King Fahd University of Petroleum & Minerals

Electrical Engineering Department

CRP 514: Geographic Information Systems (GIS)

Term Project

Mobile-Based Location Estimation
For Emergency Call Situations

BY

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1. Abstract:

The location of subscribers has received huge attention in application for the wireless services. It is well-known that the satellite-based positioning system (GPS- Global Positioning System) is a sufficient and reliable technique for coordinating services. The problem with GPS is that the accuracy drops down in sub-urban areas e.g. downtown or huge shopping centers, plus the additional service fee. To compensate this loss of accuracy, method for allocating mobile users is now emerging. Many techniques using base-stations depend on some wireless parameters such as signal strength, reflection factors, ducting are now being deployed for estimating the locations of the subscribers. In this project, we'll discuss some scenarios of wireless mobile location estimation by utilizing only base-stations (BS's). Our scenarios will take a site of ARAMCO in Dhahran in KAS and select a proper solution to them. The performance simulation results of our selected approaches will be compared with the FCC standard readings.

2. Introduction:

In wireless communications, acquiring the location for E-911 emergency calls allows a coordinated response in states where users are corrupted, cannot respond or speak, or do not know their positions. On October 2001, a decision was made for emergency calls that use cellular phones by the Federal Communications Commission (FCC). They announced that all calls must have a localized accuracy of 67% within an area of 125 m2 in these cases. In addition, service providers are attracted to wireless applications involving position-localization techniques. Position-localization capabilities lead the way to a new dimension of relatively unrealized information applications that can be provided to the consumer in addition to the standard telephony services. Moreover, improved services in the public sector, such as airway booking management, parking assistance, traffic mapping, and real time vehicles services are made possible with position-location systems. To make this all possible, the wireless service providers must have knowledge of subscriber's locations. This should not be a big concern because many radio resource managements (RRM) already utilize this additional information functionality. Finally, at least three BSs are required to achieve satisfactory precision even in the most complex positioning algorithms. In this project we will use another algorithm with only a single-BS to locate mobile terminal (MT) in cellular networks using its own antenna array. Different scenarios will be considered, one of them is regular which a site of ARAMCO in Dhahran in KSA. Also, the impairments of finite-resolution in estimating the channel-characteristics will be covered. Simulation results are compatible with those of U.S. FCC regulations.

3. Objectives:

- To identify the subscribers locations using different techniques.

- To implement our selected approaches in two possible scenarios.

- Validate the acquired results with FCC standard.

- Show the performance of selected methods compared with GPS.

4. Methodology:

- Given a general knowledge about locating subscribers via their mobiles signal.

- Types of location estimation techniques for wireless technologies will be discussed.

- The algorithm of measuring distances using time of arrival (TOA) will be covered.

- AOA or angle of arrival method which depends on the projectiles of the received signals will be illustrated.

- A single base-station technique for both line-of-sight (LOS) and non-line-of-sight (NLOS) conditions will be demonstrated.

- A site of ARAMCO in Dhahran in KAS is chosen to be a regular region case study.

- Finally, a conclusion with some suggestions is given.

Simulation tools:

- MATLAB and ArcView programs will be used.

5. Time of Arrival:

Precise position in wireless networks has gained huge interest over the past decades. Without utilizing satellite-based positioning systems (e.g., by Global Positioning System), many wireless positioning techniques have been presented by making use of only its own radio measurements while transmitting. These methods rely on one or more measurement attributes for example angle (Angle of Arrival), time (Time of Arrival) or time difference of arrivals and power profiles (Received Signal Strength).
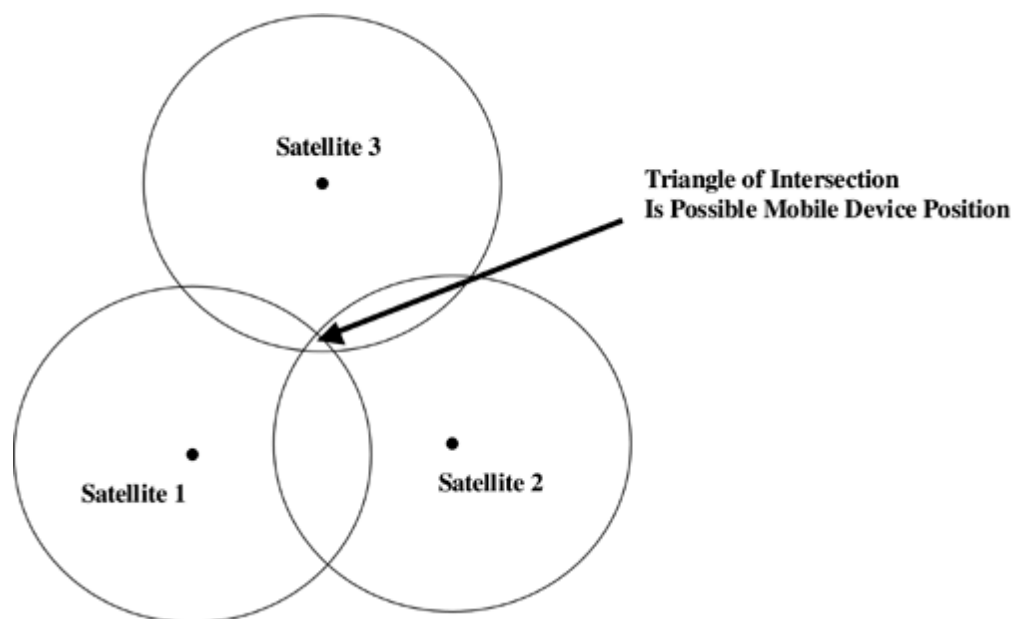

Figure 1. Basic satellite positioning

The basic principle of coordinating a mobile station depends on the triangular geometrics from a set of constant reference points such as the angular measurements case. It is enough to know L=2 paths, while it is needed at a minimum of L=3 known for measuring distances. However, in a more sophisticated wireless networks positioning

scenario these distances or angular values are not directly recognized, but must be approximated from a larger set of recorded data; typically, those data can be found in the mainstream exchanges between the base station (BT) and the mobile terminal (MT). Therfore, the measurements should be a set of L>3.
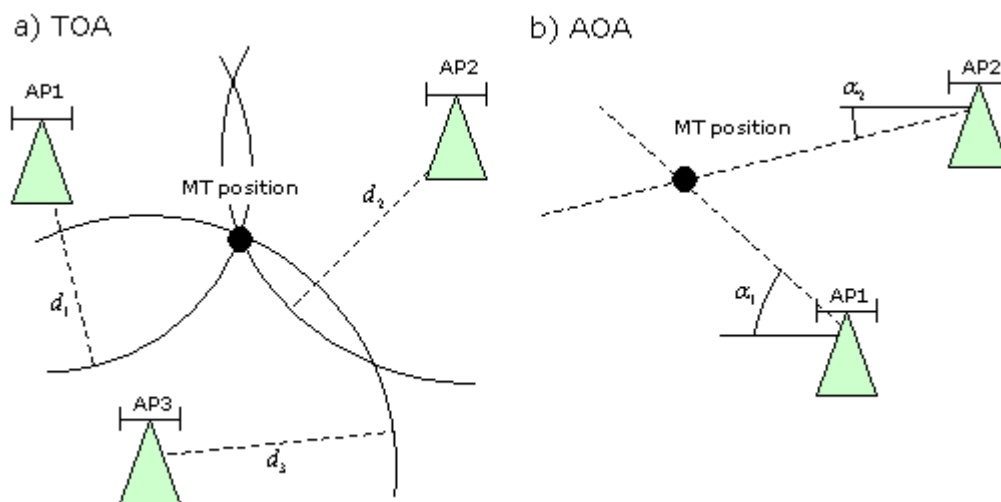

Figure 2. Basic TOA and AOA positioning

In TOA method, the distance is obtained by multiplying the speed of light with the arrival time between an MT and a tower. After three or more ranges are determined, a three-dimensional position of the MT is computed according to the triangulation principle. Here, assumed is that an MS and BS are time-synchronized so that a travel time of a radio signal between them is exactly measured. This is costly because both MS and BS are required to have accurate clocks of nano-second scale. Therefore, the TDOA method rather than TOA is commonly employed in radio location. When an MS and BSs are clock-synchronized each other, we can easily obtain the distances between the MS and BSs from the TOA measurements. A set of (M ≥ 3) TOAs gives the following relation.

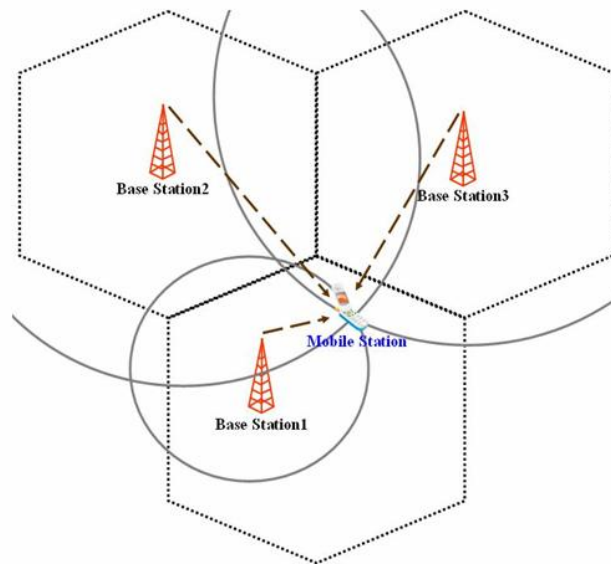$$R_i = c\tau_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \qquad\qquad i = 1,2,3,\dots,M \quad (1)$$

Figure 3. TOA (Time of Arrival).

where τ is the estimated TOA i^{th} BS signal, c is the light speed, (x_i, y_i) is the position of ith BS, and (x, y) is the position of the target MS. By using signals from to at least three BSs, the MS's position can be determined by taking the intersection of circles. Any pair of circles should intersect with at most two points, which is used to produce a straight line. The intersection of these two lines provides the location of the MS.

$$y = -\left(\frac{x_2 - x_1}{y_2 - y_1}\right)x + \frac{x_2^2 + y_2^2 - x_1^2 - y_1^2 + R_1^2 - R_2^2}{2(y_2 - y_1)} \tag{2}$$

$$y = -\left(\frac{x_2 - x_3}{y_2 - y_3}\right)x + \frac{x_2^2 + y_2^2 - x_3^2 - y_3^2 + R_3^2 - R_2^2}{2(y_2 - y_3)} \tag{3}$$

Equating these two linear equations and solving for the location of the MS gives,

$$x = \frac{(y_2 - y_1)C_2 - (y_2 - y_3)C_1}{2[(x_2 - x_3)(y_2 - y_1) - (x_2 - x_1)(y_2 - y_3)]} \tag{4}$$

$$y = \frac{(x - x_1)C_2 - (x_2 - x_3)C_1}{2[(y_2 - y_3)(x_2 - x_1) - (y_2 - y_1)(x_2 - x_3)]} \tag{5}$$

$$C_1 = x_2^2 + y_2^2 - x_1^2 - y_1^2 + R_1^2 - R_2^2 \tag{6}$$

where

$$C_2 = x_2^2 + y_2^2 - x_3^2 - y_3^2 + R_3^2 - R_2^2$$

If there are measurement errors, the least square (LS) method linearizes the set of equations by Taylor series expansion (TSE), and then uses an iterative method to solve the linear equations. With a set of TOA estimates, the method starts with an initial guess and computes the derivatives of the position estimates

$$\begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = (G_t^\tau G_t)^{-1} G_t^\tau h_t \tag{7}$$

where

$$h_t = \begin{bmatrix} R_1 - R_1^0 \\ R_2 - R_2^0 \\ \vdots \\ R_M - R_M^0 \end{bmatrix}, \qquad G_t = \begin{bmatrix} (x_1 - x^0)/R_1 & (y_1 - y^0)/R_1 \\ (x_2 - x^0)/R_2 & (y_2 - y^0)/R_2 \\ & \vdots \\ (x_1 - x^0)/R_M & (y_1 - y^0)/R_M \end{bmatrix} \tag{8}$$

There are also various methods utilizing linearized approaches to implement calculation efficiency while remaining estimate approximation of the MS's location. The TSE method needs iterative processes to get the position approximate from a linear system. The main disadvantage of the TSE method is that it might be affected from the convergence standpoint due to a wrong initial value of the MT's location. There is a two-step Least Square method established to solve the main idea of location-estimation techniques from different types of measurement. The two-step LS approach is better in its computational performance with sufficient accuracy for location estimation. However, the approach is illustrated to be appropriate only to acquire the approximate location of the MT under the LOS conditions. By transforming the circular intersections into the corresponding independent lines, the LS method can therefore be applied to estimate the position of the MS.

6. Angle of Arrival:

This technique measures angle of arrival (AOA) to identify the MT location by determining a signal from an MT at various BSs through their antennas. Obstacles around the MT and BS will affect the measured AOA. If there is no LOS signal component, the antennas will depend on a reflected signal which could not be coming from the direction of the MT. Even when there is LOS component, multipath components will still overlap with the measured angles.
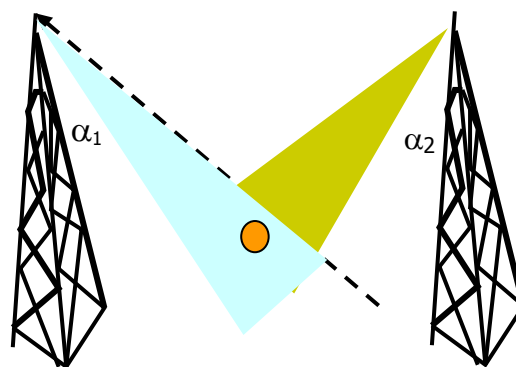

Figure 4. AOA (Angle of Arrival).

7. Single Base Station Location Technique:

The modern location estimation implemented for microcellular wireless networks utilizes just only one BS. "In a microcellular environment, the dominant propagation components are the free space path plus multiple reflections and scatterings within the cell coverage area, together with diffraction around the vertical edges of buildings and over the rooftops. So, these MPCs received in the BS can generally be processed, which are then characterized in terms of AoA, ToA, and power. On the contrary, the MPCs arriving at the BS have large angular spread. The location techniques will take advantage of this feature where a microcellular scenario is considered in the proceeding analysis." [1]

7.1 Prerequisites:

The proposed technique uses the antenna array of a single-BS to locate unmodified MTs. Using a single-BS offer many advantages.

- Synchronized MT with other BSs is not necessary.

- The problem of several BSs coverage is no longer needed.

- Signaling, (back haul), for internet service requirement is reduced.

The algorithm requires knowledge of each of the following:

$\triangleright$ AoAs $\alpha = \left[\alpha_1, \alpha_2, \ldots \alpha_N\right]$

$\triangleright$ Absolute ToAs $\tau = \left[\tau_1, \tau_2, \ldots \tau_N\right]$

Moreover, the proposed positioning algorithm requires another prerequisite which the sentinel function (SF); $\varphi(\alpha)$. This function is defined to be the Euclidean distance between the nearest obstacle and the BS in the direction along the azimuth axis identified by the angle α (Fig. 5).
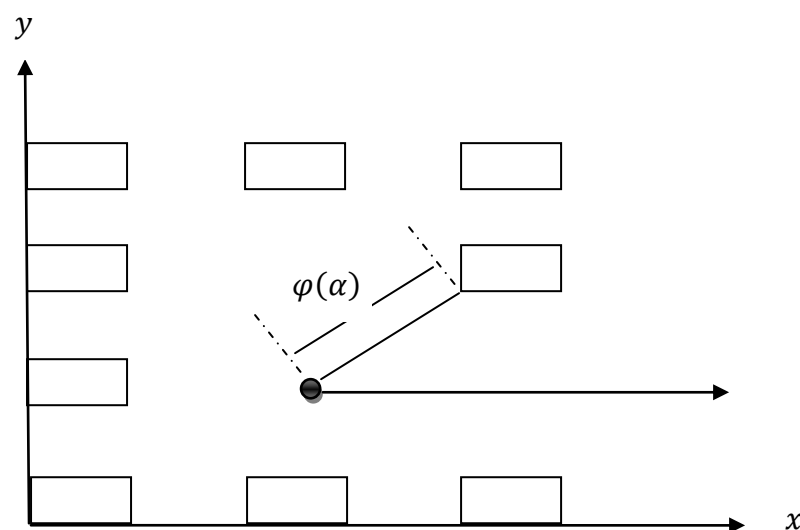

Figure 5. A definition of sentinel function

7.2 LoS versus NLoS:

➢ **Estimation in LoS Conditions:**

The absolute distance measured by the first MPC received at the BS is computed as

$$d_1 = \sqrt{(c\tau_1)^2 - (h_{BS} - h_{MT})^2} \tag{9}$$

where h_{BS} and h_{MT} are the heights of the BS and MT respectively, while τ_1 is the absolute value of propagation delay of the first MPC reaching the BS. The distance d_1, the SF, $\varphi(\alpha)$ and the AoA of the first impinging MPC α_1 are used to decide whether the MT is in LoS condition or not. If $\varphi(\alpha_1) \geq d_1$ then LoS is assumed (Fig. 5) and the position of the MT is simply estimated as

$$\begin{cases} \hat{x}_{MT} = x_{BS} + d_1 . \cos(\alpha_1) \\ \hat{y}_{MT} = y_{BS} + d_1 . \sin(\alpha_1) \end{cases} \tag{10}$$

➢ **Minimization of the Cost-Function in NLoS Conditions:**

If the above mentioned test $\varphi(\alpha_1) \geq d_1$ fails, then the NLoS condition is assumed. For instance, the MT position is determined by minimizing a given cost function. First through the scatterers, the coordinates are evaluated by the algorithm. Each MPC ray related to these scatterers are points where it has been reflected or diffracted form the previous ones before reaching the BS; their coordinates are obtained as

$$\begin{cases} x_{Si} = x_{BS} + \varphi(\alpha_i) . \cos(\alpha_i) \\ y_{Si} = y_{BS} + \varphi(\alpha_i) . \sin(\alpha_i) \end{cases} \quad i = (1, ..., N) \tag{11}$$

After the locating the scatterer positions, the algorithm computes the vector $\tau_R = [\tau_{R1}, \tau_{R2}, \dots \tau_{RN}]$ representing the propagation delays between the MT and the scatterers.

$$\tau_{Ri} = \tau_i - \frac{\varphi(\alpha_1)}{c} \qquad (i = 1, \dots, N) \qquad (12)$$

Then, the following cost function is introduced:

$$F(x, y) = \sum_{i=1}^{N} f_i^2(x, y) \qquad (13)$$

with

Since the MT cannot lie further than $c\tau_1$ from the BS, the estimated position of the MT is eventually chosen as $(\hat{x}_{MT}, \hat{y}_{MT})$ is eventually chosen as

$$(\hat{x}_{MT}, \hat{y}_{MT}) = \arg \min_{(x,y) \in D} \{F(x, y)\} \qquad (15)$$

with

$$D = \left\{ (x, y) | \sqrt{(x - x_{BS})^2 - (y - y_{BS})^2} \leq c\tau_1 \right\} \qquad (16)$$

We see now that in the three-base approach, the propagation delays from the MT to the jth BS τ_{BSj}, $j = 1, \dots, N_{BS}$, must be known for at least three BSs, i.e. $N_{BS} \geq 3$. As the followed procedure depends on a single BS only, the cost function $F(x, y)$ is now gained from $G(x, y)$ by exchanging the spatially adjacent BSs (x_{BSj}, y_{BSj}) with the (x_{Sj}, y_{Sj}) scatterers and the ToAs τ_{BSj} with the time delays τ_{Ri}.

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Many techniques for minimization can be used to solve the NL–LS problem in (15). However, this phenomenon can be effectively circumvented by involving a proper weighting vector $p = [p_1, p_2, \ldots, p_N]$ in the cost function; thus, (13) becomes

$$F(x,y) = \sum_{i=1}^{N} p_i^2 \, f_i^2 \, (x,y) \tag{17}$$

An optimum choice for the weighting vector is given by

$$p_i = \begin{cases} 1 & if \ \tau_{Ri_{min}} \leq \tau_{Ri} < (1.01 * \tau_{Ri_{min}}) \\ \dfrac{1}{100} \cdot \left(\dfrac{\tau_{Ri_{min}}}{\tau_{Ri} - \tau_{Ri_{min}}} \right) & if \ \tau_{Ri} \geq (1.01 * \tau_{Ri_{min}}) \end{cases} \tag{18}$$

The proposed flowchart for the localization technique, for implementation purposes, is shown in Fig. 6.
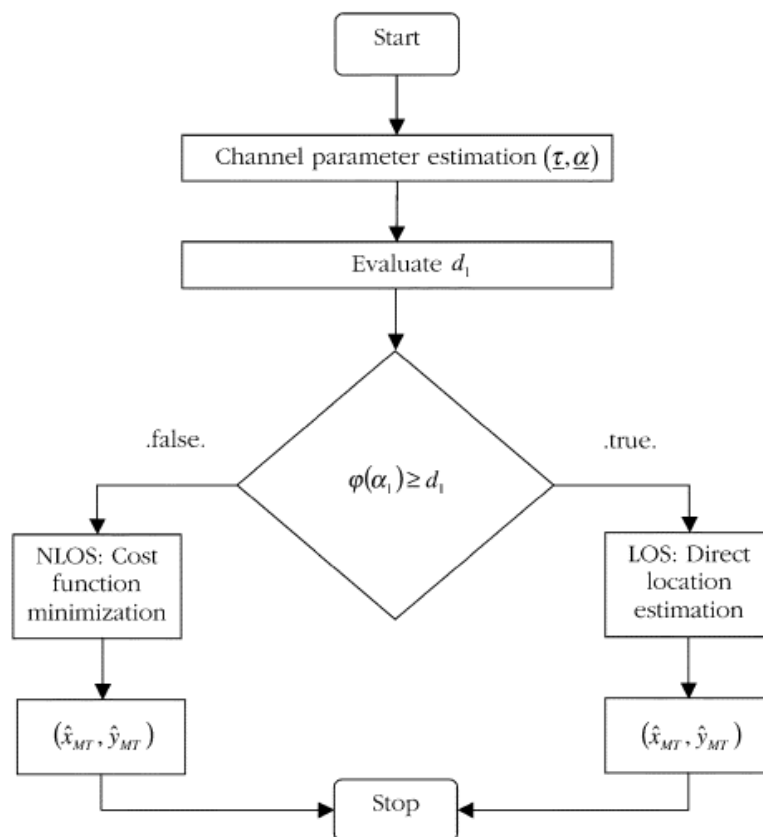

Figure 6. Flow chart of the positioning technique

8. **Case Study:**

The novel location technique has been evaluated in terms of the location error:

$$\varepsilon_d = \sqrt{(x_{\mathrm{MT}} - \hat{x}_{\mathrm{MT}})^2 + (y_{\mathrm{MT}} - \hat{y}_{\mathrm{MT}})^2}$$

If the LoS condition is verified, then the location $(\hat{x}_{\mathrm{MT}}, \hat{y}_{\mathrm{MT}})$ is estimated by (10) and otherwise by (15).

A number of microcellular scenarios have been considered in this analysis. In each scenario, the location error and the error distribution function is analyzed. In order to measure the performance of the proposed location method when the MT is in LoS and in NLoS with the BS, the distribution functions of location error conditioned on the events "MT in LoS with the BS" and "MT in NLoS with the BS" are also represented, together with the overall location-error distribution function [1 and 2].

Different scenarios will be considered, one of them is regular which is ARAMCO. Also, the impairments of finite-resolution in estimating the channel-characteristics will be covered. Simulation results are compatible with those of U.S. FCC regulations. Our measurements were taken for ARAMCO in Dhahran using Google Earth as follows:

There are 64 ARAMCO buildings considered. This scenario is characterized by the following parameters:

- Street width = 20 m

- Building height = 30 m, building width = 40 m

- Cell coverage area = 220 x 220 m^2

- All the buildings are assumed to be made of reinforced concrete while the streets are covered with asphalt.

- The MT height is 1.5 m.

- Five meters is assumed as spacing between any two points.

- As a result, 492 actual subscriber locations are available.

- Six multipath components affecting on the BS have been chosen.

Two different positions are assumed for the BS antenna.

1- Three BSs are located on (x1=50, y1=50), (x2=110,y2=170), and (x3=170, y3=50) Fig. 7 (a)

2- BS is located at (x=110, y=110) in the middle of a street junction Fig. 7 (b)

3- BS is mounted on the rooftop of a building near the street junction.

As a result, the accuracy of the proposed single-BS positioning technique is similar to that of the reference method that uses three different BSs.

Figure 7 (a) Three BSs are located

Figure 7 (b) BS is located at center of the scenario

9. Simulation and Results:

Using our approach and by applying it on site of ARAMCO in KSA, it was found that we could perform three different scenarios. The results obtained from these scenarios are illustrated as follows:

First: using three BSs: as shown in figure7 (a) three BSs scheme happens to be competitive with that of GPS in case of accuracy.

Second: using one BS located at the center: the environment surrounding the BS and MTs is very important, while the arriving signal from the MT will have multipath components. We tried to compute the LOS and NLOS users within the cell. It was found that 56% of subscribers were located with a 125 meter error as shown in figure 8.

Third: BS mounted on a corner of a building: this has the same technique in previous scenario with the transceiver in mounted to a building corner instead of being in the middle. Figure 9 show a decrease from 56% to 50% when compared to figure 8 when it was in the middle.
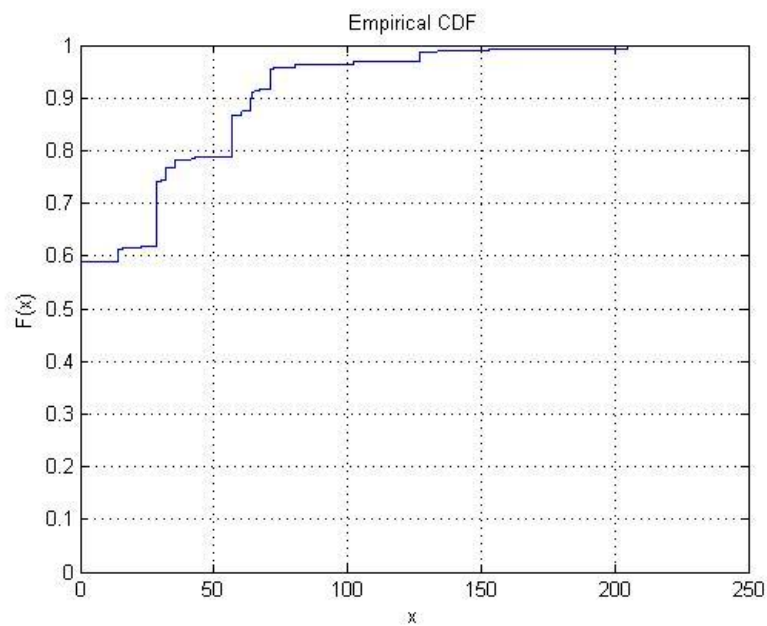

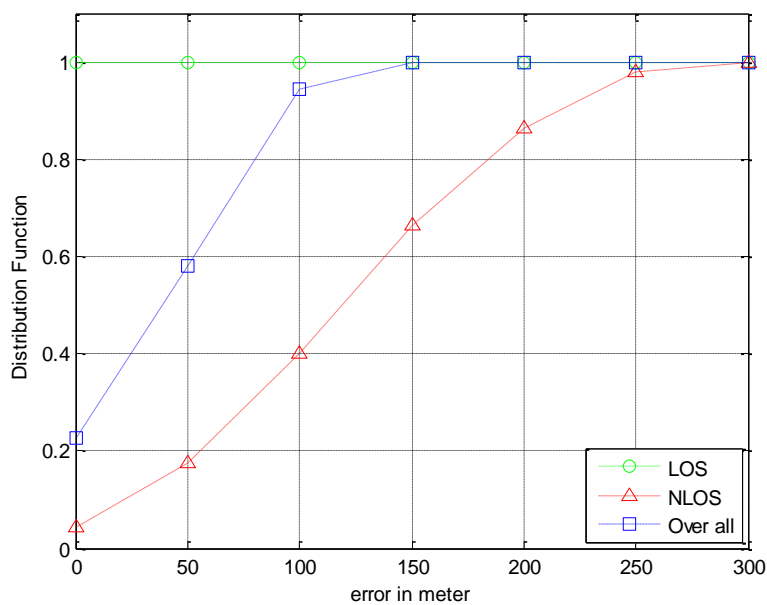**Figure 8.** The CDF of three BSs are located on the scenario

Figure 9. Single BS located at the middle of the scenario

- We compute the position of the scattered.

- The coordinates of the LOS MT are estimated by using eq (8) and NLOS MT by minimize cost function using eq (13).

- We also compute the error in LOS, NLOS, and overall states.

- Then, calculate the distribution function CDF.

- Finally, plot the error location with its CDF and compute the mean and standard deviation for the overall error
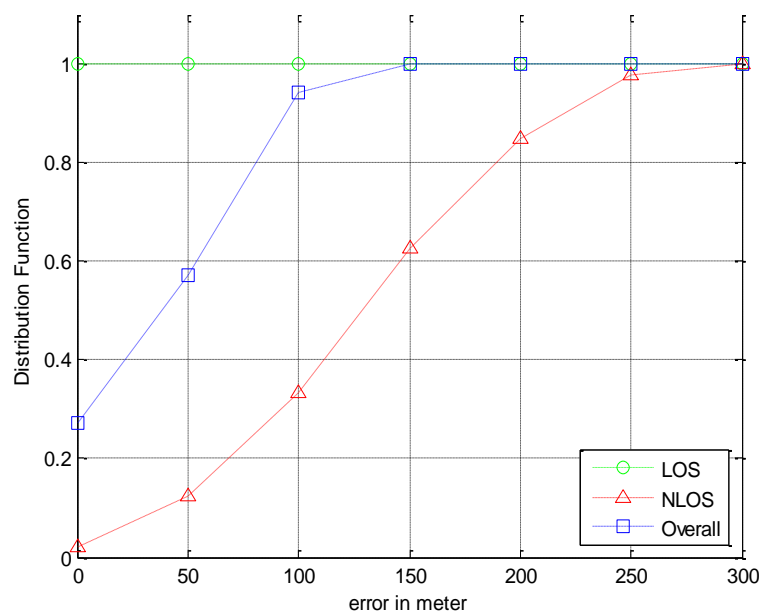

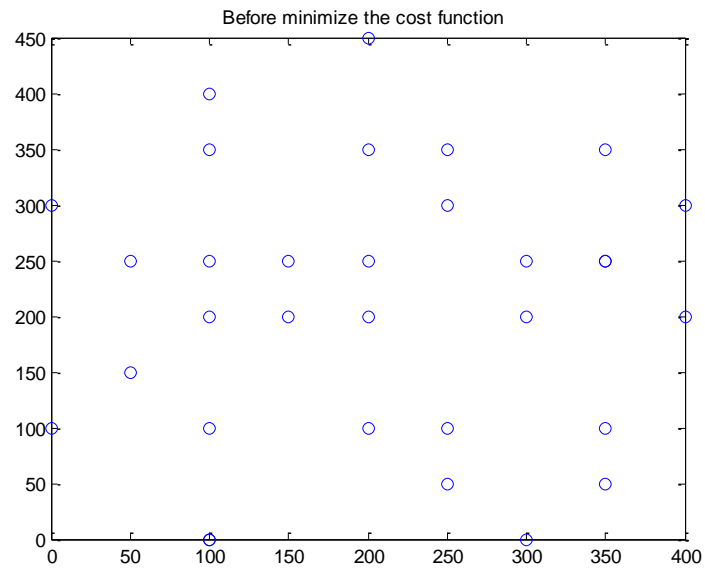**Figure 10.** Single BS located at the corner of one building

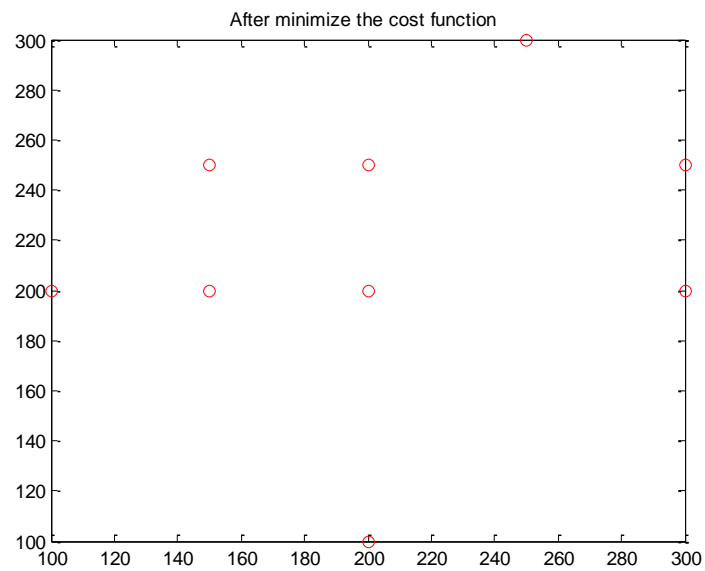**Figure 11.** MPC's before minimize the cost function

Figure 12. MPC's after minimize the cost function

10. Conclusion

In this project, we covered a location-positioning algorithm, which uses only a single-BS antenna array, an unknown MT, and some additional environmental data available about the area surrounding the BS.

The method used happens to specify the MT location with reasonable accuracy. The results were verified with practical tests by applying a deterministic ray tracer.

Various scenarios were considered and the drawbacks of finite-resolution in the channel-parameter characterization have also been exposed.

The simulation results conform to the U.S. FCC regulations, which meet the service requirements to locate E911 emergency calls with an accuracy of 67% within an area of 125 m^2.

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