

A Novel NLOS Mitigation Approach for Wireless Positioning System

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Abstract. A Non-light-of-sight (NLOS) mitigation approach based on GBSBEM was proposed in this paper. The main idea is to model the NLOS errors to the elliptical model and mitigate them with a novel method. At the first step, the semi-minor of GBSBEM is estimated, then a way to restrain the NLOS errors with the help of the semi-minor is used. When the semi-minor can not be estimated, an optimization method based on GBSBEM pdf is presented. The method has a good effect to reduce the NLOS error, especially when the NLOS effect is notable.

Keywords: nlos mitigation; gbsbem; position algorithm

1. Introduction

In the wireless positioning techniques, one of the major challenges for positioning is the NLOS error. The propagated signal between the MS (Mobile Station) and the BS (Base Station) goes through reflection and refraction of many objects in its path. That causes the position parameters inaccuracy and makes a large positive error for position system. The traditional TOA or TDOA position algorithms always base on LOS assumption [1], [2]. Thus, how to identify and mitigate the NLOS error is a concerned topic in this area.

NLOS identification and mitigation have been addressed in the literature [3]-[6]. The classical method in [3] compares the standard deviation of the range measurements with the threshold value for NLOS identification, but the noise variance is assumed known for LOS reconstruction. The approach in [4] uses the available data regarding ranges and the base station (BS) layout to adjust the measured ranges to near the true LOS value. A constrained nonlinear optimization is presented in this paper. However, the complexity of the optimization makes this measure hard to realize. [5] proposes a TOA position method based on the combination of the probability position method and the geometric position method. It can restrain NLOS propagation errors to some degree. The NLOS identification discussed in [6] is by the help of the channel model defined in IEEE 802.15.4a. Four scenarios characterize the propagated signal's log-normal pdf in graphs. This method can distinguish the LOS/NLOS scenarios under UWB system, but can not apply for the mobile system.

In some situations, especially under the urban environment, the propagated signal would reflect or refract at least once. That means all of the BSs considered in the positioning system should be assumed NLOS affected. Channel modeling can perform the channel output parameters, such as multi-path delays, and signal direction of arrival [7]. This paper focuses on the geometrically based single bounce elliptical model (GBSBEM), because of its ability to produce spatial channel characteristics that is tied to the physical propagation environment. The GBSBEM has a wide range of application for both analyzing and simulating.

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The paper is organized as follow. In section II, the general GBSBEM is introduced, and section III describes the detail of the approach based on GBSBEM for NLOS mitigation. Simulation results are presented in section IV followed by concluding remarks in section V.

2. Gbsbem Model

The Geometrically Based Single Bounce Elliptical Model (GBSBEM) is a typical urban cell model in wireless communication research area, which is applied in many related literature [7],[8], In the model, both MS and BS are surrounded by scattering obstacles. The model assumes all of the signal propagated from the multi-path reflects or refracts only once in the considered environment. The boundary of the elliptical is the furthest borderline of the refraction. The scatters are well-distributed in the region of the elliptical model.

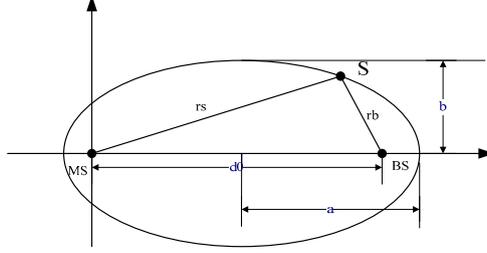


Figure 1. Geometrically based single bounce elliptical Model

Figure 1 illustrates the geometry of the GBSBEM, where S is the selected scatterer, the MS and BS are assumed on the focal spot of the elliptical, d_0 is the distance between the MS and BS. The signal propagates from the BS to MS by refracting in S, which r_s and r_b are the distances between the scatter S and the MS and the BS respectively. The distance of NLOS propagation is l , which equals r_s add r_b . a and b are the semi-major and semi-minor axes of the elliptical, and f is the focal radius. The equations are expressed as follow

$$\begin{cases} l = r_b + r_s = 2a \\ a^2 - b^2 = f^2 \\ d_0 = 2f \\ \frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \end{cases} \quad (1)$$

Assumes that the scatters are uniformly distributed in the region of Figure 1, and the area of the elliptical region is given by πab . The TOA probability density function (pdf) [8], [9] observed at the BS is given by

$$f_\tau(\tau) = \frac{c}{\beta d_0} \frac{2(c\tau / d_0)^2 - 1}{\sqrt{(c\tau / d_0)^2 - 1}}, \quad \tau_0 \leq \tau < \tau_m \quad (2)$$

$$\beta = \left(\frac{c\tau_m}{d_0}\right) \sqrt{\left(\frac{c\tau_m}{d_0}\right)^2 - 1}, \quad (3)$$

Where c is the speed of light, τ is the time delay of a multi-path component, τ_0 is the time delay between the BS and MS, τ_m is the maximum TOA of a multi-path component, d_0 is the distance between the BS and the MS.

3. Nlos Mitigation

3.1 Effect of semi-minor of GBSBEM

Assume that there are M BSs available. The range measurement of TOA data can be modeled as

$$r_j(t_i) = l_j(t_i) + n_j(t_i) + NLOS_j(t_i) \quad j=1, \dots, M, \quad (4)$$

Where $r_j(t_i)$ is the range measurement, $l_j(t_i)$ is the true distance between the BSj and the MS, $n_j(t_i)$ is the measurement error, $NLOS_j(t_i)$ is the NLOS error at time sample t_i .

The measurement error is usually modeled as Gaussian, i.e. $n_j(t_i) \sim N(0, \sigma_j)$ where σ_j is in the order of 150m [3]. The NLOS error $NLOS_j(t_i)$ can be modeled as the frequently used models for delay profiles which are exponential, uniform or delta random variable [10].

The range measurements can be smoothed by modeled as

$$r_j(t_i) = \sum_{n=0}^{N-1} a_j(n) t_i^n, \quad (5)$$

Where $a_j(n)$ is the unknown coefficients gotten by the least squares technique.

The smoothed measurements are represented as

$$s_j(t_i) = \sum_{n=0}^{N-1} \hat{a}_j(n) t_i^n, \quad (6)$$

When the NLOS errors exist and can not be ignored, the LOS propagation path can be reconstructed by the GBSBEM. The initial value of semi-minor of GBSBEM should be estimated. From the urban structure or the geo-information system, the semi-minor can be estimated. Assume that the semi-minor is b . The value of semi-minor is less than the semi-major obviously. That is

$$\begin{cases} b < a \\ a = \frac{1}{2} \max(s_j) \end{cases} \quad (7)$$

So, the half of the LOS path between the BSj and the MS, which is also the focal radius of the GBSBEM can be estimated by

$$f = \sqrt{a^2 - b^2}, \quad (8)$$

The LOS path between the MS and the BSj is

$$d_{LOS} = 2f = \sqrt{(x_{ms} - x_j)^2 + (y_{ms} - y_j)^2}, \quad (9)$$

It is well known that the location accuracy usually decreases as the NLOS errors increase. This indicates that the selection of the initial value is very important. When the initial value is appropriate, the NLOS error can be mitigated effectively. Of course, if the estimator does not rely on the initial values, the method should be more practical.

3.2 NLOS Mitigation with GBSBEM's pdf

When getting a large number of measurements, the estimator can calculate the average value of the smoothed measurements.

Let the average value is μ_s , That is expressed as

$$\mu_s = \frac{1}{N} \sum_{i=1}^N s_j(t_i), \quad (10)$$

By the pdf of GBSBEM described in (2), the mean value of the measurement can also be expressed as

$$\begin{cases} \mu = \int_{\tau_1}^{\tau_m} \tau f_{\tau}(\tau) d\tau \\ = \frac{d_0}{\beta c} \left[\sqrt{\left(\frac{c\tau}{d_0}\right)^2 - 1} + \frac{2}{3} \sqrt[3]{\left(\frac{c\tau}{d_0}\right)^2 - 1} \right] \Big|_{\tau_1}^{\tau_m} \\ \tau_m = \frac{\max(s_j)}{c} \\ \tau_1 = \frac{\min(s_j)}{c} \\ d_0 = c\tau_0 \end{cases} \quad (11)$$

Where τ_1 is the minimum time delay of NLOS propagation and τ_m is the maximum time delay of NLOS propagation, c is the speed of light.

Assume that

$$\begin{cases} \mu_s = \mu = \frac{d_0}{\beta c} \left[\sqrt{\left(\frac{c\tau}{d_0}\right)^2 - 1} + \frac{2}{3} \sqrt[3]{\left(\frac{c\tau}{d_0}\right)^2 - 1} \right] \tau_1 \\ d_0 = c\tau_0 \end{cases} \quad (12)$$

The τ_0 can be calculated by numerical method and the LOS path between the MS and the BSj is

$$d_{LOS} = c\tau_0. \quad (13)$$

This indicates that the minimum of $s_j(t_i)$ should be near the LOS path. If the minimum of $s_j(t_i)$ is far from the true distance between the MS and the BSj, the accuracy of calculated value would decrease.

With at least three reconstructed LOS values, the estimator can calculate the position of the MS.

4. Simulations

The simulations are performed to confirm the validity of the proposed method, organizing as following steps:

1. When the urban is typically distributed, the performance of NLOS mitigation by the proposed method is presented.
2. The comparison between the classical positioning methods and the proposed method is presented.

4.1 The simulation of NLOS mitigation

The distance between the MS and the given BS is

$$r = r_0 + n_0 \cdot randn(\cdot) + NLOS \cdot rand(\cdot), \quad (14)$$

Where r_0 is the true distance between the MS and the given BS. $n_0 \cdot randn(\cdot)$ is the AWGN noise which is certainly existed in the environment. $NLOS \cdot rand(\cdot)$ is the NLOS noise which is a large positive bias compared to AWGN noise.

The simulation trajectory has 200 time samples with the sample interval equals to 1s. The MS is static and the distance between the MS and BS is 200m. The NLOS error causes positive bias of 200m. The measured data positively deflects off the true data. When the semi-minor of GBSBEM is estimated, the bias of the data can be modified. The performance of the proposed method is illustrated in Figure 2.

To inspect the performance of the proposed methods under different situations, RMSE is needed which describes average error of each simulation for different situations. The definition of RMSE is

$$RMSE = \sqrt{E[(x - \hat{x})^2 + (y - \hat{y})^2]}, \quad (15)$$

Table I gives the RMSE of the simulation results.

Table I. The RMSE of above simulations

scenarios	RMSE(m)
The measured distance	194.9025
The smoothed measurement	13.1378
Simulation under situation 1	0.7010

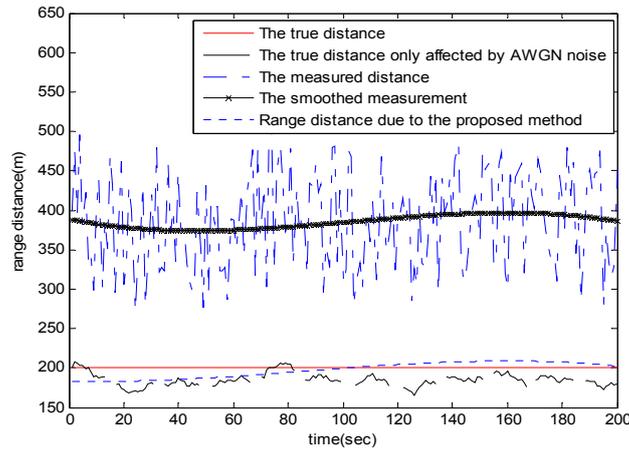


Figure 2. The performance of the NLOS mitigation by GBSBEM

4.2 The simulation of position performance

The above simulation illustrates the NLOS mitigation performance of a single BS. To discuss the proposed method sufficiently, the simulation for position algorithms is needed. LLOP [2] is a classical TOA based algorithm, which can mitigate the NLOS error in some degree. Chan algorithm [1] is a TDOA based algorithm, which uses WLS to restrain the NLOS error. The positioning estimation accuracy is checked for the scenarios of 5BS. The ratio of the NLOS error to the true distance is given by dB. The coordinates of the BSs are BS1 ($x_1=200\text{m}$, $y_1=200\text{m}$), BS2 ($x_2=-200\text{m}$, $y_2=200\text{m}$), BS3 ($x_3=-200\text{m}$, $y_3=-200\text{m}$), BS4 ($x_4=200\text{m}$, $y_4=-200\text{m}$), BS5 ($x_5=0\text{m}$, $y_5=0\text{m}$). The coordinate of the MS is ($x=40\text{m}$, $y=60\text{m}$). The propagation from the BS to MS is corrupted by NLOS error. The LLOP algorithm chooses three of the five BSs randomly while the Chan algorithm chooses all of them. The performance is illustrated in Figure 3 and Figure 4. It can be seen that when the NLOS error has minor impact, the proposed method could not efficiently restrain the NLOS error for LLOP. However, when NLOS error badly affects the true measurement, the effect of the proposed method has shown and the performance of positioning has been improved a lot. The improvement of the positioning accuracy can also be seen from Figure 4.

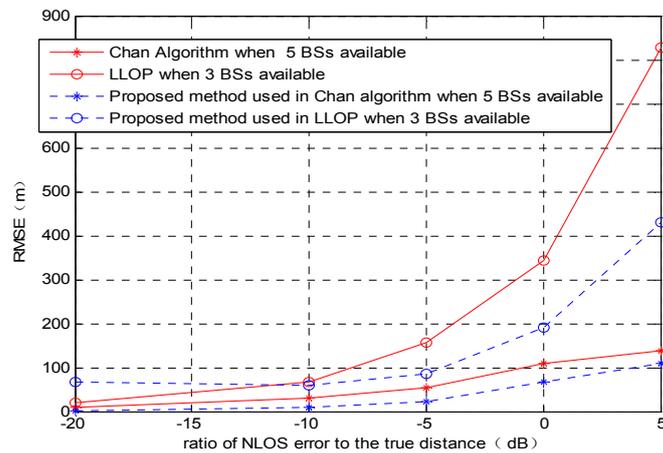


Figure 3. RMSE of different methods

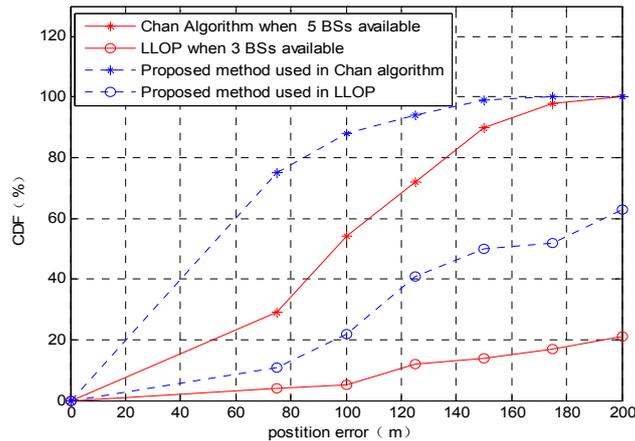


Figure 4. The position error of the proposed method compared to the Chan and LLOP algorithm

5. Conclusion

NLOS error greatly affects the accuracy of the positioning system. In this paper, a novel p-positioning approach based on GBSBEM is proposed. Theoretic analysis and simulation results show the good performance of this method, especially in bad NLOS environment.

6. Reference

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