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Passive geolocalization of radio transmitters: Algorithm and performance in narrowband context

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ABSTRACT

Passive localization commonly consists of a two steps strategy. In the first step, intermediate parameters, often called measurements (such as angles of arrival (AOA), times of arrival (TOA), etc.) are measured on several base stations equipped with sensor arrays. In a second step, the transmitted intermediate parameters are then used to estimate the position at a central processing unit. Such approach is suboptimal. To overcome this limitation, one step algorithms were recently proposed. They exploit simultaneously all received signals of all base stations seen as a global array in order to provide the source positions directly. In this paper, we propose an original one step algorithm called global MUSIC approach (GMA). The GMA offers better performance in narrowband context. Moreover it does not require the use of filter banks in the wideband signal context, contrary to the recently proposed direct position determination (DPD). GMA appears to outperform the DPD in wideband context. We also investigate in this paper by means of a Cramer–Rao bound analysis the potential gain achievable by a one step approach compared to a conventional two steps approach. Finally, numerical results illustrate the improvement of the proposed method compared to existing techniques in terms of location error and robustness to the time-bandwidth product.

1. Introduction

In radio communication the geolocalization problem of radio transmitters has always received great attention. By means of multiple sensors base stations (seen as sub-arrays), forming what we call here a global array, the problem lies in estimating the position of multiple radio emitters in far field context. Traditionally [1,2], the localization algorithm consists of two steps illustrated in Fig. 1.

In the first step, parameters (often called measurements) are independently estimated at each base station. Parameter estimation has always been an intensive research theme in the array processing community. During the last two decades it leads to a well-suited theoretical framework (see [3,4]). Among the available studied problems the angle of arrival (AOA) estimation has been widely discussed [5]. Using the narrowband assumption on a multi-sensor base station the AOA information is contained in the phase difference between the sensors. It appears to be particularly convenient for passive localization since it does not require any prior information on the transmitted signals.

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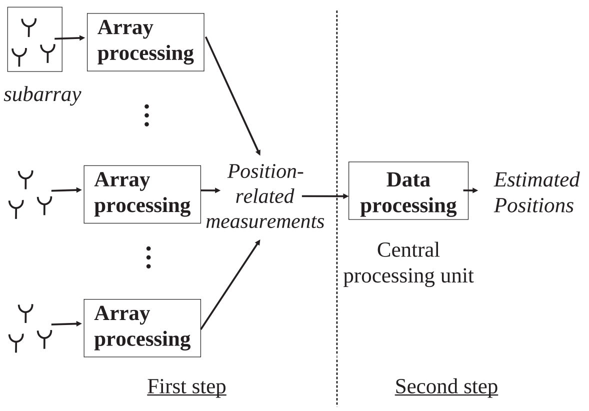

Fig. 1. Conventional two steps position determination scheme.

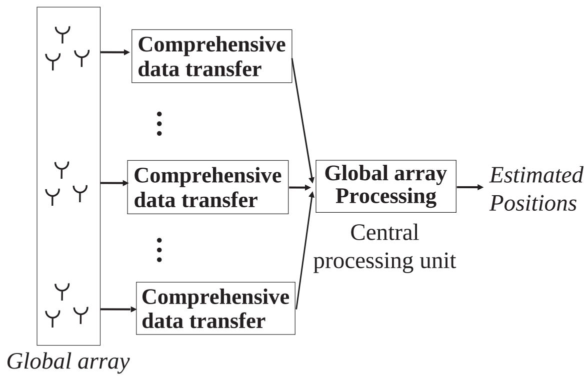

Fig. 2. One step position determination scheme.

In the second step, the geolocalization is computed based on the set of measurements available from step 1 [6,7] and transmitted to a central processing unit (CPU). Previous studies aimed to quantify and reduce the bias and the variance of this second step [8,9].

However, such two steps approach suffers from limitations [1]. First, solving the problem by means of a multiple step strategy is often suboptimal. As the first step does not take into account the fact that the received signals at the stations come from the same emitters this step is suboptimal. Secondly, in passive multi-emitter context, the problem is ambiguous since one has to identify among all available measurements, which subset of measurements characterizes each source. This problem is sometimes called "data association" [10]. Lastly, the performance and the number of resolvable emitters at each station are known to be locally limited by the number of sensors of the considered station. These are the reasons why an approach based on a one step strategy, gathering the received signals of all available stations, that directly provides the emitter location in LOS context, as illustrated in Fig. 2, appears of great interest. Such an approach assumes that each station is able to transfer all the signals to a central processing unit.

Fewer works provide one step procedures that directly estimate the position of emitters using the signal collected by all multi-sensor stations. Only [11–14] investigate recently such one step procedures. Studies [14,15] deal with the global navigation satellite system (GNSS), another [13] focuses on moving targets proposing a location algorithm based on frequency Doppler shifts exploitation. To the best of our knowledge, only Weiss and Amar [11,12] treat the passive localization problem in a one step approach called direct position determination (DPD) exploiting the information of the steering vector (angular response) of each sensor. Based on filter banks, they proposed a unique criterion gathering all signals of all stations firstly in the presence of a single emitter [11] and then proposed a MUSIC [16] approach of the problem in order to treat the multiple emitters case [12]. Their approach relies on an incoherent sum of criteria obtained for each frequency of the filter bank. It suggests that this strategy is not optimal. They proved [17] the theoretical gain of such techniques in terms of the number of resolvable emitters. They also provide a performance analysis [12] under known waveforms or random Gaussian signal assumptions. To the best of our knowledge, the performance study for deterministic signals was never provided for direct position estimation. We fill the lack in this paper.

Solving the problem by means of a one step strategy leads to estimate the emitters location but it also implies to estimate the complex gain of the signal received in all stations, seen as a nuisance parameter [11], in order to account for the possible path attenuation, which is different for each station. It underlines the need of investigating the theoretical gain of such a one step strategy compared to a conventional two steps strategy.

In this paper, we consider a global array composed of several multi-sensor base stations, each one able to transfer the data to a CPU, and we focus on passive (or non-cooperative) localization problem of multiple transmitted signals in LOS context, with no prior information on the signals. Based on preliminary work [18], we propose a one step location algorithm called global MUSIC approach (GMA) that does not require the use of filter banks in wideband signal context. We explore more soundly the performance improvement in terms of location error of such a one step approach using deterministic Cramer–Rao bounds (CRBs) comparisons. In Section 2, we formulate the problem and study the case of narrowband signals for the global array. Then in Section 3 the MUSIC approach called GMA is derived. Section 3 also provides the gradient and the Hessian required for a practical implementation based on a Newton algorithm. The Cramer–Rao bound expression of the conventional two steps and the one step approach for deterministic signals are given in Section 4. Extension of the GMA to the wideband signal case is discussed in Section 5. Simulations illustrate in Section 6 the gain of the proposed approach compared to existing techniques.

2. Signal model

We focus on the problem of locating multiple LOS emitters on L separated base stations each composed of N_l $(1 \leq l \leq L)$ sensors as illustrated on Fig. 3. Let us denote $N = \sum_l N_l$ the total number of sensors. Let $\mathbf{x}_l(t)$ be the