Beamspace based AIC and MDL Algorithm for Counting the Number of Signals in Specific Range

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***Abstract*—Since the modern wireless communication system with various signals and interferes tends to utilize an array antenna with the large size of elements, it is important to accurately estimate the number of signals. Although most of the signal number estimation algorithms calculate it for the entire range of angles, it is inefficient when signals exist in specific ranges. In this paper, we propose a beamspace based Akaike Information Criterion (AIC) and Minimum Description Length (MDL) algorithm for efficiently estimating the number of signals in the specific range. The estimation performance of the proposed algorithm is evaluated and analyzed through the computer simulation.**

Keywords—Signal number estimation, Beamspace, AIC, MDL, Square array antenna

I. INTRODUCTION

For the wireless communication system based on an array antenna with a large number of elements, it is important to accurately estimate the number of signals included in a received signal, because the information for the number of signals is required for determining the minimum number of active elements in the received antenna [1],[2]. Akaike Information Criterion (AIC) and Minimum Description Length (MDL) algorithms based on information theory approaches are representative and excellent methods for estimating the number of signals [3]-[6]. However, since these algorithms estimate the number of signals for the entire angle range, they are inefficient for estimating the number of signals in specific ranges.

In this paper, we propose beamspace based AIC and MDL algorithms for estimating the number of signals in the specific range, for a square array antenna. First, the proposed algorithm reduces the dimension of the antenna array to focus on the interested specific range from the entire range, by multiplying the receive signal to a beamspace weight matrix [7]-[9] for a square array [10]. Next, it estimates the number of signals in the focused range, by calculating AIC and MDL reference value. In order to verify the estimation performance of the proposed algorithm, we provide the computer simulation example.

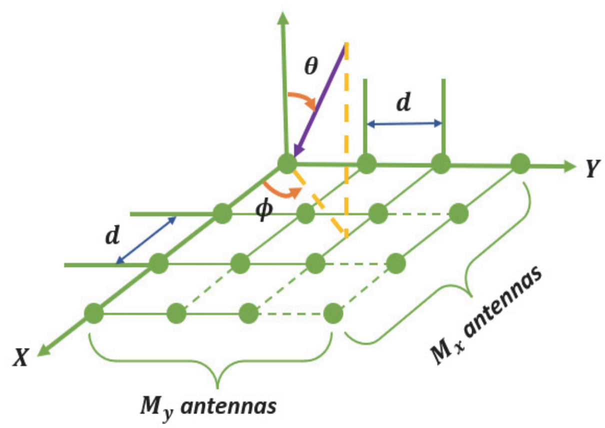

Fig. 1. The structure of square array antenna

II. RECEIVED SIGNAL MODEL

In this section, we provide the received signal model including various signals and noise and the beamspace output signal model.

A. Received Signal Model

In this paper, we focus on the square array configuration in Fig. 1 as an array antenna. Assuming that the numbers of antenna elements and signals are $M(M_x \times M_y)$ and L, respectively, the received signal model for the sample index k is given by

$$\mathbf{x}(k) = \mathbf{A}\mathbf{s}(k) + \mathbf{n}(k), \tag{1}$$

where $\mathbf{A}$ is an array response matrix with the size of $M \times L$, defined as

$$\mathbf{A} = \begin{bmatrix} 1 & \cdots & 1 \\ e^{-j\chi_1} & \cdots & e^{-j\chi_L} \\ \vdots & \ddots & \vdots \\ e^{-j(M_x-1)\chi_1} & \cdots & e^{-j(M_x-1)\chi_L} \\ e^{-j\gamma_1} & \cdots & e^{-j\gamma_L} \\ e^{-j(\chi_1+\gamma_1)} & \cdots & e^{-j(\chi_L+\gamma_L)} \\ \vdots & \ddots & \vdots \\ e^{-j((M_x-1)\chi_1+(M_y-1)\gamma_1)} & \cdots & e^{-j((M_x-1)\chi_L+(M_y-1)\gamma_L)} \end{bmatrix}, \quad (2)$$

$$\chi_i = 2\pi\left(\frac{d}{\lambda}\right)\sin\theta_i \cos\phi_i, \quad (3)$$

$$\gamma_i = 2\pi\left(\frac{d}{\lambda}\right)\sin\theta_i \sin\phi_i. \quad (4)$$

χ_i and γ_i in (2) are defined as (3) and (4), respectively, and λ and d denote the wavelength and the distance between two neighbor antenna elements, respectively. In addition, θ and ϕ represent an elevation angle and an azimuth angle, respectively. $\mathbf{s}(k)$ is a signal vector with the size of L and $\mathbf{n}(k)$ is a noise vector with the size of M with independent and identically distributed (iid) components, each of which has zero mean and variance σ^2.

B. Beamspace Output Model

An arbitrary $B(B_x \times B_y)$ dimensional beamspace output signal is defined as

$$\mathbf{x}_B(k) = \mathbf{W}_B^H \mathbf{x}(k), \quad (5)$$

where $\mathbf{W}_B$ is the $M \times B$ sized beamspace matrix [11] that can be expressed as a Kronecker product of W_{B_x} and W_{B_y}, as

$$\mathbf{W}_B = \mathbf{W}_{B_y} \otimes \mathbf{W}_{B_x}. \quad (6)$$

Through this beamspace process, we reduce the dimension of the antenna array to fit the desired specific range.

III. Beamspace Based AIC & MDL

In this section, we present beamspace based AIC and MDL algorithms to efficiently estimate the number of signals in the specific angle range, based on the output of the beamspace process for reducing the dimension of the received square array antenna. After reducing the dimension of the antenna array to fit the specific range by the beamspace processing, its output signal is applied to the AIC and MDL for estimating the number of signals. This estimated result is utilized to an adaptive signal processing unit or a beamformer for the enhanced communication performance. The main architecture of the proposed algorithm is shown in Fig. 2.

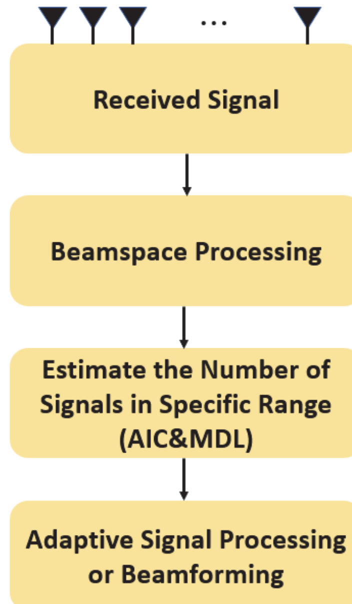

Fig. 2. The architecture of the proposed algorithm for estimating the number of signals in the specific range

A. Sample covariance matrix

The sample covariance matrix (size of $B \times B$) based on the output of the beamspace processing given by (5) is defined as

$$\mathbf{R}_B = E\left[\mathbf{x}_B(k)\mathbf{x}_B^H(k)\right]. \quad (7)$$

From this covariance matrix, we calculate B beamspace eigenvalues classified into L eigenvalues for signals and $B-L$ eigenvalues for the noise, by the eigenvalue decomposition. The proposed algorithm utilize these calculated eigenvalues for estimating the number of signals in the specific range.

B. Beamspace based AIC

A beamspace based AIC criteria for estimating the number of signals is defined as

$$AIC(L) = -2N \ln\left[\frac{\prod_{i=L+1}^{B} a_i}{\left[\frac{1}{B-L}\sum_{i=L+1}^{B} a_i\right]^{B-L}}\right] + 2L(2B-L), \quad (8)$$

where L has a value from 0 to $B-1$ and N represents the number of samples. We determine the number of signals in the desired specific range to the L value that minimizes (8).

C. Beamspace based MDL

A beamspace based MDL criteria for estimating the number of signals is defined as

$$MDL(L) = -N \ln \left[\frac{\prod_{i=L+1}^{B} a_i}{\left[\frac{1}{B-L} \sum_{i=L+1}^{B} a_i \right]^{B-L}} \right] + \frac{1}{2} L(2B-L) \ln N. \quad (9)$$

The L value that minimizes (9) is estimated as the number of signals included in the desired specific range.

Since AIC and MDL algorithms may have different estimation performances for various conditions such as the signal-to-noise ratio (SNR) level or the number of samples, these two algorithms should be complementally employed to each other.

IV. Computer Simulation

In this chapter, we provide the computer simulation result to verify the estimation performance of the proposed beamspace AIC and MDL algorithms based on the square array antenna. For this simulation, we assume that the sizes of the square array antenna and the considered beamspace matrix are 6×6 and 3×3, respectively, and the total number of signals in the received signal is five (two Continuous Wave (CW) signals, two Frequency Modulation (FM) signals, and one Wideband (WB) noise signal). The main parameters of signals are summarized in Table 1. In addition, we assume that we try to estimate the number of signals in the azimuth angle range from -10 degree to 100 degree. From the Table 1, we observe that there are three signals in this range.

The spectrum of the received signal, which has five the expected signals, is shown in Fig. 3. Fig. 4 shows the beamspace based AIC and MDL results for estimating the number of signals in the interested range. Since AIC and MDL values until the value of L is 2 can be confirmed, but beyond that, the values are extremely small and cannot be seen in one graph, we provide Fig. 5 which is the extended version of Fig. 4. In Fig.5, we observe that the beamspace based AIC and MDL values are minimized when the value of L is 3. Therefore, the proposed algorithm determines the number of the signals in the interested range to three, which is the same as the number for the given scenario.

TABLE I. RRECEIVED SIGNAL PARAMETERS

Signal	Azimuth Angle $(^\circ)$	Elevation Angle $(^\circ)$	Center Frequency	SNR (dB)
CW	-60, 30	-58	0.2, 0.45	10
FM	-45, 60	-58	0.1, 0.4	10
WB	10	-58	0.3	10

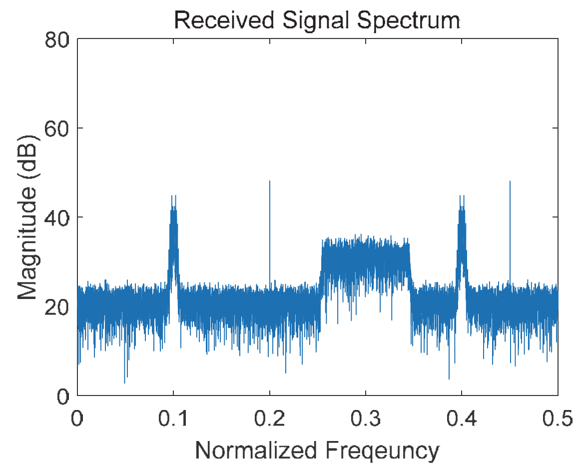

Fig. 3. Spectrum of the received signal

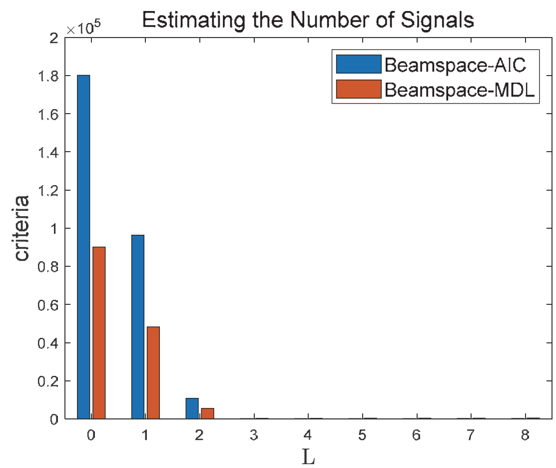

Fig. 4. Criteria of beamspace based AIC and MDL versus the number of signals in the interested range

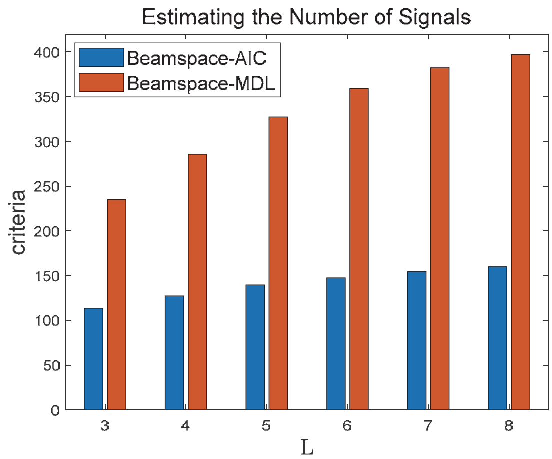

Fig. 5. The extended version of Fig. 4

V. CONCLUSION

In this paper, we proposed beamspace AIC and MDL algorithms based on a square array antenna for estimating the number of received signals in the specific range. The proposed algorithm reduces the dimension of the square antenna array to fit the desired range from the entire range, through the beamspace processing. The beamsapce output is applied to AIC and MDL algorithms to estimate the number of signals in the interested range. The proposed algorithm is not only extremely efficient to estimate the number of signals included in the specific range, but also it has the lower computational complexity comparing to the conventional signal number counting algorithm because of the reduced dimension.

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REFERENCES

[1] Y. Jing, Q. Wang, L. Wang and W. Zhu, "Research on Compressed Sensing DOA Estimation Based on Priori Space Sparsity of Information Theory," in 2019 International Conference on Electronic Engineering and Informatics (EEI), pp. 83-87, 2019.

[2] R. Schmidt, "Multiple emitter location and signal parameter estimation," IEEE Transactions on Antennas and Propagation, vol. 34, no. 3, pp. 276-280, 1986.

[3] L.C. Zhao, P.R. Krishnaiah, Z.D. Bai, "On detection of the number of signals in presence of white noise," Journal of Multivariate Analysis, vol. 20, no. 1, pp. 1-25, 1986.

[4] S. Valaee, P. Kabal, "An Information Theoretic Approach to Source Enumeration in Array Signal Processing," IEEE Transactions on Signal Processing, Vol. 52, No. 5, pp. 1171-1178, 2004.

[5] D. B. Williams, Detection: Determining the Number of Sources, CRC Press LLC, 1999.

[6] M. Wax and T. Kailath, "Detection of signals by information theoretic criteria," IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. 33, no. 2, pp. 387-392, 1985.

[7] H. V. Tress, Optimum Array Processing, Jogn Wiley & Sons, 2002.

[8] J. Steinwandt, R.C. de Lamare and M. Haardt, "Beamspace direction finding based on the conjugate gradient and the auxiliary vector filtering algorithms," Signal Process., vol. 93, no. 4, pp. 641-651, 2013.

[9] Z. Zheng, W-Q, Wang, H. Meng, H.C. So and H. Zhang, "Efficient Beamspace-Based Algorithm for Two-Dimensional DOA Estimation of Incoherently Distributed Sources in Massive MIMO Systems," IEEE Transactions on Vehicular Technology, vol. 67, no. 12, pp. 11776-11789, 2018.

[10] T. Akao, K. Watanabe, S. Kojima, M. Katsuno, K. Maruta, C.J. Ahn, "Reducing Channel Spatial Correlation by Rotating Planar Array Antenna," ICT Express, vol. 5, no. 4, pp. 271-275, 2019

[11] M.D. Zoltowski, M. Haardt and C.P. Mathews, "Closed-form 2D angle estimation with rectangular arrays in element space or beamspace via Unitary ESPRIT," IEEE Transactions on Signal Processing, vol. 44, No. 2, pp. 316-328, 1996.