LOCALIZATION OF MOBILE PHONES BASED ON UPLINK TIME DIFFERENCE OF ARRIVAL

A Project Report

submitted by

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in partial fulfilment of the requirements

for the award of the degree of

MASTER OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY MADRAS.

May 12, 2013

THESIS CERTIFICATE

This is to certify that the thesis titled **LOCALIZATION OF MOBILE PHONES BASED ON UPLINK TIME DIFFERENCE OF ARRIVAL**, submitted by **Gouda Bikshapathi**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Date: 12th May 2013

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my parents for their support and encouragement without which learning in and becoming a part of such a prestigious institution would not have been possible. I would like to dedicate this work to them.

I am ever thankful to Dr. krishna Jagannathan, Dr. Sheetal Kalyani, Dr. Radhakrishna Ganti and Dr. Gaurav Raina for their continual support and invaluable advice throughout the duration of my project. I feel honoured and encouraged to have worked under their guidance. I would also like to take this opportunity to thank my professors at IIT Madras, Prof. David Koilpillai, Prof. Aravind, Dr. Srikrishna Bhashyam, and Dr. Arun Pachai Kannu who have imparted knowledge and have motivated me to learn the intricacies of the subjects.

Last but not the least, I would like to thank my friends and labmates Anji, Prashanth, Sudharshan, Ravi, Aseem, Laxman, Anjan, Debayani, Kiran, Kiran D, Avinash, Sanjay, Rohit and Jagdeesh, some others about whom I have not mentioned here for their help and encouragement.I had fun filled sessions in the lab with my friends and enjoyed through and through my stay here.

ABSTRACT

KEYWORDS: Localization; Time Difference Of Arraival (TDOA); Adaptive Line Enhancer (ALE); Correlation

We are trying to find the location of mobile station, by sending a narrow band signal from mobile station to surrounded base stations. We will pass the received signal at each base station, through an adaptive line enhancer which will remove the broad band noise from the received signal. Then we will cross correlate the received signal with a reference base station, so that we can find the time difference of arrival at different base stations with respect to reference base station.

For more precise time information the auto correlation function of narrow band signal should decay faster near the origin (the main lobe width should be minimum).Sharper the autocorrelation function gives accurate timing information and that will also reduce the number of taps required for adaptive line enhancer, so that the computation complexity will also be reduced.

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CHAPTER 1

Introduction

Mobile phones are not just for communication, they have numerous other applications as well. Among those, there are many real time applications such as identifying the location of a person or object (ATMs, Restaurants, Shopping malls, Railway stations, etc.), navigation, security purposes, tracking vehicles and finding the traffic. All these applications depend on the location of mobile phone.

The location of mobile station is find, based on the uplink time difference of arrival. Initially the mobile station sends a narrow band signal. It will receive by all nearest base stations, then all the base stations send that signal to a core network (MSC) with a common reference time. Those signals pass through an adaptive filters to remove the broad band noise, so the SNR after the filter will improve. Now by doing cross correlation with a reference base station signal, we get the time difference of arrival with respect to that base station. Once we get the time difference of arrival at different base stations, we have many algorithm to find the optimal solution for the mobile position. In this thesis we explained Least Square, Taylor Series, Two Step algorithms. Taylor series, Two step algorithms are most commonly used. In the simulations we used Taylor series algorithm to find the optimal solution for mobile station position.

The terrains around all base stations are not same, different base stations have different channel models. The channel models are basically depends on the coverage area and obstacles in that area. We considered different channel models (such as CoST207 Typical Urban (TU), Bad Urban (BU) and 3GPP) for different base stations.

The mobile is always not in LOS with the base station, so there is error in the mobile position due to the NLOS path. Here we are characterizing the NLOS error as truncated Gaussian noise with some bias. In practical there should some error in the measurements we consider that error as unbiased Gaussian noise with 0.01 variance.

In upcoming technologies the location of mobile station will play a crucial role. The features of the mobile phone will be available based in your location.

Flow of the thesis:

The rest of the thesis is organized as follows. In Chapter 2, Brief description on different methods for localization of mobile phones based on time, angle and signal strength. In Chapter 3, we present different algorithms to find the location of mobile phone based on TDoA measurement. In Chapter 4, we will study the estimation of transmitted narrow band signal in different channel environments and find the time difference using cross-correlation. Chapter 5 is for the simulation results and Chapter 6 includes the conclusion and future work.

CHAPTER 2

Localization Techniques

Different methods have been proposed based on the requirement of application i.e. where we need the resultant location of mobile phone. Here we will discuss some methods.

2.1 Global Positioning System

GPS (Enge and Misra (1999)) was developed by the Department of Defence (DoD) for the U.S military applications. Later it was opened for public uses, such as determination of the location of mobiles users. GPS is a satellite based localization technique. Satellites send their position and transmit time to the receiver. The receiver calculates the distance from each satellite by using transit time of signal. The receiver needs signalling from at least three satellites to find its 3-dimensional position and one more satellite to synchronize the clocks between the receiver and the satellites.

GPS needs line-of-sight from satellites to mobile station (receiver) to find the accurate position of the mobile phone, which is not possible in most of the cases. However, it consumes a lot of power and also is not available in many mobile phones.

2.2 Time based location techniques

2.2.1 Timing Advance (TA)

To synchronize the TDMA frame at the Base Station (BS), the mobile phones have to send their data, advance in time. This advance in time depends on the distance of the mobile phone from the BS. The mobiles in the sector of inner radius multiple of 550m and outer radius 550m more than the inner radius around the BS have the same timing advance because the gap between the time slots of TDMA frame is 3.693μs (one GSM bit period), which corresponds to a distance of 550m from BS to MS ($distance\ (BS - MS - BS)\ = velocity \times time$). The BS sends the same TA (Axe (2005)) value to all mobile phones which are in the same sector, through a control channel so we can find the location (sector) of the mobile by knowing the TA value.

The TA is a 6 bit binary value to represent the numbers from 0 to 63. TA value 0 represents a circle with radius 550m, the maximum value of TA (63) represent the distance of greater than 34.9km, which is the maximum coverage range of a BS.

2.2.2 Uplink Time of Arrival (U-ToA)

The Mobile Station (MS) send the burst signal to the associated and neighbouring base stations, the BS calculate the distance (which is a circle around the BS with distance as the radius) of MS by multiplying the signalling time with the velocity of light. To get the unique position of mobile phone we need three circles (formed by three nearest BSs), we can find it by trilateration method (Guvenc and Chong (2009)).

In this method, to get the accurate position of mobile phone synchronization between the BS and MS clocks are necessary. The mean error of this method in urban environment is 799.4m and 645.3m in suburban environment (Axe (2005)).

2.2.3 Uplink Time Difference of Arrival (U-TDoA)

The nearest BSs receive the signal from the mobile station. All these BSs send the received signal time to a server. It calculates the time difference between two BSs and convert that into distance and form a hyperbola. We need two hyperbolas to get the unique position of mobile phone (Paria S and R).

Here we need synchronization between the clocks of BSs to locate the mobile phone accurately. To get the accuracy below 50m, the resolution of the clocks should be in nanoseconds, so it is difficult to find the position of mobile phone with accuracy below 50m, using time based localization methods.

2.3 Angle of arrival location technique

BSs calculate the angle of arrived signal from MS using antenna arrays. We know the distance between the neighbouring BSs. With the Triangulation method the location of mobile phone is calculated. For this we need two base stations.

If there is LOS path exist between BSs and MS, the location of the mobile phone can be found accurately. But this is not the case in urban areas. Moreover extra hardware is required at every base station.

2.4 Signal strength based location techniques

2.4.1 RF Fingerprint

The properties of RF signal such as signal strength, delay are measured in different locations using mobile phone, and are stored into a data base. In different locations the properties of RF signal should be different, so the values can't be same for different locations. Now in real time, observe the data samples from the mobile phone, find the location of mobile using the reference data. There are many algorithms to do this, we can use either deterministic algorithms or probabilistic algorithms (LTA (2008)).

The accuracy depends on the propagation terrain and reference data. Updating reference data is required to locate the mobile phone accurately, because the environment changes with time.

2.4.2 Received Signal Strength (RSS)

This method (Suvi A (2003)) is same as ToA. The MS measures the received signal strength of the nearest BSs, sends this data to a server through associated BS. The server calculates the circular distance of mobile phone from each base station based on the received signal strength from the MS. Three circular distances are needed to get a unique location of mobile phone.

The accuracy of this method depends on the propagation environment. Small scale fading is the main factor to reduce the accuracy of mobile phone location in this method.

2.4.3 Signal Pattern Recognition

In this method (Suvi A (2003)) there is no need of over signalling to locate the mobile phones, the location is made by using HMM and Viterbi algorithms.

When a caller makes call, the associated BS receives the information of uplink signal strength, downlink signal strength, TA, quality of the downlink signal and the neighbouring base station signal strengths for every 4.165ms (1 TDMA frame duration). This information is observed for some time period to compare this observed sequence with already predefined models, which are in the same TA zone, find a sequence from these predefined sequences. Then compute the most probable sequence using Viterbi algorithm, which is the estimated path followed by the caller.

The accuracy depends on the propagation terrain, observed signal length and the number of predefined models.The possible accuracy is less than 100m.

2.5 Hybrid location techniques

Hybrid methods (Axe (2005); Suvi A (2003)) are combination of the above methods, developed to localize the mobile phones accurately.

AoA and ToA: This is a good method to find the location of mobile phones in rural and suburban areas, where BSs are far from each other. Single BS is enough to find the location of mobile phone. By using ToA method, BS can find the circular distance of mobile phone around it. By using AoA method, BS find the angle of the received signal from MS. Taking both of these measurements into account we can calculate the position of the mobile phone.

The accuracy of this method based on the synchronization of the clocks between BS and MS as well as the beam width of the array antenna.

AoA and TDoA: This method can be used anywhere. In this method two BSs are needed to finds the location of mobile phone. In TDoA method with two BSs, the server find the distance of mobile phone from two BS and forms a hyperbolic curve. In AoA method, the associated BS sends the angle of received signal from the MS to that server. The server calculate the location of mobile phone. This method shows 20-60% improvement on normal AoA method.

The disadvantages of hybrid methods are that it requires more processing delay and more cost to implement.

2.6 Hidden Markov Model (HMM)

In Markov Model the states, their transition probabilities, and the initial probabilities are known for a system. The probability of the next state in Markov model depends only on the current state.

In HMM the states are hidden (Stamp (2011)). State, transition probabilities, initial probabilities and the observed sample probabilities of given state are known for a system. We can compute the probability of state sequence by observing sequence of samples. This can be easily explained by the following assumptions. Suppose there are N states $S = \{s_1, s_2, s_3...s_N\}$, with initial state distribution $\pi = \pi_i, (\pi_i = (Pr(s_i\, at\, initial\, time)))$ and transition probabilities $A = \{a_{ij}\}$ $(a_{ij} = Pr(s_i\, at\, time\, t+1/s_j\ at\ time\ t))$, M possible observation samples $V = \{v_1, v_2, v_3...v_M\}$ with observed sample probabilities $B = \{b_{j(k)}\}$ $(b_{j(k)} = Pr(v_k\ at\ time\ t/s_j\ at\ time\ t))$. Observe a sequence of samples from the set V (the states are unobserved in this case), for time period $T = \{t_1, t_2, t_3, ...t_l\}$, the observation sequence is $O = \{0_1, 0_2, 0_3, ...0_l\}$. Now we have to find the maximum likelihood state sequence from the observed sequence. One way to find it is compute the probabilities of all combinational state sequences, then choose the maximum probability sequence as the optimal state sequence, which is difficult task and another way is maximize the probability $Pr(I, O/\lambda)$ using Viterbi algorithm. λ is the notation for HMM $\lambda = (A, B, \pi)$.

2.6.1 HMM based GSM localization

In this method (Ibrahim and Youssef (2011)), the area of interest is divided into grids. The state set S is the collection grids of the area, the observation set V contains associated cell tower ID and RSSI of mobile phone. The state transition probability matrix is formed based on the physical phenomenon of the area, the observation sample probability matrix find by computing the RSSI value of the associated cell tower in each grid. The initial state matrix is found by computed from the state transition matrix i.e. $\pi = A\pi$. The output observation set O has cell tower IDs and RSSI of mobile phone. By using Viterbi algorithm we can obtain the maximum probability state sequence.

However the accuracy depends on the grid size. The median error of this method in rural environment is 93.85m and 50.34m in urban environment.

CHAPTER 3

Location Algorithms based on TDoA measurement

3.1 Introduction

TDoA is better technique to find the location of mobile station compared to ToA, because in ToA the synchronization between the mobile station and base stations are necessary. Whereas in TDoA no need of synchronization between mobile station and base station, but there should be synchronization between the base station clocks. In TDoA mobile station send the signal to all it's neighbouring base stations, those signals will send to a core network, where we can find the time difference of arrival of signal at different base station by using cross correlation of received signals,by taking one of the base station as a reference base station.

Let say the signal received at i^{th} base station is at time t_i where $i = 1, 2, ...k$
Now we will find the time difference of arrival at different base stations w.r.t base station 1.

$$t_{i1} = t_i - t_1 \qquad i = 2, 3, ...k \tag{3.1}$$

$$t_{i1}.C = t_i.C - t_1.C \qquad i = 2, 3, ...k$$

where k is the maximum number of base stations associated to mobile station. $C(= 3 \times 10^8\ m/sec)$ is the speed of the light. r_i is the distance of mobile station from i^{th} base station, therefore

$$r_{i1} = r_i - r_1 \qquad i = 2, 3, ...k \tag{3.2}$$

Suppose the co-ordinates of mobile station is (x, y), i^{th} base station is (x_i, y_i). $i = 2, 3, ..k$, and the co-ordinates of base station 1 (reference base station) are $(0, 0)$. So the distance between mobile station and base station can be written as

$$r_i^2 = (x_i - x)^2 + (y_i - y)^2 \quad i = 2, 3, ...k \tag{3.3}$$

and

$$r_1^2 = x^2 + y^2 \tag{3.4}$$

By solving eq.(3.2), eq.(3.3) and eq.(3.4), we can find the position of mobile station. There are many algorithms to solve the above equations. Here we are explaining the three basic and popular algorithms to solve the above equations.

3.2 Least square Algorithm

For simplicity consider the number of base stations connected to mobile station is 3. from eq.(3.2),

$$r_{21}^2 = (r_2 - r_1)^2$$

$$r_{31}^2 = (r_3 - r_1)^2$$

Substitute eq.(3.3) and eq.(3.4) in above equations, we can rewrite the equations as

$$2x_2x + 2y_2y = -2r_{21}r_1 + x_2^2 + y_2^2 - r_{21}^2$$

$$2x_3x + 2y_3y = -2r_{31}r_1 + x_3^2 + y_3^2 - r_{31}^2$$

We can write the above equations in matrix form as

$$HX = r_1c + d \tag{3.5}$$

where

$$H = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix},\ X = \begin{bmatrix} x \\ y \end{bmatrix},\ c = \begin{bmatrix} -r_{21} \\ -r_{31} \end{bmatrix},\ d = \frac{1}{2}\begin{bmatrix} (x_2^2 + y_2^2) - r_{21}^2 \\ (x_3^2 + y_3^2) - r_{31}^2 \end{bmatrix}$$

the optimal solution for X is given by the equation

$$\widehat{X} = argmin\ ||HX - (r_1c + d)||^2$$

The optimal X is

$$\widehat{X} = pinv(H).(r_1 c + d) \tag{3.6}$$

Form the above optimal value we will get x and y in terms of r_1. Substitute x and y in eq.(3.4) and get the positive root for r_1 and back substitute in the eq.(3.6) then we will get the mobile station location (Sayed *et al.* (2005)). We can extend the number base stations greater than 3, and follow the same procedure.

The least square solution doesn't give appropriate solution for non-linear equations, so that we are going for Taylor series algorithm.

3.3 Taylor Series Algorithm

In this method (Foy (1976)) instead of solving nonlinear distance equations we are going to linearize the distance function using Taylor series approximation. The distance function is

$$f_{i1}(x, y, x_i, y_i) \cong r_{i1}^0 = r_{i1} - \epsilon_{i1} \quad i = 2, 3, ...k \tag{3.7}$$

Where r_{i1}^0 is the true value and $r_{i1}$is measured value, which may contains noise ϵ_{i1}, due to the NLOS measurements.
The Taylor series expansion of the above function is

$$f_{i1} + a_{i1}\delta x + a_{i2}\delta y = r_{i1} - \epsilon_{i1} \quad i = 2, 3, ..k \tag{3.8}$$

where $a_{i1} = \frac{\partial f_{i1}}{\partial x}$ and $a_{i2} = \frac{\partial f_{i1}}{\partial y}$ at (x, y)
For $k = 3$ we can write eq.(3.8) as

$$f_{21} + a_{21}\delta x + a_{22}\delta y = r_{21} - \epsilon_{21}$$

$$f_{31} + a_{31}\delta x + a_{32}\delta y = r_{31} - \epsilon_{31}$$

The matrix form of the above equations are

$$G.\delta X = h - \epsilon$$

where

$$G = \begin{bmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{bmatrix},\ \delta X = \begin{bmatrix} \delta x \\ \delta y \end{bmatrix},\ h = \begin{bmatrix} r_{21} - f_{21} \\ r_{31} - f_{31} \end{bmatrix}$$

The optimal solution for δX, with weighted matrix Q is given by the equation

$$\widehat{\delta X} = argmin\ \ (G\delta X - h)^T Q^{-1} (G\delta X - h)||$$

The optimal δX is

$$\widehat{\delta X} = (G^T Q^{-1} G)^{-1} G^T Q^{-1} h \tag{3.9}$$

The weighted matrix $Q^{-1} = E(\epsilon\epsilon^T)^{-1}$, and for Gaussian noise with variance σ_i^2 at base station i. The covariance matrix is given by

$$Q = \begin{bmatrix} \sigma_2^2 + \sigma_1^2 & \sigma_1^2 \\ \sigma_1^2 & \sigma_3^2 + \sigma_1^2 \end{bmatrix}$$

If the variances are equal then covariance matrix

$$Q = \sigma^2 \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$$

Let the initial guess of $(x, y) = (x_g, y_g)$ and it is updated as $x = x + \delta x$ and $y = y + \delta y$, the process repeats un-til δx and δy are small enough. The position of the mobile station is the final (x, y) coordinates.

The final solution of mobile station position without weighting matrix is as close as with weighting matrix, so no need worry about the NLOS error characteristic.

3.4 Two-Step Algorithm

The Taylor series algorithm has a problem with initial guess. It may not converge all the times or it may takes more iterations to converge which is computationally expensive. Here we are looking at another algorithm (Chan and Ho (1994)), which doesn't need of any initial guess and it will converge surely.

In this algorithm initially we assume that r_1 and x and y are independent and solve for r_1, x and y, then compute (x, y) with the constraint $r_1^2 = x^2 + y^2$.
From eq (3.2) and (3.3), with k=3

$$r_{21}^2 + 2r_{21}r_1 = x_2^2 + y_2^2 - 2x_2x - 2y_2y$$

$$r_{31}^2 + 2r_{31}r_1 = x_3^2 + y_3^2 - 2x_3x - 2y_3y$$

The matrix form of the above equations are

$$\varepsilon_1 = h_1 - G_1.u_1 \tag{3.10}$$

where

$$h_1 = \begin{bmatrix} r_{21}^2 - (x_2^2 + y_2^2) \\ r_{31}^2 - (x_3^2 + y_3^2) \end{bmatrix},\ G_1 = -2 \begin{bmatrix} x_2 & y_2 & r_{21} \\ x_3 & y_2 & r_{31} \end{bmatrix},\ u1 = \begin{bmatrix} x \\ y \\ r_1 \end{bmatrix}$$

The error matrix ε_1 is due to the error in measurements. Let r_{i1} is the measured value and r_{i1}^0 is the true value, therefore $r_{i1} = r_{i1}^0 + \delta r_{i1}$, here δr_{i1} is error in measurement. The optimal solution for eq ((3.10)) is given by the equation, with weighting matrix W_1 is

$$\widehat{u_1} = argmin\ \ (h_1 - G_1.u_1)^T W_1 (h_1 - G_1.u_1)$$

The solution for the above equation is

$$\widehat{u_1} = (G_1^T W_1 G_1)^{-1} G_1^T W_1 h_1 \tag{3.11}$$

where $W_1^{-1} = E(\epsilon_1 \epsilon_1^T)$

By substituting $r_{i1} = {r_{i1}}^0 + \delta r_{i1}$ and ${r_{i1}}^0 = {r_i}^0 + {r_1}^0$, we get the approximate value of $\epsilon_1 = (2r_2^0 \delta r_{21} \ \ 2r_3^0 \delta r_{31})^T$.

Therefore $W_1 = \frac{1}{4} {B_1^0}^{-1} Q^{-1} {B_1^0}^{-1}$. where $B_1^0 = diag(r_2^0, r_3^0)$ and Q is covariance matrix of errors. i.e, δr_{21} and δr_{31}.

Here we don't know the true values, so we use the measured values instead of true values, therefore $B_1 = diag(r_2, r_3)$ and weighting matrix becomes $W_1 = \frac{1}{4} {B_1}^{-1} Q^{-1} {B_1}^{-1}$. and we also don't know the r_2 and r_3, we will approximate u_1 as

$$\widehat{u_1} = (G_1^T Q^{-1} G_1)^{-1} G_1^T Q^{-1} h_1 \tag{3.12}$$

After getting r_2 and r_3 values, we will calculate W_1 matrix and find u_1 from the eq (3.11). We can repeat this process un-til r_2 and r_3 values will converges.

After getting the u_1 matrix, we will use the relation $r_1^2 = x^2 + y^2$. and we write the equations in matrix form as

$$\varepsilon_2 = h_2 - G_2.u_2$$

where

$$h_2 = \begin{bmatrix} u_1(1)^2 \\ u_1(2)^2 \\ u_1(3)^2 \end{bmatrix}, \ G_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{bmatrix}, \ u_2 = \begin{bmatrix} x^2 \\ y^2 \end{bmatrix}$$

The optimal solution for above equation , with weighting matrix W_2 is given by

$$\widehat{u_2} = argmin \ \ (h_2 - G_2.u_2)^T W_2 (h_2 - G_2.u_2)$$

The solution for the above equation is

$$\widehat{u_2} = (G_2^T W_2 G_2)^{-1} G_2^T W_2 h_2 \tag{3.13}$$

The weighting matrix, $\quad W_2^{-1} = E(\epsilon_2 \epsilon_2^T) = \frac{1}{4} B_2^0 E[\delta u_1 \delta {u_1}^T] B_2^0$.

Here $B_2^0 = diag(u_1(1), u_1(2), u_1(3))$.
From eq.(3.11) $cov(u1) = E[\delta u_1 \delta u_1{}^T] = G_1^0{}^T W_1 G_1^0{}^{-1}$
In practical we don't know B_2^0, G_1^0, so we will B_2, G_1 in their place, the effective weighting matrix is

$$W_2 = \frac{1}{4} B_2^{-1} G_1{}^T W_1 G_1 B_2^{-1}. \tag{3.14}$$

The final position of the mobile is estimated from the eq.(3.13) and (3.14). The sign of the mobile station coordinates preserves the sign in the initial solution i.e.,u_1. The two step algorithm is more dependent on the NLOS error. Different terrains have different kind of NLOS error distribution, and it changes with time, so we have to update the algorithm with appropriate NLOS error distribution.

3.5 Comparison of algorithms

Taylor series algorithm and Two step algorithms are more popular, here we are comparing two algorithms by taking a known mobile position and then adding biased Gaussian noise to the distance to make the mobile is in NLOS to the base stations. In this simulation we didn't use any weighting matrix for Taylor series algorithm still the performance of Taylor series algorithm is better than two step algorithm (Shen *et al.* (2008)).

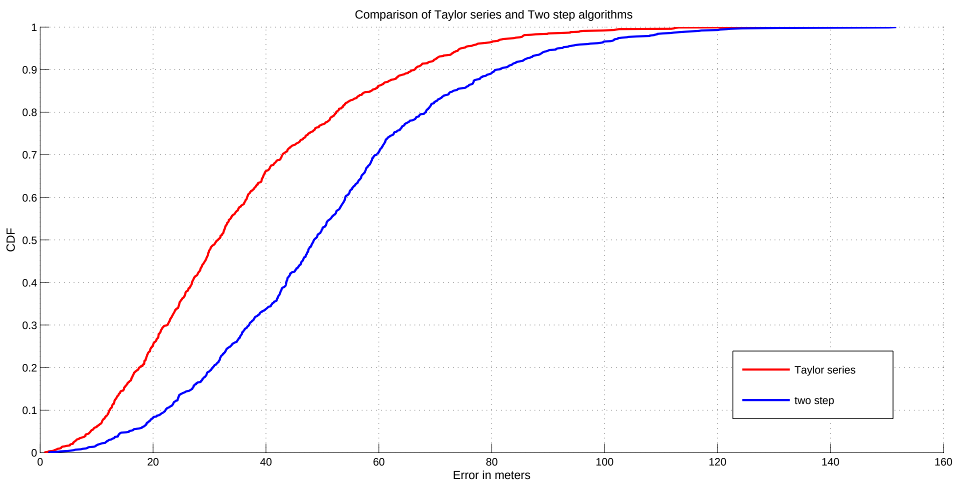

Figure 3.1: Comparison of Taylor series and Two step algorithms

CHAPTER 4

Channel modelling and adaptive filter

4.1 Channel modelling

There are many obstacles between the transmitter and mobile station. If we transmit a signal at the transmitter, it reaches the receiver (mobile user) through multiple paths. So we can model the impulse response of the channel $h(\tau)$ as sum of the impulses with different amplitudes a_i and different propagation delays τ_i.

$$h(\tau) = \sum_i a_i \delta(\tau - \tau_i) \tag{4.1}$$

These multiple paths are due to Reflections, Scatterings and Diffractions (RAP). When the EM wave hits an object which is larger in size compared to wavelength of the signal it gets reflection, scattering occurs when the signal hits an object whose size is in the order of the wavelength of the signal or less and diffraction occurs at the edge of an obstacle which is large compared to wavelength of the signal.

Here we define the parameters of wireless channel to describe the type of channel

- Doppler shift(f_D)–Change in the frequency of propagation wave due to relative motion between transmitter and receiver.
- Doppler spread(D_s)–The maximum difference between the Doppler shifts of the paths contributing to a tap.
- Coherence time(T_c)–The time interval for which the channel taps are constant. This is inversely proportional to Doppler spread.
- Delay spread(T_d)–Difference between the delay times of longest and shortest paths (considering only significant energy paths).
- Coherence bandwidth(W_c)–The range of frequencies over which the channel is coherent (flat).

4.1.1 Fading of wireless channel

The received signal strength varies with time and frequency which is known as *fading*. We can divide this variation into two types. *Small scale fading* is the rapid fluctuations in signal strength as the mobile moves through a small distance. This is mainly due to scattering. There are different types of small scale fading based on Doppler spread and delay spread: Fast fading ($T_c \ll Delay\ requirement$), Slow fading ($T_c \gg Delay\ requirement$), Flat fading ($W \ll W_c$) and Frequency selective fading ($W \gg W_c$). We can model these channel taps with Rician and Rayleigh distributions (DAV (2005)). If there is a line-of-sight (LOS) path exist between transmitter and receiver we can model with Rician distribution and if there is no LOS path exist between transmitter and receiver we can model with Rayleigh distribution. *Large scale fading* is the path loss with distance and shadowing by the large obstacles as the mobile moves through a distance of the order of cell size. We can model these channel taps with Log-normal distribution (RAP) . This Log-normal distribution determines the variation of signal strength due to shadowing for same transmitter, receiver separation.

4.1.2 Channel models

To provide better coverage we divide the area into cells as Macro, Micro and Pico (Quek (2005); Mauri (2012)). A Macro cell covers the range from 1km to 30km. The base station antennas are usually mounted on the buildings or hills, and their transmitted power is 20 to 40W. These are located in less interference areas such as rural, open places. A Micro cell covers the range from 100m to 1km. The height of the base station antenna is comparable to the buildings, and the transmitted power of these antennas is 5 to 15W. These are installed in high interference areas as traffic zones ,shopping malls. Pico cell covers the range from 4m to 400m. These antennas are very small and the transmitted power is below 1W. These are located in rooms, tunnels, airport etc.,

We use different propagation models for indoor and outdoor environment with different cell sizes, such as Okumura model, Hata model, COST models and 3GPP models. Okumura, Hata models are for narrow band channels whereas COST, 3GPP models are for wide band channels.

Okumura model (RAP) is developed based on the measurements of signal attenuation with frequency and distance in urban environment with constant base station and mobile station antenna heights. Okumura drew the curves based on these measurements, the curves were meant to determine the attenuation as a function of frequency ranges from 100MHz to 1920MHz and the distance ranges from 1km to 100km. Then he developed an equation based on this and added some correction factor to that equation to account for different propagation environments. The disadvantage of this model is its slow response to the rapid changes of propagation terrain.

Hata model (RAP) is an empirical formulation of data given by Okumura, with frequency ranges from 150MHz to 1500MHz. Hata gave some formula for correction based on propagation environment and he took the heights of antennas are also variables. This model is good for large cell sites but not for cell sites of the size less than 1km radius (Personal communications systems).

These models are developed based on the measurement data, do not suitable for all environments and also didn't specify anything about the Doppler spectrum.

COST channel models

cost207 : COST 207 (COS (1989)) channel models are developed for 2G GSM communications, with carrier frequency 900MHz and bandwidth is 8-10MHz. This model specifies four outdoor macro cell scenarios such as Rural Area (RA), Typical Urban (TU), Bad Urban (BU), Hilly Terrain (HT). It provides the Power Delay Profile (PDP) of these scenarios with different decay exponentials and four Doppler spectrums for each scenario based on the delay (τ) of PDP. The four Doppler spectrums are CLASSIC for $\tau \leq 0.5\mu s$, GAUSSIAN1 for $0.5\mu s < \tau \leq 2\mu s$, GAUSSIAN2 for $\tau > 2\mu s$ and RICE for LOS path. COST 207 uses 4 to 12 unevenly spaced taps to implement the channel PDP.

As the capacity increases, the cell size decreases from macro to micro and pico, COST 207 didn't consider the micro, pico cell scenarios. Moreover it didn't mention anything about the power loss with distance for different environments.

COST 259 : As the applications increase, the data rate of the channel changes, so the channel has to accommodate from low data rate such as voice to high data rate such as files, videos and to improve the quality of service it is better to approximate the channel models distinguishably for different environments.

COST 259 (3GP (2004-12)) specifies the channel models for different environments with cell type macro, micro and pico. The carrier frequencies for macro cell is 900MHz or 1.8GHz, for micro cell is 1.2GHz or 5GHz and for pico cell 2.5GHz or 24GHz, with the bandwidth less than 10GHz.

Macro	**Micro**	**Pico**
Typical Urban	Street Canyons	Tunnel/Corridor
Bad Urban	Open Places	Factory
Rural Area	Tunnels	Office/Residential Home
Hilly Terrain	Street Crossings	Open Lounge

Table 4.1: Cost259 specify channel models for the above environments[6]

In COST 259 models the channel is specified by the number of clusters. A cluster is group of rays which travel approximately the same distance. Each cluster decreases exponentially with delay. Channel is fully described by the following parameters { $P_i, \tau_i, \sigma_{\tau,i}$ }, where i is the number of clusters, P_i is total power in cluster i, τ_i is the delay of the first path in cluster i and $\sigma_{\tau,i}$ is i^{th}cluster rms delay spread.

COST 259 models considered different parameters of the propagation channel such as path loss, fast fading (small scale effect), shadow fading (large scale effects), delay spread and angle of arrival. The drawback of all these channels are, uses less bandwidth.

3GPP channel models

The data rates provided by the 3GPP channel models are for uplink 128kbps, 5.7Mbps, 11Mbps, 75Mbps and 500Mbps, for downlink 384kbps, 14Mbps, 28Mbps,300Mbps and 1Gbps. These channel models can be well suitable beyond 3G systems also.

3GPP (3GP (2004-12)) channel models are developed by the analysis of different channel models in different environments. These channel models are similar to COST 259 channel models and simple to implement. These channel models are also specified by the number of clusters. The total power of each cluster is normalized in such a way that the maximum total power in any of the cluster is 1W. 3GPP channel models use up to 20 taps to describe the power delay profile, these channel taps are generated as i.i.d random variables from uniform distribution in the interval $[0, 0.4\sigma_\tau]$, the Doppler spectrum is RICE for LOS path, Classic for non-line-of-sight (NLOS) paths.

3GPP specify the channel models for Typical Urban (TU) with mobile speed 3, 50 and 120kmph, Rural Area (RA) with mobile speed 120 and 250kmph and Hilly Terrain (HT) with mobile speed 120kmph. Channel modelling parameters for the above environments are listed in the table 4.2.

Terrain	**Channel shape**	N_c	$P_i(W)$	$\tau(\mu s)$	$\sigma_\tau(\mu s)$
TU	Single cluster with all NLOS paths	1 with 20 taps	$P_1 = 1$	$\tau_1 = 0$	$\sigma_{\tau,1} = 0.5$
RA	Single cluster with one LOS path	1 with 10 taps	$P_1 = 1$ $P_2 = 0.43$ (Direct path)	$\tau_1 = 0$ $\tau_2 = 0$	$\sigma_{\tau,1} = 0.14$
HT	Two clusters with all NLOS path	2 with 10 for each	$P_1 = 1$ $P_2 = 0.04$	$\tau_1 = 0$ $\tau_1 = 15$	$\sigma_{\tau,1} = 0.29$ $\sigma_{\tau,2} = 1$

Table 4.2: 3gpp channel modelling parameters for TU, RA, HT.

4.2 Adaptive line Enhancer

Adaptive line enhancer is a time varying system, which will predict the original narrow band signal from the noisy input signal. The filter contain fixed number of taps and weights of these taps are varying according to the error at the output (Storey (2013)).

Let say the input is $r[n] = s[n]+n[n]$, where $s[n]$ is the desired signal and $n[n]$ is the Gaussian noise.The desired signal $s[n]$ is narrow band signal, so there is a correlation between adjacent samples. To decorrelate the Gaussian noise we will send the delayed version of input through the adaptive filter.

The adaptive filter predict the n^{th} sample from previous $M + 1$ samples and compare with the original input, the error in predicted output and original input is used to update the filter weights.

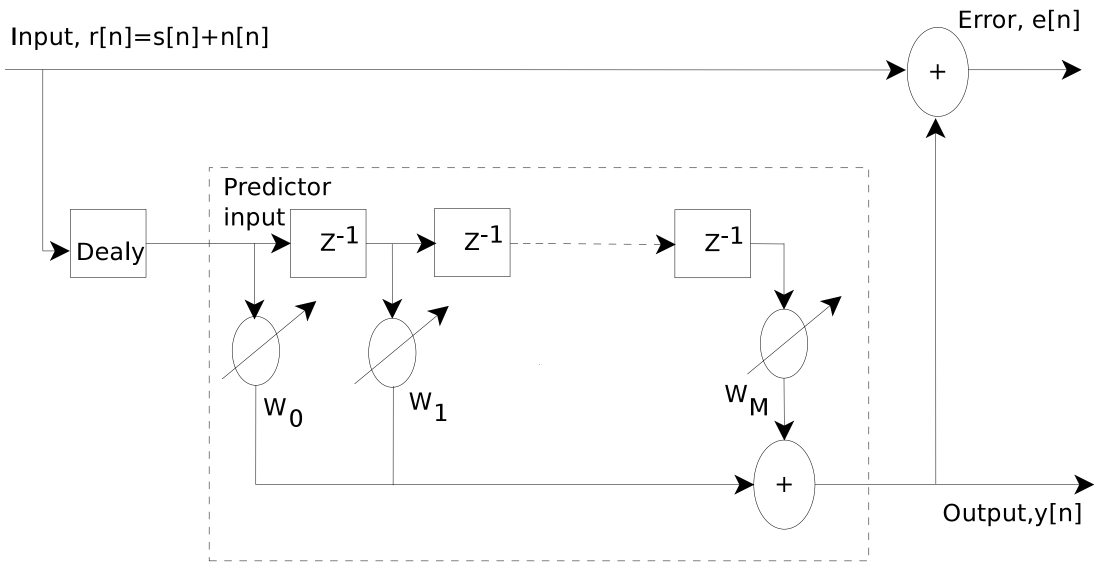

Figure 4.1: Least mean square Adaptive Line Enhancer

The Adaptive filter output

$$y[n] = \mathbf{w}_n.\mathbf{r}_{n-\Delta} \tag{4.2}$$

where $\mathbf{w}_n = [w_o\; w_1\; w_2....w_M]$ and $\mathbf{r}_n = [r_o\; r_1\; r_2....r_M]$.
The error signal $e[n]$ will be

$$e[n] = r[n] - y[n] \tag{4.3}$$

The filter weights update using NLMS algorithm as

$$\mathbf{w}_{n+1} = \mathbf{w}_n + \mu e_n \frac{\mathbf{r}_{n-\Delta}}{||\mathbf{r}_n{}^2||} \tag{4.4}$$

Where μ is the step size it varies from 0 to 1. If the μ value is high the weights will be update fastly but the error will be more. For this application the μ value is 0.001.

In figure (4.2) the red curve is sinusoidal signal added with Gaussian noise which is the input (blue colour curve) to the adaptive filter. The green curve is the adaptive filter output, which is the prediction to the input sinusoidal signal. The filter output is closer estimation of the desired sinusoidal signal. The adaptive filter remove the noise to some

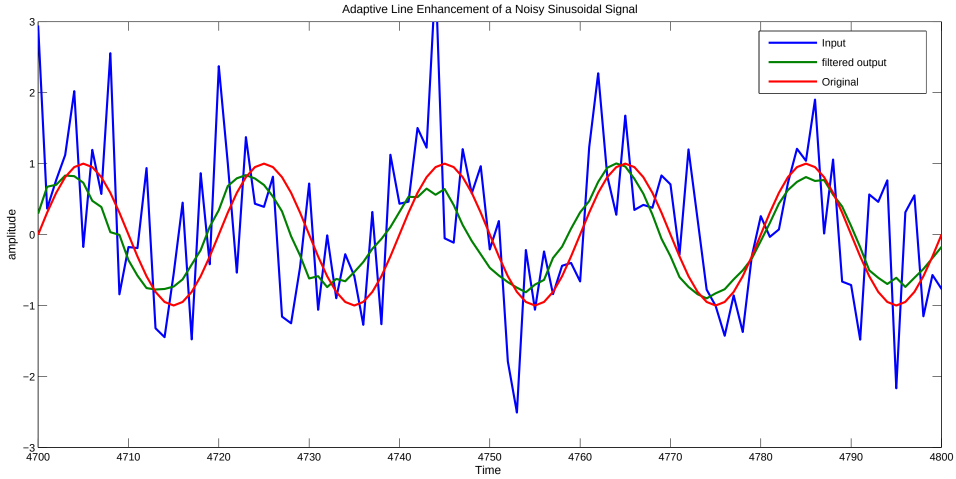

Figure 4.2: Analysis of noisy sinusoidal through Adaptive filter

extend, so the SNR at the receiver will increase.

4.3 Autocorrelation

The pilot signal, which we are sending from the mobile station will place a crucial role to get the precise time information at the receiver. The autocorrelation function of the signal should be sharp that mean it should decay faster, then only we will get the accurate timing information and it is also robust to the noise added to the signal. The signal should also be narrow band (correlation between adjacent sample), then only we can estimate it with adaptive filter.

Fig 4.3 and 4.4 are autocorrelation functions of 1hz sinusoidal of 1s duration with phase 0^0 and 90^0 respectively. The equations for the above auto correlation functions are given in the appendix.
The autocorrelation with phase 90^0 is decaying rapidly compare to 0^0 phase sinusoidal signal, so it is better to use 90^0 phase shifted sinusoidal as the pilot signal instead of 0^0 phase sinusoidal.

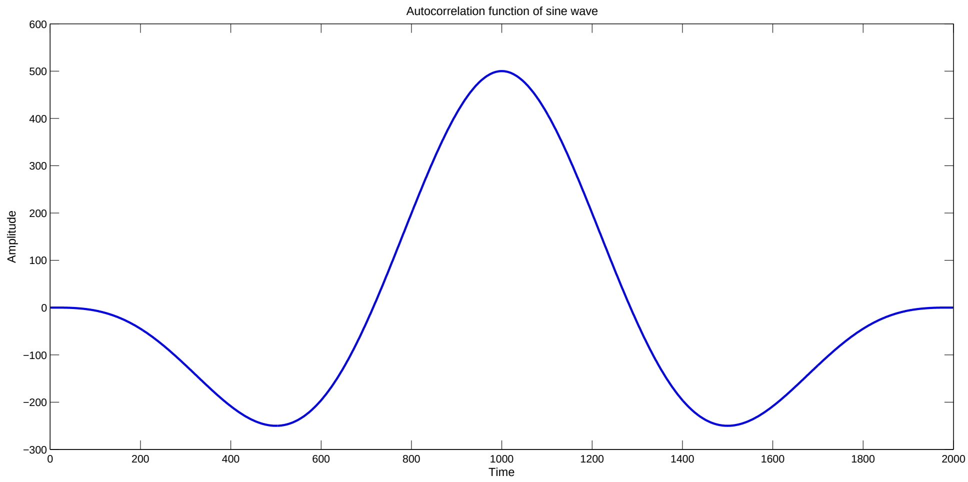

Figure 4.3: Auto correlation function of Sine wave

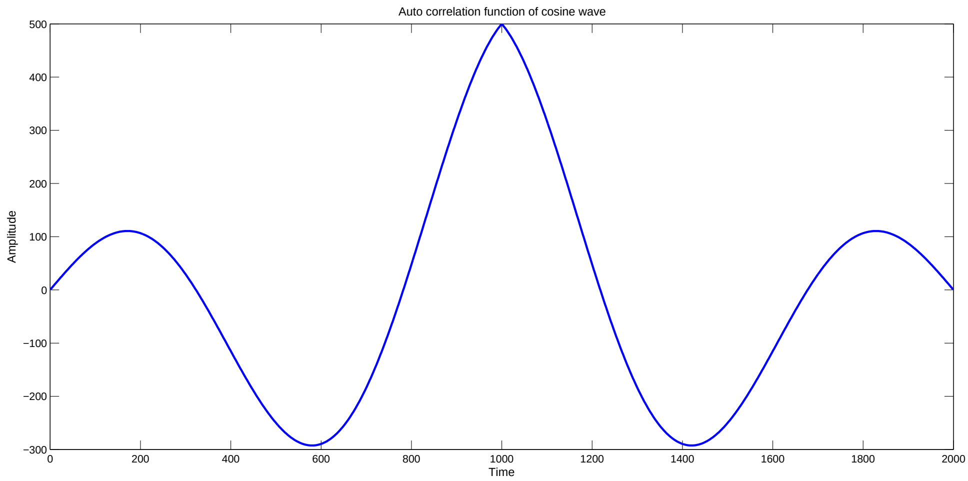

Figure 4.4: Auto correlation function of Cosine wave

CHAPTER 5

Simulations and results

The block diagram in fig 5.1 shows, how the mobile station position estimation will be done. Initially the mobile station sends the signal to all it's neighbouring base stations. The received signals pass through an adaptive filter, then we will find the time difference of arrival at different base stations with reference to a base station, using cross correlation (Mardeni *et al.* (2012)).

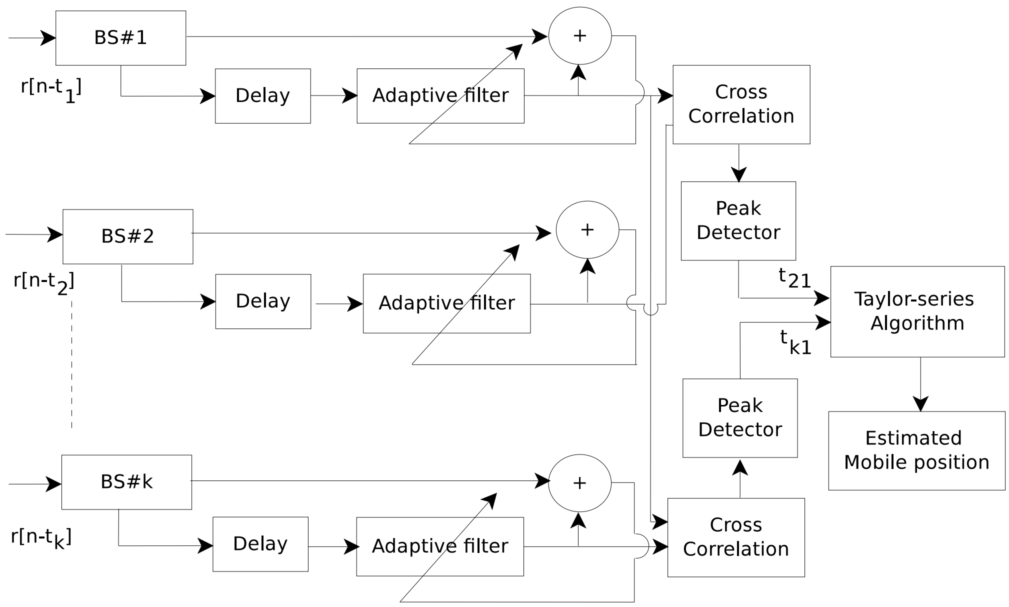

Figure 5.1: Block diagram of Localization system

For simulation purpose we considered 7 base stations placed at $(0\,0)$, $(4.5R\,\sqrt{3}R/2)$, $(1.5R\,2.5\sqrt{3}R)$ $(3R\,-2\sqrt{3}R)$, $(-1.5R\,-2.5\sqrt{3}R)$, $(-3R\,2\sqrt{3}R)$ $(-4.5R\,-\sqrt{3}R/2)$, with $R = 500$, the position of mobile station is at $(500\,600)$. The mobile station send a signal (1Khz, 1ms duration sine and cosine signals) to all base stations and it will received by base stations through different channels (for channel models refer chapter 4). It is always not be the case the mobile is in LOS with the base station, moreover in the case of urban area the mobile is NLOS with base station most of the times. So we added NLOS error to the distance from Gaussian distribution, which is shown in the figure 5.2. There is also be some error in the measurement we took it has unbiased Gaussian random variable with variance 0.01 (Hussain *et al.* (2012)). Finally we used Taylor series method to estimate the position of the mobile station.

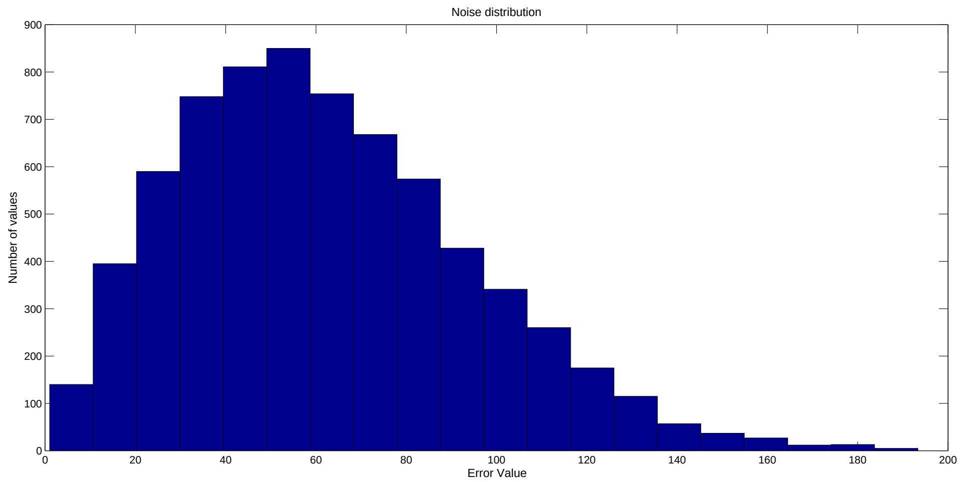

Figure 5.2: NLOS error distribution

Fig.5.3 and 5.4 are cumulative error distribution of mobile position estimation, with 32 tap adaptive filter and the SNR at the receivers are 5db and 15db respectively. Fig. 5.5 and 5.6 are also cumulative error distribution of the mobile position estimation, but with 128 tap adaptive filter and the SNR's are 5db, 15 db respectively. In both the cases cosine wave performs better than sine wave.

As the number of filter taps increases, the accuracy of estimating mobile position increases. The estimation accuracy with cosine wave at 5db SNR, with 32 tap adaptive filter is better than sine wave at 15db, with 128 tap filter. By using cosine waves we can also reduce the number of filter taps, so that the computation complexity of the system will also reduce. The mean error in estimation of mobile station with sine and cosine waves are pilot signals are shown in table 5.1.

In all the cases with cosine wave as a pilot signal,90% of error is below 100 meters. We can say that at minimum possible conditions, for 67% of call the error will be below 100 meter. So this is usefull for E911 applications and for other applications such as

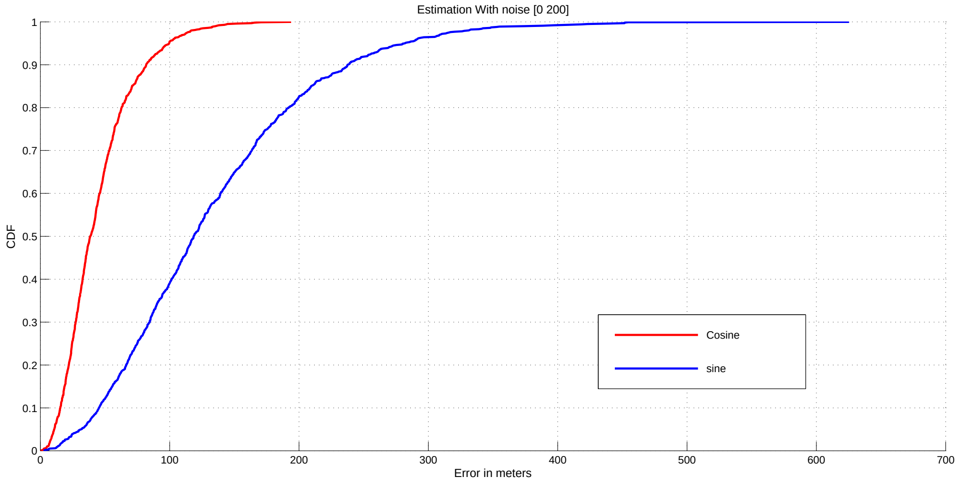

Figure 5.3: Error cdf with 5db SNR and 32 taps

S.NO	taps	SNR (db)	mean error with sine	mean error with cosine
1	32	5	133.06	44.71
2	32	15	95.322	29.71
3	128	5	116.77	37.63
4	128	15	93.79	28.64

Table 5.1: Mean errors in mobile position estimation

navigation and tracking of vehicles.

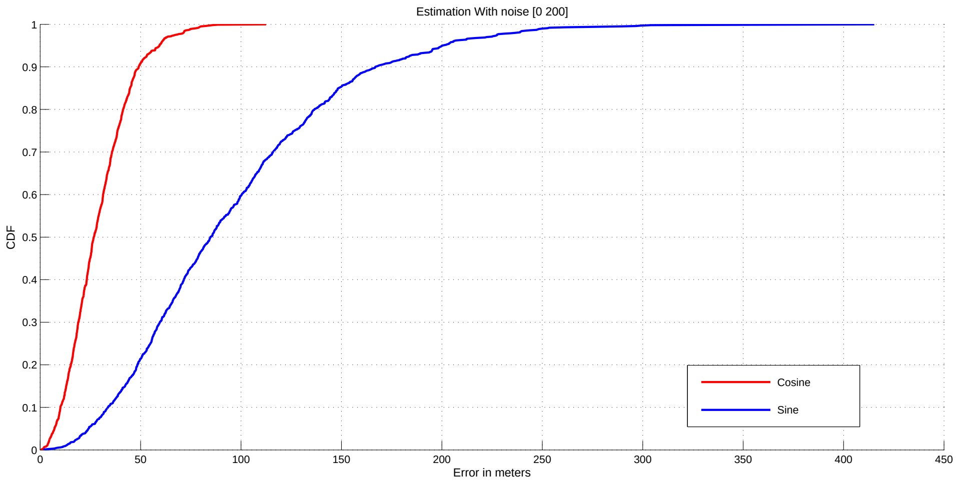

Figure 5.4: Error cdf with 15db SNR and 32 taps

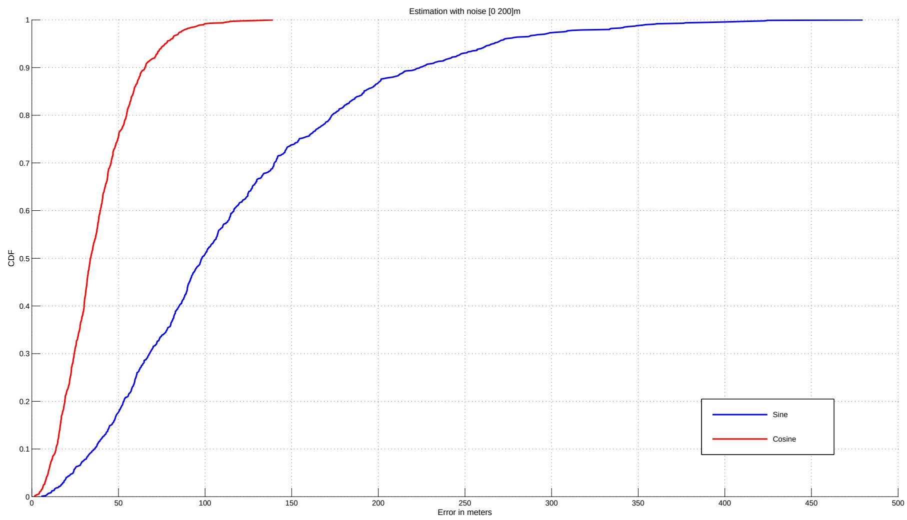

Figure 5.5: Error cdf with 5db SNR and 128 taps

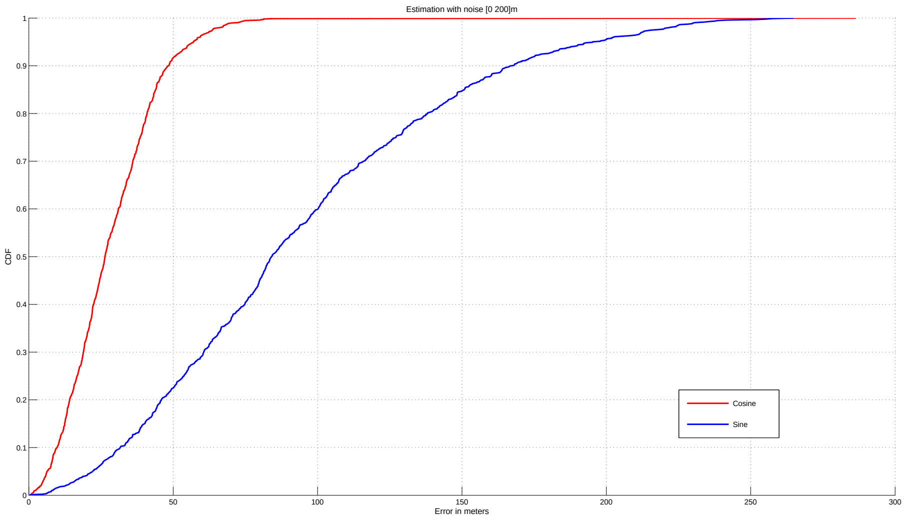

Figure 5.6: Error cdf with 15db SNR and 128 taps

CHAPTER 6

Conclusion

To estimate the mobile position using TDoA we require at least 3 base stations. The estimation is possible when the mobile is in standby mode.

The Taylor series algorithm performs better than two step algorithm, but the problem with it's initial guess. If the initial guess will be close then it will converge in lesser number of iterations, which is computationally efficient.

The time difference information is based on the autocorrelation function of the pilot signal. If the autocorrelation function of the pilot signal sharp we will get the precise time information.

We test the above system in different channel models such as COST207, 3GPP and GSM channel models. The error in location estimation also depends on the channel models. This localization system will be usefull for most of the applications including E-911 emergency services.

6.1 Future work

Choose the initial guess of the Taylor series method such that it will surely converge with lesser number of iterations.

Choose the pilot signal which has narrow bandwidth and it's autocorrelation function is sharp and decay faster, so that we will get accurate time information.

APPENDIX A

APPENDIX

The autocorrelation function of sine wave of 1hz frequency and 1s duration. Consider the duration of 1s is 1 unit.

For $0 < \tau < 1$

$$R_{xx}(\tau) = \int_{\tau}^{1} sin(2\pi t) \cdot sin(2\pi(t-\tau))\, dt \tag{A.1}$$

$$= cos(2\pi\tau) \int_{\tau}^{1} sin^2(2\pi t)\, dt - sin(2\pi\tau) \int_{\tau}^{1} cos(2\pi t) sin(2\pi t)\, dt$$

$$= \frac{1}{2}\left(cos(2\pi\tau) \int_{\tau}^{1} (1 - cos(4\pi t))\, dt - sin(2\pi\tau) \int_{\tau}^{1} sin(4\pi t)\, dt \right)$$

$$R_{xx}(\tau) = \frac{1}{2}\left(cos(2\pi\tau) \left(1 - \tau + \frac{sin(4\pi\tau)}{4\pi}\right) - \frac{sin(2\pi\tau)}{4\pi}(-1 + cos(4\pi\tau))\right)$$

The autocorrelation function is symmetric, so

$$R_{xx}(\tau) = \frac{1}{2}\left(cos(2\pi\tau) \left(1 - |\tau| + \frac{sin(4\pi|\tau|)}{4\pi}\right) - \frac{sin(2\pi|\tau|)}{4\pi}(-1 + cos(4\pi\tau))\right), \ for\ |\tau| < 1$$

$$= 0, \qquad otherwise$$

Similarly the autocorrelation function of 1hz, one second duration cosine wave is given by

For $0 < \tau < 1$

$$R_{xx}(\tau) = \int_{\tau}^{1} cos(2\pi t) \cdot cos(2\pi(t-\tau))\, dt \tag{A.2}$$

$$= cos(2\pi\tau) \int_{\tau}^{1} cos^2(2\pi t)\, dt + sin(2\pi\tau) \int_{\tau}^{1} cos(2\pi t) sin(2\pi t)\, dt$$

$$= \frac{1}{2}\left(cos(2\pi\tau) \int_{\tau}^{1} (1 + cos(4\pi t))\, dt + sin(2\pi\tau) \int_{\tau}^{1} sin(4\pi t)\, dt \right)$$

$$R_{xx}(\tau) = \frac{1}{2}\left(cos(2\pi\tau) \left(1 - \tau - \frac{sin(4\pi\tau)}{4\pi}\right) + \frac{sin(2\pi\tau)}{4\pi}(-1 + cos(4\pi\tau))\right)$$

The autocorrelation function is symmetric, so

$$R_{xx}(\tau) = \frac{1}{2}\left(cos(2\pi\tau) \left(1 - |\tau| - \frac{sin(4\pi|\tau|)}{4\pi}\right) + \frac{sin(2\pi|\tau|)}{4\pi}(-1 + cos(4\pi\tau))\right), \ for\ |\tau| < 1$$

$$= 0, \qquad otherwise$$

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