# Simulation of Mobile Station Location Determination Using Enhanced Observed Time Difference (E-OTD)

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*Abstract*—**Location Based Services (LBS) is a service provided by cellular radio services due to the location of mobile station (MS). This service was first introduced in Global System for Mobile Communication (GSM) system and it become the most important service in Third Generation (3G) system. There are many techniques to determine mobile station location, such as Global Positioning System (GPS), Angle Of Arrival (AOA), Time Of Arrival (TOA), Time Difference Of Arrival (TDOA), Enhanced-Observed Time Difference (E-OTD) and Cell Global Identity (Cell-ID). But, this paper only discussed about Enhanced-Observed Time Difference (E-OTD) technique. E-OTD used triangulation method and a simulation of this technique was created in MATLAB. This simulation is focused on the location error, which is depend on 2 environments. The environments are urban (error of magnitude, 1e-7) and rural (error of magnitude, 1e-9). This simulation also performed comparison between the number of base station (BTS) used.**

*Keywords*— **Triangulation method, Location error**

## I. INTRODUCTION

This report is the simulations of the characteristics related to the E-OTD method. This chapter will describe these simulations. The E-OTD method will first be described in detail, both the general concept and the location calculation methods. Different sources of error and the impact they have on the location prediction will also be discussed. At the end of this chapter, the simulations and the results of these will be discussed.

**Basics of E-OTD**

The Enhanced Observed Time Difference (E-OTD) method is based on the measured Observed Time Difference (OTD) between arrivals of bursts from serving and other BTSs (Figure 1).The measured time difference between pairs of base transceiver stations, are referred to as OTD. Because the transmission of frames from the base transceiver stations are not synchronized in the GSM network, the real time differences (RTD) between pairs of base transceiver stations is measured by an LMU [4].

In Figure 1, $d_i$ 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 $(x_i, y_i)$ The dashed line represents the hyperbolas calculated from the GTDs. The intersection of the hyperbolas gives the location of the MS.

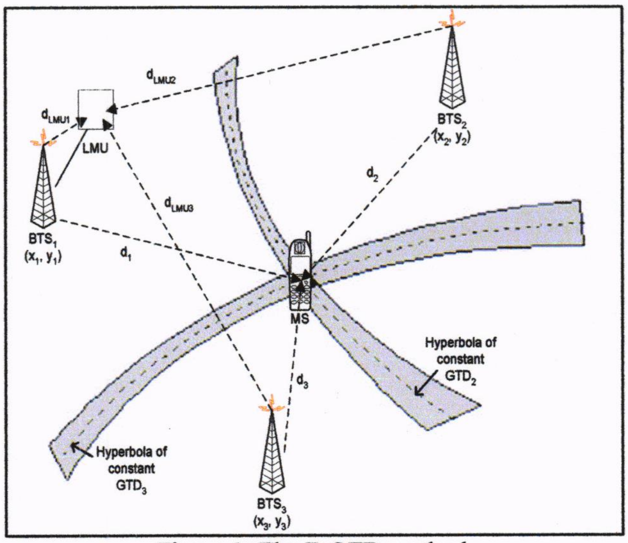


Figure 1: The E-OTD method.

The E-OTD method is based on three parameters: Observed Time Difference (OTD), Real Time Difference (RTD), and Geometric Time Difference (GTD).

**Observed Time Difference (OTD).**

This is the time interval that is observed by a mobile station (MS) between the receptions of signals (bursts) from two different BTSs in the cellular network. A burst from $BTS_1$ is received at the moment $t_{Rx1}$, and a burst from $BTS_2$ is received at the moment $t_{Rx2}$. Thus the OTD value in this case is:

$$OTD = t_{Rx1} - t_{Rx2}.$$

If the two bursts arrive exactly at the same moment, then OTD = 0.

**Real Time Difference (RTD).**

This is the relative synchronization difference in the network between two BTSs. If $BTS_1$ sends a burst at the moment $t_{Tx1}$, and $BTS_2$ at the moment $t_{Tx2}$, the RTD between them is:

$$RTD = t_{Tx1} - t_{Tx2}.$$

If the BTSs transmit exactly at the same time that means that the network is synchronized and there is no need to calculate RTD, hence RTD = 0. RTD values are measured by the LMUs in the network.

**Geometric Time Difference (GTD).**
This is the time difference between the receptions (by a MS) of bursts from two different base stations due to geometry. If the length of the propagation path between $BTS_1$ and the mobile station is $d_1$, and the length of the path between $BTS_2$ and the MS is $d_2$, then

$$GTD_{12} = \frac{d_2 - d_1}{c}$$

$d_2$ = distance between MS to $BTS_2$
$d_1$ = distance between MS to $BTS_1$
$c$ = speed of light, $3\text{x } 10^8 \text{ ms}^{-1}$

If both BST are equally far from the MS, GTD can be consider as zero GTD = 0
Overall relation: **GTD = OTD - RTD**

**MS Location Calculation**
The MS location can be formulated with a set of N-1 equations describing hyperbolas having at the BTSs' co-ordinates *(xi, yi)*

$i$ =1,2,.......N
c=3 x 10' m/s is the speed of light

$$c{*}GTDi = \sqrt{[(x_1 - x)^2 - (y_1 - y)^2} - \sqrt{[(x_i - y)^2 + (y_i - y)^2]}$$

Two equations are required to determine the MS location by simultaneous equations. This means at least 3 BTSs are required to perform the E-OTD method.

**Main Sources of Error in the Location Estimation**
The main sources of error giving a decreased location accuracy of the E-OTD method could be:
- Multipath propagation
- Base transceiver station clocks unsynchronized
- Unable to perform location prediction

• Multipath propagation
Multipath is multiple copies of the same signal arriving at different times. This makes it hard to estimate when the first signal arrived, and the accuracy of the location estimate is decreased. One of the main errors on the location accuracy using the E-OTD method is the NLOS propagation. In urban and indoor environments the E-OTD method will suffer from the absence of a line-of-sight signal component. Signals reflected from buildings, will decrease the location accuracy. The signals reflected or diffracted take a longer path than the direct path. This will produce a longer time of arrival measured. The OTD value will be affected by this, giving a decreased accuracy of the location estimate.

• Base transceiver station clocks unsynchronized
GSM networks are normally not synchronized. This will lead to the OTDs measured having an offset. This is, as explained earlier, why the LMU is needed in the network to compensate for this offset. The BTS clocks can give an error of approximately 15 – 60 m not being synchronized [5]. The LMU can correct this time difference. The RTD value measured by the LMU can reduce the error due to the unsynchronized network, to approximately <15 m.

• Unable to perform location prediction
The E-OTD method can not be used in the following cases:
1 - Only one or none neighboring cells
2 - When using repeaters in the network

When the MS only observes one or none neighboring cells, the E-OTD method can not be used. This is because the E-OTD method uses triangulation to estimate the MS location. With only two BTSs (serving and one neighbor), triangulation can not be performed. This is expected to be a problem in rural areas, where the density of BTS is low. The calculation can be performed with two BTSs with different locations (serving and one neighbor) as described in [6] by extending the E-OTD method with additional information, e.g. by using a combination of E-OTD and the TA parameter.

When using repeaters in the network, E-OTD becomes almost impossible to use. When measuring the time of the received signal, it is hard to determine if the signal has been through a repeater or not. Going trough a repeater, the measured time will be much longer than it actually is. This will cause a major error in the measured OTD value, giving a location estimate with severe errors.

## II. METHODOLOGY

A simulation model was created in MATLAB. A block diagram of the program can be seen in Figure 2. The purpose of the simulation is to analyze the accuracy of the E-OTD technique and further more to identify the solution of the error.

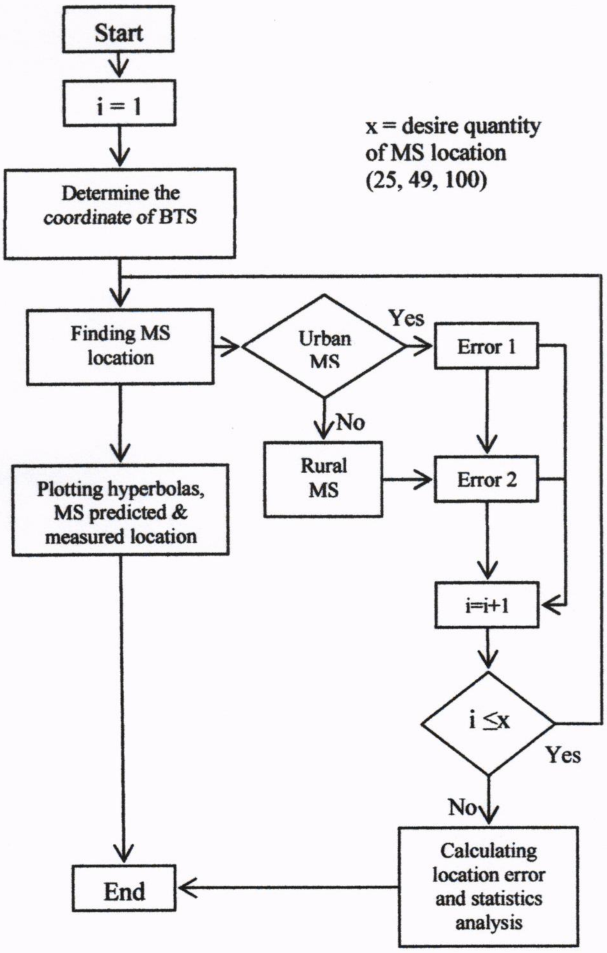


Figure 2: Block diagram of MATLAB Simulation

**Determine Coordinate of BTS**

There are three BTS are required to perform the simulation. It must consist of serving BTS and the two neighboring cells, $BTS_i$.

Table show the coordinate ($x_i$ ,$y_i$) of the three BTS.

| Base Station, BTS | coordinate (m) | |
|---|---|---|
| | **x – axis** | **y – axis** |
| BTS 1 | 0 | 0 |
| BTS 2 | 500 | 2500 |
| BTS 3 | 1500 | 500 |

Additional BTS were made to enhance the comparison analysis which the coordinate is:

| Base Station, BTS | coordinate (m) | |
|---|---|---|
| | **x – Axis** | **Y – Axiz** |
| BTS 4 | 0 | 1500 |

**Finding MS Location**

The location of MS is determined randomly in range of the three BTS. In this simulation there are 25, 49 and 100 reading of MS location taken randomly for the statistic analysis.

**Measurement scenarios**

Two different measurement scenarios have therefore been investigated. This is an urban area and a rural area.

Urban-area measurements were performed in an area consisting of micro cells [7]. These types of cells give large capacity for a small area. The tall buildings can cause a blocking of the direct-signal component. This will lead to at least one-time reflected received signals.

Measurements were carried out in a rural area with macro-cell structure [7]. Macro cells give small capacity for a large area. The geography is relatively flat with small hills, farmland and woods. For the analysis 2 cases was conducted which are:

CASE 1-All zone the measurement scenarios are specified.

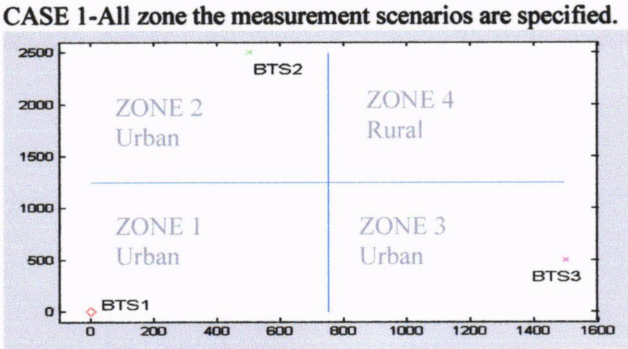


Figure 3: Measurement Scenarios Distributions Case 1

CASE 2–Zone 2 & 3 the measurement scenarios unspecified

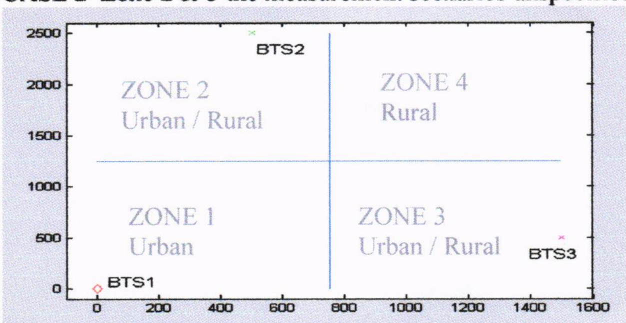


Figure 4: Measurement Scenarios Distributions Case 2

**Error OTD**

An error was inserted into the OTD parameter, this error acts as a simple channel model in the absence of a more complex channel model. The simple channel model is based on several simulation runs of the OTD parameter and assumptions about the geography of the measurement areas.

For Case 1

Table shows the magnitude for measurement scenarios

| Measurement Scenarios | Error Magnitude OTD |
|---|---|
| Urban (zone 1,2,3) | $\pm 1 \times 10^{-7}$ |
| Rural (zone 4) | $\pm 1 \times 10^{-9}$ |

For Case 2

Table shows the magnitude for measurement scenarios

| Measurement Scenarios | Error Magnitude OTD |
|---|---|
| Urban (zone 1) | $\pm 1 \times 10^{-6}$ |
| Urban/Rural (zone 2) | $\pm 1 \times 10^{-7}$ |
| Urban/Rural (zone 3) | $\pm 1 \times 10^{-8}$ |
| Rural (zone 4) | $\pm 1 \times 10^{-9}$ |

**Location error & Statistical analysis**

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

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

$i$ = quantities related to the measurement.
(x,y) = MS location
$(\hat{x},\hat{y})$ = MS location with error

Statistics on the circular error will in our case be presented by:

- Plotting the cumulative distribution function (CDF) of *ce*
- Displaying CDF percentile values.

**Plotting hyperbolas, MS predicted & Measured location**

In order to manually check the location calculation, a graphical plot was made. These plots show the hyperbolas calculated on basis of the GTD value. In addition the measured MS position and the calculated one are plotted. BTS locations are also shown.

## III. RESULTS

**E-OTD Simulation Result**

These simulations are using random measurements which are 25, 49 and 100 of location of MS. The measured values are required to determine the location of MS (minimum) that required to performing the CDF "Cumulative Density Function". After inserting the OTD error according to the measurement scenarios, the MS location plotted are not accurate. The MS location can be determined by the hyperbolas intersection lines which generated. The comparison between the MS location and MS location with error are shown in figure 5. (Graphical Simulation).

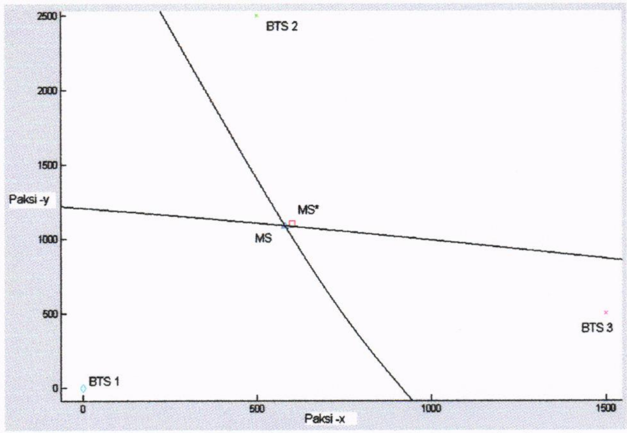


Figure 5: Intersection Point between 2 Hyperbolas Lines shows the location of MS (with error)

**Error Performance**

Error performance analyzed in this study is predicated circle error. It will be portrayed in CDF graph's form of 25, 49 and 100 reads MS location adopted. Two case studies according to zones have been set. Each this case study would give different outcomes and those results indicated in this CDF graph will be discuss in part 4.3 (Result Analysis).

**Cumulative Distribution Function of Case 1**

Figure 6.0 show cumulative distribution graph of function of circular error with 3 BTS
(25 locations MS):

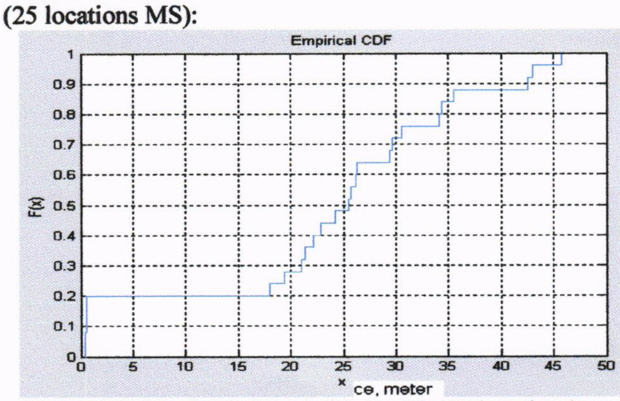


Figure 6.0: Circle error with 3 BTS (25 locations)

Figure 6.1 show cumulative distribution graph of function of circular error with 3 BTS (49 locations MS):

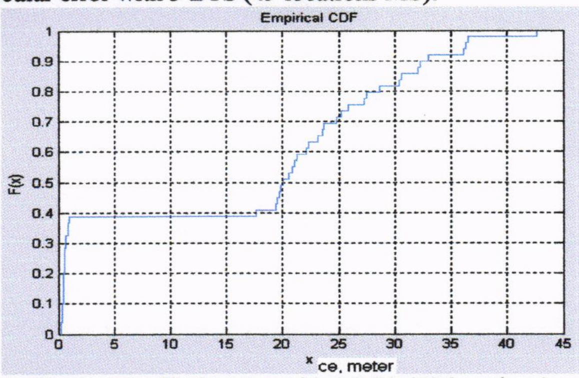


Figure 6.1: Circle error with 3 BTS (49 locations)

Figure 6.2 show cumulative distribution graph of function of circular error with 3 BTS (100 locations MS):

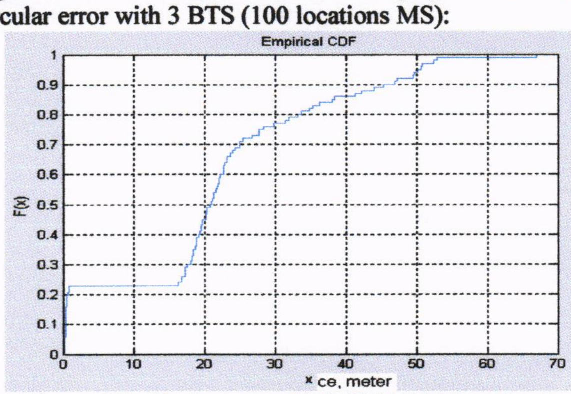


Figure 6.2: Circle error with 3 BTS (100 locations)

Figure 6.3 show cumulative distribution graph of function of circular error with 4 BTS (25 locations MS):

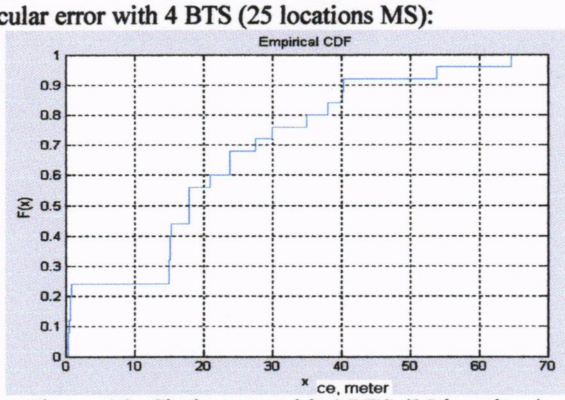


Figure 6.3: Circle error with 4 BTS (25 locations)

Figure 6.4 show cumulative distribution graph of function of circular error with 4 BTS (49 locations MS):

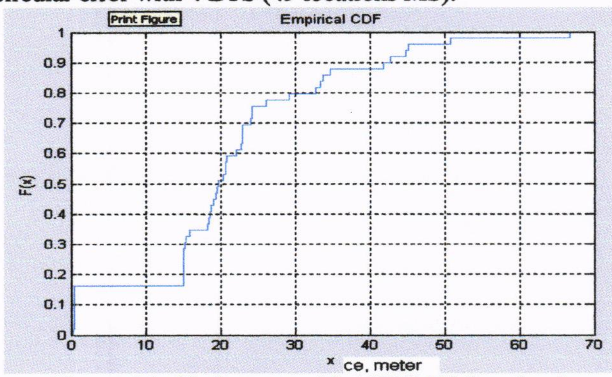


Figure 6.4: Circle error with 4 BTS (49 locations)

Figure 6.5 show cumulative distribution graph of function of circular error with 4 BTS (100 locations MS):

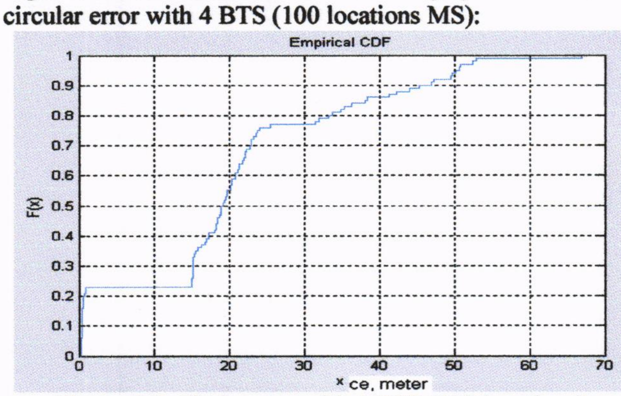


Figure 6.5: Circle error with 4 BTS (100 locations)

**Cumulative Distribution Function of Case 2**

Figure 7.0 show cumulative distribution graph of function of circular error with 3 BTS (25 locations MS):

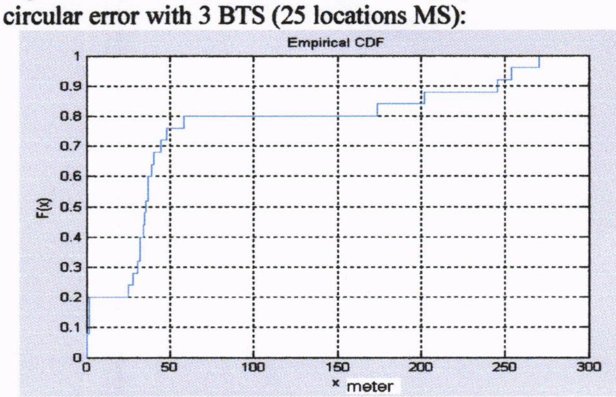


Figure 7.0: Circle error with 3 BTS (25 locations)

Figure 7.1 show cumulative distribution graph of function of circular error with 3 BTS (49 locations MS):

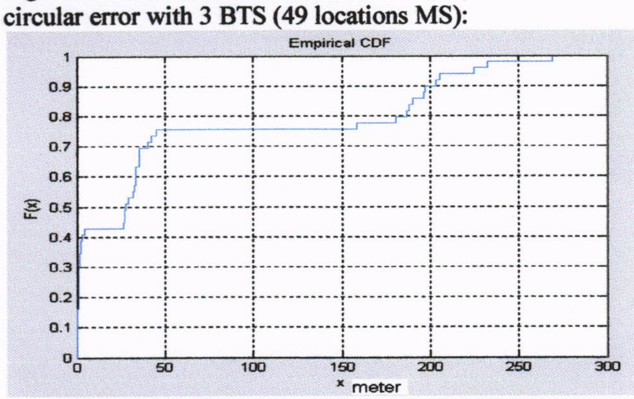


Figure 7.1: Circle error with 3 BTS (49 locations)

Figure 7.2 show cumulative distribution graph of function of circular error with 3 BTS (100 locations MS):

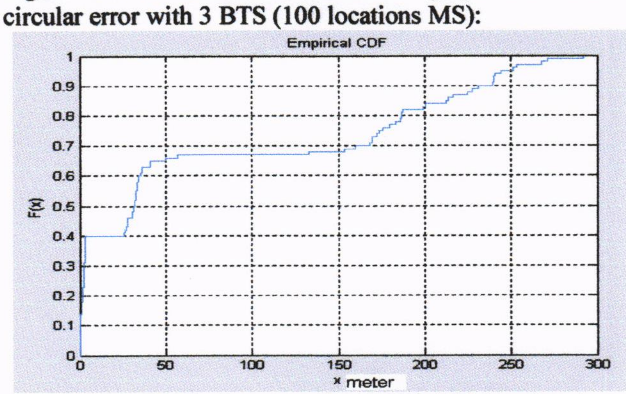


Figure 7.2: Circle error with 3 BTS (100 locations)

Figure 7.3 show cumulative distribution graph of function of circular error with 4 BTS (25 locations MS):

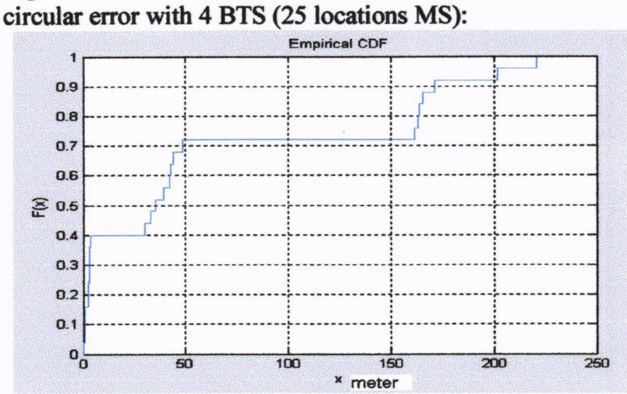


Figure 7.3: Circle error with 4 BTS (25 locations)

Figure 7.4 show cumulative distribution graph of function of circular error with 4 BTS (49 locations MS):

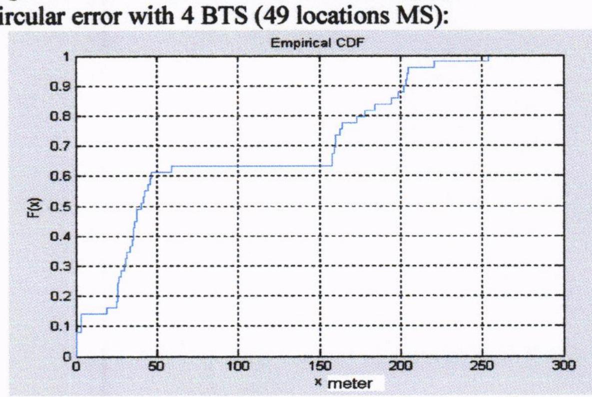


Figure 7.4: Circle error with 4 BTS (49 locations)

Figure 7.5 show cumulative distribution graph of function of circular error with 4 BTS (100 locations MS):

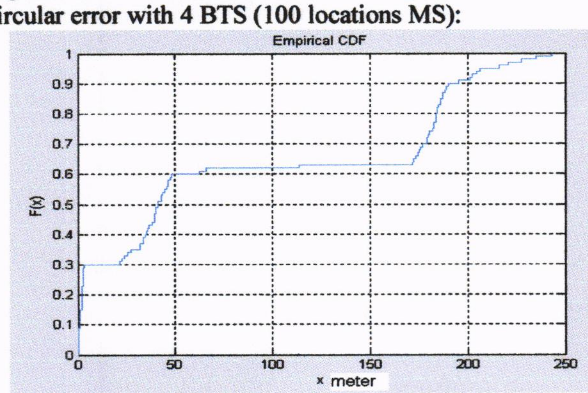


Figure 7.5: Circle error with 4 BTS (100 locations)

**Result Analysis**

The tables below shows the summary result plotted from the CDF simulation.

**CASE 1 - 3 BTS**

| Scattered MS Location by (%) | Circular Error (meter) | | |
|---|---|---|---|
| | 25 MS Location | 49 MS Location | 100 MS Location |
| 50 | 26 | 20 | 21 |
| 75 | 31 | 26 | 28 |
| 95 | 43 | 36 | 50 |

**CASE 1 - 4 BTS**

| Scattered MS Location by (%) | Circular Error (meter) | | |
|---|---|---|---|
| | 25 MS Location | 49 MS Location | 100 MS Location |
| 50 | 18 | 20 | 19 |
| 75 | 30 | 24 | 23 |
| 95 | 54 | 45 | 50 |

**CASE 2 - 3 BTS**

| Scattered MS Location by (%) | Circular Error (meter) | | |
|---|---|---|---|
| | 25 MS Location | 49 MS Location | 100 MS Location |
| 50 | 37 | 30 | 30 |
| 75 | 50 | 45 | 175 |
| 95 | 260 | 225 | 250 |

**CASE 2 - 4 BTS**

| Scattered MS Location by (%) | Circular Error (meter) | | |
|---|---|---|---|
| | 25 MS Location | 49 MS Location | 100 MS Location |
| 50 | 35 | 40 | 38 |
| 75 | 165 | 160 | 183 |
| 95 | 205 | 205 | 210 |

## IV. DISCUSSION

For Case 1, the highest OTD error magnitude entered was $1 \times 10^{-7}$s at urban area. Meanwhile the lowest OTD magnitude is $1 \times 10^{-9}$s in rural area. From the table result shows that the circular error ranges for 3 BTS are from 20-50m meanwhile the range of circular error for 4 BTS are from 18-54m.

For Case 2, the highest OTD error magnitude inserted was $1 \times 10^{-6}$s which is in urban area meanwhile the lowest OTD error magnitude was $1 \times 10^{-9}$s in rural area. From the table result shows that the roundness circular error range for 3 BTS are from 30-260m. The circular error range for 4 BTS are from 35-210m.

From the simulation result, it was found that Case 2 gave a bigger circular error range compared to Case 1 due to the OTD error magnitude instead for urban in Case 2 is much higher than Case 1.

This shows that the OTD error magnitude gives big impact on the accuracy of the technique. It was also found that the case that has 4 BTS, result in lower circular error range compared to 3 BTS. It can be concluded that the more BTS the more accuracy can be achieved for a given area.

## V. CONCLUSION

Through this study, the basic principle of "Location Decision Technique" has been stated clearly, including the comparison of each of the technique. Development for E-OTD technique was also successfully implemented and gave effective result to analyze its precision. Overall, this study was a success and simultaneously achieved the objective.

## VI. FUTURE DEVELOPMENT

This study ignores the properties of the signal propagation environment which we plan to carry out in the future work. Another possible direction of study could be to modify this algorithm for finding the position of a mobile phone in 3-D space.

## ACKNOWLEDGMENT

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