Downlink beamforming method based on delay profile in transmitting antenna arrays for FDD communication systems

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1 Introduction

Smart antenna is a powerful processing for interference reduction and signal extraction using antenna arrays. Consequently, interest in this technique has been increasing in order to improve capacity and coverage in mobile radio communications [1][2]. Of practical interest is the use of receiving antenna arrays in the uplink since it is easy to enhance the quality by various equalization algorithms. Recently, with a view to reducing interference to undesired mobile terminals, several studies [3][4] have focused on the downlink beamforming algorithm using smart antenna.

In the Time Division Duplex (TDD) system, it is effective to employ the same beamforming weights in the downlink as were obtained in the last reception time slot because the reciprocity of propagation channel characteristics holds. On the other hand, in Frequency Division Duplex (FDD) system, the receiving weights cannot often shape a desired transmitting beam pattern since fading in uplink is uncorrelated with that in downlink and the frequency on which array response depends is different [5]. Beamforming based on the DOA is a good solution because DOA is a parameter regarding which correlation between uplink and downlink channels can be high. For example, the Multiple Signal Classification (MUSIC) algorithm [6], a super-resolution DOA estimation method, is employed to find subscribers' directions [7], and another method also computes beamforming weights using eigenvalue decomposition of received signals [4]. However, these methods are subject to a significant problem in that the calculation amount required for transmitting null control is large.

This paper proposes a downlink beamforming method which requires a small amount of calculation and is also applicable to the FDD system base station antenna arrays. This method mainly consists of two-step estimation of the DOA of desired user's signal on the uplink and then beamforming using this information.

2 Beamforming method

The proposed transmitting beamforming method is harmonized with the previously proposed receiving smart antenna [8] which measures delay profiles of each antenna element and then implements adaptive array processing and path diversity combining. This transmitting beamforming method controls a beam pattern by utilizing the measured delay profiles at the receiver.

The composition of the proposed smart antenna base station is shown in Fig. 1. This antenna array consists of the N-element circular uniform array with interelement spacing of a half wavelength. The receiver selects some elements from plural directional antennas based on the results of measured delay profiles. Here, K $(K < N)$ elements with larger received power for a desired wave are selected as the input of receiving adaptive arrays [8].

At the transmitter side, the proposed method consists of two-step DOA estimation and beam pattern shaping using this information. At the first step, the DOA of a desired wave is roughly estimated in consideration of the directivity of antenna elements by comparing powers of a desired wave in each measured delay profile. The likelihood of existence of desired wave is limited in the range of narrow angular width because some directional elements do not receive a desired wave and received powers of every element are different. At the next step, the null pattern is formed by using only two elements with larger received power and the DOA ϕ_0 of a desired wave is estimated by scanning in the above range of the coarse DOA and monitoring the level of the synthesized outputs. Here, null pattern scan is carried out in every degree by digital signal processing after storing a received data burst. For the purpose, preliminarily measured or analytically obtained element patterns are memorized. Due to the observation of peaks of outputs, the DOA estimation by null pattern scan has greater potential accuracy than beam scan estimation.

Transmitting weights are determined by the excitation amplitude which is proportional to the received power of each element to point a main beam into the direction of ϕ_0 using the selected antenna elements. By this procedure, the amount of calculation required for DOA estimation can be drastically reduced compared with the high-resolution DOA estimation method such as MUSIC.

3 Simulation Result

The computer simulation was examined in order to evaluate the proposed method. Regarding simulation specification, it is assumed that antenna element directivity is cosine beam with beamwidth of 90° and total number of directional elements N is eight and three antenna elements are selected from them (K=3). The transmitted signal is modulated by QPSK and root roll-off filter (roll-off factor = 0.5) is used at both transmitter and receiver side. The burst format consists of 150-symbol data and 64-symbol preamble. The preamble includes a known pseudo-noise (PN) code as a temporal reference sequence. PN length P is 63. The delay profiles are measured by sliding correlators which carry out the convolution per symbol between the received preamble and the training sequence.

Fig. 2 and 3 show the DOA estimation results under the condition that a desired wave, one-symbol delayed wave and two-symbol delayed wave are incident from the direction of ϕ_0, $+20°$ and $-20°$, respectively. (This is shown as $[\phi_0, 20, -20]$ in this figure.) The power of all delayed waves is equal to a desired wave and the average carrier-to-noise ratio (CNR) of one element is 20dB in Fig. 2 and 10dB in Fig. 3. The number of estimation trials is ten times per degree of ϕ_0. From these figures, the standard deviation of the DOA estimation error σ is 1.03° at CNR = 20dB and 3.1° at CNR = 10dB and its resolution is much higher compared with directional beamwidth.

The comparison of the number of calculations between the proposed method and conventional MUSIC[6] is shown in Table 1. It is assumed that uniform circular antenna arrays are employed and the peak scan is carried out at intervals of one degree. N, L, M, and P are the number of antenna elements, the number of incident waves, the number of snapshots, and PN length, respectively. This table indicates the number of mathematical instructions per peak scan and except for the above, which are such calculation as delay profile measurement or correlation matrix computation and so on, separately. The proposed method has a great advantage in that the eigenvalue decomposition is not required. When the processing complexity is defined as the sum of the instruction number of addition, multiplication, and division, more than 35-fold improvement is derived from this table in the case of $N = 8$, $L = 1$(desired wave only), and $M = P = 63$. Omnidirectional antenna elements are used in MUSIC. It is confirmed from this result that the proposed method has the advantage of much lower complexity than MUSIC.

The transmitting beam pattern of $\phi_0 = 50°$ is shown in Fig. 4. In this figure, a solid line indicates excitation amplitude which is proportional to the power of measured delay profiles in selected antenna elements, a dashed line uniform excitation amplitude, and a dotted line the case that only one element of the maximum received power is used. It turns out that lower sidelobe can be realized by adopting weights which are proportional to the received power and

Table 1: The comparison of the number of calculations between the proposed method and MUSIC

Item	proposed	MUSIC
Eigenvalue decomposition	0	1
Peak scan	23	360
Multiplication per a scan	8	$4N^2 + (6 - 4L)N - 2L$
Addition per a scan	6	$4N^2 + (4 - 4L)N - 3$
Division per a scan	4	2
MUX except the above	$6NP$	$4N^2M$
ADD except the above	$4NP - N$	$4N^2M + 2M - 2$
DIV except the above	N	2

the beamwidth can be narrowed compared with the case of only one element transmission, namely, a high-gain beam is formed.

4 Conclusion

The downlink beamforming method applicable to FDD system at a base station was proposed. This method is based on the DOA estimation for a desired wave. Computer simulation results showed low complexity and high accuracy for DOA estimation and good transmitting beam pattern. In future work, we intend to study transmitting beam control in which nulls are pointed in the directions of interference waves.

References

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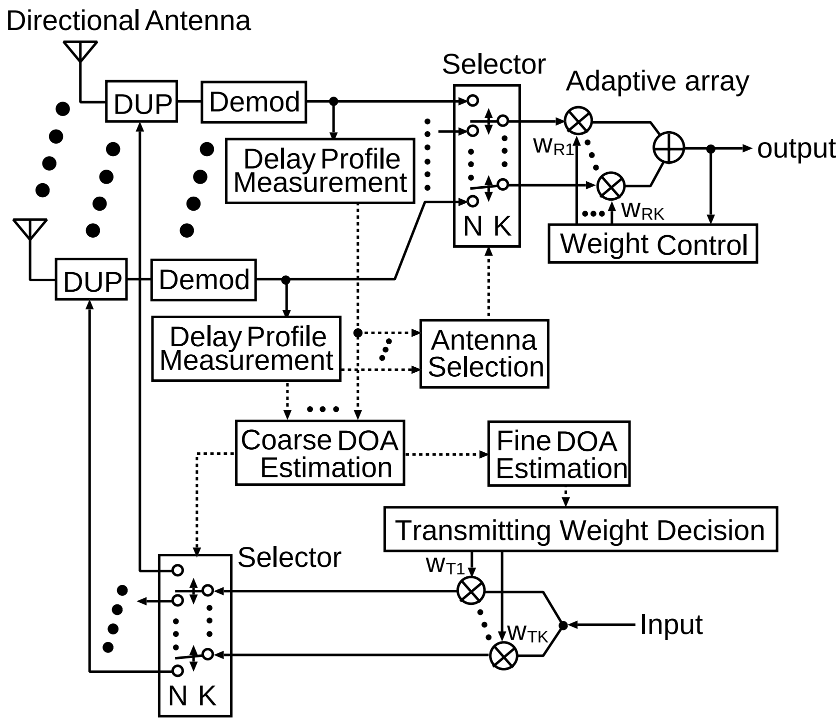

Figure 1: Block diagram of the proposed method

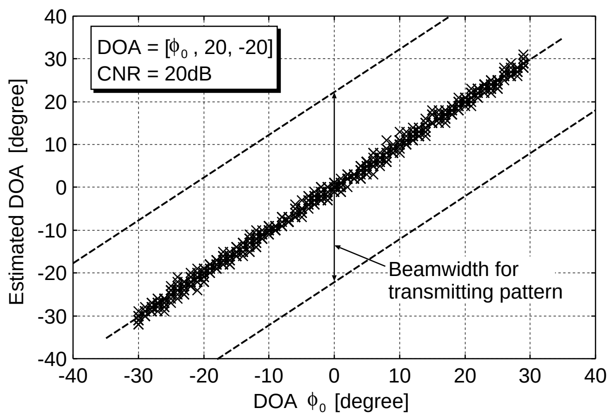

Figure 2: DOA estimation result(1)

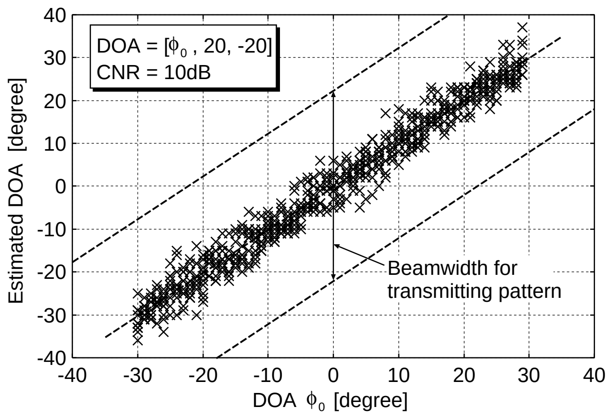

Figure 3: DOA estimation result(2)

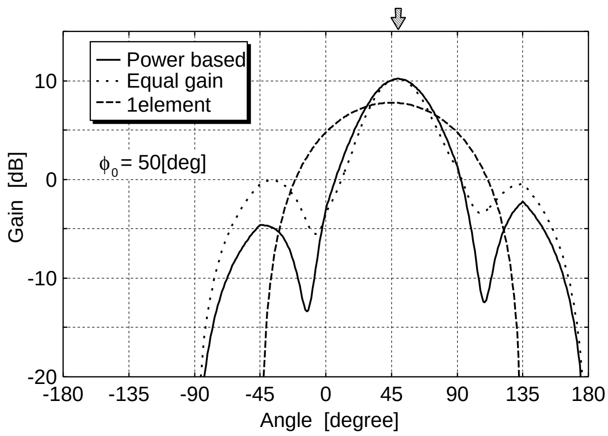

Figure 4: Transmitting beam pattern