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Mitigation of Interference in GSM Networks by Complex Weights Perturbation of Adaptive Array Antenna

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ABSTRACT

Proper weighting of array elements of an adaptive antenna system enables us to determine the desired beam pattern and place nulls in the direction of the interfering signal. Therefore array pattern synthesis is a very important aspect of the smart antenna system which makes it possible to maximize the signal-to-interference ratio. In this paper, an efficient method for array pattern synthesis in uniform linear arrays with the prescribed null and beamforming is presented. Analysis of interference control by both fixed weight and adaptive patterns synthesis are considered in this presentation.

Keywords: *Adaptive antenna, Array pattern synthesis, Uniform linear arrays, Null and beamforming*

1. INTRODUCTION

Smart antenna beams are of two categories, namely the switched beam and adaptive beam. Switched beam antennas form multiple fixed beams with heightened sensitivity in particular directions. When switched beam antennas detect signal strength, they choose from one of several fixed predetermined beams to respond to the user and as the latter continues to move, the antenna keeps on responding by switching from one fixed beam to another. Therefore by monitoring the strength of the current signal the antenna is tracking, the switched beam antenna switches to other predetermined beams as required.

Adaptive beam antennas are the most advanced smart antenna systems. They make use of complex and sophisticated signal processing algorithms to locate and track signals so as to maximize the signal-to-interference ratio as they distinguish between desired signals and interfering signals [1]. The antenna system is able to first of all estimate the directions of arrival of both signals with a view to forming appropriate complex weight values to steer the main beam towards the desired user, nulls towards the interfering signal. Therefore the algorithm that will be used to minimize interference in the system must contain those of direction of arrival estimation and pattern synthesis. By pattern synthesis, the authors mean beam enhancement and nulling. This is done by the adjustment in (1) antenna elements position (2) number of array elements and (3) complex weights [2].

2. PROBLEM FORMULATION

Let us consider the familiar M-element equispaced linear array of identical elements all having uniform current amplitude. Interference suppression is achieved by steering beam pattern nulls in the direction of interfering signal while maintaining the main lobe in the direction of the user.

Let's assume the following:

$M = 3$-element array

$\theta_D =$ Fixed known desired source

$\theta_1 =$ Fixed known interferer 1

$\theta_2 =$ Fixed known interferer 2

$\theta_D, \theta_1, \theta_2$ are all operating at the same carrier frequency. The array factor can be obtained by considering the elements to be point source. The array factor is given by [3]

$$a = [e^{-jkd\sin\theta} \quad 1 \quad e^{jkd\sin\theta}]^T$$

And for system optimization, the array weights are given by

$$w^H = [w_1 \quad w_2 \quad w_3]$$

So that the total array output is

$$Z = w^H \cdot a = w_1 e^{-jkd\sin\theta} + \quad w_2 + \quad w_3 e^{jkd\sin\theta}$$

Z_D is the array output for the wanted signal with angle of arrival θ_D. Z_1 and Z_2 are the array outputs for the unwanted signals with their angles of arrival θ_1 and θ_2. Note that all 3 signals have fixed directions of arrival. What is required here is to find the appropriate values of the array weights w_1, w_2, w_3 that will enable the antenna track θ_D and block θ_1 and θ_2. This leaves us with the following analysis:

$$Z_D = w_1 e^{-jkd\sin\theta_D} + w_2 + w_3 e^{jkd\sin\theta_D} = 1 \text{ for the desired signal}$$

$$Z_1 = w_1 e^{-jkd\sin\theta_1} + w_2 + w_3 e^{jkd\sin\theta_1} = 0 \text{ for the interferer 1}$$

$$Z_2 = w_1 e^{-jkd\sin\theta_2} + w_2 + w_3 e^{jkd\sin\theta_2} = 0 \text{ for the interferer 2}$$

Bearing in mind that $a = [e^{-jkd\sin\theta} \quad 1 \quad e^{jkd\sin\theta}]^T$ = A =matrix of steering vectors and U_1 = $[\,1 \quad 0..... \quad 0]^T$ = Cartesian basis vector the above equations can be expressed in matrix form as follows:

$w^H \cdot A = U_1^T$ from where the weights can be found as follows

$$w^H = U_1^T \cdot A^{-1}$$

These calculated optimum values of the array weights will remain the same so long as the signals directions remained constant. However, if the angles change with time as in the case of mobile terminals, it becomes imperative to devise a reliable optimization scheme that enables re-calculation of the array optimum weights once more. This is application in real time conditions where the signal processing algorithm must allow for continuous adaptation to ever-changing signals. This brings us to the concept of interference control by adaptive beamforming the adaptation process of which must satisfy a specific optimization criterion. For this paper, the least mean squares criterion will be used.

3. THE LEAST MEAN SQUARE (LMS) ALGORITHM

The technique is an adaptive algorithm which adopts a gradient-based approach. LMS algorithm uses the estimates of the gradient vector from the available data and as well incorporates an iterative approach that ensures successive corrections to the array weight vector in the direction of the negative gradient vector. This eventually leads to the minimum mean square error.

Let us consider a ULA of M-elements. The antenna output is given by

$$(x)n = s(n)a(\theta_o) + \sum_{i=1}^{Nu} u_i(n)a(\theta_i) + n(n)$$

where $s(n)$ = desired signal arriving at angle θ_o $u_i(n)$ = Interfering signals arriving at angle θ_i $a(\theta_o)$ = Steering vector for desired signal $a(\theta_i)$ = Steering vector for interfering signals

The overall aim here is to construct the desired signal from the received signal amid interference and noise $n(n)$ factors. The various outputs of each element are combined after scaling by the corresponding weights so that the array pattern is optimized. The weights will be determined using the LMS algorithm based on minimum square error criterion. The job of the LMS algorithm is to estimate the signal $s(n)$ from the received signal $x(n)$ by minimizing the error $e(n)$ between the reference signal $d(n)$ and the beamformer output $y(n)$. The reference signal has some correlation with the desired signal estimate.

3.1 LMS Algorithm Formulation

From the steepest decent approach, the weight vector equation is given by[3]

$$w(n+1) = w(n) + \tfrac{1}{2}\mu[-\nabla(E\{e^2(n)\})]$$

μ = step size parameter which controls the convergence characteristics of the LMS algorithm

$e^2(n)$ = the mean square error between the beamformer output and the reference signal which is given by

$$e^2(n) = [d(n) - w^H x(n)]^2$$

The gradient vector in the above weight update equation can be calculated as follows

$$\nabla_w(E\{e^2(n)\}) = 2Rw(n) - 2r$$

R = array correlation matrix

r = signal correlation vector

Employing instantaneous (rather than actual) values of the covariance matrices r and R we have

$$R(n) = x(n)x^H(n)$$

$$r(n) = d^*(n)x(n)$$

Hence, the updated weight can be given by

$$w(n+1) = w(n) + \mu x(n)[d^*(n) - x^H(n)w(n)]$$

$$= w(n) + \mu x(n)e^*(n)$$

The algorithm is usually initiated with an arbitrary value $w(0)$ for the weight vector at $n = 0$. The successive corrections of the weight vector eventually leads to the minimum value of mean square error.

The problem of convergence conditions of the LMS algorithm has been dealt with in [3], so that stability is insured in the system on the condition that

$$0 \le \mu \le \frac{1}{2\lambda_{max}}$$

λ_{max} = Largest eigenvalues of the correlation matrix which can be approximated to the equation below given that there is only one desired signal while the rest signals are interfering signals

$$0 \le \mu \le \frac{1}{2trace[R_{xx}]}$$

4. LMS ALGORITHM SIMULATION

The LMS algorithm for adaptive arrays is simulated using M-element uniform linear arrays with their spacing d. Let us consider two real time cases as follows

Case 1:

Desired signal direction of arrival= 0^o

Interfering signal direction of arrival = 10^o
Number of array elements, M = 16
Spacing between array elements = 0.5λ

Case 2:

Desired signal direction of arrival= -60^o

Interfering signal direction of arrival = 45^o
Number of array elements, M = 16
Spacing between array elements = 0.5λ

The adaptive antenna system continuously updates the data sampled from the sensors of the array. The processing of this data is conducted at periodic intervals in order to estimate the direction of arrival and related information regarding the signals and interferers via the multiple signal classification algorithms. The estimated information is then applied in the calculation of the array elements complex weights. The snapshots stored in the memory storage and the computed complex weights updates are synchronized. Finally the stored is weighted with the updated complex weights in the beamformer to give the desired array pattern.

In this paper, the parameters for which changes can be made are just two; the angle of arrival of the desired signal and that of the interferer. All other parameters, including the number of array elements and the distance between them are kept constant. Simulations shall be made for cases 1 and 2, and the following four plots for each case considered shall be displayed: [4]

1. Array factor (in dB) versus angle of arrival
2. Array output tracking of the desired signal
3. Array complex weights versus number of iterations
4. Mean square error versus number of iterations

5. RESULTS

Case 1:

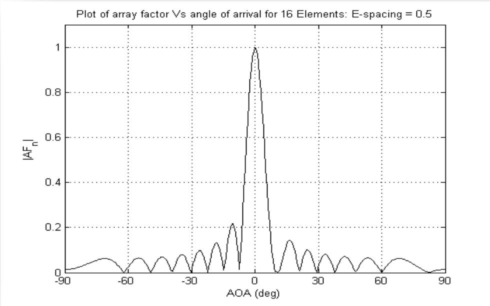

Fig. 2 Plot of Weighted Least Mean Square array versus Angle of Arrival

Comment: In Fig. 2, the desired signal is coming from 0^o and the interfering angle from 10^o. This is the case of co-channel interference. In this case, 16-element array is used and the difference is evident in both the achievement of the maximum beam in the direction of the desired signal and placement of null in the direction of the interferer. The angles are resolved with minimal errors.

Table 1: The weights for the 16 ULA

Element	W	weight
1	w1	1
2	w2	0.89946-0.084501i
3	w3	0.85736-0.2089i
4	w4	0.88593-0.33709i
5	w5	0.97685-0.43185i
6	w6	1.1038-0.46568i
7	w7	1.2298-0.42875i
8	w8	1.3184-0.33179i
9	w9	1.3438-0.20294i
10	w10	1.2986-0.079609i
11	w11	1.1961+0.0024026i
12	w12	1.0658+0.019286i
13	w13	0.94573-0.03386i
14	w14	0.87064-0.14161i
15	w15	0.86235-0.27268i
16	w16	0.92328-0.38902i

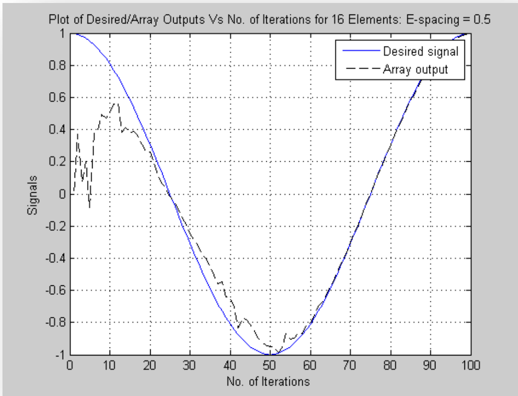

Fig. 3 Plot of Acquisition and Tracking of desired signal versus iteration number

Comment: The plot in fig. 3 shows the tracking of the desired signal. Following the wobbling at the early stage of the adaptation process, the array output converges toward the optimum value so that the weighted signal follows the movement of the desired signal more closely with small error.

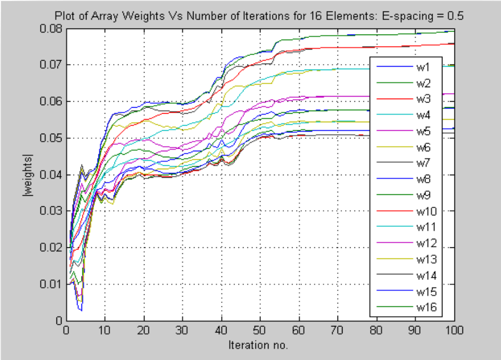

Fig. 4 Plot of magnitude of array weights versus iteration number

Comment: The optimum complex weights for which the algorithm converges are shown in table 1. The magnitude of the weights plotted against the number of iterations in fig. 4 shows the convergence of the weights for the 16 elements to their optimum values.

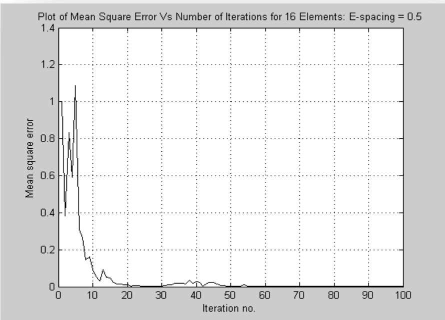

Fig.5 Plot of Mean square error versus number of iteration

Comment: The LMS error plot in fig. 5 shows that the algorithm converges to 0.001 after only 50 iterations

CASE 2

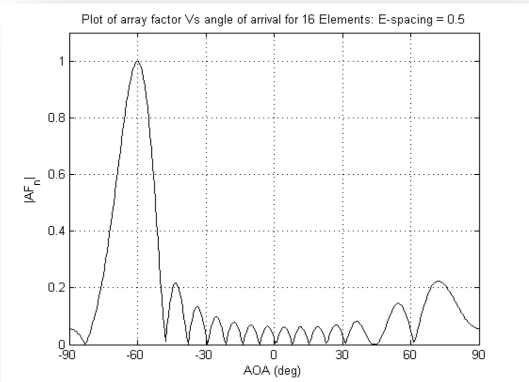

Fig.6: Plot for the weighted Least Mean Square array versus iteration number

Comment: The use of more array elements, 16, is still the case. In fig. 6, the desired signal is at -60^o while the interferer is at 45^o. With more number of elements, the plot shows that the LMS algorithm is able to update the weights in order to force null at 45^o, the direction of the interfering signal, while achieving maximum sharp beam at -60^o, the direction of the desired signal.

Table 2: The weights for the 16 element array

Element	w	weight
1	*w1*	*1*
2	*w2*	*-0.85694-0.52668i*
3	*w3*	*0.62715+0.94676i*
4	*w4*	*-0.31428-1.1427i*
5	*w5*	*-0.084312+1.0825i*
6	*w6*	*0.53198-0.82358i*
7	*w7*	*-0.9332+0.46575i*
8	*w8*	*1.164-0.090717i*
9	*w9*	*-1.136-0.26736i*
10	*w10*	*0.84992+0.60313i*
11	*w11*	*-0.39871-0.89594i*
12	*w12*	*-0.082695+1.0835i*
13	*w13*	*0.48513-1.0815i*
14	*w14*	*-0.76411+0.83916i*
15	*w15*	*0.92726-0.38824i*
16	*w16*	*-0.98861-0.15409i*

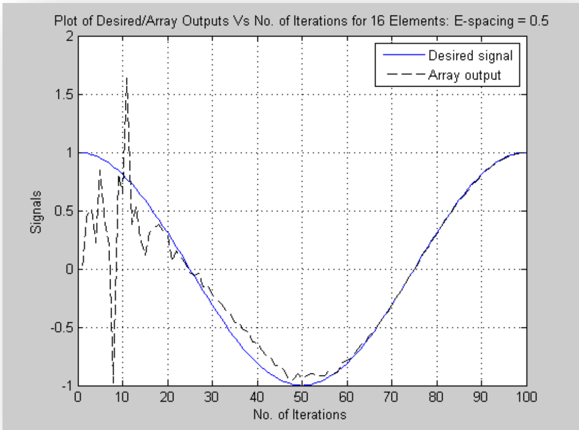

Fig. 7: Plot of Acquisition and tracking of desired signal versus iteration number

Comment: In the figure above, after initial wobbling at the start of the adaptation process, the weights converge towards optimum, giving rise to the array output tracking the desired signal more closely with minimal error.

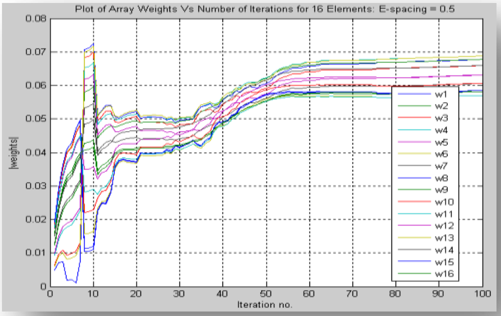

Fig. 8: Plot of Magnitude of Array weights versus iteration number

Comment: Fig.8 is a pointer to the convergence to the optimum of the array weights. The complex weights for the algorithm convergence are contained in table 2, while the magnitude of the weights plotted against the number of iterations is shown in fig. 8.

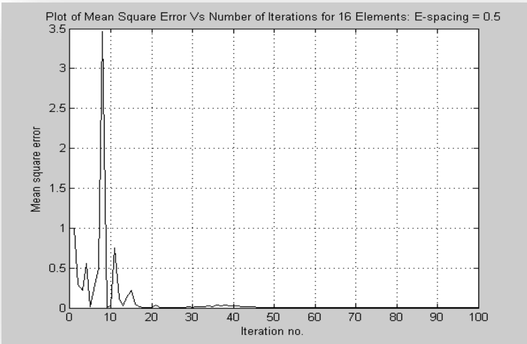

Fig. 9: Plot of Mean Square Error versus iteration number

Comment: The LMS error plot in fig. 9 shows that the algorithm converges after 50 iterations with LMS error of 0.

6. CONCLUSION

Null steering and array pattern synthesis were carried out in this paper. The combination of direction of arrival estimation and array synthesis gave a good approach towards interference mitigation. Least Mean Square technique was used to achieve null steering and beamforming. In this presentation only a single null was carried out. The numerical pattern synthesis algorithm gave a set of complex weights with tolerable amplitude changes. It is observed that even after nulling, the main beam remained undisturbed, though there few cases of observed decrease in directivity. It is therefore possible to steer the main beam in any direction of interest with nulls in the estimated direction of interferer. This makes it possible for smart antenna system to update its pattern with each set of snapshots and thereby adapting itself with the changing mobile terminal by maintaining maximum directivity in the desired direction.

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