Mobile Phone Location Determination in Urban and Rural Areas Using Enhanced Observed Time Difference Technique

[1]S.F. Shaukat, [2]M.I. Ansari, [3]R. Farooq, [1]U. Ibrahim and [1]Muhammad Faisal

[1]Department of Electrical Engineering, COMSATS IIT, Abbottabad, Pakistan
[2]Department of Physics, King Khalid University, Abha, Saudi Arabia
[3]Department of Chemistry, COMSATS IIT, Abbottabad, Pakistan

Abstract: An extensive research has been carried out to evaluate method for the tracking of mobile equipment using it's base stations in a GSM network. Enhanced Observed Time Difference (E-OTD) method is one of the promising and fairly developed positioning technologies that has been standardized for GSM systems. This Method has been utilized in this research work to locate the mobile equipment's position. Urban-area measurements were performed in an area consisting of both micro GSM900 and GSM1800 cells. Measurements were carried out in a rural area with macro-cell structure having diameters of 20 to 30 kilometers. Simulation runs were performed with only two neighbouring BTSs, to show the difference when three or four BTSs are used in the E-OTD location estimate calculation. The location accuracy increases when E-OTD is performed with four or more BTSs. The difference in the location estimate when more than four or just four BTSs are involved, is found to be minimum.

Key words: E-OTD · Mobile location · Cumulative Density Function

INTRODUCTION

Location specific services are of great significance in mobile communication. These services may be of assistance in navigation, mobile information services or emergencies. Location specific information are also being used to achieve improved accessibility and to reduce traffic on overcrowded cells in the network or in fighting crimes. The benefits of these services depend on the quality of the estimated position and it is crucial to achieve the greatest possible level of precision. The success factor of location-based services heavily depends upon the accuracy of location determining technology to predict mobile users` location and the response time to get information [1,2].

The provision of location services is a way for the operator to differentiate on the market, reduce churn and increase revenues. By using the mobile network and infrastructure or by use of integrated Global Positioning System (GPS) receivers, it is possible to pinpoint the location of a Mobile Station (MS). Accessing this new type of information opens up a whole new range of use of the mobile terminal. Existing location-servers for Global System for Mobile (GSM) Communication are usually based on a technique, which uses base station information and the timing advance-parameter. Experiments have shown that this relatively simple technique has evident limitations concerning precision, especially in rural areas [3,4].

It is particularly interesting to evaluate the precision of enhanced observed time difference (E-OTD). The E-OTD positioning method generally relies upon measuring the time at which signals from the Base Transceiver Station (BTS) arrive at two geographically dispersed locations – the Mobile Station (MS) itself and a fixed measuring point known as the Location Measurement Unit (LMU) whose location is known. The position of the MS is determined by comparing the time differences between the two sets of timing measurements. Because of the great demand for additional hardware, such as LMUs, the introduction of E-OTD requires significant investments [5-7].

Corresponding Author: Dr. Saleem F. Shaukat, Department of Electrical Engineering,
COMSATS Institute of Information Technology,
University Road, Post code 22060, Abbottabad, Pakistan

MATERIALS AND METHODS

The Enhanced Observed Time Difference (E-OTD) Method Is Based on Three Parameters: Observed Time Difference (OTD), Real Time Difference (RTD) and Geometric Time Difference (GTD). The Mathematical co-relation between these parameters is analyzed below;

Let a burst be transmitted from the ith BTS and received by a LMU at an instance t_{TXi}.

Let a burst be transmitted from the serving cell and received by a LMU at an instance t_{TX1}. Then Real Time Difference (RTD$_i$) is:

$$RTD_i = t_{TX1} - t_{TXi} \qquad (1)$$

Let a burst be transmitted from the ith BTS and received by a MS at an instance t_{RXi}. Let a burst be transmitted from the serving cell and received by a MS at an instance t_{RX1}.

Then Observed Time Difference (OTD$_i$) is:

$$OTD_i = t_{RX1} - t_{RXi} \qquad (2)$$

In Figure1, d_i is the length of the propagation paths from the BTSs to the MS and d_{LMUi} is the length of the propagation paths from the BTSs to the LMU.

The position of the BTSs is denoted as (x_i, y_i), where 'i' denotes the ith Base Station (i=1,2,.....n). The dashed line represents the hyperbolas calculated from the GTDs. The intersection of the hyperbolas gives the location of the MS [8, 9].

With the earlier definitions of OTD and RTD, Geometric Time Difference (GTD) can be written as the difference between the OTD and the RTD parameters. GTD is a scaled measure of the relative distance (RD) between the MS and the pair of BTSs (BTS$_1$ and BTS$_i$).

$$GTD_i = OTD_i - RTD_i = (t_{RX1} - t_{TX1}) - (t_{RXi} - t_{TXi}) = \frac{d_1 - d_i}{c} = \frac{RD}{c}$$

$$(3)$$

Here c is the speed of light and d_1, d_i are the lengths of the propagation paths from the MS to BTS$_1$, BTS$_i$ respectively. The possible position of an MS observing a constant GTD value is located on a hyperbola having foci at BTS$_i$ and BTS$_1$. In a two dimensional scenario, the MS position is calculated via hyperbolic multilateration at the intersection of at least two hyperbolas. The E-OTD method uses one of the available BTS as a reference BTS and uses it to calculate all GTDs. As a beneficial consequence, linear dependence between multiple equations is avoided [10].
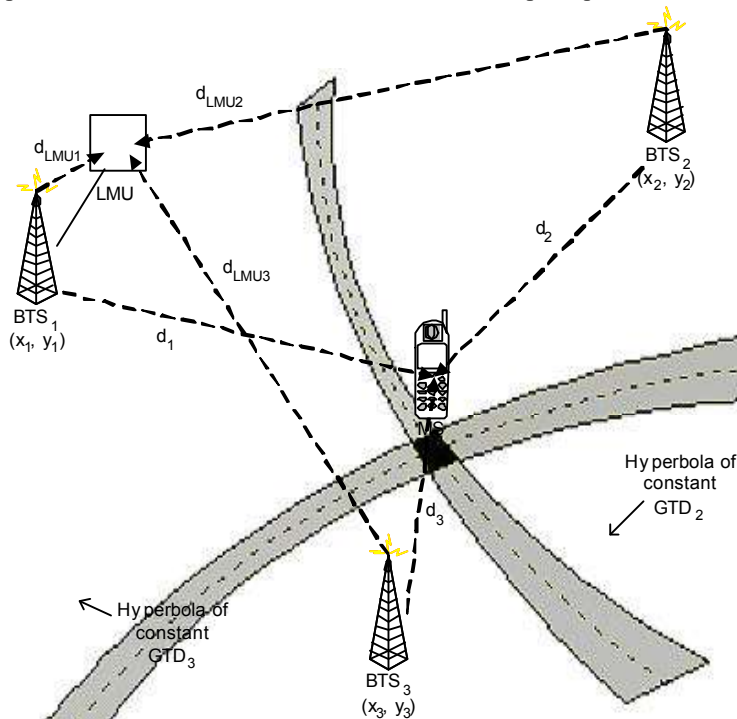

Fig. 1: The E-OTD method

The positioning problem in absence of measurement errors can be formulated with a set of N-1 equations describing hyperbolas having their foci at the BTSs coordinates (x_1, y_1) and (x_i, y_i). The hyperbolic equation is written as:

$$c \times GTD_i = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} - \sqrt{(x_i - x)^2 + (y_i - y)^2}$$

(4)

In an error free case, a unique and exact solution can be found at the intersection of the hyperbolas at P=[x,y]. In a real case however, errors will be present and a statistical solution must be sought. So an optimisation routine has been used to produce a location estimate. From Equation 4, moving the square root terms to the other side, we obtain Equation 5, where the difference between $c \times GTD_i$ and the square root terms is denoted as F_i and is written as:

$$F_i = c \times GTD_i - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} - \sqrt{(x_i - x)^2 + (y_i - y)^2}$$

(5)

In the error free case all F_i are identically equal to zero at the solution where the hyperbolas intersect. In the method a least square optimisation has been used, to minimise the sum of the F_i squared. The position estimate for each measurement point was then found, as from Equation 6, where M is the number of BTS-pairs available;

$$[x, y]_{opt} = \min_{(x,y)} \sum_{i=1}^{M} F_i^2$$

(6)

RESULTS AND DISCUSSIONS

Cell size and radio-propagation characteristics vary greatly from environment to environment. In cities cell size are kept small because of the more no of users, more buildings and other constraints as compared to rural areas. It is therefore essential to perform separate measurements in areas with different network topology and geography to be able to evaluate how different propagation properties are influencing the accuracy of the location method. Two different measurement scenarios, the Urban and Rural Areas have therefore been investigated. The simulations are performed in MatLab® software.

Urban-area measurements were performed in an area consisting of both micro GSM900 and GSM1800 cells. Micro cells are average sized radio cells with diameters of one to two kilometers. These types of cells give large capacity for a small area. The road structure is generally quadratic and separated by five- to eight-story buildings. The tall buildings can cause a blocking of the direct-signal component. This leads to at least one-time reflected received signals.

Measurements were carried out in a rural area with macro-cell structure having diameters of 20 to 30 kilometers. Macro cells give small capacity for a large area. The geography is relatively flat with small hills, farmland and woods.

The statistical evaluation is based on computing the difference between the estimated position and the $(\hat{x}, \hat{y})$ true position (x, y). One possible error measure is to define the circular error (ce_i)

$$ce_i = \sqrt{(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2}$$

(7)

Here subscript i denotes quantities related to the ith measurement.
Statistics on the circular error in this case is presented by:

- Plotting the cumulative distribution function (CDF) of *ce*
- Displaying cumulative density function (CDF) percentile values, 67%, 90% and 95% levels

Another possibility is to compute the root mean square error (rms):

$$rms = \sqrt{\frac{1}{N} \sum_{i=1}^{N} ((x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2)}$$

(8)

Here N is the total number of measurements. The rms calculation is very sensitive to occasional poor position estimates. A measure which is less sensitive to these outliers is obtained by omitting the 10% worst cases in the rms calculation.

By comparing the average T_{RX} values obtained when simulated in absence of errors and the propagation conditions in each measurement scenarios, a simple channel model can be constructed. In the urban measurement scenario, No Line of Sight (NLOS)
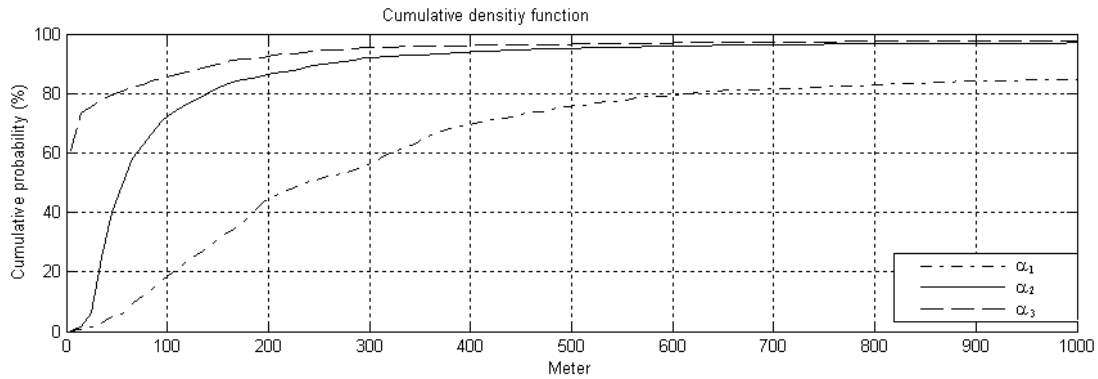
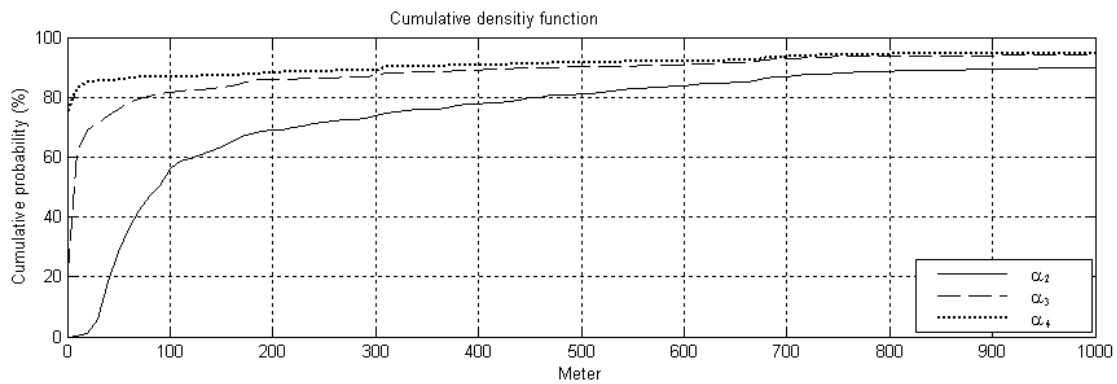Fig. 2: Cumulative density function for urban area

Fig. 3: Cumulative density function for rural area
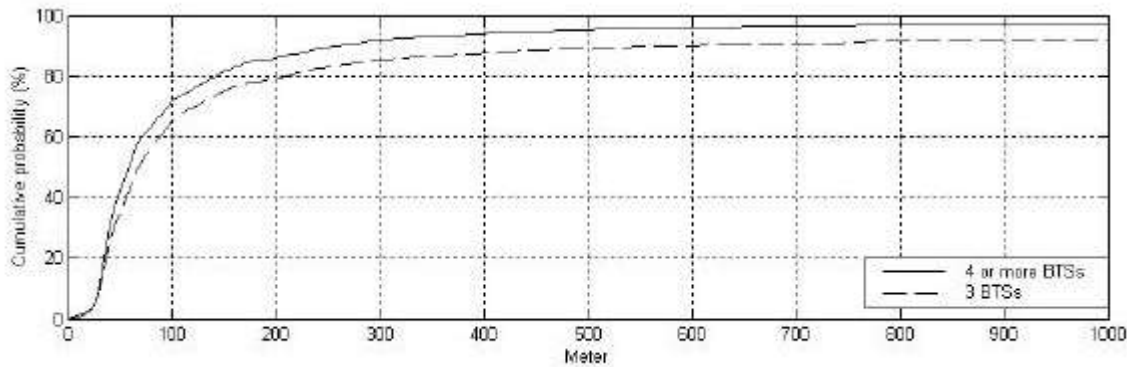

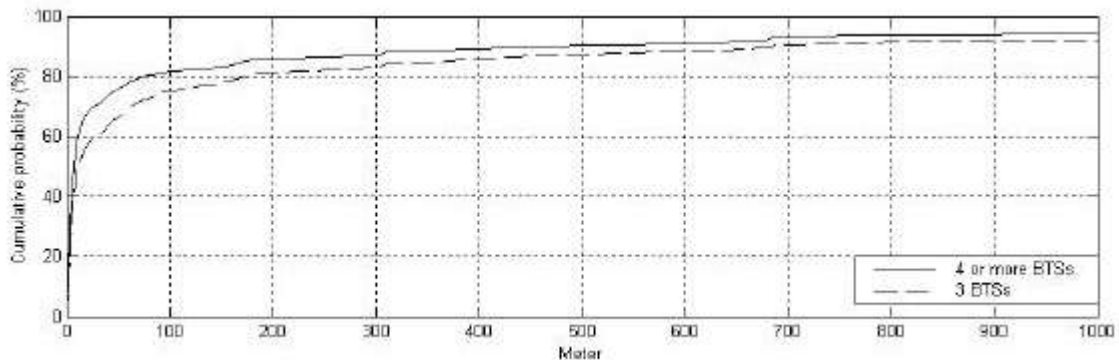Fig. 4: Difference when E-OTD is performed with three or four BTSs in urban area

Fig. 5: The difference when E-OTD is performed with two or three neighbour BTSs in the rural area

Table 1: Percentiles for urban area

	Percentile					
Error	25	50	67	75	90	95
α_1	135	245	375	485	2915	6825
α_2	35	65	95	115	265	495
α_3	5	5	15	25	155	295

Table 2: Percentiles for rural area

	Percentile					
Error	25	50	67	75	90	95
α_2	55	95	175	325	1015	2345
α_3	25	25	25	25	475	1325
α_4	5	5	5	5	315	1125

components caused by the reflection and diffraction of signals, are present and these components will decrease the accuracy. In the rural measurement scenario, a LOS component is assumed to be present and it is assumed that the OTD parameter is less influenced by reflected and diffracted signals.

By adding an error of larger magnitude on the OTD parameter for the urban area than the rural area, different propagation conditions using different values of error (α) can be compensated, where α is a parameter for simple channel model. The percentiles for urban area at different location, with values of α's ranging from 10^{-6} to 10^{-9} is summarised in table 1 below:

The cumulative density function (CDF) for the urban area has been measured and is shown in Figure 2.

It is clear from the graph that α_1 has less error probability as compared to α_2 and α_3. As distance increases the chances of error also increase. This means that position of a mobile station which is near from the base stations can be tracked more accurately and after a certain value the graph will show constant readings, because at that point the error is maximum.

Table 2 shows the percentiles, when simulated for the rural area with the values of α's ranging from 10^{-6} to 10^{-9}.

The cumulative density function (CDF) for the rural area has been simulated and is shown in Figure 3.

It is clear from the graph that α_4 has less error probability as compared with α_2 and α_3. Some simulation runs were performed with only two neighbouring BTSs, to show the difference when three or four BTSs are used in the E-OTD location estimate calculation. Figure 4 below shows the results of these simulation runs in the urban area.

A symmetric comparison of the E-OTD with three to four BTSs in urban and rural areas has been shown in Figure 4 and 5, respectively. The simulations show that the accuracy in the urban area is 35 to 265 meter and in the rural area is 25 to 475 meter, when simulated with the middle error magnitude, that is with α_2 and α_3. To compensate for the BTS clock drift in an unsynchronised GSM network, LMUs must be deployed. The requirement for an E-OTD implementation to work is that every BTS must be visible for at least one LMU. The density of LMUs found in our simulation results is, 1: 5 in the urban area and 1: 4 in the rural area. Figure 5 shows the difference when E-OTD is performed with two or three neighbour BTSs in the rural area.

The E-OTD method requires three or more BTSs to be performed. This is not a problem in the urban area where the density of BTSs is high. In the urban areas only 2.9% have only one or non neighbouring cell. The simulation results show that 74.6% of the measurements only have one or none neighbouring cells to the serving cell.

CONCLUSION

This research work describes a comprehensive comparison of performance achieved by E-OTD method for mobile tracking in urban and rural areas. Different location services require different accuracy of the location estimate. The simulation results confirm the characteristics of E-OTD method and accuracy of the E-OTD method is found very good, which makes it the promising location estimation method. The location accuracy increases particularly when E-OTD is performed with four or more BTSs. The difference in the location estimate when more than four or just four BTSs are involved, is found to be minimum. The requirement for an E-OTD implementation to work is that every BTS must be visible for at least one LMU. The density of LMUs found in our simulation results is 1: 5 in the urban area and 1: 4 in the rural area.

REFERENCES

1. Malekitabar, A, *et al*., 2005. Minimizing the error of time difference of arrival method in mobile networks, WOCN 2005, Second IFIP, pp: 328-332.
2. Fang, B.T. *et al*., 1990, Simple Solutions for Hyperbolic and Related Position fixes, IEEE transactions on aerospace and electronic systems, 26 (5).

3. Hajirezai, M. *et al*., 2009, Evaluating the effectiveness of strategic decisions at various levels of manufacturing strategy: A quantitative method, World Applied Sciences Journal, 6(2): 248-257.

4. Lagarias, J.C., J.A. Reeds, M.H. Wright and P.E. Wright, 1998, Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions, Journal of Optimization, 12: (3).

5. Wylie-Green, M.P. and P. Wang, 2000. GSM mobile positioning simulator. Emerging Technologies Symposium: Broadband, Wireless Internet Access, 2000, pp: 50-55.

6. Shaukat, S.F. and Dong Yaming, 2000. Optical studies of Heavy Metal Fluoride Glasses, Chinese J. Chemical Physics, 13(5): 571-575.

7. Spirito, M.A., 2000. Mobile station location with heterogeneous data" IEEE, 4: 1583-1589.

8. Lozano, A., F.R. Farrokhi *et al*., 2001. Lifting the limits on high speed wireless data access using antenna array, IEEE Communication Magazine, 39: 156-162.

9. Wylie-Green, M.P. and S.S. Wang, 2001. Observed time difference (OTD) estimation for mobile positioning in IS-136 in the presence of BTS clock drift, Vehicular Technology Conference, 1: 101-105.

10. Simon Haykin, 2001. Signal processing: where Physics and Mathematics meet, IEEE Signal Processing Magazine, 18(4): 6-7.

11. Lindsey, W., M. Bilgic, G. Davis, B. Fox, R. Jensen, T. Lunn, M. McDonald and W.C. Peng, 1999, GSM mobile location systems. Omnipoint Technologies Inc.