A MULTIPATH IMMUNE ADAPTIVE ANTENNA ARRAY

S.E. EL-Khamy (S.M. IEEE),

E.E. Dept., College of Eng., King Abdulaziz Univ.,
P.O. Box-9027, Jeddah, Saudi Arabia.

I.A. Mandour and M.A. Abou-Aldahab (St.M. IEEE)

E.E. Dept., Faculty of Eng., Alexandria Univ.,
Alexandria, Egypt.

Introduction: Multipath propagation effects are responsible for the most of the sever selective fading of communications links. Several countermeasures for multipath effects such as frequency and space diversity as well channel equalization are usually used. Recently, adaptive antenna arrays have been proposed to overcome multipath propagation effects [1]-[3]. In [3], a technique based on gain optimization algorithm [4] is proposed such that use is made of all the different multipath signals, arriving from different directions with random phases and amplitudes, to maximize the output of the array.

In this paper, we present a generalized technique to make adaptive arrays immune to multipath propagation effects. In particular, the adaptive array is designed such that the output power will have a constant value irrespective of the directions, amplitudes or phases of the secondary multipath signals. The adaptation of the amplitudes and phases of the complex weights of the different array elements is suggested to be made through power measurements of the array output for some given test sets of phases of the different weights.

Multipath Received Signals: Consider an adaptive antenna array consisting of N+1 isotropic elements with complex weights, $\bar{W}=\{w_o, w_1, \ldots, w_N\}$, as shown in Fig.1. The first element of the array (element number 0), will be considered as a reference element and its weight, w_o, is set fixed to unity, i.e. $w_o = 1\angle 0°$. A main signal with unit amplitude is assumed to arrive at the reference element at an angle θ_1 from the broadside direction. To simplify the analysis, only one secondary multipath signal is assumed to be present and is assumed to arrive from a direction θ_2 with relative phase δ and relative amplitude r w.r.t. the main signal.

The complex envelope of the signal received by the reference element is given by:

$$x_o = 1 + r\,e^{j\delta} = a_o\,e^{j\beta_o} \qquad (1)$$

with amplitude a_o and phase β_o given by:

$$a_o = (1 + r^2 + 2r\cos\delta)^{\frac{1}{2}} \qquad (2a)$$

and,

$$\beta_o = \tan^{-1}[r\sin\delta/(1+r\cos\delta)] \qquad (2b)$$

The complex envelope of the signals received by elements $1 \rightarrow N$ can be written as:

$$x_n = a_n\,e^{j\beta_n} = e^{-j\gamma_1} + r\,e^{j(\delta - n\gamma_2)} \quad ,1 \leq n \leq N \qquad (3)$$

where, $\gamma_1 = (2\pi d/\lambda)\sin\theta_1$, $\gamma_2 = (2\pi d/\lambda)\sin\theta_2$, λ is the wavelength of the received signals and d is the distance between successive array elements. Thus the amplitudes and phases of the received signals are given by:

$$a_n = [1 + r^2 + 2r\cos(\delta + n(\gamma_1 - \gamma_2))]^{\frac{1}{2}} \quad ,1 \leq n \leq N \qquad (4a)$$

$$\psi_n = \tan^{-1}\left[\frac{-\sin(n\gamma_1) + r\sin(\delta - n\gamma_2)}{\cos(n\gamma_1) + r\cos(\delta - n\gamma_2)}\right] \quad ,1 \leq n \leq N \qquad (4b)$$

<u>Optimum Weights</u>: If $\overline{G}$ and $\overline{\Phi}$ are the weights amplitude and phase vectors for the n=1 to n=N elements, i.e. $\overline{G} \equiv \{g_1, g_2, \ldots\ldots\ldots, g_N\}$ and $\overline{\Phi} \equiv \{\phi_1, \phi_2, \ldots\ldots\ldots, \phi_N\}$ such that $w_n = g_n\,e^{j\phi_n}$, then the combined signal S_o will be given by:

$$S_o = x_o + \sum_{n=1}^{N} Q_n\,x_n$$

$$= e^{j\beta_o}\left[a_o + \sum_{n=1}^{N} g_n a_n e^{j(\phi_n + \psi_n)}\right] \qquad (5)$$

where, $\psi_n = \beta_n - \beta_o$. The output power is thus given by:

$$P_o = |S_o|^2 = \left|a_o + \sum_{n=1}^{N} g_n a_n\,e^{j(\phi_n + \psi_n)}\right|^2 \qquad (6)$$

For a given set of weights, the output power P_o is a function of the parameters θ_1 of the main signal and θ_2, r and δ of the secondary multipath signal. To overcome the effects of multipath propagation, the weights w_n, $1 \leq n \leq N$, should be optimally selected such that P_o is independent on the parameters θ_2, r and δ . This can be done if we select $\overline{G}$

and $\overline{\Phi}$ such that,

$$\phi_n = -\psi_n \qquad (7)$$

and,

$$g_n = (K - a_o)/(N\, a_n) \qquad (8)$$

where K is an arbitrary constant. For this optimum set of weights, the output power will be constant namely, $P_o = K^2$. Thus, K can be selected to make P_o equal to its maximum possible value in the abscence of secondary multipath signals (r=0), namely, 1+N. The corresponding value of K will be,

$$K = (1 + N)^{\frac{1}{2}} \qquad (9)$$

Adaptation Algorithm: Due to the anticipated difficulties that may arise when a conventional gradient-following procedure is used to adjust the weights to their optimum values, a technique based on power measurements of the array output for some predetermined sets of weight phase vectors $\overline{\Phi}$ is adopted. This technique has been used for phase only adaptive arrays [5].

The value of a_o can be obtained by a direct power measurement of the signal received by the reference element which is equal to $|a_o|^2$, as shown in Fig.1. The values of the phase vector, $\overline{\Psi} \equiv \{\psi_1, \psi_2, \ldots\ldots, \psi_N\}$ and the amplitude vector, $\overline{A} \equiv \{a_1, a_2, \ldots\ldots, a_N\}$ can be obtained by performing a set of 6N+2 power measurements taken at 6N+2 predetermined sets of phase adjustments, namely,

$$\overline{\Phi}_0, \overline{\Phi}_{\tilde{0}}, \overline{\Phi}_1, \overline{\Phi}_{\tilde{1}}, \overline{\Phi}_2, \overline{\Phi}_{\tilde{2}}, \ldots\ldots, \overline{\Phi}_{3N}, \overline{\Phi}_{\widetilde{3N}},$$

and with unit gain, i.e. $g_1 = g_2 = \ldots\ldots = g_N = 1$, for all the phase sets, where,

$$\overline{\Phi}_m \equiv \{\phi_1^m, \phi_2^m, \phi_3^m, \ldots\ldots, \phi_N^m\} \qquad (10a)$$

$$\overline{\Phi}_{\tilde{m}} \equiv \{\phi_1^{\tilde{m}}, \phi_2^{\tilde{m}}, \phi_3^{\tilde{m}}, \ldots\ldots, \phi_N^{\tilde{m}}\} \qquad (10b)$$

$$\phi_n^m = \begin{cases} \pi & \text{if } m=3n-2 \\ -\pi/2 & \text{if } m=3n-1 \\ \pi/2 & \text{if } m=3n \\ 0 & \text{o.w.} \end{cases} \qquad (11)$$

and,

$$\phi_n^{\tilde{m}} = \phi_n^m + \pi \qquad (12)$$

If the 6N+2 resultant values of measured power are, $P_o, P_{\tilde{o}}, P_1, P_{\tilde{1}}, P_2, P_{\tilde{2}}, \ldots\ldots, P_{3N}, P_{\widetilde{3N}}$, respectively, and if, $Q_j = P_j - P_{\tilde{j}}$, $0 \le j \le 3N$, then it can be proved that,

$$\psi_k = \tan^{-1}\left[\frac{Q_{3k-1} - Q_{3k}}{Q_o - Q_{3k-2}}\right] \quad , \; 1 \le k \le N \tag{13}$$

$$a_k = (1/8a_o)\{[Q_o - Q_{3k-2}]^2 + [Q_{3k-1} - Q_{3k}]^2\}^{\frac{1}{2}} \quad , \; 1 \le k \le N \tag{14}$$

Thus, a total of 6N+3 power measurements will be needed to determine a_o, ψ and A. Once Ψ and A are determined, the optimum weight amplitudes and phases can be determined from (7) and (8).

The above technique is suitable only for slowly fading channels, i.e., when the parameters θ_2, r and δ change slowly enough to allow for the time needed to perform the suggested 3N+3 power measurements.

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Fig.1 Geometry of the problem.