Performance Analysis of Adaptive Beamforming Technique Using Lagrange Algorithm based on Modified Eigen-space Method
수정된 고유공간 방법에 근거한 라그랑제 알고리즘을 이용한 적응 빔형성 기술의 성능분석

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Key Words : Code Division Multiple Access(CDMA), Smart Antenna, Eigenvalue, Eigenvector, Adaptive Antenna Array,

ABSTRACT : This paper presents an adaptive beamforming technique based on a modified eigen-space method for computing the optimal weight vector to achieve a diversity gain in smart antenna system. The proposed technique which is applied to the IS-2000 systems under a time-varying fading channel environment shows its excellent performance compared to a typical beamforming method through which the performance is significantly degraded as the angular spread of desired signal increases. A simple iterative procedure has also been presented in this paper to compute a well approximated solution of the modified eigen-space method with a reasonable computational load.

요약 : 본 논문은 IS-2000 시스템의 역방향 신호 환경에서 각도퍼짐이 증가하여 안테나간의 신호의 상관도가 떨어지는 경우에도 안테나 어레이의 성능을 향상 시킬 수 있는 빔형성 알고리즘을 제시한다. 제안된 방법은 수신 벡터신호의 자기상관행렬의 최대 고유값에 대응하는 고유벡터를 이용하되 상대적으로 큰 고유치에 대응하는 두개의 고유벡터를 이용하여 다이버시티 이득을 얻음으로써 하나의 고유벡터를 이용하는 방법에 비해 안테나 어레이 시스팀의 성능을 향상시키는 효과를 갖는다. 본 논문의 방법으로 사용자와 각도퍼짐을 변화시키면서 기존 알고리즘과의 성능을 비교 한 결과 각도퍼짐이 증가하는 환경일수록 상대적으로 큰 고유값에 해당하는 두개의 고유벡터의 합을 빔형성 웨이트로 사용하는 제안 알고리즘의 성능이 월등히 향상됨을 확인할 수 있었다.

1. Introduction

In many beamforming application at base station of CDMA systems, it is assumed that the signal received at each antenna element of the array system is very highly correlated. This assumption seems to be reasonable because antenna separation is usually about a half wavelength. However, in practical signal environments, especially in urban areas with densely populated tall buildings around the base station, the signal transmitted from each subscriber inherently experiences multipath effect and each propagation path might consist of many scattered components of the signal. This phenomenon results in an angular spread. The coherence of the received signals at each antenna element is reduced as a result of the angular spread, which naturally degrades the receiving performance of smart antenna system(1).

In most conventional works(2-5), the beamforming algorithms have been developed for a narrow angular spread. It is, however, important that the diversity gain in this narrow angular spread does not exist[4]. In addition, the beamforming algorithms that are developed for the signal environments of narrow angular spread considerably degrade the receiving performance of the smart antenna system as the angular spread of the desired signal increases.

The objective of this paper is to present an adaptive beamforming procedure for computing an optimal weight vector which achieves the maximum signal to interference plus noise ratio (MSINR) beamforming. The beamformer of this paper is also robust enough not only to fight against the angular spread but also to enhance the receiving performance of the smart antenna system by exploiting the diversity gain available due to the angular spread of the desired signal. The methodology employed in this paper is based on the modified eigen-space technique associated with the autocovariance matrix of the received data.

This paper is organized as follows. Section 2 shows the adaptive beamforming procedures using the generalized Lagrange algorithm and deflation method. Section 3 includes the numerical results of computer simulation that have been obtained from the application of the proposed technique to the IS-2000 signal environments. Section 4 concludes the paper.

2. Adaptive Procedure

The method of eigen-space, i.e., considering plural eigenvectors, is implemented through an adaptive procedure. If the processing gains in all channels are identical to each other, the statistical properties of interferers are close to those of white Gaussian noise after the despreading if we assuming the power is well regulated. However, the processing gain is assigned differently at each channel depending on the data rate of each channel. In this case, a high bit-rate transmission should have high power because its processing gain is small. Consequently, the signal of high bit-rate poses as a strong interferer to other signals. The signal environment of IS-2000 includes the problem of strong interferers mentioned above. It is the very reason why we needed to consider the MSINR criterion for the beamforming instead of the maximum signal-to-noise ratio (MSNR) criterion in which the performance degradation due to the estimation errors becomes remarkably worse as the processing gain becomes smaller.

The optimal weight vector under the MSINR performance criterion[5] can be found as

$$\underline{w}_{MSINR} = \arg\max_{w} \frac{\underline{w}^H R_{yy} \underline{w}}{\underline{w}^H R_{xx} \underline{w}} \qquad (1)$$

where R_{yy} and R_{xx} are autocovariance matrices of the despread and un-despread received signals, respectively. The optimal weight vector, $\underline{w}_{MSINR}$, that maximizes the SINR can be obtained from the eigenvector corresponding to the largest eigenvalue of the following generalized eigen-equation[6].

$$R_{yy}\underline{w} = \lambda R_{xx}\underline{w} \tag{2}$$

From the distribution of normalized eigenvalues of the generalized eigen-equation (2), it has been observed that the dominance of the primary eigenvalue decreases as the angular spread increases. It means that the optimal weight vector that maximizes the SINR cannot likely to be obtained from the primary eigenvector only as the angular spread increases. In order to obtain the more appropriate weight vector in the signal environment of angular spread, the weight vector is to be found in eigen-space. It particularly means that the performance of a given smart antenna system can be improved by adopting a weight consisting of plural eigenvectors instead of the primary eigenvector alone. On the other hand, however, if the weight vector corresponding to an insignificant eigenvalue is used, it may increase the estimation error.

From above, in order to estimate the weight vector as accurately as possible, it is required to consider the eigenvectors corresponding to the significant eigenvalues only. Hence, it would be necessary to know how many basis vectors in eigen-space are needed to represent the weight vector in accordance with a given amount of angular spread. From our various computer simulations, to consider more than 2 eigenvectors in eigen-space is not very helpful in many practical signal environments. It particularly means that the weight vector in eigen-sapce is computed as a combination of the primary and secondary eigenvector, which corresponds to the largest and the second largest eigenvalue.

Fig. 1 illustrates a flow chart of the adaptive procedure used in this paper that generates the weight vector from the modified eigen-space method. Basically, the entire procedure consists of a repetition of generalized Lagrange's formula twice. First, the primary eigenvector which corresponds to the largest eigenvalue is computed and then the secondary eigenvector which corresponds to the second largest eigenvalue is obtained by invoking the deflation method before the Lagrange's formula is used repeatedly. The entire procedure requires about $O(12N^2+18N)$ computational complexity at each snapshot where $O(N)$ denotes the order of computational load required for a scalar product of two N x 1 complex-valued vectors. Using a high speed DSP(digital signal processor) such as TMS320C67X, the proposed technique can be implemented in a real-time processing in most practical signal environments such as CDMA system.

3. Simulation Results

In this section, we present numerical results of various computer simulations that have been obtained in IS-2000 1x signal environment. In the simulations, the pilot channel and fundamental traffic channel with data rate of 9.6kbps have been considered. The fundamental traffic channel is spread in frequency domain with the Walsh code of length 16 and PN-code of rate 1.2288Mcps. Unless noted otherwise, the number of antenna elements is 7, the angle of arrival(AOA) of undesired users are arbitrarily chosen between -60^o and 60^o. The Doppler shift has been set to 80Hz. The weight vector for each path is computed in accordance with the adaptive procedure shown in Fig. 1.

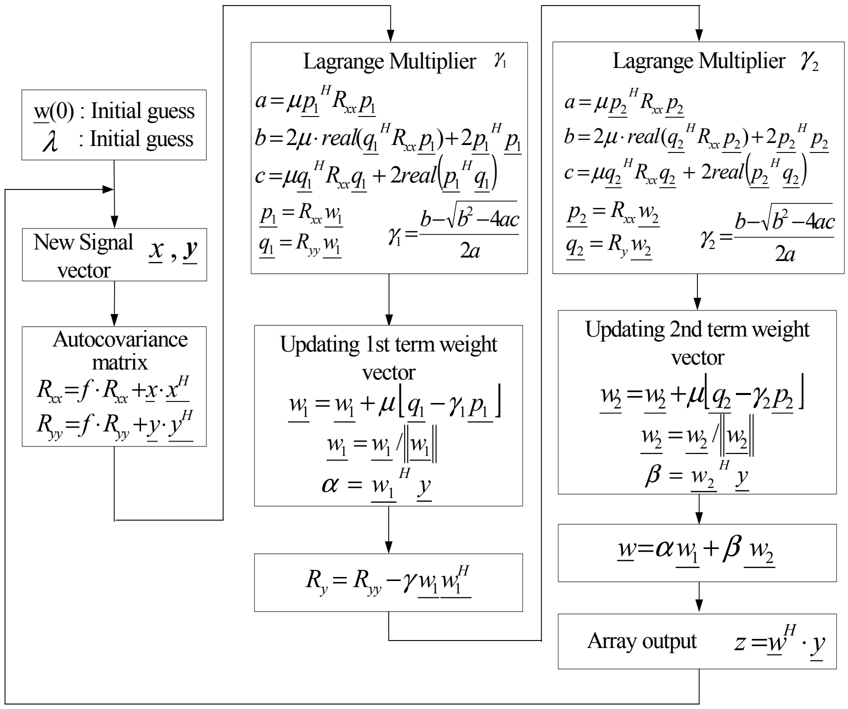

Fig. 1 Flow-chart of the adaptive procedure from modified eigen-space method

Fig. 2 illustrates the bit error rate (BER) performance of the proposed technique based on the modified eigen-space method when there exist two receiving paths. Because the spreading gain in the pilot channel can be controlled arbitrarily, the processing gain (PG) in the pilot channel is set to 64 and the angular spread Δ is set to $\pm 20^o$. As shown in Fig. 2, the performance is degraded as the number of users J increases. It is also shown that the use of two basis vectors provides a better performance than the use of one basis vector.

In Fig. 3, the BER is shown as a function of the angular spread at the desired signal when the number of users is set to 20. The BER obtained by a weight vector consisting of the primary eigenvector alone, which has been computed through the generalized Lagrange method[6], gets worse as the angular spread becomes wider. On the contrary, the BER of proposed technique is not degraded. Instead, it is even improved as the angular spread becomes wider by exploiting the diversity gain. Note that, in practical signal environments, there always exists angular spread because the signal transmitted from each subscriber inherently experiences multipath effect and each propagation path consequently consists of many scattered components.

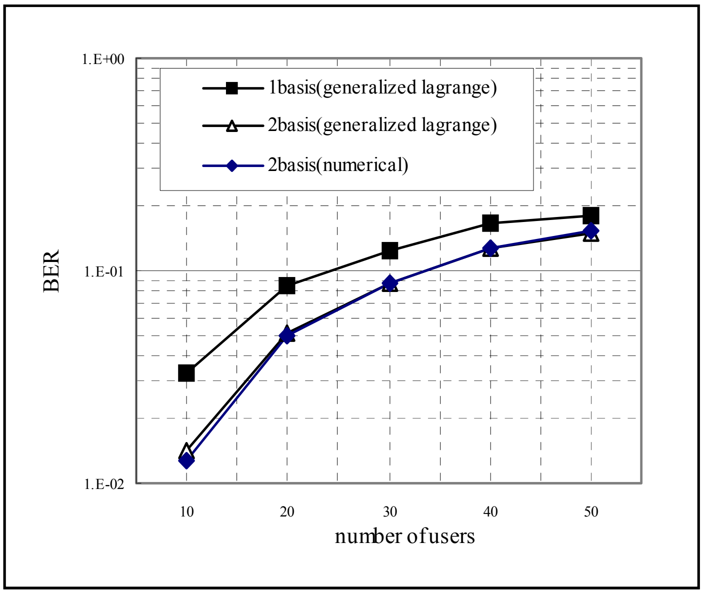

Fig. 2 BER performance for different number of users
(processing gain=128, angular spread =$\pm 20^{o}$)

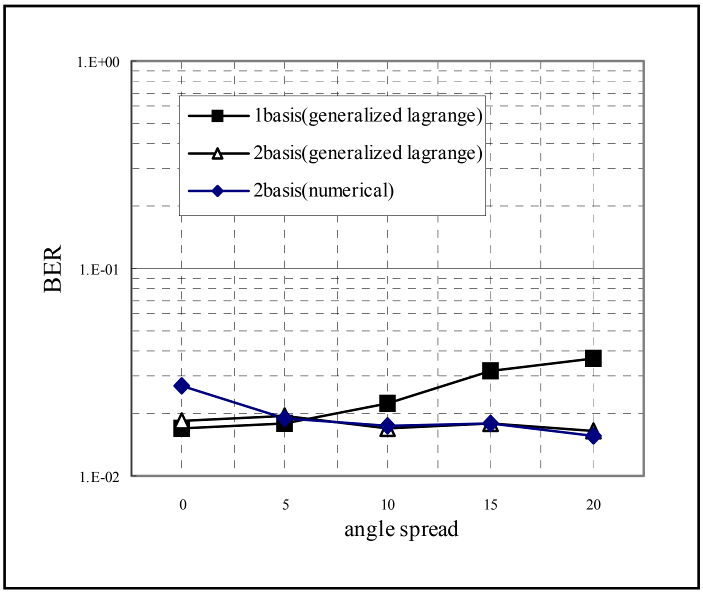

Fig. 3 BER performance as angular spread increases
(processing gain=64, number of users=20)

It is shown from the Fig. 2 and 3 that the adaptive procedure can approximate the exact computation of the eigenvectors of generalized eigen-equation (2) with reasonable agreements. From the figures, the weight vector computed through the proposed adaptive technique results in almost equivalent performance with the weight vector which has been obtained through the exact computation obtained from the eigen-function of MATLAB^{TM}. It particularly means that the adaptive procedure proposed in this paper can approximate the exact eigenvectors with a high accuracy.

Figure 4 and 5 illustrate the BER performance when the PG is set to 8 and 16, respectively. In this case, we considered the reverse supplemental channel with the Walsh length of 4. It is known that the generalized Lagrange algorithm using the MSINR performance criterion is superior to the ordinary Lagrange algorithm using the MSNR performance criterion when the processing gain for the beamforming is short such as 8 and 16. From the figures, we can see that the generalized Lagrange algorithm using the two eigenvectors is also superior to the ordinary Lagrange algorithm using the two eigenvectors of the ordinary eigenvalue equation of the autocovariance matrix. Also, we can confirm that the generalized Lagrange algorithm using modified eigen-space method under the MSINR criterion should be used as the processing gain becomes smaller.

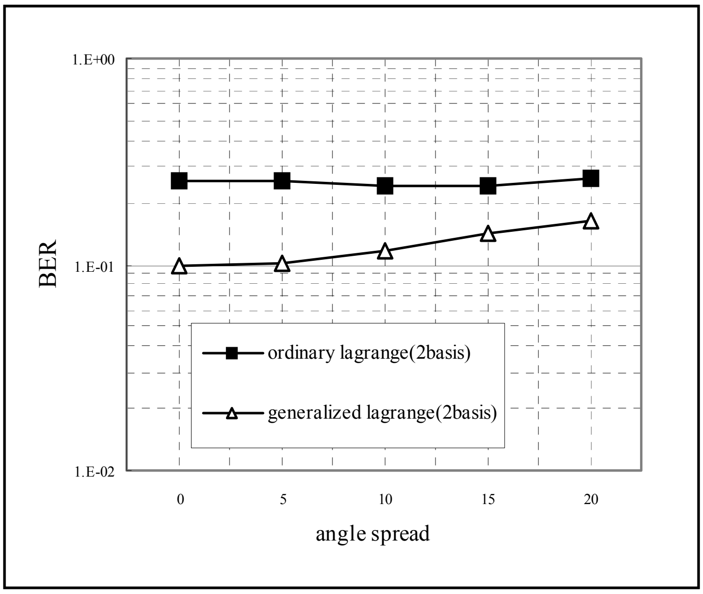

Fig. 4 BER performance as angular spread increases
(processing gain=8, number of users=20)

From our extensive simulations, it has been found that two eigenvectors in the eigen-space can satisfactorily represent the channel vector of the desired signal in practical signal environments in which angular spread exists. It is also noteworthy that the proposed technique based on the eigen-space method provides a diversity gain as the arrival angular spread becomes larger, which causes the signal received at each antenna element to fluctuate independently, which in turn causes the signal received at each antenna element to be non-coherent to each other. It particularly means that the receiving performance of smart antenna system can rather improve due to the angular spread because of the diversity gain exploited by the proposed method.

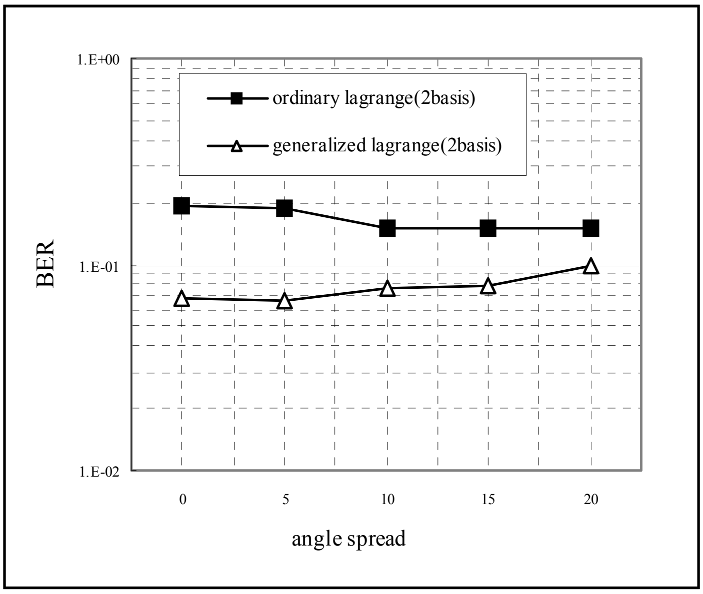

Fig. 5 BER performance as angular spread increases
(processing gain=16, number of users=2

4. Conclusion

This paper presents an adaptive beamforming technique based on the modified eigen-space method. When the desired signal is scattered from the center AOA, which results in an angular spread in the desired signal, the proposed method exhibits a conspicuous superiority in its receiving performances. The proposed technique can approximate the exact computation of eigenvectors. The performance is rather enhanced as the angular spread increases due to the diversity gain.

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