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SMART ANTENNA SYSTEMS ACTUALIZING SDMA FOR FUTURE WIRELESS COMMUNICATIONS

Keizo Cho and Toshikazu Hori
Nippon Telegraph and Telephone Corporation
1-1 Hikari-no-oka, Yokosuka. Kanagawa, 239-0847 Japan
cho@ieee.org

1. Introduction

Due to the recent popularity of multimedia and mobile communications, high data rates, a high level of reliability, and large channel capacity have become important requirements for wireless communication systems. Third generation mobile communication systems such as the IMT-2000 will be deployed in 2001 [1] and multimedia mobile access communications (MMAC) and higher data-rate wireless-communication systems are also being considered [2][3].

To achieve such high data-rate mobile communications, reducing multipath and co-channel interference is must to suppress intersymbol interference and improve the channel capacity since a broadband is required for the high date-rate systems. Space division multiple access (SDMA) is an attractive candidate to improve the channel capacity [4]. The SDMA uses smart antennas, which can adaptively form their radiation pattern suited for a considering environment as the base station antennas. SDMA uses smart antennas as the base station antennas, which can adaptively form their radiation patterns to suit the surrounding environment.

This paper first describes the techniques required for SDMA. Then results of our research on actualizing the SDMA such as a calibration technique, element arrangement, and beam control algorithm are presented.

2. Techniques required for SDMA

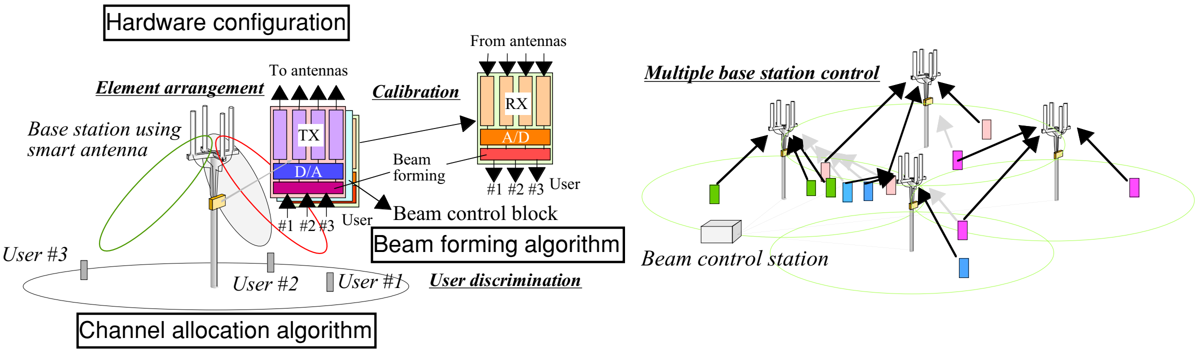
Figure 1 shows a diagram of SDMA. In SDMA, base stations that use the smart antenna form radiation patterns for each user and nullify co-channel interference for the user. To actualize SDMA, the following must be clarified.

A suitable hardware configuration of the base station for SDMA
Beam forming algorithm that discriminates among users
Channel allocation algorithm

The problem concerning hardware that must be overcome is determining a suitable antenna arrangement for SDMA because the performance of the user discrimination depends on the spatial correlation between the waves from the users, and the spatial correlation depends on the antenna arrangement [5]. Increasing the number of branches improves the user discrimination, however, hardware complexity and cost increase. Therefore, the number of branches should be optimized. Moreover, since the error in nullifying the interference severely degrades the transmission quality in SDMA, the error must be minimized. Thus, calibration is necessary to equalize the transmission characteristics of the antennas, cables, and transceiver connected to all the branches when applying the digital beam forming (DBF) configuration, which is generally used with the smart antennas. The beam-forming algorithm that discriminates among the users is important for establishing synchronization with the desired user and nullifying the interference from the other users. Since SDMA is generally used with other multiple access techniques, the algorithm obtaining the optimum channel availability by considering the multidimensional channel allocation should be clarified.

As shown in Fig. 1(b), by simultaneously gathering the information of all the branches from multiple base stations at a beam control station and controlling the antenna patterns of these base stations, the channel assignment over the area covered by the base stations can be optimized. This configuration improves the channel availability even when the traffic occurrence is concentrated in one of the cells.

In the following, our research activities for actualizing SDMA are described.



(a) Problem of actualizing SDMA *(b) Multiple base station control*

Fig. 1 Diagram of SDMA.

3. Calibration techniques

Figure 2 shows a configuration called the Automatic Calibration method using a Transmitting signal (ACT) which automatically calibrates the characteristics of the i-th transmitter, T_i, and the i-th receiver, R_i, that mostly strongly influence the smart antenna performance [6]. The compensation coefficient, $T_i R_1/T_1 R_i$, for equalizing the transmission characteristics of the transmitters and receivers is obtained by circulating the transmitting signals to the receivers. The configuration allows the removal of an additional signal generator for the calibration. Moreover, when using it in Time-Division-Duplex (TDD) systems, since the receivers are idol when transmitting signals, real-time calibration can be achieved. Figure 3 shows the pattern comparison with and without the calibration. An equilateral triangular array with the element spacing of 0.69 wavelengths is used for the antenna. The D and U indicated in the figure represent the angle of arrival of the desired and undesired signals with equal power. As shown in Fig. 3, the configuration improves the null depth by 24 dB more than that without calibration. The calibration technique for Frequency-Division-Duplex (FDD) systems considering antenna and cable characteristics will also be proposed at this conference [7].

4. Antenna arrangement for SDMA

When the absolute value of the spatial coefficient of the waves from the users decreases, the user discrimination becomes easier more tolerant. Thus, the antenna arrangement yielding the minimum absolute spatial coefficient is optimal for SDMA. Equation (1) expresses the average squared spatial coefficient (ASSC) depending on the element location.

$$\left|\rho\right|^2_{ave} = \frac{1}{N} + \frac{2}{N^2}\sum_{n=1}^{N-1}\sum_{m=n+1}^{N}\left(J_0\left(\sqrt{(x_m-x_n)^2+(y_m-y_n)^2}\right)\right)^2 \qquad (1)$$

In the equation, two users are considered that share a channel using SDMA. It is assumed that the incoming waves are plane waves with equal power and the angles of arrival of the users are uniformly distributed in a circular cell. The reason for using the squared value is to simplifying the equation. The value yielding the minimum squared value is the same as that yielding the minimum absolute value. Therefore, the element location yielding the minimum ASSC should be optimal. Figure 4 shows the relationship between the array radius and ASSC when a three-element circular array is used for the array configuration. As shown in Fig. 4, the minimum ASSC appears periodically. By avoiding mutual coupling with the element spacing of less than 0.5 wavelengths, we found that the radius of approximately 0.5 wavelengths is optimal for the three-element circular array.

5. User discrimination for SDMA

To assign multiple users to an identical channel using SDMA, the information of the angle of arrival is generally first obtained at a control channel. Then the channel allocation is determined by considering the angle separation between the users. However, since the Internet protocol that is popularly used for multimedia communications uses random access, user discrimination technique for simultaneous access is required. An eigenvector beam is one effective technique for user discrimination because the eigenvector beam does not require reference signals to form the beam [8]. Figure 5 shows an example of the eigenvector beam for each eigenvector [9]. The antenna uses a linear array with four elements and

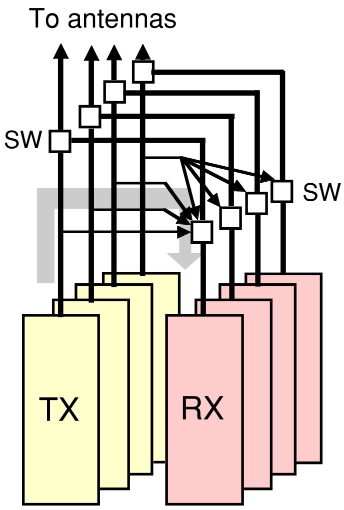


Fig. 2 Configuration of ACT

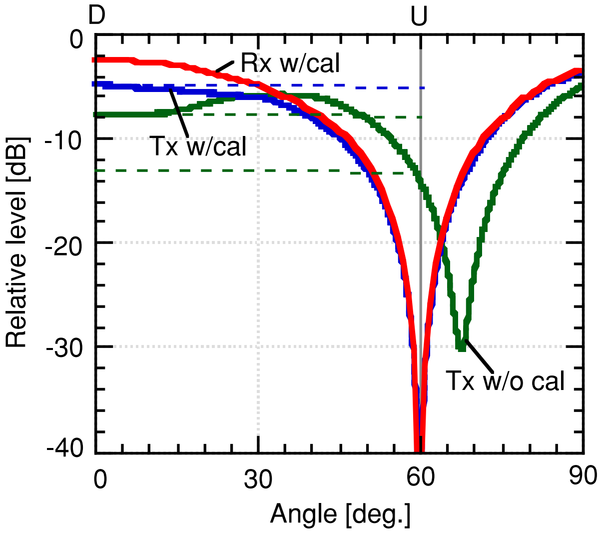


Fig. 3 Measured radiation pattern with and without ACT

three incoming waves are considered here. The incident angle and power of the waves are indicated at the top of the graph. The largest and smallest eigenvalues are expressed as λ_1 and λ_3, respectively. As shown in Fig. 5, since the eigenvector beam for the users with low power (small eigenvalue) nullifies the signal with higher power (large eigenvalue) and a sufficient signal to interference ratio (SIR) can be obtained, weak signals can be captured by using the eigenvector beam. Considering the above characteristics, a new power-control scheme for SDMA will be proposed at this conference [10].

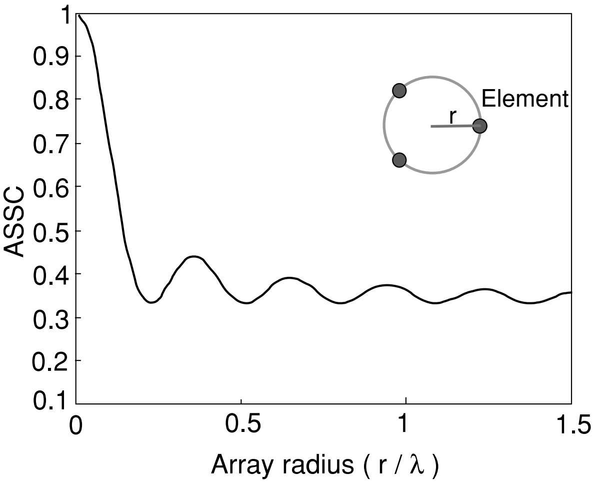


Fig. 4 Dependency of the ASSC on the radius of the circular array.

6. Multiple base station control

When communicating using the Internet protocol, the data traffic does not uniformly occur over time. Therefore, since the channel occupancy rate becomes high, a collision occurs and throughput is degraded. The channel occupancy rate of 1 means that the channel is fully occupied. Figure 6 shows the model for evaluating the data traffic distribution in a spatial domain. The number of base stations is N and a circular cell is assumed. The number of users is assumed to be 20 in a cell and the maximum line capacity of the network is 20 bits per frame per base station. The Bernoulli information source model is used as the data occurrence. The amount of information per demand is 60 Mbits. Figure 7 shows the relationship between the number of base stations that can be simultaneously accessed and the average delay time due to traffic congestion. In this scenario, it is assumed that smart antennas are used for all the base stations and the smart antennas ideally eliminate multipath and co-channel interference. As shown in the figure, when the channel occupancy rate per base station becomes high, data collision occurs and the average delay time increases. However, when allowing access to one of the three base stations near the users, the average delay time becomes half or one-third that of the access of one base station. Figure 8 shows the relationship between data quantity and the average delay time. The channel occupancy rate is 0.8 in the simulation. As shown in Fig. 8, when the data quantity is large, the average delay time is improved exponentially by using multiple base station control. This confirms the effectiveness of using multiple base station control.

7. Conclusion

This paper summarized the techniques required to realize Space Division Multiple Access (SDMA), an effective candidate for increasing channel capacity. Several techniques of actualizing SDMA were also presented. The concept of multiple base station control for SDMA was proposed and simulation results showed its effectiveness.

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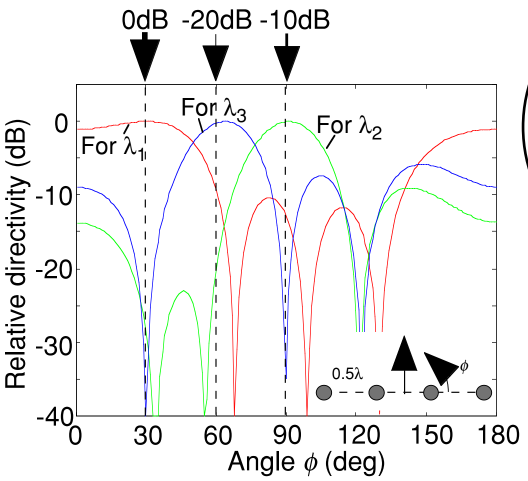

Fig. 5 Example of eigenvector beam.

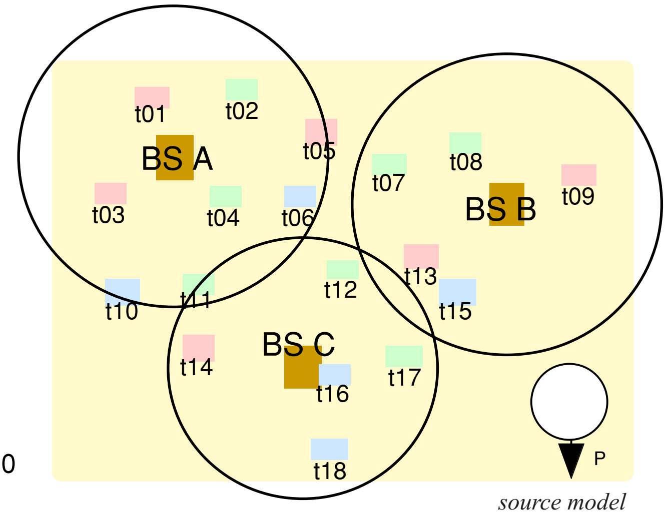

Fig. 6 Model for evaluateing data traffic distribution in a spatial domain.

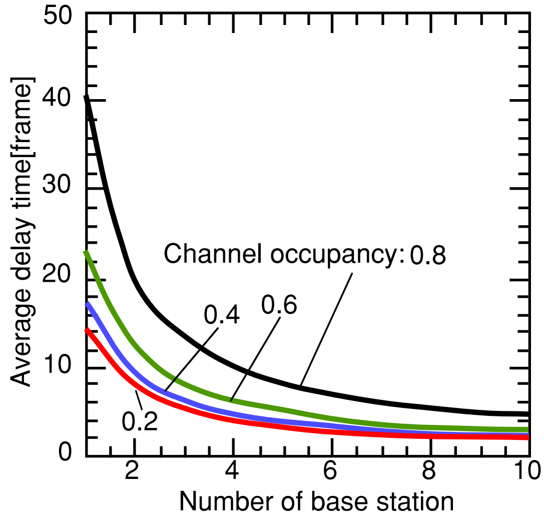

Fig. 7 Relationship between the number of base stations and the average delay time.

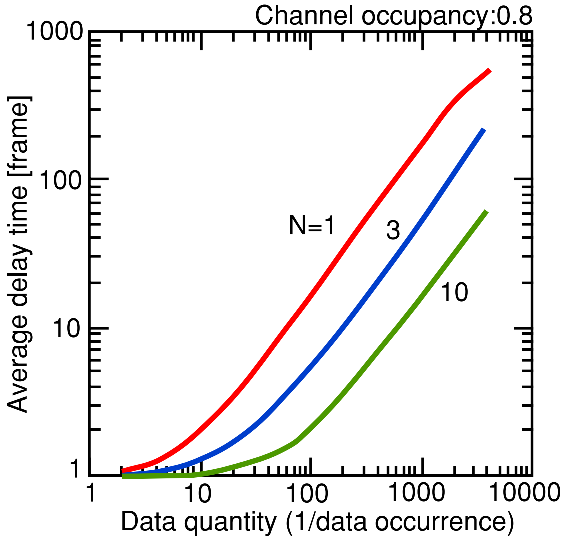

Fig. 8 Effectiveness of multi base station control.