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A General Configuration Antenna Array for Multi-User Systems with Genetic and Ant Colony Optimization

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Antenna arrays are used in the CDMA-based cellular systems in order to increase the systems capacity. Different approaches benefit from the spatial separation between users. Smart and adaptive beam antennas are the best proposed solution for these systems. Several methods are used to provide the system with a radiation pattern that increases the signal-to-interference ratio (C/I). Antenna configuration is the way the array elements are distributed in space. This distribution can influence the design of the beam formation or the adaptation method, such that, the calculation of the different parameters requires a known array configuration. Antenna configuration is discussed in several research papers including planar arrays and circular arrays. Here, we introduce a general antenna array structure and derived its optimal parameters, and then we optimize the solution under different quantization errors using a genetic algorithm (GA) and an ant colony optimization (ACO). Results showed that we can configure the antenna array to provide an acceptable C/I. Also, results showed that we can obtain a good solution that is less sensitive to quantization errors using the ACO.

Keywords antenna array, genetic algorithms (GA), ant colony optimization (ACO)

1. Introduction

Implementing antenna arrays at both base station and mobile unit will form a multiple input multiple output (MIMO) system that enhances the overall systems capacity and performance in fading channels. At base station side, the array will provide multiple beam radiation pattern each in the direction of a user. This will reduce the interference between users, and hence provide the capability of spectrum reuse within the same cell. Employing an antenna array at the mobile unit minimizes its consumed power and this will reduce its size as well as enhance its performance. Influenced by style and size, modern mobile units require special care in antenna design. This require different antenna configuration at the mobile unit to provide more flexibility in placing the elements of the array on the body of the mobile unit.

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Many approaches are used to design a good antenna array and optimize its parameters. Several techniques are implemented by optimizing the array size and complexity. The main goal in using antenna arrays in cellular systems is to implement a spatial filter that can separate users to effectively reduce other users' interference, and hence, increase the system's capacity. One optimization parameter is the geometry of the antenna array. Other parameters, including tab weights and delays, are used to steer the beam, and/or create nulls in the interference directions. Optimization techniques are widely discussed in the literature, addressing that the minimum number of weights and the number of antenna elements required. Depending on the objectives of the optimization, the solution will vary. For example, if the target is to reduce the number of antenna elements, then the optimal solution will find the minimum number of antenna elements under the maximum number of main lobs for the radiation pattern of the antenna array (Foschini & Gans, 1998; Christodoulous & Herscovicl, 2000; Mouhamadou et al., 2006; Telatar, 1995).

Different array configurations were introduced and optimized to produce desired radiation characteristics. Linear and planar arrays are discussed often in the literature (Michalewicz, 1999; Shimizu, 1994; Bucci et al., 1991). The more complicated 3-D conformal antennas on curved surfaces have been considered more recently. The analysis of 3-D conformal array requires extremely large computations. The ability to analyze and optimize arbitrary array configuration is of great practical importance. One possible approach for analyzing and optimizing the arbitrary array configuration is by using genetic algorithms (Allard et al., 2003; Chen et al., 2006; Haupt, 1994; Ayestran et al., 2006; Mitilineos et al., 2006; Johnson & Rahmal-Samii, 1997).

Ant colony optimization (ACO) is another approach that is gaining momentum in antenna array optimization and analysis. ACO is a global search procedure, inspired by the natural behavior of ants in their food searching (Ho et al., 2005; Coleman et al., 2004). The search for good array parameters depends on finding the weights and delay tabs that steer the radiation pattern main lobe. If the number of array elements is large the search for optimal solution becomes huge, here, the ACO provides a good solution with only few searching paths (Colorni et al., 1991; Quevedo-Teruel & Rajo-Iglesias, 2006).

2. System Description

In this paper, we present a general beam steering design approach, such that a multi-beam antenna is constructed for arbitrary array configuration. In more details, we assume that the antenna array is located at the origin with each element as an isotropic antenna located in space at point (x_n, y_n, z_n). Then, if a signal arrives from the direction defined by (θ, β) as shown in Figure 1, it will be detected at element n with a delay depending on the relative location of that element. We can write the output of element n!as:

$$v_n(t) = u(t)e^{j\Delta_n} \tag{1}$$

where $u(t)$ is the transmitted signal from the source and Δ_n is the delay due to the nth element relative location.

Without loss of generality, we can take our reference element to be element number (1) located at the origin of our coordinate system, and hence its relative delay $\Delta_1 = 0$. The output of each antenna element will be fed into a delay line to compensate for its lag or lead with reference to the first element and hence a coherent output is generated. Then a weight factor of w for each element is applied to compensate for the different

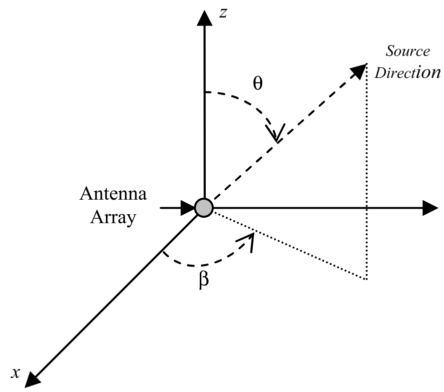

Figure 1. Coordinate system used to define the radiation pattern of the antenna array.

attenuation paths of the signal. This is shown in Figure 2. The output of each delay and weight element can be written as:

$$y(t) = u(t)we^{j\Delta}e^{j\frac{2\pi\tau}{T}} \tag{2}$$

where T is the carrier period, w is the path weight, and τ is the introduced delay at the receiver to steer the beam.

If a total of N elements are used then the output of each steering circuit is added to form the lth received signal from the lth target source $\Phi_l(t)$ as:

$$\Phi_l(t) = \sum_{n=1}^{N} y_n^l(t) = \sum_{n=1}^{N} u^l(t)w_n^l e^{j\Delta_n}e^{j\frac{2\pi\tau_n}{T}} \tag{3}$$

Here, Δ_n is the nth element path delay and τ_n is the nth element delay. The complete one-source antenna array is shown in Figure 3. To compensate for the delays due to the direction of arrival (the source location) we set:

$$\frac{2\pi\tau_n}{T} = -\Delta_n \quad \text{or} \quad \tau_n = -\frac{T\Delta_n}{2\pi} \tag{4}$$

To find Δ_n we find the difference in path at element n with respect to the element at the origin (Δd_n). From geometry this difference can be written as:

$$\begin{aligned}\Delta d_n &= [x_n\overrightarrow{ax} + y_n\overrightarrow{ay} + z_n\overrightarrow{az}] \\ &\quad \cdot [\sin(\theta)\cos(\beta)\overrightarrow{ax} + \sin(\theta)\sin(\beta)\overrightarrow{ay} + \cos(\theta)\overrightarrow{az}]\end{aligned} \tag{5}$$

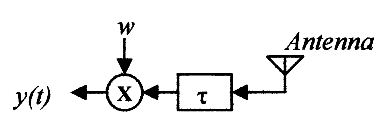

Figure 2. Steering circuit for each element.

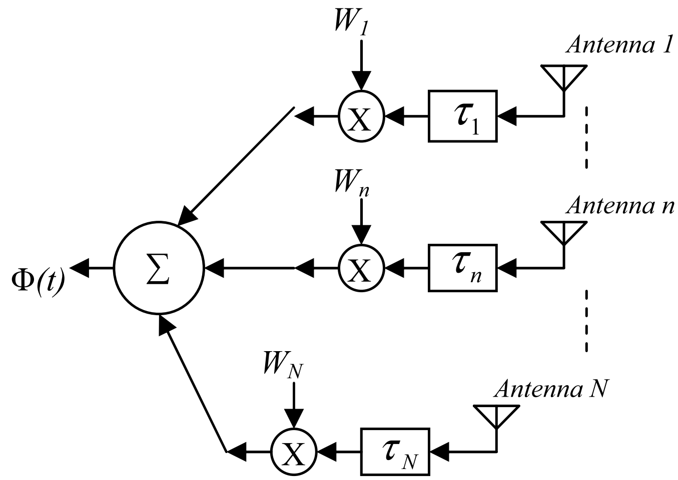

Figure 3. Antenna array for one source (one direction of arrival).

as mentioned before (x_n, y_n, z_n) is the location of the element n in space. Then we can write:

$$\Delta_n = \frac{2\pi \Delta d_n}{\lambda} \quad \text{or} \quad \tau_n = -\frac{T \Delta d_n}{\lambda} \tag{6}$$

where λ is the wave length. As a result, the output of the system represents a spatial filter with its band pass in the direction of the source (θ, β). To receive more than one source we may implement different sets of delays and weights for each source as shown in Figure 4.

If (θ_l, β_l) denotes the lth source direction, the output of the array for each source is given by:

$$\Phi_l(t) = \sum_{n=1}^{N} u_l(t) w_n^l e^{j\Delta_n^l} e^{j\frac{2\pi\tau_n^l}{T}} \tag{7}$$

and the signal from source k appears at the lth source output:

$$\Phi_l^k(t) = \sum_{n=1}^{N} u_k(t) w_n^l e^{j\Delta_n^k} e^{j\frac{2\pi\tau_n^l}{T}} \tag{8}$$

The term in Eq. (8) represents the interference on source l due to source k as appeared on the output of the antenna array. We can rewrite Eq. (7) using the same notation in Eq. (8) as: $\Phi_l(t) = \Phi_l^l(t)$. The total interference on source l can be written as:

$$I_l(t) = \sum_{\substack{k=1 \\ k \neq l}}^{L} \Phi_l^k(t) \tag{9}$$

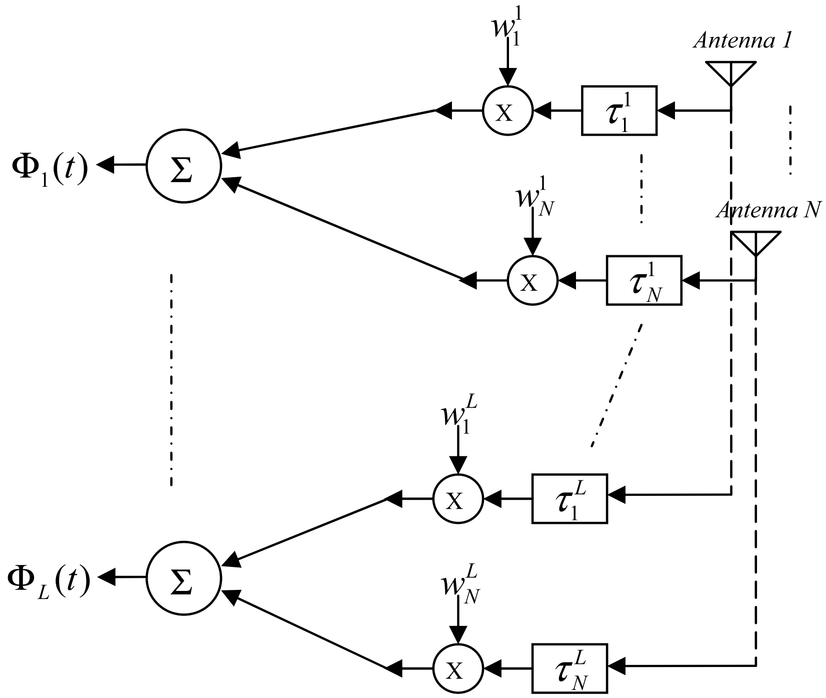

Figure 4. Antenna array for multiple beam (multiple source).

Then the signal to interference at the output of the lth source array (C/I_l) is given by:

$$C/I_l = \frac{\overline{|\Phi_l^l(t)|^2}}{\left|\sum_{\substack{k=1\\k\neq l}}^{L} \Phi_l^k(t)\right|^2} \tag{10}$$

Equation (10) can be written in matrix form as:

$$\frac{C}{I_l} = \frac{[\Delta_l^t \tau_l]^* [\Delta_l^t \tau_l]}{\left(\sum_{k\neq l} [\Delta_k^t \tau_l]\right)^* \left(\sum_{k\neq l} [\Delta_k^t \tau_l]\right)} \tag{11}$$

where:

$$\Delta_l = \begin{bmatrix} e^{j\Delta_1^l} \\ e^{j\Delta_2^l} \\ e^{j\Delta_3^l} \\ \cdots \\ e^{j\Delta_N^l} \end{bmatrix} \qquad \tau_l = \begin{bmatrix} w_1^l e^{j\frac{2\pi\tau_1^l}{T}} \\ w_2^l e^{j\frac{2\pi\tau_2^l}{T}} \\ w_3^l e^{j\frac{2\pi\tau_3^l}{T}} \\ \cdots \\ w_N^l e^{j\frac{2\pi\tau_N^l}{T}} \end{bmatrix} \tag{12}$$

Equation (11) assumes the antenna elements are all omni-directional point sources, then for an array of elements with different radiation pattern the C/I at the output of the lth source array $(\mathrm{C}/\mathrm{I}_l)$ becomes:

$$\frac{C}{I_l} = \frac{[\Delta_l^t \hat{\tau}_l]^*[\Delta_l^t \hat{\tau}_l]}{\left(\sum_{k\neq l}[\Delta_k^t \hat{\tau}_l]\right)^* \left(\sum_{k\neq l}[\Delta_k^t \hat{\tau}_l]\right)} \tag{13}$$

where the effect of the radiation pattern is merged with the complex weight factors $\hat{\tau}$ as:

$$\hat{\tau}_l = \begin{bmatrix} R_1(\theta_l, \beta_l) w_1^l e^{j\frac{2\pi\tau_1^l}{T}} \\ R_2(\theta_l, \beta_l) w_2^l e^{j\frac{2\pi\tau_2^l}{T}} \\ R_3(\theta_l, \beta_l) w_3^l e^{j\frac{2\pi\tau_3^l}{T}} \\ \cdots \\ R_N(\theta_l, \beta_l) w_N^l e^{j\frac{2\pi\tau_N^l}{T}} \end{bmatrix} \tag{14}$$

where $R_k(\theta_l, \beta_l)$ is the value of the kth element radiation pattern in the lth source direction. Equation (14) shows the effects of different users on each other, such as larger C/I for the mth user (source) means greater interference for the nth user (source). In the following, we consider two important applications for antenna arrays, the first is an array for mobile unit constructed on the case of the unit and the second is a planar array that can be used in the base station of a cellular system.

Mobile Unit Example

Consider a mobile unit with its antenna array is distributed on its outside case as shown in Figure 5 (right). At 1,800 MHz, the elements are located at $(0, 0)$, $(0, 2)$, $(0, 4)$, $(1, 6)$, $(3, 6)$, $(4, 0)$, $(4, 2)$, and $(4, 4)$, expressed in cm. This mobile unit is required to provide two-beam radiation for a different base station that can be adapted according to the units orientation. If the required directions are: one in the direction of $(\theta_1, \beta_1) = (80°, 35°)$

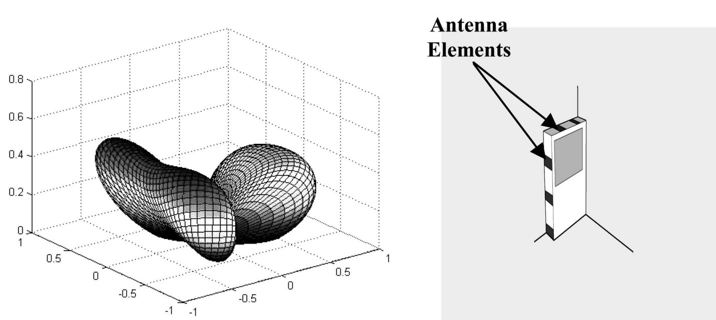

Figure 5. Radiation pattern for 8 elements array at a mobile unit (right).

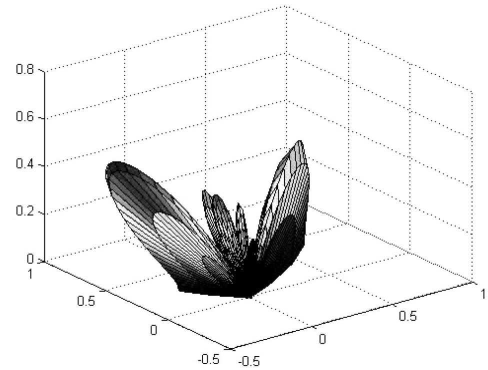

Figure 6. Radiation pattern for 10×10 planar array at base station.

and the other at $(\theta_2, \beta_2) = (80°, 110°)$. The radiation pattern can be obtained as:

$$R(\theta, \beta) + \sum_{l=1}^{L} \sum_{n=1}^{N} w_n^l e^{j\Delta_n^k(\theta_l, \beta_l)} e^{j\frac{2\pi\tau_n^l(\theta,\beta)}{T}} \tag{15}$$

where Δ_n and τ_n are given by Eqs. (5) and (6). The radiation pattern is shown in Figure 5 (left).

Base Station Example

At base station it is required to provide larger number of beams, each for different user. For a 10×10 planar array (uniformly distributed in a matrix with spacing of $\lambda/2$ at 1,800 MHz) vertically mounted at base station side. We assume 10 users at different locations (as an example we select the following angles (in degrees): $\theta_l =$ [65 35 55 45 88 22 18 120 100 10] and $\beta_l =$ [35 60 120 100 70 45 145 128 35 35], where l goes from 1 to 10, then the radiation pattern is found from Eq. (16) as in Figure 6.

Here, we can repeat the same carrier 10 times in the same cell if the location separation between users exceeds the C/I threshold (that set to be reflected as 10 dB in C/I for this example). This minimum separation depends on the number of users such that it increases as the number of users increase. Solving Eq. (13) for this configuration will produce minimum C/I ratio of 6.43 dB; therefore, we need to find an optimal solution that satisfies the C/I criterion. Next we discuss different optimization techniques for multi-user systems.

3. System Optimization

The main application for this system is to make use of the possible spatial separation between users in a cellular system and share them with the same radio resources. This will increase the system's capacity. The main limiting factor for the systems capacity is the C/I ratio, therefore, maximizing the minimum C/I is the optimization goal (i.e., the optimization here is done by finding the optimal weights and delays for the antenna array that maximize the minimum C/I). Considering Eq. (13), we can see that by minimizing the denominator and maximizing the nominator, we will maximize the C/I for each user.

Table 1a
CIR (in dB) results in the optimal case using 10-bit quantization for a 10×10 antenna array for 10 users

	User									
No.	1	2	3	4	5	6	7	8	9	10
1	26.9	26.1	26.5	25.87	22.75	24.9	29.44	24.54	29.13	25.02

Table 1b
The corresponding main lob directions

	User									
	1	2	3	4	5	6	7	8	9	10
θ_l	65	35	55	45	88	22	18	120	100	10
β_l	35	60	120	100	70	45	145	128	35	35

In mathematical form, we can write this condition as:

$$\begin{aligned} \Delta^t \hat{\tau} &= I_{L\times L} \\ \Delta &= [\Delta_1 \quad \Delta_2 \quad \cdots \quad \Delta_L]_{N\times L} \\ \hat{\tau} &= [\hat{\tau}_1 \quad \hat{\tau}_2 \quad \cdots \quad \hat{\tau}_1]_{N\times L} \end{aligned} \tag{16}$$

where I is the identity matrix, then Eq. (16) is solved using the pseudo-inverse (Kreyszig, 1999) where:

$$\tau = [\Delta^t \Delta]^{-1} \Delta \tag{17}$$

This solution will force nulls in the direction of interferers and maximize the directivity in the user direction for each steering group of weights and delays. This solution forces the denominator in Eq. (13) to become zero. This will cancel the co-channel interference, leaving only the external noise and interference. This solution is usually produces precise values for the weights and delays. If the delays are quantized by 10 bits, the C/I is obtained from Eq. (13) as in Table 1.

Another optimization technique can be used to find a near optimal solution that is less sensitive to quantization errors. We implement a genetic algorithm such that it finds the delays and weights values that meet the C/I criteria. The constraint here is to have similar C/I ratio for every user in the cell and to have its value above the minimum possible working C/I in the system. This genetic algorithm does not need to specify the solution range; rather we specify the increment in every iteration. Here we describe the genetic algorithm (Bucci et al., 1991; Johnson & Rahmal-Samii, 1997):

1. Initialize the solution space using the calculated values from Eq. (4) for each arrival direction (user).
2. Generate the solution space for the weights and the delays from Eq. (13).

3. Select the first 10 good solutions (called parents) that satisfy the optimization criteria (fitness function).
4. Mutation (apply random changes to individual parents to form children) and Crossover (combine two parents to form children).
5. Keep the best solutions to the next generation, this will keep non-decreasing fitness function (elitism).
6. Repeat step 3 until the criteria are satisfied.

The constraint function is written as:

$$\min(\mathrm{C}/\mathrm{I}_l) \geq \gamma_{th} \forall l \tag{18}$$

where γ_{th} is the minimum acceptable C/I. Using the same planar antenna array as described previously, we found that using this algorithm will produce the optimized results listed in Table 2 (here we selected the best eight solutions obtained by running the algorithm, then the optimal one is selected to be the one with maximum minimum C/I). Figure 7 shows the fitness function as the optimization iteration goes for the second user that has the minimum C/I ratio. Figure 8 shows the optimized radiation pattern using GA for the same 10×10 planar antenna array used in the base station example, where we obtained a minimum C/I ratio at the second user location of 14.0 dB (the seventh row in Table 2). In this example we set 2% mutation and 50% cross over rates. To insure good

Table 2a
CIR (in dB) results using GA optimization for a 10×10 array and 10 users

	User									
No.	1	2	3	4	5	6	7	8	9	10
1	15.6	14.1	22.4	23.9	17.9	16.2	23.1	20.6	12.4	32.6
2	14.6	14.7	22.6	24.2	18.3	18.0	20.9	28.8	12.0	31.6
3	15.0	13.7	15.8	22.6	20.1	18.4	19.8	17.4	12.8	24.1
4	16.4	18.0	17.6	26.8	21.2	17.0	23.3	19.4	12.0	26.3
5	15.3	14.1	13.3	26.9	19.1	16.6	25.1	20.0	12.0	27.3
6	15.6	17.0	16.2	27.2	18.8	17.6	24.0	21.6	12.6	28.1
7[a]	16.5	14.0	14.3	25.6	17.3	16.9	20.9	17.3	14.2	30.2
8	13.6	14.6	20.2	24.4	17.8	16.5	21.8	22.0	12.2	27.8

[a]The selected solution.

Table 2b
The corresponding main lob locations for the optimal solution

	User									
	1	2	3	4	5	6	7	8	9	10
θ_l	65	35.9	56	45.1	88.3	23.6	18.2	120.4	100.1	10.2
β_l	36.7	61.1	120.7	101.6	70.9	45.7	146.2	128.3	35.1	35.9

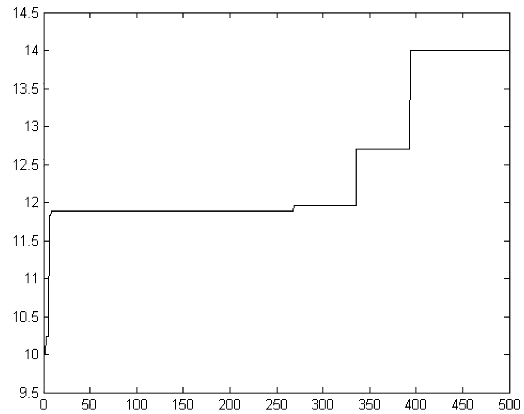

Figure 7. The GA fitness function for the second user (min C/I).

solutions, we used elitism procedure, where we kept the best solutions that produce the highest C/I ratios.

Another optimization technique called ant colony optimization (ACO) can be used to find the optimal weights and delays of the general antenna array. This algorithm is used for binary cost functions; here we apply ACO technique by converting the weights and delays into their equivalent m bit binary representation. Then the optimization algorithm will be as follows:

1. Initialize the ants (initial solution for the weights and the delays) and the pheromones (a value that describes the age of that ant). Here the initial weights and delays from Eq. (12) will be written as N-tuple binary vector:

$$w_i^l = [1\,1\,1\,1\,1\,1 \ldots 1\,1\,1\,1\,1\,1], \qquad i = 1, 2, \ldots, N$$
$$\tau_i^l = [1\,1\,1\,1\,1\,1 \ldots 1\,1\,1\,1\,1\,1], \qquad i = 1, 2, \ldots, N \tag{19}$$

where N is the number of antenna elements.

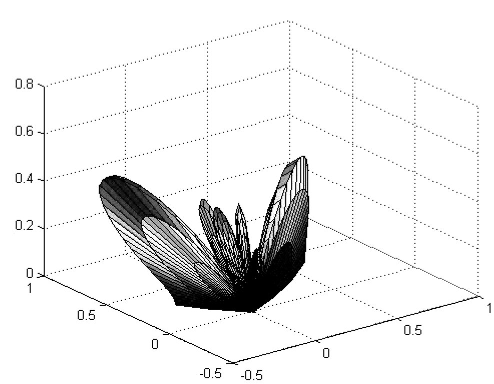

Figure 8. Optimized antenna array radiation pattern for ten sources using GA.

2. Calculate the fitness function and the pheromones for each ant. The lth user pheromones at iteration k are given by:

$$r_i^l(k) = e^{(\mathrm{C/I}_l - \gamma_{th})/10k} \qquad i = 1, 2, \ldots, N \tag{20}$$

and the lth user fitness functions at iteration k are given by:

$$f_i^l(k) = \frac{r_i^l(k)}{\sum_{j=1}^{N_G} r_j^l(k)} \qquad i = 1, 2, \ldots, N \tag{21}$$

where N_G is the number of the global ants (here it equals N).
3. Activate the local search procedure (this sends some local ants to the region of global ants). Then create new global ants. The local search procedure will flip the ones and zeroes in Eq. (19) randomly.
4. Select the highest fitness functions for each global region.
5. Repeat from (2) until all C/I exceeded the minimum threshold for all ants and select the ants with the highest fitness function.

Using this algorithm for the 10×10 planar array, will produce the optimized results listed in Table 3 (also here, we selected the best 8 solutions obtained by running the algorithm, then the optimal one is selected to be the one with maximum minimum C/I). Figure 9 shows the C/I as iteration goes for the user with minimum final C/I. Figure 10 shows the optimized radiation pattern using ACO for the same 10×10 planar antenna array, where we obtained a minimum C/I ratio at the first user location of 15.4 dB (the third row in Table 3).

When comparing the GA with ACO we can see that a better solution was found using the ACO. The mathematical solution is optimal where all users get similar C/I ratios and almost all interference has vanished. Here, the solution suffers instability due to quantization errors since the pseudo-inverse of the matrix is usually has a small conditioning number.

To investigate the sensitivity of each solution for quantization in the weights and delays, we truncate the resulting values to different levels and calculate the C/I for

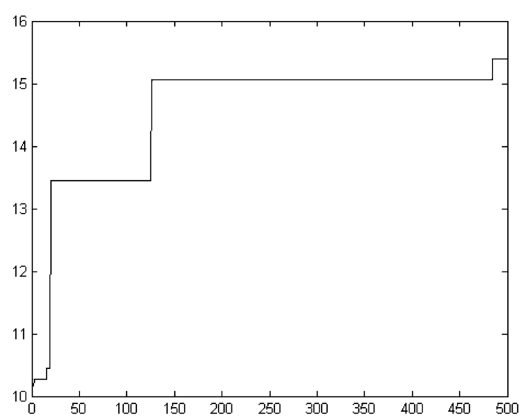

Figure 9. The ACO C/I for the first user.

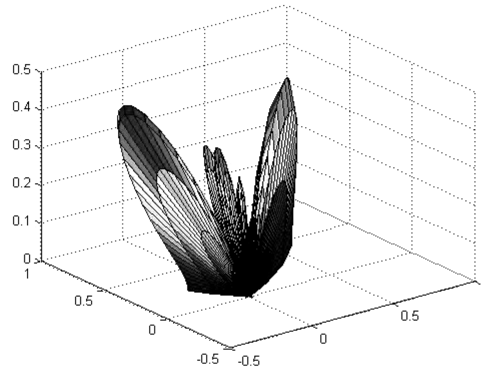

Figure 10. Optimized antenna array radiation pattern for ten sources using ACO.

each user for the same example of 10×10 planar array used before. Table 4 shows the quantization effect on the devised optimization algorithms, where we find that the mathematical solution is the most sensitive solution for quantization errors. ACO showed the best stability results such that, at seven bits, we still get a valid solution that satisfies the minimum C/I criterion.

Table 3a
CIR (in dB) results using ACO for a 10×10 array and 10 users

	User									
No.	1	2	3	4	5	6	7	8	9	10
1	12.4	19.8	16.2	24.6	18.3	19.7	27.7	14.3	17.3	28.1
2	12.5	18.0	15.5	21.5	17.8	19.9	33.0	13.7	14.5	27.2
3[a]	15.4	21.2	18.4	28.8	19.0	20.3	21.0	15.5	16.6	28.9
4	13.3	22.9	18.4	24.1	19.0	19.9	24.9	16.0	18.3	30.4
5	13.4	18.8	16.0	21.8	18.6	20.7	24.3	13.8	14.5	29.3
6	12.9	18.6	16.6	22.0	19.9	20.4	21.9	13.6	12.3	28.6
7	12.9	18.2	16.5	21.0	18.3	20.0	31.8	13.8	19.2	27.5
8	12.4	21.1	18.2	27.8	18.8	19.8	22.4	15.9	21.9	28.7

[a]The selected solution.

Table 3b
The corresponding main lob locations for the optimal solution

	User									
	1	2	3	4	5	6	7	8	9	10
θ_l	65.16	35.1	55.1	45.2	88.2	22.2	18.57	120.0	103.2	10.33
β_l	39.5	60.4	120.5	100.2	70.4	45.4	145.2	128.4	38.4	35.1

Table 4
CIR (in dB) for the optimal, GA, and ant algorithms at different quantization levels

	User									
No.	1	2	3	4	5	6	7	8	9	10
Using 10-bit quantization										
Opt	26.9	26.0	26.5	25.8	22.7	24.9	29.4	24.5	29.1	25.0
GA	16.6	14.0	14.4	25.3	17.3	17.0	20.8	17.0	14.0	30.4
Ant	15.7	21.2	18.4	28.6	19.1	20.4	21.0	15.4	16.5	28.9
Using 9-bit quantization										
Opt	20.7	19.0	22.3	19.0	13.9	17.5	21.4	17.0	20.8	20.1
GA	16.8	14.0	14.3	25.1	17.4	17.1	20.7	17.0	13.8	30.6
Ant	16.3	21.3	18.2	28.9	19.1	20.5	21.1	15.2	17.1	28.5
Using 8-bit quantization										
Opt	8.6	12.1	12.4	16.3	5.2	7.5	13.7	10.7	12.6	13.8
GA	16.6	14.0	14.3	24.3	17.8	17.3	20.5	16.1	13.6	31.5
Ant	17.3	21.3	17.8	28.7	19.1	20.8	21.4	15.0	18.1	28.4
Using 7-bit quantization										
Opt	1.3	4.6	1.0	2.5	–4.5	3.0	0.7	2.3	4.0	0.7
GA	18.1	13.5	13.9	21.4	18.3	17.5	20.4	15.4	13.0	30.2
Ant	16.3	21.8	17.6	30.7	19.0	21.3	21.9	15.0	17.7	28.0

4. Conclusion

Optimized solutions for the generalized antenna array are presented in this paper. It has been found that, for many antenna configurations, we can find a good multiple-beam radiation pattern that support multi-user system with an acceptable C/I ratio. The generalized configuration can be used on the mobile unit, where the shape of the unit is influenced by the style and shape of the mobile device. Health hazards are reduced when the mobile unit steers its main beam away from the user and connects to a base station in the other direction.

It has been found that the C/I criteria can be satisfied by creating simultaneous main lobs in the direction of users and create nulls in the radiation pattern in the other users directions. Adapting this solution, as the environment is mobile in nature, will keep good C/I values for all users in cellular system and increase its capacity by reusing the same frequency spectrum for each beam. This result is obtained in the literature using several methods; here, we utilize GA and ACO to find a near optimal solution and as well a stable solution that is less sensitive to errors in the delay values.

Implementation of the results obtained here is easy by utilizing the ACO technique to obtain the weights and delays for the antenna array every time the users in the system change their locations. The ACO technique requires the minimum quantization values for the delays and, hence, fewer control steps in the delay elements. The optimization technique can be also applied on the elements locations (array configuration) and since the user's motion is slow, a mechanical system might be employed to adaptively configure the array to meet the C/I requirement.

References

Allard, R. J., D. H. Werner, & P. L. Werner. 2003. Radiation pattern synthesis for arrays of conformal antennas mounted on arbitrarily-shaped three-dimensional platforms using genetic algorithms. *IEEE Trans. Antennas Propagat.* 51:1054–1062.

Ayestran, R. G., J. Laviada, & F. Las-Heras. 2006. Synthesis of passive-dipole arrays with a genetic-neural hybrid method. *JEMWA* 20:2123–2135.

Bucci, O. M., G. Mazzarella, & G. Panariello. 1991. Reconfigurable arrays by phase-only control. *IEEE Trans. Antennas Propagat.* 39:919–925.

Chen, T. B., Y. L. Dong, Y. C. Jiao, & F. S. Zhang. 2006. Synthesis of circular antenna array using crossed particle swarm optimization algorithm. *JEMWA* 20:1785–1795.

Christodoulous, C., & N. Herscovicl. 2000. Smart antennas in wireless communications: Base-station diversity and handset beamforming. *IEEE Antennas Propagat.* 42:142–151.

Coleman, C. M., E. J. Rothwell, & J. E. Ross. 2004. Investigation of simulated annealing, ant-colony optimization, and genetic algorithms for self-structuring antennas. *IEEE Trans. Antennas Propagat.* 52:1007–1014.

Colorni, A., M. Dorigo, & V. Maniezzo. 1991. Distributed optimization by ant colonies. *Proc. Eur. Conf. Artificial Life*, pp. 134–142.

Foschini, G. J., & M. J. Gans. 1998. On limits of wireless communications in a fading environment when using multiple antennas. *Wireless Personal Commun.* 6:311–355.

Haupt, R. L. 1994. Thinned arrays using genetic algorithms. *IEEE Trans. Antennas Propagat.* 42:993–999.

Ho, S. L., S. Yang, H. C. Wong, K. W. E. Cheng, & G. Ni. 2005. An improved ant colony optimization algorithm and its application to electromagnetic devices designs. *IEEE Trans. Magnet.* 41:1764–1767.

Johnson, J. M., & Y. Rahmal-Samii. 1997. Genetic algorithms in electromagnetics. *IEEE Antennas Propagat. Mag.* 39:7–25.

Kreyszig, E. 1999. *Advanced engineering mathematics*. New York: John Wiley & Sons.

Michalewicz, Z. 1999. *Genetic algorithms + data structures*. New York: Springer-Verlag.

Mitilineos, S. A., S. C. A. Thomopoulos, & C. N. Capsalis. 2006. Genetic design of doul-band, switched-beam dipole arrays with elements failure correction, retaining constant exitation coefficients. *JEMWA* 20:1925–1942.

Mouhamadou, M., P. Vaudon, & M. Rammal. 2006. Smart antenna array patterns synthesis: Null steering and multi-user beamforming by phase control. *Progress Electromagnet. Res.* 60:95–106.

Quevedo-Teruel, Ó., & E. Rajo-Iglesias. 2006. Ant colony optimization in thinned array synthesis with minimum sidelobe level. *IEEE Trans. Antennas Wireless Propagat. Letters* 5:349–352.

Shimizu, M. 1994. Determining the excitation coefficients of an array using genetic algorithms. *Proc. IEEE AP-S Int. Symp. and URSI Radio Science Meet.* 1:530–533.

Telatar, E. 1995. Capacity of multi-antenna Gaussian channels. AT&T-Bell Labs, Internal Tech. Memo.