Journal of Engineering and Applied Sciences 13 (11): 4009-4014, 2018
ISSN: 1816-949X

Smart Antenna Array Patterns Synthesis Using LMS Algorithm

Musa H. Wali, Israa Amer Dahham and Lina Y. Kadhim
Department of Electrical Engineering, University of Al-Qadisiyah, Al-Diwaniyah, Iraq

Abstract: This study presents a new technique for the linear array antenna with suggested nulls and beam-forming with multi-lobe characteristics is offered. Using the least mean square algorithm and the linear array to achieve multi-lobe pattern with prescribed nulls. Verifying the validity of the proposed technique through the simulation of Smart Antenna System (SAS) by considering multiple paths with multiple directions of arrival signals. The simulations results confirms that the proposed SAS has the facility to separate the desired signal from interferes signals by adjusting beams directions towards the desired signals and nulls are facing the interferers.

Key words: Smart antenna, LMS algorithm, facility, signals, nulls, beam

INTRODUCTION

The channel capacity in wireless systems must be maximized because of the fast spreading of the mobile subscribers. The acceptable level of co-channel interference is the key factor that limits the frequency reuse in present cellular systems. SAS is a capable technology using to neutralize the interference and hence increasing the capacity of CDMA systems (Liberti and Rappaport, 1999). The use of SAS technology has resulted in a dual advantage. First, increasing the number of subsurface subscribers through the use of Space-Division Multiple-Access (SDMA). The second is to offer a approach to decrease multipath impact (Liberti and Rappaport, 1999; Liu and Xu, 1997).

The beam forming in classical SAS is accomplished by collecting and weighting the outcome of every and each element of the array group in a constructive manner. Figure 1 shows the Digital Signal Processing (DSP) system uses to adjust the coefficients weighting.

In this research, the focusing is on SAS pattern. The anticipated user's Direction of Arrival (DOA) information is utilized in ASA to direct the main beam towards that user (Lehne, 1999).

The output pattern of SAS can be tuned to maximize the required signal, summing the power of the multipath signals and eliminates or reduce interference. SAS radiation pattern can be modified to follow any active subscriber using the Direction of Arrival (DOA) process. In closing whenever interference effect reduces by any mean that leads to includes more subscribers in the system services (Steyskal, 1982; Liberti and Rappaport, 1999). All the above are powerful procedures uses to enhance the signal-to-interference level (Liberti and Rappaport, 1999). This study presents a new technique utilizes the LMS method to produce multi-beams pointed towards the users and null in the undesired direction by tuning the coefficients weights (Winters and Gans, 1999).

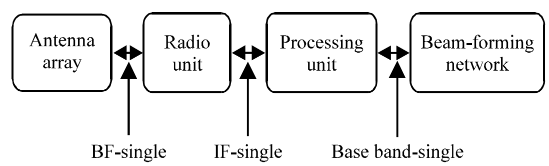

Fig. 1: Block diagram of SAS

MATERIALS AND METHODS

System design: An array consisting of (M) isotropic elements linearly and uniformly distributed will be analyzed in this study. The first antenna will be considered as a reference element as illustrated in Fig. 2.

Letting (L) be the number of uncorrelated mobile stations, treated as point signal sources and located sufficiently far away from the base station, the signal received $r_m(t)$ at the m-th element from i-th source will be given by:

$$r_m(t) = A_i \exp[j2pf(t-t_m(\theta_i))] \quad (1)$$

Where:

A_i = The signal amplitude
f = The carrier frequency
τ = The time delay of arrival of i-th source signal at m-th element

Corresponding Author: Musa H. Wali Israa, Department of Electrical Engineering, University of Al-Qadisiyah, Al-Diwaniyah, Iraq

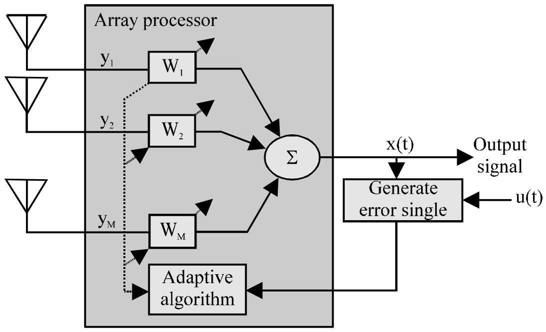

Fig. 2: Operation theory of SAS

In consequence, the signal from all sources at the mth element is described by Eq. 2:

$$r_m(t) = \sum_{i=1}^{L} A_i \exp[j2pf(t - t_m(\theta_i))] \quad (2)$$

The signal induced at all elements x(t) represents the received signal r(t) and the noise nn(t):

$$\begin{aligned} x_m(t) &= r_m(t) + nn(t) \\ x(t) &= [x_1(t), x_2(t), ..., x_m(t), ..., x_M(t)] \end{aligned} \quad (3)$$

The signal received at the mth element is:

$$r_m(t) = A.u(t)\ e^{-j\ (2\pi/\lambda)(m-1)d\sin\theta}.e^{-j(2\pi f T)} \quad (4)$$

where, T is the propagation time of the particular multipath from transmitter to receiver. After weighting the signals from all receivers and combining them, the output signal y(t) will be in the form:

$$y(t) = \sum_{m=1}^{M} w_m^* . r_m(t) \quad (5)$$

Equation 5 can be expressed in vector form as:

$$Y(t) = W^H . X(t) \quad (6)$$

where, the superscript H represents the transpose of the complex conjugate. The weight vector will be given as where (w_m) is mth element weight that is given by:

$$w_m = \exp[j2\pi f \tau_m(\theta_i)] \quad (7)$$

There are several methods of the weights calculation. The weights are selected to locate the zeros of the antenna array characteristics in these directions from which the undesired signals arrive. In order to consider this case the so-called steering factor (bi) will be introduced that is given by the equation:

$$b_i = [\exp(j2f\tau_1\theta_i), \exp(j2\pi f \tau_2(\theta_i), L, L, \exp(j2\pi f \tau_M(\theta_i)] \quad (8)$$

The steering vector is determined by the phase shift caused in the elements due to the ith signal (source). It contains the reaction of all elements of the array to a narrowband source (Winters and Gans, 1999). Letting (θ_1) be the angle of arrival of the wanted signal whereas (θ_2, θ_3, θ_4, θ_5, ..., θ_L) are the angles of arrival of the intrusive signals. The vector of weights which sets the zeros in the antenna characteristics in the directions is indicated by the angles (θ_2, θ_3, θ_4, θ_5, ..., θ_L) and exposes the desired signal arriving at the angle (θ_1) is determined from the following sets of equations:

$$\begin{aligned} W_m\ b_i &= 1, \text{ for } i = 1 \\ W_m\ b_i &= 0, \text{ for } i = 2, 3, 4, ..., L \end{aligned}$$

The same set of equations can be written in matrix form as:

$$W_m^H B = e^T$$

where, B is the matrix with its columns being the steering vectors:

$$\begin{aligned} B &= [b_1, b_2, b_3, ..., b_i, ..., b_L] \\ e &= [1, 0, 0, ..., ..., ..., 0]^T \\ W_m^H &= e^T B^{-1} \\ W_m^H B^H &= e^T B^{-1} B^H \\ W_m^H &= e^T B^{-1} B^H (B^H)^{-1} = e^T B^H (B.B^H)^{-1} \end{aligned} \quad (9)$$

Te calculation of weights requires the exact knowledge of the angles (θ_2, θ_3), θ_4), θ_5, ..., θ_L) for all interfering sources (Winters and Gans, 1999).

RESULTS AND DISCUSSION

Least Mean Squared (LMS) algorithm: Typical Least Mean Squared (LMS) procedure is commonly used in adaptive filtering due to its computational simplicity, stabile performance and relative immunity against errors (Winters and Gans, 1999).

The good stability properties, computational simplicity made the typical LMS procedure is commonly used in adaptive filtering (Winters and Gans, 1999). Evaluating the error changing used to update the weight vectors in typical LMS and next tuning the coefficients to reduce the MSE, this will improve the SNR level (Steyskal, 1982). The vector Weights (W_{t+1}) at the moment (t+1) is received from the Weights vector (Wt) at the t-th moment by adding the updating terms depending on the current error e(t), the signals x(t) at the output of each antenna branch and a small constant (μ) which is called the step size of the algorithm. So, at time (t+1), the updated value of the weight vector is:

$$w_{(t+1)} = w(t)\text{-}\mu.\nabla_w.E\ (e^2(t)) \quad (10)$$

Where:

(t+1) = The new weights at the (t+1)th
∇w (E (e2 (t)) = An estimate of the gradient of the (MSE) (Stevanovic *et al*., 2003)

Generally, the training sequence updates the weight vector is fast due to its rapid convergence rate. Equation 10 with respect to w(t), the instantaneous estimate of the gradient vector is given by:

$$\nabla_w.E(e^2(t)) = 2x(t).e^*(t) \quad (11)$$

The weight update Eq. 8, results from substituting Eq. 10 into 11:

$$w_{(t+1)} = w(t)+\mu.x\,(t).e^*(t) \quad (12)$$

The process of updating weights is done recursively, starts with certain initial value. Therefore, the results will be better if it uses large amount of iteration.

Since, mobile channels are scattered in the spatial domain where some of the areas in between active regions are generally passive (zero reply) there will be problems in applying standard LMS approach specially in case of large size arrays as well as environments with many multipath components that is because all the impulse response taps are permitted to be active or non zero. LMS estimation of channels with large number of adaptive taps, leads to poor convergence and high computational requirements.

Detection guided LMS: Scheme is proposed with the aim of detecting the active taps and subsequently LMS estimating through only these taps. The key to this approach is to determine when a particular unknown channel tap is active or inactive. This algorithm involves two tasks, first the update of the tap weight of the system using the adaptive method and the second, decides which tap are to be updated due to the active tap recognition (Steyskal, 1982).

Since, components or taps of a SAS in spatial domain relates to diverse DOAs, forming an active measure based on the active taps corresponding to the wanted signal.

To find the Measure of Activity (MA) it is required to reduce the undesired signals (γ), giving using vector (Liberti and Rappaport, 1999; Stevanovic *et al*., 2003; Vigneswaran, 2003):

$$\gamma = \left[\gamma_1, \gamma_2, \gamma_3, ..., \gamma_N\right] \quad (13)$$

$$\gamma = \sum_{k=1}^{n} u(k).\,\text{conj}\,(x(k)) \quad (14)$$

By taking the DFT of γ across the group of array elements, the obtained vector Γ is:

$$\Gamma = \left[\Gamma_1, \Gamma_2, \Gamma_3, ..., \Gamma_N\right] \quad (15)$$

Then, measure of activity (MA) for a spatial angle is:

$$MA = \Gamma(k).\text{conj}\ \Gamma(k) \quad (16)$$

where, Γ vector is the DFT of γ. For the purpose of distinguishing between the active and passive taps, the threshold T is set as:

$$T(k) = \frac{2\log\,(k.N)\left(\sum_{i=1}^{k} x(i).x^*(i)\right)\left(\sum_{i=1}^{k} u(i).u^*(k)\right)}{k.N} \quad (17)$$

Where:

X(k) = The FFT of the received signal plus noise
(N) = The taps number
μ = The step-size
W(k) = The FFT of the weight vector
x(k) = The incoming signal plus noise
u(k) = The sending signal

$$X(k) = FFT\ (x(k)) = FFT\left(r(k)+nn(k)\right) \quad (18)$$

The error will be given as:

$$e(k) = u\ (k)\text{-}x(k).w^H \quad (19)$$

Therefore, any tap at the sampling instant (k) is active if:

$$AM>a.T\ (k) \quad (20)$$

where, α is an integer from 0-1 which serves as a control for the threshold. During using LMS algorithm with the

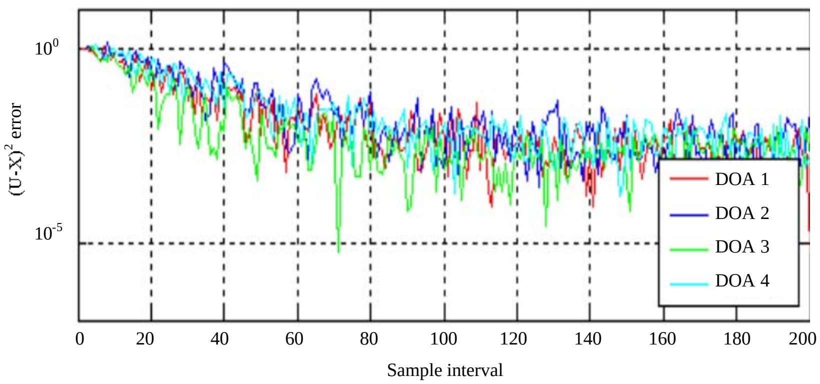

Fig. 3: Received signal error for 1-user, 4 DOAs

detection of active tap, each tap in the antenna array will be verified by Eq. 20 at each sample interval (k). The active taps are only the ones will be adapted using the following Eq. 21:

$$w(k+1) = w(k) + \frac{\mu x(k).e^{*}(k)}{\sum_{m=1}^{N} A_m(k)} \quad (21)$$

Where:
A(k) = The active tap
m = The tap number

If the tap is active, then MA = 1, otherwise for a passive tap (MA = 0) (Selvarju and Vigneswaran, 2003).

Sas simulations: For the simulations of SAS to mimic a source sending binary numbered labeled as 1 or -1 for 3000 feeding samples of the training system. A 200 out of 3000 sampling intervals are needed for the system to be converging. Setting the step size factor (μ) for the LMS process to keep the simulation process more actual, every multipath have a different gain value in the virus simulations. The transmitted frequency f of the output sequences is set to 900 MHz, result in λ = 3 m. A $\lambda/2$ spacing LA is used for simulations with one transmitted signal, 20 and 30 μ sec are the propagation delays for the first and the second elements.

Test case (one white signal with four DOA): One training sequence (u) with four multipath (u1-u4) that have direction of arrival of 60, 30, 20 and 45°, respectively is transmitted to a base station. Gains introduced to the corresponding input signal paths of the multipath signal parts have the following amplitudes 0.8, 0.66, 1.0 and 0.75, respectively as they are propagated to the antenna.

Figure 3 shows the received signal error with the effect of different gain paths. It is clear that the larger the gain amplitude, the faster the antenna array to adapt the transmitted signal and correctly estimate convergence rate of each multipath in terms of the number of samples. The mean values of the received signal error of each multipath at approximately 0.0062, 0.009, 0.00032 and 0.007 respectively, after convergence.

Figure 4 shows that the four beams from each set of weights areable to correctly identify the direction of arrival of each multipath component. It demonstrates the capability of SAS to steer separate beams in multiple directions and placing nulls in the direction of interferers. As can be seen from the figure, the gain of each main beam is the inverse of the gain introduced to each corresponding multipath component. This means that when receiving the first multipath signal, the other three multipath signals are also received but it can be deemed as negligible. This is the case for the reception of the other three multipaths.

Figure 5 shows the convergence rate of each multipath in terms of the number of samples required to reach steady state during using.

Detection guided LMS algorithm: It is observed that a smaller gain leads to a longer response for the taps to adapt and estimate the signal. The mean squared error of each multipath lies at approximately 0.0034, 0.0029, 0.0027 and 0.0018, respectively after it converges. The delay shown in Fig. 5 corresponds to the number of samples before the adaptive array starts to adapt for each path. It can be noticed that the delay for the first path is about 125 samples for the second path is 80 samples for the third path is 50 samples and for the fourth path is 75 samples. This in turn corresponds to the number of samples required before one (or more) of the weights are detected as being active. Figure 5 shows the convergence rate of each multipath in terms of the number of samples required to reach steady state during using.

Detection guided LMS algorithm: It is observed that a smaller gain leads to a longer response for the taps to

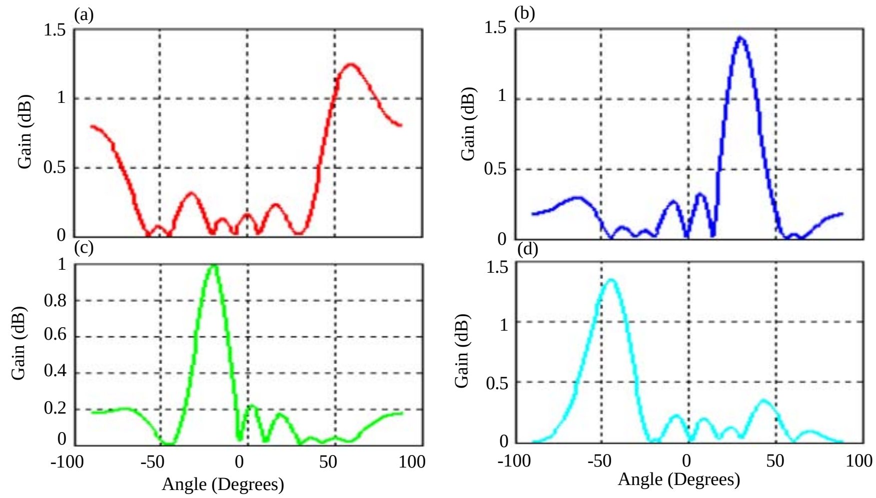

Fig. 4: Linear beam pattern of a signal with four paths: a) Linear plot pattern of single 1st DOA; b) Linear plot pattern of single 2nd DOA; c) Linear plot pattern of single 3rd DOA and d) Linear plot pattern of single 4th DOA

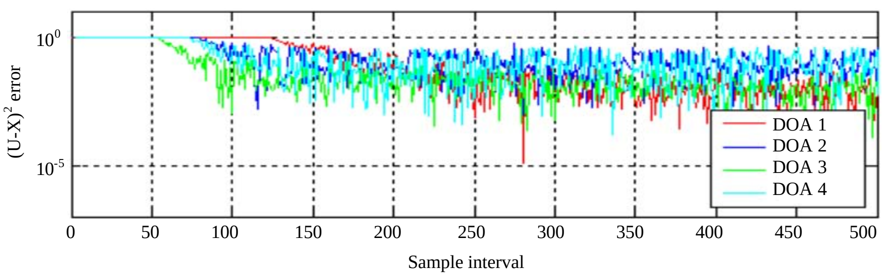

Fig. 5: Linear beam pattern of a signal with four paths

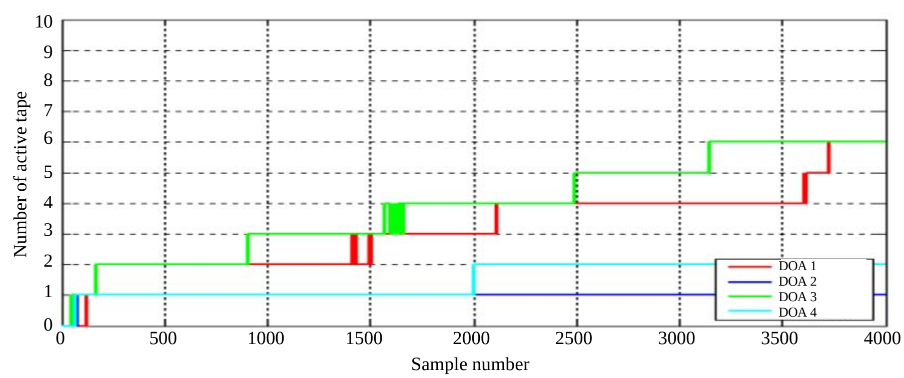

Fig. 6: Number of taps detected for 1-user, 4 DoAs, using detection guided LMS

adapt and estimate the signal. The mean squared error of each multipath lies at approximately 0.0034, 0.0029, 0.0027 and 0.0018, respectively after it converges. The delay shown in Fig. 5 corresponds to the number of samples before the adaptive array starts to adapt for each path. It can be noticed that the delay for the first path is about 125 samples for the second path is 80 samples for the third path is 50 samples and for the fourth path is 75 samples. This in turn corresponds to the number of samples required before one (or more) of the weights are detected as being active.

Figure 6 illustrates the number of taps being adapted for detection guided LMS algorithm. It can be seen that the active taps detected are 4 for the first path of the signal, 1 for the second path, 6 for the third path and 2 for the fourth path.

CONCLUSION

In this study, the LMS algorithm presented. First of all, the main obstacles of adaptive array pattern systems discussed. Also, Least Mean Square (LMS) algorithm for the proposed system is presented. The novel architecture for implementing a Least Mean Square (LMS) using an adaptive system is presented. SAS proposes numerous advantages compared to the conventional antennas. Coverage expansion, increasing of operating capacity and lower power consumption. The power reduction influence on base station is presented. Observing that the power transmitted by the cellular phone is reduced due to the achieved gain of proposed antenna which means reduction of electromagnetic radiation effluence on public health. As a result, the size of the network of the network of the base stations will reduced because of the power reduction.

REFERENCES

Lehne, P.H., 1999. An overview of smart antenna technology for mobile communications systems. IEEE. Comm. Surv. Fourth Quarter, 2: 2-13.

Liberti, J.C. and T.S. Rappaport, 1999. Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications. Prentice Hall, Upper Saddle River, New Jersey, USA., ISBN:978013 7192878, Pages: 376.

Liu, H. and G. Xu, 1997. Smart antennas in wireless systems: Uplink multiuser blind channel and sequence detection. IEEE. Trans. Commun., 45: 187-199.

Stevanovic, I., A. Skrivervik and J.R. Mosig, 2003. Smart antenna systems for mobile communications-final report. Master Thesis, Ecole Polytechnique Fedrerale de Lausanne, Lausanne, Switzerland.

Steyskal, H., 1982. Synthesis of antenna patterns with prescribed nulls. IEEE. Trans. Antennas Propag., 30: 273-279.

Vigneswaran, S., 2003. Spatial frequency domain NLMS algorithm for smart antenna systems. Master Thesis, School of Computer Science and Electrical Engineering, University of Queensland, Brisbane, Australia.

Winters, J.H. and M.J. Gans, 1999. The range increase of adaptive versus phased arrays in mobile radio systems. IEEE. Trans. Veh. Technol., 48: 353-362.