ON THE CONCEPT OF TAMED ADAPTIVE ARRAY

Kazuaki TAKAO and Nobuyoshi KIKUMA
Dept. of Electrical Engineering, Kyoto University
Kyoto 606, Japan

INTRODUCTION

An adaptive array must be provided with some instruction how to discriminate the desired signal from the unwanted interference. In the case of the adaptive antenna under the algorithm of directionally constrained minimization of power(DCMP)[1], the system is taught the direction of arrival of the desired signal, and forced to make a constant voltage response of the transfer function to this signal. Several problems arise from this very guideline:

(1) If an interference which is coherent with the desired signal arrives, the system tends to utilize this interference in order to minimize the output power by cancelling the desired signal[2].

(2) When the prescribed angle of arrival of the desired signal is not accurate enough, the system takes the desired signal for unwanted interference and tries to suppress it[3].

Both (a) and (b) result from the excessive fidelity of the system to the given mission to minimize the output power. In those cases, the variable weights usually reach some extremely large(either positive or negative) values, which may be compared to super-directive arrays. By analogy, it is expected that the cancelling can be moderated if we add some amount of internal noise to prevent the system from being too much super-directive, with the least sacrifice in terms of its ability to suppress the true interference. Fortunately, the nature of the DCMP system allows us to add "pseudo" noise in the course of its feedback processing instead of real noise, so that we may avoid deteriorating the SNR(signal to noise ratio) of the output. We, the present authors named this procedure "Tamed Adaptive Antenna Array"[3].

PRINCIPLE

The Tamed Adaptive Array(TAA) system has the same hardware structure as the conventional DCMP adaptive array(CAA) system. We denote the inputs and variable weights in the form of column vectors, $\mathbf{X}$ and $\mathbf{W}$, respectively. Thus, y, the output of the array system and P_{out}, the output power can be expressed as follows.

$$y=\mathbf{X}^T\mathbf{W}=\mathbf{W}^T\mathbf{X},\quad P_{out}=\mathbf{W}^T R_{xx}\mathbf{W},\quad R_{xx}=E[\mathbf{X}\mathbf{X}^T] \tag{1}$$

where the superscript T denotes the transpose and R_{xx} is the correlation matrix of the input signals. E[ ] denotes the expectation.

The CAA system works to minimize the output power while maintaining a specified response to the signal from the desired direction. As the result, the maximum signal-to-interference-plus-noise ratio(SINR) is attained. Although the TAA system also works on the DCMP, it operates to minimize the fictious output power corresponding to the input that is modified by the pseudo noise. The situation is thus equivalent to having the input with exaggerated thermal noise. Actually, a quantity α is added to all the diagonal elements of the matrix R_{xx}. The principle of TAA can now be formulated as follows.

$$\min_{W}(W^T R_{xx} W + \alpha W^T W) \quad \text{subject to } C^T W = H \qquad (2)$$

where α denotes the pseudo noise power(non-negative) of present interest and C and H are the constraint matrix and constrained response vector with respect to the specified(desired) direction, respectively. The ultimate optimum weight vector is given as follows[2].

$$W_{opt} = (R_{xx} + \alpha U)^{-1}[C^T(R_{xx} + \alpha U)^{-1}C]^{-1}H \qquad (3)$$

where U is the identity matrix. The case where $\alpha=0$ corresponds to CAA. On the other hand, the case where α tends to infinity reduces to uniform weighting. This means the system loses the capability of eliminating the interferences. Therefore, the optimum value of α should exist in between these two extreme values. Namely, it is given by $\alpha_{opt}=KP_s/\sqrt{2}$ where K is the number of antenna elements and P_s is the input power of the desired signal. It seems that an accurate value of P_s must be known to determine the optimum value of α, but it was found out that the system performance of SINR is not so sensitive on the error of optimum α. Therefore, approximate prediction of P_s suffices.

EXAMPLES

The performance of a 4-element, 2-tap, linear, equispaced array of isotropic elements with the spacing of a half wavelength is studied by first calculating Eq.(4), then putting the results in Eq.(1). The desired signal, coherent interference and non-coherent interference are considered. All of them are assumed to be monochromatic. Each weight is assumed to produce thermal noise which is statistically independent of each other and has the equal power. The parameters used in the following examples are shown in Table 1.

(1) The case of coherent interference: The strength of the coherent interference is expressed by the parameter, r which is given by $r=P_c/P_s$, where P_c and P_s are the input powers of the coherent interference and desired signal, respectively. Fig.1 shows the output SINR after the adaptation when r varies from -50dB to 0dB. The solid and dashed lines in the figure denote the TAA and CAA systems, respectively. By the CAA system, the output SINR decreases fast with the increase of the coherent interference resulting from the cancellation of the desired signal. In contrast, the TAA system keeps good SINR throughout. Fig.2 (a) and (b) show the directional patterns of the CAA and TAA, respectively, for the case of r being 0dB. In (a)(CAA), the response to the coherent interference is identical in magnitude to that of the desired signal, which means they are cancelled by each other. By the TAA system, however, the response to the direction of the coherent interference is low so that the desired signal may not be totally cancelled. It should also be noticed that in both (a) and (b), the system achieves making a null at -50^{o}, the direction of non-coherent interference.

(2) The case of pointing error: The pointing error is expressed

by the parameter δ which is given by $\delta=\theta_s-\theta_d$, where θ_d and θ_s are the constrained direction and actual arrival angle of the desired signal, respectively. Fig.3 shows the output SINR after the adaptation. By the CAA system(the dashed line), even a small pointing error causes a very poor SINR. This reveals that the CAA requires very accurate information on the direction of the desired signal. The TAA system(the solid line), however, maintains good SINR for some considerable amount of pointing error. Fig.4 (a) and (b) show the directional patterns of the CAA and TAA systems, respectively, for the case of δ being 6 degrees. The difference between the responses to the direction of the desired signal for CAA and TAA systems is evident. In the former case(CAA), the desired signal is almost eliminated.

CONCLUSION

This paper described the concept of the improved adaptive array named "Tamed Adaptive Antenna Array" which is the modified version of the DCMP(directionally constrained minimization of power) adaptive antenna array. The system is proved to be useful in the radio environment such as:
(1) the presence of multipath waves(coherent interferences), or
(2) the beam pointing error(inaccurate direction setting).

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Table 1 Input data used in the computation

	(1)	(2)	
desired signal (S)	$\theta_s=0°$, $P_s=1$	θ_s=var., $P_s=1$	θ:angle
coherent interference (C)	$\theta_c=60°$, P_c=var.	---------	P:power
non-coherent interference (I)	$\theta_i=-50°$, $P_i=100$	$\theta_i=-50°$, $P_i=100$	
thermal noise (N)	$P_n=0.01$	$P_n=0.01$	
constraint (D)	$\theta_d=0°$	$\theta_d=0°$	

(1) the case of the coherent interference (2) the case of the pointing error

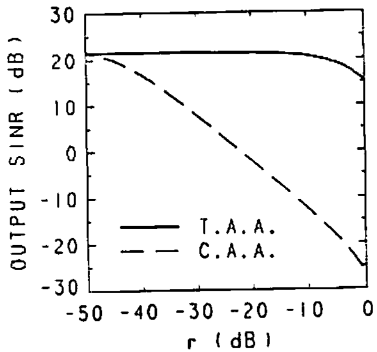
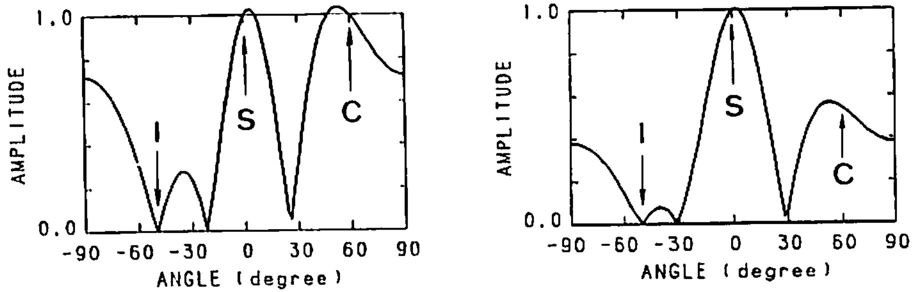


Fig.1 The output SINR vs. r, the power ratio of the coherent interference to the desired.



(a) CAA (SINR=-26.51dB)

(b) TAA (SINR=15.18dB)

Fig.2 Adapted directional patterns when a coherent interference is incident (r=0dB)

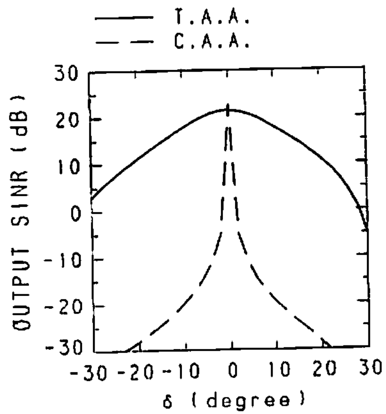
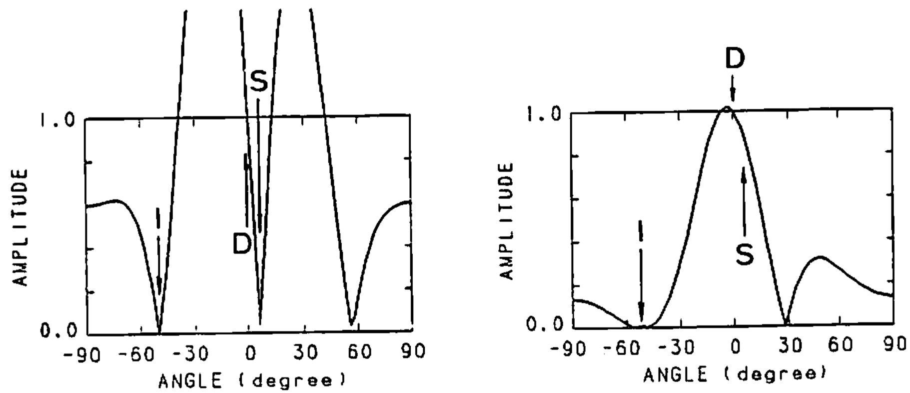


Fig.3 The output SINR vs. the pointing error, δ



(a) CAA (SINR=-14.57dB)

(b) TAA (SINR=19.90dB)

Fig.4 Adapted directional patterns when the pointing error, δ = 6 degrees