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By B R Jadhavar, T R Sontakke
*Siddhant College of Engineering Pune, India*

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IMPROVED CHAN-HO MODEL FOR INDOOR MOBILE USER LOCATION ESTIMATION USING TDOA INFORMATION

*Strictly as per the compliance and regulations of:*

# Improved Chan-Ho Model For Indoor Mobile User Location Estimation Using TDOA Information

B R Jadhavar[α], T R Sontakke[Ω]

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## I. Introduction

The positioning systems that are used to track and determine the users location in 3G telecommunication systems have gained increasing interest. In indoor location systems global positioning system (GPS) is not efficient due to obstruction and shielding of satellite signals. In indoor environment, there are many positioning systems based on different technologies such as received signal strength, ultrasound and Infrared, video surveillance. The basic characteristics of signals are utilized such as received signal strength (RSS), angle of arrival (AOA) estimation, time of arrival (TOA) estimation and time difference of arrival (TDOA). In the past, time delay estimation has been proposed and implemented by Knapp and Carter (1976) and Aarabi (2001) [10].

Different techniques have been proposed with different complexcity and restrictions. Carter's focused on beam forming [1], requires a search over a set of possible target locations. Hahn's method [2] assumes distant source. Abel and Smith [3] provide an explicit solution that can achieve the Cramer -Rao Lower Bound (CRLB) in the small error region. The situation is more complex when sensors are distributed arbitrarily. Here emitter position is determined from the intersections of a set of hyperbolic curves defined by TDOA estimates. Solution is not easy as the equation are non linear. Fang [4] gave an exact solution when number of TDOA measurements are equal to number of unknowns. This solution cannot make use of extra measurements, available when there are extra sensors, to improve position accuracy. The more general situation with extra measurements was considered in [5, 6, 8, 9]. The divide and conquer (DAC) method [7] by Abel can achieve optimum performance, but it requires sufficiently large information. To obtain a precise position estimate at reasonable noise levels, the Taylor-series method is commonly employed. It is an iterative method. It starts with an initial guess and improves the estimate at each step by determining the local linear least-squares (LS) method. Selection of such a starting point is not simple in practice. Moreover, convergence of the iterative process is not assured. It is also computationally intensive as LS computation is required in each iteration.

The AOA requires antenna arrays at each node which increases the complexity of the existing system, and performs worse in multipath environment. In this case accurate estimation of TOA from received communication signals are required. Indoor multipath interference is the main factor that limits deploying indoor positioning systems, the multipath is sever and complex which leads to inaccurate estimate of the TOA using conventional techniques.

TOA (Time of Arrival) method is to calculate a position using a measured value of an arrival time of electric wave and TDOA method uses an arrival time lag of electric waves that are sent from different base stations (BSs). Among these, TOA and TDOA are widely used methods in positioning system.

TDOA estimates the difference in arrival times of the signals between synchronized reference nodes. In TDOA absolute time of transmission is not important but only synchronization of nodes is necessary. Each range determines a hyperbola. For this technique at least three nodes are required for positioning in two dimension plane. The intersection points of three hyperbolas give the position of moving object. Chan-Ho algorithm [12]

*Author* [α] *: Department of Electronics & Telecommunication Siddhant College of Engineering Pune : 412109, India.*
*E-mail : brjadhavar@yahoo.co.in*
*Author* [Ω] *: Department of Electronics &Telecommunication Siddhant College of Engineering Pune : 42109, India.*
*E-mail : trsontakke@gmail.com*

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is effective technique in locating object based on intersections of hyperbolic curves defined by the time differences of arrival of signal received at number of sensors is proposed. This can achieve high accuracy however it cannot work efficiently if the measurement has large NLOS errors.

Both TOA and TDOA are technologies in radio location systems based on cellular networks. TOA is implemented by calculating the time of signal arrival from mobile station and base transreceiver station directly. However TDOA calculates the time difference of signal arrival between two base stations. The cross-correlation of the two versions of the signal at pairs of base stations is done and the peak of the cross-correlation output gives the time difference for the signal arrival at those two base stations. This method offers many advantages over other competing techniques. Since, all the processing takes place at the infrastructure level, no modifications are needed in the existing handsets. In this work we present modified location method based on Chan-Ho algorithm to solve hyperbolic equations which results in reduced positioning error.

This paper is organized as follows. In section two, mathematical model for hyperbolic TDOA equations is explained. in section three proposed improved Chan-Ho model is described. In section four simulation method and conclusion in section five is given.

## II. Mathematical Model for Hyperbolic TDOA Equations

This is general model for two dimensional location position estimation of source having M base stations. Referring all TDOAs to the first base station (BS), which is assumed to be base station controlling the call and first to receive transmitted signal. Assuming real coordinates of source be $(x, y)$ and that of $i^{th}$ base station to be $(X_i, Y_i)$.Therefore the distance between source and BSi is

$$R_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2} = \sqrt{X_i^2 + Y_i^2 - 2X_i x - 2Y_i y + x^2 + y^2} \qquad (1)$$

The difference between base stations with respect to the base station where the signal arrives first is

$$R_{i,1} = cd_{i,1} = R_i - R_1 \qquad (2)$$

$$= \sqrt{(X_i - x)^2 + (Y_i - y)^2} - \sqrt{(X_1 - x)^2 + (Y_1 - y)^2} \qquad (3)$$

Where c is speed of propagation of signal, $R_{i,1}$ is range difference between first base station and $i^{th}$ base station, $R_1$ is the distance between first base station and source and $d_{i,1}$ is the estimated TDOA between first base station and $i^{th}$ base station. This defines the set of nonlinear hyperbolic equations whose solution gives 2-D co-ordinates of the source. The solution of nonlinear equations is difficult hence these equation must be linearized [14]. Nonlinear equations can be transformed into another set of equations. Rearranging (3) into

$$R_i^2 = (R_{i,1} + R_1)^2 \qquad (4)$$

Equation (1) can be rewritten as

$$R_{i,1}^2 + 2R_{i,1}R_1 + {R_1}^2 = K_i^2 - 2X_i x - 2Y_i y + x^2 + y^2 \qquad (5)$$

Where, $K_i^2 = X_i^2 + Y_i^2$

At $i = 1$, subtracting (1) from (5), results in

$$R_{i,1}^2 + 2R_{i,1}R_1 + R_1^2 = X_i^2 + Y_i^2 - 2X_{i,1}x - 2Y_{i,1}y + x^2 + y^2 \qquad (6)$$

Where, $X_{i,1} = X_i - X_1$ and $Y_{i,1} = Y_i - Y_1$

The set of equations (6) are nonlinear with source location $(x, y)$ and range of first receiver to source $R_1$ is unknowns and can be easily handled.

These are nonlinear equations whose solution gives $(x, y)$. These equations are difficult to solve. Linearizing (2) by Taylor series method of expansion and solving them iteratively is one way. With the set of TDOA estimates$d_{i,1}$, the method starts with initial position guess $(x_0, y_0)$ and compute position deviation [8] [9].

In next iteration, $x_0$, $y_0$ are then set to $x_0 + \Delta x$ and $y_0 + y_0$. The whole procedure is repeated until $\Delta x$ and $\Delta y$ are sufficiently small. This method has difficulty of requiring close enough starting and large computations. Again convergence is not guaranteed. An alternative method [5] [6] is to first transform equation (2) into another set of equations.

Taylor series method linearizes set of equations in (3), this method begins with initial guess and improves estimates at each iteration by determining linear least-square solution. However, it requires good initial guess and requires large computations. Fang's method [4] provides exact solution to equation (6) and his solution does not make use of redundant measurements made at additional receivers to improve position accuracy. This method has ambiguity due to inherent squaring operations.

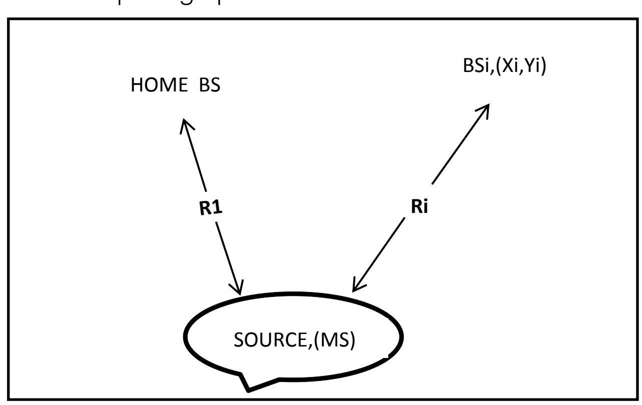


*Figure 1*

## III. The Improved Chan-ho Model

Chan-Ho [12] gives non-iterative solution to hyperbolic position estimation problem which give optimum performance for arbitrarily placed sensors.

It gives solution in closed form. Furthermore, it provides explicit solution form that is not available in Taylor series method. This was developed for three sensors which gives two TDOA's.

From equation (1) for $i = 1$, gives

$$R_1^2 = X_1^2 + Y_1^2 - 2X_1x - 2Y_1y + x^2 + y^2 \qquad (7)$$

Now combining (7) and (5), we get

$$R_{i,1}^2 2R_{i,1}R_1 = K_i^2 - K_1^2 - 2(X_i - X_1)x - 2(Y_i - Y_1)y \qquad (8)$$

And finally we get

$$R_{i,1}{}^2\, 2R_{i,1}R_1 = K_i^2 - K_1^2 - 2X_{i,1}x - 2Y_{i,1}y \qquad (9)$$

In Chan's algorithm for M=3. Then equation (9) becomes

$$-2X_{2,1}x - 2Y_{2,1}y = 2R_{2,1}R_1 + R_{2,1}^2 - K_2^2 - K_1^2 \qquad (10)$$

$$-2X_{3,1}x - 2Y_{3,1}y = 2R_{3,1}R_1 + R_{3,1}^2 - K_3^2 - K_1^2 \qquad (11)$$

and (10) and (11)

can be represented in the form of the following matrices:

$$-2\begin{bmatrix} X_{2,1} & Y_{2,1} \\ X_{3,1} & Y_{3,1} \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} = 2\begin{bmatrix} R_{2,1} \\ R_{3,1} \end{bmatrix} R_1 + \begin{bmatrix} R_{2,1}^2 & K_2^2 & K_1^2 \\ R_{3,1}^2 & K_3^2 & K_1^2 \end{bmatrix} \qquad (12)$$

Or

$$\begin{bmatrix} x \\ y \end{bmatrix} = -\begin{bmatrix} X_{2,1} & Y_{2,1} \\ X_{3,1} & Y_{3,1} \end{bmatrix}^{-1} \times \left\{\begin{bmatrix} R_{2,1} \\ R_{3,1} \end{bmatrix} R_1 + \frac{1}{2}\begin{bmatrix} R_{2,1}^2 & K_2^2 & K_1^2 \\ R_{3,1}^2 & K_3^2 & K_1^2 \end{bmatrix}\right\} \qquad (13)$$

Here $(x, y)$ represents location of source $R_1$ is obtained from (7), and we get $R_{2,1}, R_{3,1}$ from (9), assuming that :

$$K_1^2 = X_1^2 + Y_1^2$$
$$K_2^2 = X_2^2 + Y_2^2 \qquad (14)$$
$$K_3^2 = X_3^2 + Y_3^2$$

After getting first set of prediction of $x, y$ it can be recalculated for better improvement. Generally this requires 2 to 5 cycles. From equation (13) it can be noted that values of $x, y$ are dependent on $R_1$, which is distance between source and BS1 and the process is iterative. To improve accuracy of location of original Chan-Ho method, we adapt new term which improves accuracy. This new value uses different values resolved from two base stations to estimate right distance.

This new term specifies error on vertical and horizontal to the distance obtained.

$\frac{(x_i - xo_i)}{R_i}$ ; for the x-axis ratio, and

$\frac{(y_i - yo_i)}{R_i}$ ; for the y-axis ratio.

Where $(xo_i, yo_i)$ is obtained coordinates of source by each BS, $(x_i, y_i)$ coordinates of $i^{th}$ BS. From this we get two ratios,

$$Z = \begin{bmatrix} \frac{(x_i - xo_1)}{R_1} & \frac{(x_2 - xo_2)}{R_2} \\ \frac{(y_1 - yo_1)}{R_1} & \frac{(y_2 - yo_2)}{R_2} \end{bmatrix} \qquad (15)$$

To create a symmetrical matrix, we will multiply the matrix by its transpose. Then we will obtain the eigenvalues, by calculating the trace; which leads to the nearest accurate solution. The final value obtained will be corrected by taking the square root of the arithmetic mean of the trace, as following:

$$\Omega = \sqrt{\frac{tr\,(Z' Z)}{2}} \qquad (16)$$

This yields new calculation system as given below.

$$\begin{bmatrix} x \\ y \end{bmatrix} = -\begin{bmatrix} X_{2,1} & Y_{2,1} \\ X_{3,1} & Y_{3,1} \end{bmatrix}^{-1} \times \left\{\begin{bmatrix} R_{2,1} \\ R_{3,1} \end{bmatrix} \Omega + \frac{1}{2}\begin{bmatrix} R_{2,1}^2 & K_2^2 & K_1^2 \\ R_{3,1}^2 & K_3^2 & K_1^2 \end{bmatrix}\right\} \qquad (17)$$

With this method it is possible to reduce error in position.

## IV. Simulation and Analysis

This simulation utilizes timing information from source to base stations only in reverse link. The simulation set up is as shown in fig. 2, having coordinates of three base stations (0, 0), (750, 433), (750, -433). The source is assumed at (100, 100). Each base station has its own radio coverage. BS1 is home base station.

| Simulation setup co-ordinates | | | | | |
|---|---|---|---|---|---|
| x1 | y1 | x2 | y2 | x3 | y3 |
| 0 | 0 | 750 | 433 | 750 | 433 |

*Table 1*

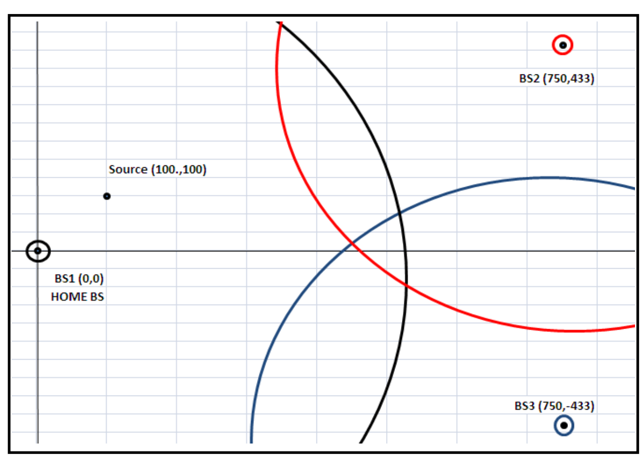


*Figure 2*

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TDOA position location system can be implemented in two different ways. Either by subtracting the time of arrival at two BTSs, which requires the implementation of the absolute TOA mechanism or by cross-correlating the received signals from the two BTSs. Here we use cross-correlation method is used. Let $s(t)$ be the signal generated by source.

$s(t) = u(t)e^{j\omega t}$ [13] The received signal at BS from ith path is

$$s_i = r_i u(t-\tau_i) e^{j[(\omega_0+\omega_{1i}+\omega_{2i})(t-\tau_i)+\emptyset_i]} \qquad (18)$$

Where $\omega_0 = RF\ carrie$, $r_i =$ Rayleigh-distributed random variable, $\emptyset_i =$ uniformly distributed random phase, $\tau_i =$ time delay on ith path and $\omega_{1i} =$ Doppler shift of transmitting mobile unit on ith path, $\omega_{2i}$ =Doppler shift of BS which is stationary here.

The signals generated by at two base stations can be modeled as [11]

$s_1(t) = s\left\{\frac{t+D_1}{b_2}\right\}$ and $s_2(t) = s\left\{\frac{t+D_2}{b_2}\right\}$, here $D_1\ and\ D_2$

Corresponds to propagation time from source to two base stations and $b_1, b_2$ are time scales resulting from relative motion between source and receiver. The signals at two receivers will be $x_1(t) = s(t) + \emptyset(t)$ and $x_2(t) = s\left\{\frac{t+D}{a}\right\} + \psi(t)$, where $\emptyset(t)$ and $\psi(t)$, are additive white Gaussian noise with zero mean. Above equations takes in to account the relative velocity between source and receiver. If $\tau = \Delta t_2 - \Delta t_1$, then TDOA can be calculated from the maximum value of cross-correlation

$$R_{x_1x_2}(\tau) = \int_{-\infty}^{+\infty} x_1(\tau)x_2(t-\tau)dt \qquad (19)$$

| Test point | | Ts | 0.5 |
|---|---|---|---|
| X | 100 | Num | 10 |
| Y | 100 | vx,vy | 10 |
| Num | x_predict | y_predict | Error |
| 1 | 110.5532 | 96.4175 | 10.2224 |
| 2 | 112.75 | 90.067 | 20.1218 |
| 3 | 112.1963 | 118.3225 | 4.3474 |
| 4 | 112.655 | 128.2435 | 11.041 |
| 5 | 132.895 | 107.2847 | 19.3949 |
| 6 | 72.1096 | 178.2374 | 75.3534 |
| 7 | 78.974 | 182.8584 | 73.684 |
| 8 | 140.7444 | 139.0545 | 1.2034 |
| 9 | 136.6439 | 154.5825 | 12.7141 |
| 10 | 145.9833 | 154.826 | 6.2789 |
| Mean Square Error | | | 24.9043 |
| Normalised MSE | | | 0.036 |

*Table 2*

In original Chan-H0 method the term $R_1$ is used and that was obtained from BS1and modified term $\Omega$ is obtained from BS1 and BS2. Results obtained from our simulation method are much better than Chan-Ho method.

All estimated points are in the range of home base station located at (0,0). We calculated MSE which indicates higher performance. The source position was assumed to (100,100). Values of $V_x\ and\ V_y$ are changed from 5 to 15. And we obtain $x, y$ predicted values and error is found. This indicates that MSE is less for smaller values of $V_x$ and $V_y$ These are indicated in tables 2 to 5.

The simulation is done in MATLAB. We get results as shown in fig. 3, fig. 4 and fig. 5. Finally cumulative probability distribution function (CDF) of absolute position error between original position and obtained values can be calculated by

$$\Delta d = \sqrt{(x-x_0)^2 + (y-y_0)^2} \qquad (20)$$

| Test point | | Ts | 0.9 |
|---|---|---|---|
| X | 100 | Num | 10 |
| Y | 100 | vx,vy | 5 |
| Num | x_predict | y_predict | Error |
| 1 | 112.1236 | 104.7796 | 5.2506 |
| 2 | 91.3624 | 143.3303 | 36.7585 |
| 3 | 134.2383 | 115.5469 | 13.5486 |
| 4 | 25.3137 | 231.6768 | 146.3062 |
| 5 | 147.528 | 141.6894 | 4.1654 |
| 6 | 151.4806 | 157.0849 | 3.9829 |
| 7 | 121.5537 | 203.5833 | 58.0069 |
| 8 | 170.7211 | 173.6032 | 2.0508 |
| 9 | 182.9053 | 178.5213 | 3.1264 |
| 10 | 201.1724 | 172.8173 | 20.4956 |
| Mean Square Error | | | 32.049 |
| Normalised MSE | | | 0.0704 |

*Table 3*

| Test point | | Ts | 0.6 |
|---|---|---|---|
| X | 100 | Num | 10 |
| Y | 100 | vx,vy | 15 |
| Num | x_predict | y_predict | Error |
| 1 | 108.2665 | 94.9721 | 9.6012 |
| 2 | 79.8407 | 130.1446 | 35.5987 |
| 3 | 75.0657 | 138.977 | 45.2786 |
| 4 | 85.3848 | 136.9084 | 36.4527 |
| 5 | 39.0348 | 169.6687 | 93.5916 |
| 6 | 94.5704 | 140.7746 | 32.6746 |
| 7 | 59.391 | 169.8236 | 78.6092 |
| 8 | 131.6413 | 105.875 | 19.6699 |
| 9 | 127.3928 | 126.5056 | 0.6314 |
| 10 | 132.7981 | 126.3026 | 4.6368 |
| Mean Square Error | | | 38.5715 |
| Normalised MSE | | | 0.0794 |

*Table 4*

| | | | |
|---|---|---|---|
| Test point | | Ts | 0.1 |
| X | 100 | Num | 10 |
| Y | 100 | vx,vy | 15 |
| Num | x_predict | y_predict | Error |
| 1 | 101.4991 | 101.5011 | 0.0014 |
| 2 | 107.5732 | 96.3458 | 8.0742 |
| 3 | 43.9985 | 149.4084 | 75.3472 |
| 4 | 105.7579 | 85.5612 | 20.4403 |
| 5 | 94.7848 | 120.6955 | 18.3248 |
| 6 | 69.0601 | 142.9913 | 52.4462 |
| 7 | 82.4949 | 136.3488 | 38.1109 |
| 8 | 92.7415 | 131.0388 | 27.0807 |
| 9 | 112.6631 | 114.5245 | 1.3229 |
| 10 | 90.782 | 138.2347 | 33.5614 |
| Mean Square Error | | 30.5232 | |
| Normalised MSE | | 0.0543 | |

*Table 5*

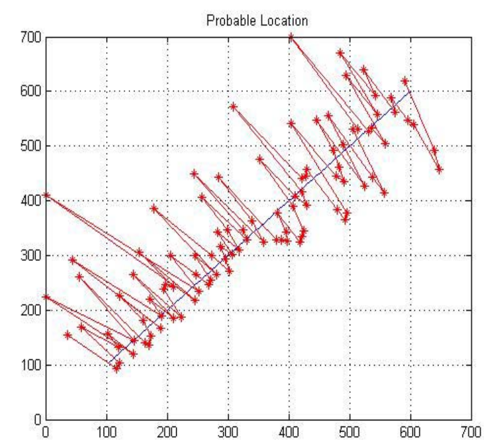


*Figure 3*

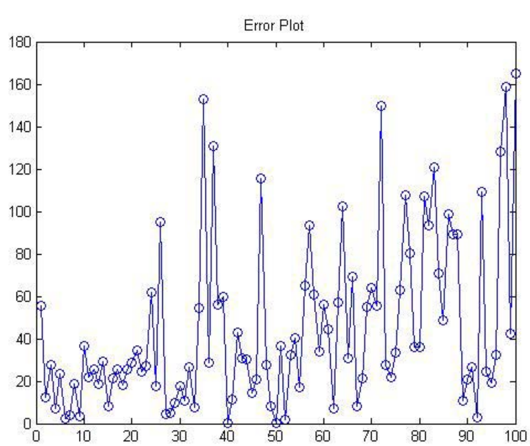


*Figure 4*


*Figure 5*

## V. Conclusion

From the above table we conclude that Chan's TDOA algorithm improves the computation of mobile user locator. We perform various experiment with setting up fix mobile user location i.e. x=100, y=100 in the area of 750 X 750 plane, with two base stations at BS1 & BS2. The distance between mobile user and BS1, BS2 is calculated. We predict the probable movement of mobile user and calculate the error for each sample location and estimates its error occurred for same mobile user.

From above experiments we found that this is best set up to achieve less error in the distance calculation. We predicted Vx, Vy to be 10 and Ts=0.5. With these parameters we found that MSE is less i.e. 24.9043.

So, finally this experiments for Chan-Ho algorithm for mobile user location is less time consuming & estimates accurately its location.

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