Initialization Scheme with Least Square Optimization based-DOA Estimation for CMA Adaptive Antenna

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Abstract

This paper presents an initialization scheme for a constant modulus algorithm (CMA) adaptive antenna. With the proposed scheme, the direction of arrival (DOA) of signals is estimated by using nonconventional least square optimization. The antenna steering vector associated with the estimated DOA is used as an initial weight vector for CMA. Simulations were conducted to evaluate the performance of proposed scheme. Simulation results in term of total system response were shown to investigate the capturing behavior of CMA with initialization of estimated DOA. Moreover, SIR trajectories are shown to compare the convergence rate of the proposed CMA and conventional one.

Keywords : CMA, Initialization, DOA, Nonconventional least square optimization

1. Introduction

In wireless communication systems, interference among communications becomes a serious problem. It is well known that reducing the interference effect can increase capacity of the systems. One of the popular solutions used to eliminate interference is an adaptive antenna. A constant modulus algorithm (CMA) which is a blind adaptive algorithm was proposed to eliminate interference without requiring the training sequence [1]. There are two shortcomings to apply CMA to adaptive antenna. First, the convergence rate of CMA is slow. Second, CMA may capture interference rather than a desired signal. There are several attempts to resolve the problems seen in [2]-[3]. In [4], it is found that capturing behavior of CMA heavy depends upon its initial condition.

In this paper, the initialization scheme for CMA adaptive antenna is proposed. The proposed scheme utilizes the nonconventional least square optimization presented in [5] to estimate DOA of signals. The estimated DOA is then used to initial CMA. The proposed scheme along with its associated equations is presented in Section 2. Simulation results are shown in Section 3 to evaluate the performance of the proposed adaptive antenna. Finally, conclusions are drawn in Section4.

2. Proposed Initialization Scheme for CMA Adaptive Antenna

The conventional CMA was widely used for adaptation of the adaptive antenna because of its advantage of not requiring any training sequence. To eliminate interference, CMA exploits a known property of transmitted signal, i.e. its constant envelope. Examples of this type of signal include FM, QPSK, etc. As aforementioned, applying CMA to an adaptive antenna has two main shortcomings. In this paper, we present an initialization scheme which can resolve the underlying problem.

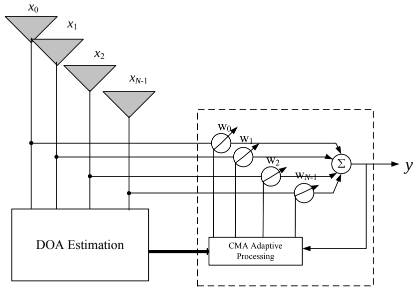


Figure 1: Basic configuration of the proposed adaptive antenna.

Let us consider a basic configuration of the CMA adaptive antenna along with DOA estimation as shown in fig. 1. The complex signals $\mathbf{x}(k) = [x_0(n), x_1(n),\ldots, x_{N-1}(n)]^T \in \Im^N$ received by i^{th} element of the antenna array can be written as

$$\mathbf{x}(n) = \sum_{m=1}^{M} a(\phi_m)s_m(n) + \eta(n)$$
$$= \mathbf{A}(\boldsymbol{\phi})\mathbf{s}(n) + \boldsymbol{\eta}(n) \quad (1)$$

where $\mathbf{A}(\boldsymbol{\phi})=[\mathbf{a}(\phi_1)\ \mathbf{a}(\phi_2)\ldots\ \mathbf{a}(\phi_M)] \in \Im^{N \times M}$ is the array response matrix, $\mathbf{s}(n) = [s_0(n), s_1(n),\ldots, s_{M-1}(n)] \in \Im^{M \times 1}$ is the vector of source signals, $\boldsymbol{\eta}(n) = [\eta_0(n), \eta_1(n),\ldots, \eta_{N-1}(n)]^T \in \Im^{N \times 1}$ is the additive noise and n is a time index. Let the vector $\mathbf{a}(\phi_m)$ be a true steering vector indicating that the transmitted signal $s_m(n)$ arrives in the direction of ϕ_m.

The proposed initialization scheme is here described via a uniform linear array comprising N omnidirectional point sources with element spacing d. The true steering vector $\mathbf{a}(\phi_m)$ of the array can be written as

$$\mathbf{a}(\phi_m) = \begin{bmatrix} 1 & e^{jk\cos\phi_m} & \ldots & e^{j(N-1)k\cos\phi_m} \end{bmatrix} \quad (2)$$

where $k = 2\pi/\lambda$ is the wave number and ϕ_m is the DOA of the m^{th} signal with respect to the end-fire direction of the array. Generally, the array response matrix $\mathbf{A}(\boldsymbol{\phi})$ is unknown. Therefore, based on the nonconventional least square optimization for DOA estimation, an array response matrix of the true steering vectors $\tilde{\mathbf{A}}(\boldsymbol{\phi}_c)$ must be first measured a priori. This can be done offline in an operating environment. Note that the tilde sign '~' indicates that the matrix can be known by measuring the array antenna response. The dimension of the matrix $\tilde{\mathbf{A}}(\boldsymbol{\phi}_c)$ depends upon the number of antenna elements N. In the context of DOA estimation, we need to know the transmitted signal direction assumed as $\boldsymbol{\phi} = [\phi_1\ \phi_2\ldots\ \phi_M]^T$ while the calibration angles Q is denoted by a vector $\tilde{\boldsymbol{\phi}}_c = [\tilde{\phi}_1\ \tilde{\phi}_2\ldots\ \tilde{\phi}_Q]^T$.

With the nonconventional least square optimization, we can estimate the received signals by using the following equation

$$\hat{s}_{ncls} = \tilde{\mathbf{A}}^{\dagger}(\boldsymbol{\phi}_c)\mathbf{x}(n) \quad (3)$$

, where $\tilde{\mathbf{A}}^{\dagger}(\boldsymbol{\phi}_c) = \tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)[\tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)\tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)]^{-1}$ is the pseudo inverse of $\tilde{\mathbf{A}}(\boldsymbol{\phi}_c)$. Here, n is equal to zero because we calculate the estimated signal only at the first index time. To inverse the term of $[\tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)\tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)]$, the singular value decomposition (SVD) is applied to reduce the dependency of the columns in $\tilde{\mathbf{A}}(\boldsymbol{\phi}_c)$. The dependency is due to a small increment step of the calibration angles $\boldsymbol{\phi}_c$. With SVD, the matrix inversion can be obtained from

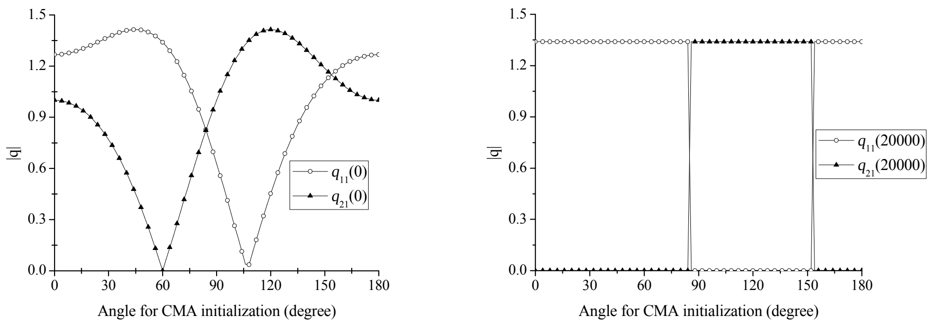
$$[\tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)\tilde{\mathbf{A}}^{H}(\boldsymbol{\phi}_c)]^{-1} = \tilde{V}\tilde{\Sigma}^{-1}\tilde{U}^{H} \quad (4)$$

, where $\tilde{V}$ and $\tilde{U}$ are unitary matrix with the first k columns which are the associated left and right singular vectors. According to (3), the estimated signal $\hat{s}_{ncls}$ is calculated from a matrix multiplication of $\tilde{\mathbf{A}}^{\dagger}(\boldsymbol{\phi}_c)\mathbf{x}(k)$. The DOA can be estimated by detecting the peak values of the signal amplitudes $\hat{s}_{ncls}$ along each direction. After estimating the DOA by using the nonconventional least square scheme, the estimated DOA $\boldsymbol{\phi}_0$ is then utilized for CMA processing in order to generate initial weight vectors. In fact, an initial weight vector being used in a CMA is a true steering vector of the measured array response $\tilde{\mathbf{A}}(\boldsymbol{\phi}_c)$ along estimated DOA. With reference to fig. 1, the complex signal received by i^{th} elements of the antenna array is multiplied by an adjustable complex weight $w_i(n)$. By using means of the proposed scheme, an initial weight vector is a true steering vector corresponding to the estimated DOA. The weight vector can be calculated by using the update weight equation as seen in [1].

3. Simulations

Simulations were conducted to evaluate the performance of the proposed technique and verify that the proposed technique can guarantee capturing the desired signal. In our simulations, the desired and interference signals were π/4-QPSK modulated and propagated through a channel in the absent of noise. The powers of the desired and interference signals were set to be equal. The incident angles of the desired and interference signals are $\phi_D = 45°$ and $\phi_I = 120°$, respectively. The antenna exploited in the simulations is a uniform linear array consisting of two isotropic, omnidirectional point radiators with λ/2 spacing. Before applying the nonconventional least square optimization for DOA estimation, the estimated DOAs ϕ_0 are assumed to observe capturing behavior of CMA. The steering vector associated with the estimated DOAs will be used as initial weight vector for CMA. To investigate the behavior of capturing signals, let us consider the total system response defined by

$$\mathbf{q} = \mathbf{w}^H \mathbf{A}(\boldsymbol{\phi}) \quad (9)$$

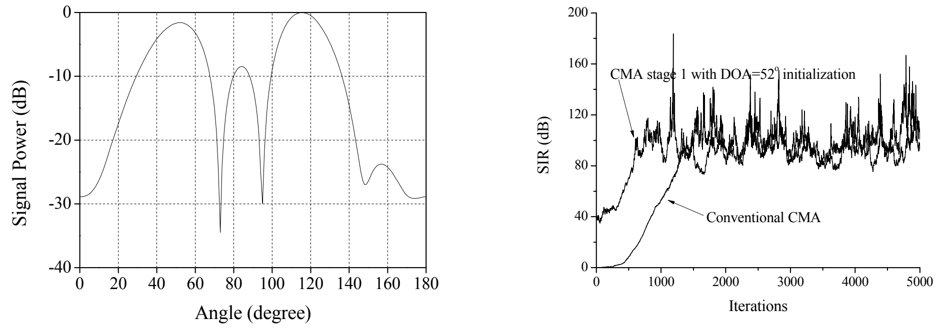


(a) (b)

Figure 2: Absolute of total system response at (a) first iteration. (b) 20000 iterations.

Figure 2 (a) shows the amplitude of the system response $|\mathbf{q}(0)|$ obtained from the product of initial weight $\mathbf{w}(0)$ (true steering vector along the estimated DOA) and array response $\mathbf{A}(\phi)$ measured a priori. Namely, this figure is obtained from (5) at the first iteration. Here, the estimated DOAs are varied from 0° to 180°. In the figure, the amplitude of the element $q_{21}(0)$ is higher than that of the element $q_{11}(0)$ when $86° < \phi_0 < 152°$ and vice versa. At initial iteration, it should noticed that the power of interference will be stronger than that of the desired signal when an initial weight vector is used as the steering vector associated with estimated DOA close to interference direction (ϕ_I). The angles yielding the peak amplitude coincide those of incident signals. The amplitude of the system response at 20000 iterations is shown in Fig. 2 (b) after performing CMA with the initial weight vectors of the true steering vectors along the estimated DOAs. The figure reveals that CMA capture interference when $86° < \phi_0 < 152°$. Otherwise, if estimated DOA ϕ_0 is closer to direction of the desired signal than interference, CMA will capture the desired signal and eliminate interference. This total system response corresponding to capturing behavior coincides with the total system response of CMA initialization using DOA estimation.

To this end, the performance of the proposed scheme must be evaluated. Since two-element array antenna cannot estimate directions of both desired and interference signals, the antenna element is increased to be N = 5. The transmitted signals are propagated through additive white Gaussian noise (AWGN) channel. By using the nonconventional least square optimization [5], Figure 3 (a) shows powers of estimated signal complex amplitudes for various directions of arrivals. Two peak powers are at 52° and 116° almost corresponding to direction of transmitted signals (ϕ_D = 45° and ϕ_I = 120°). The estimated DOA (ϕ_0=52°) is used for CMA initialization. The trajectories of signal-to-interference ratio obtained from CMA with and without the proposed initialization scheme are shown in Fig. 3 (b). Clearly, the convergence rate of the proposed adaptive antenna is faster than that of conventional CMA.



(a) (b)

Figure 3: Simulation results of (a) Estimated DOAs at 52° and 116° (b) SIR trajectories.

4. Conclusion

In this paper, initialization scheme for CMA adaptive antenna has been proposed. The scheme utilizes the nonconventional least square optimization to estimate DOA of signals. The estimated DOA is then used to initial CMA. In processing of initialization, the true steering vector along that estimated DOA is used as an initial weight vector for CMA. The true steering vector can be generally measured a priori offline. Simulations have shown that the capturing behavior of CMA depends upon the estimated DOA. CMA will capture the signal whose directions close to estimated DOA exploited for CMA initialization. Simulation results also show superior convergence behavior of the proposed CMA than conventional one.

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