A New geometric Approach to Mobile Position in wireless LAN reducing complex computations

Monji ZAIDI, Rached TOURKI
Electronic and Micro-Electronic Laboratory (EµE, IT-06)
FSM, Monastir, Tunisia
Monji.Zaidi@fsm.rnu.tn

Ridha OUNI
College of Computer and Information Sciences (CCIS),
King Saud University Riyadh, KSA
rouni@ksu.edu.sa

Abstract—Positions estimation from Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Angle of Arrival (AOA) measurements are the commonly used techniques. These approaches use the location parameters received from different sources and they are based on intersections of circles, hyperbolas, and lines, respectively. The location is determined using standard complex computation methods that are usually implemented in software and need relatively long execution time. An important factor in achieving this is to minimize and simplify the instructions that the mobile station (MS) has to execute in the location determination process. Finding an effective location estimation technique to facilitate processing data is the main focus of this paper. Therefore, in the wireless propagation environment the Received Signal Strength (RSS) information from three base stations (BSs) are recorded and processed and they can provide an overlapping coverage area of interest. Then an easy geometric technique is applied in order to effectively calculate the location of the desired MS.

Keywords: Received Signal Strength (RSS), Wireless, Position estimation, geometric technique

I. INTRODUCTION

Mobile location estimation has attracted a significant amount of attention in recent years. The network-based location estimation schemes have been widely adopted based on the radio signals between the mobile device and the base stations. Currently, given that many buildings are equipped with WLAN (Wireless Local Area Network) access points (shopping malls, museums, hospitals, airports, etc.) it may become practical to use these access points to determine user location in these indoor environments.

A variety of wireless location techniques have been studied and investigated [1], [2], [3]. Network-based location estimation schemes have been widely proposed and employed in wireless communication systems. These schemes locate the position of the MS based on the measured radio signals from its neighborhood BSs. The representative algorithms for the network-based location estimation techniques are the Time-Of-Arrival (TOA), the Time Difference-Of-Arrival (TDOA), and the Angle-Of-Arrival (AOA). The TOA scheme estimates the MS’s location by measuring the arrival time of the radio signals coming from different wireless BSs, whereas the TDOA method measures the time difference between the arriving radio signals. The AOA technique is conducted within the BS by observing the arriving angles of the signals coming from the MS. The equations associated with the network-based location estimation schemes are inherently nonlinear.

In this paper, an efficient geometry location estimation algorithm is proposed to obtain the estimated position of the MS, under Line-of-sight (LOS) and/or Non-Line-of-sight (NLOS) environments. The MS’s position is obtained by refining the estimation based on the signal variations and the geometric layout between the MS and the BSs. Both the 2D and 3D locations of the MS can be estimated using the proposed technique scheme. Reasonable location estimation can be acquired within some of computing iterations even with the existence of NLOS errors. The remainder of this paper is organized as follows:

Section 2 describes related work for wireless location estimation. The proposed algorithm is explained in Section 3 for the 2D location estimation. The simulation and analysis are dealt in section 4. The performance evaluation of the proposed scheme is conducted in Section 5. Section 6 draws the conclusions and the future works.

II. RELATED WORKS

Different location’s estimation schemes have been proposed to acquire the MS’s position. Therefore various types of information (for example, the signal traveling distance, the received angle of the signal, and the Receiving Signal Strength (RSS)) are involved to facilitate the algorithm design for location estimation. The primary objective in most location estimation algorithms is to obtain higher estimation accuracy.

Given the coordinates of BSj, (j = 1, 2, 3) as (Xj, Yj), and the distances dj between MS and BSj, the simplest geometrical algorithm for TOA positioning (Figure. 1(a)) is given in [4]. Coordinates of MS position (x, y) relative to BS1 can be calculated as:

\[
\begin{align*}
\frac{x}{y} &= \frac{1}{2} \left( \frac{X_2}{X_3} - 1 \right) \left( X_2^2 + Y_2^2 + d_1^2 - d_2^2 \right) + \left( X_3^2 + Y_3^2 + d_1^2 - d_3^2 \right) \\
&= \frac{1}{2} \left( \frac{X_2}{X_3} - 1 \right) \left( \frac{1}{d_2^2} + \frac{1}{d_3^2} \right) \left( d_2^2 - K_2 + K_3 \right) \left( d_3^2 - K_3 + K_1 \right)
\end{align*}
\]

The simplest geometrical algorithm for TDOA positioning (Figure. 1(b)) is given in [5]. There are two estimated TDOA-s d_j, j between BS_i and the jth base station (j = 2, 3). Coordinates of MS position (x, y) relative to BS1 can be calculated in terms of d_1:

\[
\begin{align*}
\frac{x}{y} &= - \left( \frac{X_2}{X_3} - 1 \right) \left( \frac{d_{2,1}}{d_{3,1}} \right) \left( d_1 + \frac{1}{2} \left( d_{2,1}^2 - K_2 + K_1 \right) \left( d_{3,1}^2 - K_3 + K_1 \right) \right)
\end{align*}
\]

Where:
\[ K_1 = X_1^2 + Y_1^2 \]
\[ K_2 = X_2^2 + Y_2^2 \]
\[ K_3 = X_3^2 + Y_3^2 \]

Inserting this intermediate result into the following equation with \( j = 1 \) gives a quadratic equation in terms of \( d_1 \).
\[ d_1^2 = X_1^2 + Y_1^2 - 2X_1x - 2Y_1y + x^2 + y^2 \]

Taking its positive root and substituting it into (*) results in the final solution. The AOA technique determines the MS position \((x, y)\) based on triangulation, as shown in (Figure. 1(c)). The intersection of two directional lines of bearing with angles \( \theta_1 \) and \( \theta_2 \) defines a unique position, each formed by a radial from a BS to the MS. The simplest geometric solution can be derived using [6] with two AOA measurements \( \theta_1 \) and \( \theta_2 \):

\[
\begin{align*}
x &= \frac{Y_2 - Y_1 + X_1\tan(\theta_1) - X_2\tan(\theta_2)}{\tan(\theta_1) - \tan(\pi - \theta_2)} \\
y &= Y_1 + (x - X_1)\tan(\theta_2)
\end{align*}
\]

Using any of the mentioned methods, the calculation can be done either at the BS [network-based schemes] or at the MS [mobile-based schemes]. Network-based schemes have high network cost and low accuracy [7]. Mobile-based location schemes are more interesting.

However, since the MS has limited energy source, in the form of the battery pack, energy consumption should be minimized. An important factor in achieving this is to minimize and simplify the instructions that the MS has to execute in the location determination process. The conventional algorithms use complex computation methods that needed relatively long execution time.

III. NEW LOCATION ALGORITHM BASED ON THREE BSs

In the general geometrical triangulation location researches, they assumed that the measured noise is additive and the NLOS error is a large positive bias which causes the measured ranges to be greater than the true ranges [8].

Under the assumption, the MS location will guarantee to lie in the overlapped region (enclosed by points A, B and C) of the range circles as shown in Figure. 2. Thus the MS is necessarily located in the region formed by the points BS1, BS2 and BS3.

But, it is noted that the intersection of three circles may not be overlapped with the real measurement results. Therefore, with the above assumption we have to judge whether the three circles intersect or not in our location algorithm.

If circles intersect as depicted in Figure. 3, then three triangles can be drawn as: BS1MSBS2, BS2MSBS3 and BS3MSBS1.

Assumptions:
- Different BSs are placed (two to two) at an equal distance
- The coordinates of BSs are known by the MS
- The MS can inquire only on the received power coming from the BSs (i.e. the distance which separates it from each BS).

\[ d_1 + d_2 > D ; d_2 + d_3 > D \text{ and } d_3 + d_1 > D \]
Note by:
- D: The distance between two BSs.
- A0, B0 and C0 are the orthogonal projections of the MS on (BS1 BS2), (BS2, BS3) and (BS3 BS1) respectively.
- d1, d2 and d3 are the distances that separate the MS from BS1, BS2 and BS3 respectively.
- $\theta_{12}$: is the geometrical angle between the MS-BS1 and BS1-BS2. (Same things for the other angles).

We focus firstly on the triangle BS1MSBS2.

Based on the above assumption and the following figure, we can write.

$$r_1 = d_1 \cos \theta_{12}$$

We can also write

$$d_2^2 = (D - r_1)^2 + (d_1^2 - r_1^2) \Rightarrow$$

$$d_2^2 = (D - d_1 \cos \theta_{12})^2 + (d_1^2 - d_1 \cos \theta_{12}^2) \Rightarrow$$

$$d_2^2 = D^2 + d_1^2 - 2Dd_1 \cos \theta_{12} = D^2 + d_1^2 - 2Dr_1 \Rightarrow$$

$$r_1 = \frac{D^2 + d_1^2 - d_2^2}{2D}$$

We define here the first factor $q_1$ by

$$q_1 = \frac{r_1}{D} = \frac{D^2 + d_1^2 - d_2^2}{2D^2}$$

The range of the parameter $q_1$ can determine the shape of the triangle BS1MSBS2. For example.

If $0 < q_1 < 1 \Rightarrow$

If $q_1 > 1 \Leftrightarrow d_1 > d_2 \Rightarrow$

If $q_1 < 0 \Leftrightarrow d_1 < d_2 \Rightarrow$

Coordinates $(x_{12}, y_{12})$ of the point $A_0$ are given in [9] by

$$x_{12} = q_1 x_2 + (1 - q_1) x_1$$

$$y_{12} = q_1 y_2 + (1 - q_1) y_1$$

Where:

$(X_1, Y_1)$ and $(X_2, Y_2)$ are the coordinates of BS1 and BS2, respectively.

Let the distance between BS1 and BS0 be $r_2$ and the distance between BS1 and BS3 be $r_3$

As we described previously, we can get the coordinates of points $B_0$ and $C_0$ as:

$$x_{23} = q_2 x_3 + (1 - q_2) x_2$$

$$y_{23} = q_2 y_3 + (1 - q_2) y_2$$

$$x_{31} = q_3 x_1 + (1 - q_3) x_3$$

$$y_{31} = q_3 y_1 + (1 - q_3) y_3$$

Where:
\[
q_2 = \frac{r_2}{D} = \frac{D^2 + d_1^2 - d_2^2}{2D^2},
\]
\[
q_3 = \frac{r_3}{D} = \frac{D^2 + d_1^2 - d_3^2}{2D^2}.
\]

MS is then located in a new triangle \(A_0B_0C_0\), which is smaller in terms of area compared to the starting triangle \(B_1S_1B_2S_2\). In the other word we have just created three new virtual BSs placed at \(A_0, B_0\) and \(C_0\).

It is very easy to calculate the distances between the MS and the new points \(A_0, B_0\) and \(C_0\) using the Pythagoras formula. Thus
\[
d(\text{MS}, A_0) = \sqrt{d_1^2 - r_1^2},
\]
\[
d(\text{MS}, B_0) = \sqrt{d_2^2 - r_2^2},
\]
\[
d(\text{MS}, C_0) = \sqrt{d_3^2 - r_3^2}.
\]

Now, with the three new virtual BSs, MS can repeat the same calculations as shown above. During this second iteration, the orthogonal projections of MS on \((A_0B_0), (B_0C_0)\) and \((C_0A_0)\) must be done to obtain new point \(A_1, B_1\) and \(C_1\) that their coordinates may be determined as previously. \(A_1B_1C_1\)'s area is smaller that the \(A_0B_0C_0\) one.

At the \(i^{\text{th}}\) iteration, the MS will be located in an \(A_iB_iC_i\) triangle which is smaller than \(A_{i-1}B_{i-1}C_{i-1}\) one. This \(A_iB_iC_i\) triangle allows to designing the next triangle \(A_{i+1}B_{i+1}C_{i+1}\). After a small number of iterations, the coordinates of three vertices of the triangle \((A, B\) and \(C)\) converge to the actual coordinates of the MS. At the limit, the triangle \(A_{\text{conv}}B_{\text{conv}}C_{\text{conv}}\) with vertices \(A_{\text{conv}}, B_{\text{conv}}\) and \(C_{\text{conv}}\) will be considered as a point. So, it is possible to write:
\[
x_{A_{\text{conv}}} \approx x_{B_{\text{conv}}} \approx x_{C_{\text{conv}}}
\]
\[
y_{A_{\text{conv}}} \approx y_{B_{\text{conv}}} \approx y_{C_{\text{conv}}}
\]

We can then take the coordinates of the MS as:
\[
x_{\text{MS}} = \frac{x_{A_{\text{conv}}} + x_{B_{\text{conv}}} + x_{C_{\text{conv}}}}{3}
\]
\[
y_{\text{MS}} = \frac{y_{A_{\text{conv}}} + y_{B_{\text{conv}}} + y_{C_{\text{conv}}}}{3}
\]

The division by 3 implies that the MS is equivalent to the gravity center of the \(A_{\text{conv}}B_{\text{conv}}C_{\text{conv}}\) triangle.

The following figure (section 4) shows the evolution and the convergence of the three vertices coordinates for different values of \(d_i\) (\(d_1, d_2\) and \(d_3\)).

IV. SIMULATION RESULTS

- BS1 coordinates (in meters): \((X_1, Y_1) = (0, 0)\)
- BS2 coordinates (in meters): \((X_1, Y_1) = (100, 0)\)
- BS3 coordinates (in meters): \((X_1, Y_1) = (50, 86)\)

![Figure 4](image-url)
V. PERFORMANCE ANALYSIS

The reception of a tuple of signal strengths does not lead directly to the position of the device. A conversion of this tuple of received signal strengths into a position is required. The following model introduces some wall attenuation factors to describe more closely the environment. The walls’ materials must be characterized, and their properties must be introduced in the model, leading to the following approximation [10]:

\[ P_{\text{received}}(d) = P_{\text{received}}(d_0) - 10 \cdot \alpha \cdot \log \frac{d}{d_0} + \sum_{i=1}^{N_w} n_i \cdot w_i \]

Where \( P_{\text{received}}(d) \) is the signal strength received by the mobile at distance \( d \), \( P_{\text{received}}(d_0) \) the signal strength received at the known distance \( d_0 \) from the AP, and \( \alpha \) a coefficient modeling the radio wave propagation in the environment. For example, in free path loss environment, we have \( \alpha = 2 \). In indoor environments, this factor will be closer to 3 [11]. \( N_w \) is the number of walls of different nature, \( n_i \) is the number of walls having an attenuation of \( w_i \). It is clear that the received power is always sullied with errors. Therefore errors on the distance and on the position of MS can take place. Those errors appear because the propagation models are too simple in comparison to the complex indoor RF propagation.

Now, it is necessary, as in any positioning method, to evaluate the error or deviation (in m) between actual (measured) and simulated values obtained by our method. For this two cases have to be considered:

A. Line-of-sight (LOS) condition

This case occurs in open areas or in very specific spots in city centers, in places such as crossroads or large squares with a good visibility of BS. Sometimes, there might not be a direct LOS signal but a strong specular reflection off a smooth surface such as that of a large building will give rise to similar conditions. The received signal will be strong and with moderate fluctuations. Therefore, the extracted distance from the received signal is correctly calculated.

In the table 1 we give some actual locations of the MS (Actual x and y). Corresponding values of the true distances \( d_1 \), \( d_2 \) and \( d_3 \) which separate it from BS1, BS2 and BS3 are calculated. Then the estimated position and position error can be determined using our geometric method.

B. Non Line-of-sight (NLOS) condition

This case will typically be found in Indoor environments. This is a worst-case scenario since the direct signal is completely blocked out and the overall received signal is only due to multipath, thus being weaker and subjected to marked variations. Under these conditions the geometric method can be applied. However, the position error increases significantly.
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Mean=0.4321

C.t = Convergence Time.
(I.n) = Iterations number.

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Mean=1.6357

VI. CONCLUSION

This paper presents new geometric oriented algorithm that is based on three distances measurements to determine the position of a mobile object. Provided that all operations in our proposed algorithm are additions, subtractions and multiplications based, the implementation is simplified which reduces complexity.

Our results show that for a very reduced number of iterations (k < 10), the proposed method converges and provides with a good accuracy the position of MS. Hence, the major advantages of our algorithm are: implementation simplicity, and low computation overhead.

The very fast growth of modern VLSI technology offers a hardware realization of an ever-growing share of mathematical means, so, in our future works, the proposed algorithm for location determination will be implemented in hardware using for example, a simple field programmable gate array (FPGA) chip.
REFERENCES


