 5% averagely after optimized by this method.

1. INTRODUCTION

The Long Term Evolution (LTE) system has been specified by the Third Generation Partnership Project (3GPP) on the way towards fourth-generation (4G) mobile to ensure 3GPP keeping the dominance of the cellular communication technologies. Through the design and optimization of new radio access techniques and a further evolution of the LTE systems, the 3GPP is developing the future LTE-Advanced (LTE-A) wireless networks as the 4G standard of the 3GPP. With the increase of mobile users, communication network environment is more complex, especially in some special scenes broadcast coverage requires some special beams.

Smart antenna could realized the beamforming by each antenna array element excitation (also known as weights, including amplitude and phase), to make the antenna beam. The TD-SCDMA and TD-LTE systems include broadcast model and business model. The broadcast beam is 65 degree in general. For the special broadcast coverage, the current method is provided the table for some special beam weights, such as 90 degrees, 120 degrees and saddle shape beam.

At present the main achievement is the business beamforming, however the broadcast beamforming study is lack, and the existing broadcasting beamforming simulation software is mainly according to the manufacturers to provide the weights data to generate waveform simulation. These methods are lack of flexibility and accuracy. In addition, the system of TD-LTE, in the TM7 mode, using a single beamforming can also encounter this similar situation [1–3].

Based on the expected pattern, integrated the antenna array analysis with modern optimization algorithm, the weights of antenna ports can be optimized in the paper [4]. TDD antenna broadcast beam weights adaptive design is realized by this method and the optimized broadcast patterns coincide with expected pattern. Smart antenna broadcast shaped beam weights adaptive design technology is applied to improve the wireless network coverage. The antenna array weights can be deduced through the broadcasting beam. The simulated beam patterns match with cell's actual coverage. This technique can greatly reduce the workload of network optimization, and improve the coverage of the wireless network rate, success rate and handover success rate.

2. CONFIGURATION AND DESIGN

Figure 1 shows the antenna array, which is composed of uniform linear N unit antenna component, called the uniform linear array.

The pattern of uniform linear antenna array is [5]

$$f(u) = \sum W_n \exp\left[jkd\left(n-1\right)\sin\theta\right] f_n'\left(\theta\right) \tag{1}$$

where $f_n'\left(\theta\right)$ is the nth element pattern, and W_n is the nth element excitation. From the formula, the antenna pattern can be control through the weight W_n. The special patterns can achieve through the weights optimization.

2.1. Processing Analysis

Not only the beam width would change (usually become wider), but also maybe presents. When the beam of antenna array scans. The pattern mainly relates to mechanical parameters and frequency, shown in Figure 2.

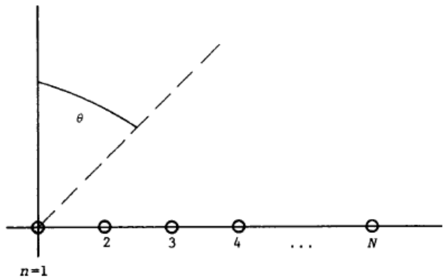

Figure 1: Uniform linear antenna array.

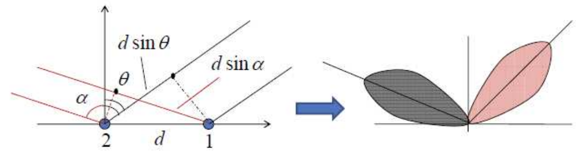

Figure 2: Grating lobe of antenna array.

Relationship of angle of antenna array with scanned angle is shown below [6]

$$\frac{d}{\lambda} = \frac{n}{\sin\theta_0 - \sin\theta_{GL}} \tag{2}$$

When the space of array element is less than or equal to $\lambda/2$, the beam would scan at $[-90°, 90°]$. During the scanning, array antenna pattern would not have grating lobes. The beam will have grating lobe pointing at 0 degree, given space d equal to λ.

Notably, the grating lobe cannot be cancelled by optimizing the array weight, therefore,

$$\theta_G = \arcsin\left(\frac{\lambda}{d} - 1\right) \tag{3}$$

According to the formula 3, we can get the 3 dB beam during scanning. So

$$\theta_{3\,\mathrm{dB}} = \arcsin\left(\sin\theta_0 + 0.4429\frac{\lambda}{Nd}\right) - \arcsin\left(\sin\theta_0 - 0.4429\frac{\lambda}{Nd}\right) \tag{4}$$

As a special case, the outer edge of the 3 dB beam reach $\pm 90°$ degrees. For the directional antenna, such beams may no practical value in engineering application. Therefore in the process we give a angle (θ_{90}). θ_{90} satisfies with

$$\theta_{90} = \arcsin\left(1 - 0.4429\frac{\lambda}{Nd}\right) \tag{5}$$

2.2. Optimized Algorithm for Smart Coverage

The optimization design of antenna array beamforming is looking for the best feed weight to obtain the desired pattern. From the mathematical view, it is a multi-variable, multiple targets, multi modal optimization problems.

The modern global optimization design methods for antenna array pattern include genetic algorithm (GA), the particle swarm is (PSO), differential evolution algorithm (Differential, Evolution, DE). Differential evolution algorithm has the advantages of simple operation, strong robustness, so the project using differential evolution algorithm as the main optimization method. Standard differential evolution algorithm flow diagram is shown in Figure 4, including the population initialization, mutation, crossover process, the selection process, the treatment of boundary conditions and termination conditions.

2.2.1. The Population Initialization

Differential evolution algorithm use real vector with a dimension D as each generation of the population, each individual is expressed as

$$\mathbf{X}_j = (x_{j1}, x_{j2}, \ldots, x_{jD}), \quad 1 \le j \le N_P \tag{6}$$

where j is a sequence number for the individual in the population. N_p is the population size. The population size remains constant in the course of evolution. Before the optimized searching, population must be initialized. Usually the initialization of population was given in random within a boundary constraint. Give parameter variable boundaries $x_i^L \le x_i \le x_i^U$, there is

$$x_{ji} = \mathrm{rand}[0,1] \times \left(x_i^U - x_i^L\right) + x_i^L \qquad i = 1, 2, \ldots, D \quad j = 1, 2, \ldots, N_P \tag{7}$$

where $\mathrm{rand}[0,1]$ is random number from 0 to 1.

2.2.2. Mutation Operation

Mutation refers to the parent between two random individual. Difference vector and the addition of a random vector superposition produce a variation vector, expression is as follows

$$v_j^{G+1} = x_{r_3}^G + F \times \left(x_{r_1}^G - x_{r_2}^G\right) \tag{8}$$

2.2.3. The Crossover Operation

In order to increase the diversity of individuals, the crossover operation implement between the target vector individual x_j^G and variable vector v_j^{G+1}. The test individual u_j^{G+1} is generated. The specific expression is shown below:

$$u_j^{G+1} = \begin{cases} v_j^{G+1} & \text{rand}[0,1] \leq CR \quad \text{or} \quad i = \text{rand}n[i] \\ x_j^G & \text{rand}[0,1] > CR \quad \text{and} \quad i \neq \text{rand}[i] \end{cases} \tag{9}$$

where $\text{rand}[i] \in (1, 2, \ldots, D)$, the i expresses the ith variable. CR is crossover probability constant. Its value range is $[0, 1]$. Control of CR size could achieve a balance between global search and convergence speed.

2.2.4. Selection Operation

Differential evolution algorithm with "greedy" search strategy, the mutation and crossover operation is generated after the test individual and the current population of the target vector to compete. It will fit better vector selected for generation. To minimize the optimization selection operation, the equation is:

$$x_j^{G+1} = \begin{cases} u_j^{G+1} & f\left(u_j^{G+1}\right) < f\left(x_j^G\right) \\ x_j^G & f\left(u_j^{G+1}\right) \geq f\left(x_j^G\right) \end{cases} \tag{10}$$

2.2.5. Objective Function

Considering with the simple operation, good versatility and higher computational efficiency, the objective function is constructed below

$$E = \min\left\{\alpha \frac{1}{N} \sum_1^N \left[f(i) - f_E(i)\right]^2 + \beta \left\{f(\theta_0) - \max\left[f(j)\right]\right\}^4 + \gamma E' + \tau E''\right\}$$

where

$$E' = \frac{1}{M} \sum_{j=1}^{M} \begin{cases} [f(j) - 0.056]^2 & f(j) > 0.056 \\ 0 & f(j) < 0.056 \end{cases}$$

In formula (11), the first part is used to emphasize the main lobe area; the second part is used to constrain the maximum direction of the pattern. The third part is used to calculate the rear area of the pattern. The fourth part is used to constrain weight efficiency. α, β and γ are weighting factor for each part.

3. ANALYSIS AND TEST

The smart broadcast beamforming module structure is shown in Figure 5, including the input file, antenna element pattern, antenna optimization target pattern, optimized weight, actual optimized pattern and input file library.

The following example illustrates the process of simulation. Firstly, the element pattern and array pattern are shown in Figure 3. Input file is mainly pattern and target pattern, including the element number, frequency, amplitude, phase array spacing, and half power beam width.

Optimizing time is about a minute, and the optimized result is shown in Figure 4.

Figure 5 shows the target pattern and optimized pattern. The target pattern was constrained by 9 points. The optimized pattern coincides with the target pattern from the Figure 5.

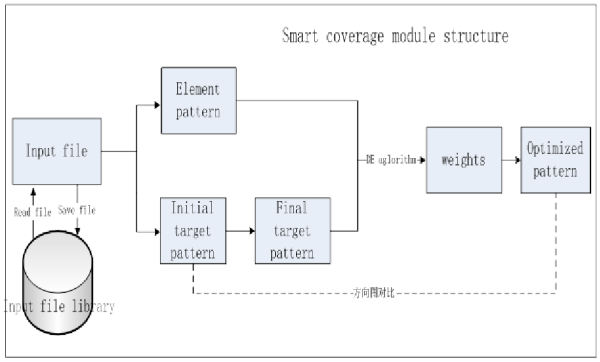

Figure 3: Optimized design of beamforming module structure.

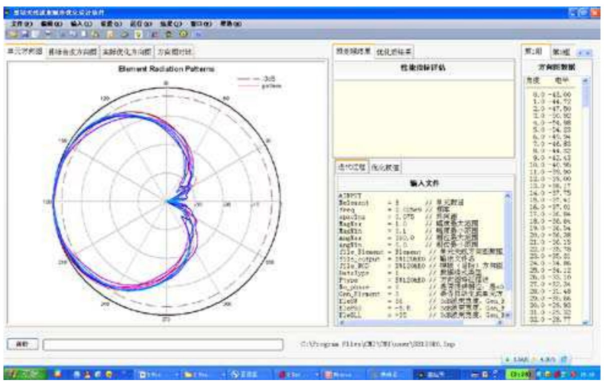

Figure 4: Simulation of interface of smart cover software.

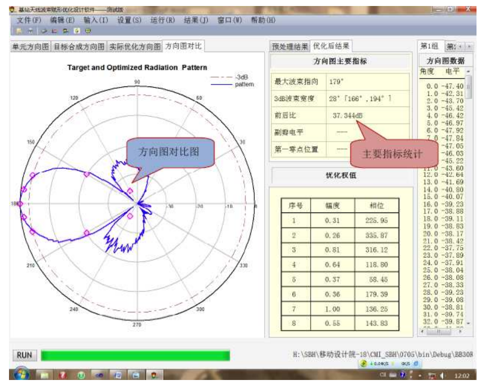

Figure 5: Optimized pattern with the target pattern.

4. CONCLUSIONS

This paper presented the smart coverage optimized algorithm for broadcast beam of smart antenna, based on the beamforming and global optimization algorithm. This method can implement adaptive broadcast beamforming weights adaptive signal processing of the TD-SCDMA or TD-LTE antenna. The application of this technology will greatly improve the network planning and optimization efficiency, and improve the quality of the coverage network.

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