A proposal on virtual massive array using fast beam switching and blind algorithm

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Abstract: In future wireless communication systems, massive multiple-input multiple-output (MIMO) is attracting attention for improving transmission rate. However, there is an issue that a large scale of hardware is needed due to massive numbers of antennas, transmitters, receivers, A/D and D/A convertors in massive MIMO. In this study, we propose a method to realize a virtual massive array with only one receiver by changing the beam pattern and performing A/D conversion at high speed within one symbol. The basic performance and effectiveness of the proposed method is demonstrated via a computer simulation.

Keywords: massive MIMO, virtual massive array, propagation environmental control, Robust ICA

Classification: Antennas and Propagation

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1 Introduction

With the fast spread of wireless communication devices in recent years, mobile communication traffic is increasing rapidly. The total wireless communication traffic volume in 2021 is estimated to be nearly 200 times the traffic volume in 2010 [1, 2]. Concurrently, a high-speed wireless communication technology is needed. Multiple-input multiple-output (MIMO) technology using multiple antennas both at the transmitting and receiving sides has been introduced to improve the communication speed in a limited frequency band [3]. In addition, long-term evolution (LTE)-Advanced and IEEE 802.11ac standards introduce multiuser MIMO (MU-MIMO) [4, 5, 6]. In MU-MIMO, the nulls are created for other users, and high-speed communication is realized through digital signal processing. However, it has been observed that the transmission efficiency per user considerably reduces when the total number of antennas at the user terminals approaches the number of antennas at the base station [6].

To solve this problem, in the fifth-generation (5G) mobile communication systems, the application of massive MIMO using a large number of antennas at the base station has attracted attention [7, 8, 9]. Massive MIMO assumes that the number of antennas at the base station is sufficiently larger than the total number of antennas at the user terminals so that the transmission rate does not significantly decrease even if the number of users increases [9]. However, the issue in massive MIMO is that transmitters, receivers, A/D and D/A convertors are required for each antenna. Hence, the hardware scale is larger and the cost regarding the hardware increases as the number of antennas increases.

So far, there has been research on direction of arrival (DOA) estimation using beam-space processing instead of element space one with one receiver [10]. To apply beam-space beamforming for the communication with one receiver, we propose a method to realize a virtual massive array with only one receiver by changing the beam pattern and performing A/D conversion at high speed within one symbol. Hence, our purpose is different from the purpose in [10]. Moreover, the proposed method realizes the multiple signal separation without even channel state information (CSI) which is essential in massive MIMO by using blind algorithm. In this letter,
the basic performance and effectiveness of the proposed method is presented by computer simulation when considering the different pattern with over sampling within one symbol using an actual modulation scheme.

The remainder of this paper is organized as follows. In Sect. 2, the basic configuration and procedure of the proposed method are presented. The principle of the robust independent component analysis (ICA) is denoted. In Sect. 3, the basic performance and effectiveness of the proposed method is shown by using minimum shift keying (MSK) with over sampling.

2 Proposed method

2.1 Basic idea of proposed method

Figure 1(a) shows the basic configuration of the proposed method. As the function changing the beam pattern, a total of $P$ beam patterns are generated by changing the weight at high speed while receiving a signal within one symbol. As configuration examples for changing the beam pattern, we consider the rotation of the directional antenna, the rotation of the parasitic element, antenna switching, and antenna combination. In this study, we evaluated the case of antenna combination and changed the weight of a four-element half-wave circular array to make variable beams.

Figure 1(b) shows an example of the relationship between sampling timings and beam patterns. By sampling multiple times at different timings while changing the beam pattern within one symbol, it is possible to obtain multiple received signals with different propagation environments even with one receiver. We call this method Propagation Environment Control.

Next, $Q \leq P$ received signals are selected from the $P$ received signals. Finally, to completely cancel the interference signal, we use the Robust independent component analysis (ICA) [11] with the selected signal as the input. The detail of the Robust ICA is shown in Sect. 2.2. The Robust ICA is a blind adaptive array algorithm that uses only the received signal and does require neither user-terminal

![Fig. 1. Proposed configuration and an example of the relationship between sampling timings and beam patterns](image-url)
transmission timing synchronization nor the CSI estimation. The weight of the Robust ICA is estimated not by using amplitude such as the constant modulus algorithm (CMA) but by using kurtosis, which is a measure of non-Gaussianity.

### 2.2 Principle of Robust ICA

Robust ICA is a method for optimizing the step size and maximizing the kurtosis [11]. If the weight after $m$ iterations is $W(m)$, the equation for updating the weight using Robust ICA is given by

$$W(m + 1) = W(m) - \mu_{\text{opt}} \nabla W \kappa(m),$$

$$\mu_{\text{opt}} = \arg \max_\mu |\kappa(W(m) - \mu \nabla W \kappa(m))|,$$

where $\kappa$ is the kurtosis and $\mu$ is the step size. In addition, $\nabla W \kappa(m)$, which is the gradient of $\kappa$ with respect to $W$, is expressed as

$$\nabla W \kappa(m) = \frac{4}{E^2(|y(i)|^2)} \left\{ E\{|y(i)|^2 y(i)^* X(i)\} ight.$$

$$\left. - E\{y(i) X(i)\} E\{y(i)^2\} \right. $$

$$\left. - \frac{(E\{|y(i)|^4\} - E\{|y(i)|^2\}^2 E\{y(i)^* X(i)\})}{E\{|y(i)|^2\}} \right\},$$

where $X(i) (i = 1, \cdots, n)$ and $y(i) (i = 1, \cdots, n)$ are the input vector and output signal, respectively, at the $i$-th sample. $W$ is updated to maximize the absolute value of the kurtosis using the optimized step size $\mu_{\text{opt}}$ for each iteration.

Robust ICA realizes a rapid and stable convergence performance. Moreover, it is reported that the calculation load per iteration is small because the root of the fourth degree polynomial of $\mu$ is a candidate for $\mu_{\text{opt}}$ [11]. In this study, $\mu$ is calculated from 0.1 to 50, and $\mu$ with the maximum kurtosis is derived as $\mu_{\text{opt}}$.

### 3 Effectiveness of proposed method

The results after evaluating the effect of the proposed method via computer simulation is demonstrated. Table I shows the simulation conditions. An environment with one desired wave and one interference wave is assumed and the direction of arrival is set to random. The SNR was 30 dB and the modulation scheme MSK, whose amplitude is constant. The smoothing size is the number of samples used for weight update. In the simulation, $P$ over sampling is applied within one symbol.

| Parameter               | Value |
|-------------------------|-------|
| SNR                     | 30 dB |
| Modulation scheme       | MSK   |
| Number of symbols       | 10000 |
| smoothing size          | 1000  |
| Number of iterations    | 3     |
| Number of trials        | 1000  |
and the received signals are obtained by each sampling signal. Note that fading is not considered, and sufficient symbols are given, because the basic performance is evaluated in this study. Note that we confirmed that the weight of Robust ICA can be converged with a few iterations. We should evaluate the performance using a realistic number of symbols as future work.

Figure 2 shows the cumulative distribution function (CDF) characteristics versus Bit Error Rate (BER) when the pattern variation, when $P$ is changed. Here, the results when the pattern variation $P$ is 2, 4, 8, and 16 and when $Q$ is 2 are shown. From Fig. 2, it can be seen that the BER is reduced by increasing $P$. The dotted line shows the results when the MMSE with the CSI estimation is used in a two-element half-wave linear array. When $P$ is 16, the BER is lower than that of the two-element linear array. The higher performance can be achieved by further increasing the value of $P$. From the results, there is a possibility that the proposed method can realize a virtual massive array even with one receiver without the CSI estimation.

![Fig. 2. CDF characteristics versus BER](image.png)

4 Conclusion

This paper proposed a method to realize a virtual massive array with only one receiver by changing the beam pattern and performing A/D conversion at high speed within one symbol. We have evaluated the basic performance of the proposed method and we can confirm that the BER is reduced by increasing the pattern variation $P$. From this result, we revealed that even if one receiver was used, the same effect as using multiple receivers could be expected by utilizing multiple antenna patterns at high speed in one symbol and acquiring multiple signals with different propagation environments.
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