Smart Antenna Testbed System for 3G Cellular Systems: An Overview of Field Trials

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1. Introduction

W-CDMA and cdma2000 that support multi-rate services such as the voice, the Internet and the image transmission have been launched in Japan. In these systems, the capacities are dominated by the high-rate users, because the high-rate signals are the dominant interference ones with much larger the powers for the other users. A smart antenna based on an adaptive array antenna technology is expected to suppress the interference signals in the spatial domain and to enhance the channel capacity of the systems.

In order to investigate the feasibility of a smart antenna system for the 3rd generation (3G) Cellular Systems, we developed a testbed system by installing in the base transceiver station (BTS) of the frequency division multiplex (FDD) wideband CDMA testbed system [1] and have been carried out field trials [2,3].

This paper describes the overview of the field trials with the smart antenna testbed system.
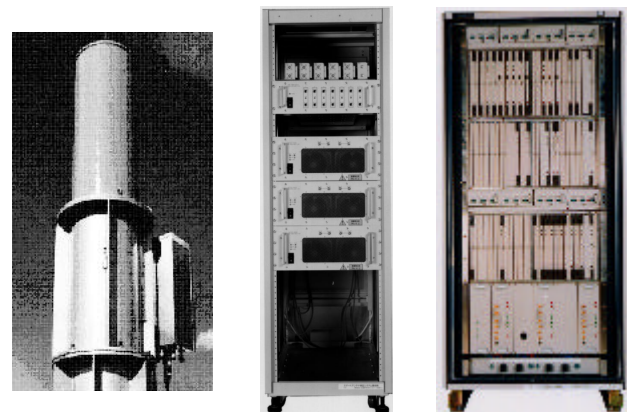
2. Smart Antenna Testbed System

Figure1 shows the array antenna, the front end (FE) and the base band (BB) equipment of the smart antenna testbed system. The block diagram is illustrated in Fig.2.

A) Array antenna

12-element circular array antenna was employed for the testbed system. The 8 antenna elements are mounted on the array antenna and the inner 6 antenna elements are connected with feeder cables. Thus, the array antenna covers 180-degree sector area. Each antenna element is composed of patch antennas aligned in vertical, forms the high-gain vertical beam, and adjusts the tilt angle with a phase shifter.

B) Uplink system

The uplink system supports 2 dedicated traffic channels (DTCHs). Our system employs two types of beamfomer; one is the fixed beamformer (FBF) and the other is the adaptive beamformer (ABF). The FBF aggregates the desired signals into a few beam space signals to reduce the multi-user interference for path timing detection. The ABF can perform the beamforming individually for up to 7 fingers with the weighting vectors to reduce the harmful interference in the spatial filtering, where the

(a) Array Antenna   (b) FE Equipment (c) BB Equipment
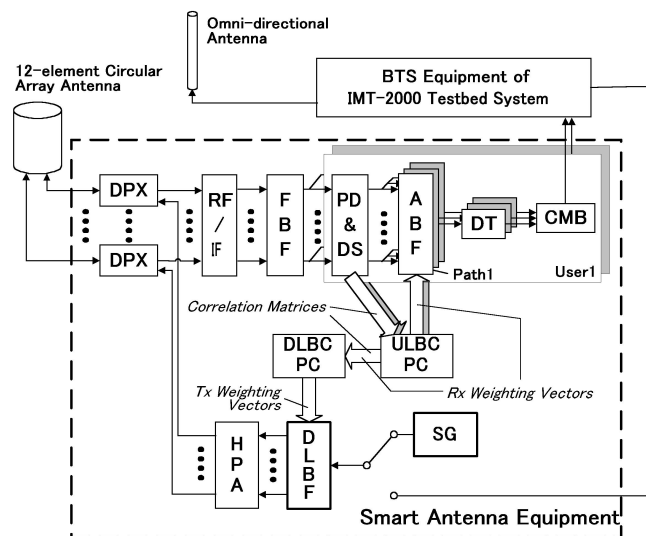
Figure 1: Smart Antenna Testbed System

Figure 2: Block Diagram of Smart Antenna Testbed System

finger means the despread signals detected at different path timings. The weighting vector is calculated in the uplink beam control PC (ULBC-PC) from the correlation matrices of the desired signals and the multi-user interference and noise. The correlation matrices are obtained from 6-element despread signals by accumulating the correlations in parallel over a number of time slots. Then, the period of accumulating slots is much longer than that of the transmit power control (TPC), it is considered that the ABF does not corrupt the TPC.

C) Downlink system

The downlink beamforming is implemented by an RF unit composed of phase-shifters and variable attenuators. The weighting vector that is dedicated to the downlink beamformer (DLBF) is calculated in the downlink beam control PC (DLBC-PC) based on the uplink weighting vectors and the correlation matrices.

3. Field Trials

We have evaluated the performance of the uplink and downlink beamformings in order to investigate the effects on the FDD wideband CDMA system in real field environment.

3.1 System configuration

The field trials were carried out around our laboratory which lies in Kamifukuoka-shi Saitama Japan, which is categorized as suburban area. The array antenna was installed on the rooftop of the building, whose height was 26 meters from the ground.

The system configuration of the field trials is illustrated in Fig. 3. The mobile stations (MS1 and MS2) and a CDMA signal generator as an interference signal source (Fig.1) were used with the smart antenna BTS. The experimental vehicle was equipped with the MS1 to measure in the field. The MS2 is installed inside the building and connected to the smart antenna BTS with coaxial cables. The transmitting signal of MS2 is combined with the RF signals received at the array antenna through a pseud-propagation equipment (PPE), which is a facility to control the direction of arrival (DOA) of the uplink signals by controlling relative phases of the signals. In the field trials we set up PPE in a way comparable to the signal of MS2 coming from the south or southwest (0 or 60 degrees).

Figure 4 show the routes of the vehicle (MS1) in the field trials.

3.2 Uplink Beamforming

The criterion of the basic uplink beamforming algorithm that we adopted in the testbed system is based on the maximizing signal-to-noise ratio (MSN) algorithm by solving Wiener solution directly. The procedure to optimize the criterion resembles the sample matrix inversion (SMI) with accumulated the correlation matrices. For the steering vectors, the eigenvector of the correlation matrix of the desired signal is used. The uplink weighting vectors are calculated the following equation,

$$W_{Rx} = \left([M_U] - [M_D]/G_p \right)^{-1} \cdot \mathrm{eigvec}\left([M_D] - [M_U] \right), \tag{1}$$

where $[M_D]$ and $[M_U]$ denotes the accumulated correlation matrices of the desired and undesired signals respectively, eigvec(*) represents one of the eigenvectors of *, and G_p denotes the processing
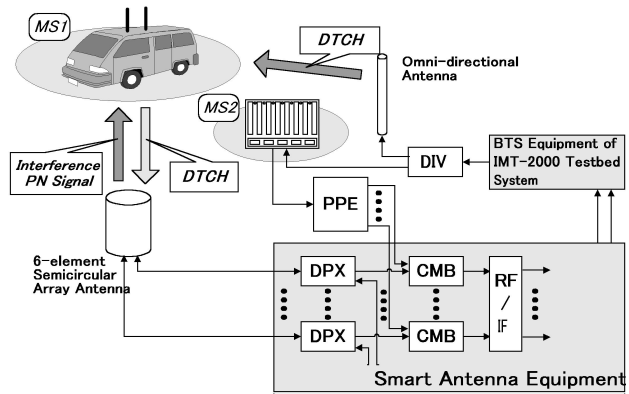

Figure 4 : Field Trial System (Downlink: Null / Beam Evaluation for Downlink Beamforming)
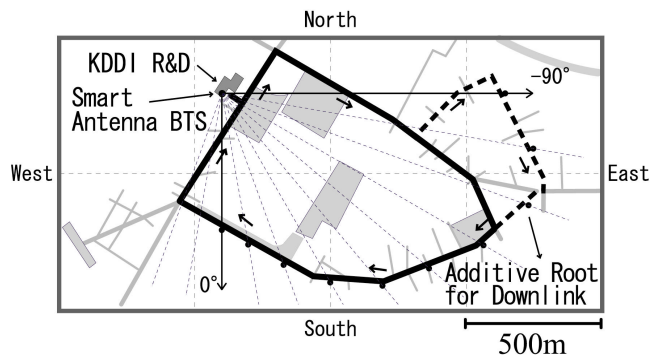

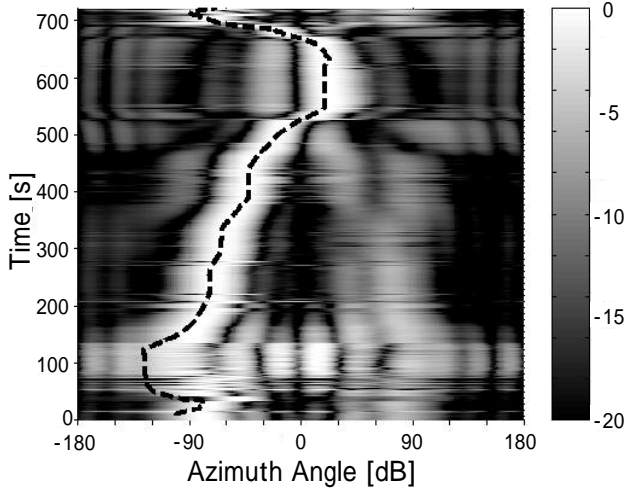*Figure 3 : Field Trial Routes (In Kamifukuoka-city, Japan)*

Figure 5 : The Example of Uplink Beamforming Performance: Algorithm WIC1 (Black dashed line indicates the direction of MS1 and that of MS2 is 0 degree)

Figure 6 : The Cumulative Probability Distribution Performances of Relative MS Transmission Power to That of Fixed Sector Beam Reception.

gain of the desired signal.

The testbed system is capable of performing the uplink beamforming on respective fingers detected in the time domain, and carrying out the beam diversity combining of the orthogonal beams formed in each finger. For the weighting vectors of the orthogonal beams, the eigenvectors of the correlation matrices are utilized. The uplink beamforming algorithms we evaluated are summarized in Table 1.

The results in the field trials are shown Figs. 5 and 6. Fig. 5 shows the example of uplink beamforming performance against MS1 with the uplink beamforming algorithm WIC1, when the beamforming control period was set to 1 second. The horizontal axis is azimuth angle at the BTS, the vertical axis is time and the shading is relative beam gain to the maximum beam gain. The black dashed line also indicates the direction of the MS1 that was calculated from the GPS data. It is considered that the beam and null were steered in the directions of MS1 and MS2 respectively.

Figure 6 shows the cumulative probability distribution performances of relative transmission power of MS1 to that of the fixed sector beam reception. All algorithms reduce MS transmission power more than 4 dB over that of sector beam at cumulative probability 95 %. The performances of STC1 and WID1 are almost the same. The performance of WID1 and WIC1 that has smaller calculation amount are almost the same. WIC2 was the best performance out of the 4 algorithms, because it is consider that the beam diversity works against multipath received simultaneously.

Table 1: Uplink Beamforming Algorithms

STC1	1st eigenvector of 1st finger (only beam-steering)
WID1	Wiener solution with 1st eigenvector against each finger as steering vector
WIC1	Wiener solution with 1st eigenvector of 1st finger against all finger as steering vector
WIC2	Wiener solution with 1st and 2nd eigenvectors of 1st finger against all finger as steering vector

'1st eigenvector': The eigenvector corresponding to the maximum eigenvalue.
'1st finger': The finger having the maximum power

3.3 Downlink Beamforming Evaluation

In FDD-CDMA systems, the differences of propagation characteristic as well as array antenna element radiation characteristics in the uplink and downlink frequencies should be considered. Because beams and nulls does not agree with DOA of desired and undesired signals respectively when uplink weighting vectors are directly utilized for downlink beamforming.

The propagation characteristics of the transmitted and received signals at a BTS are regarded as the same distribution in the space domain concentrated in the direction of a MS with narrow angular spread, when the beamforming is performed on the accumulated despread received signals in longer interval than fading signal fluctuation.
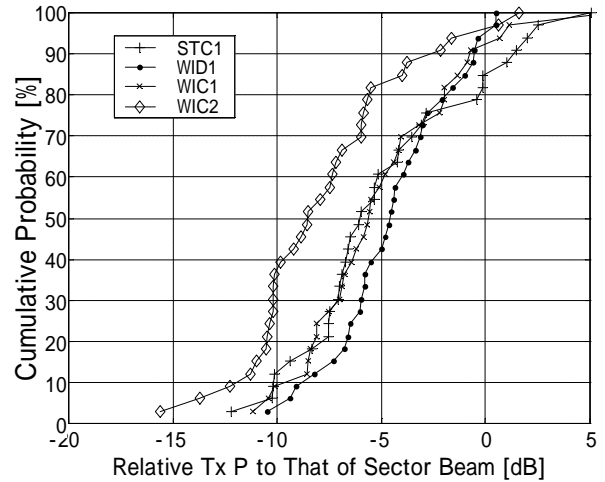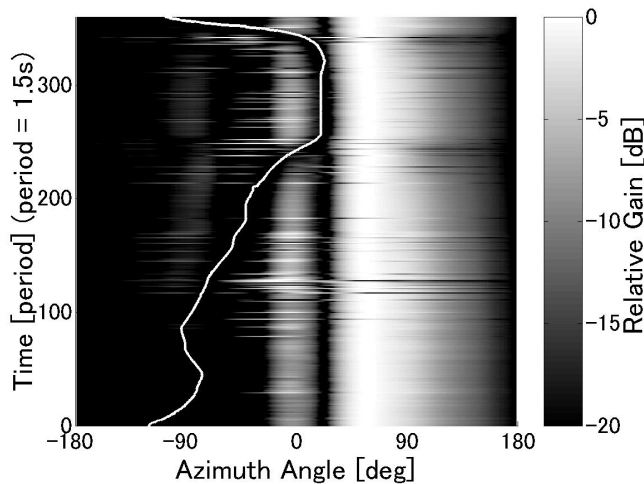
Figure 7 : The Example of Dowlink Beamforming Performance: TR-BPCal Algorithm (white line indicates the direction of MS1 and that of MS2 is 60 degree)
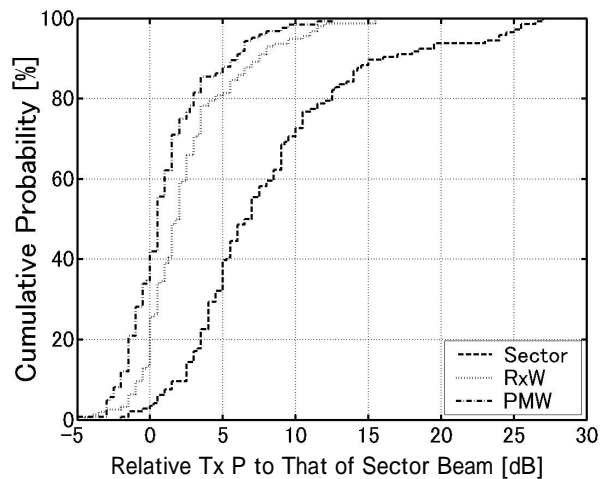

Figure 8 : The Cumulative Probability Distribution Performances of Relative BS Transmission Power to That of No Interference.

For the above reason, we developed the downlink beamforming algorithm to calibrate the downlink beam pattern so as to fit to that of the uplink based on the uplink weighting vector and array antenna element radiation characteristics vector data in the uplink and downlink frequencies (TR-BPCal algorithm) [3,4].

The results in the field trials are shown Figs. 7 and 8. Fig. 7 shows the example of downlink beamforming performance against MS2 with the TR-BPCal algorithm, when the beamforming control period was set to 1.5 seconds. The white line indicates the direction of the MS1. It is considered that the null and beam were steered to the directions of the MS1 and MS2 respectively..

Figure 8 shows the cumulative probability distribution performances of relative BS transmission power ratio to that of no interference signal on MS1 with respective down beamforming algorithms. The parameter 'RxW' indicates the performance when the uplink weighting vector is utilized for the downlink one directly and the parameter 'PMW' reveals the performance when the downlink weighting vector is calculated with the TR-BPCal algorithm. Compared with the performance in the case of the sector beam, those in the both case with RxW and PMW reduce the MS transmission power more than 15 dB in the cumulative probability 95 %. The PMW outperforms the RxW about 3 dB in the cumulative probability 95 %.

4. Conclusion

We have described the field trials of the smart antenna testbed system. The experimental results prove that the uplink and downlink beamformings can work very well and reduce the MS and BS transmission power respectively.

Acknowledgement

References

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