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DOA ESTIMATION SYSTEM BY A SYNTHESIZED VIRTUAL PLANAR ARRAY USING PILOT SIGNALS

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1. Introduction

The quality of mobile communication should be improved especially in urban districts, and it is important to know where is in a bad condition for the electric wave propagation. In urban districts, the DOA cannot be estimated by a linear array antenna system since electric waves are arrived reached from all the directions. Uniform planar arrays would be required for such DOA estimation, however array antennas with a fewer number of elements are suitable for the low cost receiver. To solve this problem, we proposed a 'T' character-type array antenna system, and confirmed its performance [1-2]. This method is that the virtual uniform planar array is made by shifting a 'T'-character array in parallel, and DOA are estimated by using its data of a virtual uniform planar array. This system is only applied to unmodulated signal, then this paper proposes an algorism for modulated pilot signal.

It is assumed that arrival waves come from transmitters of the only Code Division Multiple Access (CDMA) system. Pilot signals are always included in arrival waves, and are the identical repeated signals. Therefore, to estimate DOA by using pilot signals is possible. In this paper, we propose the method of DOA estimation using pilot signals, and demonstrate the proposed method by simulations and experiments in the outdoor environment.

2. The method of synthesizing the virtual planar array using pilot signals

How to synthesize the data of the M x N virtual planar array by 'T' character-type array antenna as shown in Fig. 1(a) is described for instance, when N is odd number. The proposed method can be applied to the linear array and a fixed antenna element for the reference.

Figure 1 shows the method to synthesize the data. First, the data of the 'T' character-type array are measured, and are defined as

$$X_1 = \left[x_{1,1}, x_{1,2}, \cdots, x_{1,N}, x_{1,N+1}\right]$$

where $x_{1,n}(n = 1,\cdots,N+1)$ is the despreaded data by a synchronized PN sequence at a #(N+1)/2 element. Then, the 'T' character-type array is shifted so that the central element (#(N+1)/2) of the original position and the outstanding element (#N+1) after movement may overlap (see Fig. 2), and the measurement is conducted. These data are defined as

$$X_2 = \left[x_{2,1}, x_{2,2}, \cdots, x_{2,N}, x_{2,N+1}\right]$$

where $x_{2,n}(n = 1,\cdots,N+1)$ is the despreaded data by synchronized PN sequence at the #N+1 element. There is a only phase different $\phi_{1,2}$ between $x_{1,(N+1)/2}$ and $x_{2,(N+1)}$ by different measured times, because each measured data positions is measured are the same. $\phi_{1,2}$ is given by comparing $x_{1,(N+1)/2}$ with $x_{2,(N+1)}$. And it is possible to synthesize X_1 and X_2 as follows,

$$\hat{X}_2 = [X_1^{'}, X_2^{'}] = \left[x_{1,1}, x_{1,2}, \cdots, x_{1,N}, x'_{2,1}, x'_{2,2}, \cdots, x'_{2,N}\right]$$

where $X_i^{'}(i = 1,2)$ are the data after the calibration of the phase different $\phi_{1,2}$ between first and second lines. Repeating this operation M-1 times, the data $\hat{X}_M$ of the M x N virtual planar arrays

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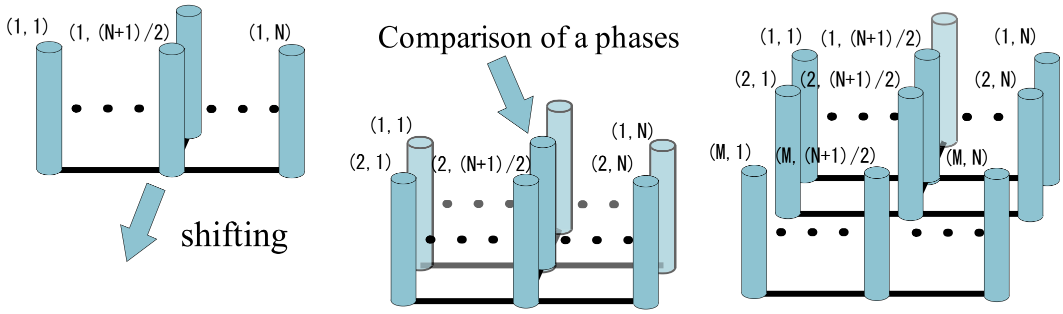
with calibrated the phase different is obtained. In this method, arrival waves, which have the identical pilot signal, can be estimated only. If there are arrival waves that include the others pilot signals and these waves are desired to estimate DOA, the despreaded data by each PN sequence are synthesized as shown before. And DOAs are calculated by using $\hat{X}_M$ that is added using all data.

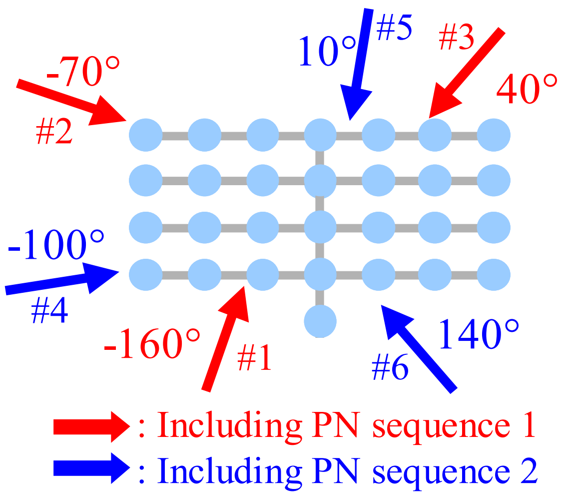


(a)The 'T' character-type array antenna (b) The overlap elements (c)The virtual rectangular array

Fig. 1 Synthesizing the data of virtual planar array

3. Simulations

In order to evaluate the effectiveness of the virtual planar arrays, we present simulation results. The number of arrival waves is 6 and have the same power level, and #1-#3 are the waves which include in the same pilot signal (PN sequence 1), and #4-#6 are the waves which include in the other pilot signal (PN sequence 2). Figure 2 shows the situation of arrival waves. The number of elements of virtual planar array is 28(7 x 4), and sub arrays are 3 x 3 planar array for a spatial smoothing. Element intervals are 0.4-wavelength. We use the MUSIC method [3] as DOA estimation algorithm.



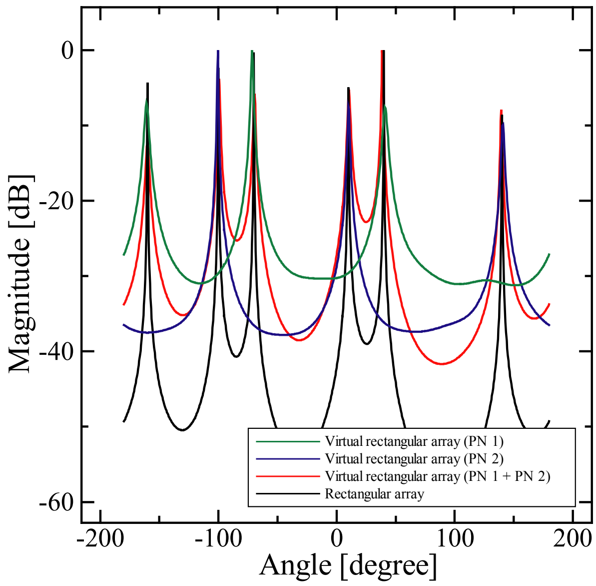


Fig. 2 Situation of arrival waves

Fig. 3 MUSIC spectrum of simulations

Figures 3 shows the results by of real planar array and by virtual planar array. In the case of PN sequence 1 only, #1-#3 can be estimated, but #4-#6 cannot be estimated. The case of PN sequence 2 only is the same as the case of PN sequence 1. When the despreaded data by PN sequence 1 and the despreaded data by PN sequence 2 are added, all waves are estimated correctly. This figure shows that the virtual planar array can estimate DOA with almost the same accuracy as the real planar array, although a dynamic range of virtual planar array is narrower than a planar array. From these simulations, the effectiveness of the proposed system is confirmed

4. Experiments

The performance of the proposed system in DOA estimation is evaluated by some experiments. First, we make the experiments in an anechonic chamber as shown in Fig. 4. The 5 x 4 virtual planar array is obtained by shifting the 5+1 'T'-type array antenna, where a transmitting antenna is shifted to decrease estimation errors. Radio frequency is 900 MHz band, I and Q PN rate is 1.2288Mcps, sampling frequency of ADC is 5MHz, and MUSIC method is used for DOA estimation. The estimation errors are summarized in Fig. 5. This figure shows that DOA has been estimated accurately.

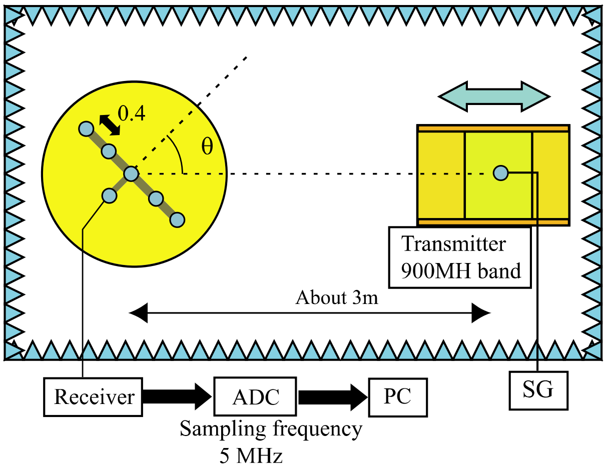


Fig. 4 Situation of experiments (anechonic chamber)

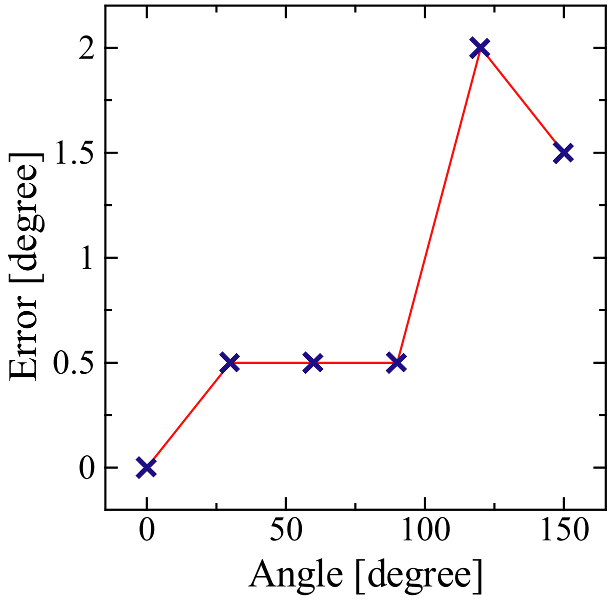
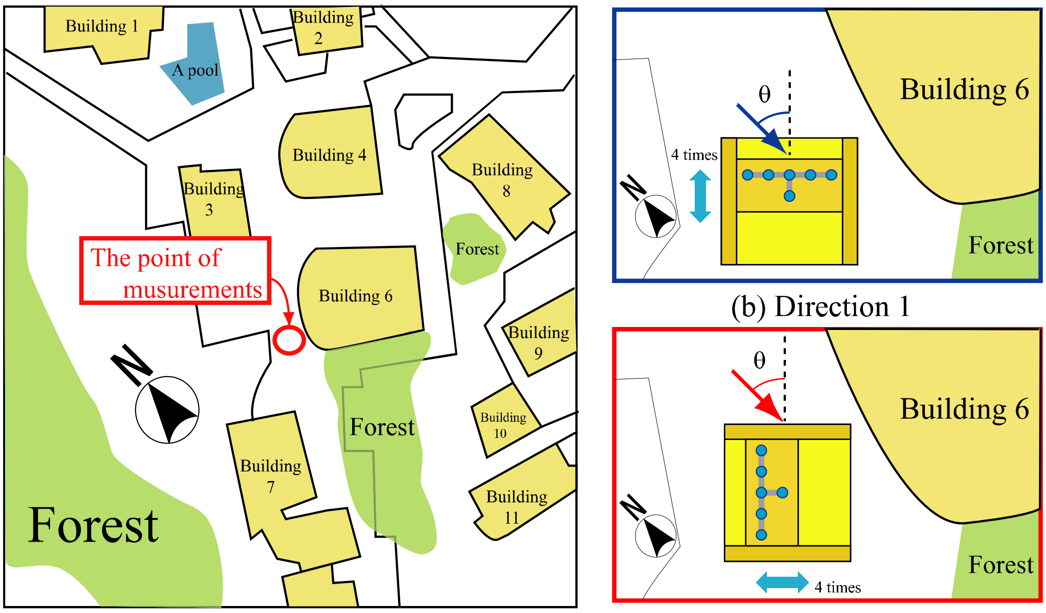


Fig. 5 Result of experiments (anechonic chamber)

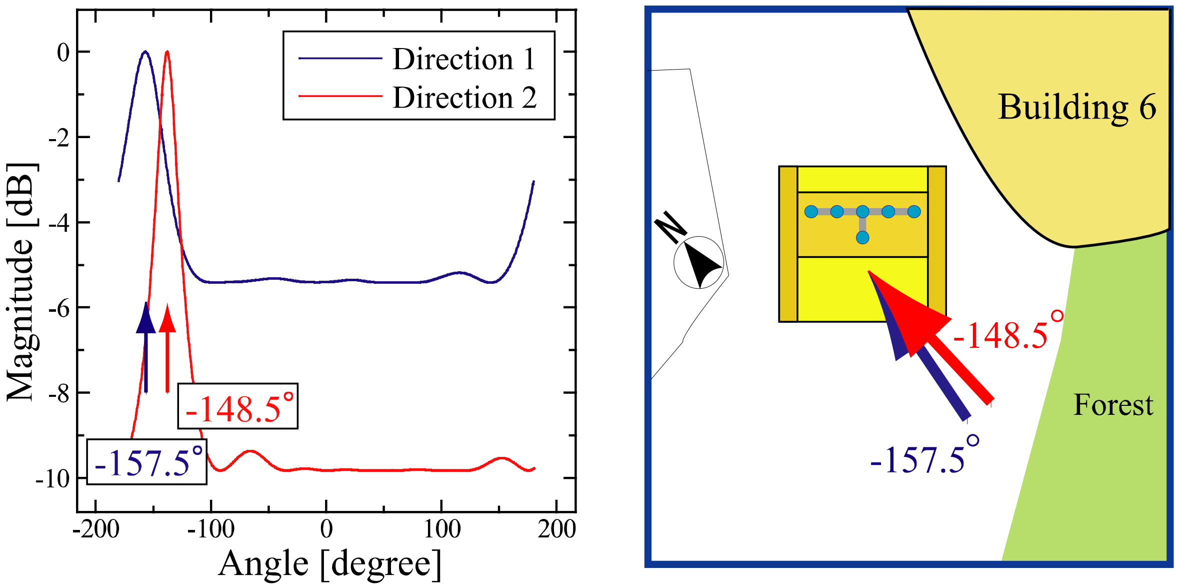


(a) Measurement locations

(b) Direction 1

(c) Direction 2

Fig. 6 Situations of experiments



(a) MUSIC spectrums (b) Direction of avirral wave

Fig. 7 Results of measurements in the outdoor environment

The experiment in the outdoor environment is carried out. In this experiment, we measure arrival waves from base stations that are used for current cellular system. The propagation environment is shown in Fig. 6(a). It is impossible to know the DOA from base stations accurately, therefore we confirm the accuracy of the result by changing the direction of shifting the 'T' character-type array (see Fig.6 (b) (c)). The number of elements are 6, the number of shifting the array antenna are 4 times. The results of the experiments are shown in Fig. 7. These figure shows that DOA has been estimated accurately. From these results, the performance of the proposed method in DOA estimation is confirmed experimentally

5. Conclusion

In this paper, we proposed the method of DOA estimation using pilot signal. DOA could be estimated by using the virtual planar array created from the original 'T' character-type array. The performance of the proposed system was confirmed through some simulation and experiments. The future works would be measurements in the various place, and a decrease of DOA estimation error when there are fading in the open air.

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