論　文

Suppression of Multipath Signals by Applebaum Type Adaptive Array

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애플범 어댑티브 어레이를 이용한 다중경로 신호의 억제

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ABSTRACT

The potential ability of the Applebaum type adaptive array to suppress the multipath signals is examined.

The output Signal-to-Noise Ratio is expressed in terms of (1) the input SNR, (2) relative multipath signal amplitude, and (3) ambient noise when a multipath component is present Computer simulation is done on several performance measures to learn that the performance of the array depends upon the magnitude and the phase of the correlation coefficient.

It is also shown that the performance is maximized when the phase of the correlation coefficient is zero degree.

要　約

다중 경로 신호를 억제하기 위하여 적응등화기, 다이버시티 컴바이너등의 사용은 이미 보편화 되어 있으나 어댑티브 안테나의 사용 가능성을 타진한 논문은 극히 그 수가 제한되어 왔다. 본 논문에서는 이에 착안, 애플범 타입의 어댑티브 안테나 어레이를 다중경로 신호 페이딩의 해결책으로 사용할 수 있는 이론적 근거를 제시하였으며 어레이 출력신호가 다중 경로 신호의 존재에도 불구하고 어떻게 선명도가 보장되는지를 수식화 하고 컴퓨터 시뮬레이션에 의해 그 효용성을 입증하였다.

Ⅰ. INTRODUCTION

Modern digital radio operating on terrestrial paths under normal propagation conditions will operate essentially error free, that is with bit error rates less than 10^{-10}. However, for some particular times, meteorological conditions lead to the formation of unusual temperature and humidity profiles and these cause layered atmospheres. In a layered atmosphere, energy that would normally be radiated into space can be refracted down to the receiving antennas by other paths, as shown in Fig.1.

Of those couple of models[1] wich characterize the channel of Fig 1., two path model is considered to be the simplest and best one to perform the analysis, which is

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$$H(jw) = 1 - b\exp(-j(w - w_0)\tau)$$
$$\text{or}\quad h(t) = \delta(t) - b\,\delta(t - \tau)\exp(jw_0 t) \qquad (1)$$

where $H(jw)$: Transfer function of the multipath channel
$h(t)$: Impulse response of the multipath channel
b : Relative amplitude of delayed lay
τ : Delay
w_0 : Notch frequency

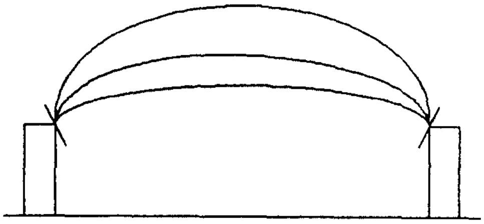

Figure 1. Multipath Propagation.

For the small fraction of the time that any given link is affected by such propagation anomalies, system availability may be drastically reduced unless appropriate countermeasures are employed.

Since the emerging mobile communication technology inherently involves the multipath fading problem, the importance of the countermeasures in cellular environments can not be underestimated.

The most widely used techniques for multipath fading reduction are diversity system with IF combiners, frequency domain equalizers, and time domain equalizers. And one or couple of these methods have been of course employed in both basestations and mobile stations in cellular communication systems. Moreover, recently, the application of adaptive antenna array to combatting the multipath fading in mobile communication has been attracting a lot of attention.

The usage of adaptive array, however, has been restricted to the Widrow type array which uses a pilot signal injected into the feedback loop. An Applebaum type adaptive array has not yet been introduced to such an application.

In this paper, accordingly, we show the possibility of multipath fading reduction by using Applebaum type adaptive array. An Applebaum type adaptive array[2] is capable of pointing a beam toward a desired signal and suppressing interferers automatically by the use of a steering vector. Thus an Applebaum type adaptive array has a potential to reduce the multipath fading.

If the multipath components are not correlated with one another, it is well known that an Applebaum array tracks the desired signal and rejects all the delayed multipath signals provided that the Applebaum array has a priori knowledge of desired signal direction, which is the case we are going to deal with. However, it is known that multipath components are in general correlated with one another. We, therefore, examine the effect of the correlation on the performance of the Applebaum type adaptive array.

II. FORMULATION OF THE PROBLEM

We consider the N-element linear Applebaum type adaptive array shown in Fig.2.

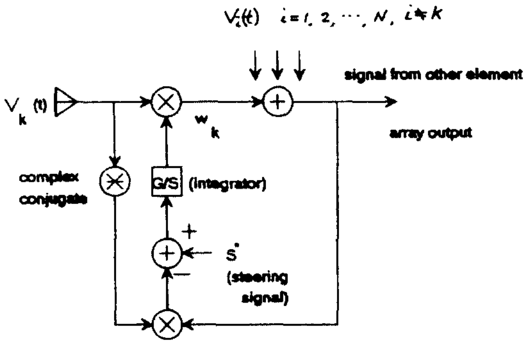

Figure 2. Feedback loop for k^{th} element of Applebaum array

We assume that the desired signal, d(t) and multipath delayed signal m(t) are incident on the array from angles θ_d (completely known at receiver) and θ_m relative to broadside, respectively, as in Fig. 3.

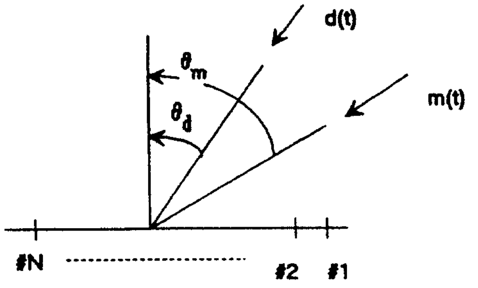

Figure 3. Signals arrival profile

We present the kth array element signal(k = 1, 2, ..., N) by $d_k(t)$. It is easily seen, then $m_k(t)$ becomes, based on [1],

$$m_k(t) = bd_k(t-\tau)\exp(jw_0\tau) \qquad (2)$$

Assuming the presence of $n_k(t)$ which is stationary Gaussian noise process with zero mean, power σ_n^2, and mutually uncorrelated, the array element input(which is denoted by $v_k(t)$ in Fig.2) becomes,

$$v_k(t) = d_k(t) + bd_k(t-\tau)\exp(jw_0\tau) + n_k(t) \qquad (3)$$

Here, we note $n_k(t)$ is also independent of the signal $d_k(t)$. We define an N-dimensional input signal vector as

$$V(t) = [\, v_1(t)\ v_2(t)\ \ldots\ldots\ v_N(t)\,]^T \qquad (4)$$

where T denotes transpose.

We give some thoughts and assumptions(which are for most cases true) in connection with the array geometry shown in Fig.3 as follows ;

* d(t) is a narrowband waveform.
* The array elements are isotropic.
* Interelement spacing, $X_i - X_{i-1}$, is half wavelength.
* The wavefront is planar.

Based on above assumptions, Eqn. [4] becomes,

$$V(t) = d(t)\,S_d + bd(t-\tau)\,S_m + N(t) \qquad (5)$$

where S_d is an N-dimensional desired signal phase vector,

$$S_d = [\, 1\ \exp(j\pi\sin\theta_d)\ \ldots.\ \exp(j(N-1)\pi\sin\theta_d)\,]^T$$

and S_m is an N-dimensional multipath signal phase vector,

$$S_m = \exp(jw_0\tau)[\, 1\ \exp(j\pi\sin\theta_m)\ \ldots.\ \exp(j(N-1)\pi\sin\theta_m)\,]^T$$

and $N(t) = [\, n_1(t)\ n_2(t)\ \ldots.\ n_N(t)\,]^T$

The weights of Applebaum array, w_k, shown in Fig.2 are derived adaptively using the a priori information contained in the steering vecotr. In the steady state, the weight vector,

$W = [\, w_1\ w_2\ \ldots.\ w_N\,]^T$ is given by

$$W = M^{-1}\,S^* \qquad (6)$$

where S^* is the steering vector and the asterisk denotes complex conjugation. M is the covariance matrix, and $V^*(t)$ is the complex conjugate pair of the signal vector V(t).

$$M = E[\, V^*(t)\ V^T(t)\,] \qquad (7)$$

where E denotes the expectation.

From [7], the (p, q)th element of M is given by

$$\begin{aligned} & E[\, v_p^*(t)\ v_q(t)\,] \\ & = p_d\exp(j(q-p)\pi\sin\theta_d) + b^2 p_d\exp(j(q-p)\pi\sin\theta_m) \\ & + bR_d(\tau)\exp(j(\pi(q-1)\sin\theta_m - \pi(p-1)\sin\theta_d + w_0\tau)) \\ & + \sigma_n^2\,\delta_{p,q} \\ & + bR_d^*(\tau)\exp(j(\pi(q-1)\sin\theta_d - \pi(p-1)\sin\theta_m - w_0\tau)) \end{aligned}$$

where $p_d = E[d^*(t)\ d(t)]$ .... Desired signal input power

$d^*(t)$ .... complex conjugate pair of the desired signal

$\delta_{p,q} = 1$ when $p = q$, 0 otherwise.

$R_d(\tau) = E[d^*(t)\ d(t-\tau)]$ .... Autocorrelation

Here, we establish the expression for the correlation coefficient in terms of the parameters shown above.

The complex valued correlation coefficient between d(t) and m(t) is,

$$\rho_{dm} = \frac{E[d^*(t)\ m(t)]}{\sqrt{P_d}\ \sqrt{P_m}} \tag{8}$$

where P_m is the power of the multipath signal.

Form equation [2], equation [8] becomes

$$\rho_{dm} = \frac{R_d(\tau)}{P_d}\ \exp(jw_0\tau) \tag{9}$$

The assumption that we know the arrival direction of desired signal leads us to rewrite the equation [6],

$$W = M^{-1} S_d^* \tag{10}$$

i.e., the steering vector is identical to the desired signal phase vector.

In order to evaluate the performance of the Applebaum adaptive array, we have to calculate the array output SNR, more specifically, the output Signal-to-Interference plus Noise power Ratio, the output SINR,

$$SINR_{out} = \frac{P_{do}}{P_{mo} + P_{no}} \tag{11}$$

where P_{do} : Output power of desired signal

P_{mo} : Output power of multipath interference

P_{no} : Output power of thermal noise

The output desired signal power can be expressed as

$$P_{do} = E[\ |d(t)\ S_d^T W|^2\ ] \tag{12}$$

$$\text{or} \quad P_{do} = P_d\ |S_d^T W|^2 \tag{13}$$

The output multipath signal power can be expressed as

$$P_{mo} = E[\ |bd(t-\tau)\ S_m^T W|^2\ ] \tag{14}$$

$$\text{or} \quad P_{mo} = b^2 P_d\ |S_m^T W|^2 \tag{15}$$

The output thermal noise power is

$$P_{no} = E[\ |N^T(t)\ W|^2\ ] \tag{16}$$

$$\text{or} \quad P_{no} = \sigma_n^2\ W^T W^* \tag{17}$$

Obtaining equation [17], we have used the fact that $n_k(t)$ is mutually uncorrelated stationary Gaussian process.

Using Eqn. [13], [15] and [17] we formulate the array output SINR as

$$SINR_{out} = \frac{P_d\ |S_d^T W|^2}{b^2 P_d\ |S_m^T W|^2 + \sigma_n^2\ W^T W^*} \tag{18}$$

As mentioned earlier in introduction, we are going to examine the effect of the correlation on the performance of the Applebaum type array. This task is to be done by computer simulation of $SINR_{out}$ in equation [18] with varying the correlation coefficient shown in equation [9] under various parameters. These parameters include number of array elements ; signals arrival direction ; input desired signal-to-noise ratio ; relative amplitude of delayed lay. If we restrict our observation to the minimum phase fading case, the reciprocal of the square of relative amplitude of delayed ray is interpreted as the input desired signal-to-multipath signal ratio.

Ⅲ. COMPUTER SIMULATION RESULTS

In the following simulation, we have used 486 PC as a platform and the MATLAB as a computing software. We note that, based on Eqn.[9], by properly changing the values for the center frequency(w_0) and delay(τ), the complex valued correlation coefficient, ρ_{dm} can easily be changed. For the convenience of the analysis, we take the amplitude and phase of ρ_{dm} as follows ;

$$C \triangleq |\rho_{dm}| = \frac{R_d(\tau)}{P_d} \tag{19}$$

$$\phi \triangleq \angle \rho_{dm} = w_0 \tau \tag{20}$$

Fig.4 shows the output SINR versus C for several values of ϕ, phi, for the case of 5 elements linear array, that is, $N=5$.

Desired signal and the multipath signal are assumed to come from the boresight and 30 degree direction, that is, θ_d = theta − d = 0 and θ_m = theta − m = 30, respectively. Desired signal input power and the multipath signal input power are both assumed to be 20 dB above the antenna array thermal noise, that is, α = alpha = P_d/P_m, β = beta = P_d/σ_n^2.

It is seen that the output SINR depends upon both the magnitude and the phase of the complex correlation coefficient. As is mentioned in introduction, when the desired signal and multipath signal are not correlated with one another, i.e., $C=0$, our Applebaum array completely rejects the mutipath signal. We claim the suppression as follows ;

Array antenna is characterized to have a linear SNR increase with the number of array elements. In other words, where there is only a desired signal existing as the input to any array antenna, the output SNR is equal to the product of the number of array elements and the array input SNR. If there is an interferer, however, the array output SNR, in this case, SINR will be degraded.

In Figure 4, we note that when $C=0$, the output SINR is 27 dB despite there are desired signal input and undesired signal(multipath signal input) due to the multipath signal suppression by Applebaum adaptive array.

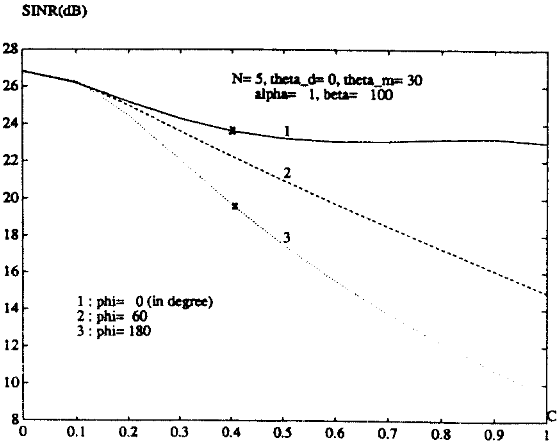

Figure 4. Output SINR vs C for various values of ϕ, phi.

It is also worthwhile to mention the heavy dependence of the output SINR on the phase of correlation coefficient. When the two signals are partly correlated with one another by $C=0.4$, the output SINR is 23.7 dB when $\phi=0$ degree while it is 19.7 dB when $\phi=180$ degree. The 180 degree difference in the phase of correlation coefficients results in 4 dB performance deviation. Figure 4 clearly shows us that even when the desired signal and multipath signal are almost correlated($C \approx 1$), an Applebaum adaptive array has the potential ability to suppress the multipath signal.

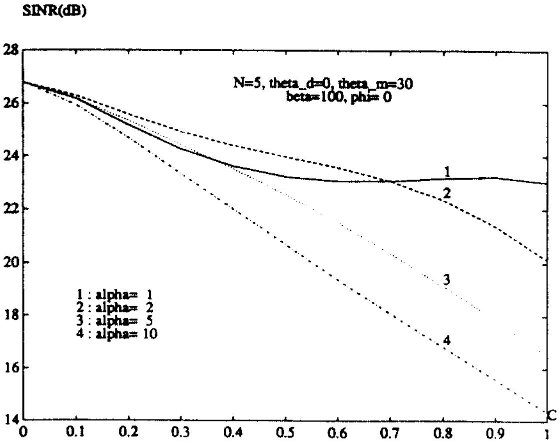

Figure 5. Output SINR vs C for various values of α = alpha = p_d/p_m

In Fig.5., we assumed the same scenario as in Fig.4. except that, in this case, the phase of correlation coefficient is fixed at 0 degree while the desired signal to multipath signal ratio, α = alpha, is varied from one to ten. It is interesting to note that the performance of the array even in multipath fading environments generally conforms the nature of power conversion[3] of an Applebaum adaptive array. When C is greater than or equal to the vicinity of 0.7, in other words, under multipath condition, the output SINR of our array decreases as the input desired signal to multipath signal power ratio increases.

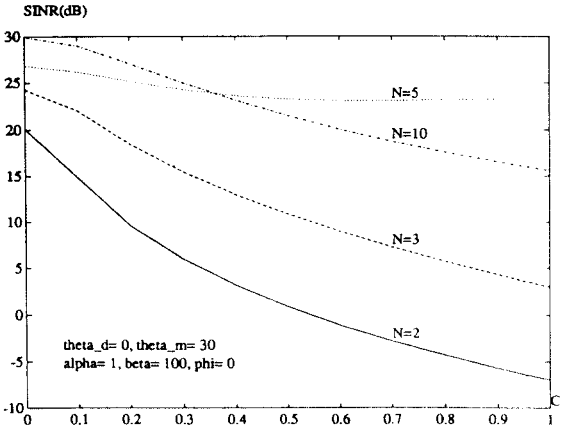

Figure 6. Output SINR vs C for various values of the number of array elements N

Figure 6. illustrates the effect of the number of the array elements, N, on the performance. When C is less than or equal to the vicinity of 0.3, which means that the two signals are uncorrelated or hardly correlated with each other, the performance improves with the number of array elements and this is one of the well known characteristics of array antenna. As C increases, however, the linear dependence starts to be violated. We see the output SINR for the case of N = 5 starts dominating the output SINR for N = 10 when C is around 0.4. This discrepancy has yet to be further studied associated with the mutual correlation of two signals.

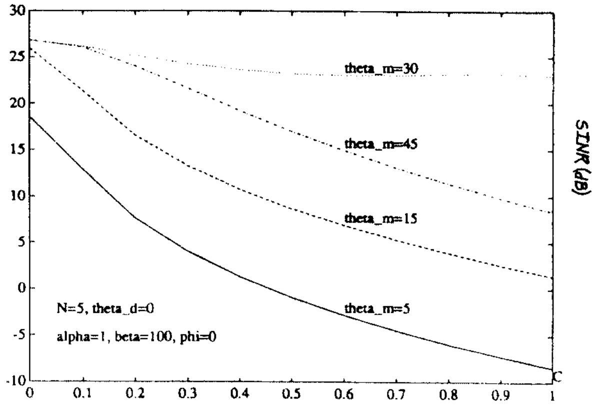

Figure 7. Output SINR vs C for various values of θ_m = theta m, direction angle of multipath interference

In Fig.7., the direction, θ_m, from which the multipath components is coming has been varied. Desired signal is subject to cancellation particularly when the undesired signal is coming from within the main lobe of the beam pattern of the Applebaum adaptive array and this cancellation phenomenon is explained in literatures[4]. In the figure, the lower two curves, represent the situation that undesired signal is coming near the desired signal and obviously the output performances have been degraded. Note that when the multipath component is coming from 30 degree apart from the broadside, the output SINR remains almost unchanged over the whole range of C. The reason is believed to be that the original beam notch is located very near 30 degree and therefore with few pattern update, our array is completely able to nullify the multipath component signal.

The effect of the phase of the correlation coefficient has been shown in Fig.8. As mentioned before, when the coefficient phase is zero degree, the array performance is maximized. Fig.8 also indicates that the array performace is deteriorating

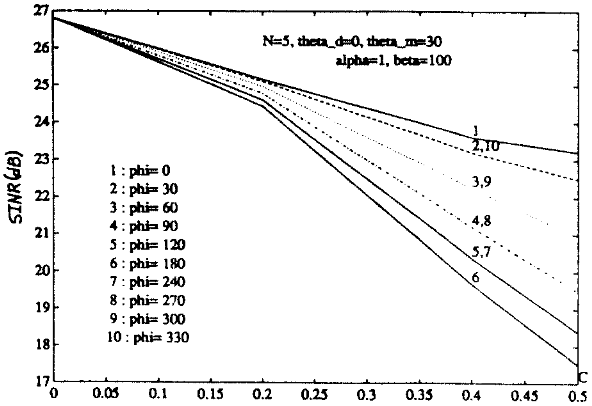

Figure 8. Output SINR vs C for various values of phase ϕ of correlation coefficient

with the coefficient phase until the phase reaches 180 degree and it bounces back once the phase exceeds 180 degree.

Ⅳ. CONCLUSION

We have examined the performance of an Applebaum type adaptive array on multipath components. The potential ability of the adaptive array to suppress the multipath component has been shown by computer simulations. Couple of interesting facts are found and they are :

(1) The performance depends upon the magnitude and the phase of the correlation coefficient.

(2) The performance is maximized when the phase of the correlation coefficient is zero degree.

As was introduced in the beginning, mobile communication system is suffering from the multipath fading and the Applebaum type adaptive array could be an useful countermeasure. The implementation difficulty including the settings for steering vector, high cost, etc., however, has yet to be resolved and a lot of efforts has been made and will be made continuously.

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