# Multi-Source Localization Using Linear DoA Sensor Network

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***Abstract*—A simple multi-source localization system using a linear DoA (Direction of Arrival) sensor network is investigated. It can be simply verified that the DoA curves of two separate signal sources meet and cross if and only if they have different perpendicular distances from the linear sensor network. In this paper, we propose a scheme to detect the DoA curve crossing and to properly cluster the DoAs. The simulation results show that the proposed scheme works even in noisy environments.**

***Index Terms*—localization, direction of arrival, clustering, sensor network**

## I. Introduction

Recently, localization technology is widely used in various fields. The most popular and widely used localization system is GNSS (Global Navigation Satellite System) such as GPS (Global Positioning System) and GLONASS (Global Navigation Satellite System of Russia). The global localization systems are being enhanced or complemented for accuracy. However, the needs for highly accurate and precise localization is increasing – especially in autonomous driving and various IoT (Internet of Things) services.

In this paper, we consider a simple signal source localization system where the signal sources transmit identical signals – that is, no transmitter identification information is embedded in their signals – and the sensor network consists of only DoA sensors linearly aligned. Compared to two-dimensional layouts [1], this linear configuration is simple to deploy but has limited capabilities against multiple concurrent signal sources. If two sources transmit signals at the same time, each DoA sensor detects one or two DoAs according to the DoA difference between the sources. As the DoAs are not accompanied by the transmitter information, a proper clustering scheme is necessary to distinguish DoAs of each signal source only by analyzing the pattern of estimated DoAs. In this paper, we analyze the characteristics of DoA patterns for the assumed linear DoA sensor network and propose a simple DoA clustering scheme. Finally, the proposed scheme is evaluated by simulation.

## II. System Model

Fig. 1 shows configuration of the linear DoA sensor network for signal source localization. We consider a very simple system where DoAs are the only information available: no time of arrivals [2], no received signal strength indication [3], and no frequency of arrivals [4]. This configuration greatly limits its capabilities but, if the signal source mobility is low and transmitter discrimination is unnecessary, it benefits very simple system design and cost-efficient implementation with low complexity transmitters and sensor network.

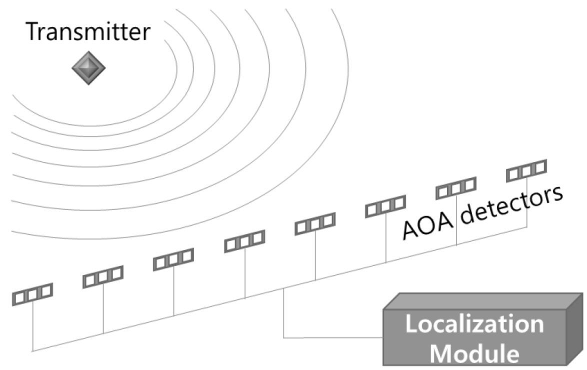



Fig. 1. Signal source localization system based on a linear DoA sensor network.

## III. DoA Patterns in Multi-Source Cases

### A. DoA pattern for linear sensor network

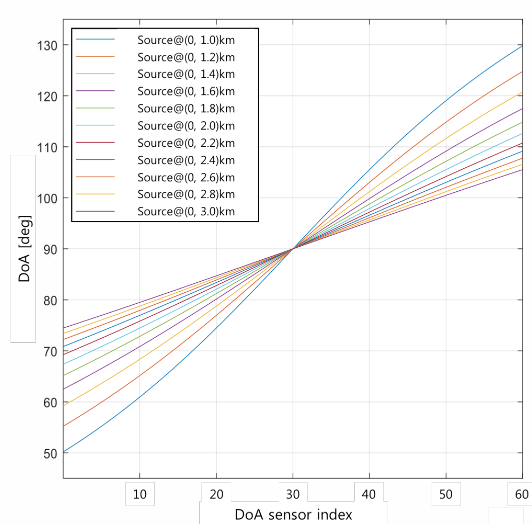



Fig. 2. DoAs observed from sensors in the linear network

for various distances from the network.

Fig. 2 shows the relationship between the sensor position and DoA. The DoA can be written by arctan($\Delta y/\Delta x$), where $\Delta x$ and $\Delta y$ are the differential coordinate between the two in X- and Y-axis, respectively. Let us denote the line of the sensors as X-axis and its horizontal perpendicular line from the center of the linear sensor network as Y-axis.

In Fig. 2, we can see the slope of the curve is steeper as the signal source is closer to the linear sensor network – that is, the signal source has smaller Y-axis coordinate. Note that Fig. 2 only shows the curves when the signal source is on the Y-axis. If the signal source is off the Y-axis, the center of the arctan($\cdot$) curve is only shifted in the X-axis direction to be aligned with the X-axis coordinate of the signal source. Therefore, if there are two signal sources with different Y-axis coordinates, it is unavoidable to have a crossing in their DoA curves.

## B. DoA clustering

If the two DoA curves of the signal sources cross, the classification of DoAs after the crossing should be reverse of that before the crossing.

We observe the detected number of signals [5] to find the DoA crossing. If the average detected number of signals is small over a group of adjacent DoA estimates, we can consider the crossing is near. A simple scheme can be designed as follows:

Step 1: Calculate running average of the detected number of signals with an observation window of width $W$ over all the DoA sensor indices.

Step 2: Find the first and the last window indices where the average detected number of signals is less than a threshold $T$, $1 < T < 2$.

Step 3: The middle index of the first and the last window indices found in Step 2 is the estimated DoA crossing point.

The observation window width $W$ should be less enough than the minimum DoA difference for which the DoA estimation algorithm can detect both the two signal DoAs. For example, if we assume the minimum perpendicular distance between the linear sensor network and signal sources is 1 km, $W$ << 175 m as shown in Fig. 4 when the DoA estimation algorithm cannot distinguish two signals of DoA difference less than 5°. When the minimum distinguishable DoA difference is 1°, $W$ << 34.9 m. On the other hand, the value of $T$ is not a critical issue unless $T$ is close to 2.

Once the DoA crossing point has been detected, the DoAs are clustered as follows:

Step 1: The DoAs at each DoA sensor are sorted in ascending (or descending) order. Let us denote them by $\theta_A[k]$ and $\theta_B[k]$ for the $k$th DoA sensor.

Step 2: If we denote the index of the detected DoA crossing point as $k_0$, the DoAs can be clustered as

$$C_A=\{\theta_A[k], k=0, 1, \ldots, k_0-1\} \cup \{\theta_B[k], k=k_0, k_0+1, \ldots, M-1\}$$

$$C_B=\{\theta_A[k], k=k_0, k_0+1, \ldots, M-1\} \cup \{\theta_B[k], k=0, 1, \ldots, k_0-1\},$$

where $M$ is the number of DoA sensors in the sensor network.

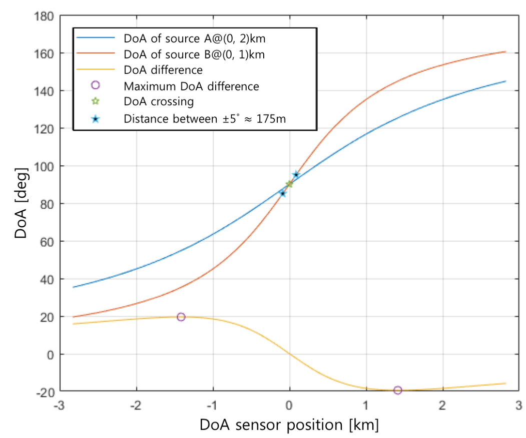
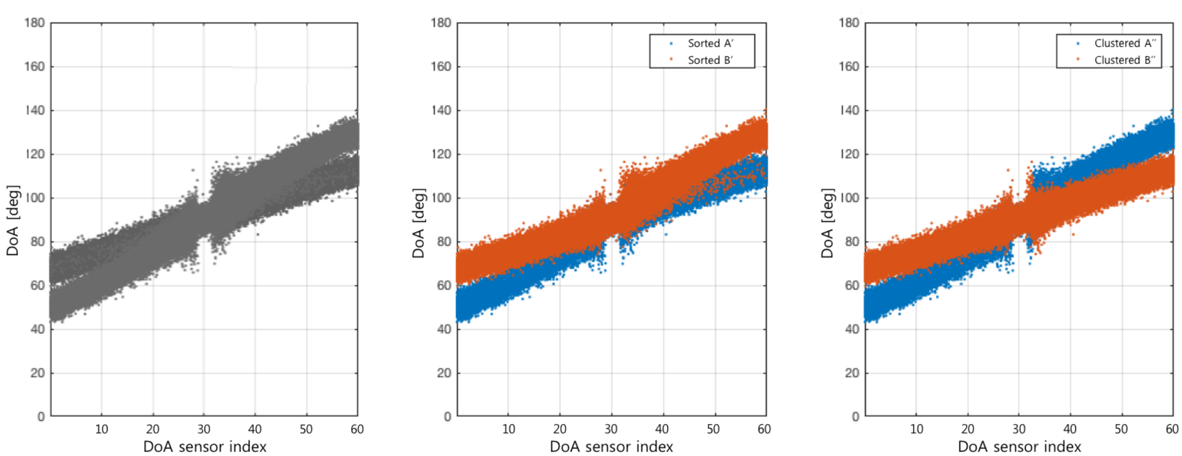



Fig. 4. DoAs for two signal sources at (0, 1) km and (0, 2) km.




(a) DoAs without source identification (b) DoAs after simple sorting (c) DoAs after clustering

Fig. 3. Simulation example of the proposed DoA clustering procedure.

## IV. Simulation Results

In this section, the results of the proposed DoA clustering scheme for two signal sources at (0, 1) km and (0, 2) km are verified by simulation. In this paper, we assumed $W = 3$ m and $T = 1.5$. As we consider a two-dimensional localization, a linear antenna array is assumed for each DoA sensor and the MUSIC (Multiple Signal Classification) [6] is employed for azimuth DoA estimation. Note that it only has to be replaced with a two-dimensional antenna array [7] for three-dimensional localization.

The simulation results in Fig. 3 show DoA clusters at each stage of the proposed scheme: Fig. 3(a) shows the DoAs without transmitter identification, where each DoA sensor detects two signal DoAs except those near (0, 0) km. The first step of the proposed DoA clustering scheme results in Fig. 3(b), where the DoA estimates obtained at each DoA sensor are simply sorted. It is obvious that the localization will fail to converge on the vicinity of the target position if performed based on these clusters. The final step of the proposed DoA clustering scheme results in Fig. 3(c) where we can see the DoAs of the two signal sources are properly clustered so that they can be localized successfully.

## V. Conclusion

In this paper, a simple scheme of DoA clustering for multi-source cases is proposed for a linear sensor network for signal source localization where only DoAs of the signals are measured and utilized. For the design of the DoA clustering scheme, we analyzed the characteristics of DoA patterns and found that the DoA curves for two distinct signal sources crosses if and only if the signal sources have different perpendicular distance from the linear sensor network. Based on this fact, we proposed a scheme to detect the DoA crossing point from the detected number of signals and the DoA clustering scheme only reverses the sorting order of the DoAs estimated at each sensor. Finally, the simulation results show that a reliable localization can be expected with the help of the proposed DoA clustering scheme.

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