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# A Novel Weighting Factor Method in NLOS Environment

Xufeng Guan, Soojun Hur, Jeonghee Choi*

Abstract : Non-line-of-sight (NLOS) error is the most common and also a major source of errors in wireless location system. A novel weighting factor (NWF) method is presented in this paper, based on the RSS(Received Signal Strength) measurements, path loss model and Circular Disk of Scatterers Model (CDSM). The proposed positioning method effectively weighted the TOA distance measurements for each Base Station (BS). Simulation results show that the proposed method efficiently weighted the distance measurements and achieve higher localization accuracy than that of Linear Line of Position (LLOP) and Believable Factor Algorithm (BFA).

Keywords : Time-of-arrival (TOA), Received signal strength (RSS), Novel weighting factor (NWF), Non-line-of-sight (NLOS).

## 1. Introduction

Radiolocation can be derived from measurements of Time of Arrival (TOA), Angle of Arrival (AOA), Time Difference of Arrival (TDOA) and Received Signal Strength (RSS)[1]. A major problem that affects the accuracy of mobile location estimate is Non-Line-of-Sight (NLOS) propagation, where the absence of a direct Line-of-Sight (LOS) path between the Mobile Station (MS) and Base Station (BS) results in biased measurements and inaccurate positioning as illustrated in Fig. 1. As a consequence, time measurements are positively biased with high probability, since the first multipath component travels a distance that is in excess of the true LOS distance. A similar effect is seen in the case of signal strength measurements, where the received signal power is reduced due to the obstruction of the LOS path. Another similar effect is seen in the case of angle measurements, where the angle of received signal has an angle bias of the true LOS angle. NLOS effects take a result of the larger range error in radiolocation.

The problem of location estimation with biased NLOS range estimaties has been considered before. The literature on the NLOS problem typically falls in two categories: i) identifying LOS/NLOS BSs and using LOS BSs only ii) using scattering models to estimate NLOS bias and cancel it, and iii) weighting LOS/NLOS measurements.

In [2, 3], the identification procedure may be carried out through an analysis of a time history of TOA measurements and the knowledge of NLOS error statistics, residual information, maximum likelihood or probabilistic models. This technique offers reliable NLOS mitigation, but it requires at least 3 LOS BSs, which may not necessarily be available in a real-world scenario.

In [4, 5], NLOS effects are mitigated by using a scattering model that is appropriate to space-time radio channel propagation

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characteristics. The scattering models include the Circular Disk of Scatterers Model (CDSM) and Effective Scatterer Model (ESM) for macro cellular environment [6]. This method with using the CDSM and ESM can improve the accuracy, but it need to assume the distance between the scatterer and MS for each BS and it has a high computation complexity.

NLOS effects can also be mitigated by using variable LOS/NLOS weighting, in such a way that improves accuracy. The technique proposed in this paper belongs to this category.

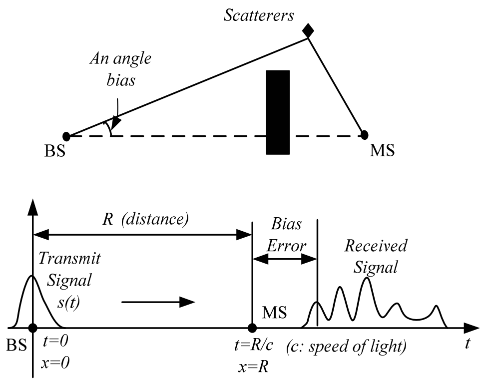


Fig. 1. The bias introduced in the absence of LOS between the BS and the MS.

The Range Scaling Algorithm (RSA) was proposed in [7], a range scale was defined to describe the real range between MS and BSs. The location accuracy was indeed improved by RSA in the NLOS environment. Although this method can still work even when all BSs are NLOS, it does not completely mitigate the NLOS bias. The Believable Factor Algorithm (BFA) was proposed in [8]. The BFA is a kind of weighting to minimize the effects of the NLOS contributions in cellular networks, and is shown to than the other conventional algorithms when the assumed channel models, that is, the assumed path loss exponents are perfectly matched to the real ones. However, as written above, we often have no prior knowledge about the path loss exponents. In addition the BFA needs some assumptions that are not favorable for wireless sensor networks. First is that, the MS must be surrounded by three BSs. Second is that the BFA uses only three BSs to localize the MS.

Considering the NLOS effect and the limitation of BFA, we proposed novel weighting factor (NWF) method, based on the RSS measurements, path loss model and CDSM. The NWF method weights the TOA measurements for each BS and does not consider a measurement including NLOS error or not. The NWF method utilizes the RSS and a specific path loss model to define a novel weighting factor based on the CDSM. We can estimate the position of MS using the weighted TOA distance measurements by the NWF method. Our proposed method is not limited to three BSs, and can improve the positioning accuracy.

The remainder of this paper is organized as follows. The received measurement model is outlined in Section II. The proposed method is outlined in Section III. The simulation results are discussed in Section IV. Finally, Section V concludes this paper.

## II. Received Measurement Model

The TOA measurement for the $i^{th}$ BS is described as

$$d_i = R_i + u_i + n_d,\ i = 1,2,...,N \tag{1}$$

where $R_i$ is the distance between the $i^{th}$ BS and MS, is the TOA measurement noise and $u_i$ is the NLOS range error for the $i^{th}$ BS. $n_d$ is AWGN (additive white Gaussian noise), whose distribution is the normal probability distribution function $N(0,\sigma\frac{2}{d})$ with zero-mean and the variance of the TOA measurement noise $\sigma\frac{2}{d}$ . The $i^{th}$ BSin NLOS condition is contaminated with not only $n_d$ but also $u_i$.

The RSS measurement for the i^th^ BS is described as

$$L_i(dB) = L(r_o) + 10k_i \log_{10}\frac{R_i}{r_0} + n_{p,}\ i = 1,2,\ldots,N \quad (2)$$

where $L(r_0)$ is the RSS measurement at unit distance $r_0$ from the target. $k_i$ is the path loss exponent, which is set to the $i^{th}$ BS. The $k_i$ takes generally, the value within the range from 2.0 to 4.0 and it may change according to the environments [9]. $n_p$ is AWGN, whose distribution is $N(0,\sigma\frac{2}{p})$ . $\sigma\frac{2}{p}$ is the variance of the RSS measurement noise.

## III. Novel Weighting Factor Method

In this section, we propose a NWF method to weight the LOS/NLOS measurement for each BS. The NWF method weight the TOA distance measurements based on the RSS measurements, path loss model and CDSM.

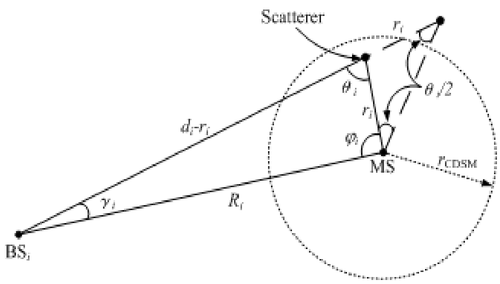


Fig. 2. TOA measurements based on the CDSM

Based on the CDSM, the TOA measurement of the $i^{th}$ BS is shown as Fig. 2.

In Fig. 2. $r_i$ is the distance between the scatterer and MS, $\gamma_i$ is the angle bias at the i^th^ BS, $\theta_i$ is the change angle at the scatterer, $\phi_i$ is the angle bias at the MS and $r_{CDSM}$ is the radius of CDSM. If the ith BS in LOS condition, $\gamma_i = 0$ and $\theta_i = \pi$.

The NWF is defined by

$$\alpha_i = \frac{R_i}{d_i},\ \ i = 1,2,\ldots,N \quad (3)$$

which shows how credible an range measurement is and how close a range measurement accesses to the true range traveled by signal from MS to the i^th^ BS. Because the NLOS error is positive, it can be concluded that the NWF is not more than 1. If and only if there is no NLOS error, the NWF equates to 1.

In trigonometry, the law of sine is an equation relating the lengths of the sides of an arbitrary triangle to the sines of its angle. According to the law in Fig.1,

$$\frac{R_i}{\sin\theta_i} = \frac{r_i}{\sin\gamma_i} = \frac{d_i - r_i}{\sin\phi_i} \quad (4)$$

Through (4), the NWF is estimated as

$$\alpha_i = \frac{\sin(\theta_i/2)}{\sin(\gamma_i + \theta_i/2)},\quad i = 1,2,\ldots,N \quad (5)$$

For (5), if we know $\gamma_i$ and $\theta_i$, we can calculate i, $\alpha_i$ for the i^th^ BS.

The estimation of $\gamma_i$ is as follow. In cellular system, the real distance $R_i$ is much larger than the NLOS range error $u_i$ in NLOS condition. So that, the angle bias $\gamma_i$ at the i^th^ BS is very small. Based on the CDSM, the maximum of $\gamma_i$ is defined as

$$\max\gamma_i = \arctan(\frac{r_{CDSM}}{d_i - r_{CDSM}}) \quad (6)$$

In order to reduce the error of $\gamma_i$, we set $\gamma_i$ as follow

$$\gamma_i = \frac{1}{2}arctan(\frac{r_{CDSM}}{d_i - r_{CDSM}}) \quad (7)$$

In the definition of NWF, we use the change angle at the scatterer $\theta_i$, but it is unknown. However, the signal strength is also a factor that can reflect the distance from MS to BS. The received signal strength can be obtained by channel estimation or by other parameter estimation process. Therefore, we utilize the TOA measurements and a path loss model to estimate the change angle at the scatterer $\theta_i$.

Here we select COST231-Walfish-Ikegami model [10] of medium city outdoor, and assume the BS antenna is higher than the MS antenna and building ceilings. Of course one can select any other model, as long as it can approximate the real propagation environment. The selected model describes the path loss under LOS and NLOS condition respectively as

$$\begin{aligned} L_{los} &= A_{los} + 26\log d \\ L_{nlos} &= A_{nlos} + 26\log d \end{aligned} \tag{8}$$

where $d$ means the distance traveled by the signal from MS to BS, $A_{los}$ and $A_{nlos}$ are parameters dependent on the carrier frequency, antenna height of MS and BS, signal incident angle and MS moving direction, etc. Given the TOA measurements $d_i$ by (1), through (8), $L_{los,i}$ and $L_{nlos,i}$, could be

$$\begin{aligned} L_{los,i} &= A_{los} + 26\log d_i \\ L_{nlos,i} &= A_{nlos} + 26\log d_i \end{aligned} \tag{9}$$

Comparing $L_i$ with $L_{los,i}$ and $L_{nlos,i}$ , the relationship of them is a follows:

a) $L_i \le L_{los,i}$

b) $L_{los,i} < L_i < L_{nlos,i}$

c) $L_{nlos,i} \le L_i$

In the case $a$, because that $L_i \le L_{los,i}$, so we can assume the $i^{th}$ BS is in the LOS condition, and $\alpha_i$=1. In the case b, based on the CDSM, we assume that $0 < u_i < 2r_{CDSM}$. Therefore, we can find the ranges of $\gamma_i$, $\theta_i$ and $d_i$ as $0 < \gamma_i < \max\gamma_i, 0 < \theta_i < \pi$ and $R_i < d_i < R_i + 2r_{CDSM}$. In the case b, based on the relationship of $L_{los,i} < L_i < L_{nlos,i}$, we can make a function of the RSS measurement as follow.

$$f(L_i) = \frac{2L_i - (L_{los,i} + L_{nlos,i})}{L_{nlos,i} - L_{los,i}} \tag{3-8}$$

Through (3-8), we can know that the made function $f(L_i)$ is a linear change and -1 <$f(L_i)$<1. This linear change of the made function $f(L_i)$ approximates that of $\cos\theta_i$, and the change angle at the scatterer $\theta_i$ can be calculated by a arccosine function as

$$\theta_i = \arccos\left(\frac{2L_i - (L_{los,i} + L_{nlos,i})}{L_{nlos,i} - L_{los,i}}\right) \tag{10}$$

In the case c, based on the CDSM, we assume that the TOA measurement of $i^{th}$ BS has the biggest of NLOS range error $(u_i = 2r_{CDSM})$. Therefore, the NWF $\alpha_i$ could be

$$\alpha_i = \frac{d_i - 2r_{CDSM}}{d_i} \tag{11}$$

The NWF is defined as follow

$$\alpha_i = \begin{cases} 1, & L_i \le L_{los,i} \\ \dfrac{\sin(\theta_i/2)}{\sin(\gamma_i + \theta_i/2)}, & L_{los,i} < L_i < L_{nlos,i} \\ \dfrac{d_i - 2r_{CDSM}}{d_i}, & L_{nlos,i} \le L_i \end{cases} \tag{12}$$

where

$$\gamma_i = \frac{1}{2} arctan\left(\frac{r_{CDSM}}{d_i - r_{CDSM}}\right)$$
$$\theta_i = \arccos\left(\frac{2L_i - (L_{los,i} + L_{nlos,i})}{L_{nlos,i} - L_{los,i}}\right)$$

Through (12), the TOA distance measurement for the $i^{th}$ BS is weighted by the NWF method as

$$\alpha_i d_i = \sqrt{(x-x_i)^2+(y-y_i)^2} \qquad (13)$$

where $X=[x,y]^T$ is the MS position to be determined and $[x_i, y_i]^T$ is the known coordinates of the $i^{th}$ BS.

Through(13), we can find that

$$(x_i-x_1)x+(y_i-y_1)y=\frac{1}{2}(K_i^2-K_1^2-\alpha_i^2 d_i^2+\alpha_1^2 d_1^2) \qquad (14)$$

where

$$K_i^2=x_i^2+y_i^2 \qquad (15)$$

The equation can be written in matrix form as

$$HX=b \qquad (16)$$

where

$$H=\begin{bmatrix} x_2-x_1 & y_2-y_1 \\ x_3-x_1 & y_3-y_1 \\ \cdots & \cdots \end{bmatrix}$$

$$b=\begin{bmatrix} K_2^2-K_1^2-\alpha_2^2 d_2^2+\alpha_1^2 d_1^2 \\ K_3^2-K_1^2-\alpha_3^2 d_3^2+\alpha_1^2 d_1^2 \end{bmatrix}$$

The least-squares solution of (16) is given by

$$\hat{X}=(H^T H)^{-1} H^T b \qquad (17)$$

Here, the position of MS is calculated by the least-square TOA method based on a NWF method in the NLOS environments.

## IV. SIMULATION RESULTS

Computer simulation using MATLAB had been conducted to evaluate the performance of the proposed NWF method, BFA and Linear Line-Of-Position (LLOP) [11] algorithm.

In the simulations, the BSs are assumed to be located at (0,0), (0,6), (0,-6), $(3\sqrt{3},3)$, $(3\sqrt{3},-3)$, $(-3\sqrt{3},3)$ and $(-3\sqrt{3},-3)$ km. The MS location is fixed at (2, 0) km. Suppose that the antenna of BS and MS are 20m and 2m high respectively, the average height of block buildings is 12m, much lower than the BS antenna, the carrier frequency is 2000MHz, and the signal incident direction is vertical to MS moving direction. The standard deviations of TOA and RSS measurements are assumed to be 30 m and 6 dB. The NLOS range errors are modeled as positive random variables having support over [0, 0.4] km, generated according to different density function, such as the CDSM. The RSS measurement in NLOS conditions is set at 20% larger than that in LOS conditions.

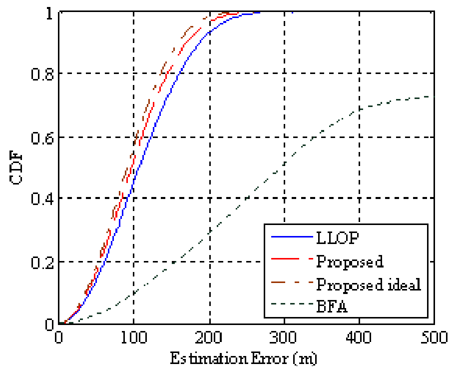


Fig. 2. Comparison of estimation error distribution, LOS BSs:0, NLOS BSs:7, number of BSs: 7.

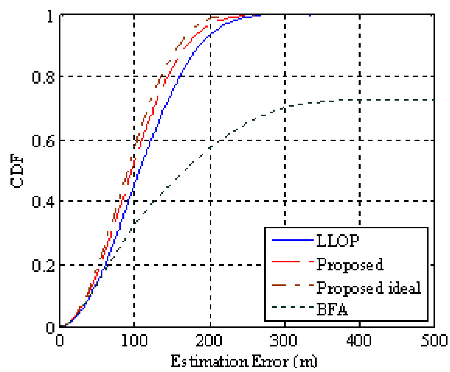


Fig. 3 Comparison of estimation error distribution, LOS BSs:1, NLOS BSs:6, number of BSs:7.

In all figures, “LLOP” means the LLOP localization, “Proposed” represents the performance of the proposed method with the estimated path loss exponents and distances, “Proposed ideal” represents the performance of the proposed method when the path loss exponents and estimated distances are perfectly known, “BFA” represents the performance of the conventional BFA with three sensor nodes and the estimated path loss exponents.

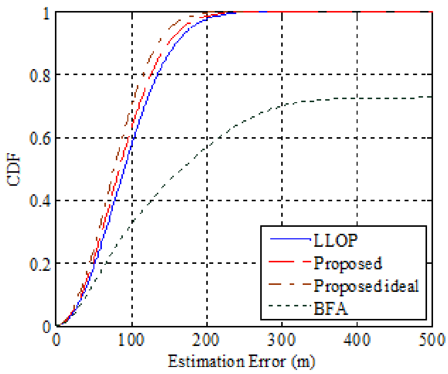


Fig. 4. Comparison of estimation error distribution LOS BSs:2, NLOS BSs:5, number of BSs:7.

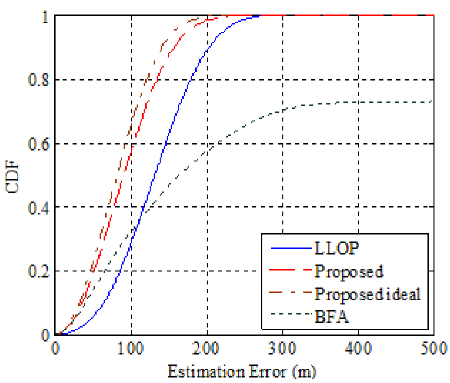


Fig. 5. Comparison of estimation error distribution LOS BSs:3, NLOS BSs:4, number of BSs:7.

Fig. 3 shows the results of using 7 NLOS BSs. Fig. 4 shows the results of using 1 LOS BS and 6 NLOS BSs. Fig. 5 shows the results of using 2 LOS BS and 5 NLOS BSs. Fig. 6 shows the results of using 3 LOS BS and 4 NLOS BSs. In these figures, the abscissa axis shows the estimation error between the real target position and the estimated one, the vertical axis shows the CDF (Cumulative Distribution Function) of estimation error.

From Fig. 3 to Fig. 6, we can conclude that the proposed method achieves better performance than the other conventional methods. This is because in the proposed method, the TOA measurement is weighted by its reliability, so that the effect of NLOS is reduced. In addition the proposed method can be used for more than three BSs. Thus, the proposed method can achieve the better performance. The reason why the conventional BFA has worst performance is as follows. In the conventional BFA, two intersections of two circles are calculated and one intersection nearer to the remaining BS is selected. If the MS is not surrounded by three BSs, the wrong intersection is selected with higher probability and thus the positioning accuracy becomes worse. In addition, the conventional BFA uses only three BSs for localization. Thus the conventional BFA is the optimized method for the cellular systems.

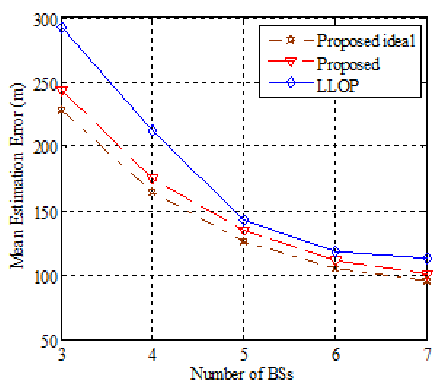


Fig. 6. Comparison of mean estimation error with using different number of BSs, LOS BSs:0.

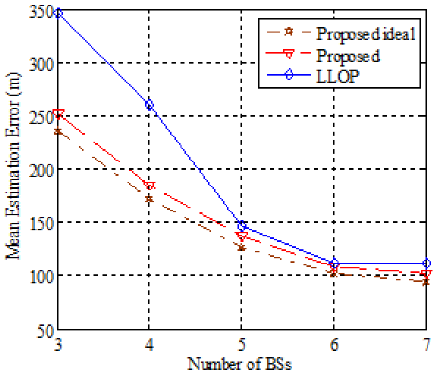


Fig. 7. Comparison of mean estimation error with using different number of BSs, LOS BSs:1.

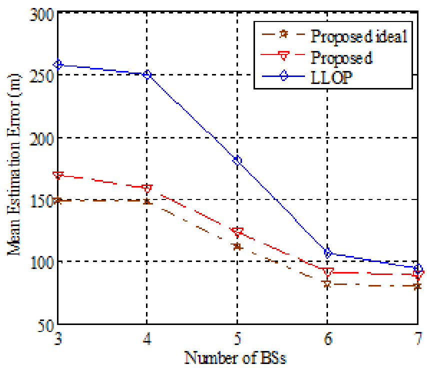


Fig. 8. Comparison of mean estimation error with using different number of BSs, LOS BSs:2.

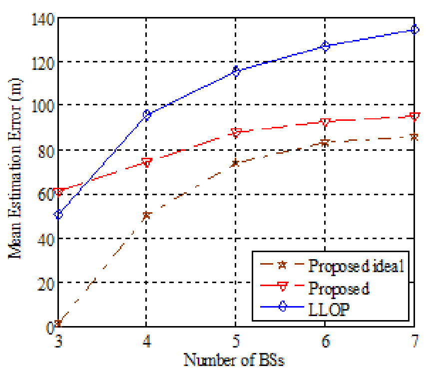


Fig. 9. Comparison of mean estimation error with using different number of BSs, LOS BSs:3.

Fig. 7 shows the comparison of mean estimation error with using different number of BSs, when the number of LOS BSs is zero. Fig. 8 shows the comparison of mean estimation error with using different number of BSs, when the number of LOS BSs is one. Fig. 9 shows the comparison of mean estimation error with using different number of BSs, when the number of LOS BSs is two. Fig. 10 shows the comparison of mean estimation error with using different number of BSs, when the number of LOS BSs is three. In these figures, the abscissa axis shows the number of BSs, the vertical axis shows the mean estimation error.

From Fig. 7 to Fig. 10 we can conclude that the proposed method can be applied to more than three BSs, and the BS is more the performance of proposed method is better. And when the BSs are in the mixing of LOS and NLOS conditions, and only in the NLOS condition, the proposed method always has a better performance than that of LLOP. But, in Fig. 10, when the number of BSs is three and these three BSs are in LOS condition, the proposed method has a bad performance. Therefore, the proposed method can improve the positioning accuracy by using more BSs and it is better to be used in the NLOS environments.

## V. CONCLUSION

We proposed a NWF method to weight the TOA distance measurements, based on the RSS measurements, path loss model and CDSM. This method is no need to identify LOS/NLOS range measurements and assume the distance between the scatterer and MS for each BS in CDSM. Simulation results show that the positioning accuracy of NWF method is higher than that of LLOP and BFA. The better performance is achieved by using more BSs in the NWF method.

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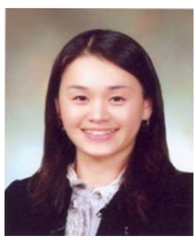

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