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Robust location algorithm for NLOS environments*

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Abstract: One of the main problems facing accurate location in wireless communication systems is non-line-of-sight (NLOS) propagation. Traditional location algorithms are based on classical techniques under minimizing a least-squares objective function and it loses optimality when the NLOS error distribution deviates from Gaussian distribution. An effective location algorithm based on a robust objective function is proposed to mitigate NLOS errors. The proposed method does not require the prior knowledge of the NLOS error distribution and can give a closed-form solution. A comparison is performed in different NLOS environments between the proposed algorithm and two additional ones (LS method and Chan's method with an NLOS correction). The proposed algorithm clearly outperforms the other two.

Keywords: wireless location, time-of-arrival, non-line-of-sight, robust objective function.

1. Introduction

Geolocation in terms of geographic coordinates of a mobile station (MS) with respect to base stations (BSs) in wireless communication systems has gained considerable attention over the past decade, especially since the Federal Communication Commission (FCC) passed a mandate requiring cellular providers to generate accurate location estimates for Enhanced-911 (E-911) services[1]. This has boosted the research in the field of wireless location as an important public safety feature, which can also add many other potential applications to the future cellular systems: location-sensitive billing, fraud protection, person/asset tracking, fleet management, mobile yellow pages, wireless system design, radio resource management, and intelligent transportation systems (ITS)[2].

An introduction to the basics of MS localization is given in Refs. [3-5]. Conventional geolocation techniques include time-of-arrival (TOA), time-difference-of-arrival (TDOA), angle-of-arrival (AOA), signal strength (SS) based methods, or a combination of these. Among these location techniques, a method based on TOA has attracted much attention[3−4]. In the multipath propagation environment, TOA is the measured propagation delay of the earliest distinguished path in the receivers. With the data of TOA, the location algorithms are used to estimate the position of the source in the location service center.

The main problem of cellular wireless location systems is the NLOS situation, when the signal arrives at a BS from reflections. There is no direct or line-of-sight (LOS) path. This often happens in an urban environment. For ranging measurements (or equivalently, TOA), it will add a large positive error in addition to standard measurement error [3]. Unfortunately, traditional TOA algorithms[14−15] have been developed based on LOS assumptions between the MS and BSs, and consequently, they perform very poorly when the TOA measurements are corrupted by NLOS errors. Thus, methods that can provide improved accuracy over the traditional algorithms in NLOS environments are needed.

Several methods for mitigating NLOS errors have been addressed in published works[6−13]. The methods presented in Refs. [6−8], which require a time series of range measurements from a moving user work well when MS is moving. The methods in [9−10]

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first measure the propagation characteristics of the channel, and then, determine the MS location from a database. The difficulties are in obtaining an accurate model, and the model might change with the seasons and addition or removal of building structures. The methods in Refs. [11−12] use different constrained conditions to restrain NLOS errors. These methods require a search process and cannot give a closed-form solution to mobile location. The inefficiency incurred by these algorithms might not be feasible to be applied in practical systems. The method in Ref. [13] uses the mean of NLOS errors to correct the measured distances in the Chan's method, which needs the prior knowledge of the NLOS error distribution.

Traditional location algorithms [14−15] are based on classical techniques under minimizing a least-squares error function and it loses optimality when the NLOS error distribution deviates from Gaussian distribution [17]. Robust estimation theory [16−19] is applied when the classical estimation theory fails. In this article, an effective location algorithm based on a robust objective function is proposed to mitigate NLOS errors, which does not require the prior knowledge of the NLOS error distribution known to be the main problem in location estimation. In addition, compared to other NLOS mitigation algorithms, our method does not require time-history based measurements and can give a closed-form solution.

2. The NLOS location algorithm

Here, we consider TOA based method. The proposed algorithm can be scaled up to other location techniques, such as TDOA, SS, and AOA.

Assuming that (x, y, z) is the position of the MS, (x_i, y_i, z_i) is the position of the ith BS, the first BS position is $(0, 0, 0)$ m, and d_i is the TOA measured in BS i. Here and below, denote the (i, j) th entry of a matrix M as $[M]_{i,j}$ and the true value of $\{*\}$ as $\{*\}^0$. The ith range measurement r_i is modeled as

$$r_i = cd_i = r_i^0 + n_i + NLOS_i,\ i = 1, \ldots, M \quad (1)$$

where c is the signal propagation speed, M is the number of the BSs, r_i^0 is the true distance between the MS and BS i, n_i represents the standard measurement error subjected to zero mean Gaussian distribution, and $NLOS_i$ is a random variable representing the error because of NLOS propagation, which is subjected to different statistical distributions in the different channel environments[20], such as exponential, uniform, and Delta distribution. Thus, traditional location algorithms lose optimality when MS located NLOS environments, and a new location algorithm based on a robust objective function is needed. Now, we construct the objective function

$$J = \sum_{i=1}^{M} \rho([e]_i) \quad (2)$$

where $\rho(\bullet)$ is a robust objective function for suppressing NLOS errors and $[e]_i$ is a residual error in BS i. To locate MS in the presence of NLOS propagation, an objective function with more tolerance for outliers is required. The Talvar estimator[16] is such a function and is proposed for this application, which can suppress outliers with weights. There, $\rho(\bullet)$ is chosen as the more general Talvar M-estimate function, which is given as follows[16]

$$\rho(e) = \begin{cases} e^2/2, & |e| \leqslant \beta \\ \beta^2/2, & \text{other} \end{cases} \quad (3)$$

where β is the cutoff value, estimated by the median absolute deviation from the median of $[e]_i$[19]

$$\beta = med\{|[e]_i - med\{|[e]_i|\}|\} \quad (4)$$

The score function $\psi(e)$ is given by[16]

$$\psi(e) = \frac{\partial \rho(e)}{\partial e} = \begin{cases} e, & |e| \leqslant \beta \\ 0, & \text{other} \end{cases} \quad (5)$$

The weight function $[\psi(e)/e]$ for Talvar M-estimator is given by [16]

$$q(e) = \frac{\psi(e)}{e} = \begin{cases} 1 & |e| \leqslant \beta \\ 0 & \text{other} \end{cases} \quad (6)$$

The squared distance between the MS and BS i is

$$r_i^2 = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = \quad (7)$$

$$K_i - 2x_i x - 2y_i y - 2z_i z + x^2 + y^2 + z^2, i = 1, 2, \ldots, M$$

where $K_i = x_i^2 + y_i^2 + z_i^2$.