A Study on the Configuration of Adaptive Array Antenna Equipment and the Performance of DOA Estimation and Beam Forming in an Anechoic Chamber

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1. Introduction
The directivity control of a base-station antenna for mobile communication can improve channel capacity by reducing co-channel interference and multipath fading. We have developed the experimental system to evaluate the performance of antenna directivity control using adaptive array antenna technology. Our approach to antenna directivity control utilizes adaptive beam forming based on the estimated DOA for mobile-stations. This approach can not only easily adjust beam pattern in FDD system, but also is independent of modulation or transmission data format. In this paper, we propose a configuration of adaptive array antenna equipment utilizing adaptive beam forming based on the results of DOA estimation, and evaluate its performance in an anechoic chamber [1][2]. In section 2, the hardware configuration of this equipment is described, and signal transmission and digital sampling are explained. In section 3, we explain the signal processing flow that consists of the MUSIC algorithm for DOA estimation, the fast DOA algorithm [3][4] for DOA tracking, the Spatial Smoothing method for the DOA estimation of multipath waves, and the DCMP algorithm based the estimated DOA for weight adaptation. In section 4, we report on the experimental results of beam pattern measuring, DOA estimation and tracking and interference suppression characteristic.

2. Hardware Configuration
Fig. 1 shows the configuration of the 2.3GHz-band adaptive array antenna equipment. A photograph of the equipment is shown in fig. 2 and system parameters are listed in Table 1. This equipment consists of an array antenna, RF circuit, DOA estimation and tracking block, weight adaptation block and beam-forming block. Initially, 8-element micro-strip linear array antenna receives RF signals. The distance between adjacent antennas is half a wavelength, and two dummy elements are placed at both ends of the antenna elements to equalize the characteristics. The RF circuit converts RF (2.335GHz) signals to IF signals (450kHz) which is situated behind the array antenna. The IF signals are carried at a distance of 10m by eight coaxial cables and fed into three signal processing blocks equipped with A/D converter units.

When signal transmission between array antenna and signal processor is done by RF signal, the composition of array antenna is simplified. However, the accuracy of DOA estimation deteriorates and the desired beam pattern is not realized because the phase characteristic between each array element changes based on how the RF cables are set up. On the other hand, IF signal, or baseband signal can be thought of as a signal that does A/D sampling. In regard to baseband sampling, though the sampling rate can be lowered, the offset of I, Q signals influences the phase accuracy. For these reasons, we adopted IF signal transmission between the array antenna and the signal processor, as well as IF sampling.

3. Signal Processing flow
3.1 DOA estimation and tracking
In the DOA estimation and tracking block, we can select the algorithms for DOA estimation, such as, MUSIC, Spatial Smoothing MUSIC (SS-MUSIC), ESPRIT, and the fast DOA algorithm. In this paper, we report the experimental result using MUSIC, SS-MUSIC and the fast DOA algorithm. MUSIC and SS-MUSIC are based on the eigen structure of the received correlation matrix. In calculation, they use 1024 digitized sampling data from each array element. The processing time takes about 70 ms, including the data transfer time.

On the other hand, the fast DOA algorithm uses two digitized data that consist of real and imaginary part of the received signal, and the processing time takes about 0.66 ms. However, this algorithm needs the initial value of DOA in the calculation of DOA estimation because of the characteristics of the algorithm. In concretely, we estimate the DOA using MUSIC or SS-MUSIC, and then we repeat 1000 times calculation using the fast DOA algorithm (fig.3). We presume that SS-MUSIC is used in multipath environment, because SS-MUSIC can estimate the DOA of coherent signals.

3.2 Adaptive Weight Control

In the adaptive weight control block, the optimum weight vectors of each array element are calculated based on the result of DOA estimation in the DOA estimation and tracking block. We can select the DCMP algorithm for the weight calculations. Using DCMP, a peak of array beam pattern is formed in the direction of desired signal and nulls are formed in the direction of undesired signals. The calculated weight data output to the beam forming block.

4. Anechoic Chamber Experiment

In an anechoic chamber, we experiment following terms. The distance between Tx antenna to Rx antenna (8-element array antenna) is about 10m.

4.1 Beam pattern measurement

When beam forming is done by digital processing, it is necessary to measure beam pattern of array antenna by digitized data. In our equipment, the digitized baseband signal was converted in D/A and the strength of this signal was measured with a digital oscilloscope, synchronizing with the trigger pulse of the antenna rotator. Fig. 4 shows each measured beam pattern when the direction of main beam was swept from 0 to -90° every 10°. Here, all elements have the same weight. The maximum error of the peak direction is 5° within range from 0 to -60°. However, the peak direction and the antenna gain deteriorate after -70° because of the characteristics of the micro-strip antenna elements that show in fig. 5.

4.2 DOA estimation and tracking results

Two transmitters were located at the interval of 20° in front of the array antenna. Here, one transmitter sent CW and the other sent the modulation signal (π/4-shift QPSK, 42 kbps). We measured the estimated DOA by rotating the Rx from -60° to 60° every 10°. Fig.6 shows the DOA estimation results using MUSIC. The mean estimation error is 1.7°.

Next, we confirmed the performance of DOA estimation in the case that two coherent signals came. Fig. 7 shows the MUSIC spectrum in following cases; (a) One transmitter sent CW and the other sent the modulation signal. (b) Two transmitters sent CW. The line and the solid line indicate the result using MUSIC and SS-MUSIC, respectively. In calculation of SS-MUSIC, we set the number of sub-array elements as 5. From fig. 7, we can see that the estimated DOA deteriorates in (b) when MUSIC used, while SS-MUSIC obtained the high resolution in both cases.

Fig. 8 shows the performance of the DOA tracking when the array antenna was rotated at a speed of 4°/s. We set one transmitter in front of Rx. The horizontal axis shows the trial number of the estimation using MUSIC.

4.3 Interference suppression characteristic

Fig.9 shows the measurement results of the BER performance when we set two transmitters in front of the array antenna with an interval of 5. The modulated signal was transmitted from 0° and the CW was transmitted from -5° as a interference signal. We measured the BER in three cases; Case 1: A single element of array antenna received, Case 2: 8-element of the array antenna received with the weight control that made a peak of beam
for the desired direction. Case 3: 8-element of the array antenna received with the weight control using DCMP. As for case 2, the BER improves about 2-5 dB, and as for case 3, the BER improves about 15 dB, as compared to Case 1. Fig. 10 shows the beam pattern using DCMP, and it can be confirmed that the peak of the beam is formed in the direction of the modulation signal, and the null is formed in the direction of the interference.

5. Conclusion

This paper proposes the configuration of the 2.3GHz-band adaptive array antenna equipment, and reports the performance of DOA estimation by MUSIC and interference suppression by the DCMP beam forming in an anechoic chamber. The accuracy of DOA estimation by MUSIC is 1.7° and by using Spatial Smoothing, the resolution of DOA estimation is improved. The BER improved about 15dB by DCMP. In the near future, we will evaluate the performance in a multipath fading environment, such as that an urban area.

References


Table 1. System parameters

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<tr>
<th>Parameter</th>
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<td>Modulation</td>
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<td>Array antenna</td>
<td>8-element linear</td>
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<td>Antenna element</td>
<td>Micro-strip antenna</td>
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<td>IF frequency</td>
<td>450kHz</td>
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<td>12bit, 1.8MHz</td>
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<td>The fast DOA algorithm</td>
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<td>Weight adaptation</td>
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<td>AD converter 2</td>
<td>12bit, 200kHz</td>
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Fig. 1 Configuration of the equipment

Fig. 2 Photograph of the equipment

Fig. 3 DOA estimation and tracking process flow