SMART ANTENNA FOR SDMA USING MULTIPLE EIGENVECTOR BEAMS

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1. Introduction

With the increasing proliferation of multimedia communications, wireless access systems have gained popularity as free access systems. As the number of users increases, efficient utilization of scarce radio resources has become necessary. Space-Division-Multiple-Access (SDMA) is an attractive candidate for utilizing the resources because of its efficiency [1]. In the SDMA system, adaptive array antennas are generally introduced to base stations, and they generate multiple beams for each terminal station. In this system, signals from multiple terminals can be spatially separated and this feature enables the terminals to use the same frequency and the same timing [1]. Before optimizing the beam pattern, the adaptive antennas generally use an omni-directional pattern as an initial beam pattern. However, in fading environments, since the signal-to-noise-ratio (SNR) at the base station is degraded, acquisition errors occur when using the omni-directional pattern and even a special code preamble is adopted. Thus, the adaptive antenna cannot optimize the beam pattern.

Pre-beam-forming is effective in improving the acquisition performance and some techniques have been proposed such as FFT, retro-directive, and eigenvector beams [2][3]. In these studies, the pre-beam-forming techniques have been applied only to improve the synchronization performance of one desired user. Pre-beam-forming to improve the synchronization performance of multiple users, which is required for the SDMA, has not yet been investigated.

In this paper, we propose a new smart antenna suitable for SDMA systems. The smart antenna uses eigenvector beam forming and transmission power control together as pre-beam forming. The operation of the proposed beam-forming technique is also described. Finally, we evaluate by computer simulation the effectiveness of the proposed smart antenna when installing the antenna into an SDMA system.

2. Proposed smart antenna for SDMA

Figure 1 shows the hardware configuration of the proposed smart antenna. All analog devices, frequency converters, quasi-coherent detectors, and A/D converters were shared by each user. Beam forming network (BFN), fractionally spaced-tapped-delay-line (FS-TDL) and auto-frequency-controller (AFC) are placed for each user and these are carried out by digital signal processing. The fractionally-spaced-tapped-delay-line (FS-TDL) and the auto-frequency-controller (AFC) established the timing and the carrier recoveries after the BFN, whose output signal was spatially filtered for each user. Thus, no feedback loops were required for analog devices and stable operation was achieved.

The beam forming procedure had two stages. The first stage used eigenvector beam forming with transmission power control and the second stage used MMSE beam forming. The smart antenna assigned an occupied channel to other users by using the SDMA technique. In the first stage, the smart antenna first measured the power of the signal occupying the channel and notified the new users to transmit the signals at the channel with lower power than the occupied signal. Next, eigenvector beam was formed for the signal from each user and synchronization was established for the new users. If synchronization could not be established, the smart antenna refused to establish the links with the users. After capturing the users, the smart antenna notified the new users to transmit the signals with the same power as the occupied signal. Then the beam patterns for both the occupied and new users were revised. In the second stage, since synchronization was already established, MMSE beam forming was applied and the beam patterns were optimized.

In the following sections, we show the behavior of the eigenvector beam for the power differences among

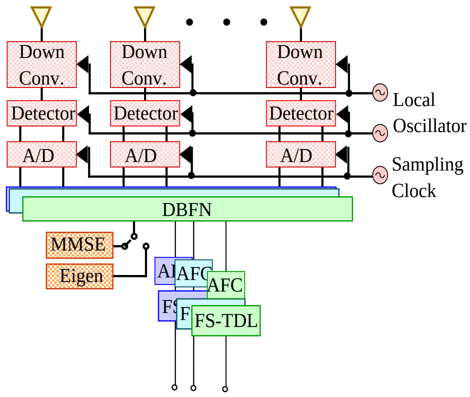
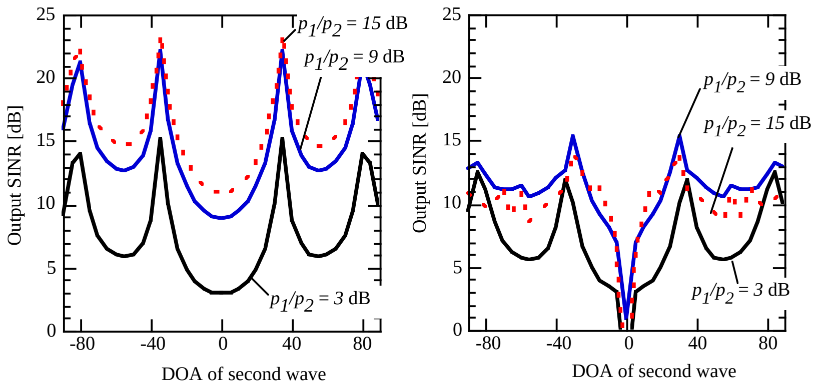


Fig. 1 Smart antennas at base stations



(a) BFN for terminal 1 (b) BFN for terminal 2

Fig. 2 Eigenvector beam performance in 2-terminal systems

the incoming waves.

3. Operation of eigenvector beams with power control

Eigenvector beams were generated from the correlation matrix among the signals received by the antenna branches, Rxx, and are expressed as

$$\mathbf{R_{xx}} = E\left[\mathbf{xx}^{\dagger}\right], \quad \mathbf{x} = \left(x_1 \quad x_2 \quad \cdots \quad x_N\right)^T \tag{1}$$

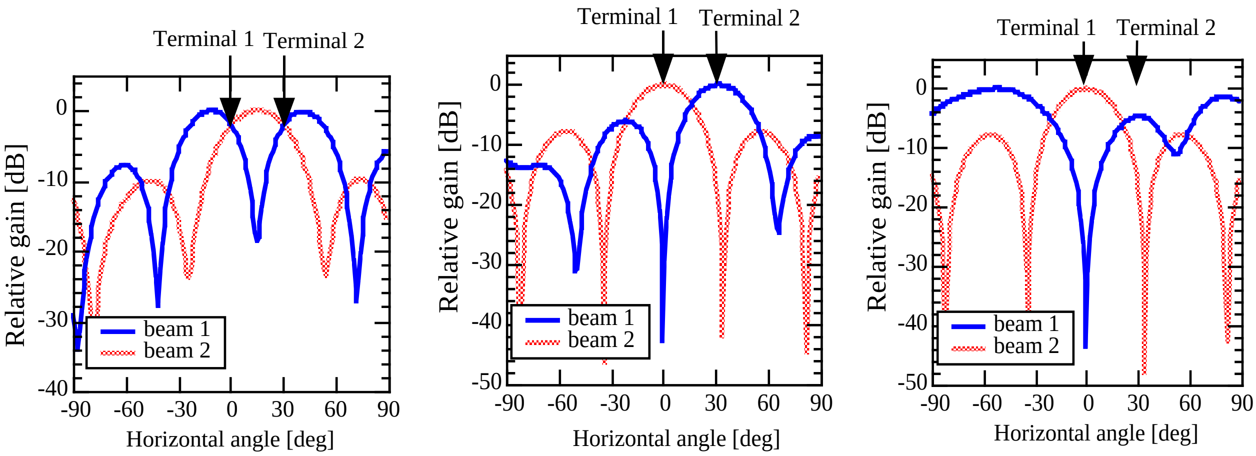
where **x** is the input signal vector, x_i is the received signal at antenna branch *i*, *N* is the number of antenna branches, superscript T denotes a transposition, superscript denotes the transposition of a complex conjugate, and E[ ] denotes the expectation. The output signal of the m-th BFN, y_m, is expressed as

$$y_m = \mathbf{w}_m^{\dagger}\mathbf{x}, \quad \mathbf{w}_m = \left(w_{m,1} \quad w_{m,2} \quad \cdots \quad w_{m,N}\right)^T \tag{2}$$

where $\mathbf{w_m}$ is the weight vector of the m-th BFN and $w_{m,i}$ is the weight connected to antenna branch *i*. The eigenvector beam sets the weight vector equal to the eigenvector of the m-th eigenvalue of $\mathbf{R_{xx}}$, $\mathbf{v_m}$.

The performance of the eigenvector beam depended on the spatial correlation between the terminal stations. If the spatial correlation was sufficiently small, the m-th eigenvector beam synthesized multiple waves from the m-th terminal station [1]. However, a small spatial correlation is not guaranteed in actual environments. The behavior for the spatial correlation is discussed below considering the power difference of the terminal stations.

Figure 2 shows a dependency of the output signal-to-interference-ratio (SINR) on the direction of arrival (DOA) of the incoming wave when two waves arrive at a smart antenna using eigenvector beams. The DOA of the other user (terminal 1) was fixed at 0 degree and that of the other user was varied. And eigenvector beams were generated from the 20 data symbols. Figure 2 (a) and (b) represent the output SINR for the terminal 1 and 2, respectively. The gray, black and dotted lines represent the cases that the power ratios between the signals, P1/P2, are 3dB, 9 dB and 15 dB, respectively. The input SNR for the terminal 1 was set to 10dB at each antenna branch and no multipath wave were considered here. As can be seen in Fig. 2, higher signal power ratio enabled to obtain better output SINR for both the terminals, while, in general, the received power must be increased to improve the transmission performance. It is also found that the output SINR of the signal power ratio of 15 dB for the terminal2 was worse than that of 9 dB. This is because the signal power of the terminal 2 was lower than the input noise level. Therefore, the transmission power of the lower power terminal must be higher than the input noise level. These results are acceptable by the analogy from the power inversion effect [4]. Power inversion (PI) adaptive array antennas generated deeper nulls toward the incoming waves of higher power [4], and the pattern formed by the PI algorithm corresponded to the eigenvector beam pattern for the minimum eigenvalue. Using the same analogy, the aforementioned results are reasonable because the eigenvector beam



(a) P_1/P_2=0 dB (b) P_1/P_2=10 dB (c) P_1/P_2=20 dB

Fig. 3 Eigenvector beam pattern

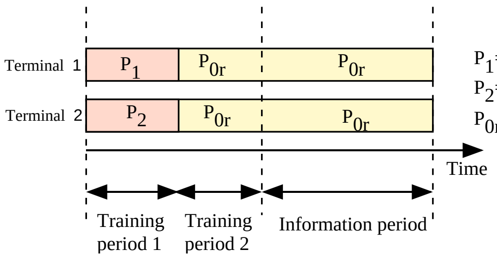
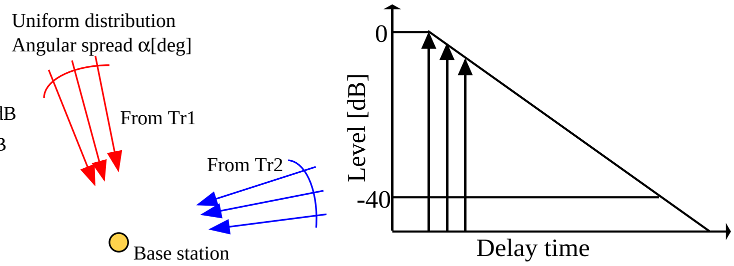


Fig.4 Power control scheme at terminal stations



(a) DOA (b) Delay profile from each terminal

Fig. 5 Simulation model

for the second eigenvalue generated deeper nulls toward the first user as the received power difference between the first and second users increased. Furthermore, if the received power of the second user decreased below the noise figure, the eigenvector beam of the second eigenvalue was generated for the noise signals and the transmission performance was degraded.

Figure 3 shows radiation patterns generated by the eigenvector beam forming when the received signal power ratios were 0 dB, 10 dB and 20 dB. When P_2 was nearly equal to P_1, the first and second beams receive both signals from the two terminal stations. When $P_2 < P_1$, an eigenvector beam for the largest eigenvalue directed toward Terminal 1 and the eigenvector beam for the second largest eigenvalue was not only directed toward Terminal 2 but also generated a null toward Terminal 1. If P_2 was less than the noise figure, the eigenvector beam set the nulls to the incoming signal waves and the SNR performance was degraded.

4. Effectiveness of proposed smart antenna in SDMA systems

To evaluate the effectiveness of the proposed smart antenna, an example system using the SDMA is considered here. In the example system, the SDMA is applied to two terminals and a base station uses the proposed smart antenna. Figure 4 shows the frame structure of the system. It was assumed that the frame synchronization was established within the error of the guard time for both the terminals. It was also assumed that the channel was already occupied by terminal 1 and the smart antenna tried to assign a new packet from terminal 2 to the same channel by using the SDMA technique. The frame was composed of two parts of training symbols and information symbols. In the first part, transmission power of the new user, terminal 2, was controlled such that they were less than that of the on-line user, terminal 1. Thus the proposed smart antenna generated the eigenvector beam and tried to establish synchronization with the new terminal. When the synchronization was established, all terminals transmitted such that the same level was received at the base station In the second

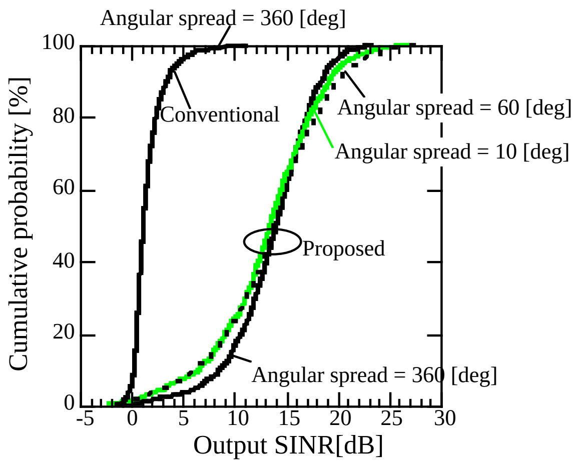


Fig. 6 Transmission quality just prior to synchronization

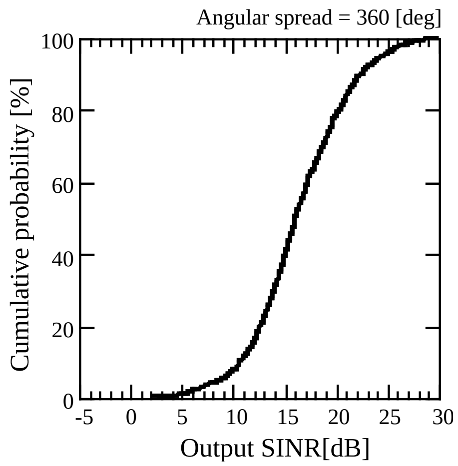


Fig. 7 Transmission quality of information period

part, a weight set for each user was determined using the MMSE algorithm Then, information data were transmitted with general power control, which realized equal received power levels at the base station. The simulation model is shown in Fig. 5. The DOA was uniformly distributed with angular spread of α degrees. Uniform distribution is considered over the angle α. The exponential delay profile was also considered as the propagation model. In this simulation, the power difference between the on-line user and the new user was set 10 dB and the delay spread was set to a small value, 0.1 Ts. This assumption was acceptable for the OFDM systems or the pre-equalizer implemented systems. Figure 6 shows the transmission quality after the first period of the training symbols. We performed 1000 trials uniformly varying the directions and the phases of incoming waves and evaluated the cumulative probability of the output SINR. If the angular spread decreased, the separation performance was slightly degraded. While even when the angular spread was equal to 10 degrees, less than 10% of the time an SINR < 5 dB was achieved. Figure 7 shows the transmission performance of this proposed system at the information period when the angular spread was equal to 360 degrees. Figure 7 shows that the output SINR of 10 dB was achieved almost 90% with the proposed smart antenna system. These results confirmed that this proposed system achieved signal separation.

5. Conclusion

In this paper, a new smart antenna suitable for SDMA systems was proposed. The proposed configuration was the mixture of eigenvector beam forming and power control scheme. It was shown that the proposed beam forming method can improve the user acquisition performance of multiple users, which is suitable for SDMA. Finally, The effect was exhibited in two-terminal models and it confirmed that the proposed smart antenna is effective in both narrow and wider angular spread and the output SINR of 10 dB is achieve in the two user case.

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References

[1] J. Ward, et al., “High throughput slotted ALOHA packet radio networks with adaptive arrays,” IEEE trans. Commun., Vol. 41, No. 3, pp. 460-470, March 1993.
[2] Y. Takatori, et al., “Novel adaptive array antennas for highspeed wireless access systems,” to be published in IEE AP2000, April 2000.
[3] A. W. Rudge, et al., “The Handbook of Antenna Design,” Peter Peregrinus Ltd., Vol. 2, 1986.
[4] N. Kikuma, “Study toward wider application of adaptive arrays,” Doctoral thesis of the faculty of engineering Kyoto Univ., 1987.