Localization by OSS and BSS Collected Data

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***Abstract*— This paper proposes a solution for locating an individual using his/her Mobile Station / Mobile Equipment (MS / ME) number MSISDN or MS / ME details IMEI number, without making any addition or changes to the existing Mobile Network Operator (MNO) side or in the MS / ME itself. Our approach leverages the data that MNOs record for subscriber's billing or for the network operations and maintenance purposes. Notably, our solution also allows for locating an individual without raising any suspicion, as it does not involve making voice calls or sending text messages that may alert him/her.**

Keywords—Localization, Mobile Station / Mobile Equipment (MS / ME) Based Localization, Mobile Network Operator-Based Localization, Trilateration, Okumura-Hata Model, Mobility Management, Measurement Report (MR), Timing Advance (TA).

I. Introduction

Initially, people were identified by faces, names, seals, and signatures. Later, scientific methods like fingerprints and ID cards were introduced, but we could only identify individuals who were physically present at that time in front of us. With the rise of digital technology, however, new possibilities have emerged. For example, MS / ME have become ubiquitous, and people now carry them everywhere. Thus, if we can locate a MS / ME, we can locate the person who owns it or we can say who possess it at that time. This is the foundation of MS / ME localization, which can be achieved either through software applications installed in the MS / ME itself or through MNO based techniques. Although MNOs do not have a dedicated infrastructure at their side for locating MS / ME, they do record data for subscriber's billing and for network operations and maintenance purposes, which also can be used to locate a MS / ME precisely. In this paper, we will also explore the different techniques and data parameters used for MS / ME localization, as well as the commonly adopted methodologies and our proposed solution. We will also discuss the limitations and factors that affect the accuracy of MS / ME localization.

II. Localization Techniques

There are two main categories of MS / ME localization techniques [1]: MS / ME based localization and MNO-based localization. In the MS / ME based approach, a software application is installed in the targeted MS / ME, which calculates the received signal strength and the time taken for the signal to travel from the mobile network operator Base Transmission Station (BTS). By analyzing this information, the application determines the distance between the phone and the BTS. It's important to note that a single MS / ME can receive signals from multiple BTSs simultaneously, which improves the accuracy of the localization. In both the MS / ME based and MNO-based localization techniques, the trilateration method is used, with the received signal strength, Received Power Level (Rx Lev) and time taken, Timing Advance (TA) as the key variables [2].

MNO-based localization technique use the same calculations as MS / ME based technique does. However, in this approach, the calculations are performed by the network operator, rather than an application installed on the targeted MS / ME set. Due to certain constraints, such as a lack of physical access to the targeted MS / ME, MS / ME based localization may not be a feasible option for law enforcement agencies. As a result, our proposed solution is MNO-based localization.

III. Trilateration

Once a technique for localization has been selected, the next step is to understand the trilateration method and how it works. To illustrate, let's assume that there are three MNO's BTSs with known positions, we know the latitude and longitude coordinates of all the three BTSs. Each BTS sends out a signal at a specific time interval that a MS / ME can receive. From the received signal, we can calculate the signal strength at the receiver end, as shown below in equation (1), MS / ME power received, Pr (Rx Lev) which is equal to the strength of the transmitted signal at the transmission end, MNO's BTS power transmitted, Pt (TX Level) reduced by the path characteristic power loss, Pl [3].

$$Pr = Pt - Pl \tag{1}$$

This is known as Free Space Path Loss (FSPL) and represents how the BTS transmitted signal is attenuated over the space free from both natural and human made barriers, such as through the air. Free Space Path Loss (FSPL) equation follows the mathematical inverse square law, which means that the signal attenuation grows with the rate of the square of distance between the BTS and the MS / ME [4]. This means that as the distance between the BTS and MS / ME, the signal attenuation becomes four times higher, and the strength at the MS / ME is reduced to one-quarter of the reference transmitted signal from the BTS, shown in equation (2).

$$PL_{FS} = 10 \log\left(\left(\frac{4\pi d}{\lambda}\right)^2\right) \tag{2}$$

Distance d in free space is

$$d = \text{Antilog}\left(\frac{PL_{FS}}{20}\right)\frac{\lambda}{4\pi}$$

Where

PL_{FS} – Free Space Path Loss

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d − distance from the BTS
λ − carrier wavelength in the same units as d

While the concept of calculating the distance in free space is helpful in understanding the interplay between mobile network variables, but it is not sufficient for practical modeling of radio signal propagation. To have an accurate and effective model, extensive measurements of the surrounding environment are necessary. The Okumura-Hata model offers an equation, (equation 4) that is considered to be the most reliable for calculating path loss in the real world scenario [5]. This model takes into account signal propagation in a large urban areas and also applies correction functions for other geographical environments, making it a highly accurate and precise model for predicting radio signal strength [6].

The geographical environment categories used in the Okumura-Hata model are:

- Rural area: space with minimum number of physical obstacles.
- Suburban area: space with natural and manmade both obstacles typically trees and houses.
- Urban area: space with skyscrapers and mega structures [7].

Parameters in Okumura-Hata model:

L − Path loss
f_c − Carrier frequency, with defined range 150 MHz ≥ fc ≥ 1500 MHz
h_b − BTS height, with defined range 30 m ≥ h_b ≥ 200 m
h_m − MS / ME height from ground level, with range 1 m < h_m < 10 m
d − circle distance between BTS and MS / ME

$$L = A + B \log d - \begin{Bmatrix} C\ Rural\ areas \\ D\ Suburban\ areas \\ E\ urban\ areas \end{Bmatrix} \quad (3)$$

After simplifying for the distance d,

$$\mathrm{d} = \mathrm{Antilog}\left(\frac{L - A + \begin{Bmatrix} C\ Rural\ areas \\ D\ Suburban\ areas \\ E\ urban\ areas \end{Bmatrix}}{B} \right) \quad (4)$$

Where,

$$A = 69.55 + 26.16 \log f_c - 13.82 \log h_b$$

$$B = 44.9 - 6.55 \log h_b$$

$$C = 4.78\ (\log(f_c))^2 - 18.33 \log f_c + 40.94$$

$$D = 2\left(\log\left(\frac{f_c}{28}\right)\right)^2 + 5.4$$

$$E = \begin{Bmatrix} \begin{Bmatrix} 3.2(\log(11.75.h_m))^2 - 4.97 & f_c \geq 300MHz \\ 8.29\ (\log(1.54.h_m))^2 - 1.1 & f_c < 300MHz \end{Bmatrix} \\ (1.1 \log f_c - 0.7).h_m - (1.56 \log f_c - 0.8) \end{Bmatrix}$$

For rural areas,

$$\mathrm{d} = \mathrm{Antilog}\left(\frac{L - 69.55 + 26.16 \log f_c - 13.82 \log h_b + C}{44.9 - 6.55 \log h_b} \right)$$

For suburban areas,

$$\mathrm{d} = \mathrm{Antilog}\left(\frac{L - 69.55 + 26.16 \log f_c - 13.82 \log h_b + D}{44.9 - 6.55 \log h_b} \right)$$

For urban areas,

$$\mathrm{d} = \mathrm{Antilog}\left(\frac{L - 69.55 + 26.16 \log f_c - 13.82 \log h_b + E}{44.9 - 6.55 \log h_b} \right)$$

Once we have the distance (d) from each MNO's BTS, we can form a circle around the targeted MS / ME possible locations. The targeted MS / ME's location could be anywhere on the circle at that specific radius. When the MS / ME receives a second signal, we can again form a circle by that signal, and the MS / ME's location could be anywhere on that circle as well. With two known distances from two MNO's BTSs, the precise location could be any of the two points where the circles intersect. But with a third BTS, we can reveal the targeted MS / ME's true location by identifying where all three circles intersect [8]. By using three distances, trilateration can pinpoint a precise location as shown in figure 1.

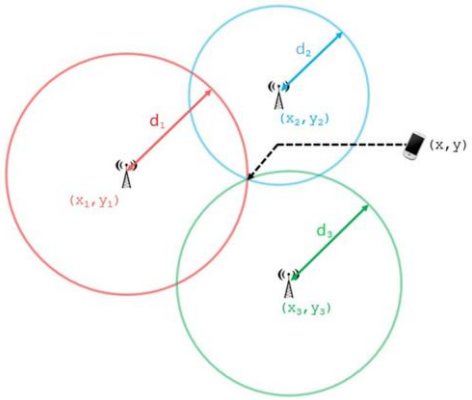


Fig. 1. Trilateration

However, it's important to note here that in our three-dimensional world, BTSs broadcast signals as a sphere. Each BTS is at the center of a sphere, and the MS / ME's location is where all the spheres intersect with each other. As the location of the targeted MS / ME changes, the radius of each sphere (distance) will also change. Therefore, trilateration can determine the targeted MS / ME's location by determining the intersection of the spheres that represent the signals from the three BTSs.

IV. Mobility Management

MS / ME network composed of numerous cells, uses BTSs in each cell for subscriber's access to the network. The BTS is the key network component that manages all communication and signaling between the MS / ME set and the MS / ME network over the air. To ensure widespread connectivity, a vast number of BTSs are deployed across the country, operating on different frequencies to prevent interference between them. The MS / ME set continuously

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measures the signal strength of surrounding BTSs and automatically switches to the most attractive BTS for optimal network connectivity as the subscriber or the MS / ME set moves [9]. All MS / ME networks rely on only two unique identifiers, International Mobile Equipment Identity (IMEI) a unique 15-digit code (MS / ME) identity) and International Mobile Subscriber Identity (IMSI) an internationally standardized unique identifier to identify a MS / ME service subscriber (SIM card identity), for communication. To protect subscriber identities, these two identifiers IMEI and IMSI are only transmitted in certain situations, such as when MSs / MEs are turned on or when crossing special cell boundaries between different Local Area Code (LAC). Temporary Mobile Subscriber Identity (TMSI), a third identifier, is used instead by networks to communicate with MS / ME, which changes multiple times in a single day. Targeting a specific MS / ME to obtain its information covertly is almost impossible without knowing the target's unique identity IMEI or IMSI [10]. Once the target's IMEI or IMSI is known, MS / ME can be located.

MNOs keep and monitor various parameters to ensure quality of service and accurate billing for their subscribers. However, it is questioned here how we can use these parameters to track or locate any individual. The answer lies in the two subsystems that MNO's use: Operations Support Subsystem (OSS) and Business Support Subsystem (BSS). The OSS manages the provider's inventory and subscriber records, such as SIM card sales and the associated subscriber information. The BSS handles real-time functions such as charging (pre-paid/post-paid), rating different tariff plans and special offers. When a subscriber makes a call, the usage details, also known as the Usage Detail Record (UDR), are recorded and used for billing purposes [11]. Although MNOs do not intentionally monitor subscriber location or activity, but we can use the UDR to determine Cell of Origin. A UDR file has the following details:

1. Call Type
2. Calling number
3. Called number
4. Date and Time
5. Call duration
6. Call Identifiers
    a) Cell ID
    b) IMEI
    c) IMSI
    d) Site

MS / ME service provider's subscriber UDR file as shown in figure 2.

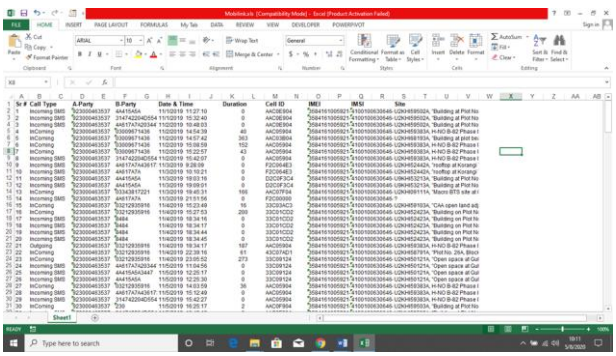


Fig. 2. Mobilink's User Detailed Record (UDR) file.

When we make a call or use data on our MS / ME, information about the activity is saved in a file called a UDR. This file is stored in the MS / ME MNO's Mobile Switching Centre (MSC) and later processed by the MS / ME network operator's Charging System (CS). The CS analyzes the UDR and determines how much to charge for each entry. This is called a rated UDR. However, even before this process is complete, we can use the information in the UDR to identify patterns of behavior and track the location of the MS / ME user.

Other MS / ME service providers UDR files and formats shown in figure 3.

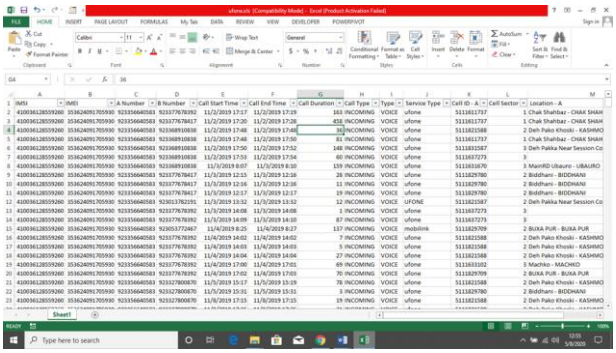


Fig. 3. Ufone's User Detailed Record (UDR) file.

It's worth noting that for us, the only important information in the UDR is the Call Identifier. In the UDR file for Ufone, a cell sector is also included in the Call Identifier. Cells are typically represented as hexagons, which cover the largest area with the least overlap. However, in reality, cell coverage areas are circular. Including the cell sector narrows down the area to a 120-degree slice of the circle for tracking the subscriber's or the MS / ME location. Other MNOs, like Telenor, Warid, and Zong, have similar UDR files and formats. In Zong's UDR, shown in figure 4 there are even latitude and longitude coordinates included as additional data.

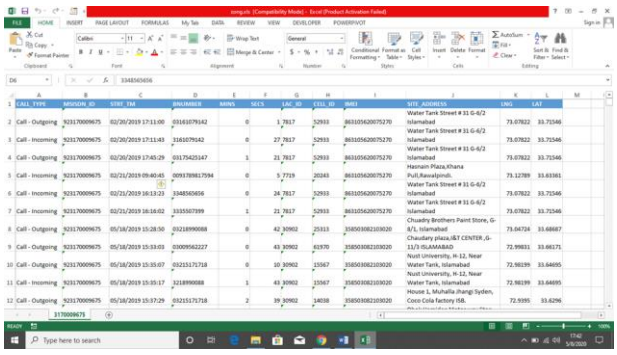


Fig. 4. Zong's User Detailed Record (UDR) file.

Mobility management is a crucial function in any MS / ME network that allows MS / ME sets to work. The network keeps track of the location of all active subscribers to ensure that calls, text messages, and other MS / ME services are delivered to them. The MS / ME network is made up of individual cells, each covered by a BTS, and also called a Base Transceiver Station in GSM. The coverage of each BTS is integrated to provide a radio coverage over a wider area.

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The MS / ME's location update procedure allows the MNO to know when a MS / ME moves from one location area to another. The MNO has access to the location of its BTSs and the signal strength of nearby towers based on the frequent reports, Measurement Report (MR) also referred as MEAS_REP sent by the MS / ME. The Radio Resource Location Services Protocol (RRLP) is used in GSM MS / ME networks, while the LTE Positioning Protocol (LPP) is used in LTE MS / ME networks to exchange position messages between the MS / ME set and BTS. The BTS can request measurement data such as signal strength from the MS / ME and compute the distance to the MS / ME. Alternatively, the MS / ME can calculate its own position and request its coordinates from the MS / ME network operator's BTS. This request can be made outside of any session such as a call or SMS, without the MS / ME's knowledge [12]. Although this is originally intended for emergency services, RRLP / LPP we can use for localization. MS / ME continuously sends MR, MEAS_REP, even during in idle mode to the BTS over the Stand-Alone Control Channel (SACCH). The MNO decodes these MR, MEAS_REP reports shown in figure 5, to allocate radio resources, with Radio Resource Management (RRM) communicating the necessary messages to the MS / ME.

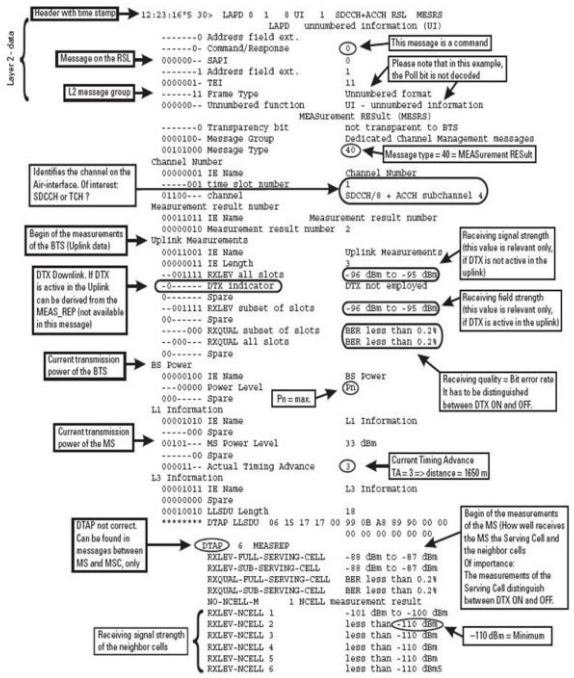


Fig. 5. Measurement Report (MR).

Due to the limited resources of radio, the control channel uses short form notation for commands and responses. MEAS_REP includes the current measurement results of the MS / ME, including the sending levels of the serving cell and neighboring cells. When the MS / ME is in active connection, it sends a MR, MEAS_REP to the BTS every 480ms via the SACCH. The BTS forwards the MR, MEAS_REP to the Base Station Controller (BSC) embedded in its own measurement results MR, MEAS_REP. MR, MEAS_REP helps the network control MS / ME handovers and power output, while MR, MEAS_REP provides building blocks for track and trace of a MS / ME to a particular group of cells and other surveillance tasks. It's important to note that there are different MS / ME states, including being switched on, idle, and in full dedicated mode. In idle mode, the MS / ME can update its position through network commands, moving to another radio area, or periodic updates from the Subscriber Identity Module (SIM) card. In dedicated mode, the fast timing of MR, MEAS_REP sent every 480ms enables combined results to be used with other processes to locate a MS / ME to within tens of meters of a particular location.

The following parameters are important and monitored in two categories in the MR, MEAS_REP:

- Serving Cell Reports
- Neighbor Cell Reports

Serving Cell Reports, which cover Radio Frequency parameters like Timing Advance, Transmitted and Received Power Levels (Tx Level, Rx Level), and the Received Signal Quality RX Quality [13].

Neighbor Cell Reports, which cover parameters such as Radio Access Technology (RAT), UTRA Absolute Radio Frequency Channel Number (UARFCN), Network and Base Station Color Codes (NCC and BCC) and SC (3G FDD) in the case of 3G Frequency Division Duplexing, as well as the report and quantity of each neighbor cell [13].

During the reporting period for General SACCH Measurement Reports, the MS / ME returns information on up to 6 GSM neighbor cells. TA is a dedicated mode parameter that can only be monitored when the MS / ME user is on a call or during SMS receiving or transmitting periods.

The TA parameter is important, as it is based on the bit travelling time from MS / ME to BTS. The TA signal is transmitted in the SACCH frame multi-frame between 0 and 63, in units of bit periods (3.69 microseconds). Each increase in the value of TA corresponds to a distance of 550 meters between the MS / ME and BTS. For example, a TA value of 0 means that the MS / ME is up to 550 meters from the BTS, TA = 1 means it is between 550 and 1100 meters, TA = 2, from 1100 to 1650 meters, and so on (Table I).

TABLE I. TIMING ADVANCE (TA) CHART

TA Value	FROM (km)	TO (km)	TA Value	FROM (km)	TO (km)
0	0.00	0.55	**32**	17.60	18.15
1	0.55	1.10	**33**	18.15	18.70
2	1.10	1.65	**34**	18.70	19.25
3	1.65	2.20	**35**	19.25	19.80
4	2.20	2.75	**36**	19.80	20.35
5	2.75	3.30	**37**	20.35	20.90
6	3.30	3.85	**38**	20.90	21.45
7	3.85	4.40	**39**	21.45	22.00
8	4.40	4.95	**40**	22.00	22.55
9	4.95	5.50	**41**	22.55	23.10
10	5.50	6.05	**42**	23.10	23.65
11	6.05	6.60	**43**	23.65	24.20
12	6.60	7.15	**44**	24.20	24.75

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13	7.15	7.70	**45**	24.75	25.30
14	7.70	8.25	**46**	25.30	25.85
15	8.25	8.80	**47**	25.85	26.40
16	8.80	9.35	**48**	26.40	26.95
17	9.35	9.90	**49**	26.95	27.50
18	9.90	10.45	**50**	27.50	28.05
19	10.45	11.00	**51**	28.05	28.60
20	11.00	11.55	**52**	28.60	29.15
21	11.55	12.10	**53**	29.15	29.70
22	12.10	12.65	**54**	29.70	30.25
23	12.65	13.20	**55**	30.25	30.80
24	13.20	13.75	**56**	30.80	31.35
25	13.75	14.30	**57**	31.35	31.90
26	14.30	14.85	**58**	31.90	32.45
27	14.85	15.40	**59**	32.45	33.00
28	15.40	15.95	**60**	33.00	33.55
29	15.95	16.50	**61**	33.55	34.10
30	16.50	17.05	**62**	34.10	34.65
31	17.05	17.60	**63**	34.65	35.20

V. PROPOSED SOLUTION

The MR, MEAS_REP provides information about the Transmitted and Received Power Levels (Tx Level, Rx Level) of both the Serving Cell and the Neighboring Cells. By using the Okumura-Hata model, a circle can be drawn around each BTS to represent its coverage area. The radius of each circle corresponds to the Tx Level and Rx Level of the MS / ME. When these circles intersect with each other, the point of intersection provides an accurate approximation of the location of the targeted MS / ME.

Program written in MATLAB.

```
%% Reset

clc
clear all
close all

%% Input Parameters

pt1 = input('Power Transmitted by 1st BTS: ')
pr1 = input('Power Received at MS: '); %
pt2 = input('Power Transmitted of 2nd BTS: ');
pr2 = input('Power Received at MS: '); %
pt3 = input('Power Transmitted by 3rd BTS: '); % 20
pr3 = input('Power Received at MS: '); %
fc  = input('Enter Frequency: '); % 900
hb  = input('Height of BTS: '); % 100
hm  = input('Height of MS: '); % 2
x1  = input('Enter x1-cordinate: '); % 24.8747
y1  = input('Enter y1-cordinate: '); % 67.0395
x2  = input('Enter x2-cordinate: '); % 24.8798
y2  = input('Enter y2-cordinate: '); % 67.0321
x3  = input('Enter x3-cordinate: '); % 24.8846
y3  = input('Enter y3-cordinate:'); % 67.0395

%% Okumura-Hata model

A = 69.55+26.16*log10(fc)-13.82*log10(hb);
B = 44.9-6.55*log10(hb);
L1 = pt1 - pr1; % path loss
L2 = pt2 - pr2; % path loss
L3 = pt3 - pr3; % path loss

%% Rural Area

C = 4.78*(log10(fc))^2-18.33*log(fc)+40.94;
d1 = (L1-A+C)/B;
r1 = 10^d1;
d2 = (L2-A+C)/B;
r2 = 10^d2;
d3 = (L3-A+C)/B;
r3 = 10^d3;

%% Suburban Area

D= 2*(log10(fc/28))^2+5.4;
d1 = (L1-A+D)/B;
r1 = 10^d1;
d2 = (L2-A+D)/B;
r2 = 10^d2;
d3 = (L3-A+D)/B;
r3 = 10^d3;

%% Urban Area

E = 3.2*(log10(11.75*hm))^2-4.97;
d1 = (L1-A+E)/B;
r1 = 10^d1;
r1 = r1/1000;
d2 = (L2-A+E)/B;
r2 = 10^d2;
r2 = r2/1000;
d3 = (L3-A+E)/B;
r3 = 10^d3;
r3 = r3/1000;

%% Point of Intersection

syms x y
[a12,b12] = solve([(x-x1)^2+(y-y1)^2==r1^2 ,(x-x2)^2+(y-y2)^2==r2^2],[x,y]);
[a23,b23] = solve([(x-x2)^2+(y-y2)^2==r2^2, (x-x3)^2+(y-y3)^2==r3^2],[x,y]);
[a31,b31] = solve([(x-x3)^2+(y-y3)^2==r3^2, (x-x1)^2+(y-y1)^2==r1^2],[x,y]);

x_12 = double(a12);
y_12 = double(b12);
x_23 = double(a23);
y_23 = double(b23);
x_31 = double(a31);
y_31 = double(b31);

%% Check if x_12 and x_23 have a common element

% Define x_12, x_23, and x_31
x = [x_12 x_23 x_31]
y = [y_12 y_23 y_31]
x = x(:);
```

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```
- y = y(:);
- x = mode(x)
- y = mode(y)

- geoplot(x1 + r1*cos(linspace(0,2*pi)),y1 + r1*sin(linspace(0,2*pi)),'-');
- hold on
- %axes(handles.axes1)

- geoplot(x2 + r2*cos(linspace(0,2*pi)),y2 + r2*sin(linspace(0,2*pi)),'-');
- hold on
- %axes(handles.axes1)

- geoplot(x3 + r3*cos(linspace(0,2*pi)),y3 + r3*sin(linspace(0,2*pi)),'-');

- hold on
- grid on;
- geobasemap 'street'

- title('Point of Intersection')
```

Point of Intersection as shown in figure 6.

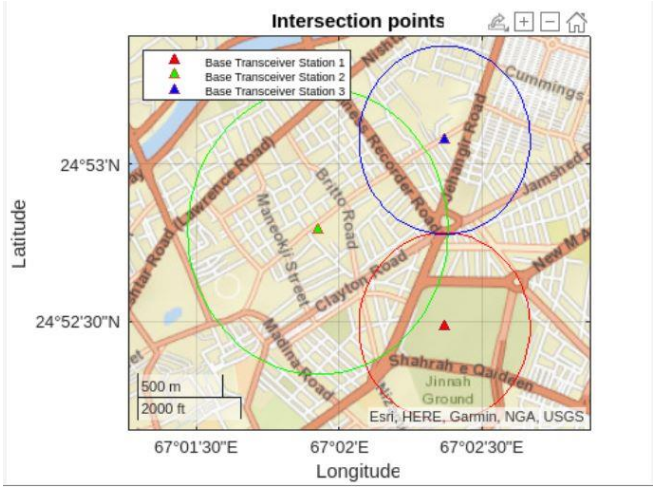


Fig. 6. Point of Intersection

The circle 1, 2 are from the same BTS Site, i.e. 3606 and circle 3 originates from BTS Site 3623. These circles intersects and predict the location of MS / ME. However, circle 4 is the back-lobe of the BTS Site 3606 cell B, which is optional but does assist in formation of coverage pattern.

VI. Factors Affecting Precision and Accuracy

Clutter classification and the frequency reuse are two important factors that can cause inaccuracy and variance in distance during localization. Clutter classification refers to the different types of terrain and environments that exist in an area, such as rural, suburban, urban and dense urban etc. These different types of clutters can affect the accuracy of localization because they can impact the signal strength and quality of the radio waves that are transmitted between the MS / ME and the BTS. For example, tall buildings in urban areas can cause signal reflection and interference, which can affect the accuracy of localization.

Second important factor that can cause inaccuracy and variance in distance during localization is cell splitting. In general, there are two broad categories of cell splitting: permanent cell splitting and dynamic cell splitting. Permanent cell splitting involves planning everything before implementing the split, including assigned frequencies, transmitter power, and traffic load. Dynamic cell splitting, on the other hand, is performed based on the utilization of dedicated spectrum and the traffic load. Radio Frequency (RF) network statistics are monitored, and precise measurements are taken to ensure accurate cell splitting.

VII. Conclusion

The proposed solution for localization is a simple and cost-free approach compared to commercially available solutions. It focuses on using the MR, MEAS_REP, based on Transmitted and Received Power Levels (Tx Level, Rx Level) of both the Serving Cell and the Neighboring Cells. The solution was tested in two different locations in Karachi City, and it was found to provide accurate results with a distance error of approximately 10 meters in center of the city and 50 meters in suburban areas of Karachi. This solution has the potential to increase the MNO capacity and presents a new architectural approach to the concept of localization.

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