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Non-line-of-sight Error Mitigation in Wireless Communication Systems

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Abstract. When there is non-line-of-sight (NLOS) path between the mobile station (MS) and base stations (BSs), it is possible to integrate many kinds of measurements to achieve more accurate measurements of the MS location. This paper proposed hybrid methods that utilize time of arrival (TOA) at five BSs and angle of arrival (AOA) information at the serving BS to determine the MS location in NLOS environments. The methods mitigate the NLOS effect simply by the weighted sum of the intersections between five TOA circles and the AOA line without requiring *priori* knowledge of NLOS error statistics. Simulation results show that the proposed methods always give superior performance than Taylor series algorithm (TSA) and the hybrid lines of position algorithm (HLOP).

1 Introduction

And the primary network-based techniques include signal strength, angle of arrival (AOA), time of arrival (TOA), and time difference of arrival (TDOA) techniques. The AOA scheme utilizes antenna array to determine the direction of arrival of signal. TOA location scheme measures the propagation time it took for the signal to travel between the mobile station (MS) and the base station (BS). The accuracy of mobile location estimation strongly depends on the propagation conditions of the wireless channels. The radio signals are usually corrupted by additive noise, multipath propagation, multiple access interference, and NLOS propagation in wireless location system. To enhance the precision of the location estimation, appropriate steps must be taken to mitigate these impairments.

A common requirement for high location accuracy is the presence of a line-of-sight (LOS) path between the MS and each participating BS. In practice, LOS paths are not always readily available. The non-line-of-sight (NLOS) propagation occurs usually in urban or suburban areas and will heavily degrade the precision of the location estimation. Due to the reflection or diffraction of the signals between the MS and the BSs, NLOS propagation results in significant errors in the time and angle measurements.

To improve the accuracy of MS location, it is reasonable to integration two or more schemes give location estimation of the MS. We have proposed hybrid geometrical positioning schemes to estimate MS location under the condition that the MS can be heard by only two BSs in [1]. In this paper, we apply the hybrid geometrical positioning schemes to locate MS when five BSs are available for location purposes. We present a mobile positioning system that adopts TOA-aided AOA information at five BSs to estimate the location of an MS. By acquiring the intersections of five TOA circles and AOA line, it is possible to locate the desired MS in wireless communication systems. The proposed positioning methods are based on the weighted sum of the intersections of five TOA circles and the AOA line. Simulation results show that the proposed methods always achieve better location accuracy than Taylor series algorithm (TSA) [2] [3] and the hybrid lines of position algorithm (HLOP) [4].

The remainder of this paper is organized as follows. The system model is given in Section 2. Section 3 presents the commonly used positioning methods TSA and HLOP. Section 4 describes various approaches using the intersections of the five TOA circles and the AOA line to estimate the position of MS. Simulation results are presented in Section 5. Conclusion is given in Section 6.

2 System Model

TOA measurements from five BSs and the AOA information at the serving BS can be used to give a location estimate of the MS, as shown in Fig. 1 [5]. Let t_i denote the propagation time from the MS to BS i, and the coordinates for BS i are given by (X_i, Y_i), $i = 1, 2, \ldots 5$. The distances between BS i and the MS can be expressed as

$$r_i = c \cdot t_i = \sqrt{(x - X_i)^2 + (y - Y_i)^2} \tag{1}$$

where (x, y) is the MS location and c is the propagation speed of the signals. We assume that BS1 is the serving BS, and denote by θ as the angle between MS and its serving BS.

$$\theta = \tan^{-1}\left(\frac{y - Y_1}{x - X_1}\right) \tag{2}$$

3 Taylor Series Algorithm (TSA) and Hybrid Lines of Position Algorithm (HLOP)

To determine the MS location, TSA [2] [3] and HLOP [4] are commonly used schemes.

3.1 Taylor Series Algorithm (TSA)

The process starts with an initial guess for the MS location and can achieve high accuracy. This method is recursive but tends to be computationally intensive. TSA may suffer from the convergence problem if the initial guess is not accurate enough [2] [3].

3.2 Hybrid Lines of Position Algorithm (HLOP)

The new geometrical interpretation makes use of linear lines of position (LLOP) to replace the circular LOP for estimating the MS location. The detail algorithm of the linear LOP approach can be acquired by using the TOA measurements as in [6], and the hybrid linear LOP and AOA measurement (HLOP) in [4].

4 Proposed Hybrid TOA/AOA Geometrical Schemes

In the TOA schemes, the propagation time is directly proportional to its traversed distance. The distance can be used to form a circle and the MS lie on a circle centered at the BS. A single AOA measurement constitutes the MS along a line. The equations of the five TOA circles and the AOA line can be expressed as

$$\text{Circle 1-5: } (x - X_i)^2 + (y - Y_i)^2 = r_i^2, \quad i = 1, 2, \ldots 5 \tag{3}$$

$$\text{Line 1: } \tan\theta \cdot x - y = 0 \tag{4}$$

Under the assumption of LOS propagation and there exists no measurement error, the circles intersect one single common point. However, it is very often that the LOS does not exist for propagation of signals between an MS and some fixed BSs. Therefore, the NLOS effect could cause five circles and a line to intersect at various points, which will be offset from the true MS location. With NLOS propagation, the measured TOA values are always greater than the true TOA values due to the excess path length. The true MS location should be inside the region enclosed by the overlap of the five circles. The intersections that are within this are defined as feasible intersections. The feasible intersections must satisfy the following inequalities simultaneously:

$$(x-X_i)^2+(y-Y_i)^2 \le r_i^2, \quad i=1,2,\ldots 5\,. \tag{5}$$

The proposed methods utilize five TOA circles and the AOA line to find all the possible intersections to locate the MS. In order to enhance the performance of MS location estimation with less complexity, the hybrid geometrical positioning methods which we have proposed in [1] are applied in five BSs. In comparison, for the cases presented in [1], we used two AOA measurements to eliminate the least likely intersection. Note that the region of overlap of five circles is usually smaller than that of two circles, it is not necessary to eliminate the least likely intersection.

5 Simulation Results

Computer simulations are performed to show the proposed methods is appropriate for location estimation. The distance between these BSs is $d=3464$ m and the MS locations are uniformly distributed in the center cell, as shown in Fig. 1. 10,000 independent trials are performed for each simulation. Three different NLOS propagation models were used to model the measured ranges and angle, the circular disk of scatterers model (CDSM) [7] [8], the biased uniform random model [4] and the uniformly distributed noise model [7].

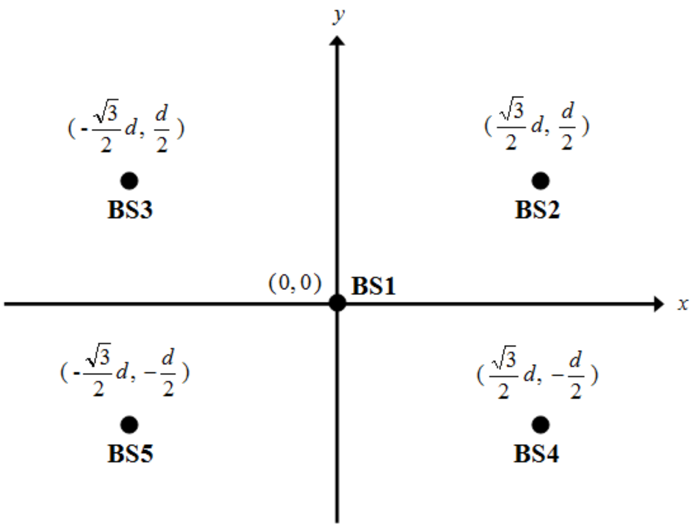

Fig. 1. Five-cell system layout.

The CDSM assumes that there is a disk of scatterers around the MS and that signals traveling between the MS and the BSs undergo a single reflection at a scatterer. The BS1 serving a particular MS is called the serving BS which can provides more accurate measurements. The radius of the scatterers for BS1 and the other BSs were taken to be 100m and 300m, respectively. The improvement in MS location accuracy using the proposed method can be obtained in the cumulative distribution function (CDF) curves, as illustrated in Fig. 2. From the simulation results, it is clear that TSA and HLOP predict the MS location with poor accuracy and the proposed methods always achieve the best performance.

The second NLOS propagation model is based on a biased uniform random variable [4], in which the measured error of TOA between the MS and BSi is assumed to be $\eta_i = p_i + u_i \cdot q_i$, where p_i and q_i are constants and u_i is a uniform random variable over [0, 1]. Similarly, the measured error of AOA, is modeled as $|f_1| = \alpha_1 + u_1 \cdot \beta_1$, where α_1 and β_1 are constants. The error variables are chosen as follows: $p_1 = 50$m, $p_2 = p_3 =100$ m, $q_1 = 150$ m, $q_2 = q_3 =300$ m, $\alpha_1 = 2.5°$, and $\beta_1 = 2°$. Figure 3 shows CDFs of the location error for different algorithms. It can be observed that the proposed methods can promote the location precision effectively.

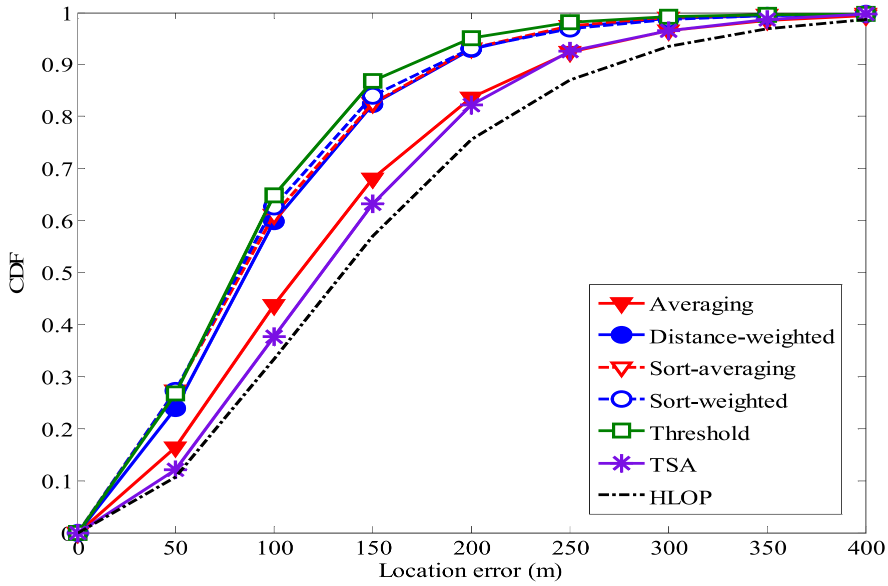

Fig. 2. CDFs of the location error when CDSM is used to model the NLOS error.

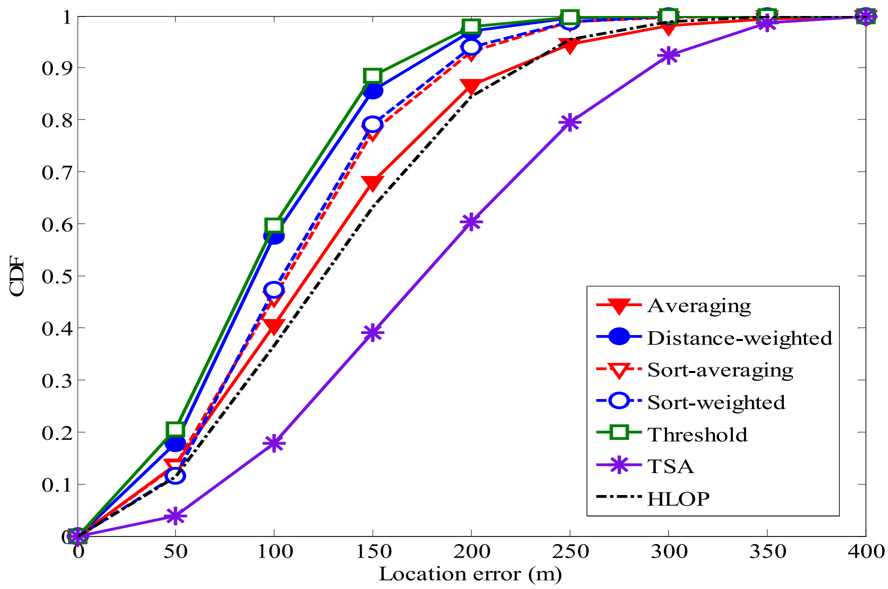

Fig. 3. Comparison of error CDFs when NLOS errors are modeled as biased uniform random variables.

The final NLOS propagation model is based on the uniformly distributed noise model [7], in which the TOA measurement error is assumed to be uniformly distributed over $(0,U_i)$, where U_i is the upper bound and the AOA measurement error is assumed to be $f_1 = w_1 \cdot \tau_1$, where w_1 is a uniformly distributed variable over [-1, 1] [9]. Figure 4 provides the root mean square (RMS) error as the upper bound on uniform NLOS error increases. The upper bound for BS1 is 200 m and the other BSs are taken from 200 m to 700 m. As expected, it is observed that the location error increases with the upper bound of NLOS. The proposed methods always give better accuracy than TSA and HLOP for the error model considered. The performance degradation of the proposed methods is not pronounced under harsher NLOS error conditions.

6 Conclusions

Based on the NLOS situation and the knowledge of NLOS error statistics is not obtained, we proposed the hybrid methods that utilize all the possible intersections of five TOA circles and the AOA line to provide the improved MS location estimation. Simulation results demonstrate that the proposed methods with different chosen weights generate more accurate MS location estimates than the conventional TSA and HLOP.

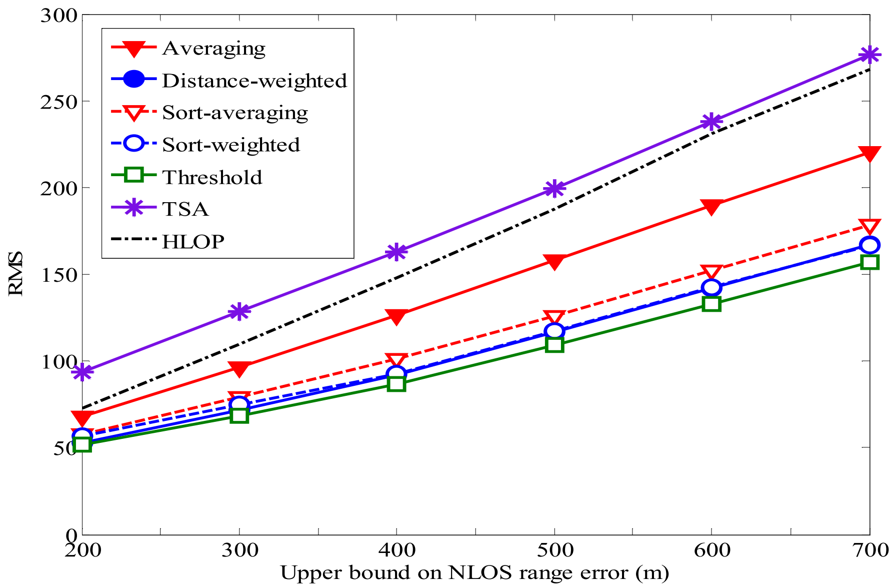

Fig. 4. Performance comparison of the location estimation methods when the upper bound is used to model the NLOS.

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