DOA Measurements Using Synthetic Aperture Method in Outdoor Environments

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***Abstract* –, It is important to understand the DOA characteristics in order to develop massive-array antennas for 5th generation mobile communication systems. In this paper, a simple and effective DOA measurement method for LOS and NLOS environments is introduced that uses a synthetic aperture technique with a 2ch-vector receiver. Test results confirm that the proposed method can accurately measure DOA in outdoor environments.**

***Index Terms* — synthetic aperture, direction of arrival estimation, antenna**

1. Introduction

Multi-element array antenna technologies (such as Massive MIMO) are being researched for the 5th generation mobile communication systems in high frequency bands above 6 GHz [1]. In order to develop these array antenna systems it is necessary to understand the characteristics of multi-path waves given the use of narrow beams. Therefore, a number of studies on direction of arrival (DOA) measurements have been reported. There are 2 approaches to DOA measurements. The first uses a large scale aperture antenna such as parabolic antenna or horn antenna. The second uses a high resolution estimation algorithm with just a few antenna elements such as MUSIC, ESPRIT [2][3][4].

In this study, we select the first approach and combine it with the synthetic aperture technique [5] with 2ch-vector receiver. We introduce a simple but effective method for measuring DOA in outdoor multi-path environments.

2. Measurement principle

The proposal improves the DOA angle resolution by constructing a virtual circular synthetic aperture array antenna with radius of R. Assuming that the wave source(Tx) exists in the far-field, the measurement principle of this method is shown in Fig.1. The receiver antenna (Rx) is placed on a turn table R[cm] from the center, and the transmission characteristics between receiver antenna (Rx) and wave source (Tx) are measured while the turn table is rotated from -180 degrees to 180 degrees. Array weights corresponding to the optical path difference are needed for constructing the virtual circular array antenna. The synthetic aperture array antenna is formed according to (1) by using measured electric field and array weight.

$$E_{SA}(\theta_i) = \sum_{j=-N}^{N} E(\theta_i + \phi_j) \cdot \exp(-\frac{\phi_j^{\,2}}{2\sigma^2}) \cdot \exp\{jkR(1-\cos(\phi_j))\} \quad (1)$$

$E_{SA}(\phi_j)$, $E(\theta_i + \phi_j)$, ϕ_j , θ_i , $\exp(-(\phi_j^{\,2}/2\sigma^2))$, and $\exp\{jkR(1-\cos(\phi_j))\}$ are the synthesized electric field, the measured electric field, the setting angle of the j'th virtual antenna, the rotation angle, the Gaussian window and the array weight, respectively. The $2N$+1 receiver antennas (Rx) are formed at intervals of one degree. $2N$+1 Rx at θ_i = 0 degrees is the real receiver antenna, $2N$ of $2N$+1 is the virtual antenna. The response from Rx is captured once by the vector receiver, and then synthesized numerically using a PC in an offline manner. A 2ch-vector receiver is used in this measurement because it is necessary to fetch a reference signal (magnitude and phase) given the outdoor environment. For this, a reference antenna is set at the receiver. The response data is calculated from the reference signal and the received signal from Rx, which is synthesized in off-line manner on a PC.

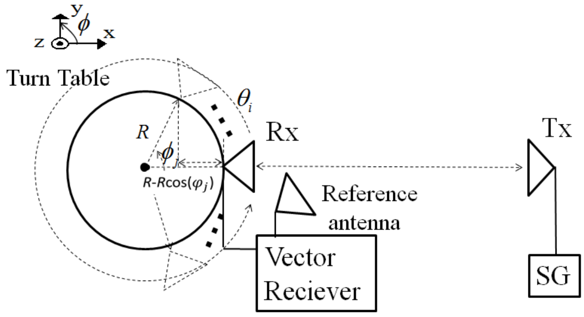

Fig. 1: Measurement Principle

3. Experiments outdoors

To confirm this measurement method, we used it to measure DOA in LOS and NLOS outdoor environments (around Koto-ku, Tokyo Japan). Measurement environment is shown in Fig.2. The receiver antenna (Rx) and reference antenna were placed at a height of 60 m, transmitting antenna was placed 400m away. The gray parts in Fig.2 indicate buildings. Table 1 lists the measurement parameters. In this test, array radius, number of elements, and the standard deviation of the window function are 64cm (18λ), 121, and 25 degrees, respectively. Thus, the beam width of the virtual circular array antenna is about 3 degrees, equivalent to a DOA measurement resolution of 3 degrees.

Table 1: Measurement parameters

Frequency	8.45 GHz (CW)
Antenna element (Rx)	Horn antenna (11 dBi)
Antenna element (Reference)	Horn antenna (18 dBi)
Antenna element (Tx)	Sleeve antenna (2 dBi)
Radius of array(R)	64 cm (18 λ)
Number of elements ($2N+1$)	121
Standard deviation of window function (σ)	25 deg.

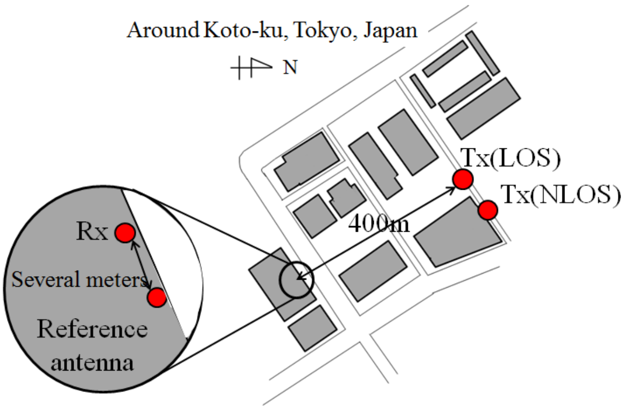

Fig. 2: Measurement environment

3.1. Measurement of LOS environment

Results of the LOS measurement are plotted in Fig.3. The red circle in the picture is the location of transmitted antenna. The red circle in the results indicates the direct-path. The blue circles indicate reflected paths. There is a reasonable match between reflected wave angles and the surrounding buildings. Therefore, the proposed method can estimate DOA in LOS environments.

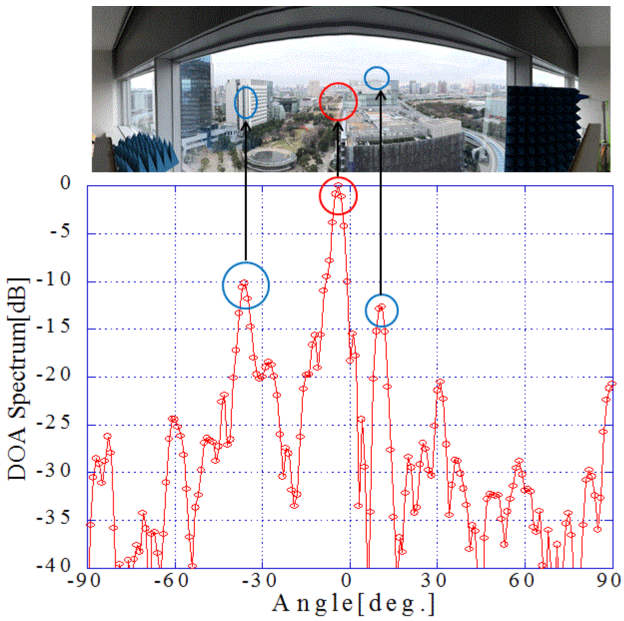

Fig. 3: Result of DOA Estimation in LOS

3.2. Measurement of NLOS environments

Results of the NLOS measurement are plotted in Fig.4. The red broken circle in the picture is the location of the transmitting antenna. Clearly, there is no dominant path to the receiving antenna. The blue circles indicate reflection paths. There is a good match between reflected wave angles and the surrounding buildings. These results show that the dominant path is formed by a reflected wave. Therefore, the proposed method can measure DOA in NLOS environments.

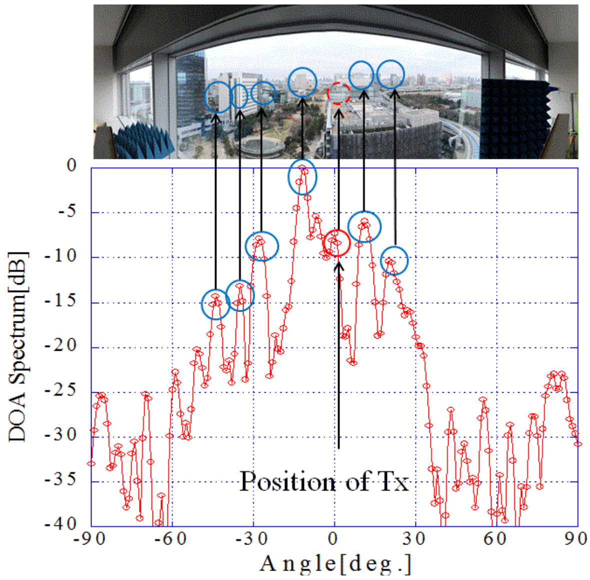

Fig. 4: Result of DOA estimation in NLOS

4. Conclusion

We introduced a method that can capture outdoor DOA data in both LOS and NLOS environments by using the synthetic aperture method. Tests in Tokyo confirmed the validity of the proposed method. It outputs high-resolution DOA data by placing the receiving antenna off-center on a turn table and thus increasing the number of virtual elements. Therefore, the proposal is simple but highly precise.

Future work includes elucidating delay characteristics, which should enhance the reliability of the method. We hope to report delay characteristic measurements in the near future.

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