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Emitter localization using received-strength-signal data

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ABSTRACT

This paper considers a scenario in which signals from an emitter at an unknown location are received at a number of different collinear locations. The receiver can determine the received signal strength, but no other parameters of the signal. Postulating a log-normal transmission model with a constant but unknown path loss exponent and, also, an unknown transmit power and known noise variance, the paper shows how the localization problem can be solved, along with estimating the parameters appearing in the log-normal transmission model, given enough measurements at different points. The log-normal transmission model parameters can be determined first. An algorithm based on construction of a Gram matrix is proposed to estimate the path loss exponent and transmit power parameters from the received noisy power measurements. Since the estimated parameters are biased due to the nonlinearity of the model and constraints, a pattern-matching algorithm is also proposed to remove the bias in the estimates. The distances corresponding to the different received signal strength measurements can then be bounded, and finally the location estimation is formulated as a convex optimization problem where the estimated distances are used as the new measurements. Simulation results are finally provided to assess the efficacy of the proposed methods in the parameter and location estimation.

1. Introduction

1.1. Background and motivation

Emitter localization using signals received in a number of different locations is a common task arising in security and surveillance problems. The scenario considered in this paper consists of a single emitter with unknown location and a sensor platform that receives the signal transmitted by the emitter in different and known locations. Different types of measurements such as Time Difference of Arrival (TDOA), Time of Arrival (TOA), and Received Strength Signal (RSS) [20] can be received by the sensor. However, ease of hardware implementation, inexpensive cost, and securing less energy consumption have increased the popularity of signal processing using RSS data. Now in practice, besides the unknown location of the emitter, parameters of the RSS measurement model such as the transmitted power and Path Loss Exponent (PLE) may be both unknown. In addition, the position of the emitter appears implicitly in the nonlinear RSS model in terms of the distances between the emitter and the sensor in different locations. These distances are also

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coupled with other parameters of the model which, consequently, results in a highly nonlinear and multi-dimensional parameter estimation problem for the two RSS model parameters and the emitter-sensor distances. From the distance estimates, the emitter location can then be estimated.

Self-localization using RSS data has been extensively studied in the literature [2,9,13–16,18–21,23,25,28,29]. Most literature has dealt with the localization problem by, first, estimating the inter-sensor distances and, then, applying an appropriate position estimation algorithm using the estimated distances. These distance-based methods have been mostly implemented using a Maximum Likelihood (ML) estimator. While the ML approach leads to a nonconvex optimization problem, some other modifications have been also proposed in order to deal with the nonconvexity in the optimization [16]. In addition, the special statistical characteristics of the range noise have been studied in [14,29]. It is shown that besides additive log-normal noise, some other disturbances such as NonLine-of-Sight (NLOS) propagation can degrade the performance of localization. A Gaussian Mixture Model (GMM) has been postulated in [29] to deal with the NLOS propagation. An alternative version of the ML estimator has been also offered in [14] in order to improve the accuracy of localization in the presence of the log-normal additive noise. In brief, it can be observed that most effort has been made to the improvement of sensor localization based on using estimated distances and potential presence of additive disturbances.

Although localization techniques based on distances have been extensively studied in the context of wireless sensor networks, there are still some less studied issues relating to estimating the parameters of the RSS measurement model (as distinct from the emitter location). First, most articles assume that the parameters of the signal model are known a priori. Although this assumption may be reasonable for simulated RSS data, there is frequently no information about the PLE and the transmitted power in experimental data. Furthermore, sensors may not have any prior information about the values of these measurement parameters. On the other hand, an accurate knowledge of parameters plays an important role in achieving the accuracy of the estimated distances which is also a requirement for location estimation. Determining the PLE by direct measurements may be very expensive and, recently, alternative means of PLE estimation have been addressed in the literature [1,15,26]. The proposed approach in [26] is based on finding the empirical and analytical distribution of the received mean power or outage probability. The PLE can then be found by comparing the empirical and the theoretical distributions. However, the accuracy of the distribution estimation significantly depends on the number of received measurements. For example, simulations in [26] show a significant error in the estimates when the number of received RSS data becomes smaller than 1000. When the frequency offset due to the transmitter and receiver clock shift is available, Doppler shift data have been also employed in [1] for PLE estimation. A unique feature of the proposed method in [1] is that the PLE is assumed to be different in multiple links and, also, time variant. It also uses the frequency offset in the receiver and RSS in order to reduce the dimension of the estimation problem. Nevertheless, it is clear that such frequency information is often not available in practice and then the proposed approach in [1] cannot be used. An ML estimator combined with the geometrical constraints imposed by the Cayley–Menger determinant (CMD) [7] has been also proposed for the PLE estimation in [15]. The authors show that the ML estimation leads to a number of equations that cannot alone provide a unique estimate of distances and the PLE, but CMD constraints are then utilized to find a unique estimate of the PLE from the ML estimator equations.

A problem with this PLE estimation method is that it normally leads to a significant bias in the estimated PLE, due to the nonlinearity of the RSS model and constraints [15]. Simulations in [15] show that the bias can be even larger than the actual value of the parameter. An empirical approach was proposed in [15] in order to reduce the bias in PLE estimation. The idea is to find an empirical pattern of bias versus PLE and the variance of the additive noise covering sufficiently large ranges of the variables to be applicable in almost all scenarios. Then, parameters are estimated in a way that the empirical pattern is matched to the sampled pattern. Results confirm a significant improvement in the accuracy of estimation. Another approach was also provided in [10] although parameters of the model such as variance and transmitted power are assumed to be known.

1.2. Main contributions

The main goal of this paper is to propose a robust procedure for estimating the location of an emitter with available RSS data, and we make a number of advances on earlier work. In particular, our contributions can be characterized as follows:

- *Estimating the transmitted power, path loss exponent and target position jointly*
  Although an algorithm was proposed in [6] for estimating the transmitted power, there is no algorithm for jointly estimating PLE, transmitter power, and the location of the emitter. The number of parameters to be estimated will normally exceed the number of scalar RSS measurements and some more constraints are needed to guarantee the uniqueness of the solution.
- *A Gram-matrix formulation for the parameter estimation*
  A Gram-matrix approach is formulated for the parameter estimation using RSS data. It is shown that geometrical constraints imposed by the Gram-matrix method provide extra information required for solvability of the parameter estimation problem. In addition, compared to the recently used CMD method in [15], the superior performance of the Gram-matrix is demonstrated through the lower bias in the estimates of parameters.
- *Bias correction*
  Although the Gram-matrix enjoys lower bias level compared to the CMD method, the given algorithm