An Experimental Study of the DOA Estimation Using the Fast DOA Algorithm in Urban Area

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Abstract
We report on our experimental estimation of the direction of arrival of a signal by using the adaptive array antenna equipment in an urban area. The result demonstrates the DOA estimation using a fast DOA algorithm and improved BER performance by using this estimated DOA.

1. Introduction
In a macro- or micro-cell system with a radius of 500-2000 m, a one to two GHz frequency is now used, but it has become a crowded. The number of personal digital cellular system (PDC) and personal handyphone system (PHS) subscribers in Japan has reached 60 million. Moreover, the available services have grown from voice to data to picture. This means that techniques that effectively reuse frequency resources while improving a quality of signal (QoS) are required.

The use of the adaptive array antennas in mobile communication systems is one technique to improve channel capacity or QoS by reducing co-channel interference and multipath fading. An array antenna is installed at a base station (BS), the desired signals can be received while undesired ones can be suppressed. This results in an improvement of the quality of the up-link signal. Moreover, by controlling the antenna gain at the transmission point, the BS can avoid transmitting in undesired directions. As a result, the quality of the down-link signal also improves because interference signals from other BSs are suppressed at the users' position. At the viewpoint of the frequency reuse problem, the improvement of CIR makes it possible to reduce the channel reuse distance keeping the required QoS.

To achieve the type of control described above, being able to estimate the direction of arrival (DOA) of a signal and to determine the antenna weights are the important problems to surmount. We need to especially clarify the performance of DOA estimation when the target user is moving at high speed.

In this paper, we report on the performance of our DOA estimation of a user moving at 40 km/h in an urban area with a particular condition. In Section 2, we describe the system concept of using an array antenna at a BS. In Section 3, we explain our experimental equipment and report the results of our experiments in an urban line-of-sight (LOS) environment. We summarize our report in Section 4.

2. The mobile communication system using adaptive array antenna
2.1. System concept
Figure 1 shows our concept using adaptive array system, in which the BS has the array antenna. It seeks the directions of a mobile station (MS) and forms a beam to its target. The system improves not only the carrier to interference ratio (CIR) and bit error ratio (BER) but also optimizes the frequency resources through adaptive beam control. We developed this system to confirm the characteristics for an accurate DOA estimation and the BER performance caused by the array weight control.
2.2. Problems using an array antenna

In the micro-cell system, the BS is situated at a high position to cover a service area of about one km in radius. Generally, a user situated near a BS tends to be on a LOS with the antenna and transmits a signal with a high signal-to-noise ratio (SNR). This user’s signal changes direction at a high velocity. On the other hand, a user who is far from a BS tends to be situated in a non LOS (NLOS) and transmits a signal with a low SNR, and whose changes in direction are at a low velocity. Consequently, we needed two types of DOA estimation for our experiment.

The multiple signal classification (MUSIC) [2] and estimation of signal parameters via rotational invariance techniques (ESPRIT) algorithms [3] are based on the eigen structure of the signal. They can estimate the DOA, even when the signal has a low SNR. A recursive algorithm using linear approximation for fast tracking (here, called the fast-DOA algorithm) has been proposed to reduce a calculation complexity. It can calculate the DOA of a user moving at high velocity, but it requires a high SNR and the initial value of the DOA [1]. To determine the initial value, we need to combine another algorithm with the fast-DOA algorithm. We use the MUSIC algorithm to obtain the initial value.

2.3. Experimental equipment [4][5]

Figure 2 shows a block diagram of our experimental adaptive array system. Table 1 shows the experimental system parameters. The array antenna system consists of an array antenna block, frequency conversion block, and digital processing block. The array antenna has eight equi-spaced elements with micro-strip patch antennas. The distance between adjacent antennas is half a wavelength. A dummy element is placed at each end of the elements to equalize their characteristics.

The frequency 2.335 GHz of the RF signals received at the array elements is converted to 450 kHz by the down converters and analog filters in the frequency conversion block. Then, the IF signals are sent to the digital processing block, which consists of an A/D converter, DOA estimation block, weight adaptation block, and beamforming block. The IF signals are digitized by the A/D converter, which operates at a 1.8-MHz sampling clock rate with 12-bit resolution. The digitized IF signals are then converted to I and Q base-band signals. The data bus transfers the I/Q channel data to the DOA estimation, weight adaptation, and beamforming blocks. The DOA estimation block applies to the received signal one of three types of DOA estimation algorithms: MUSIC, ESPRIT (eigen-space-based algorithm) or the fast-DOA algorithm.

In our experiments, the DOA estimation block used 1024 samples from each element for the MUSIC calculation. For the fast-DOA algorithm, one data sample was used for the calculation. The weight adaptation block calculates the optimum weight vector based on the estimated DOA. The beamforming block synthesizes the data by using the calculated weight vector.

To measure the BER of a signal coming from the moving transmitter, we recorded the output level of the synthesized signal and its BER every second.

3. DOA estimation experiment in urban area

Figure 3 shows the grand plan for the experimental environment. The width of the road on which we experimented was about 20 m and the average height of the buildings along the road was more than 20 m. The BS (developed system) is mounted on the top of a building. Then above ground height of array antenna installation is 60 m. For our experiment, we selected a course which lies in front of the building the antenna is mounted on, because it keeps LOS with BS. We defined the start and end positions of the course based on the antenna characteristics for the vertical directions. The elevation angle was less than 10° over the course. The distance between the start position and the antenna was about 562 m, and between the end position and the antenna was about 242 m. The start position was -15.7° and the end position is –17° from the antenna. The mobile transmitter (MS), which was situated in a vehicle, that was driven at 40 km/h along the road. The transmission power of the MS was 6 dBm. The BS received the signal and calculated the DOA using MUSIC and fast-DOA algorithm. The results are shown in Fig.4.

For each estimation using MUSIC (initial value), we calculated fast-DOA algorithm 1000 times. The figure shows that the fast-DOA algorithm estimated the DOA as roughly –16°.
Next, to confirm the feasibility of DOA estimation, we controlled the weight of the array antenna at the beamforming block by adjusting the phase of the signals using the estimated DOA. We measured the BER performance of the signals received by using 1-element and 8-element arrays with phase control. Figure 5 shows the BER vs. the level of received power. The horizontal axis shows the power of the synthesized signal and the vertical axis shows its BER performance. From this figure, we can see that the BER improves more than 8 dB by controlling the weight in accordance with the estimation result. This indicates that the array could synthesize the signals from each element with the same phase. That is, the error of the estimated DOA is an allowable value for demodulation control, though the estimated DOA fluctuates around –16 degrees.

4. Conclusions

We experimentally estimated direction of arrival of a mobile station that was moving at 40 km/h in an urban area. The results show that the fast-DOA algorithm can estimate the DOA with an allowable error, and by using this estimated DOA, the synthesized signal can be improved more than 8 dB.

In the near future, we will examine the effect of the DOA estimation in an NLOS environment.

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References

Table 1 Experimental system parameters

<table>
<thead>
<tr>
<th>Array antenna</th>
<th>microstrip patch antenna</th>
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<tbody>
<tr>
<td>Polarization</td>
<td>vertical polarization</td>
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<tr>
<td>RF frequency</td>
<td>2.335GHz</td>
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<tr>
<td>IF frequency</td>
<td>450kHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>$\pi/4$-DQPSK, 42kbps</td>
</tr>
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</table>

Fig. 3 The experimental environment

Fig. 4 Estimated DOA using MUSIC and fast-DOA algorithm.

Fig. 5 BER vs. level of the received signal power