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SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT

Investigation of Mobile Station Position Location Technique for Cellular System

By
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APPROVAL BY BOARD OF EXAMINERS

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Abstract

Wireless position location (PL) is a relatively recent technology in the field of wireless communication. The US federal communication commission FCC recommendation is the driving force for PL research since it requires that the wireless service provider include PL service for emergency calls. It is believed the majority of emergency calls come from mobile subscribers. In order to locate these subscribers by public safety answering point (PSAP) a lot of research is going on.

Wireless PL is also an attractive business for service provider in the field of advertising, navigation, effective workforce management, information broadcast and other value added services for users. In this thesis an investigation of different PL technique is made. The advantages and disadvantages of the PL techniques are surveyed. Based on the investigation an optimum PL technique proposed.

On investigation it is found that most PL techniques need three or more base stations (BS). There should be synchronization among them; which increases the signaling load of the network. Moreover these techniques assume a line of sight signal which is not valid specifically for urban environment. In order to solve this problem, this work focuses on PL technique using single BS using smart antenna.

In an urban environment where line of sight assumption is not valid Fingerprint Matching Technique is an optimum solution. Implementation of this technique across a test route near Tikur Anbessa Hospital shows 67% of location error is less than 72m.

For suburban and rural environment with the assumption that at least one line of sight signal is available, a hybrid TOA/AOA technique using smart antenna is found to be an optimum solution for this environment. The simulation result shows that location error below 66m for 67% cab be attained.

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GLOSSARY ACRONYMS

A-GPS	Assisted Global Positioning
ARFCN	Absolute Radio frequency channel number
AOA	Angle of Arrival
AWGN	Adaptive white Gaussian noise
BS	Base station
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CEP	Circula Error Probability
DCM	Database Correlation Method
DOA	Direction of Arrival
d	Inter- element antenna spacing
E-911	Emergency 911
EOTD	Enhanced Observed Time Difference
ETC	Ethiopian Ttelecommunication Corporation
FCC	Federal Communication Commission
GPS	Global Positioning System
3GPP	3rd generation project partnership
GSM	Global System for Mobile Communication
IPDL	Ideal Period Downlink
IPDL-PE	Ideal Period Downlink positioning element
L	Number of antenna element
LMU	Location Measurement Unit
LOS	Line of sight
LS	Least square
MS	Mobile Station
MSC	Mobile switching center
MUSIC	Multiple Signal Classification
NLOS	None line of sight
OTDA	Observed Time Difference of arrival
PL	Position location
PSAP	Public safety answering point
RMS	Rout Mean Square
RSS	Received signal strength
RTD	Real time difference
RTT	Round trip time
SNR	Signal to noise ratio
TA	Time Advance
TOA	Time of arrival
TDOA	Time Difference of arrival
UMTS	Universal mobile telephone system
U-TOA	Uplink time of arrival

P_t	Transmitted power
P_r	Received power
R_{xx}	Covariance matrix
R_{ss}	Source correlation matrix
n	Path loss exponent
λ	Wave length
τ	Time delay
w	Correlation Window Length

Chapter 1
Outline of the Thesis

1.1 Introduction

Information transfer originating from one terminal to one or more other terminals is the main task of wireless communication. Another use has been added to wireless systems by using characteristics of the transmitted signal itself. It involves estimating how far one terminal is from another, or where that terminal is located. The use of position location is varied and their applications are constantly growing. They are included in areas of personal safety, industrial monitoring and control, and commercial applications [1].

Historically the driving force for position location technique was the recommendation of the US Federal Communication Commission (FCC) that all wireless service providers should include position location service for emergency calls. This is because a majority of emergency 911 (E911) calls are from mobile subscribers, which is a direct result of the growing number of cellular subscriber. The European equivalent call number is E112. Location information for emergency calls permits a coordinated response in emergency situation where callers are disabled, unable to speak or do not know their location. In USA, the FCC mandated an E911 location accuracy of 50m for 67% of the time out of some trials and 100m for 95% of time for mobile based location method. If the implementation of the technique is based on the network the accuracy should be 100m for 67% of the time and 300m for 95% of the time [2] (see Table 1.1).

Percentage	***Mobile Based (meter)***	***Network Based (meter)***
67%	***50 m***	***100 m***
95%	***150 m***	***300 m***

Table 1-1 FCC Recommendation for accuracy in emergency service

Besides emergency service wireless location has an enormous application. It adds additional location based service for wireless service providers. The service providers can charge the subscribers based on the distance like wire line services. Tracking of person or asset and proper management of work force is also additional service. Advertising based on location for specific geography and real time information broadcast such as traffic information and weather forecast service can also be given to customers.

1.2 Objective of the Thesis

1.2.1 General objective

The general objective of this thesis is to investigate different position location techniques for cellular systems and based on the investigation to propose an optimum position location technique for the problem at hand.

1.2.2 Specific Objective

- To propose optimum position location technique.
- To develop simulation model.
- Conduct simulation for different environment.
- Analyzing simulation result.
- Evaluate performance and drive conclusions.

1.3 Motivation

Beside the FCC requirement for safety purposes, the wireless service provider can give additional location based services, which motivates so many researchers to focus on wireless position location (PL). Moreover PL techniques implemented by some wireless service providers do not have or perform well in all areas of interest with acceptable degree of accuracy. Due to this reason to study and find optimum PL technique has become an active research area.

1.4 Methodology

The necessary backgrounds about position location techniques in general, specifically for cellular system are covered through literature review from IEEE journals and books. For the implementation of the technique a network planning tool TEMS Investigation 8.2.1 Data Collection software used to collect fingerprint data across the test route. For simulation of the techniques MATLAB simulation software was used.

1.5 Structure of the Thesis

The thesis contains six chapters and their content is briefly outlined below:

Chapter 2 Accuracy Measurement of Position Location and its Applications.

The necessary performance measures of position location technique such as central error probability, cumulative distribution function and root mean square are described. The potential application of position location in the field of navigation, entertainment, safety and information transfer are introduced.

Chapter 3 Mobile Station Positioning Technique and Data Fusion Method

Different position location technique based on time of arrival (TOA), angle of arrival (AOA) and received signal strength (RSS) and their data fusion techniques are described in details. Position location technique standardized for GSM and UMTS are also presented.

Chapter 4 Fingerprint Matching PL under NLOS Condition.

Implementation of fingerprint matching under non line of sight, which is the case in urban area, is presented. The simulation result of the technique is also discussed.

Chapter 5 Hybrid TOA/AOA PL under LOS conditions.

In the assumption of at list one line of sight signal is available in sub urban and rural area, a hybrid technique that combines time and angle of arrival technique implementation is presented. Simulation results of the technique are discussed.

Chapter 6 Conclusion and Future Works concludes the thesis work and proposes the possible enhancements technique of position location accuracy and field of research areas which is not covered in this thesis.

Chapter 2
Accuracy Measurement of Position Location and its Applications

2.1 Introduction

In this chapter accuracy measurement of position location (PL) techniques and its application are presented. There are different accuracy measurement techniques, the most basic ones which are useful in performance measurement are Circular Error Probability, Cumulative Distribution Function, and Root Mean Square Error. Most of the time performance of PL is also compared with recommendation of E911 service.

To see the potential of location based services (LBSs) some applications are discussed in this chapter. The basic location based services are public safety, vehicle and personal navigation, logistics, entertainment, information broadcasting, and resource management in cellular system. Different accuracy measurements and finally application of position location are discussed in this chapter.

2.2 Measures of PL Accuracy

To measure the performance of PL technique and tell how good it is there are different measurement methods. Some of them are: circular error probability (CEP), cumulative distribution function (CDF) and root mean square error (RMS). The FCC recommendations are also used to measure PLs technique since it is the driving force for wireless location research. In this section a brief introduction of these measures are presented below.

2.2.1 Positioning Error

The difference between the true position and the estimated position is called positioning error. For analysis, the location error e is expressed as the

Euclidian distance (distance between two point), i.e. between the true and estimated position. In two dimensions the error is expressed as

$$e=\sqrt{(x_t-x_e)^2 + (y_t-y_e)^2} \qquad (2\text{-}1)$$

where (x_t, y_t) are the true position coordinates and (x_e, y_e) are estimated position coordinates. For any PL technique the performance is evaluated in terms of location error *e.*

2.2.2 Circular Error Probability

A circle centered at the true position with radius of maximum location error is also used to measure PL. This performance metrics is called circular error probability (see figure 2.1). The error is expressed in terms of radius (location errors in terms of distance) how far from the center (from the true position). The length of the radius is equal to the maximum value of location error. *R50* is the median of the PL error distribution. Usually with relation to FCC recommendation *R67* and *R95* are used for PL performance measures [5].

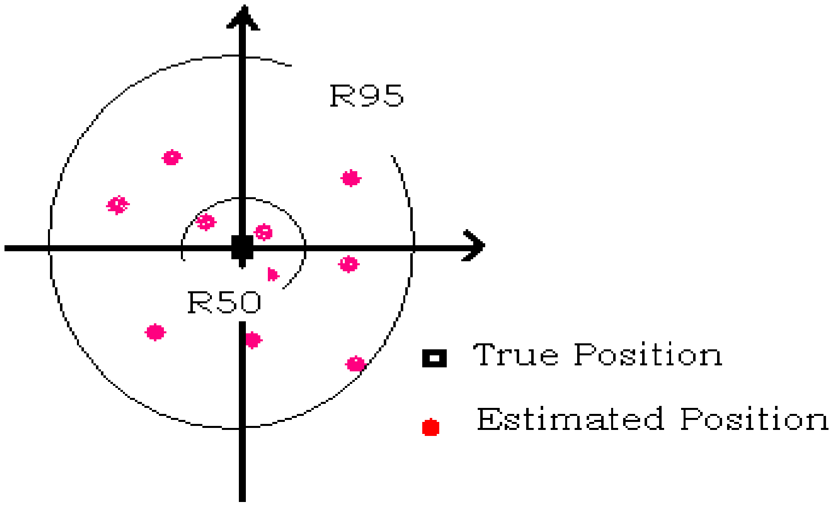
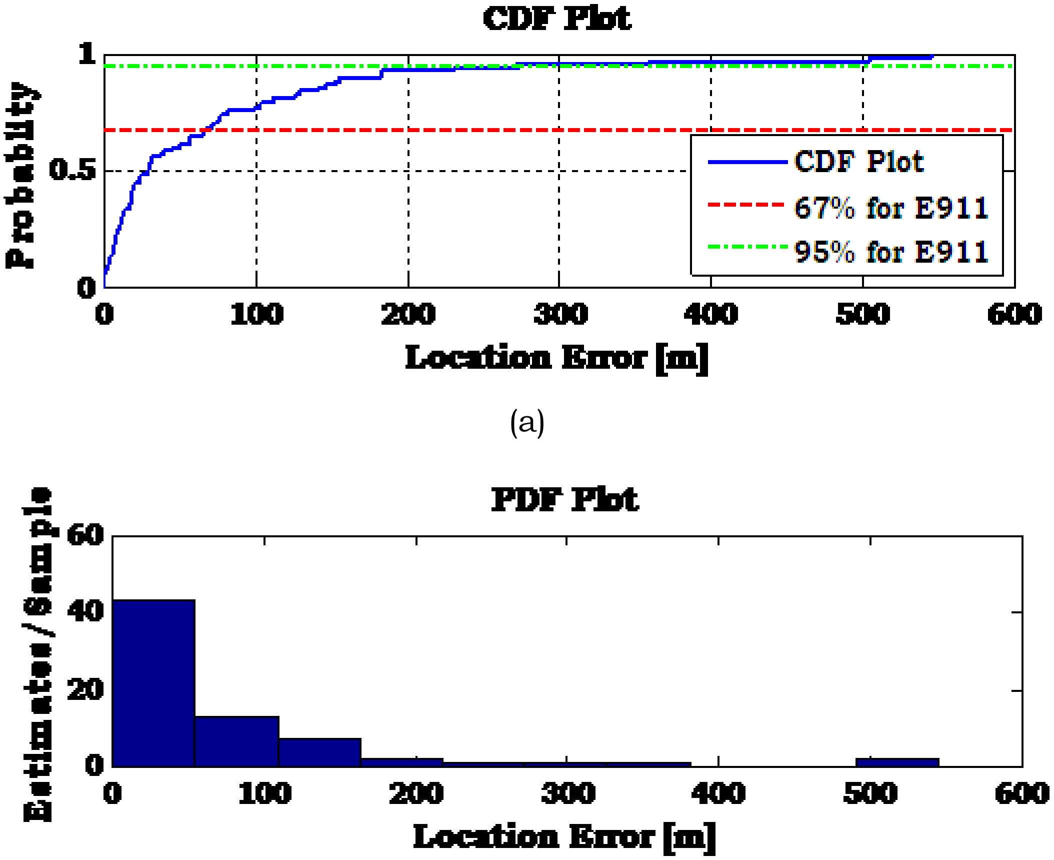


Figure 2.1 Circular Error Probabilities (CEP)

2.2.3 Cumulative Distribution Function

The most frequently used position location measure is cumulative distribution function (CDF). Any distribution of the error can be read from the graph easily.

For example in figure *2.2 67%* of position location error is below 65m and 95% below 275m which satisfies the FCC recommendation. For more information histogram plot is used in addition to cumulative distribution function plot for the statistics of the error distribution. In figure *2.2* histogram plot shows more than 60 samples of PL error are less than 100 meters.



(a)

(b)

Figure 2.2 CDF and Histogram Plot of Error Distribution

2.2.4 Root Mean Square Error

Root mean square error express PL error with single value calculated as follow,

$$RMS=\sqrt{1/M\sum_{i=1}^{M}(e_i)^2} \qquad (2\text{-}2)$$

Where e_i: Position location error

M: Number of sample

As compared to other methods RMS is a general measure; it does not give as much information as cumulative distribution function.

2.2.5 FCC Recommendation for E911

The FCC recommendations for network based implementation are 67% of MS must be located with 100 meter location error and 95% with 300 meters. For handset based location system 67% location error should be below 50m and 95% of location error below 150m. The PL technique is compared with the E911 recommendation whether it satisfies for emergency service or not. Most of the time CDF is used to measure PL error, since it is the most illustrative measures. Additionally R67 and R95 are used in relation to FCC E911 recommendation.

2.3 Application of Position Location

Wireless position location has an enormous application in the field of navigation, entertainment, information, broadcasting, and intelligent fleet management. Some of the potential applications are discussed below briefly.

2.3.1 Location Sensitive Billing

In wired communication the subscribers are charged based on their distance. Knowing the position of mobile subscriber enables wireless service provider to give variable call rate based on call location. This will enable wireless service providers to offer competitive rate package to those of wire-line phone companies [2], [3].

2.3.2 Person/Asset Tracking

Advanced public safety application such as locating and retrieving lost children and Alzheimer patients can be provided using wireless technology. Valuable assets such as vehicles that might be lost or stolen can be tracked.

Furthermore, wireless location system could be used to monitor and locate criminals.

2.3.3 Fleet Management

In order to minimize response time of fleet operators, such as transport companies, emergency vehicles and other service, the wireless location technology can be used to track and operate their vehicles in an efficient way. This technology is also used to control the driving pattern of the driver to avoid accident [2].

2.3.4 Mobile Yellow Pages

Roadside service such as the nearest gas station, hospitals and other services that the user might need can be available for mobile users. The mobile station can be used as mobile yellow page on demand. Cellular users could obtain real time information according to their location [2], [4].

2.3.5 Mobile Advertising

Advertising based on location benefits most service providers. It enables companies to track customers. By flashing customized coupons on customer's mobile station they can advertise their product [2].

2.3.6 Safety

A high percentage of emergency call originates from mobile phone. These wireless E911 calls do not receive the same quality of emergency service assistance as fixed network E911 caller. Position location of MS can solve this problem [3].

2.3.7 Cellular System Design and Management

Based on call location statistics a cellular network planner can improve cell planning of a wireless network. Improved channel allocation could be based on the location of the user. This can be done by gathering information from wireless location system [3].

Chapter 3
Mobile Station Positioning Technique and Data Fusion Method

3.1 Introduction

Wireless location refers to obtaining the position of a mobile subscriber in cellular environment. Such position information is usually given in terms of geographic coordinates of the mobile subscriber with respect to a reference point like a base station that serves the mobile subscriber. Wireless location is also commonly termed as mobile positioning, radiolocation, and geolocation [3].

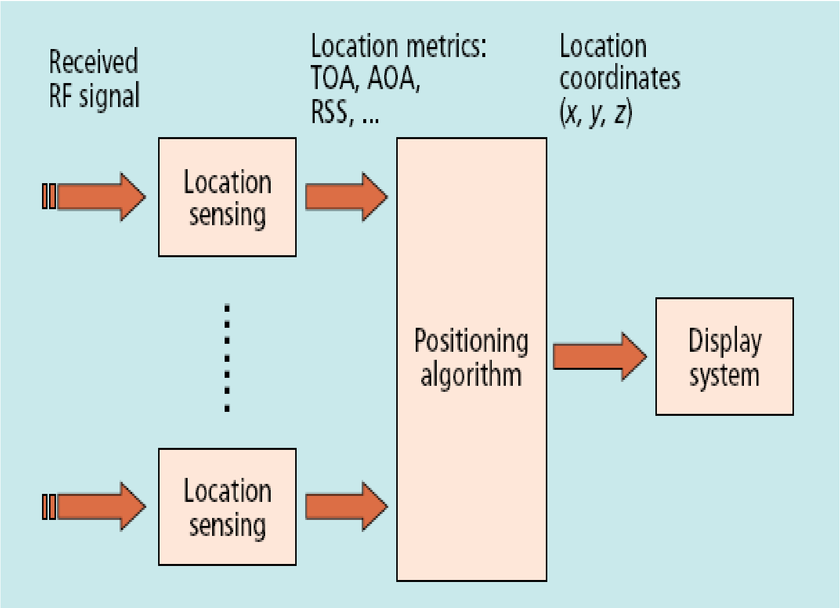


Figure 3.1 A functional block diagram of wireless location [3]

3.2 Classification of Wireless Location

Based on whether the MS or BS determines the PL of the subscriber, wireless location techniques fall into two main categories, Handset Based and Network Based techniques. In Handset based location system, the mobile station determines its own location by measuring signal parameter of an external system. The external system can be the signals of the cellular base station or satellite signals of the Global positioning system (GPS). On the other hand, Network based location system determines the position of the mobile station by measuring signal parameters those are received at the network cellular base stations [2], [3]. The necessary signal parameter for position location can be received signal strength (RSS), delay or time of arrival (TOA) and angle or direction of arrival (AOA) of the signal. A functional block diagram of wireless positioning is shown in figure 3.1.

3.2.1 Handset Based wireless location

As explained in the introductory part the necessary signal parameter for position determination is found from base station or from satellite. GPS handset based location system and cellular handset based location systems are the two technique used in this category.

3.2.1.1 GPS Handset Based Location Systems.

In GPS-based location systems, the MS receives and measures the signal parameters of at least four different satellites of a currently existing network of 24 satellites that circle the globe at an altitude of 20,000 km and which constitute the Global Positioning System. Each GPS satellite periodically transmits its location and the corresponding time stamp, which it obtains from a highly accurate clock that each satellite carries. The satellite signal parameter, which the MS measures for each satellite, is the time the satellite signal takes until it reaches the MS.

After measuring the satellite signal parameters, the MS can proceed in one of two manners. The first is to calculate its own position and then broadcast this position to the cellular network. In the other scenario, the MS broadcasts the unprocessed satellite signal parameters to another node (or server) to estimate of the MS position. The latter systems are known as server aided GPS systems, while the first are known as pure GPS systems [2], [3].

GPS based mobile location systems have the following advantages,

- GPS receivers usually have a relatively high degree of accuracy, which can reach less than 10 meters.
- Moreover, the GPS satellite signals are available all over the globe, thus providing global location information everywhere.
- Finally, GPS technology has been studied and enhanced for a relatively long time and for various applications, and is a rather mature technology.

Due to the following disadvantages wireless service provider may be unwilling to embrace GPS fully as the principal location technique.

- Embedding a GPS receiver in the mobile handset directly leads to increased cost, size, and battery consumption of the mobile handset.
- The need to replace hundreds of millions of handsets that are already in the market with new GPS aided handsets. This will directly impact the rates the wireless carriers offer their users and can cause considerable inconvenience to both users and carriers during the replacement period.
- The degraded accuracy of GPS measurements in urban environments, when one or more satellites are obscured by buildings, or when the mobile antenna is located inside a vehicle.
- The need for handsets to support both server-aided and pure GPS modes of operation, which increases the average cost, complexity and power consumption of the mobile handset. Furthermore, the power consumption of the handset can increase dramatically when used in the pure GPS mode. Moreover, the need to deploy GPS aiding servers in wireless base stations adds up to the total cost of GPS aided location systems.

- GPS-based location systems face a political issue raised by the fact that the GPS satellite network is controlled by the U.S government, which reserves the right to shut GPS signals off to any given region worldwide. This might make some wireless service providers outside the United States unwilling to rely solely on this technology.

3.2.1.2 Cellular Handset Based Location Systems.

Similar to GPS based location technique, cellular mobile based wireless location uses external signal to determine its own position. In this case, the MS relies on wireless signal originated from cellular base stations. These signals could be actual traffic cellular signals or special purpose signals, which are specifically broadcast for location purposes. Although this approach, which is also known as forward link wireless location, avoids the need for GPS technology, it has the same disadvantages that GPS location systems have, which is the need to modify existing handsets, and may even have increased handset power consumption over that of the GPS solution. In addition, this solution leads to lower location accuracy than that of the GPS solution. This makes cellular mobile-based location systems less favorable to use by wireless service providers [3].

3.2.2 Networks Based Wireless Location

In network-based location system, the base stations measure the signal transmitted from MS and relay them to a central site for processing and calculation of the MS location. The central processing site then relays the MS location information to the associated service, the service can be public safety answering point (PSAP), weather forecast and other location based services. Such a technique is also known as reverse link wireless location. Revere link wireless location has the main advantage of not requiring any modifications or specialized equipment in the MS handset, thus accommodating a large cluster of handsets already in use in existing cellular networks. The main disadvantage of network-based wireless location is its relatively lower accuracy, when compared to GPS-based location methods.

Network based wireless location systems do not require any modification to existing handset since the MS is not involved in location finding process. This is the significant advantage of network based location techniques. Moreover, they do not require the use of GPS components, thus avoiding any political issue that may arise due to their use. However, unlike GPS location systems, many aspects of network-based location are not fully studied yet. This is due to the relatively recent introduction of this technology [3], [2]. Both handset-based system and network based system have their advantages and disadvantages in particular applications. Following are the most important advantages in each category [1].

Handset based

- When the position information is used by MS itself, handset based location is most secure. Location information and tracking of the MS are not available in the network.
- The system does not use facility and resources of the network, so network capacity is not affected.
- The handset is not limited by the network on the number of measurements it can take, so location accuracy can be improved as required by taking various measurements.

Network based

- All legacy handsets can receive location service without subscribers having to upgrade their device.
- The network has more computing power than the handset so it can take advantage of positioning method that would be impractical at a handset.

- A network based system frees the power consumption of the handset that would be used to carry out positioning tasks.
- The system can initiate the MS positioning without intervention or action by the MS.

3.3 Data Fusion Method

Processing the measured signal parameter to obtain a position estimate is known as data fusion. The position location technique has to do two things to estimate the location of a MS. The BSs have to measure some signal parameter such as time or angle of arrival of the received MS signals. Then the measured signal parameters are combined in a data fusion to provide the final estimate of a MS location.

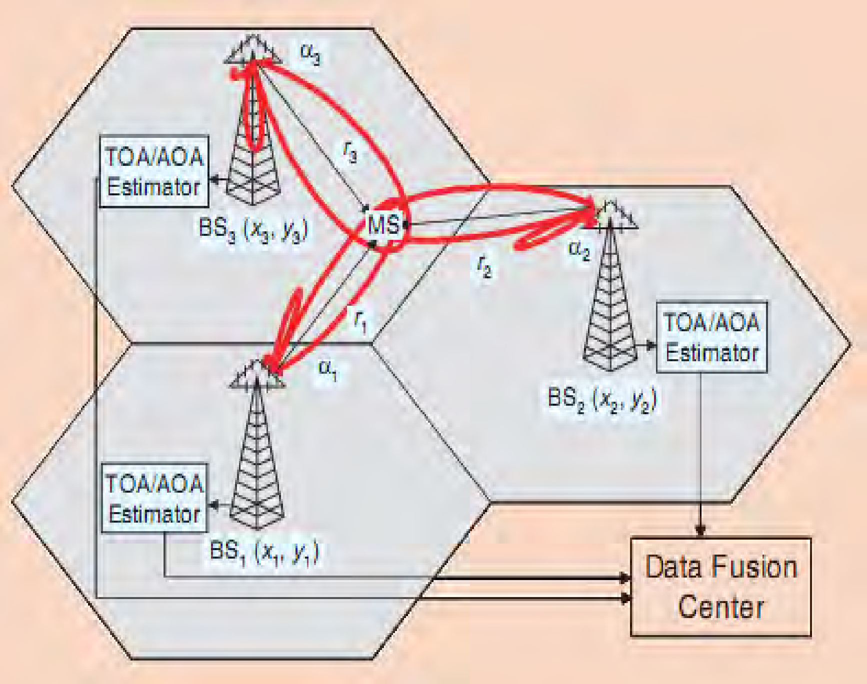


Figure 3.2 Network based wireless location finding [3]

Assume the MS is surrounded by three BSs. Measurements from different BSs are combined together in the data fusion to obtain an estimate of MS. Let location (x_m, y_m) denote location of MS and (x_1, y_1), (x_2, y_2) and (x_3, y_3) denote the location of BS_1, BS_2, and BS_3 respectively in two dimensional (see figure 3.3). For simplicity assume the BSs and the MS are located on a relatively flat plane. The x and y coordinates are considered in the derivations and the z coordinate is ignored. Several data fusion techniques exist and the most common signal parameters used for PL are the time of arrival (TOA), angle of arrival (AOA), and received signal strength (RSS) of the MS signal [3].

3.3.1 Time of Arrival Data Fusion

This positioning method is based on the measurement of the absolute time of arrival (TOA) of a known data sequence (burst) transmitted by the MS. The TOA estimate from three or more BSs can be used to obtain a location estimate as follows. First, knowing that wireless signals travel at the speed of light, each TOA estimate can directly be converted to an estimate of distance between the MS and the corresponding BS forming a circular locus on which the MS may lie and the BS at its center. The intersection of three of these loci forms a MS location estimate.

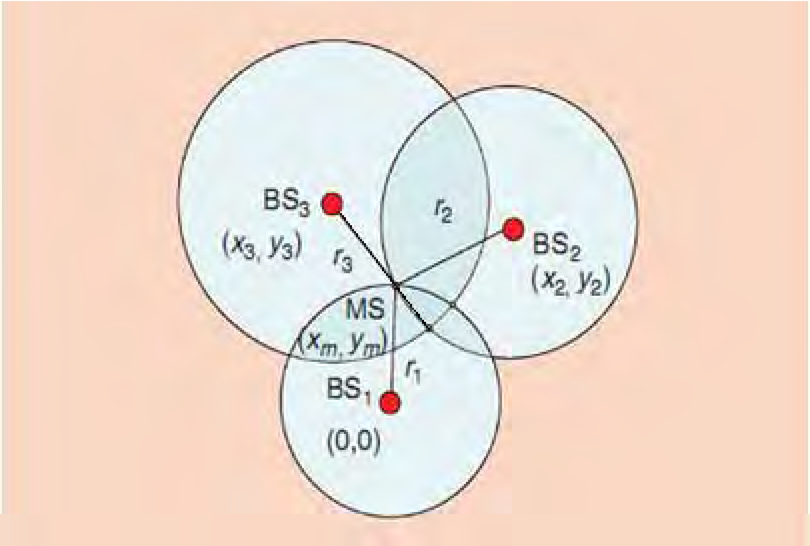


Figure 3.3 TOA data fusion using three BSs [3]

The distance between the MS and BS is given by

$$r_i=(t_i-t^0)c \qquad (3\text{-}1)$$

Where t^0 is the time instant at which the MS begins transmission and t_i is the TOA of the MS signal at BS_i. Let r_1, r_2 *and* r_3 denote the distance between the MS position denoted as (x_m, y_m) to base stations coordinates BS_1 at (x_1, y_1), BS_2 at (x_2, y_2) and BS_3 at (x_3, y_3), respectively [3].

$$r_1^2=(x_1-x_m)^2+(y_1-y_m)^2$$

$$=x_1^2-2x_1x_m+x_m^2+y_m^2-2y_1y_m+y_m^2$$

$$r_1^2=x_1^2+y_1^2+x_m^2+y_m^2-2x_1x_m-2y_1y_m \qquad (3\text{-}2)$$

$$r_2^2=(x_2-x_m)^2+(y_2-y_m)^2$$

$$=x_2^2-2x_2x_m+x_m^2+y_m^2-2y_2y_m+y_m^2$$

$$r_2^2=x_2^2+y_2^2+x_m^2+y_m^2-2x_2x_m-2y_2y_m \qquad (3\text{-}3)$$

$$r_3^2=(x_3-x_m)^2+(y_3-y_m)^2$$

$$=x_3^2-2x_3x_m+x_m^2+y_m^2-2y_3y_m+y_m^2$$

$$r_3^2=x_3^2+y_3^2+x_m^2+y_m^2-2x_3x_m-2y_3y_m \qquad (3\text{-}4)$$

Subtracting (3-2) from (3-3)

$$r_2^2- r_1^2= (x_2^2+y_2^2+x_m^2+y_m^2-2x_2x_m-2y_2y_m)-(x_1^2+y_1^2+x_m^2+y_m^2-2x_1x_m-2y_1y_m)$$

$$=(x_2^2 - x_1^2) +(y_2^2 - y_1^2) -2x_m(x_2-x_1) -2y_m(y_2-y_1)$$

Without loss of generality, the origin of Cartesian coordinates system is set at BS_1 $(x_1,y_1)=(0,0)$ resulting in:

$$r_2^2- r_1^2=x_2^2+y_2^2-2(x_mx_2 +y_my_2) \qquad (3\text{-}5)$$

Subtracting (3-2) from (3-4)

$$r_3^2- r_1^2= (x_3^2+y_3^2+x_m^2+y_m^2-2x_3x_m-2y_3y_m)-(x_1^2+y_1^2+x_m^2+y_m^2-2x_1x_m-2y_1y_m)$$

$$=(x_3^2 - x_1^2) +(y_3^2 - y_1^2) -2x_m(x_3-x_1) -2y_m(y_3-y_1)$$

But $(x_1,y_1)=(0,0)$

$$r_3^2- r_1^2=x_3^2+y_2^2-2(x_mx_3 +y_my_3) \qquad (3\text{-}6)$$

Rearranging equation 3-5 and 3-6 together in matrix form

$$\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix}\begin{bmatrix} x_m \\ y_m \end{bmatrix}=1/2\begin{bmatrix} (x_2^2+y_2^2)-r_2^2+r_1^2 \\ (x_3^2+y_3^2)-r_3^2+r_1^2 \end{bmatrix} \qquad (3\text{-}7)$$

Equation 3-7 can be written as

$$Hx=b \tag{3-8}$$

where

$$H=\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix} \quad x=\begin{bmatrix} x_m \\ y_m \end{bmatrix} \quad b=1/2\begin{bmatrix} (x_2^2+y_2^2)-r_2^2+r_1^2 \\ (x_3^2+y_3^2)-r_3^2+r_1^2 \end{bmatrix}$$

If more than three base station measurements are available,

$$H=\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \\ . & . \\ x_n & y_n \end{bmatrix} \quad b=1/2\begin{bmatrix} (x_2^2+y_2^2)-r_2^2+r_1^2 \\ (x_3^2+y_3^2)-r_3^2+r_1^2 \\ (x_4^2+y_4^2)-r_4^2+r_1^2 \\ . \qquad . \\ (x_n^2+y_n^2)-r_n^2+r_1^2 \end{bmatrix}$$

The least square estimate for (x_m,y_m) is given by [3].

$$x=(H^TH)^{-1}H^Tb \tag{3-9}$$

Let $(x_1^0,y_1^0),(x_2^0,y_2^0)$ and (x_3^0,y_3^0) be point of intersection of three BSs. An initial guess (x_m^0,y_m^0) for MS location can be obtained by averaging coordinates of point of intersection$(x_1^0,y_1^0),(x_2^0,y_2^0)$ and (x_3^0,y_3^0).i.e

$$x_m^0=\frac{x_1^0+x_2^0+x_3^0}{3} \qquad y_m^0=\frac{y_1^0+y_2^0+y_3^0}{3}$$

Note that TOA data fusion method needs accurate synchronization between the BSs and MS clocks.

3.3.2 Time Difference of Arrival (TDOA) Data Fusion

The TDOA technique is based on measuring the difference in the time of reception of signal at different BSs. This technique avoids the need for MS clock synchronization to BSs. Each TDOA measurement form a hyperbolic locus for the MS. Combining two or more TDOA measurement results in a MS location estimate that avoids MS clock synchronization error, which are cancelled when obtaining TDOA measurements. For two base stations the TDOA τ_{ij} is:

$$\tau_{ij}=\tau_i-\tau_j \qquad (3\text{-}10)$$

Where τ_i and τ_j are absolute time of arrival taken by MS signal to reach base stations BS_i and BS_j. The MS must lie on a hyperbola whose equation is

$$\begin{aligned} c\tau_{ij}&=c(\tau_i-\tau_j) \\ r_{ij}&=c(t_i-t^0)-c(t_j-t^0) \\ &=c(t_i-t_j) \\ r_{ij}&=\sqrt{(x-x_i)^2+(y-y_i)^2}-\sqrt{(x-x_j)^2+(y-y_j)^2} \qquad (3\text{-}11) \end{aligned}$$

Using a third base station a second hyperbola on which the MS must lie can be obtained using the second TDOA measurement. The interception of the two hyperbolas gives the location of the MS.

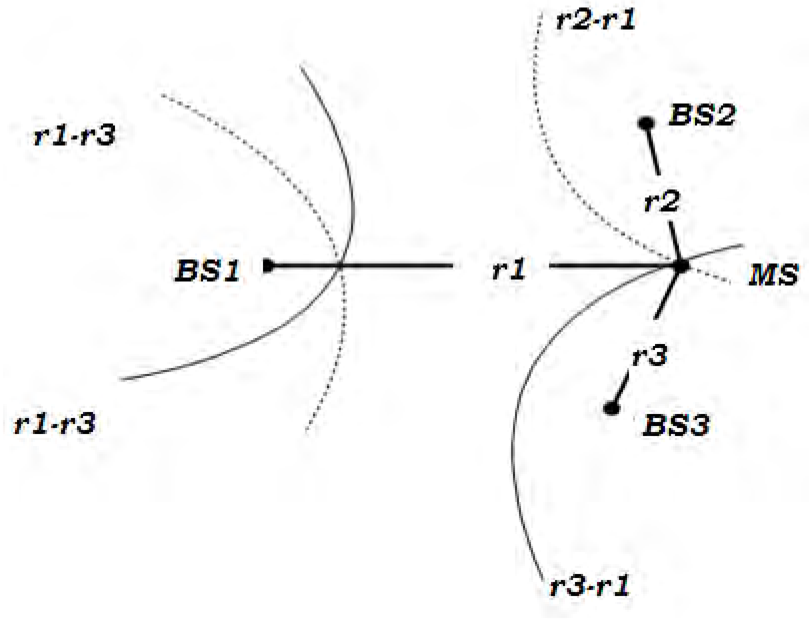


Figure 3-4 Hyperbolic position location

Equation 3-3 can be rewritten in terms of TDOA measurement r_{21} as given in [3]. Recall that

$$r_2^2=x_2^2+y_2^2+-2x_2x_m-2y_2y_m+r_1^2$$

This can be written interims of r_{21}

$$(r_{21}+r_1)^2= x_2^2+y_2^2-2x_2x_m-2y_2y_m+r_1^2 \qquad (3\text{-}12)$$

To verify the equation

$$r_{21}=\sqrt{(x_2-x_m)^2+(y_2-y_m)^2}-\sqrt{(x_1-x_m)+(y_1-y_m)^2} \qquad \text{but } (x_1,y_1)=(0,0)$$

$$r_{21}=\sqrt{(x_2-x_m)^2+(y_2-y_m)^2}-r_1$$

$$r_{21}^2 = x_2^2+y_2^2-2x_2x_m-2y_2y_m+r_1^2 -2r_1\sqrt{(x_2-x_m)^2+(y_2-y_m)^2}+r_1^2$$

Substituting these values in the following quadratic equation verifies equation 3-12.

$$r_{21}^2+2r_{21}r_1+r_1^2 =0$$

Expanding and rearranging equation 3-12 gives

$$2x_2x_m+2y_2y_m=1/2(x_2^2+y_2^2-r_{21}^2)-r_{21}r_1$$

Similarly, (3-4) leads to

$$2x_3x_m+2y_3y_m=1/2(x_3^2+y_3^2-r_{31}^2)-r_{31}r_1$$

Rewriting these equations in matrix form gives

$$\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix} \begin{bmatrix} x_m \\ y_m \end{bmatrix} =1/2 \begin{bmatrix} x_2^2+y_2^2-r_{21}^2 \\ x_3^2+y_3^2-r_{31}^2 \end{bmatrix} + r_1 \begin{bmatrix} -r_{21} \\ -r_{31} \end{bmatrix} \qquad (3\text{-}13)$$

In general form $Hx=r_1c+d$ (3-14)

where $c=\begin{bmatrix} -r_{21} \\ -r_{31} \end{bmatrix}$ $\quad d=1/2 \begin{bmatrix} x_2^2+y_2^2-r_{21}^2 \\ x_3^2+y_3^2-r_{31}^2 \end{bmatrix}$

In terms of r_1 the MS location estimated as

$$x=r_1H^{-1}c+H^{-1}d \qquad (3\text{-}15)$$

The final solution can be found by substituting equation 3-15 into equation 3-2 which gives a quadratic equation in r_1.

$$r_1^2-r_1H^{-1}c+H^{-1}d=0 \qquad (3\text{-}16)$$

Solving for r_1 and substituting the positive root back into *(3-15)* gives the final estimate.

$$r_1=1/2[H^{-1}c+((H^{-1}c)^2+4H^{-1}d)^{1/2}] \qquad (3\text{-}17)$$

For more number of base stations equation 3-14 becomes

$$H=\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \\ . & . \\ x_n & y_n \end{bmatrix} \quad c=\begin{bmatrix} -r_{21} \\ -r_{31} \\ -r_{41} \\ . \\ -r_{n1} \end{bmatrix} \quad d=1/2\begin{bmatrix} x_2^{\ 2}+y_2^{\ 2}-r^2{}_{21} \\ x_3^{\ 2}+y_3^{\ 2}-r^2{}_{31} \\ x_4^{\ 2}+y_4^{\ 2}-r^2{}_{41} \\ . \qquad\qquad . \\ x_n^{\ 2}+y_n^{\ 2}-r^2{}_{n1} \end{bmatrix}$$

The least square solution in terms of r_1 is

$$x=(H^TH)^{-1}H^T(r_1c+d) \qquad (3\text{-}18)$$

Likewise estimating the value of r_1

$$r_1^2-(H^TH)^{-1}H^Tcr_1+(H^TH)^{-1}H^Td=0 \qquad (3\text{-}19)$$

Solving the quadratic equation and taking the positive root of r_1 and substituting in equation 3-18 gives the final estimate

$$r_1=-1/2(H^TH)^{-1}H^Tc+((H^TH)^{-1}H^Tc)^2-4(H^TH)^{-1}H^Td))^{1/2} \qquad (3\text{-}20)$$

3.3.3 Angle of Arrival Data Fusion

Angle of arrival technique uses measurement of direction of arrival of a known sequence sent by MS to different BSs. The system requires deployment of antenna array at the base station and direction of arrival (DOA) estimation algorithm like MUSIC algorithm. By combining the AOA estimates of two BSs estimate the MS position can be obtained. The number of BSs needed for the location process is less than that of the TOA and TDOA methods. Another advantage of AOA location methods is that they do not require BS or MS clock synchronization [3].

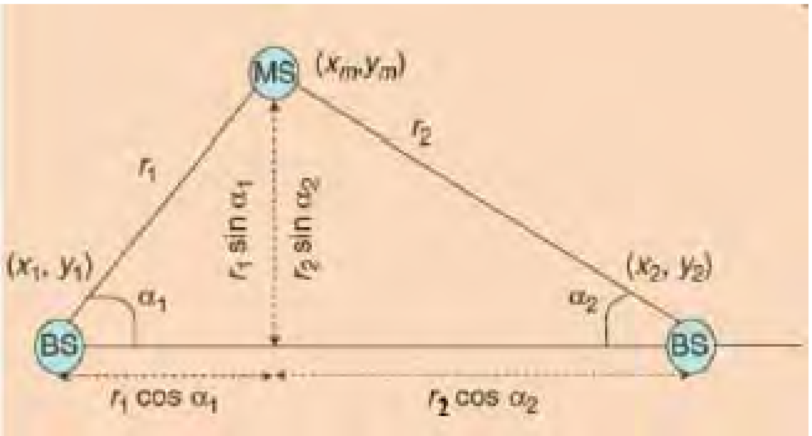


Figure 3.5 Angle of Arrival Technique [3]

Let α_1 and a_2 denote the direction of MS signal at BS_1 and *BS2* respectively. Then the location of MS from BS_1 is given as

$$\begin{bmatrix} x_m \\ y_m \end{bmatrix} = \begin{bmatrix} x_1 + r_1 \cos\alpha_1 \\ y_1 + r_1 \sin\alpha_1 \end{bmatrix}$$

And similarly the location of *MS* from BS_2

$$\begin{bmatrix} x_m \\ y_m \end{bmatrix} = \begin{bmatrix} x_2 + r_2 \cos\alpha_2 \\ y_2 + r_2 \sin\alpha_2 \end{bmatrix}$$

For any base station

$$\begin{bmatrix} x_m \\ y_m \end{bmatrix} = \begin{bmatrix} x_n + r_n \cos\alpha_n \\ y_n + r_n \sin\alpha_n \end{bmatrix}$$

Collecting these relations into a single equation yields

$$Hx=b \tag{3-21}$$

where

$$H=\begin{bmatrix}1 & 0\\ 0 & 1\\ 1 & 0\\ . & .\\ 1 & 0\\ 0 & 1\end{bmatrix} \quad x=\begin{bmatrix}x_m\\ y_m\end{bmatrix} \quad b=\begin{bmatrix}r_1\cos\alpha_1\\ r_1\sin\alpha_1\\ x_2+r_2\cos\alpha_2\\ y_2+r_2\sin\alpha_2\\ .\\ x_n+r_n\cos\alpha_n\\ y_n+r_n\sin\alpha_n\end{bmatrix}.$$

.

The least square solution is given as

$$x=(H^TH)^{-1}H^Tb \tag{3-22}$$

2.3.4 Received Signal Strength Data Fusion

On the average, signal strength at a receiver decrease as distance from the transmitter increases. If the relationship between signal strength and distance is known, analytically or empirically the distance between the BS and MS can be determined. When several base stations are involved, triangulation can be applied to determine the mobile station location [1]. Triangulation in general refers to calculation of two or three dimensional position from measurement. The received signal strength can be represented as [14]

$$RSS=10\log_{10}P_t-10\,n\log_{10}d+X_\sigma \tag{3-23}$$

where

RSS : Receiver signal strength

P_t : Transmitted power

n : Distance power gradient exponent

d : Distance from MS to BS

X_σ : Shadowing effect

$$d=10^{(RSS-(10\log 10\ Pt + X\sigma)\ /\ 10n)} \qquad (3\text{-}24)$$

The distance power gradient or path loss exponent indicates the rate at which the path loss increases. The log normal distribution (X_σ) describes the shadowing effect due to clatter in the propagation environment. The data fusion technique is the same as TOA technique. Received signal at three base stations and a path loss model provides distance or range estimate between MS and BS. Each estimated range gives a circle at the receiver *(BS)* on which the transmitter *(MS)* must lie. Intersection of three circles gives an estimate of MS.

The received signal strength varies due to shadowing and also the path loss model used may not adequately represent the area for which the technique is implemented. Hence the accuracy of this technique is not satisfactory especially if less number of base stations are involved in position determination.

3.3.5 Hybrid Data Fusion Techniques

Location accuracy can be increased by hybrid approach. Many position location techniques use three or more base stations. If the mobile subscriber is very close to the serving cell, the other base stations receive low SNR due to power control mechanism of MS. In this case a hybrid data fusion that combines AOA measure with TOA can be used [4]. From *(3-9),* the least squares estimate of (x_m, y_m) using TOA measurements is given by

$$x_{\mathrm{TOA}} = (H^T_{TOA}\ H_{TOA})^{-1}\ H^T_{TOA} b_{TOA} \qquad (3\text{-}25)$$

where

$$H_{TOA} = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y4 \\ . & . \\ x_n & y_n \end{bmatrix} \quad b_{TOA}=1/2 \begin{bmatrix} x_2^{\,2} + y_2^{\,2} - r_2^{\,2} + r_1^{\,2} \\ x_3^{\,2} + y_3^{\,2} - r_3^{\,2} + r_1^{\,2} \\ x_4^{\,2} + y_4^{\,2} - r_4^{\,2} + r_1^{\,2} \\ . \\ x_n^{\,2} + y_n^{\,2} - r_n^{\,2} + r_1^{\,2} \end{bmatrix}$$

Similarly, from *(3-15),* the least-square estimate of (x_m, y_m) using only AOA measurement is given by

$$x_{AOA} = (H^T_{AOA} H_{AOA})^{-1} H^T_{AOA} b_{AOA} \qquad (3\text{-}26)$$

where

$$H_{AOA} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ & . & \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \quad b_{AOA} = \begin{bmatrix} r_1 \cos\alpha_1 \\ r_1 \sin\alpha_1 \\ x_2 + r_2 \cos\alpha_2 \\ y_2 + r_2 \sin\alpha_2 \\ . \\ x_n + r_n \cos\alpha_n \\ y_n + r_n \sin\alpha_n \end{bmatrix}$$

A linear combination of the two estimates gives a final estimate of MS as [3]

$$x = \eta \; x_{TOA} + (1-\eta) \; x_{AOA} \qquad (3\text{-}28)$$

where η is a relative accuracy of the two hybrid techniques in the range of $0< \eta<1$. Depending on the relative accuracy of TOA and AOA measurement the positive parameter η is chosen. The accuracy of TOA and AOA estimates is usually a function of the environment. For example, in rural areas, AOA measurements can be more accurate than TOA measurements if a large-size antenna array is deployed. On the other hand, TOA measurements are more accurate than AOA measurements if the BS antenna array is surrounded by many scatterers [3].

3.4 Standard Outdoor Cellular Positioning

In wireless positioning technique many researchers have proposed different techniques. Among these techniques GSM standardization includes two methods based on cellular signal timing measurements, uplink Time of Arrival (TOA) and downlink Enhanced Observed Time Difference (EOTD). In UMTS the 3GPP (third generation partnership project an international organization which is responsible for standards of mobile communication) standard location techniques are Cell Identification (Cell ID), OTDOA and Assisted Global Positioning System (A-GPS) [8].

3.4.1 Uplink Time of Arrival (U-TOA) for GSM

The uplink TOA positing method is based on measuring a given signal sent from the mobile and received by three or more measurement units. This method requires additional measurement unit (LMU) hardware in radio access network to accurately measure the TOA of the bursts. Since the geographic coordinates of measurement unit are known, the mobile position can be calculated via triangulation. Usually, the burst that is used to locate the user is due to virtual handover request i.e. a request forced by the network to make the user terminal transmit the access burst.

3.4.2 Enhanced Observed Time Difference (EOTD)

The MS is located based on the existing observed time difference (OTD) feature of GSM system. OTD calculate the time difference of arrival of the signal from two base stations measured by MS. The hyperbolic equation of EOTD is given as

$$GTD = RTD - OTD \qquad (3\text{-}29)$$

Where GTD (Geometric time difference) is the difference of propagation time between two base stations and mobile station (see figure 3.5). RTD (Real time difference) is the difference of signal transmission of two base stations. RTD is used to synchronize the base stations.

Let the signal transmitted time from BS_1 and BS_2 be at time t_{TX1} and t_{TX2} respectively. These signals are received at MS at time t_{RX1} and t_{RX2} then

$$\begin{aligned} RTD &= t_{TX2} - t_{TX1} \\ OTD &= t_{RX2} - t_{RX1} \end{aligned} \tag{3-30}$$

Time difference of arrival is given as

$$\begin{aligned} GTD &= RTD - OTD \\ &= (t_{TX2} - t_{TX1}) - (t_{RX2} - t_{RX1}) \\ &= (t_{RX1} - t_{TX1}) - (t_{RX2} - t_{TX2}) \end{aligned} \tag{3-31}$$

Thus the hyperbolic equation of EOTD is given as

$$\begin{aligned} TDOA &= c\ GTD \\ &= c\left((t_{RX1} - t_{TX1}) - (t_{RX2} - t_{TX2}) \right) \end{aligned} \tag{3-32}$$

Where c is the speed of light. The above equation defines a hyperbola. Using more TDOA measurement, the intersection point of hyperbolas gives estimate of the MS location.

Location measurement unit (LMU) device is therefore required to compute the clock and then broadcast the synchronization information to various mobile device. In addition they require software modified handset which means that they cannot be used to provide location specific service to old version of MS [8].

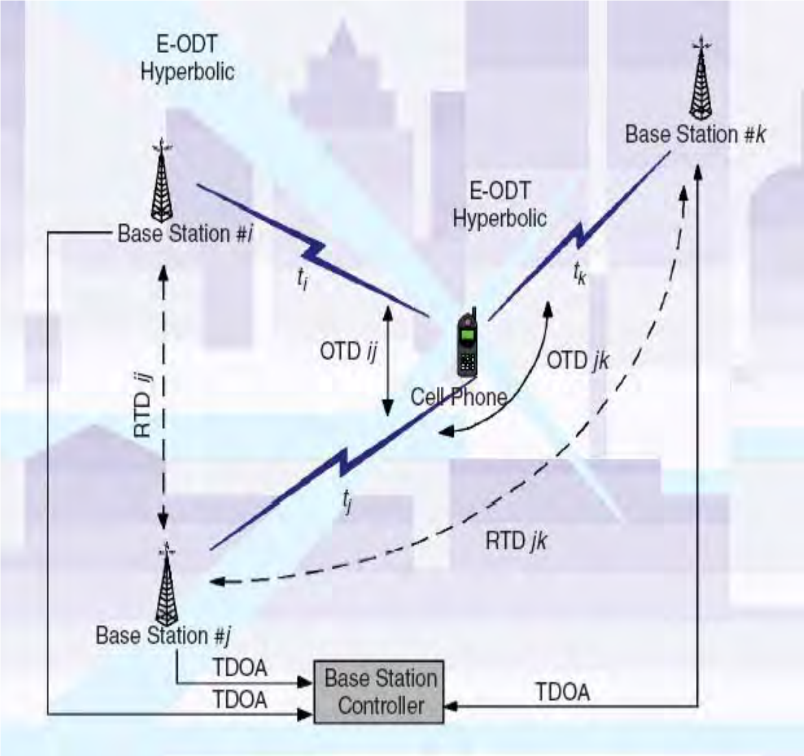


Figure 3.6 E-OTD positioning solution [8]

3.4.3 Assisted-GPS for Narrowband CDMA

The use of GPS in urban and indoor environment is not a satisfactory solution due to the invisibility of satellite signal. In order to solve this problem a cellular network provides satellite constellation information directly to GPS receiver. This information is called assistance information which is used by A-GPS. Compared to the standalone GPS solution, the benefits of A-GPS include:

- An increase in the sensitivity of the GPS receiver by providing receiver with auxiliary information to ensure that positioning functions accurately even in bad communication environment.

- A reduction in the initial time to synchronize the GPS receiver with its serving satellite from more than 30s to just a few seconds.

- An increased positioning accuracy [8].

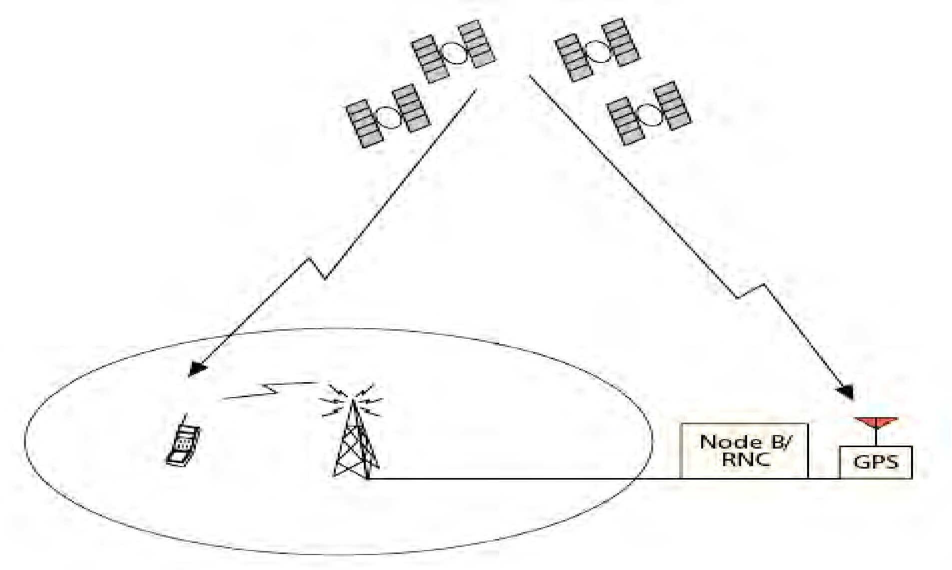


Figure 3.7 Assisted GPS

3.4.4 Observed Time Difference of Arrival (OTDOA) for WCDMA

Observed time difference of arrival is an EOTD version for wide code division multiple access (WCDMA) network. It is based on TDOA approach. OTDOA uses LMU synchronize the downlink measurements from neighboring base stations for individual mobile users. A position can be estimated if measurements from three or more base stations are available. It has the same weakness as EOTD. Location estimation cannot perform in area without at list three visible base stations.

When the user terminal is very close to serving base station, the signal from other base stations may be low. This problem is called hearablity problem. Several proposals aimed to improve the hearablity of neighboring base stations are suggested. The most significant of these are presented below.

3.4.4.1 Idle period downlink (IPDL)

Some base station stop transmitting for short period of time called idle period. During these period mobile users within the cell can measure from other base stations, thus mitigate the hearablity problem. Ideal period are announced through the radio interface so that the terminal are aware of the time period in which they should make the OTDOA measurements. The presence of ideal period directly affects the downlink throughput of the system.

3.4.4.2 Positioning element (IPDL-PE)

The MS determine its position by measuring radio signal from a number of positioning element (PEs). PEs are placed at surveyed location other than those of BSs. This improves the accuracy of the location system because the transmitter can be placed in the best place in terms of location error.

3.4.5 Cell-ID

Cell-ID is a simple positioning method based on cell sector information recommended by the third generation partnership project (3GPP). It requires the Cell ID to be associated with BS location coordinates. In mobile based positioning the BS continuously transmit the coordinates of the BS. In this technique calculation of PL is not required. The disadvantage of this technique is the accuracy depends on the size of cell radius. The accuracy is better for small cell radius Pico cells. To improve the method's accuracy, Cell-ID+TA (time advance) and Cell-ID+RTT (round trip time) hybrid position method are proposed [8].

3.4.5.1 Cell-ID+TA/RTT

Within a cell the MS can be any where, hence the distance between MS and BSs vary. Due to the mobility of the subscriber, the signal propagation time also vary accordingly. For this reason the burst received at base station would be offset. Bursts transmitted by different MS in adjacent time slots must not overlap when received at the BS by more than the guard period, even if the propagation time within the cell are very different. To avoid such collisions, the start of the transmission time from MS is advanced in proportion to the distance from BS.

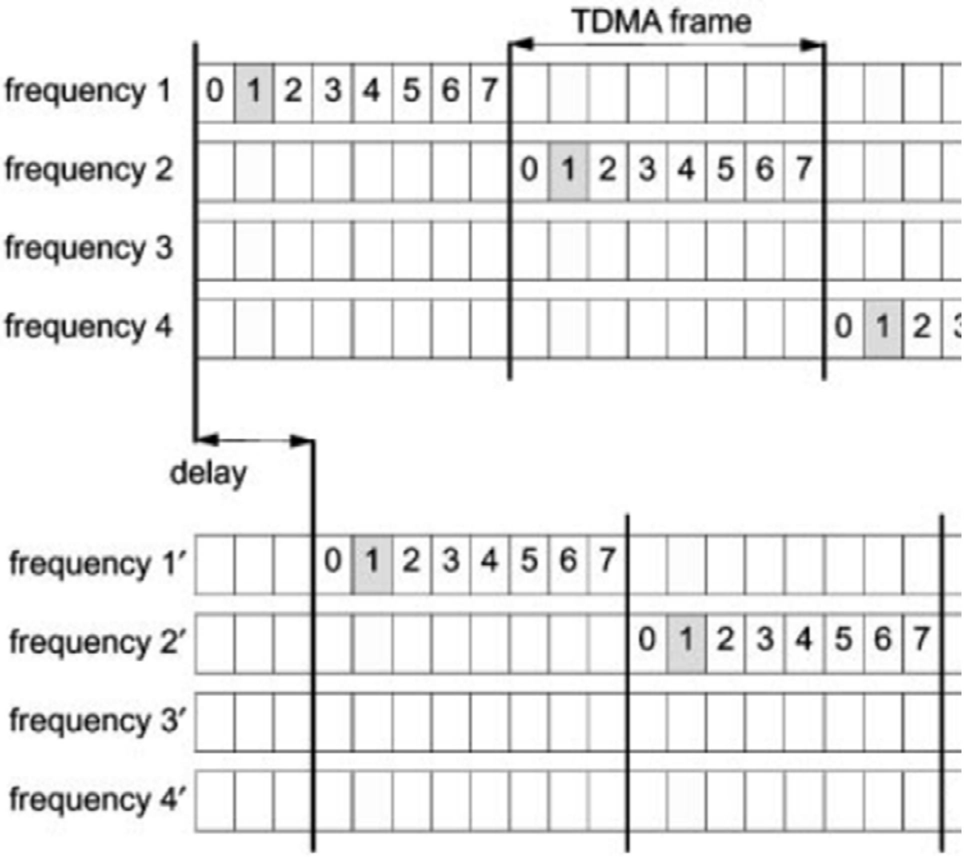


Figure 3.8 Operation of Time Advance [17]

For this purpose, the parameter Timing advance (TA) is used that represent the round trip delay between BS and MS expressed as an integral multiple of bit period. There are 64 steps for the timing advance which are coded as 0 to 63. One step corresponds to one bit period of 3.69µ second. Step 0 means no timing advance, i.e. the frame are transmitted with a time shift of three slots or 468.75 bit duration with regard to the downlink (3*156.25 bit duration) . At step 63, the timing of the uplink is shifted by 63 bit duration, such that the TDMA frame are transmitted on the uplink only with delay of 405.75 bit durations. So the required adjustment always corresponds to twice the propagation time or is equal to the round trip delay. In this way, the available range of values allows compensation over a maximum propagation time of 31.5

bit period approximately 113.3µs ((63/2)*.3.69µs). This corresponds to a maximum distance between MS and BS of 35 km (113.3µs*3e8m/s). A GSM cell may therefore have maximum diameter of 70km [17]. The distance from the BS or the current valid TA value for a MS is therefore an important handover criterion in GSM network. From network measurement report, information of TA/RTT (Round Trip Time for CDMA) can be used to enhance the performance of Cell-ID.

3.5 Prior work on Data Fusion techniques

Most researchers focused on time difference of arrival since it doesn't require synchronization between MS and BSs. Other data fusion techniques such as TOA and AOA combines with TDOA techniques. In [24] reverse link location for IS-95 that uses TDOA technique was studied. The performance was described as location successes as a function of distance from controlling cell sit for different mobile transmit power levels. The result shows, as a MS is away from the controlling BS, percentage of successes increases.

In [26] a hybrid TDOA/RTT positioning for 3G WCDMA network was studied. The performance of TDOA/RTT algorithm for multipath propagation, different scenario are considered and the following multiple delay propagation were used. ATDMA Macro, CODIT Macro, ITU A vehicular and ITU vehicular B (a 3GPP2 channel model for WCDMA). for suburban CODIT model the error is below 95m for 67% of time and below 160m for 90% of the time. For ATDMA channel the error is within 59m for 67% of time and 92m for 90% of time. For ITU vehicular A channel model in suburban environment the location error is within 55m for 67% of time and 104m for 90% of time. Finally for ITU vehicular B channel model the location error is within 53m for 67% of time and 91m for 90% of time.

In [21] and [29] practical Network-Based techniques for Mobile positioning in UMTS. This paper presents results of research on network-based positioning for UMTS (universal mobile telecommunication system). Two new applicable network-based cellular location methods are proposed and assessed by field measurements and simulations. The obtained results indicate that estimation of the position at a sufficient accuracy for most of the location-based services does not have to involve significant changes in the terminals and in the network infrastructure. In particular, regular UMTS terminals can be used in the presented PCM (pilot correlation method), while the other proposed method the Cell-ID+RTT (cell identification + round trip time) requires only minor software updates in the network and user equipment. The performed field measurements of the PCM reveal that in an urban network, 67% of users can be located with an accuracy of 70 m. In turn, simulations of the Cell-ID+RTT report accuracy of 60 m for 67% of the location estimates in an urban scenario.

A hybrid TDOA/AOA mobile user location for wideband CDMA cellular system was proposed [30]. The location technique combines the time difference of arrival (TDOA) measurement from the forward link pilot signal with angle of arrival (AOA) measurement from reverse link pilot signal. A smart antenna used at the BS. For two dimension location it consider a hexagonal cell surround by six neighboring cell with radius of 5km. the result shows 60% of location is bellow 0.15km and bellow 0.4km for 90% of time.

In [31] Signal correlation method (SCM) based on artificial neural network introduce when measurement are only available from serving BS. The final result shows that 67% of the estimated location is at 85 meters of accuracy, 95% estimated location error is at 291.5 meters of accuracy, and maximum error is at 721 meters as shown in the Figure. The 67% and 95% definitely meets FCC requirements for location accuracy. The mean estimated location error is at 31.92 meters.

Chapter 4
Fingerprint Matching PL under NLOS Condition

4.1 Introduction

In chapter three different position location techniques were discussed. What are the limitations of these techniques on the implementation in cellular system? First the main problems of these techniques are presented. Finally the possibilities to alleviate this problem will be discussed.

4.2 Problem of wireless location

Based on investigation of different position location techniques, the following are the main problems when used in cellular system. Each one of them is discussed below.

4.2.1 Hearability

In TOA, TDOA and RSS techniques three or more BSs are used in MS location. When the MS is much closer to serving BS than the other BSs, the accuracy of these methods is significantly degraded due to the relative low signal to noise ratio (SNR) of the received MS signal at one or more BSs. The accuracy is further reduced due to the use of power control, which require the MS to further reduce its transmitted power when it approach a BS, causing what is known as hearability problem. In Figure 4.1 the simulation of received signal strength (RSS) from three base stations (refer equation 3-23) with base stations coordinates of (0, 0), (1500, 2500) and (3000, 0) meters and path loss exponent of (n=2) and random shadowing effect of value (sigma=0.5) is shown. It is seen that under given condition the received signal strength of BS_2 and BS_3 are very weak at BS_1. The horizontal color bar shows the magnitude of the received signal strength in *dBm*.

4.2.2 Non Line of Sight

Most of position location technique like TOA, TDOA and AOA require line of sight propagation for accurate location estimate. With these methods, the location of MS is calculated with the assumption of line of sight propagation between BSs and the MS. This assumption is not valid in city centers where high buildings often block the line of sight signal. In figure 4.2 simulation of received signal strength (RSS) using log-distance path loss model with path loss exponent (n=4), and random shadowing effect value of (sigma=11.8) shown (see equation 3-23). It can be observed that different distance may have the same signal strength due to shadowing, so it is not an ideal environment for position location technique based on RSS.

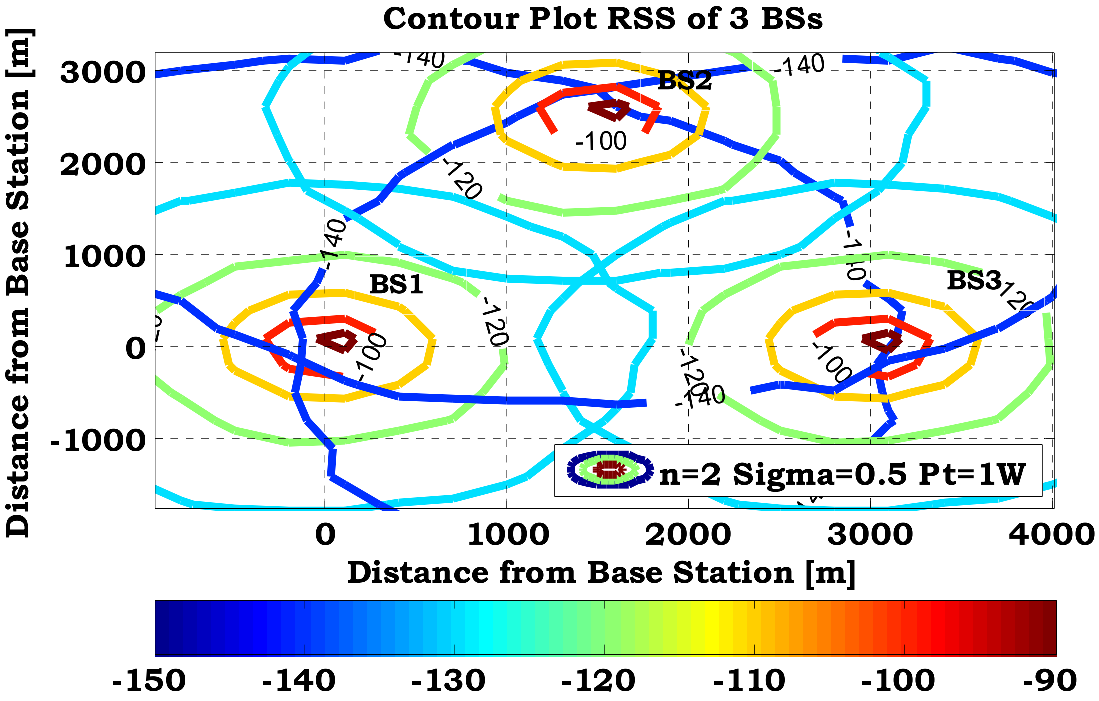


Figure 4.1 Received Signal Strength (RSS) of Three Base Stations

In Figure 4.3 simulation of received signal strength using log-distance model with path loss exponent of (n=2) and random shadowing effect value of (sigma=1.8) is shown. It has fairly better environment for position location when it is compared to simulation result of Figure 4.2. Additionally in Figure 4.4 simulations of RSS with path loss exponent of 2 and no shadowing effect is shown. This is an ideal environment for position location since it assumes line of sight environment. For estimation of MS the geometry of base station and mobile station is a perfect circle.

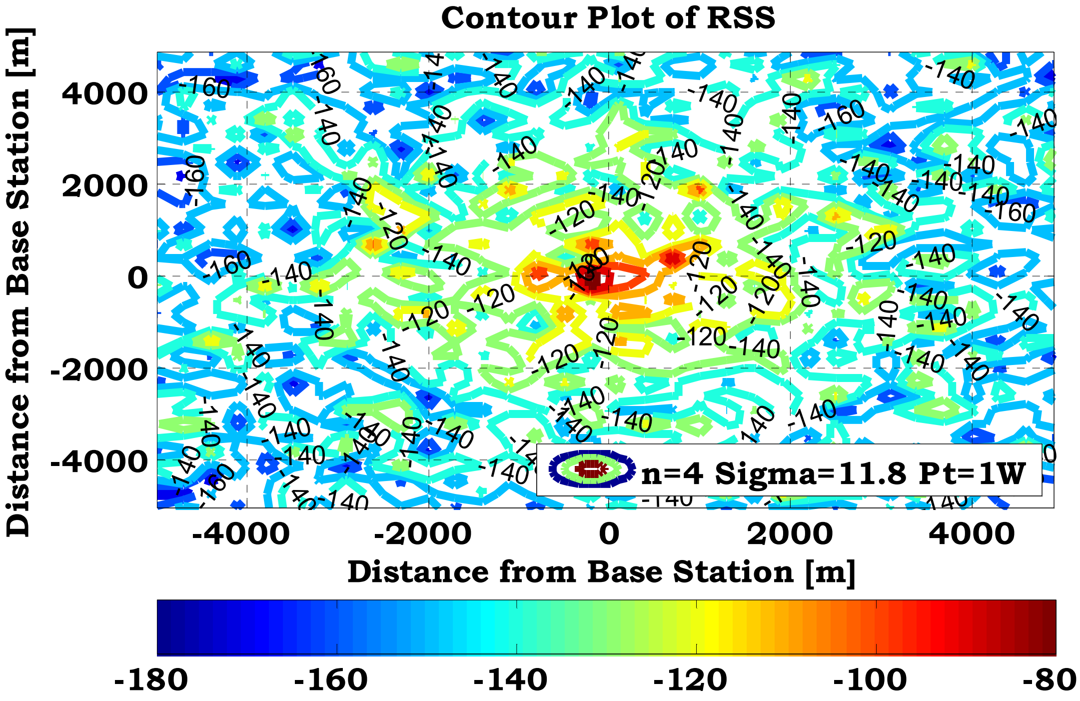


Figure 4.2 Simulation of Received Signal Strength for n=4 and sigma=11.8

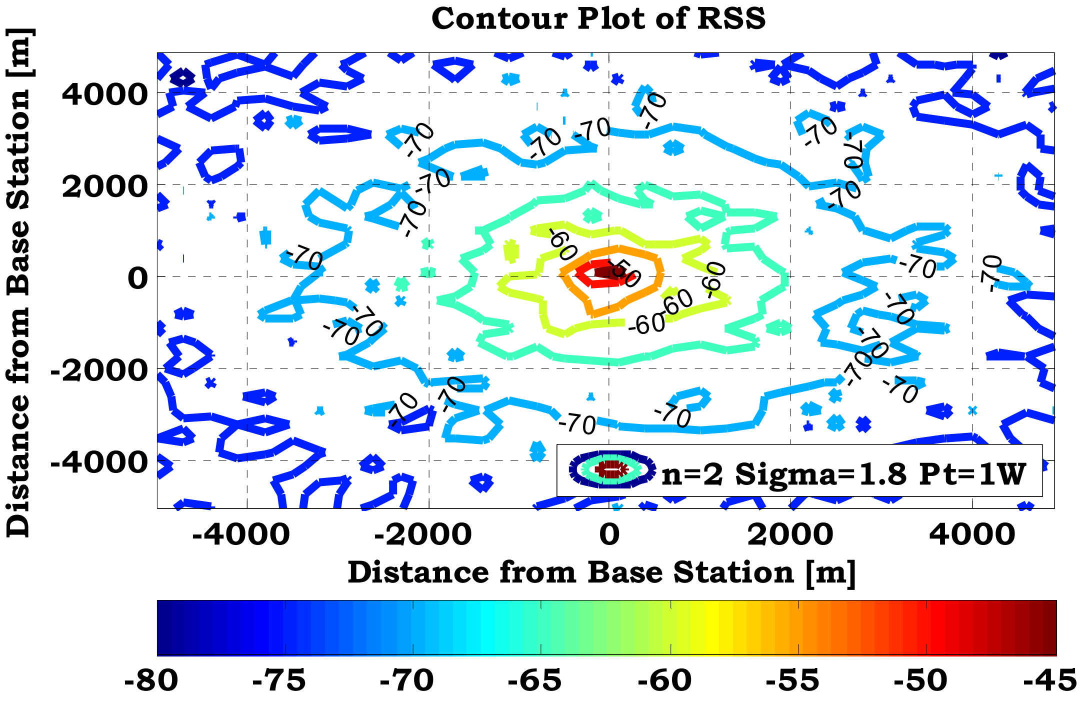


Figure 4.3 Simulation of Received Signal Strength for n=2 and sigma=1.8

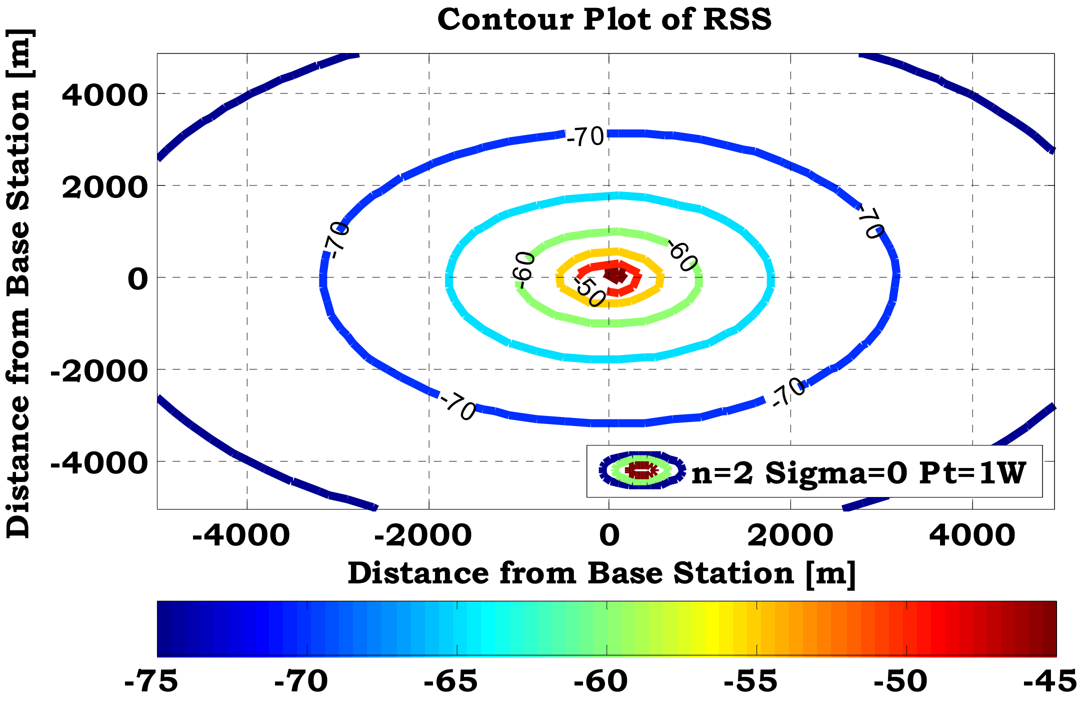


Figure 4.4 Simulation of Received Signal Strength for n=2 and sigma=0.

4.2.3 Multipath

Several multipath propagation characteristics of the environment make it difficult to detect angle of arrival or time of arrival of the direct component i.e. the resolution of these method is not as good as in more open propagation environment.

4.2.4 Multiple Co-operations

In most position location technique the coordination of three or more BSs are required. This condition increases implementation complexity and the signaling overhead of the entire network. Due to this reason the capacity of the network decreases.

4.2.5 Dependence on Geometry

Most position location techniques assume geometry where the MS is surrounded by three or more base stations. The estimation can be calculated by intersecting three circles. This type of geometry may not be available if the base stations are along straight line such as on a high way. In this situation it is impossible to find an intersection point among the three base stations, hence we cannot implement geometric location algorithm. This situation is shown in Figure 4.5.

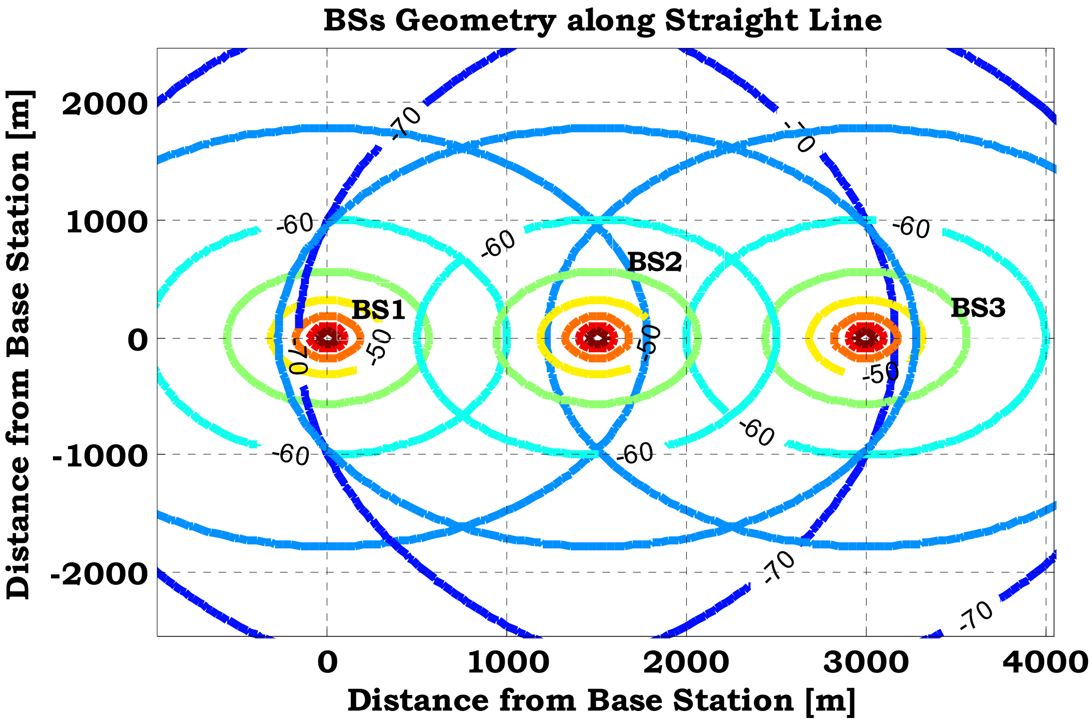


Figure 4.5 BSs Geometry along Straight Line

4.3 Single Base Station PL

Due to the above problems position location techniques using single base station solve most of the problem. The following are the advantage over the above techniques.

- It eliminates the need for cooperation among multiple distributed parties to solve the position location problem. The BS does not have to be synchronized with other BSs.
- Hearability is no longer a problem since position location is performed by a single BS.

- The inter network signaling is reduced since no coordination is needed among several BSs for position estimation.

Position location using a single base station has great advantage. But we can not use the same position location technique for different environment. In urban environment where line of sight assumption is not valid finger print matching technique is an optimum solution. For suburban and rural areas with the assumption that at list one line of sight signal is available, a hybrid TOA/AOA technique using smart antenna can be used. This will be discussed in chapter five.

4.4 Fingerprint Matching PL

The implementation and usage of many location based services focus on densely populated urban areas. Conventional location techniques based on time or angle of arrival techniques relay on line of sight (LOS) path between the base station antenna and the mobile station. In urban environment the line of sight assumption is rarely valid for three base stations at the same time, which degrades the location performance of conventional technique and creates a need for the development of more accurate techniques suited for these areas[6][7]. For the mentioned reason fingerprint matching for urban area is an optimum solution. In this section fingerprint matching PL under non line of sight condition is presented in detail.

As compared to location determination based on RSS range measurements, better results may be achieved by comparing a set of signal strength between MS and BS acquired in real time with signal strength measurements taken previously off-line at known locations throughout the coverage area. The techniques that employ database comparison are called fingerprinting, pattern recognition, or pattern matching [1].

The advantage of the database estimation method is that it is based on actual path loss at point near the MS location and therefore unknown factor of shadowing and multipath are bypassed. The database is applicable only for the particular site where it was created, and physical changes that affect radio propagation at the site may require creating a new database [1].

4.4.1 Offline Phase

The location estimation process has two measurement phases. The first phase, called the off-line or survey phase, is a creation of a database. During the survey, recording a set of information (in a database) as a function of the user's location covering the entire zone of interest, and forming a set of fingerprints is made. Each fingerprint corresponds to fingerprint information associated with a known user location.

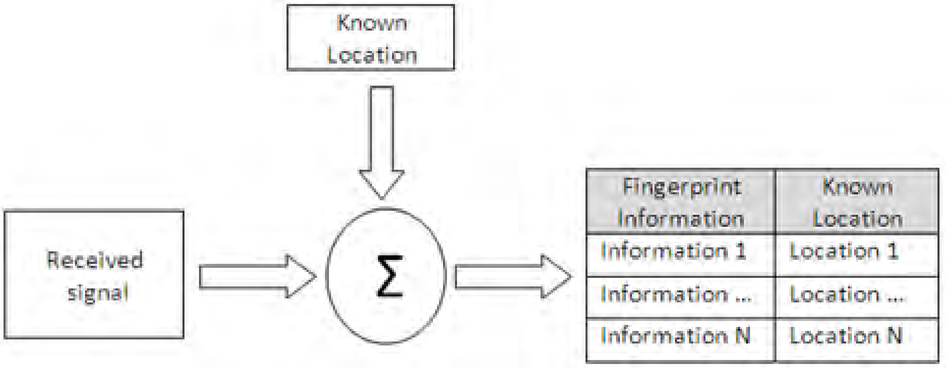


Figure 4.6 Offline Phase Received Signal Fingerprint

Signal strength varies over time due to small movements of the mobile station and movement of the object in the propagation paths, which may be people in the office or trees and vehicles in an outdoor scenario. Therefore, the raw data for each reference position point contains repeated received signal strength (RSS) measurement [1].

4.4.2 Online Phase

The second phase of the location procedure is the real time online signal strength measurement process when the location of an MS is to be estimated. For real time phase specific fingerprint information is obtained from received signal and compared with recoded set of fingerprint (database). A pattern matching algorithm is then used to identify the closest recorded information of the database to the measured one, thus defining the corresponding user's location.

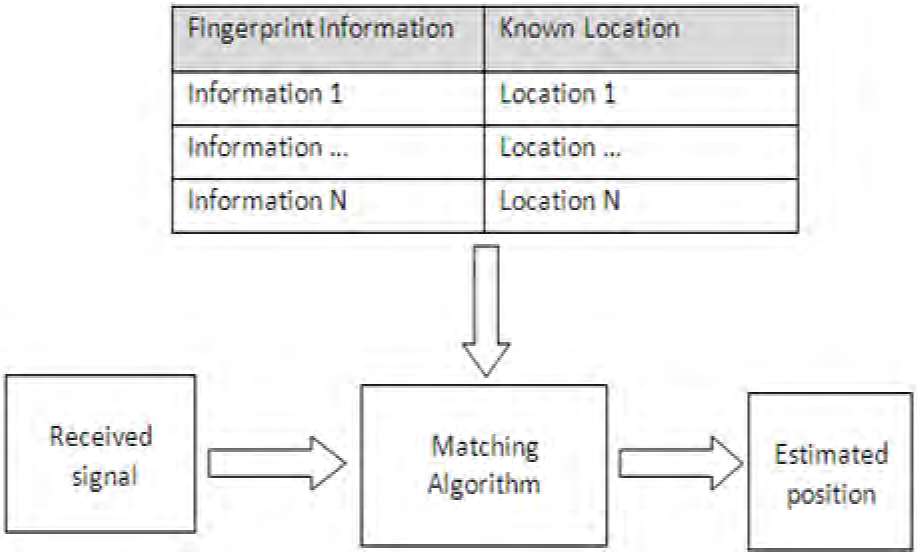


Figure 4.7. Real Time Phase of Received Signal Fingerprint

4.4.3 Pattern Matching Algorithm

The MS can listen to (receive) signals from the serving cell and six other neighboring cells (see Table 4.1) [6].

RSS	dBm
RSS-1	*-67*
RSS-2	*-63*
RSS-3	*-66*
RSS-4	*-66*
RSS-5	*-69*
RSS-6	*-70*
RSS-7	*-80*

Table 4-1 RSS from seven BSs

Most of the time the MS can not receive signal from all six neighbor cells. Two or three of BSs signal can be received by MS due to the random nature of the propagation environment. This phenomenon can happen both in offline and online phases.

RSS	dBm
RSS-1	*-67*
RSS-2	*-63*
RSS-3	-
RSS-4	-
RSS-5	-
RSS-6	-
RSS-7	-

Table 4-2 RSS from two BS and five missed values

The matching algorithm simply finds the best match among database variables. This done by comparing the input fingerprint (online phase) to each row of database fingerprint (offline phase). The missing RSS value is replaced by minimum value such as 120 dBm. Based on equation 4-1 the closest neighbors are selected and its coordinate taken as an estimate of the MS location.

$$d(k)=\sqrt{(\Sigma_i (f_i - g_i(k))^2+\Sigma_j (f_j - l_{max})^2+\Sigma_k (l_{max} - g_k(k))^2)+(AOA_d - AOA_e)} \qquad (4\text{-}1)$$

where

$d(k)$: The difference between the input fingerprint and the k^{th} database fingerprint.

f_i : The average RSS of the i^{th} hearable cell in the input fingerprint.

$g_i(k)$: The average RSS of the same cell in the k^{th} database fingerprint.

f_j : The average RSS of the j^{th} hearable cell in the input fingerprint which is not hearable in the k^{th} database fingerprint.

$g_k(k)$: The averaged RSS of the k^{th} hearable cell in the database fingerprint which is not hearable in the input fingerprint.

l_{max} : Replace the missing signal strength value.

AOA_d : Angle of arrival in the database

AOA_e : Angle of arrival estimated for input to the database.

Greater precision of the MS location may be achieved by choosing more than one neighboring database location and averaging their coordinates to get an estimate. For K number of the nearest estimates neighbors the position of the MS estimated as follows [1].

$$x=\frac{1}{K}\sum_{l=1}^{K} x_l \qquad \text{and} \qquad y=\frac{1}{K}\sum_{l=1}^{K} y_l \qquad (4\text{-}2)$$

Where K is number of nearest neighbor and x and y are the coordinate of the MS location.

4.5 Prior work

Data base correlation method using signal strength as database variable was proposed in [6]. A location trial in two environments: a densely built urban environment (the center of Helsinki, Finland) and suburban environment (the campus area of Otaniemi in Espoo, Finland) shows 67% of location error are below 44m and 90m for 90% of time in urban environment, and 74m for 67% and 190m for 90% of time in a suburban environment. In [7] Data base correlation method for UMTS location using measured power delay profile in location estimate is proposed. The test network used in the simulation is constructed by a network planning tool. The simulation result shows 67% of the location estimate are with in 25m and 95% of it within 140 m.

In [5] Database correlation method for multi-system location, using received signal strength for GSM network and received code power strength for UMTS network was investigated. In the field trial across Keka II, Helsinki Finland, for GSM network 67% of location errors are less than 67m and 95% are less than 227m. In UMTS network 67% location errors are below 114m and 95% are below 455m. It also uses RSSI for location estimation for wireless local area network. Received signals strength taken from different access points are used as data base variable.

4.6 Implementation of Fingerprint Matching PL

The technique is implemented using signal information seen both by MS and (BS) in GSM network. The received signal strength (RSS) at the MS was selected as the fingerprint variable. A single fingerprint in the database consists of GPS coordinates with Received signal strength (from serving base station and other neighboring base station) in that location. This technique uses Network Measurement Report (NMR). NMR contains cell information such as signal strength measurement from serving and six different neighboring base stations. The MS regularly forwards the NMR to the serving cell to assist handover (hand off) decision. A typical measurement report seen by MS is shown in figure 4.8. It consists of signal strength measured from different base station, cell name, Cell-ID and allocated absolute radio frequency channel number (ARFCN).

These signal information seen by MS is collected through drive test using TEMS Investigation 8.2.1 Data collection software. This software is used in network planning and optimization in cellular network. TEMS Investigation is a tool designed for spotting possible problem areas and malfunction in mobile cellular networks. It basically consists of a TEMS user equipment (UE) controlled by software running on a personal computer. The most basic feature of TEMS investigation Data collection is the presentation of the air interface in CDMA, WCDMA and GSM cellular network systems. In various windows one finds information presented as specified in the CDMA, WCDMA and GSM standards [28].

Angle of arrival was selected as fingerprint variable for signal information seen by the network. MATLAB simulation was used in the assumption that the necessary modification of the base station is made i.e. antenna array is used for the measurement.

Measurement and simulation setup is shown in Figure 4.8. RSS and AOA recorded as a function of location covering the entire zone of interest. Figure 2 illustrates the data collection process. The drive test equipment used for data collection consists of:

- Laptop installed with drive test software.
- GPS (Global positioning system) antenna connected to the laptop so real reading of the coordinates could be obtained for each sample.
- GSM phone (MS) connected to the laptop. This phone is set to active voice call mode so the drive test tool could collect active serving cell's signal strength and Cell ID.

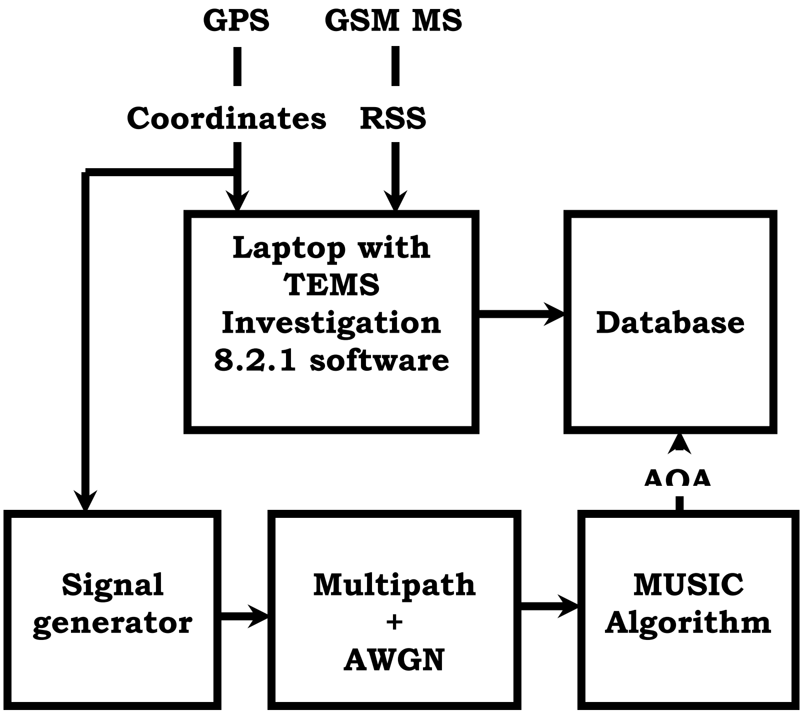


Figure 4.7 Measurement and simulation setup.

Cell Name	BSIC	ARFCN	RxLev
ZTE-ETC HQ3	1-1	7	-67
EXCHANGE2	2-5	515	-63
ZTE-EXCHANGE2	1-2	113	-66
EXCHANGE1	1-0	521	-66
		7	-67
ETC HQ3	2-6	528	-69
ZTE-EXCHANGE1	1-7	118	-70
ETC HQ2	2-2	520	-81

Figure: 4.8 A Typical Measurement Report seen by MS

A test route near Tikure Anbessa around Ethiopian Telecommunications Corporation (ETC)'s mobile center was selected. Using GSM and GPS receiver received signal strength (RSS) measurement at different location were collected through drive test (offline data collection) for the database across the test route. For real time implementation another received signal strength measurements were carried out randomly (online phase). Using fingerprint matching algorithm the measured received signal strength data are compared with received signal strength information stored in the database as fingerprint variable. Finally to see the performance of the position location, error was calculated and cumulative distribution and histogram of the location error plotted using MATLAB.

Figure 4-9 A Test Route for Test Drive

4.7 Simulation Results

First four nearest estimate of MS are chosen and their position averaged. RSS and RSS together with AOA were used as database variables. The simulation result shows using only RSS 67% of location errors are less than 72m and 95% of them are less than 221m. Using RSS together with AOA 67% of location error are less than 70m and 95% are 176m. In this scenario using RSS together AOA has better performance than using only RSS. In order to compare the result with FCC recommendation 67% and 95% of position location error are shown in cdf plot of Figure 4.10. To see the distribution of error a histogram plot of location error is shown in figure 4.11. Next using only single estimate is used. In this scenario using RSS together AOA 67% of the location errors are less than 88m and 95% of errors are less than 166m. Using RSS only as database variable 67% of the errors are below 58m and 95% of the errors are 224m. Cdf and histogram plots are shown in Figure 4.12 and in figure 4.13. Comparing the two scenarios using more number of estimates decreases the total error margin.

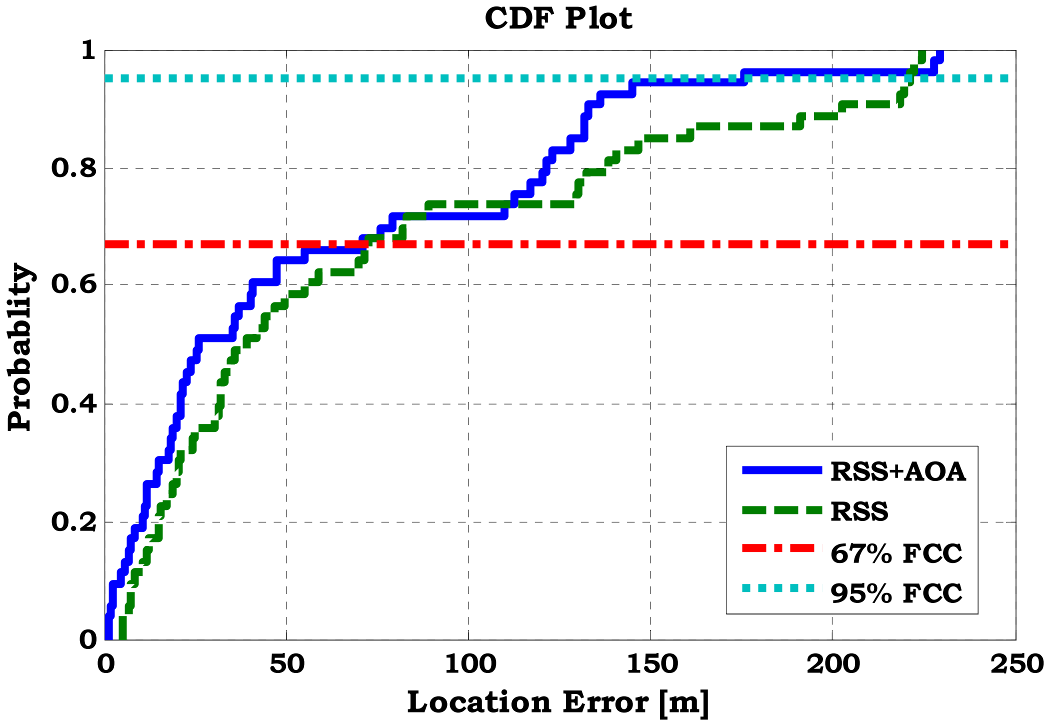


Figure 4.10 CDF Plot of the PL Error Using Four Estimates

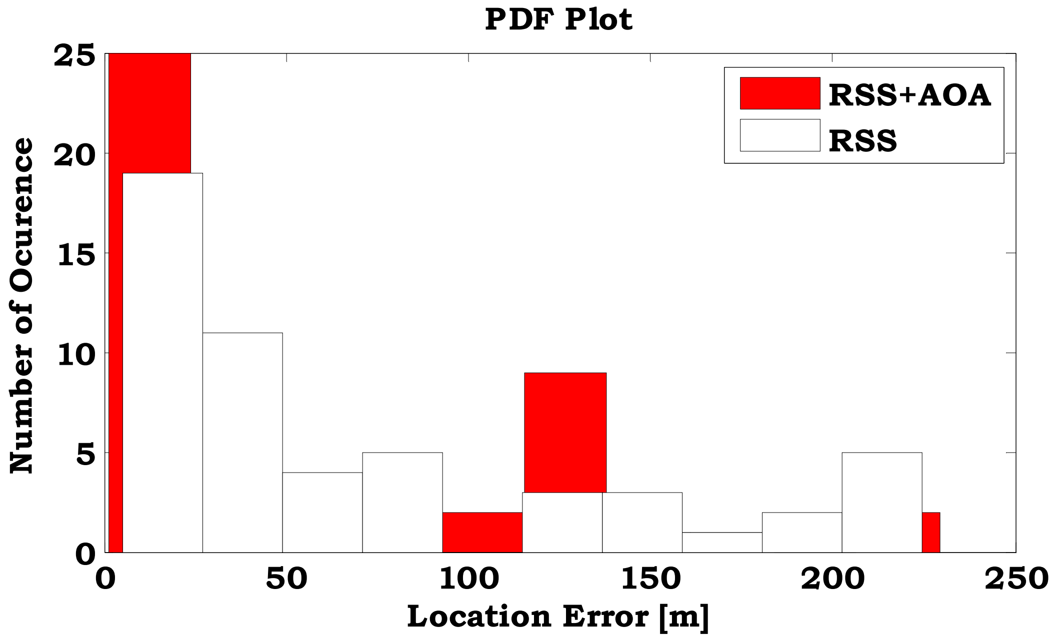


Figure 4.11 Histogram plot of the PL error using four estimates

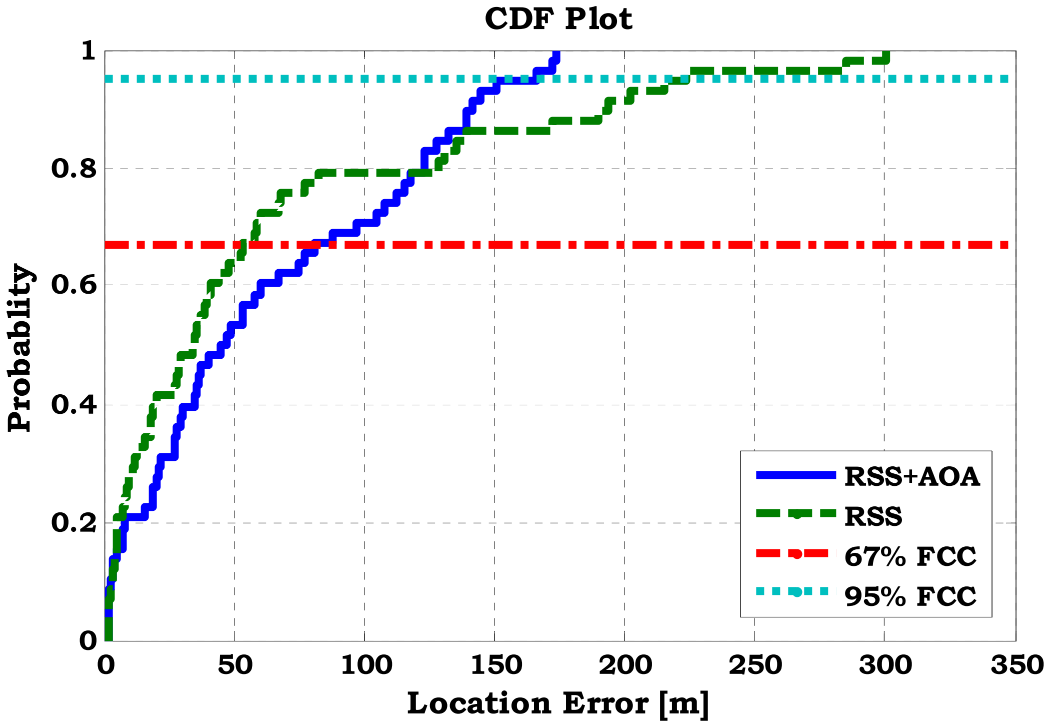


Figure 4-12 CDF plot of the PL error using single estimate

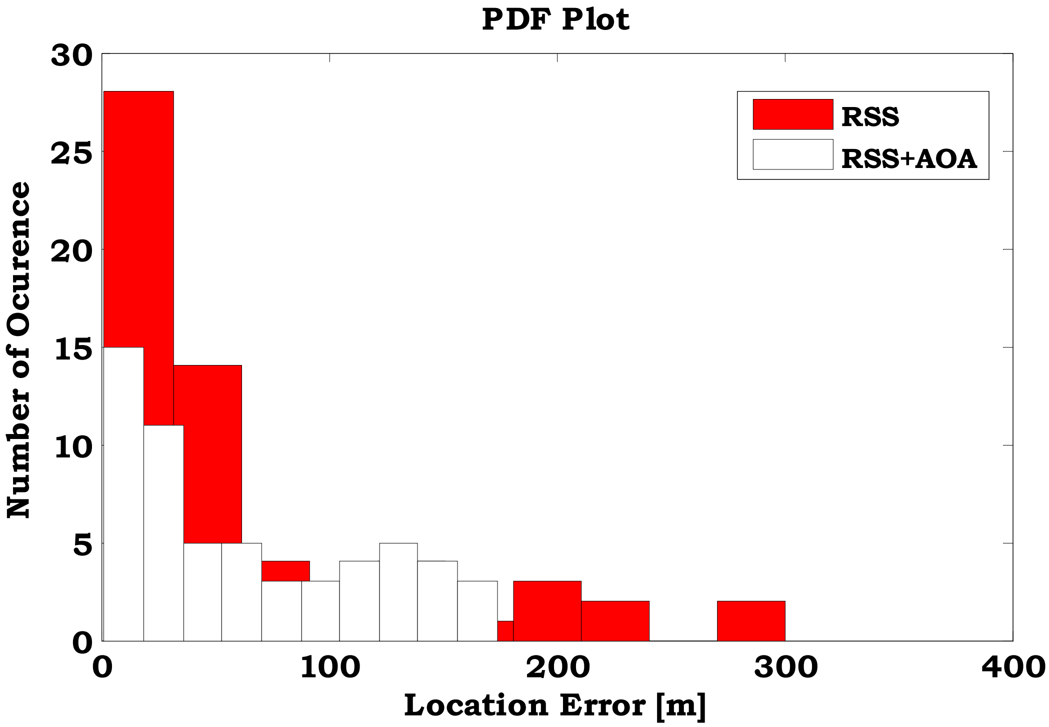


Figure 4.13 Histogram plot of the PL error using single estimates

4.8 Conclusions

Position location technique based on time of arrival and angle of arrival measurement depends on line of sight between the mobile station and the base station. Implementation of these techniques in urban environment cannot give better location for most of location service. Fingerprint matching solves the problem with LOS assumption, fingerprint variables are take from the measurement report of the mobile station so there is no modification of the already existing mobile apparatuses.

The short coming of this technique is the need to prepare a database which is site specific and cumbersome. Any change in the area like construction of new building decreases the accuracy. For optimization and planning service provider's teams always take drive taste data so these data can be taken as an input for the database as well. The other problem is the size of the data base, using distributed database can solve this problem.

Chapter 5
Hybrid TOA/AOA PL under LOS Condition

5.1 Introduction

As discussed in chapter four getting adequate signal to noise ratio of the MS at different BSs is one of the problems of wireless location. In rural and suburban environment distance between two or more BSs are larger when compared to urban environment. To alleviate this problem, with the assumption that at least one line of sight signal is available in suburban and rural environment, a hybrid TOA/AOA position technique using one base station with smart antenna at the base station is recommended. In this chapter the simulation technique for time of arrival and angle of arrival is discussed. Time of arrival estimation using correlator and peak detector, and angle of arrival estimation using MUSIC algorithm are also briefly presented.

5.2 Smart Antenna

Smart antenna is composed of a collection of two or more antennas working together to establish a unique radiation pattern for the electromagnetic environment at hand. The antenna elements are allowed to work together by means of array element phasing, which is accompanied with hardware or is performed digitally [11].

The two element array is shown in Figure 5.1 below and, it gives an insight into how multiple element linear array works. The wave front reaches antenna B before it reaches an antenna A causing a phase difference between the signal at the terminal of the two antenna. The signal delay τ at A with respect to the wave front arriving at B is the distance a divided by the speed of propagation, c [1].

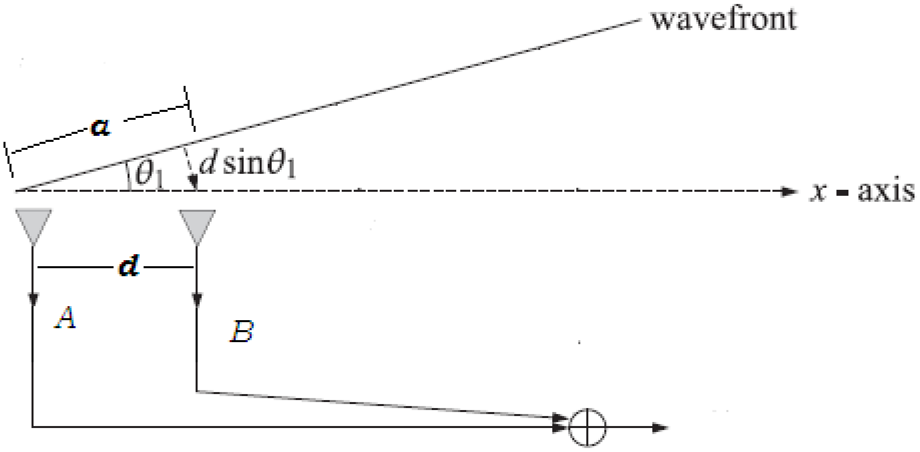


Figure 5.1 two element array antenna

i.e $\tau = a/c$ (5-1)

a depends on the angle of arrival θ and the distance d between the two antenna elements, i.e

$$a = d \sin(\theta) \quad (5\text{-}2)$$

The phase in radian between the signal arriving at A and B is then:

$$\beta = \tau . 2\pi . c/\lambda$$

$$\beta = (a/c)(2\pi c/\lambda)$$

$$\beta = 2\pi (d/\lambda) \sin(\theta)$$

$$\beta = 2\pi k \sin(\theta) \quad (5\text{-}3)$$

Where $k = d/\lambda$ is called a relative element separation. For L element of the antenna array, the phase difference in the antenna elements is called array steering vector. Its values with respect to the first antenna element is given as [10]

$$a(\theta) = [1, e^{j2\pi k \sin\theta} \ldots e^{j2\pi k(L-1)\sin\theta}] \quad (5\text{-}4)$$

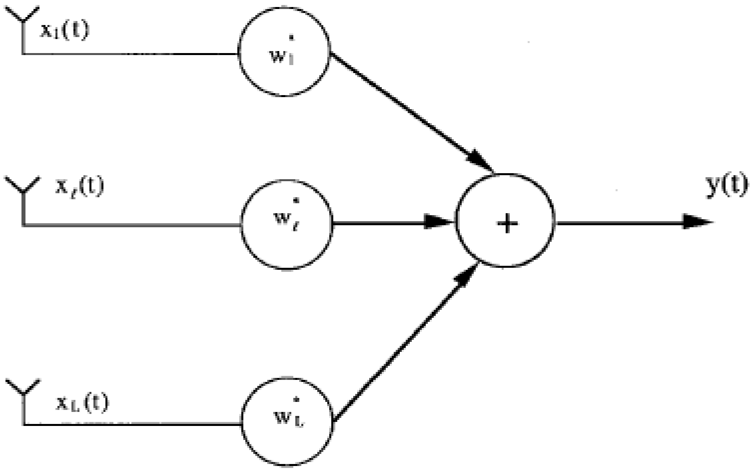


Figure 5.2 Conventional Beam Former Structure

The output of the array element is

$$X(t) = a(\theta)s(t) \tag{5-5}$$

where $X(t)=[x_1(t),x_2(t),\dots x_L(t)]$ and $s(t)$ is the source signal. If we have N number of sources, the array output is

$$X(t)=A(\theta)S(t) \tag{5-6}$$

where $A(\theta)=[a(\theta_1),a(\theta_2),\dots,a(\theta_N)]$ is array manifold and $S(t)=[s_1(t),s_2(t),\dots,s_N(t)]$ the signal sources. The output of the beam former

$$y(t)=W^HX(t) \tag{5-7}$$

Where $W=[w_1,w_2,\dots,w_L]$ is the weight vector. The antenna tap weight is determined to satisfy certain optimum criteria. These criteria could be

- Maximizing the *signal-to-interference ratio* (SIR)
- Steering towards a signal of interest

- Nulling the interference signal and Tracking a moving emitter to name a few

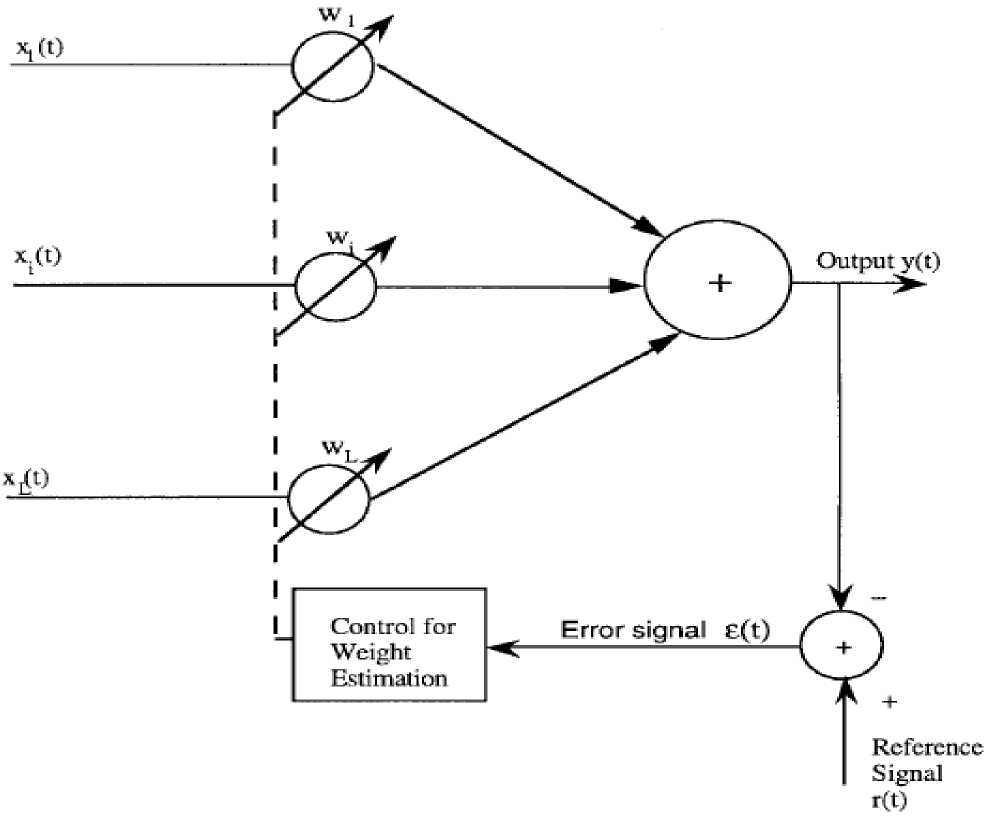


Figure 5.3 Beam former structure using reference signal [11]

Different algorithms are used in order to satisfy these optimal criteria. The implementation of these algorithms can be performed electronically through an analog device but it is generally more easily performed using digital signal processing. This requires that the array outputs be digitized through the use of analog to digital convertor (A/D) converter. This digitization can be performed at either intermediate frequency (IF) or baseband. Since an antenna pattern is formed by digital signal processing, this process is often referred to as digital beam forming.

5.3 Angle of Arrival Estimation

In order to locate the desired user, the receiver array should be able to estimate the angle of arrival. Angle of arrival (AOA) estimation has also been known as spectral estimation, directional of arrival estimation, or bearing estimation. Bearing estimation is a term more commonly used in the sonar community and AOA estimation for acoustic problems. For AOA estimation, antenna array and estimation algorithm is required. In this thesis we use MUSIC algorithm.

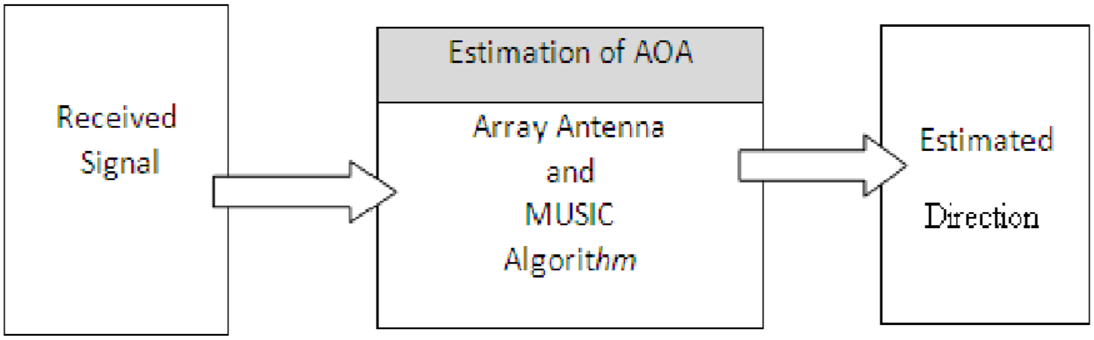


Figure 5.4 AOA estimation for position location

Figure 5.4 shows AOA estimation for position location. MUSIC is an acronym which stands for MUltiple SIgnal Classification. MUSIC promises to provide unbiased estimates of the number of signals, the angle of arrival, and the strength of the wave form. If the number of signals is N, the number of signal eigenvalue and eigenvectors is N and the number of noise eignvalues and eigenvectors is L-N (L is the number of array elements). Because MUSIC exploits the noise eigenvector subspace, it is sometimes referred to as a subspace method.

The array correlation matrix assuming uncorrelated noise with equal variances is given in by [9]

$$R_{xx}=AR_{ss}A^{H}+\sigma^{2}I \qquad (5\text{-}8)$$

We next find the eigenvalues and eigenvector for R_{xx} and we then produce N eigenvectors associated with the signal and L-N eigenvectors associated with the noise. We choose the eigenvector associated with the smallest eigenvalues. For uncorrelated signals, the smallest eigenvalues are equal to the variance of the noise. We can then construct the L X (L-N) dimension subspace spanned by the noise eigenvectors such that [9]

$$E_N=[e_1, e_2,\ldots,e_{L-N}] \qquad (5\text{-}9)$$

The MUSIC pseudo spectrum is now given as [9]

$$P_{MU}(\theta) = 1/\,|a(\theta)^H E_N E_N^H a(\theta)| \qquad (5\text{-}10)$$

The peak gives us an angle or direction of arrival of the signal.

5.4 Time of Arrival Estimation

For the estimation of time of arrival or time delay a correlator is used. This can be implemented by correlating a known signal with the received signal. A known signal *s(n)* is correlated with received signal *r(n).* We can model *r(n)* by [3]

$$r(n)=\alpha s(n-\tau_k)+\upsilon(n) \qquad n=1,2,\ldots,k \qquad (5\text{-}11)$$

Where $s(n-\tau_k)=b(n)PN(n-\tau_k)$ and α is an attenuation factor and τ is the time delay and $\upsilon(t)$ is channel noise. The maximum likelihood (ML) estimate of τ is given by [3]

$$\tau=\arg\max[p(r(1),\ldots,r(k)/\tau)] \qquad (5\text{-}12)$$

For sufficiently large *k*,

$$\tau = \max_{\tau} J(\tau) \qquad \text{for } 0 \leq \tau_k \leq w \qquad (5\text{-}13)$$

Where $J(\tau)=1/k\Sigma_{n=1} r(n)s(n-\tau)$ and w is correlation window length. If τ is the time delay, then $s(n)$ and $r(n)$ should be correlated at $n = \tau$. Assuming MS processing delay is minimum round trip time delay is estimated. Half of it is an estimate in one direction. The target will be located at a distance of $c\ \tau$, where c is the speed of electromagnetic wave in free space. The output of the correlator is fed to the peak detector. The peak detector outputs the time the correlator output peak occurs. This gives us an estimate of time of arrival.

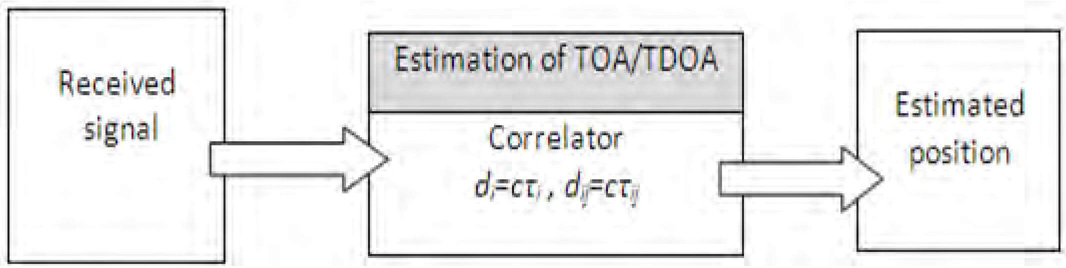


Figure 5.5 TOA/TDOA Estimation for Position Location

5.5 Hybrid TOA/AOA PL Method

The hybrid TOA/DOA method requires only one base station to locate a mobile station. For ease of analysis, we consider the LOS case where the direct path between the MS and BS is not blocked. The MS is estimated as the unique intersection point of the circle and line of bearing (LOB). i.e

$$x_m = x_b + (c\tau)\cos(\theta)$$
$$y_m = y_b + (c\tau)\sin(\theta) \qquad (5\text{-}14)$$

where (x_b, y_b) represents the known coordinate of the serving BS, (x_m, y_m) is the estimated position of MS and c is the speed of light.

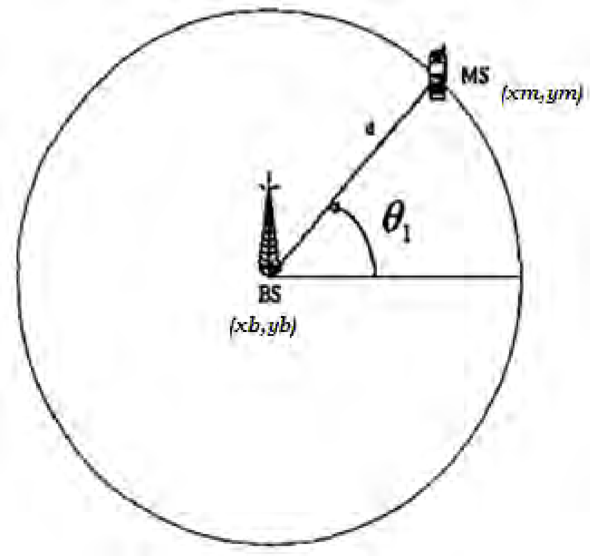


Figure 5-6 Hybrid TOA/AOA location.

In hybriding geolocation approaches, the strength of one technology compensates for the shortcoming of the other one. In environment where AOA techniques performance is not good TOA or some other technique may perform well. This fact makes the hybrid method among the best technique available for location estimation. The hybrid TOA/AOA method has particular interest because it eliminates the need for cooperating multiple distributed parties to solve the position location problem. The biggest advantage of this method is that it requires no more than one base station to provide an estimate for a position of a mobile [4].

5.6 Outdoor Propagation Model

In order to see the effect of outdoor propagation and to choose the more realistic simulation model for the problem at hand some of outdoor propagation models are presented next.

5.6.1 Free Space Propagation Model

Free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, unobscured line of sight path between them. Satellite communication systems and microwave line of sight radio links typically undergo free space propagation. As with most large scale radio waves propagation model, the free space model predict that the received power decay as a function of T-R separation distance raised to some power. The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance *d* is given by the frii's free space equation [14].

$$P_r(d)=P_t\,G_tG_r\lambda^2/(4\pi d)^2 \qquad (5\text{-}15)$$

where P_t : The transmitted power. $P_r(d)$: The received power which is the function of T-R separation. G_t : The transmitter antenna gain

G_r : The receiver antenna gain.

d : The T-R separation

λ : wave length of the signal.

The path loss, which represents signal attenuation as a positive quantity measured in dB, is defined as the difference between the effective transmitted power and the received power. The path loss for the free space model is given by [14]

$$\begin{aligned} PL(dB) &= 10\log P_t/P_r \\ &= -10\log G_tG_r\lambda^2/(4\pi d)^2 \qquad (5\text{-}16) \end{aligned}$$

5.6.2 Okumura Model

Okumura mode is one of the most widely used models for signal prediction in urban area. This model is appropriate for frequencies in the range 150MHz to 1920 MHz and distances of 1 km to 100km. It can be used for base station antenna height ranging from 30 to 300 m. The model can be expressed as [14]

$$L_{50}(dB)=L_F+A_{mu}(f,d)-G(h_{re})-G(h_{te})-G_{AREA} \qquad (5\text{-}17)$$

where $L_{50}(dB)$: The median value of the propagation path loss

L_F : The free space propagation path loss

A_{mu} : The median attenuation relative to free space

$G(h_{re})$: The mobile antenna height gain factor

$G(h_{te})$: The base station antenna height gain factor

G_{AREA} : The gain due to the type of environment

The value of $G(h_{re})$ and $G(h_{te})$ is given by

$$G(h_{te}) = 20\log(h_{te}/200) \qquad 30<h_{te}<1000 \text{ m}$$

$$G(h_{re}) = 10\log(h_{re}/3) \qquad h_{re} \leq 3\text{m}$$

$$G(h_{re}) = 20\log(h_{re}/3) \qquad 3 <h_{te}<10 \text{ m}$$

Okumura's model is based on measured data and does not provide any analytical expression. Additionally it has slow response to rapid change in terrain, therefore the model is fairly good in urban area and suburban area but not so good in rural areas.

5.6.3 Hata Model

The Hata model is an empirical formulation of the graphical path loss data provided by Okumura, and is valid for frequencies from *150 MHz* to *1500MHz*. Hata presented the urban area propagation loss as a standard formula and supplied a correction equation for application to other structure. The standard formula for median path loss in urban area is given by [14]

$$L_{50}(urban)(dB)=69.55+26.16\log_{10}(f_c)-13.82\log_{10}(h_{te})-a(h_{re}) + (44.9-6.55\log h_{te})\log_{10}d \qquad (5\text{-}18)$$

Where f_c : The frequency (in MHz) from 150MHz to 1500 MHz

h_{te} : The effective transmitter BS antenna height in meter from 30m to 200m

h_{re} : The effective MS height in meter ranging from 1m to 10 m

d : T-R separation distance (in km)

$a(h_{re})$: The correction factor for effective mobile antenna height which is a function of the size of the coverage area. For a small to medium sized city, the mobile antenna correction factor is given by

$$a(h_{re})=(1.11\log f_c-0.7)h_{re}-(1.56\log f_c-0.8)dB \qquad (5\text{-}19)$$

and for large city it is given by

$$a(h_{re})=8.29(\log 1.54\, h_{re})^2-1.1)dB \quad \text{for} \quad f_c\leq 300MHz \qquad (5\text{-}20)$$

$$a(h_{re})=3.2(\log 11.75\, h_{re})^2-4.97)dB \quad \text{for} \quad f_c\geq 300MHz \qquad (5\text{-}21)$$

To obtain the path loss in suburban area, the standard Hata formula is modified as

$$L_{50}\,(dB)=L_{50}(urban)-2[\log(f_c/28)]^2-5.4 \qquad (5\text{-}22)$$

And for path loss in open rural areas the formula is modified as

$$L_{50}\,(dB)=L_{50}(urban)-4.782(\log f_c)^2+18.33\log f_c-40.94 \qquad (5\text{-}23)$$

5.6.4 COST 231Extend Hata Model

The European cooperation for scientific and technical research formed the COST-231 working committees to develop an extended version of the Hata model. COST-231 proposed the following formula to extend Hata's model to 2GHz. The proposed mode for path loss is given by [14]

$$L_{50}(urban)=46.3+33.9\log f_c-13.2\log h_{te}-a(h_{re})+(44.9-6.55\log h_{te})\log d+C_M \qquad (5\text{-}24)$$

where C_M *is 0 db* for medium sized city and suburban areas and 3 dB for metropolitan center. The COST 231 extension of the Hata model is restricted to the following range of values

f : 1500 MHz to 2000MHz
h_{te} : 30m to 200m
h_{re} : 1m to 10m
d : 1km to 20km

5.6.5 Log-distance Path Loss Model

Both theoretical and measurement based propagation models indicates that the average received signal power decreases logarithmically with distance whether in outdoor or indoor radio channel. The average large scale path loss for an arbitrary T-R separation is expressed as a function of distance by using a path loss exponent n [14].

$$PL(dB)=PL(d_0)+10n\log(d/d_0) \tag{5-25}$$

where n is path loss exponent and indicates the rate at which the path loss increase with distance. d_0 a reference distance which is determined from measurement close to the transmitter and d is the T-R separation distance. The value of n depends on the specific propagation environment, some values for different environment is given in Table 5.1 below.

Environment	Path loss Exponent n
Free space	2
Urban area cellular radio	2.7-3.7
Shadowed urban cellular	3-5
In building line of sight	1.6-1.8
Obstructed in building	4-6
Obstructed in factories	2-3

Table 5.1 Path loss exponent for different environment

5.6.6 Log-normal Shadowing

The model in equation 5-25 does not consider the fact that the surrounding environment clutter may be vastly different at two different locations with the same T-R separation. This leads to measured signal which is vastly different from the average value predicted by equation 5-25. Measurement at a particular location is random and distributed log-normally about the mean is distance dependent value, that is [14]

$$
\begin{aligned}
PL(d)[dB] &= PL(d) + X_\sigma \\
&= PL(d_0) + 10n \log (d/d_0) + X_\sigma \qquad (5\text{-}26)
\end{aligned}
$$

Where X_σ is a zero mean Gaussian distribution random variable (in dB) with standard deviation σ (in dB).

The received power $P_r(d)$ is given by [14]

$$Pr(d)[dBm] = P_t[dBm] - PL(d)[dB] \qquad (5\text{-}27)$$

The log normal distribution describes the random shadowing effect which occurs over a large number of measurement locations which have the same T-R separation, but have different type of clutter in the propagation environment.

5.6.7 Small-scale Propagation

A rapid fluctuation of the amplitude, phase or multipath delay of a radio signal over a short period of time or travel distance is called small scale fading. Fading is caused by interference between two or more version of the transmitted signal which arrives at the receiver at slightly different time. In urban environment , fading occurs because the height of the mobile antenna is well below the height of the surrounding structure , so there is no single path to the BS. Even when a line of sight exits multipath still occurs due to reflection from the ground and the surrounding structure.

The incoming radio waves arrive from different direction with different propagation delay. The signal received by the mobile at any point in space may consist of a large number of plane waves having randomly distributed amplitude, phase and angle of arrival. These multipath components combine vectorialy at the receiver antenna and can cause the received signal to be distorted or fade. Even when a mobile receiver is stationary, the received signal may fade due to the movement of the surrounding object in the radio channel.

5.6.7.1 Rayleigh Fading Distribution

The Rayleigh distribution is commonly used to describe the statistical time varying nature of the received signal or the envelop of an individual multipath component. The Rayleigh distribution has a probability density function *(pdf)* given by [14]

$$p(r)=\begin{cases} (r/\sigma^2)\ exp(-r^2/2\sigma^2) & for\ \ (0 \le r \le \infty) \\ 0 & for\ \ (r<0) \end{cases} \qquad (5\text{-}28)$$

where σ is the rms value of the receiver voltage signal before envelop detection and σ^2 is the time varying power of the received signal before envelop detection.

5.6.7.2 Rician Fading Distribution

When there is a dominant stationary signal component present such as a line of sight propagation path, the small scale fading envelops distribution is racian. In such situation random multipath component arriving at different angle are superimposed on a stationary dominant signal. The Rician distribution is given by [14]

$$P(r)=\begin{cases} (r/\sigma^2)e^{-(r2+A2)/2\sigma2}\ Io(Ar/\sigma^2) & for\ (A \ge 0,\ r \ge 0) \\ 0 & for\ (r < 0) \end{cases} \qquad (5\text{-}29)$$

The parameter A denotes the peak amplitude of the dominant signal and $I_0(.)$ is the modified Besel function of the first kind and zeroth order.

5.7 Simulation Model

A mobile station of the following parameters is assumed which is used for CDMA specification. A base station that uses antenna array with antenna element of 4 is assumed. The gain of antenna, both for base station and mobile station is assumed unity i.e. $G_t = G_r = 1$.

Parameter	**Value**
Transmitted Power	1W
Carrier Frequency	2GHz
SNR	20dB
Band Width	1.25 M Hz
Modulation Scheme	BPSK
Oversampling Rate	4
Correlation Length	1.6/3.2/4.8ms
Pulse Shaping Roll of Factor	0.22
Gain G_t and G_r	1
Number of antenna element	4
Path loss model	COST-231
Fading channel	Rician
Doppler frequency	80Hz
Base station antenna height	200m
Mobile station antenna height	10m
Cell Radius	20 km

Table 5.2 Simulation Parameter

In CDMA a user message is spread by spreading code that produces large bandwidth. The transmitted signal is described as [11], [12]

$$s(t)=m(t)g(t) \tag{5-30}$$

Where *m(t)* is the message signal and *g(t)* is the spreading code. In this simulation for simplicity the random bit generated is taken as *s(t). A* sample of 270 different distance and directions are selected as a true position. The bits are delayed based on the assumed distance of MS from the BS. The generated signal is modulated with BPSK modulation scheme and raised cosine pulse shaping signal. The parameters are as given above. In order to allow practical simulation, the multipath propagation models will consider:

- A discrete number of taps, each determined by their time delay and their average power.
- The Ricean distributed amplitude of each tap, varying according to a Doppler spectrum, S(f).

[13] defines the two types of Doppler spectra which will be used for the modeling of the channel. The maximum Doppler shift is given as

$$f_d=\upsilon/\lambda \qquad (5\text{-}31)$$

With υ (in ms^{-1}) representing the vehicle speed, and λ (in m) the wavelength. Two types of Doppler spectrum are used in the channel model

- CLASS is the classical Doppler spectrum and is given as [13]

$$S(f)=A/(1-(f/f_d)^2)^{0.5}) \qquad \text{for } -f_d\leq f\leq f_d \qquad (5\text{-}32)$$

- RICE is the sum of a classical Doppler spectrum and one direct path, such that the total multipath contribution is equal to that of the direct path and is given as [13].

$$S(f) = 0.41/(2\Pi f_d(1-(f/f_d)^2)^{0.5}) + 0.91\ \delta(f - 0.7 f_d)\ \text{for } f \geq -f_d \text{ and } f_d \leq f \qquad (5\text{-}33)$$

To see the effect of small scale fading a simulation model given by 3GPP for line of sight environment is used (Table 5.3 and 5.4). The channel models [13] for mobile radio were standardized to enable different communications designers to simulate their systems using a common set of channel models. Four propagation models are defined: rural area (RA), typical urban area (TU), bad urban area (BU), and hilly terrain (HT). Each tap is characterized by a relative delay (with respect to the first path delay), a relative power, and a Doppler spectrum category. There are two RA models, RA-1 and RA-2 and are given in the tables below. The difference between the two is the number of taps.

Tap Number	Relative Time (μs)	Average relative Power(dB)	Doppler Spectrum
1	0.0	0.0	RICE
2	0.2	-2.0	CLASS
3	0.4	-10.0	CLASS
4	0.6	-20.0	CLASS

Table 5.3 Simulation parameter of multipath delays for RA-1 environment

Tap Number	Relative Time (μs)	Average relative Power (dB)	Doppler Spectrum
1	0.0	0.0	RICE
2	0.1	-4.0	CLASS
3	0.2	-8.0	CLASS
4	0.3	-12.0	CLASS
5	0.4	-16.0	CLASS
6	0.5	-20.0	CLASS

Table 5.4 Simulation parameter of multipath delays for RA-2 environment

COST-231 path loss model is used to simulate path loss. The effect of shadowing in rural and suburban is assumed less than that of urban. In this simulation the effect of shadowing is neglected. The delayed signal is passed through AWGN and Rician fading object channel model. For the effect of background and receiver noise AWGN is added to the channel. The delayed signal is demodulated at the base station and using one element of the array antenna, input is correlated with the known bit to find the time of arrival of the signal. The time when maximum value of the correlation is detected, is the time delay estimate. The estimated time delay multiplied by speed of light ($c=3*10^8$ m/s) gives us the distance of the mobile station from the base station.

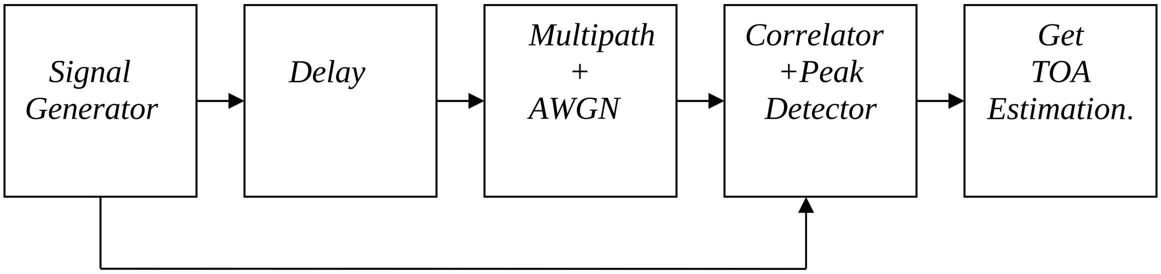


Figure 5.7.Simulation Model for TOA Estimation

For angle of arrival estimation the received signal is generated the same way as the time of arrival. Using antenna array and MUSIC algorithm the angle of arrival is estimated. The simulation block diagram is shown in figure 5.7. The direction of the mobile station is estimated by using the array antenna, By doing so the position of a MS calculated through geometric means i.e. the estimated distance making the base station as the center a circle is drawn. The MS can be in any place around the circle. This creates ambiguity since we do not know the exact position. The ambiguity is solved by using the estimate on direction of arrival of the signal; hence the intersection of a circle and a line gives us the position of a mobile station.

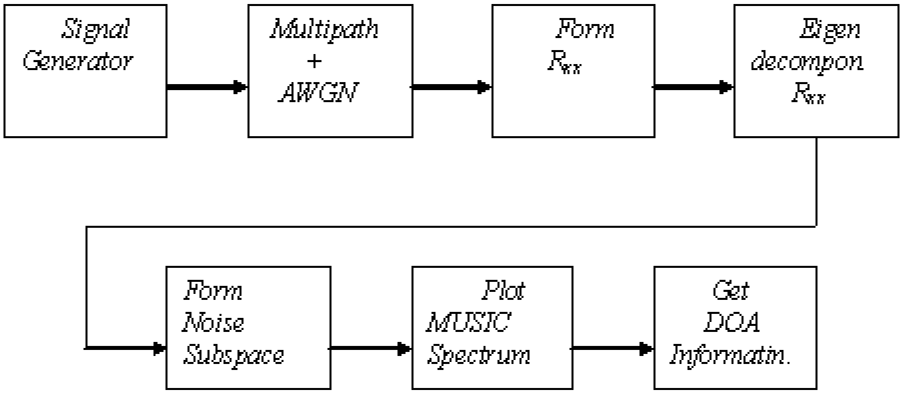


Figure 5.8.Simulation Model for AOA Estimation

5.8 Simulation Results

The simulation result for RA-1, and RA-2, channel models which have different multipath delay are discussed. In Figure 5.9 up to figure 5.13 the simulation result of CDF and histogram plotted for RA-1 channel model is shown. In the simulation three different correlation window lengths (w) of 1.6ms, 3.2ms and 4.8ms were used (refer equation 5-13). For channel model RA-1, the location error is within 66m for 67% of the time and 273m for 95% of the time at correlation length of 1.6ms. At correlation length of 3.2ms the location error is within 65m for 67% of the time and 196m for 95% of the time. Similarly for correlation length of 4.8ms, the location errors are 41m 67% of the time and 210m for 95% of the time. It is found that as the length of snapshot increase the performance of PL increase dramatically. A better accuracy is achieved because of the assumption that there is one strong line of sight signal available in rural environment.

The result also shows that for most of position location service the location error is within the limit set by FCC recommendation for network based position location technique. For channel model RA-2 with correlation length of 1.6ms the location error is within 66m for 67% of the time and 273m for 95% of the time. The location error is within 57m for 67% of the time and 196m for 95% of the time at correlation length of 3.2ms. Similarly for correlation length of

4.8ms, the location errors are 39m 67% of the time and 218m for 95% of the time.

Simulation is also conducted to see the effect of distance between MS and BS. Obviously the result shows as the MS is close to BS the RMS error decreases. Moreover correlation window length has great effect in location accuracy. As the length of correlation window length increase the RMS error decreases. Simulation result showing effect of distance from BS on PL for both RA-1 and RA-2 channel model are shown in figure 5.13 and 5.14 respectively

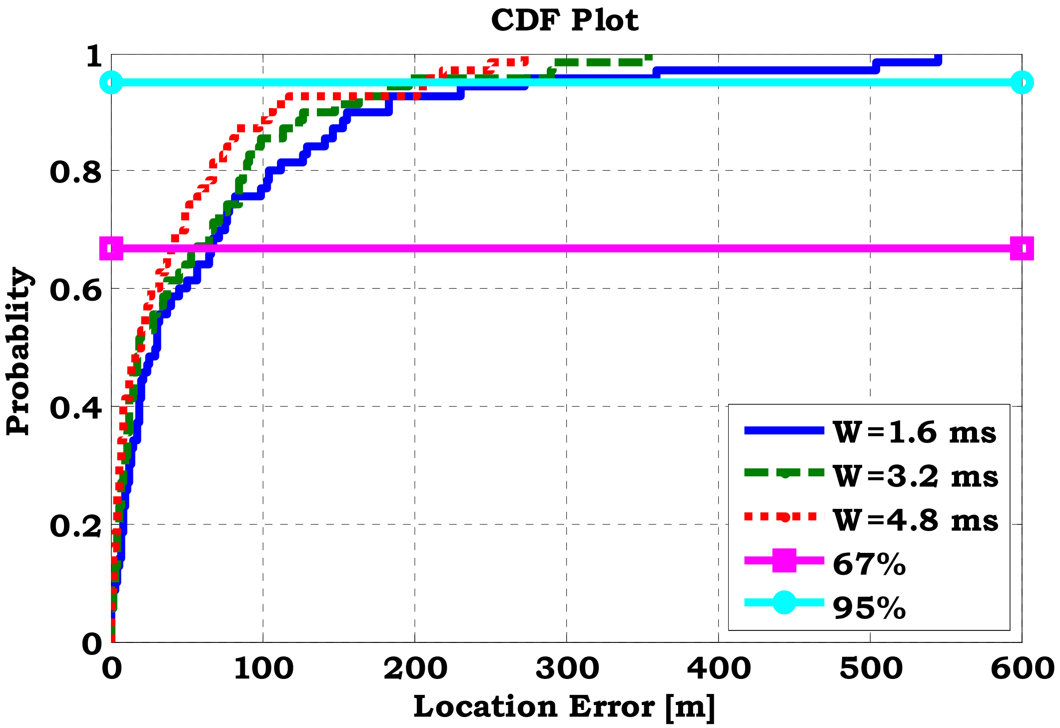


Figure 5.9 CDF plot of PL Error for RA-1 Channel Model

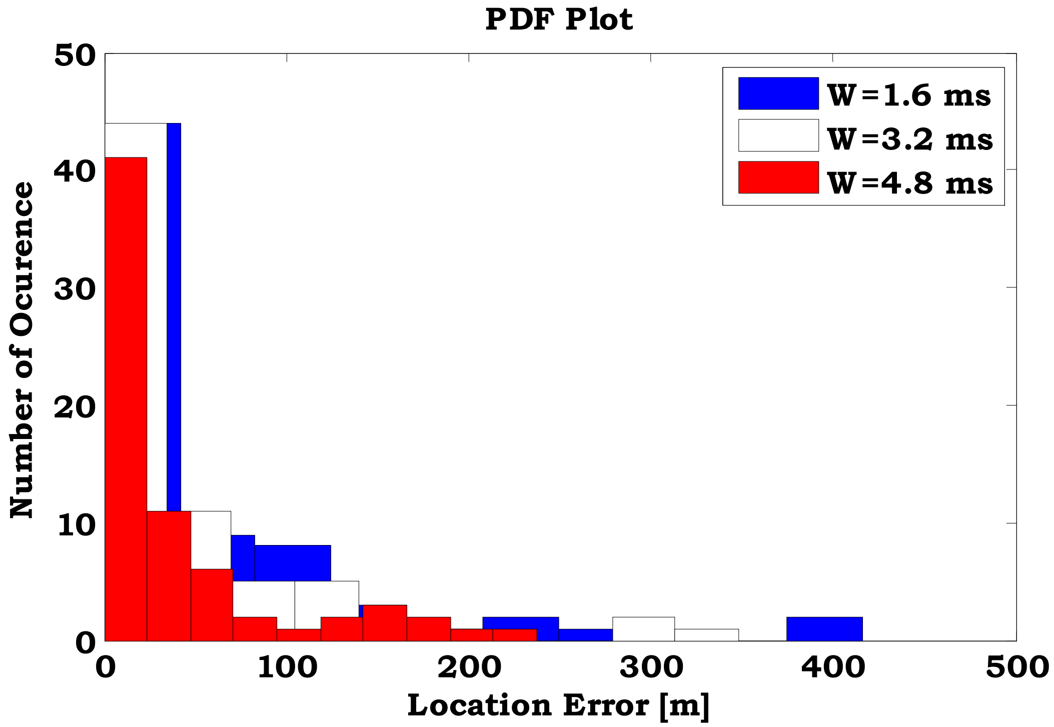


Figure 5.10 Histogram plots for RA-1 Channel Model

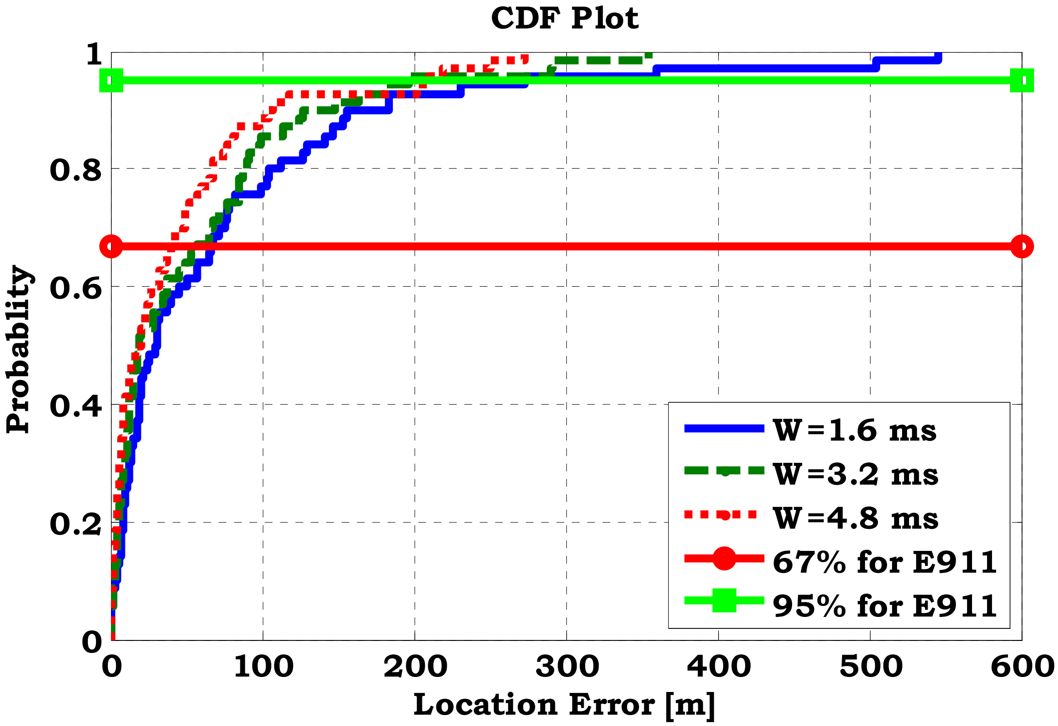


Figure 5.11 CDF of PL Error for RA-2 Channel Model

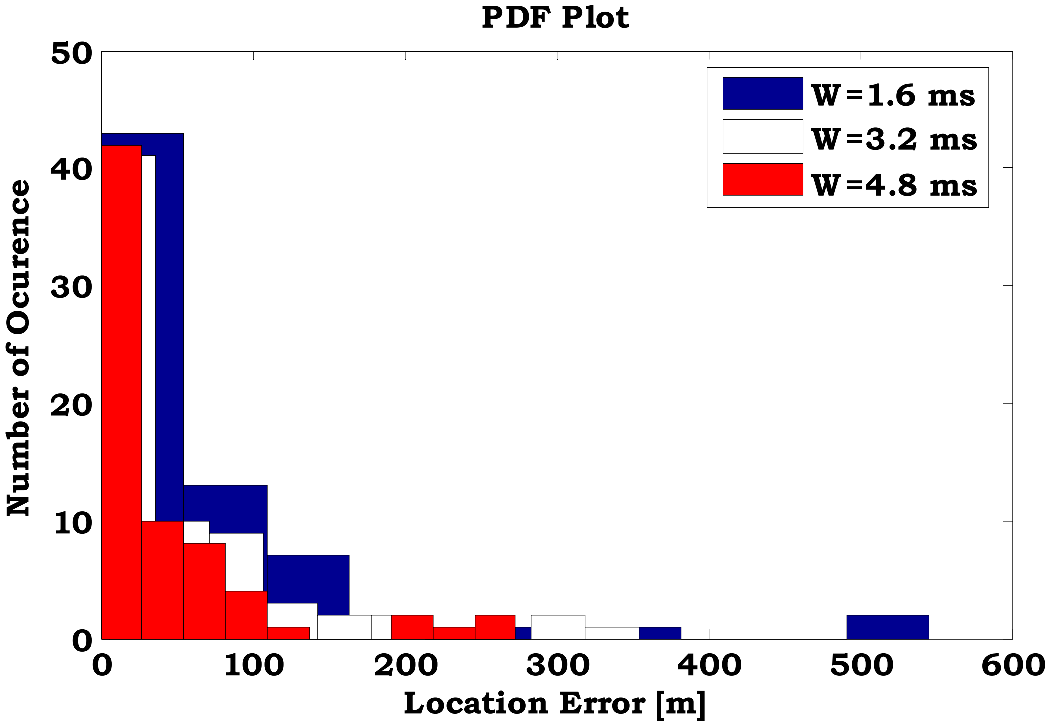


Figure 5.12 Histogram plots for RA-2 Channel Model

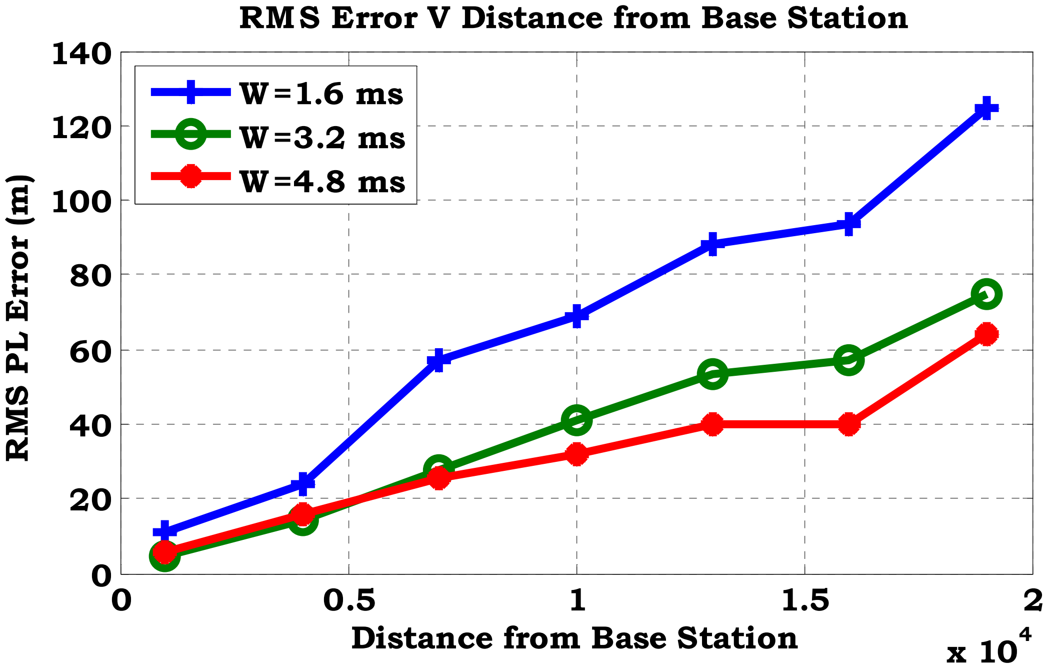


Figure 5.13 Effect of Distance from BS on PL for RA-1 Channel Model.

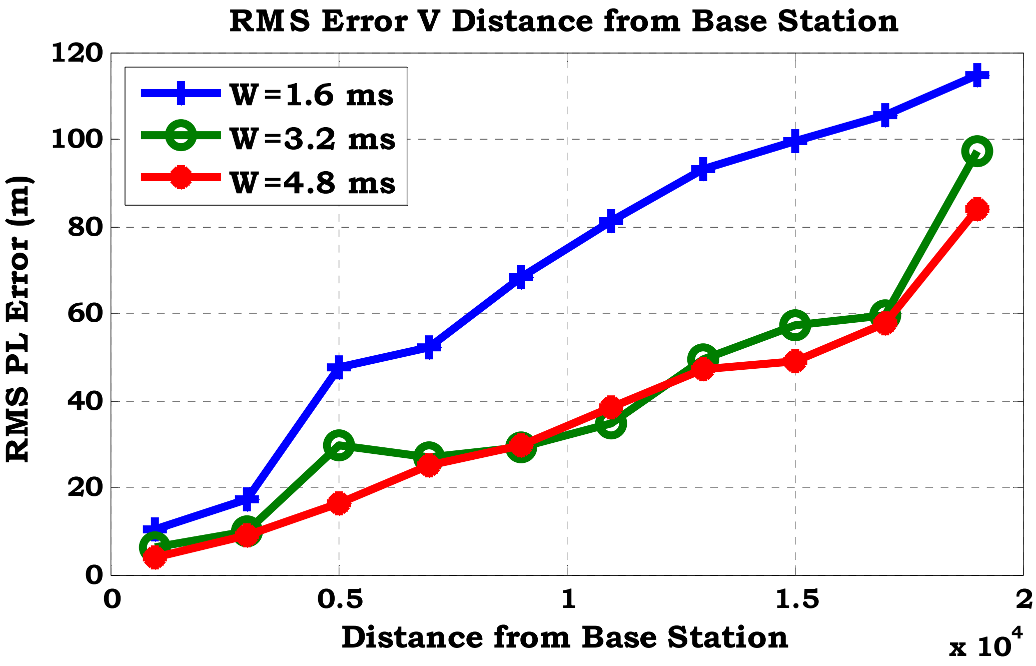


Figure 5.14 Effect of Distance from BS on PL for RA-2 Channel Model.

5.9 Conclusion

For RA-1 and RA-2 channel models we assume the first incoming path is the strongest and the multipath components are weaker. Hence for the implementation of the position location technique it is fairly good environment than urban environment. Application of fingerprint matching for rural area is not acceptable due to large coverage area. To take fingerprint variable measurement for large area is tedious.

Moreover base station distributions in rural environment are not as close to each other as in urban micro cells. This scenario makes it difficult to implement even other position location technique due to low signal to noise ratio when the MS is close to serving base station.

A hybrid TOA/AOA technique is very accurate only if the MS is in LOS with the serving base station. With NLOS propagation the signal arrive at the base station after reflection and diffraction in urban environment. As a result of this estimation of TOA and AOA are erroneous. Rural and suburban environments are a candidate for the implementation of the hybrid TOA/AOA technique.

5.10 Summary

In this chapter position location technique using hybrid PL technique based on time and angle of arrival technique using smart antenna was discussed. This technique is suited for environment where there is strong line of sight signal. The simulation model for the technique and the simulation result for RA-1 and RA-2 channel model were also presented.

Chapter 6
Conclusion and Recommendations for future works

6.1 Conclusions

In this thesis we have seen different position location techniques for cellular system. Broadly position location classified in two groups, handset based and network based. In handset based, position location is calculated at the handset. All the necessary signal parameter is measured from satellite or from base station. The coordinate of the base station must be known to the MS. GPS receiver is one technology in this category. This technique also called forward link position location technique. Handset based location system require the modification both software and hardware of the apparatus. To use GPS technology in current cellular system a hardware change is required which makes millions of legacy apparatus not compatible for location service.

Network based location techniques, also called reverse link position location technique, which use signal parameter from mobile station for position estimation. This technique does not need modification of the legacy apparatus. Position location is calculated at network side which has high computational capacity compared to handset.

Most of the location techniques studied so far needs a minimum of three base station measurements for location of mobile station. As the number of base station measurement increases the accuracy of the location increases. In addition most of position location techniques which depend on time or angle measurement requires or assumes a line of sight signal for location estimation. Line of sight may be assumed for rural and suburban environment. A hybrid TOA/AOA technique is an optimum solution in this environment. When compared to urban micro cell the radius of cell in suburban and rural environment is large. It is difficult to get three measurements adequately because of the size of the cell. Due to this, position location technique using single BS has great advantage.

Location technique which is good for one environment may not have equal performance when implemented in other environments i.e. position location that assume a line of sight signal is not feasible for urban environment. Fingerprint matching is an optimum solution for urban environment. It uses the actual path loss of the propagation environment. The technique can be implemented using single base station. Additionally no modification of handset is required.

Using more number of base stations for position location needs a coordination of all base station involved in location measurement, this increase the signaling link of the communication network. This is also one disadvantage of using multiple base stations even though the accuracy of the location increases.

Smart antennas beside its great advantage in wireless communication can also improve position location technique. Using smart antenna both time and direction can be measured, and hence a position of a mobile subscriber can be located with an intersection of a line and a circle. Most of the problem in other location technique is solved since we can locate a subscriber using only a single base station. There is no coordination between base stations so there is no increase in signaling link. In an urban environment, sometimes it is difficult to get three or more base station for position estimation. Using smart antenna address the solution for this problem.

Smart antenna also gives an additional variable for the database finger print i.e. the directions which give better accuracy for the implementation. It helps to solve ambiguity when two different locations have nearly the same signal strength contribution from the same base stations.

6.2 Recommendation for Future Works

There are other techniques which are not covered in this work. In most position location techniques assumes LOS signal. If the signal is not LOS the performance of the technique degrades. Identifying the LOS and NLOS and using LOS signal for position location is one of research area.

Position location using neural network and position location using Kalman filter is also another research area. Kalman filtering is also used to remove noise in the received signal strength. These techniques in conjunction to the already exiting techniques may improve the position location techniques. Based on hybrid position location technique a combination of different technique can be studied. Limitation of other technique can be compensated by the other technique. A combination of AOA/TDOA, AOA/RSS or Cell-ID/TA/RSS and any other combination may gives us better performance for the propagation environment we need to implement the position location technique.

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