PROCEEDINGS OF ISAP2000, FUKUOKA, JAPAN

THINGS TO BE DETERMINED IN SMART ANTENNA SYSTEMS

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Abstract This paper addresses some miscellaneous problems arising in smart antenna systems (SAS), which, however, should not be neglected for a given SAS to be able to provide the desired features. The problems considered in this paper are: (1)Does it have to be a switching-beam system or adaptive tracking-beam system? (2)How should the criterion of computing the optimal weight vector be determined? (3)How should the reference antenna element be selected? (4)What happens when the direction-of-arrival angle (DOA) of the desired signal is spread widely? In addition to these, a more basic question, i.e., whether we should go for the beam-forming SAS or diversity system is also treated in this paper.

I. Introduction

The objective of adopting the SAS is to increase the communication capacity and enhance the communication quality with an appropriate beam pattern having its maximum gain along the direction of the target subscriber in a given cell/sector. For achieving the same purposes, the antenna diversity system is also considered as being a promising candidate as well. Therefore, the first question about the SAS is "Which one is more appropriate in a given signal environment, the beam-forming SAS or diversity system?". To answer this question correctly, we should compare the beam-forming gain and the diversity gain. Since this comparison is dependent upon the amount of angle spread and the antenna spacing, we postpone answering this question until the performance degradation due to the angle spread is analyzed in Section III. Once we select the SAS rather than the diversity system, we have to decide whether the SAS is to be a fixed switching-beam system or adaptive tracking-beam system. As this problem is already addressed in our previous work[1], we jump to the next question regarding the criterion of determining the optimal weight vector assuming the SAS is to be formed with an adaptive tracking-beam system.

II. Criterion for Adaptive Procedure

There are two basic criteria, one is to minimize[2] an error and the other is to maximize[3] a desired quantity such as

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received signal power etc, i.e., to find $\underline{w}$ such that

$E[(d-\underline{w}^H\underline{x})^2]$ be minimized, (1) or, $E[|\underline{w}^H\underline{x}|^2]$ be maximized (2)

subject to $|\underline{w}|^2$ = 1 where d and $\underline{x}$ are the signal of interest (SOI) and received signal vector, respectively, and $\underline{w}$ is the weight vector to be computed.

As shown in (1), in order to formulate the error functional, however, the SOI, i.e., d, has to be known at the receiving SAS. Therefore, it is in general common that the adaptive SAS which adopts the minimization criterion (1) requires a pilot sequence because the SOI should be available for the adaptation. On the other hand, the SAS based on the maximization criterion can compute the weight vector through a blind adaptation.

In the blind adaptation, instead of maximizing the received signal power as shown in (2), we can also maximize the ratio of the desired and undesired signal power.[4] This is indeed possible in CDMA signal environments without being able to separate the desired and undesired signals from each other. The key idea is that instead of maximizing the ratio between the desired and undesired signal power, we can maximize the ratio between the power of post-correlation signal and pre-correlation signal at the receiving SAS operating in CDMA channels. Consider the power ratio between the post- and pre-correlation signal as follows:

$$E[|\underline{w}^H\underline{x}_{POST}|^2]/E[|\underline{w}^H\underline{x}_{PRE}|^2]=[GD+U]/[D+U]=G-\frac{G-1}{(DUR)+1} \tag{3}$$

where $\underline{x}_{POST}$ and $\underline{x}_{PRE}$ are the post- and pre-correlation signal vector, respectively, G is the processing gain, D and U are the desired and undesired signal power, respectively, and DUR denotes the desired-to-undesired signal power. From (3), it can be observed that to maximize the power ratio between the post- and pre-correlation signal is equivalent to maximize the power ratio between the desired and undesired signal power, DUR. What is good about using the criterion of maximizing the DUR instead of the received signal power is that (1)it works even when the processing gain is somehow not sufficiently large, (2)the larger interferers get reduced more severely. Fig. 1 illustrates the beam pattern obtained from the criterion of maximizing the DUR. Note that, when the degree of freedom ($N-1$ = 7) of a given array is less than the number (14) of interferers, the pattern nulls are generated along the directions of the strong interferers while the relatively weak ones are ignored. It is very attractive feature when the channels are used with different powers as in IMT2000.

Fig. 2 illustrates the bit error rate (BER) performances of the adaptive SAS adopting the criterion of maximizing the DUR. It compares the SAS that employing the maximization of DUR criterion to the SAS that has been designed by the least mean square (LMS) algorithm[2], which adopts the minimization criterion,.

III. Angle Spread

In order to understand what happens in a given signal environment with the angle spread, let’s take a closer look at the signal received at the m th antenna element (at the despreader output) at n th snapshot as follows:

$$x_m(n)=\{\sum_{k=1}^{K}s_D(n-n_k)\sum_{i=1}^{L_k}e^{j2\pi(f_d\cos\xi_{k,i}nT_s-f_c\tau_{k,i})}e^{-j(m-m_0)\pi\sin\theta_{k,i}}\}+z_m(n). \tag{4}$$

Here, $s_D(n)$ is the signal transmitted from the desired subscriber as received at the SAS, n_k is the propagation delay measured at the level of an integer multiple of the snapshot period, K is the number of propagation paths of the desired subscriber, L_k is the number of scattered components at the k th path, f_d and $\xi_{k,i}$ are the Doppler terms,

T_s is the snapshot period, $\tau_{k,i}$ is the propagation delay, $\theta_{k,i}$ is the DOA, and $z_m(n)$ represents the undesired terms consisting of interference and noise, which are assumed to be zero-mean white Gaussian. Note that it is implied in (4) that the m_0 th element has been designated as the reference antenna element.

Observe, at each path, there are L_k components each of which is incident upon the SAS with a distinct DOA, i.e., $\theta_{k,i}$, centered at θ_k. This causes the carrier phase delay at each antenna element to be different from one another. More specifically speaking, when the carrier phase is compensated by multiplying the complex conjugate of the term $\sum_{i=1}^{L_k} e^{j2\pi(f_d \cos\xi_{k,i} n T_s - f_c \tau_{k,i})}$ to the received signal induced at every antenna element, the carrier phase delay is not compensated precisely except for the reference antenna element because, as mentioned above, the amount of carrier phase delay is different at each antenna element due to the angle spread. The error in compensating the carrier phase delay increases as the distance from the reference antenna element becomes farther and farther. Fig. 3 illustrates the difference of the carrier phase delay measured relatively from the carrier phase delay at the reference antenna element as a function of antenna element index. The element index of the reference element is referred to as being 1 in Fig. 3. Note that the difference increases as a given antenna element is located farther from the reference antenna element.

As shown in Fig. 3, the compensation for the carrier phase delay cannot be provided correctly in the beamforming SAS when the incident angle is spread. It is one of the main reasons why the performance of beamforming SAS degrades in the signal environments of wide angle spread. The error occurring in the compensation of the carrier phase delay is really inevitable in the beamforming antenna array system because the phase difference between the antenna elements should be maintained in the beamforming array system such that the carrier phase at each antenna element cannot be compensated separately. Nevertheless, the optimal weight vector can still be computed in such a way that the phase differences among antenna elements are compensated (even after the errorneous carrier phase compensation mentioned above) as long as the computation procedure is perfect in a given situation. In angle spread situations, even if the procedure of computing the weight vector is so robust that the desired signal at each antenna element can be added in a coherent direction with the phase of the reference antenna element, (which is not likely the case in real signal environments), this unrealistically robust weight vector should be computed for every individual symbol period because the angle spread must vary at every symbol period, which in turn, results in a different mismatches in carrier phase compensation. It particularly means that the weight vector should be updated whenever a new symbol arrives at the SAS with a different statistic of the angle spread.

From the above discussions, it becomes clear that the antenna element located at the center of the array geometry should be selected as the reference antenna element. Fig. 4 illustrates the BER performance of the SAS with two different choices for the reference element when the array consists of 8 elements. As shown in the figure, the SAS which adopts the center element as being the reference one conspicuously outperforms the other one with the first element being selected as the reference element. This remarkable difference in BER performance is due to the accumulated error in carrier phase compensation as the element located farther and farther from the reference element as discussed previously. It can also be observed from this discussion that the number of antenna elements is recommended to be odd. Now, we are ready to answer the very first question, i.e., whether we should go for the beamforming SAS or the diversity system. The answer is “It depends on the angle spread!”. From our simulations,

when the angle spread is tolerable for the weight vector to cope with the phase error mentioned above, say, within center angle $\pm 7^0$, then, the beamforming SAS has been found to be better than the diversity system, and vice versa
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References

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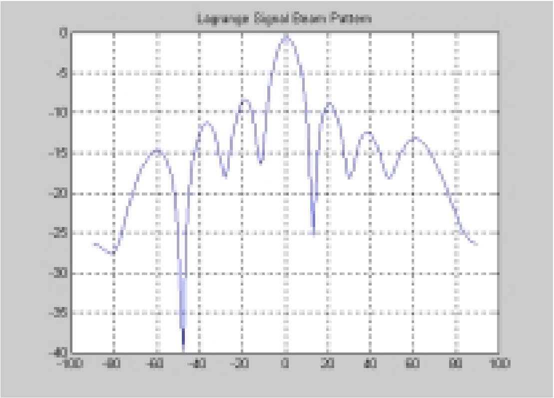

Fig. 1 Beam pattern provided by the criterion of maximizing the DUR .

DOA of Strong Interferers : –50, -30, -10, 10, 30, 50°, DOA of Weak Interferers: –70, -60, -40, -20, 20, 40, 60, 70°, SNR = 20dB.

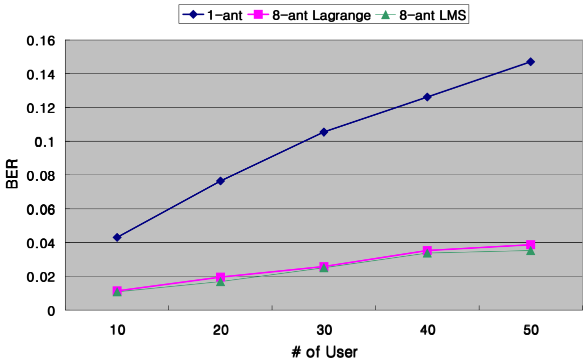

Fig. 2 BER performance of the LMS SAS and e-vector SAS operating in a CDMA (processing gain (PG) of 64) when the angle spreading is $\theta_i \pm 5^0$.

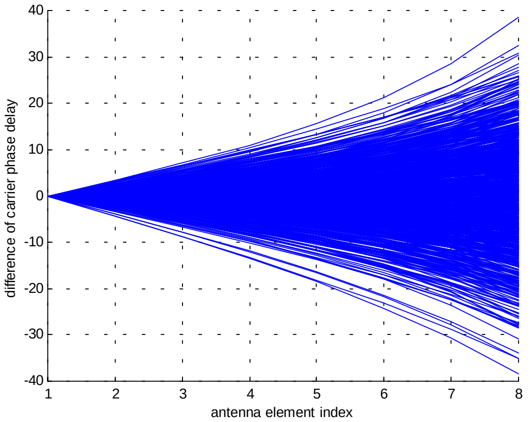

Fig. 3 Difference of the carrier phase delay at each antenna element when the angle spread is 10^0 . (DOA of each scattered component is uniformly distributed in the interval from $\theta_k - 5^0$ to $\theta_k + 5^0$.)

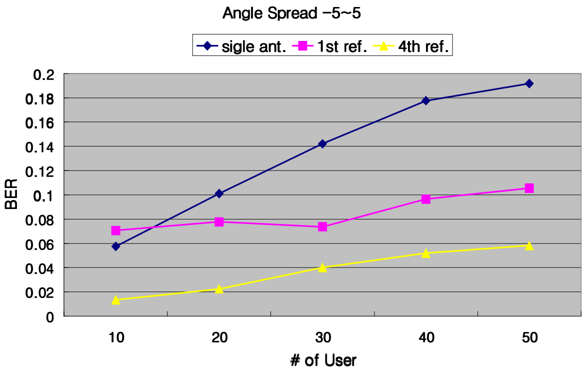

Fig. 4 BER performance of the SAS with two different choices for the reference element. (N=8)