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A decoupled algorithm for geolocation of multiple emitters ☆

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Abstract

The problem of determining the positions of multiple emitters by widely separated arrays is considered. We propose an iterative algorithm for estimating the positions based on the maximum likelihood (ML) criterion. The position of each emitter is decoupled from the other emitters, and in each iteration is determined by a two dimensional grid search. This approach substantially reduces the computation load of a straightforward implementation of the ML estimator, which requires a multidimensional search. Numerical examples are provided to illustrate the performance. We demonstrate that only a few iterations are required to achieve convergence. The results are compared with the Cramér–Rao lower bound.

Keywords: Array-processing; Emitter-localization; Maximum-likelihood estimation

1. Introduction

The position estimation of multiple emitters, intercepted by several receiving stations, is usually performed by a sub-optimal two step procedure. Recently, several papers discussed optimal estimation methods based on exploiting the raw data intercepted by all stations in a fusion center. The recent increase of cellular communications generated a renewed interest in this field. Cellular providers may use the location of subscribers for a variety of applications, such as commercial advertisement, self navigation, rescue requests, etc.

Most publications on decentralized localization methods (two-steps methods) concentrate on the first step, i.e., Angle-of-Arrival (AoA) estimation, or Time-of-Arrival (ToA) estimation, performed by each station independently [1]. Several mathematical algorithms were proposed for performing the second step: position determination based on triangulation using the results of the first step. Details can be found in [2], and the reference therein. Wax and Kailath [3] proposed an intermediate approach between decentralized and centralized (single-step methods) geolocation. Instead of transmitting the raw data to the fusion center, as is done in the centralized approach, each station transmits only the sufficient statistic (the sample correlation matrix). The geolocation is determined using a cost function based on eigendecomposition of the complete set of sufficient statistics.

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Surprisingly, the number of publications on centralized geolocation is rather small. Chen et al. [4] discussed Maximum-Likelihood (ML) geolocation estimation for near-field emitters. Kozick and Sadler [5] examined the geolocation of a single aero-acoustical emitter, focusing on the correlation between the signals intercepted by different stations. Recently, the authors presented several geolocation algorithms for unknown and known signals [6]. The analysis and simulations showed that the proposed method (Direct Position Determination (DPD)) outperforms conventional, two-steps methods, based on AoA or ToA.

The objective of the current correspondence is to present a Decoupled Geolocation Maximum Likelihood (DGML) algorithm for centralized geolocation. Up to date, a centralized ML position determination of multiple emitters with unknown waveforms has not been presented. A straightforward solution of the ML requires a multidimensional search with high complexity. We resort to an iterative least squares algorithm to overcome this difficulty. The proposed algorithm estimates the positions of Q emitters in a plane by a two-dimensional search in each iteration, instead of a single $2Q$ multidimensional search. It is shown that convergence to the Cramér–Rao Bound (CRB) is achieved with a small number of iteration steps. It is worth mention that the algorithm, as any other iterative algorithms, depends on the initial estimate of the emitters' positions. However, the algorithm can be applied to tracking of multiple emitters, where there is an initial estimate of the positions. Such initial estimate can be provided using the centralized algorithms presented in [6].

2. Problem formulation

Consider L stations located at geographically separated sites within a plane. Each station is equipped with an antenna array. Each array consists of M sensors. One of the sensors in each array is used as a reference sensor and its location is denoted by $\mathbf{d}_\ell \triangleq (X_\ell, Y_\ell)$. Assume that the Q sources are located in the far-field of the arrays. This implies that the wave-front can be considered planar w.r.t. the array aperture. However, since the stations are widely separated, the wave-front curvature should be taken into account when considering all the arrays together. Denote by $\mathbf{p}_q \triangleq (x_q, y_q)$, $q \in \{1, \dots, Q\}$, the position of the qth source. The propagation time from the qth source to the reference sensor of the ℓth array is given by $\tau_{q,\ell} \triangleq (1/c)\|\mathbf{p}_q - \mathbf{d}_\ell\|$, where c is the wave propagation speed. Let the $M \times 1$ column vector, $\mathbf{a}_{q,\ell}$ denote the ℓth array response to the qth source.

The complex envelopes of the signals observed by the ℓth array are given by

$$\mathbf{r}_\ell(t) = \sum_{q=1}^{Q} b_{q,\ell}\mathbf{a}_{q,\ell}s_q(t - \tau_{q,\ell}) + \mathbf{n}_\ell(t), \quad 0 \leqslant t \leqslant T, \tag{1}$$

where T is the observation time, $b_{q,\ell}$ is an unknown non-zero complex scalar representing the attenuation of the qth signal as observed by the ℓth station, $s_q(\cdot)$ is the qth signal waveform, and $\mathbf{n}_\ell(\cdot)$ represents the noise and interference observed by the array.

We assume that:

(1) The signals are realizations of a continuous-time, ergodic, zero-mean, wide-sense stationary, complex Gaussian random processes.
(2) The noise at the output of each of the array elements is wide-sense stationary, zero mean, complex Gaussian process, uncorrelated with the noise at the other antenna elements and uncorrelated with the signals.
(3) The signals and noise processes have the same bandwidth, W, and the same center frequency ω_0, (both in rad/s).
(4) The length of the observation interval T is long compared with the correlation time of the signals and the correlation time of the noise processes, and also long compared to the propagation time between the stations.
(5) Without loss of generality the attenuations to the reference (first) station are assumed real, i.e., $Im\{b_{q,1}\} = 0, \ \forall q$ and $\sum_{\ell=1}^{L}|b_{q,\ell}|^2 = 1$. These constraints eliminate the trivial solution.

The first stage of the processing consists of partitioning the observation interval to K sections, each of length $T' \triangleq T/K$. Since the observed signal is a stationary process, it can be represented by a set of Fourier coefficients

$$\mathbf{r}_\ell(k,j) \triangleq \frac{1}{\sqrt{T}} \int_{(k-1)T'}^{kT'} \mathbf{r}_\ell(t) \mathrm{e}^{-\mathrm{i}\omega_j t}\, \mathrm{d}t, \tag{2}$$

where $k = 1, \dots, K$, and $\omega_j \triangleq (2\pi/T')j, j = 0, 1, \dots, J$. The Fourier coefficients of (1) satisfy

$$\mathbf{r}_\ell(k,j) = \sum_{q=1}^{Q} b_{q,\ell}\mathbf{a}_{q,\ell}s_q(k,j)\mathrm{e}^{-\mathrm{i}\omega_j\tau_{q,\ell}} + \mathbf{n}_\ell(k,j), \tag{3}$$