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Locating Mobile Station Using Received Signal Parameters

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Abstract

The importance of tracking a Mobile Station (MS) came into account after the act by Federal Communication Commission (FCC) on 1999. Emergency mobile phone services and Location Based Services (LBS) are the results where the MS has to be identified within a standard range. There are several approaches for tracking MS. The main aim of this paper is to find the position of a MS in a particular cell, by the distance calculation between Base Station (BS) and MS, also the mitigation of this with the angle of arrival (AOA).

Keywords: Tracking, distance calculation, HATA model, AOA, area of approximation.

1. INTRODUCTION

In the world of rapidly emerging telecommunication technologies, the tracking of MS becomes very important. For example, in emergency call service, such as Enhanced *991* (E911), the call center needs to locate the caller exactly for providing assistance. Moreover, the LBS give the service providers a platform for profit projection businesses, such as, in exchange of money a MS's position will be provided by the operator to the user, by which the trail the MS holder can be obtained.

Several techniques are proposed and implemented for tracking a MS. Using GPS, Time of Arrival (TOA), and Time Difference of Arrival (TDOA) etc. Firstly GPS aided tracking uses signals transmitted by satellite to give a very precise location approximation. But, the high consumption of battery, time delay for the tracking, and unavailability in indoor environment and canyon situation (high walls and buildings) accounts for the disadvantages of GPS aided system [1]. Another technique is the TOA where the round trip time (RTT) of signal transmission to base station and back to mobile station or vice versa (i.e. initiated by base station) is estimated. The distance from base station is related to half of the RTT value and is calculated using '*c*' the speed of light. It is obvious that TOA requires system-wide synchronization. Since GSM uses time division multiplexing (TDMA), it is hard to achieve accurate timing; hence there is every possible chance that the base station will ignore signal after the slotted time [2]. Moreover, "system delay" occurs, which means that the system has to take time to process the received signal and prepare for the transmitting signal [3]. For TDOA location methods, the distance differences of the MS to at least three BSs are measured. Each TDOA measurement provides a hyperbolic locus on which the MS must lie and the position estimate is determined by the intersection of two or more hyperbolas. For this, a Location Measurement Unit is added to every single BS, so that the time difference of arrival can be measured and hyperbolic-lateration techniques can be used (e.g. E-OTD and U-TDOA). Both options have a high rollout cost, due to the extra hardware at every BS, and yield only high-to-medium accuracy position estimates [4], [5].

In this paper, the position of the MS is calculated using distance and AOA from two neighboring BS. The distance is calculated from the received signal strength (RSS) using HATA Model and the AOA is find out using antenna array geometry. Mainly none of these techniques requires synchronization, moreover, automatically they also accounts for the Doppler shift, Line of Sight (LOS), Non Line of Sight (NLOS), and scattering phenomenon included in radio transmission.

2. USING RECEIVED SIGNAL STRENGTH FOR DISTANCE MEASUREMENT

The signal strength for six corresponding BS are always recorded within a MS and it is connected to the one with highest strength. After a fixed time interval, all the MS sends a report to the BS it is connected with. The distance between the MS and BS can be calculated by using the difference between transmitted and received strength, i.e. path-loss. Because of symmetry, the calculation can be carried out at both the MS or BS end.

Hata Model, also known as the Okumura-Hata model since it is a developed version of the Okumura Model, is the most widely used model in radio frequency propagation for predicting the behavior of cellular transmissions. This model incorporates the graphical information from Okumura model and develops it further to better suite the need. Hata Model has three subsections for different kind of areas: Urban, Suburban and Open Space. [6]

$$\Delta PL_{hata} = 69.55 + 26.1\log_{10}(f_{MHz}) - 13.82$$
$$\log_{10}(h_b) - a(hm) + [44.9 - 6.55\log_{10}(h_b)].$$
$$\log_{10}(r_{Km})^b - K \tag{2.1}$$

Where,
ΔPL_{hata} = Path loss in Urban Areas. (in dB)
h_b = Height of base station Antenna. (in meter)
h_m = Height of mobile station Antenna. (in meter)
f_{MHz} = Frequency of Transmission. (in MHz).
$a(h_m)$ = Antenna height correction factor
r = Distance between the base and mobile stations. (in kilometer).
b = Recommendation ITU-R P.529-3 Adjustment Factor. It is “1” for cell size to be less then 20km.
From the above equation, making distance “r” the subject:

$$r = anti\log_{10}\{\frac{[\Delta PL_{hata} - 69.55 - 26.1\log_{10}(f_{MHz}) + 13.82\log_{10}(h_b) + a(hm) + K]}{[44.9 - 6.55\log_{10}(h_b)]b}\} \tag{2.2}$$

Type of area	$a(h_m)$	K
Open	$(1.1\log_{10}f_{MHZ} - 0.7)h_m - (1.56\log_{10}f_{MHZ} - 0.8)$	$4.78(\log_{10} f_{MHZ})^2 - 18.33\log_{10}f_{MHZ} + 40.94$
Suburban		$2(\log_{10}(f_{MHZ}/28))^2 + 5.4$
Medium-small City		0
Large city (f_{MHZ}>300)	$3.2(\log_{10}11.75 h_m)^2 - 4.97$	0

Table 1.1 Antenna height correction factor for different region.

For this paper the area is assumed to be suburban where buildings exist, but the mobile station does not have a significant variation of its height.

3. ANGLE OF ARRIVAL (AOA) FOR LOS SYSTEM

At the BS, angle of arrival (AOA) estimates can be obtained using an antenna array. The direction of arrival of the MS signal can be calculated by measuring the phase difference between the antenna array elements or by measuring the power spectral density across the antenna array in what is known as beam forming. By combining the AOA estimates of two BSs, an estimate of the MS position can be obtained (see Figure 1).

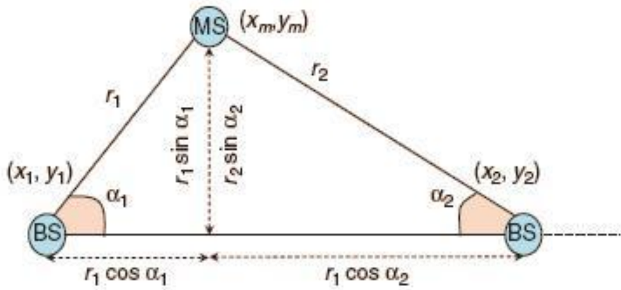

Fig. 1: combining AOA measurements

Now, if we take two BSs the AOA for BS_1 and BS_2 will be α_1 and α_2 and r_1 and r_2 will be their distances from the actual mobile position or LOS distance from mobile. So,

$$\begin{bmatrix} x_m \\ y_m \end{bmatrix} = \begin{bmatrix} r_1 \cos \alpha_1 \\ r_1 \sin \alpha_1 \end{bmatrix} \quad (3.1)$$

And

$$\begin{bmatrix} x_m \\ y_m \end{bmatrix} = \begin{bmatrix} x_2 \\ y_2 \end{bmatrix} + \begin{bmatrix} r_2 \cos \alpha_2 \\ r_2 \sin \alpha_2 \end{bmatrix} \quad (3.2)$$

Now if we consider the following,

$$\mathrm{H} = \begin{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \\ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \end{bmatrix}, x = \begin{bmatrix} x_m \\ y_m \end{bmatrix}, b = \begin{vmatrix} \begin{bmatrix} r_1 \cos \alpha_1 \\ r_1 \sin \alpha_1 \end{bmatrix} \\ \begin{bmatrix} x_2 + r_2 \cos \alpha_2 \\ y_2 + r_2 \sin \alpha_2 \end{bmatrix} \end{vmatrix} \quad (3.3)$$

We will get the combined equation

$$\mathrm{Hx} = \mathrm{b}$$

So from the equation above we can solve it for the location estimation as below:

$$\mathrm{x} = \mathrm{H}^{-1}\mathrm{b}$$

Here the errors in AOA measurements, such as noise and interference, AOA measurement corruption by non-line-of-sight (NLOS) effects and errors in the angular orientation of the installed antenna arrays are not considered since we are considering it a LOS region. The issue of NLOS will be discussed in the next section.

4. LOCATION ESTIMATION IN NLOS SYSTEM

The r_1 and r_2 taken in the equations (3.1) and (3.3) are considered in line of sight conditions. But in practice, the distance measurements r_i in (3.1) are generally corrupted by NLOS offsets arising from the presence of obstacles between the MS and the BS, as well as by measurement noise. Similarly, the AOA measurements α_i is corrupted by NLOS effects and by noise.

So the distance and angle measurements for the NLOS condition will be as follows:

$$\bar{r_i} = r_i + r_{e,i}$$

$$\bar{\alpha_i} = \alpha_i + \varphi_i$$

Here, $\bar{r_i}$= NLOS distance from BS_i to MS

r_i = LOS distance from BS_i to MS

$r_{e,i}$= distance error for NLOS

$\bar{\alpha_i}$= NLOS path AOA from BS_i to MS

α_i = LOS path AOA from BS_i to MS φ_i= AOA angle spread due to NLOS

Now from the equations above we can get the LOS distance and AOA as follows:

$$r_i = \bar{r_i} - r_{e,i} \quad (4.1)$$

$$\alpha_i = \bar{\alpha_i} - \varphi_i \quad (4.2)$$

Now if we replace equation (4.1) and (4.2) we will get the equation for solving for location estimation as follows:

$$\mathrm{x} = (\mathrm{H^T H})^{-1}\mathrm{H^T b} \quad (4.3)$$

Where,

$$\mathrm{H} = \begin{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \\ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \end{bmatrix}, x = \begin{bmatrix} x_m \\ y_m \end{bmatrix}, b = \begin{bmatrix} \begin{bmatrix} (\bar{r_1} - r_{e,1}) \cos(\bar{\alpha_1} - \varphi_1) \\ (\bar{r_1} - r_{e,1}) \sin(\bar{\alpha_1} - \varphi_1) \end{bmatrix} \\ \begin{bmatrix} x_2 + (\bar{r_2} - r_{e,2}) \cos(\bar{\alpha_2} - \varphi_2) \\ y_2 + (\bar{r_2} - r_{e,2}) \sin(\bar{\alpha_2} - \varphi_2) \end{bmatrix} \end{bmatrix} \quad (4.4)$$

The distance, calculated using Hata Model, has already considered the NLOS error, but still it is not accurate enough to totally remove the error. So the distance calculated from hata model will always be a greater than the LOS distance; as a result, there will always be an overlapped area between the circles drawn by taking the distances as the radius from the two BTS's. The MS must reside within this region.

Now, the φ_i can be described accurately by a Gaussian random variable in a microcell, where the standard deviation of this variable can be derived experimentally or from any theoretical model. The LOS path AOA must be in an interval with a certain high confidence level. It is assumed that $\alpha_{min,i}$ and $\alpha_{max,i}$ are corresponding upper and lower bounds. Then the following inequality holds (or holds with a sufficiently high confidence level)[3]:

$\alpha_{min,i} \leq \alpha_i \leq \alpha_{max,i}$, i = 1, 2. (4.5)

Since it is quiet impossible to know the exact value of the angle spread, AOA spread can be restricted within a smaller region and the angle is no longer spread between [0, 2Π]. A circular mode was proposed in [10], to describe the AOA probability density function (pdf) as seen in Figure 3, where the scatters are assumed to be uniformly distributed in a circle and an MS is the center of the circle. This method is called circular disk of scatters model (CDSM). Now AOA seen at the BS in a macro cell is like a Gaussian distribution with typical standard deviation of angle spreads approximately 6 degrees. If the angle spread seen at BS_i is modeled as a Gaussian distribution $N(0, \sigma^2)$, α_i must be in the interval $[\bar{\alpha}_i - 2\sigma, \bar{\alpha}_i + 2\sigma]$ with confidence level 95.4%, where σ is the standard deviation. Therefore, the MS position is further constrained to a small enclosed region overlapped by the two circles and the angular bounds, as illustrated in Figure 1 where the range of the angle spread is farther constrained into [-12, +12] degrees. [10]

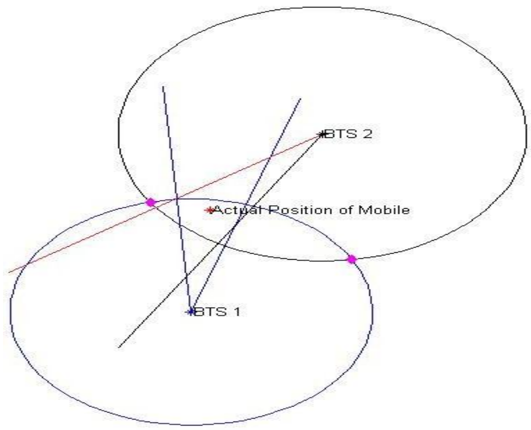

Fig. 2 Approximate area for finding MS

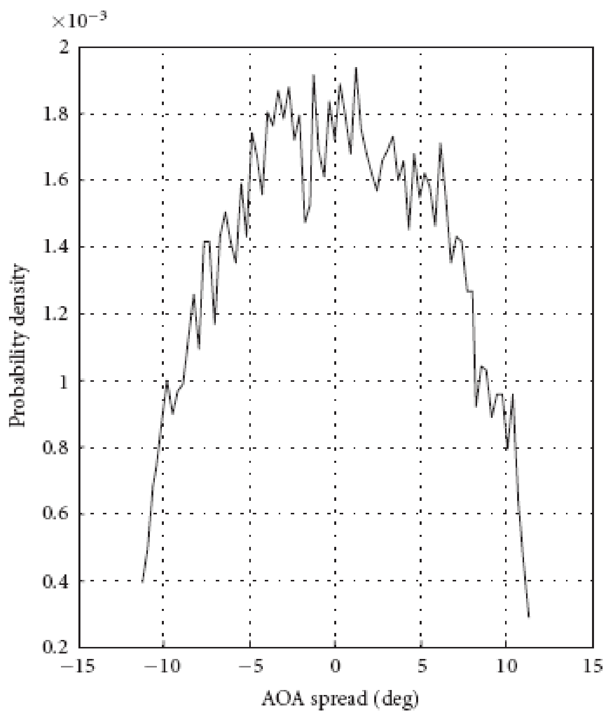

Fig. 3: AOA Spread in CDSM [3].

5. NLOS AOA ERROR MITIGATION

Now if we take a look at the fig. 1 we will see that if we consider both BS lying on the x-axis the perpendicular distance of the MS from the x-axis will be equal for the case of both BSs. That means for α_1 and α_2 and r_1 and r_2 , $r_1 \sin \alpha_1 = r_2 \sin \alpha_2$. From this we can say that:

$$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{r_2}{r_1}$$

(5.1)

But in this equation the α_1 and α_2 and r_1 and r_2 are taken for LOS propagation. So, for NLOS propagation this equation may not be true.

Now we consider the scatter region to be uniform for both the BSs. Now since the BS_2 is in greater distance from BS_1 it will suffer more scattering than the 1st BS. But since the scattering is uniform, the distance error rate will be same for both the BSs.

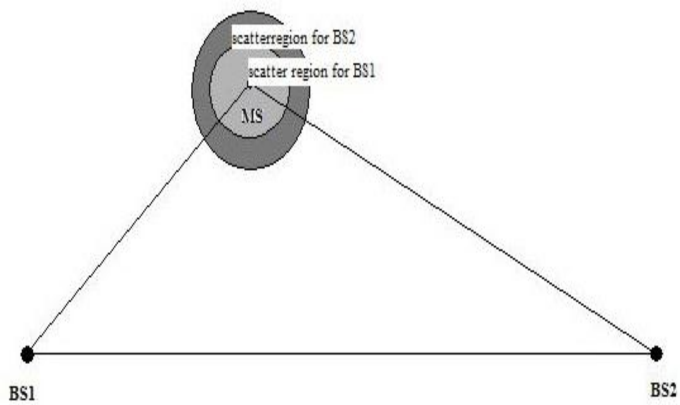

Fig. 4 different scatter region for BS_1 and BS_2

Since the error rate is same for both BSs we can say that

$$\frac{\overline{r_2}}{\overline{r_1}} = \frac{r_2}{r_1}$$

(5.2)

Now for NLOS propagation if we replace (4.2) and (5.2) in (5.1) we will get,

$$\frac{\sin(\alpha_1 - \varphi_1)}{\sin(\alpha_2 - \varphi_2)} = \frac{\overline{r_2}}{\overline{r_1}}$$

(5.3)

Now we already know the values for $\varphi_1$and φ_2 will be within [-12,+12] so if we check for the values within the range [-12,+12] we will get the angle spread for the MS in NLOS. Since it is not always possible be the scatter region uniform, the NLOS distance ratio can be greater than the actual ratio. So if we consider a range for the ratio we will get a small area for which the MS must lie within.

6. RESULTS AND DISCUSSIONS

The empirical system, Hata model, incorporates inappropriate distance calculation, because of NLOS, fading and other effects. The estimated positions of the MS from the neighboring BS are shown in figure 4. It is assumed that these calculated distances are more than the accurate values, and so there is an overlapped area between the two circles of radius $\mathbf{r_i}$, drawn from the neighboring BS_i, as in figure 5. If distance and AOA were used, the area could be minimized into a polygon as in figure 6. The area of approximation is further decreased by the proposed method, where from the simulation it can be seen that the area of approximation within which the MS will exist, decreases by a huge amount (figure 8).

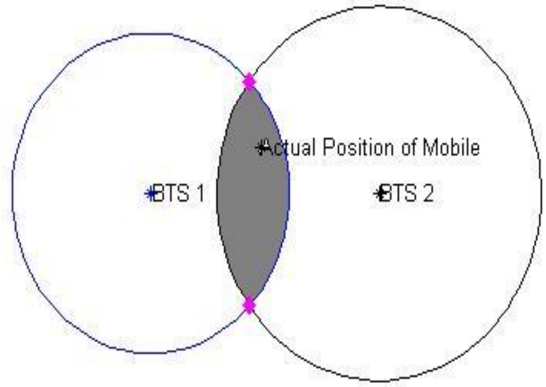

Fig. 5: overlapped area of MS location for NLOS distance

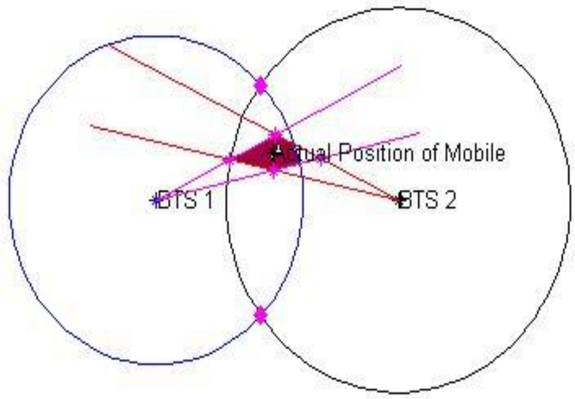

Fig. 6: Superimposing the areas from AOA angle spread and NLOS distance.

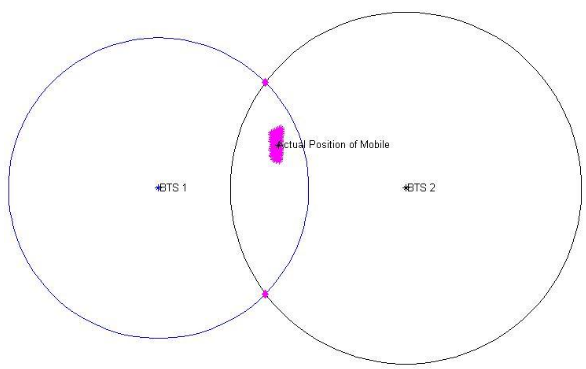

Fig. 7: Area from the proposed AOA mitigation method

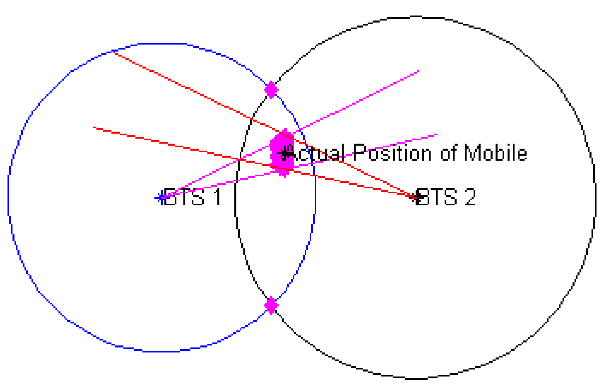

Fig. 8: Comparing between the proposed method and the area before applying it

CONCLUSION

The main purpose of the paper was to decrease the area of approximation within which the MS can be traced. Firstly, finding the region overlapped by the two BS and then using the angle spread to minimize this area, gave a more confined region to work with.

The distance calculations use empirical formula which is affected by surrounding environment, moreover, the Gaussian variable used are random in nature which may vary a lot when the behavior of NLOS scattered changes. Future works on the NLOS errors in distance calculation can help to decrease the distance which will further limit the MS position region. The most important thing to work with can be constraining the angle spread into further smaller values. Future works on these things can replace complicated calculations and the system can be made more cost effective if antenna gain is used in place of antenna array. Tracing dynamic MS, Cell Breathing and many other options can be the next step for telecommunication enhancement.

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