A Hardware-Oriented Hybrid TDOA/AOA Mobile Positioning Estimation Scheme

Saif Abdullah Enad

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Computer Engineering

Eastern Mediterranean University
June 2015
Gazimagusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Serhan Çiftçioğlu
Acting Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Computer Engineering.

Prof. Dr. Işık Aybay
Chair, Department of Computer Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Computer Engineering.

Assoc. Prof. Dr. Muhammed Salamah
Co Supervisor

Prof. Dr. Omar Ramadan
Supervisor

Examining Committee

1. Prof. Dr. Omar Ramadan
2. Assoc. Prof. Dr. Muhammed Salamah
3. Asst. Prof. Dr. Adnan Acan
4. Asst. Prof. Dr. Yıltan Bitirim
5. Asst. Prof. Dr. Cem Ergün

ABSTRACT

Location based services have fascinated many researchers and initiatives. One of the important characteristics of location based service is positioning technology. In view of a broader and more complex field like universal computing, position is the vital section. This work emphasizes on a new algorithm that can be used to estimate the position location of the target efficiently. Wireless LAN is one of the utmost prevalent schemes that are used for positioning for indoor locations and civic places. The angle of arrival and time difference of arrival are the primary position location techniques that are studied in this thesis and a novel based algorithm is developed by combining these two techniques. This new algorithm proposed is a low cost, high speed and high accuracy method. The new algorithm works in two cases (α_1, α_2), and the computational cost and error for each angle are approximately possess same amount. The proposed algorithm utilizes simple addition, subtraction and shift operators and it totally avoids trigonometric functions or complex calculation which makes speed higher for the algorithm. The total cost that is used in implementing the algorithm into FPGA is cost effective and it is superior when compared to angle of arrival and time difference of arrival techniques. The comparison with respect to cost and errors in estimating the location are done for the proposed algorithm is done. MATLAB 7 is the used for simulation and analysis of the proposed algorithm. The simulation results depict and demonstrate that the proposed algorithm is superior to angle of arrival and time difference of arrival methods.

Keywords: Wireless communication, Signal processing, Time difference of arrival, Angle of arrival, Hybrid positioning

ÖZ

Konum tabanlı hizmetler çoğu araştırmacıyı ve girişimciyi etkilemiştir. Konum tabanlı hizmetlerin önemli özelliklerinden biri konumlandırma teknolojisidir.Evrens.l hesaplama gibi daha karışık alanların geniş bakış açısından bakıldığında konum bölümü hayati önem taşımaktadır. Bu çalışma hedefin yer konumunu verimli bir şekilde ölçmek için kullanılan yeni algoritmada vurgulanmıştır. Kablosuz yerel alan ağı son derece yaygın olan, kapalı konumlar ve sivil yerler için konumlandırmada kullanılan şemalardan biridir. Bu tezde üzerinde çalışılan varış açısı ve varış zaman farkı, konum yerini belirleyen temel tekniklerdir. Bu teknikler birleştirilerek yeni bir algoritma geliştirilmiştir. Önerilen bu yeni algoritma düşük maliyete, yüksek hıza ve yüksek hassasiyete sahip bir yöntemdir. Bu yeni algoritma iki durumda çalışır (α_1, α_2), ve her bir açı için hesaplanan maliyet ve hata yaklaşık olarak aynı miktara sahiptir. Önerilen algoritma basit toplama, çıkarma ve kaydırma operatörleri kullanır ve algoritma için hızı yüksek yapan trigonometrik fonksiyonlardan ve karışık hesaplamalardan tamamen kaçınır. Algoritmayı APLD(Alan Programlanabilir Lcapi Dizini)'nın içine uygulamak için uygun maliyet kullanıldı ve varış açısı ve varış zaman farkı teknikleri ile önerilen algoritma karşılaştırıldığı zaman önerilen algoritma üstün olmuştur. Konum ölçmek için yapılan maliyet ve hatalar ile ilgili karşılaştırma önerilen algoritma için yapılmıştır. Önerilen algoritmanın analiz ve simulasyonu için MATLAB 7 kullanılmıştır. Simulasyon sonuçları önerilen algoritmanın varış açısı ve varış zaman farkı yöntemlerinden üstün olduğunu betimliyor ve gösteriyor.

Anahtar Kelimeler: Kablosuz iletişim, Sinyal işleme, varış zamanı farkı, geliş açısı, Hibrit konumlandırma DEDICATION

DEDICATION

To My Family

ACKNOWLEDGEMENT

First, I want to thank Almighty God for his faithfulness and for guiding me through this chapter of my life.

I would love to extend great gratitude to my supervisor, Prof. Dr. Omar Ramadan and Assoc. Prof. Dr. Muhammed Salamah for them immense support, knowledge sharing and fatherly guide given throughout the period of this research.

Finally, I would like to thank my family and dedicate my thesis to them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

TERMS	ABBREVATION
LBS	Location Based Services
PDA	Personal Digital Assistants
GPS	Global Positioning System
GIS	Geographic Information Systems
NICTS	New Information and Communication Technologies
PSAP	Public Health Safety Answering Point
PL	Position Location
WSN	Wireless Sensor Network
AOA	Angle of Arrival
TDOA	Time Difference of Arrival
TOA	Time of Arrival
LM	Location Manager
DR	Dead Reckoning
LORAN	Long Range Navigation
DOD	Department of Defense
GTD	Geometrical Theory of Diffraction
EOTD	Enhanced Observed Time Differences
LSC	Location Service Center
BTS	Base Trans-receiver Station
MS	Mobile Station
CDMA	Code Division Multiple Access Technique
TA	Time Advance

IOC	Initial Operational Capability
DGPS	Differential Global Positioning System
GRI	Group Repetitive Interval
LOP	Line of Position
PNT	Position Navigation and Timing
RSS	Received Signal Strength
AGPS	Assisted Global Positioning System
WLAN	Wireless Local Area Network
NIC	Network Interface Card
FCC	Federal Communication Commission
FPGA	Field Programmable Gate Array
BS	Base Station
HTDA	Hybrid Time Difference of Arrival /Angle of Arrival

Chapter 1

INTRODUCTION

An exceptional popular element used in the world are wireless phones. Before the introduction of cell phones general public were left in crisis for emergency situations while out roaming and be inept in communicating for help. But with the advent of the introduction of cell phones has helped mankind overcome these snags and hitches.

Internet and mobile phones have transformed the communication and routine of the general public around the globe. With this transformation majority of the general public wants to access data and figures with the help of personal digital assistants (PDA) and mobile phones irrespective of their location. Location based services (LBS)

Is one of the widely used fields that emerged a couple of years ago. But this field got it enhancement in the late 1990's when the proficiencies of GPS started appearing in mobile devices like cell phones. The United States federal enhanced emergency services requirements widely adopted the mobile devices along with the pervasiveness of GPS competencies within the mobile devices. These led to the development of location based services (LBS) based on mobile location technologies. The location based services is a concoction of three different technologies namely geographic information systems (GIS), internet and new information and communication technologies (NICTS). This is shown in Figure 1. The privacy status, the physical locus and traits of a place will be described by location information.

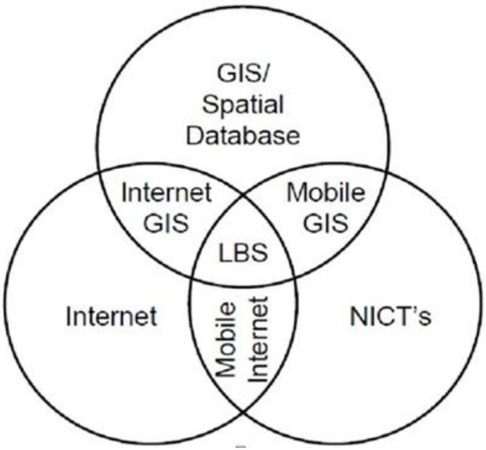

Figure 1. Location Based Service an Intersection of Different Technologies

Location information aids many solicitations which embraces overhaul concepts like fleet management, navigation, tracking etc [2].

Location based services empowers itself to various fields like health, personal life and exertion. Location based services can also be used as pull type services which mainly fall under inquiry based services. Nearest hotels, ATM's and the location information in the unknown places will be marked by using location based services. Location based services not only curbs to these applications but also it can be used for selective mobile advertisement. In the selective mobile advertisement, the information can be sent to the customers according to their specific geographic location. The best possible service can be rendered according to the user's surroundings.

Location based services have been presented and endorsed as ‘killer services’ for third generation telecom networks. Nevertheless there are few restraints on location based services as there are technological precincts, concerns in privacy and disputes in standardization.

1.1 Motivation

1.1.1 FCC Regulations for Wireless E-911

The emergency 911 service was developed as an emergency response and disaster awareness system. The E911 is a later modification of the 911 service. This service enables the user to reach out the public health safety answering point (PSAP) through wired telephone at emergency situations.

The public safety answering points is intended to assent and route voice media in the time of emergency services in spells of individual, regional and general need. In the earlier designed 911 service the vital data of caller’s location and phone number was not always accessible.

In order to overcome these limitations enhanced 911 (E-911) services was bought in as a upgraded service. E-911 overcame the limitations by reaching out individuals in the time of disaster by lesser response time for requests, authorize a call back if the call is disconnected, identification of the caller and much more.

In October 1996, the federal communications commission mandated for the enactment of emergency services for cellular phone calls. This stride was engaged as the position location (PL) determines and provides a faster reach to those who are in the need of aid. Thus position location plays a vital role in such applications.

1.2 Applications of Positioning Location

Positioning location technology suits a precarious power that can be used by everyone convoluted in the wireless value chain. With current evolution of smart mobile policies and enhancement in wireless sensor technologies, awareness in positioning location technology is also amassed. Fresh positioning location merchandises endure to be arrayed for a diversity of applications with enhanced steadfastness at lower rates.

Numerous applications can be amended by positioning location technology submitting innumerable resolutions to geospatial hitches whichever in private, technical and engineering submissions. Conventionally, the significant attentiveness for position location has been for military and security submissions. Currently the position location technology has appeared in many applications such as WSN, steering, tracking, indoor positioning, emergency 911 in USA, and emergency 112 in Europe.

1.2.1 Navigation Services

Navigation is the skill of discovering the position of itinerant objects and their method safely and professionally to terminus. Primarily navigation technique starts through defining the position of an entity with the assistance of one of the positioning systems such as Loran-C or GPS. The second phase is directing the moving object to a programmed course to touch the preferred endpoint. Radio navigation systems rest on few factors to develop eventual outcomes. These factors are precision, accessibility, volume, and continuity. These parameters are used to calculate the performance of radio navigation systems.

GPS technology is reachable universally and the consumers have admittance to continuous restructured position information of high eminence as long as the GPS receiver is functioning properly and accept steady satellite signals. The GPS system customs a novel form of navigation, known as electronic navigation. The electronic navigation is a method that delivers a diversity of navigational parameters over the solicitation of the electronic sciences. Typically, the GPS receiver is the principal means of defining position location in electronic navigation. Supplementary gadgets such as radar and electronic compasses offer data about the adjacent surroundings and the associated course of the entity [3].

1.2.2 Location Based Services

Location-based services (LBS) permit service suppliers to mark clients and offer them amenities explicitly custom-made to wherever they are besides what they need at together a given moment in time and a specified location in space. Location based services obligate the authority to transmute mobile services, creating interfaces more pertinent, appropriate and private. Numerous aspects add to fruitful Location Based Services, counting positioning technologies, service plans, and content alteration and personalization. Foremost communication sources, equipment suppliers, and application designers are dynamically associated for LBS standards expansion to embolden foremost rollouts of LBS [4].

The utmost noticeable technologies behind LBS are the positioning technologies and the far and wide renowned GPS. Nevertheless, there remain network centered locating technologies that stereotypically impart on triangulation of a signal as of cell spots aiding a mobile phone and the aiding cell spot can be utilized as a resolution for pinpointing the user. There is a necessity to upkeep manifold location determination technologies (LDT) and solicitations for pinpointing the mobile device. A cohesive explanation should sustenance various sorts of existing location determination technologies such as angle of arrival (AOA), time difference of arrival (TDOA), global positioni.ng system (GPS) and time of arrival (TOA).

Environmental figures are precarious for any location based systems. Geographical Information Systems (GIS) offer implements to provide and govern base map information such as constructed assemblies (paths and structures) and territory (peaks, streams, etc.). Geographical Information Systems is likewise used to accomplish point-of-interest information such as position of petrol bunks, boardinghouses etc. Geographical Information Systems also embraces data around the radio frequency characteristics of the mobile network, which permits the scheme to regulate the serving call location of the consumer.

The location supervision function routes the locating and geographical information systems information on behalf of location based systems solicitations, performing as a gateway/facilitator amid placing tools and location based equipment infrastructure. The location manager (LM) or gateway will cumulate the position evaluations for the mobile device from the numerous location determination technologies, figure the consumer position and evaluate the exact of that position before being accelerated to the request.

Location based services bring in locating, topographical data schemes and position supervision function with mobile devices i.e. notebooks, PDA, smart phones, GPS receivers, etc. creating potent bridge amongst topographical information record and broadcastings technologies [4, 5].

Location based services deliver widespread choice of applications. More or less of these applications are concisely listed further down.

1.2.2.1 E-119 in USA and in E-112 Europe

An emergency request transmits spontaneous location data of the users when they dial in the number of the emergency service of call. This service delivers locating and position data to the law enforcement agency and emergency medical teams to accompany the caller in little stretch.

1.2.2.2 Mobile Yellow Pages

Outsources data dynamically wanted by the user around their current place. For instances conveying the user demanded instructions to touch nearby gas station although the user is on the way travelling. The user likewise can acquire real-time stream of traffic data based on their locality.

1.2.2.3 Fleet Management

Many fleet operatives, such as navy and marine forces can utilize the use of positioning location data to trail and regulate their means of transportation and to respond in an operative way with little time, to escape a hectic direction that interrupts them from getting to their journey's end.

1.2.2.4 Tracking Services

Tracking services can be used to observe the precise location position of public or objects to increase security, safety and observation. It can also be used for public security services, society and organizations to use locating position data of public by tracing their cell phones. Countless enterprises at the moment deliver consumers tracking of entities by witnessing using the internet or smart phones.

1.2.2.5 Network Capacity Planning

The positioning location of users can be utilized from the cellular system to develop the arrangement from the figures that are generated from the records of the cellular systems. The data collected from wireless position services can be utilized to develop the channel distribution of the network with respect to the locality of lively consumers. Smart handoff in the set-up can be enhanced by utilizing the consumer's position and signal strength. Cell planning of the wireless networks can use the prevailing information of locating position data to set up a dynamic system with high capability and economical.

1.2.2.6 Navigation Using Mobile Station

Location based services provides the capability to determine the topographical location position of a cell phone and thus on the basis of position location it delivers the information and services. Celestial navigation in location based services comprises approaches for ultimate location positioning, course, and distance covered. Location based services engages accurate and real-time location positioning services and geographical information systems to discover the position of mobile receivers. The information generated by these services is useful to the current location of the end user and can be used to lead the end users to their closing terminus.

The location based services also adds to several other applications in as travel data and information, universal computing, gaming etc [6].

1.2.3 Climate and Environment Monitoring

The location positioning service can be utilized to gather data concerning temperature, pressure, humidity and other related data with the help of immobile and mobile weather conditions stations. Several approaches are in practice to gather and update the data of the weather conditions. The utmost general technique is by utilizing fixed or mobile stations furnished with global positioning system receivers to deliver the essential location positioning. Additional technique is by distributing a cluster of wireless sensors spread in a big expanse to study the respective area adjacent to the physical occurrences. This technique of amassing the essential data for ecological monitoring such as change in climate, global warming etc. is in effect and economical.

The concentration of water vapors existing in the atmosphere can be found by the global positioning system satellites signals. The position errors caused by water vapors in each sectional volume of the atmosphere beyond each base station at the ground can be calculated as each base station can estimate the specific position of the GPS satellites and their orbits [7].

The three most commonly used positioning techniques are:

1. Stand alone
2. Satellite based
3. Terrestrial radio based

1.2.3.1 Stand Alone

Before the development of satellite based techniques came into existence dead reckoning (DR) was the method used by the sailors. This dead reckoning method which falls under stand-alone determines the current location by incrementally integrating the travelled distance and voyaged direction relative to a known start position. A magnetic compass was used to calculate the ship's direction and using the speed of the ship and the time of travel distance travelled can be calculated. For the land based navigation systems sensor devices can be used accordingly. Initial measurement units, wheel rotation counters and gyroscopes are a few examples covering the sensors used in land based navigation. But the limitation of the standalone technique is to determine the exact distance travelled from the starting point, this leads to estimation errors. Hence a constant update is necessary with respect to fixed positions.

1.2.3.2 Satellite Based

In the case of satellite based positioning systems, a GPS receiver is used. With the assistance of GPS any space around the earth can determine its geographic location in latitude, longitude and elevation ascending from the equator.

Trilateration is method used by GPS receiver where in it's a method through which location can be found from objects that have known locations.

This helps in time synchronization of all the satellites for clock corrections by computing the precise orbital data. The positioning service renders two types of services namely: precise positioning service and standard positioning service. The detailed explanation of satellite based location technology will be explained in detail in the 2nd chapter.

1.2.3.3 Terrestrial Radio Based

Long range navigation (LORAN) is a typical example of terrestrial based technology. To provide accurate system for long range navigation US department of defense (DOD) bought out LORAN as a long range radio navigation service during World War II. This LORAN system runs in low-frequency band (90-110 kHz) on a center carrier frequency of 100 kHz. Numerous nations round the globe are using this system. Several kinds of the LORAN system were bought out as A, B, C, E and F. The recent type is termed as enhanced-LORAN. The enhanced-LORAN system is intended to deliver locating position and ground speed data to users above huge coverage zone. The detailed explanation of LORAN will be given in chapter 2.

1.3 Literature Review

The subsequent subcategories recapitulate earlier exertions for the characterization of location determination technologies and the processing algorithms that are in current practice to overcome the outcome of the computational costs and errors of the respective algorithms. Primarily, a transitory summary of channel characterization policies are described.

Kalman filter-based approaches were defined by Thomas et al (2001). The projected Technique was on the basis of three stages namely:

1. Smooth sampling of measurement noise and removal of NLOS data to a greater extent using profiteering.
2. KF tracking to offer a constant locality approximation.
3. TDOA-based position approximation by means of standard weighted least-squares (WLS) solution or Chan's method (Chan 1994).

The author Tarighat et al (2003) in his research explains a parametric technique on the basis of Maximum Possibility for TOA approximations and a Least-Squares technique for AOA approximations were discoursed for a CDMA schemes. In this technique there is a hefty computational load in arrears to a multi-dimensional examination for the factors.

A few methods and techniques that were proposed beyond were network-based systems and proved with the help of simulation results. Wang et al (1994) projected a technique to expand the AOA approximation on the basis of actual information and stats from a VHF system. Several researchers published articles on the basis of the AOA-only or the TOA-only method. There were also numerous papers approximating individually AOA and TOA standards from adapted algorithms as array signal comprises together of spatial and temporal data (Wang et al 2001, Van der Veen et al 1997, Zoltowski et al 1996).

Modeling methods presented in the collected works for the categorization of the location based service channel can be broadly classified into three groups: *Empirical models, Deterministic or Physical models* and *Statistical models* (Fontan et al. 1997, Ibnkahla 2004). The classification of Statistical models can be extended as Single and Mixture models (Abdi et al. 2003). Along with this numerous amalgamations of Deterministic and Statistical models also exist in the literature (Fontan et al. 1997).

Empirical models are the utmost prevalent methods which use data like geographical settings, frequency of the transmitted signal to gauge their bounds and angle of elevation of the satellite. Typical empirical models are listed in (Fontan et al. 1997, Rapp port 2001).

Deterministic or Physical models deliver great estimation in precisions of the signal distinctions; though, these models need a enormous volume of data concerning the local topography. Classically, deterministic models are mainly made up of the amalgamation of Geometrical Theory of Diffraction (GTD), rough surface theory and scattering theories (Fontan et al. 1997). Since this locating technique deliver universal analysis, it turns out to be very hard to illustrate a gigantic expanse of situations over deterministic models.

Statistical models are not as much of computationally exhaustive as deterministic models and they are largely phenomenological compared to the empirical models (Ibnkahla 2004). In this method it is purely based on standard distributions are presumed on the basis of the kind of situation in which the receiver is in operation. For an instance, the reliable factors can be the sorts of reflectors, the existence or nonexistence of line of sight constituents, receiver dynamics and signal blocking elements etc. Once the dissemination is selected, factors for that dissemination are attained empirically on the basis of the field trials.

Pluses of the statistical models are their suppleness and effective system enactment and estimations for a varied choice of signal characteristics and situations.

Factors for statistical description of the multipath channel diverge dependent on the channel classification as *narrowband* or *wideband*. In Narrowband channels the time between multipath rays are substantially reduced than the symbol period, roughly it reduces to 10 percent of a chip, (Ibnkahla 2004).A symbol can be considered for one code chip .In such situations, it can be demonstrated that all multipath signals reach at the receiver antenna closely at the identical time with dissimilar amplitude and phase features. in a wideband channel, the delay spread is significantly larger than the symbol period . Thus the bandwidth of the transmitted signal is smaller than that of the channel. These outcomes in as *frequency selective* fading channel (Rappaport 2001).

1.4 Thesis Outline

There are five chapters in this dissertation and the subsequent chapters are as listed.

Chapter 1 provides basic introduction on location based services, their application. This chapter also gives the details about the motivation for this outline along with the literature survey.

Chapter 2 explains different types of location determination technologies and methods, mobile positioning techniques are discussed

Chapter 3 discuss about the existing algorithm and the new proposed mixed algorithm and their comparison

Chapter 4 discuss the simulation results and graphs

Chapter 5 explains the conclusions and future work

Chapter 2

LOCATION DETERMINATION TECHNIQUES AND BACKGROUND

2.1 Classification of Positioning Systems

In this chapter, positioning location in wireless networks is explained in detail. The different types of position system classification are also discussed.

A wireless positioning location system is made up of at least two operating units; a computing element that typically lugs the major portion of the system along with a signal transmitter. The transmitter in the meekest circumstance is made to direct beacon signals. The classification of wireless position locating systems can be classified on the basis of their functionality of the components they bear along with their schematic interactions.

The classification can primarily be characterized into three sets, namely:

1. Handset-Based Positioning
2. Network-Based Positioning
3. Hybrid-Positioning System.

2.1.1 Handset-Based Positioning System

In handset based positioning system, the handset utilizes the signals produced from several orientation stations to compute and analyze its specific location. Global positioning systems are an illustration for handset-based positioning system.

Handsets with global positioning system receivers can estimate one's location on the basis of signals obtained from four different satellites. These different satellites are in continuous motion, in spite of this their exact positions at the time of transmission is received by the node receiver to estimate the location.

In the case of handset-based positioning location the mobile station considers the signals communicated from multiple base stations to estimate its location. The network capacity is not altered in the case of handset-based location since the system does not utilize the resources of the network. Handset-based location is by far the secure systems. One such example for handset based positioning system in the cellular network is enhanced observed time differences (E-OTD).

Several transmitting satellites are in movement but their correct positions at the time of transmission are used by the node receiver to calculate its position [8].

2.1.2 Network–Based Positioning System

Network-based location system relies on present wireless networks to attain data about consumer location. In this type of technique, quite a lot of receiver stations quantize the signals transferred from wireless consumers and transmit this data to a central location for analyzing and computing the consumer's position. Examples for network based positioning systems can be airborne early warning and control system [9]. The network-based positioning location has the choice of manifold base stations observing the mobile station signal over the network. These calculations which are mostly of time of arrival (TOA) are mutual in a system typically known as the location service center (LSC). The location service center estimates the time difference of arrival factors and implements the approximation with both time of arrival and time difference of arrival methods in the crucial position of the network. Figure 2, explains the positioning location technique in cellular network.

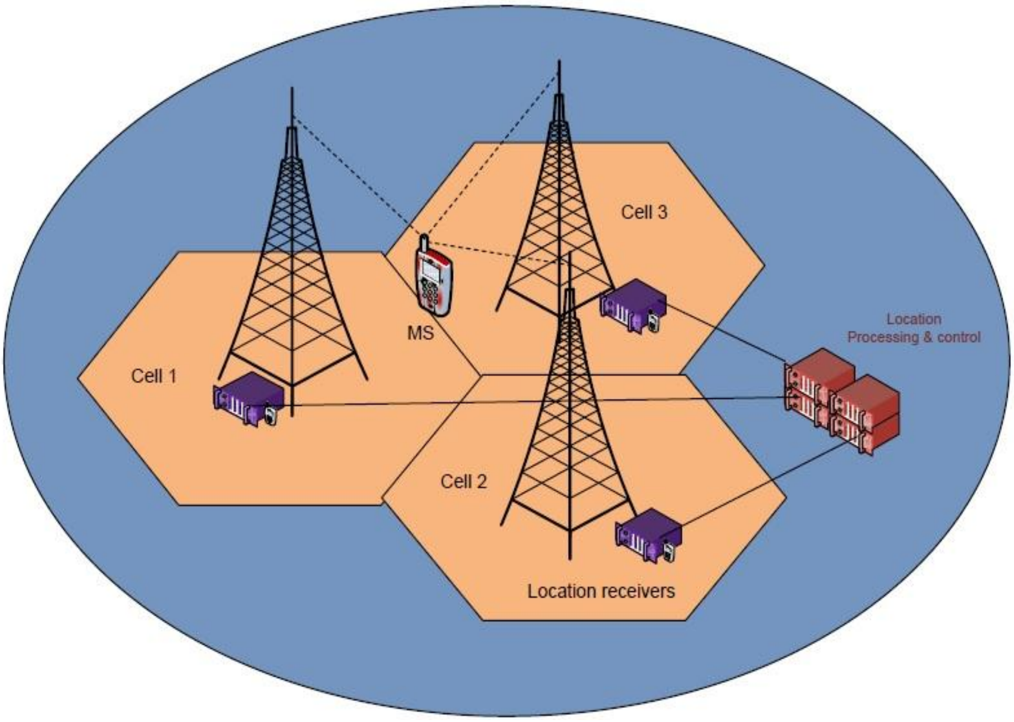

Figure 2. Network Based Positioning Location Technique in Cellular Network

In this network based positioning system the benefit lies in not needing the modifications in user node’s software’s or hardware’s. Thus in the operators system the positioning location of user nodes is allowed due to this solution.

2.1.3 Hybrid-Positioning System

A hybrid-positioning system involves technique that combines handset based positioning system and network positioning system info to produce the positioning location approximation. One such instance is the circumstance where approximations are completed by the handset and later the data are sent to the network which then completes the position location approximations. The hybrid system could perhaps deliver greater precision. The only drawback of hybrid positioning system when compared to handset based and network based positioning system is that the complexity in the design. Assisted global positioning system is an illustration for hybrid–positioning system [10]. The benefit from the hybrid positioning technology is that it reduces the glitches that befall in former positioning location techniques by aiding assistive data one of the systems to the other. Thus the information and data gets enhanced for estimating the position of the nodes.

2.2 Mobile Phone Positioning Existing Techniques

In the early 1980’s the cell phone services became commercially available in spite of testing the first mobile phone in 1946 at Sweden (http://en.wikipedia.org). When the mobile phones were introduced the size of them was huge and it went on for the next twenty years as. The purpose of the cell phone at that period was restricted to calls and the eminence as well as the clarity of the speech was poor. Later two decades had prompt progress wherein they have grown from the first generation to the fifth generation, and now a later generation is being projected by scholars. The mobile linkage has now concealed huge portions of the sphere. The cell phones that are available currently have much higher features than just limiting to short message services and telecommunications. The cell phones are such influential instrument for the mankind and according to the survey it is heading to be more powerful than before. Positioning and navigation are one of the features that are being updated. Much investigation is engrossed on utilizing the cell phone network for locating and navigation.

2.2.1 Angle of Arrival

Angle of arrival is a network-based positioning location technique that estimates the time taken by the radio signals to reach at several nodes. Angle of arrival technique utilizes an antenna comprising of multiple element array in which the precise position of each angle of arrival element is recognized accurately. Every element is tiny and it is proficient enough to accept a distinct signal. By calculating strength of signal, arrival time and phase at every element of the array one can compute the line-of-sight trail from source to receiver. Assigning additional receiver with the same antenna configuration in an altered position permits to repeat the procedure. The location of the transmitting node can be characterized by the intersection point of the two line of sight paths.

The angle of arrival technique needs at least two reference stations with steering antennas with narrow beam widths. Implantation of this technique is easy. It is used in wide number of applications namely tracking target nodes, surveying, locating the source of illegal transmitter.

2.2.1.1 Estimating the Position with Angle of Arrival

The angle of arrival technique practices modest triangulation principle to compute the position of the node which is estimated on the basis of vector ranging. The technique requires a minimum of two reference stations to calculate the direction of the radio signals that are received. The point of intersection of lines that are drawn from reference stations to the target node represents the target node. A single angle in a point is formed by a pair of two vectors as soon as they intersect each other. The angle of arrival computation and further essential data can be utilized to compute the location of a target node. To obtain accurate estimations of the target information trans-receiver stations with known coordinates should be used.

The data about angle of arrival can be computed in three ways. Type one is computed on the basis of calculating the obtain phase differences of the signals amongst the antenna array elements. The second is to estimate a beam-forming or spectral density over's the antenna array of the receiver. The third type involves approximating the location of the user by using sectored multi beam antennas. This method is practiced on the variation amongst the estimation of the amplitude of the signal arriving at the main beam. The related amplitude of signal arrival is computed at the adjacent beam. This technique is practiced in cellular networks which were already adopted cell-sectoring in the network to accomplish additional and consistent communications [8, 13, 28].

2.2.2 Time Difference of Arrival

Time difference of arrival (TDOA) uses multilateration or hyperbolic positioning to detect the target. It is almost alike to time of arrival where in which it utilizes the time taken from the transmitter to reach the receiver for measuring distances. The difference in the time to travel from each sensor is used to calculate the distance between each sensor rather to use the travel time from each receiver to calculate the distance between the receiver and transmitter. Several hyperbolas are obtained as a result; the intersection of these will give the position location [35]. For higher accuracy in the case of time of arrival technique there should be proper synchronization for different time measurement. But in the case of time difference of arrival no synchronicity is needed between the transmitter and the sensor as it does not considers the distance between transmitter and the receiver. Synchronicity is simply essential amongst all sensors since the estimation is on the basis of difference in time or distance.

2.2.2.1 Positioning Location Using Time Difference of Arrival Method

To approximate the location of a receiving station by the use of time difference of arrival technique it needs time synchronization among the transmitter and receiver. To limit clock synchronization in some circumstances, the distances can be calculated by using the time of arrival differences for signals that are transmitted from two reference nodes.

In this technique there should be proper synchronization between all beacons within the network. The time difference of arrival technique uses hyperbolic mathematical principle to approximate the location of the target. The receive node lies on the lines of two pair of base stations. The lines have constant distances among two reference stations in the hyperbolic.

2.2.3 Cell ID

The most basic and simplest type of mobile phone techniques are Cell ID. This positioning method does not necessitate any complex network or terminal exaltation which intern makes it cost-effective simple. Cell ID was a technique which many cell phone network companies had used it due to its simplicity and cost effectiveness. Messages along with the cell ID can be broadcasted to the end instrument from every base trans-receiver station (BTS).

A mobile station (MS) continuously receipts these broadcasting messages and hence it is known as its Cell ID. Once the cell ID is known, a mobile station can estimate its real position just by utilizing the terrestrial coordinates of the aiding base trans-receiver station BTS. Figure 3, represents the working of Cell ID. Despite of its simplicity Cell ID does not have essential amount of precision (Laitinen etc., 2000;Frédéric, 2002). The scope of a cell may stretch up to few meters to some kilometers. For example, the measurement of a picocell is fewer than 100 m, whereas that of a macrocell ranges to 35 km (Holtzman and Goodman, 1993). Furthermore, the stretch of a cell is indeterminate, affecting from other parameters such as interferences, current traffic and the sensing ability of the MS’s antenna. By broadcasting the centroid of the sector coverage area the enhancement is possible for cell ID in their sectored areas which is shown in Figure 4. The exactness can be enhanced, but the characteristic difficulty of the Cell ID will prevail forever. Though cell ID is still the simplest method in mobile phone positioning techniques.

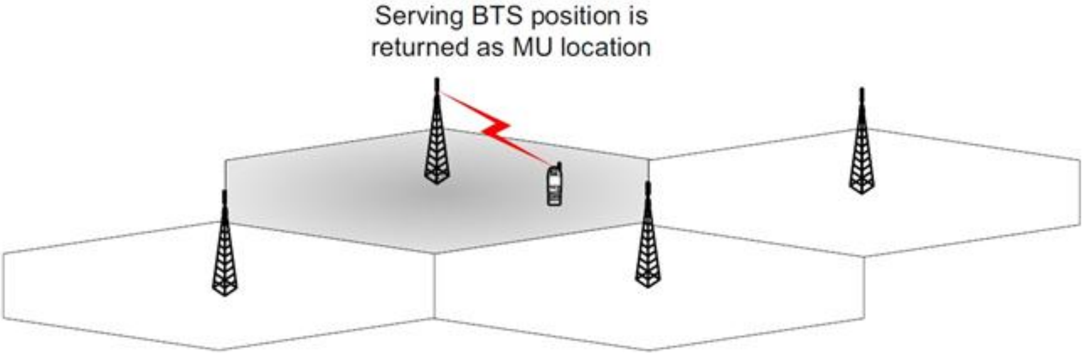

Figure 3. Cell ID Based Positioning in Which Serving BTS Position Returning As Mu Location

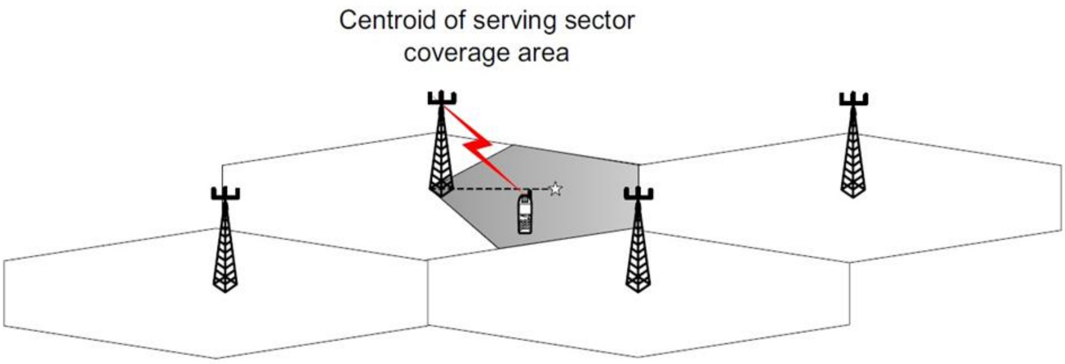

Figure 4. Enhancement of Cell ID in Sectored Sites

2.2.4 Signal Strength

Signal strength is one of the most effective and simpler method that is widely used using signal strength measurements for introspecting the position and location (Laitinen etc., 2000). For illustration the signal strength of control conduits in GSM and the pilot conduit in Code Division Multiple Access technique can be calculated and estimation can be done by calculating the distance between mobile station and base trans-receiver station. The signal losses can be effortlessly foretold in the free space propagation as the signal level outlines as circles about the transmitter. In this technique the signal strength that are received from a minimum of three base trans-receiver station are calculated and by using this data the mobile station location can be found by intersection of the circles. This technique is shown in Figure 5, But virtually the conditions on propagation are not the same when compared from free space propagation.

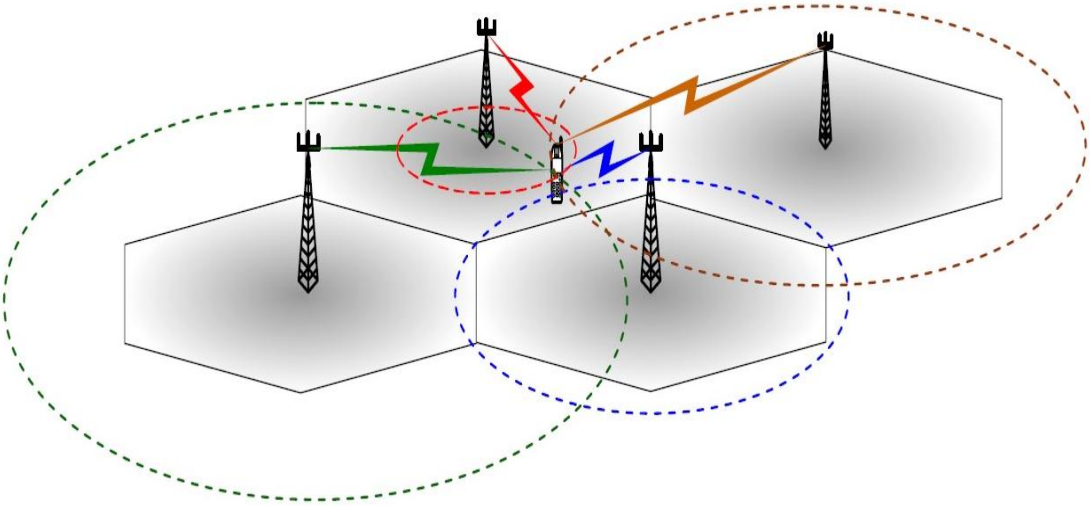

Figure 5. Positioning Technique Based on Signal Strength Method

In this technique it is suitable to use environmental dependent propagation models. These pragmatic models can be seen in Hata (1980) and Lee (1993). It is tedious to find an upright pragmatic model since there will be significant variation in the environment. The models that are proposed cannot be used to every environment but it may work well for specific environment. The problems that occur while calculating the base trans-receiver and mobile station distance is multipath fading and shadowing. Multipath fading can be flattened out by taking average over signal strength with respect to time and frequency band. But shadowing is a constraint which cannot be recompensed due to unsystematic variations.

2.2.5 Time Advance

In Global System for Mobile Communications service, there is a particular time slot and precise frequency to retrieve and send data. In order to complete as an effective process all the signals should converge at the base trans-receiver station at the right time. Time advance (TA) technique calculates the interval for the signal to travel from the mobile station until it reaches the base station. This technique is to ensure that the time slot supervision is controlled appropriately. Conversely time advance is accessible only in steadfast mode, whereas Cell-ID is constantly identified. By uniting the cell ID technique and time advance technique, the location approximation of mobile station can be known. The accurateness of this technique is classically from five hundred meters to four kilometers. The below Figure 6, represents Time Advance along with Cell ID.

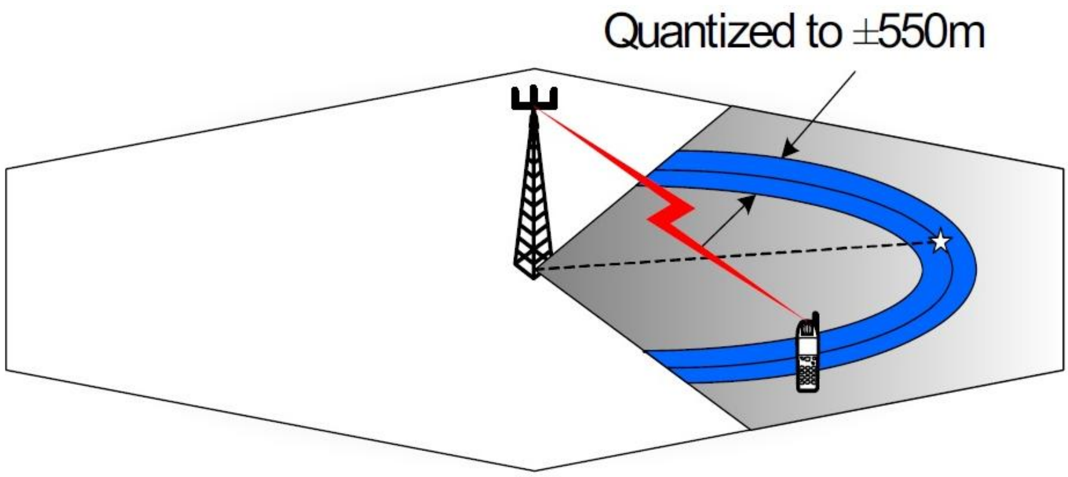

Figure 6 .Time Advance Technique Along with Cell ID

2.3 Global Positioning System (GPS)

Satellite positioning services are universal practices that offer 3D location data and velocity data in a meticulous, firm and uninterrupted method on the sphere in which satellite signals can be perceived. The United States department of defense developed this satellite based navigation system in the initial 1970's. Global positioning system was first launched in 1978. The primary system was initiated in 1994 with about twenty four satellites and in 2005 third generation of global positioning system was introduced. Global positioning system offers uninterrupted location and timing data, around the globe under whatever meteorological circumstances. Global positioning system is a system which possess only one-way-positioning. The consumer's instrument of this service can estimate once location by utilizing the satellite signals [11].

Space segment, user segment, and the control segment are the different segments that add to Global positioning system. The representations of these segments are as shown in Figure 7.

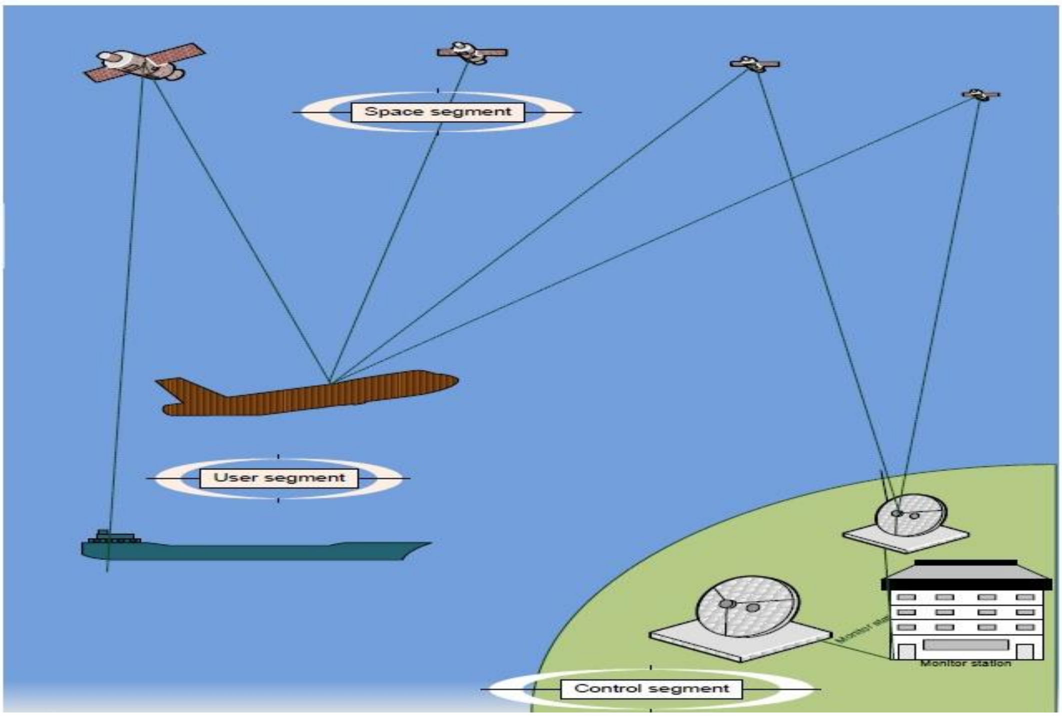

Figure 7. Representation of Different Segments in Global Positioning System

The segments of the global positioning system are explained as below.

2.3.1 The Space Segment

This is segment that comprises of satellites of the system. Global positioning system entails of a collection of twenty four satellites. This collection is known as the initial operational capability (IOC). To assure perpetual universal coverage, global positioning system satellites are organized in such a way that four satellites are positioned in each of the six orbital planes. With such organization a minimum of four to maximum of eleven GPS satellites will be perceived by user's device around the globe at once.

The satellites essentially need to be broadly spread out in angle to curtail the shared interference through real-time estimation processes and to aid the desired symmetrical strength for high-accuracy locating position.

Essentially, for the customers only four satellites are required to estimate the location in all three dimensions. For these satellites it has a period of 11 hours and 58 minutes with a height of 20,163 kilometers above earth.

The inclinations of the orbits are set to an angle of 55° with reference to equatorial plane and it is almost circular in shape [11, 12]. Each global positioning system satellite sends a signal which consists of two carrier frequencies, two digital codes, and a navigational message. The carrier frequencies and the digital codes are primarily used to estimate the expanse of the node's receiver and the global positioning system satellites. The steering communication enfolds the position of the satellites as a function of time. The transmitted signals are taken care by precise atomic clocks that are used in the system.

2.3.2 The Control Segment

There are three different components in this system. They are master control station, monitor stations, and ground antenna stations. Each monitor station has numerous global positioning system receivers along with atomic clocks that uninterruptedly trail the visible global positioning satellites. The estimations from every monitor station are time labelled and are sent to the master control station. These data which are sent to the master control station then processes these data in calculating the triangulation data such as errors in clock, orbits of satellites, ecological data and additional satellite procedure components for every satellite.

The master control station then computes and updates the triangulation note for every satellite and broadcasts it to the base stations which will then upload the triangulation message to the global positioning system satellites. The navigation note is then communicated with every satellite signal will then be received by global positioning system satellites. The master control station remotely controls monitor stations and ground stations.

2.3.3 User Segment

The user segment is the one of the segments in global positioning system which helps in obtaining the location data .The user segment has a wide variety of possible applications. The receiver of the global positioning system is made up of antenna, RF elements, electronic hardware, system for synchronization and software for various operations. Different receiver mockups are present subject to different applications. In military solicitations the receiver is further precise. Distinctive GPS receivers can get great correctness [12].

2.4 Assisted Global Positioning System

The Assisted GPS or A-GPS is a technique that deduces the accessibility of a global positioning system receiver on the mobile station. In the primary global positioning system technique the receiver of the GPS is accountable for gaining all the location and timing factors from the signal that are transmitted through the satellite. In most cellular situations the signals that are received are very noisy and distorted due to multipath fading that are being practiced for ranging operations. But in the case of assisted global positioning system technique, these problems are limited by using additional global positioning information to the mobile station from the cellular service provider. Whenever there is request on location positioning data, A supplementary data is also sent to the mobile station in the case of AGPS. These supplementary data that are sent comprises of the number of satellites that falls within the range of the mobile station, orbital factors and their Doppler offsets. The Figure 8, represents A-GPS technique. The network the aforementioned can attain this data by deploying a set of GPS receivers at labelled reference points.

The global positioning system data and the information provided can be used by the by the mobile station to precisely decide the pseudo range information which is associated with the reference points.

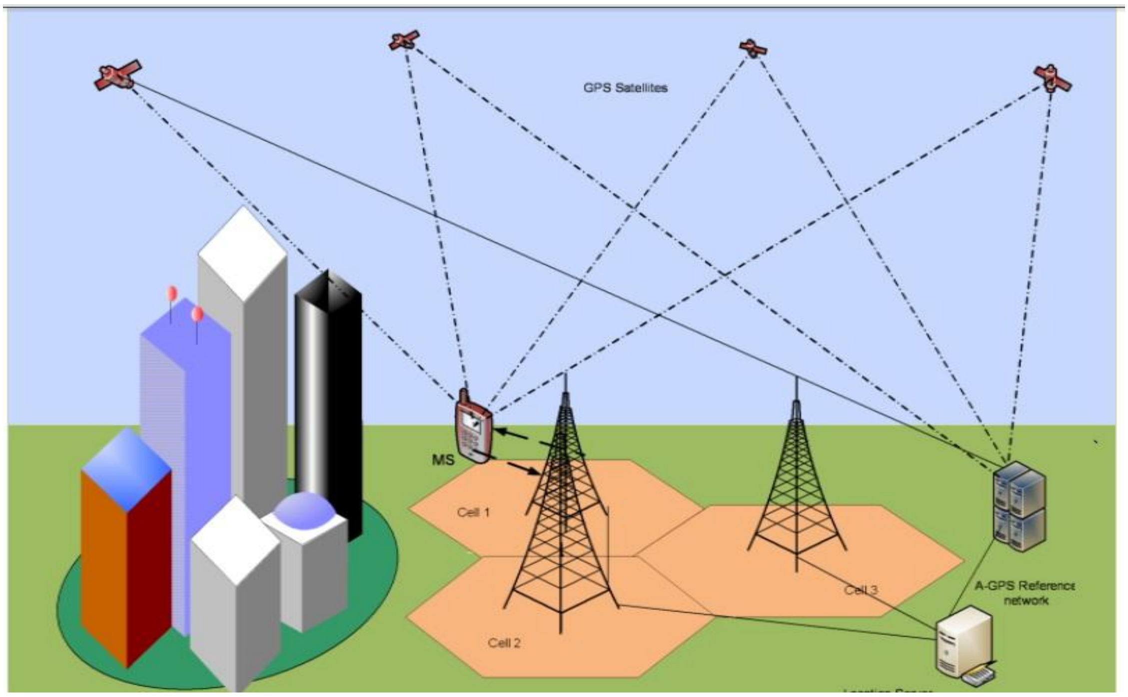

Figure 8. Representation of Assisted GPS in Cellular Network

2.5 The Location Techniques in Global Positioning System

The key objective of using global positioning system is to discover the location position of the consumer's devices. The motto in using global positioning system is the estimation of distance amongst satellites and the receiver. The satellites send the information regarding their precise trajectories and the time once the information is directed alongside additional beneficial data. The receiver analyzes this data and calculates the time differences of these signals to attain the exact location.

The distance between the satellite and the receiver is the radius of the sphere. We need a minimum of four satellites to estimate the location in three dimensions. The midpoint of each sphere signifies one satellite and the receiver falls on the reference of the surface of the sphere. The receiver instrument signifies the connection among four spheres surfaces which offers the location position of the receiving device [12, 13].

2.5.1 Differential GPS

Differential global positioning system (DGPS) is a technique used for reducing the faults in global positing system derived location position by using supplementary information from a reference global positioning system receiver at a known location. The simplest form of differential global positioning system determines the significances of errors in satellite clocks and navigation messages. It also transmits pseudo range adjustments in real time to consumer's receiving instrument which helps in calculating the exact position.

2.6 LORAN System

Long range navigation (LORAN) is a typical example of terrestrial based technology. To provide accurate system for long range navigation US Department of Defense (DOD) bought out LORAN as a long range radio navigation service during World War II. This LORAN system runs in low-frequency band (90-110 kHz) on a center carrier frequency of 100 kHz. Numerous nations round the globe are using this system. Several kinds of the LORAN system were bought out as A, B, C, E and F. The recent type is termed as enhanced-LORAN. The enhanced-LORAN system is intended to deliver locating position and ground speed data to users above huge coverage zone.

There are numerous worldwide stations in the ground segment over a vast coverage area that sends in set of pulses periodically. These LORAN based stations are organized into chains. Every chain has at least one master station and secondary stations have two to five stations. Every chain is characterized by group repetitive interval (GRI) which can be varied from fifty to hundred meters. The master signal entails nine pulses whereas secondary signals contain eight pulses which is transmitted a few microseconds later. Within the chain every transmitter yields a cluster of pulses every group repetition interval with proper synchronization among master and secondary stations. Any given station can act as master station as well as serve as secondary station for other chains.

A hyperbolic method is used as the primary technique in LORAN-C method. A hyperbola is the locus of every point's defined as ratio of distance from both line and point. A hyperbolic curve is categorized by a continuous difference in space from two recognized points. In the case of LORAN-C system the user receives the signal and estimates the difference in time of arrival technique amongst the group of pulses from both master and secondary stations. Thus estimated time difference defines a hyperbolic line of position (LOP) for the end user. The user position location is identified by the intersection of two lines [14]. Figure 9, represents the LORAN system. The difference between master signal and the secondary signal can be found in the LORAN-C receiving element. The ultimate result is a single hyperbola, this is because it estimates the accuracy of the hyperbolas and chooses the accurate hyperbola and excludes the other.

Continuous supply of ground speed information, remaining distance information and remaining time information to the users are a few advantages of the LORAN-C system. Calculations for remaining time and distance remaining to the terminus get simplified as ground speed information and position location information are calculated in this method [9, 15].

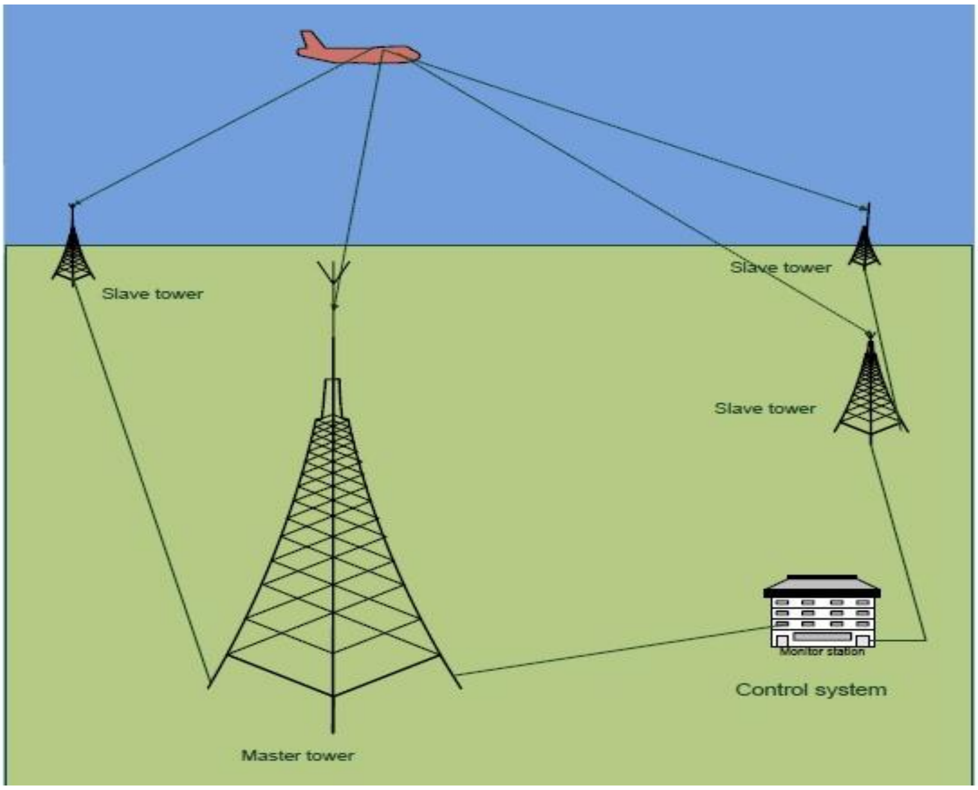

Figure 9. Representation of LORAN System

2.6.1 Enhanced LORAN (E-LORAN)

This is the newest generation of the Loran course plotting system. Enhanced Loran or E-LORAN is a sub type of Loran system that combines the updated receiver, antenna, and transmitting system technology. These supplementary features enable Loran to aid as a reserve and balanced global positioning system for timing and navigation. The E-LORAN technology offers considerably improved performance compared to Loran-C.

Enhanced Loran is the outcome of integration of two progressed features namely:

1) The transformation of the Loran-C system.

2) The consciousness that satellite course plotting has perceptible susceptibilities.

The later feature is specifically significant as most of the components are of precarious cost-effective and protection substructure are mainly depending on position navigation and timing (PNT) services which are presently aided by global positioning systems and other satellite navigation systems.

2.7 The Positioning Location in Cellular Networks

The objective for enhanced cellular subscriber security along with mounting cognizance of the commercial projections has shaped substantial notice in cellular positioning location technology. Federal communication commission issued a decree in 1996 at United States of America to all its wireless service providers. In this decree it was clearly specified to all wireless service providers stating they had to provide the location of the user calling 911 with a precision of one hundred and twenty five to three hundred meters of its original position. The same goes for European Union as well for dialing the emergency service in E-112.

The foremost theme is to pinpoint the mobile station (MS) with a mandatory exactness and limited latency. The vital indication after any mobile station positioning location system is to calculate few crucial factors from wireless signals that are received at the mobile after quite a few stable reference points. Based on the sight in which the position location estimation is calculated, these systems are considered as handset-based or network-based positioning system. In the network-based case, the calculations and estimations are completed at the base stations and the data collected is transmitted to a central place for analysis of determining the position of mobile station [16].

2.7.1 Fingerprint Method

Fingerprint method is one such wireless network substructure that is recommended for enclosed areas where global positioning system might fail working. Fingerprint method can provide added supplement to the current wireless network. This technique is relatively simpler in setting up in comparison with angle of arrival and time of arrival techniques.

In the case of time of arrival and angle of arrival methods, it calculates the position location on the basis of triangulation technique. Due to this it needs a line of sight between the receiver and the transmitter. The signals in the multipath effects would increase substantially in the multipath environment which makes the position accuracy decrease. Also a special hardware is needed for calculation of angle and time of arrival which leads to higher cost in the system. The above mentioned constraints are reduced by using fingerprint technique by utilizing the received signal strength (RSS) at the displaying location to generate a "radio map" to the node environment. Different positions are analyzed and the fingerprints of these locations are stockpiled in a database. The estimated fingerprints are then compared with the current position location of the current area [17].

Offline and online are the two steps that are involved in fingerprint technique. Offline step is an initial step where in at every precise position the data for signal strength is collected. This is done in order to generate a radio map for matching which is based on the correlation among signal strength and position location through the course of online step. In the case of online step, this method estimates the received signal strength in real time and calculates the position coordinates on the basis of the data that was preserved in the offline step [18-20]. The representation of fingerprinting technique in the cellular network is as shown in Figure 10. There should be a constant update in the radio map so that the novel modifications in the radio coverage area should be accommodated which will increase the precision and accuracies in the estimations and calculations. Numerous algorithms exist similar to K-neighbor that is used in this technique.

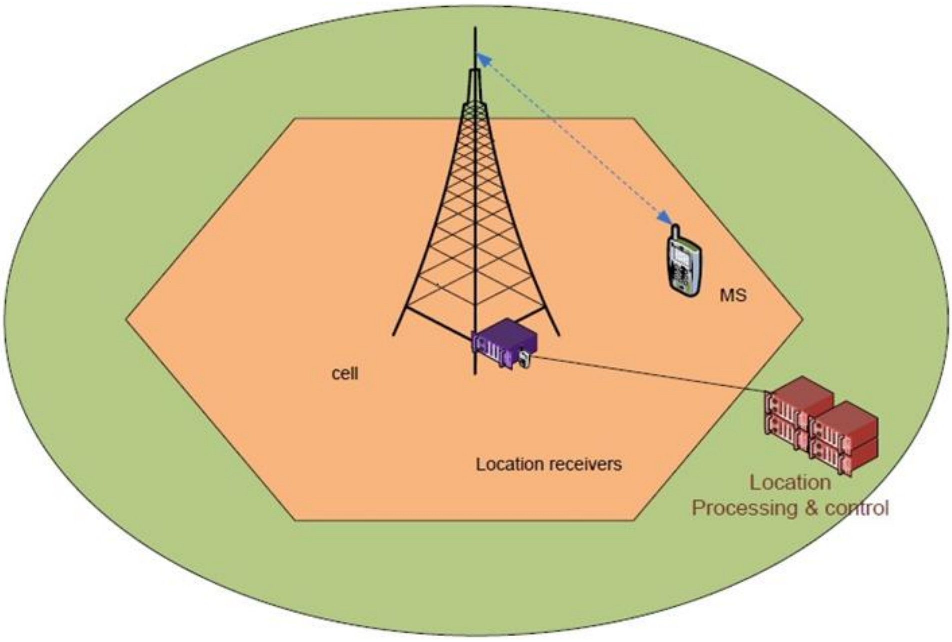

Figure 10. Fingerprinting Technique in the Cellular Network

Assisted global positioning satellite system is likewise utilized to increase the effectiveness inside the structures where the GPS signals are excessively feeble. By enabling the data to the receiver of the GPS in the mobile station it is capable of connecting the signals being established through the satellite when the signal is small in strength. By this method it is likely to increase substantial amount of correctness in gauging the position locations of the mobile station [13, 10].

2.7.2 Enhanced Observed Time Difference (E-OTD)

The Enhanced Observed Time Difference (E-OTD) is alternative technique to govern the location position of the consumer’s mobile station in the cellular system. It calculates the time of arrival of signals from many base stations at the mobile station. The time difference amongst the arrivals of the signals from unlike base stations is used to accomplish the consumer's position location with regards to the base stations only if that the base stations coordinates are identified and they transmit time-synchronized signals. The base stations are fitted out with receivers of global positioning systems for location estimation and timing dedications. As in the case of global positioning system the base stations functions as reference points in Enhanced observed time difference technique.

By practicing this technique, the correctness of locating position is improved and also the mobile station does not need to ensure a distinct sight of four GPS satellites at least. E-OTD technique necessitates added tools at just about every single base station which intern surges the price for the wireless service suppliers.

2.8 Position Location in the Wireless Local Area Network

The wireless local area network (WLAN) positioning location system utilizes the WLAN setup to determine the position location of the user for the indoor locations. By means of the prevailing WLAN set-up to approximate position location, numerous methods are seen such as angle of arrival, time of arrival and received signal strength technique. Received signal strength technique is comparatively reasonable in terms of both effortlessness and cost when compared to the former methods.

2.8.1 The Locating Technique in Wireless Local Area Network

The wireless local area network locating position denotes to the method of tracking down of mobile devices like laptops or personal digital assistants by means of wireless local area network arrangement. Locating position is done by using the reliance amongst the position of a mobile device and the signal broadcasted between the mobile device and a set of wireless local area network access points.

Received signal strength technique is the suitable method used in wireless local area network locating position methods as it can be accomplished openly from network interface card (NIC) that is present in almost all laptops and personal digital assistants. This authorizes the estimation of locating position algorithms in the central site of prevailing wireless local area components and hence reducing the necessity for additional hardware. Figure 11 represents the fingerprinting technique using received signal strength method in wireless local area network for indoor situations.

By precision in the choice of one to five meters, wireless local area network locating position methods can be utilized to compute the locating position data in supposedly in two or three dimensions Cartesian coordinates wherein the third dimension corresponds to a floor number [22, 23].

Existing wireless local area network locating position methods can be categorized into model-based and fingerprinting methods on the basis of the calculation of dependence in received signal strength position.

2.8.2 Model-Based Method

This technique targets to discriminate the received signal strength location dependence by means of hypothetical prototypes and elements that are calculated on the basis of sequence information such as received signal strength measurements. At the received end the signal strength drops out as it is moved away from the transmitter. If the correlation among signal strength and distance is identified then the distance amongst two terminals can be calculated.

There is a substantial effect on the signal strength for the indoor locations. These factors which add to it are floor materials, ceiling, walls, number of rooms, , room size etc, have significant effects on the signal strength [24-27].

2.8.3 Fingerprinting Method

Mobile station transmitting signals are pre-scanned with the coverage area. A central system allocates a distinctive initial for every portion in the position grid. The system transmits a matching signal from a transmitter of mobile station with the pre-determined record and reaches at the right location. Nearby are various algorithms utilized and verified with wireless local area network to detect the location of the cellular devices. Particular algorithms and expertise for interior and indoor locating methods are MIT Cricket, Microsoft RADAR and Skyhook Wireless WPS [25, 28], Figure 11, explain Fingerprinting technique.

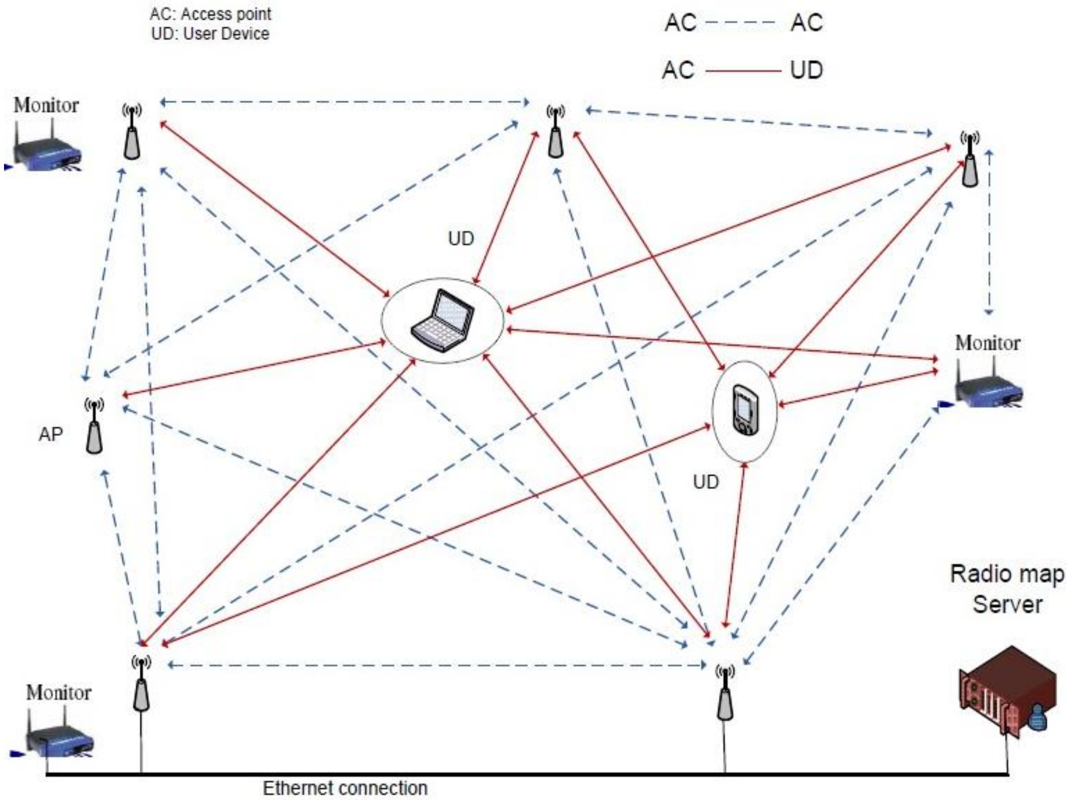

Figure 11. Fingerprinting Technique Using Received Signal Strength Method in Wireless Local Area Network for Indoor Situations

2.9 The Position Approximation in the Wireless Sensor Networks

In the case of wireless sensor networks, the position location can be done applied by dividing the nodes by ones individualities. In wireless sensor network, an identified position can be allocated to few nodes which intern generates a network among nodes. Each node becomes a gateway to other nodes in the network. Communications between nodes are direct or in multi-hop states mode.

In wireless sensor networks nodes are connected as an unforeseen method in which no preceding information of the position location is known. The sensor nodes must manage themselves by seeking new techniques for position location without banking on prevailing methods.

In wireless sensor networks few nodes are further progressive than rest within the system. These multifaceted nodes identify their locating position previously through appropriate methods. These nodes later perform as guiding beacons by transmitting ones positioning location intermittently. Hence by using these beacon nodes the other nodes gathers information of the former and uses it to find their own position locations. This technique is known as proximity based method [29-31].

For mobile nodes of wireless sensor networks, the locating position of a node within the system can be calculated by range-based technique. This range-based technique utilizes only local data. It uses range computations amongst nodes to mark a network management system along with coordinates. This technique needs additional hardware to approximate the time of arrival of signals between two nodes of the mobile [32, 33].

2.10 The Position Location in Ultra Wideband (UWB)

Ultra wideband is a broadcasting method which utilizes ultra-short pulses which are smaller than a nanosecond. Conferring to the Federal Communications Commission in USA the Ultra wideband is demarcated as some wireless transmitter with a range that inhabits about twenty percent of the slight bandwidth or a bandwidth equivalent to or greater than five hundred MHz that lights the power bounds consigned by Federal Communications Commission. The fractional bandwidth is given as $2\times\frac{(F_h - F_l)}{(F_h + F_l)}$ where F_h= upper edge frequency and F_l= lower edge frequency.

The Ultra wideband method offers higher data rates (more than 100 Mbps) by a small budget and delivers a size much advanced than existing in narrowband systems. Ultra wideband method can attain overlap ultra-wideband range on channels that are in usage by narrowband consumers and restricts the power spectral density to a assessment that will not start interfering with former signals [34]. This method is permitting corporations to develop novel products to aid numerous sectors such as public security, emergency response and viable applications.

Chapter 3

NOVEL HARDWARE ORIENTED HYBRID TDOA/AOA (HTDA) MOBILE POSITION ESTIMATION TECHNIQUE

In this chapter the proposed hybrid algorithm is explained in details. The proposed low cost hybrid technique combines the AOA and TDOA measurements in an efficient manner to provide a highly accurate estimation for the mobile position. The proposed algorithm which is a hybrid version utilizes the advantages of angle of arrival algorithm and time difference of arrival algorithm. The proposed algorithm is a hybrid location positioning method which has a better edge over angle of arrival and time difference of arrival algorithms in terms of computational cost and accuracy of the location position. The main advantage of the proposed hybrid technique is the utilization of only two antenna arrays that are needed to implement using two base stations that provide AOA and TDOA measurements for the purpose of less cost and accurate estimation of mobile position On the other hand, using TDOA only measurements, three base stations are involved in the positioning process with specific restriction of the cell shape.

It is worth to mention that all the investigated methods presented in this thesis (AOA, TDOA, TDOA /AOA) are designed to estimate fixed MS position. These algorithms can be amended to take in to consideration the tracking scenario of the MS position.

Firstly, throughout chapter, the traditional hybrid TDOA/AOA based method is presented. Then, the material presented in this chapter is sequenced to focus on the description of the hardware friendly hybrid TDOA/AOA method, highlighting in details the basic steps in the estimation process.

3.1 Traditional Hybrid TDOA/AOA (HTDA) Algorithm

To achieve high location accuracy and low cost, hybrid TDOA/AOA location scheme has been proposed. The proposed hybrid TDOA/AOA location has the merits of both AOA and TDOA methods; the proposed location scheme requires only two BSs for a location estimate, while the only TDOA approach requires minimum three BSs. It combines the time difference of arrival (TDOA) measurements from the two BSs with the angle of arrival (AOA) measurement from one BS. With the proposed hybrid method the AOA information will solve the ambiguity, high cost and physical restriction that the TDOA approach has and the drawbacks of AOA only location estimation approach. Two types of measurements carried out for the location purpose: TDOA measurements at the MS receiver and AOA measurements at the BS. MS location can be determined using two BSs (BS_1 and BS_2), spacing in two locations (0, 0) and (0, D) where D is the distance between BS_1 and BS_2. The MS with coordinates (x, y) is located by distance R_1 from the BS_1 and R_2 from BS_2 as shown in Figure 12.

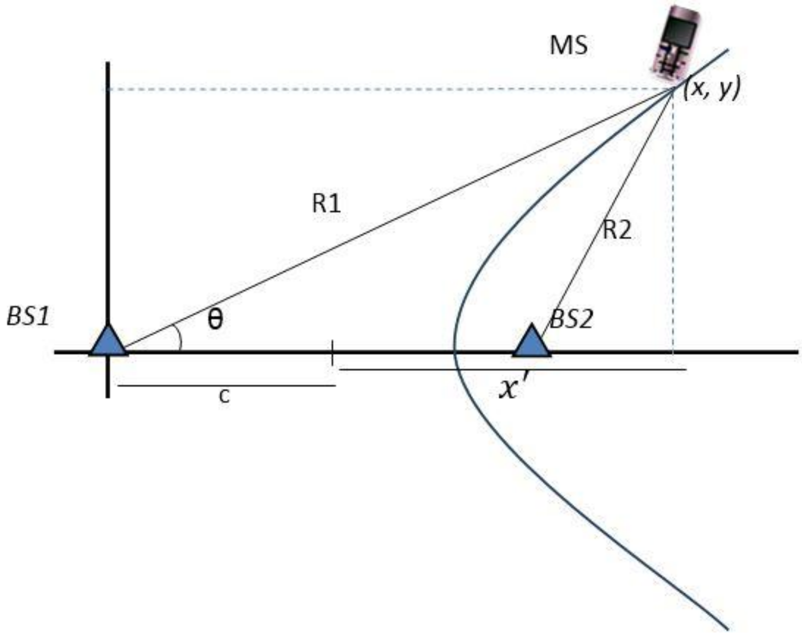

Figure 12. Traditional Hybrid (HTDA) Method

The range difference between BS_1 and BS_2 which can be converted hyperbolic equation where:

$$R_{12} = ct_{12} = R_1 - R_2$$

$$= \sqrt{(x - X_1)^2 + (y - Y_1)^2} - \sqrt{(x - X_2)^2 + (y - Y_2)^2} \quad (3.1)$$

Where c is the signal propagation speed ($3*10^8$ m/s), t_{12} is the estimated TDOA between BS_1 and BS_2, (X_1, Y_1) and (X_2, Y_2) are the coordinate of BS_1 and BS_2 respectively.

Now, by squaring both two side of equation (3.1) we get:

$$R_{1,2}^2 = y^2 + x^2 - 2\sqrt{(y^2 + x^2)}(y^2 + x^2) - 2X_2x + X_2^2) + y^2 + x^2 - 2Xx + X_2^2 \quad (3.2)$$

After some manipulations, the hyperbolic equation can be re-written as:

$$\frac{(x-\frac{1}{2}X_2)^2}{(R_{1,2}/2)^2}-\frac{(2y)^2}{\sqrt{\left(X_2-R_{1,2}\right)^2+\left(X+R_{1,2}\right)^2}}=1$$

Finally, the hyperbolic equation is:

$$\frac{x^2}{a^2}-\frac{y^2}{b^2}=1 \qquad (3.3)$$

Where

$a=(R_{1,2}/2)^2$

$c=X_2/2$

$b=\sqrt{c^2-a^2}$

Hence,

$$x=x^{'}+c \quad \rightarrow \quad x^{'}=x-c \qquad (3.4)$$

Now, Depending on AOA measurement:

$$x_i=R_i \, cos \, \alpha_i \qquad (3.5)$$

$$y_i=R_i \, sin \, \alpha_i \qquad (3.6)$$

Then,

$$\frac{y_i}{x_i}=tan \, \alpha_i \qquad (3.7)$$

Where α_i is the AOA measured angle.

Substituting equations (3.3) and (3.6) in equation (3.7) to get a second order equation which can solve to estimate the mobile position:

$$x = \frac{-b_0 \pm \sqrt{b_o^2 - 4a_0c_0}}{2a_0} \qquad and \qquad y = x\,.\tan\alpha \tag{3.8}$$

Where:

$$a_0 = \frac{1}{a^2} - \left(\frac{\tan\alpha}{b}\right)^2 \tag{3.9}$$

$$b_0 = \frac{2c}{a^2} \tag{3.10}$$

$$c_0 = \left(\frac{c}{a}\right)^2 - 1 \tag{3.11}$$

3.2 Hardware Friendly Hybrid TDOA/AOA (HTDA) Based Positioning Algorithm

In the proposed algorithm, simple add, subtract and shift operations are used. This simplicity makes this algorithm attractive to the RISC (Reduced Instruction Set Computer) processors and FPGA chips. In signal processing projects implementation systems, since RISC processors run faster, easier to design, test and manufacture, it is preferred to use them to process the algorithm. The proposed algorithm is hardware-oriented location estimation method and is suitable to be implemented on reconfigurable hardware devices and RISC processors, which is a privilege over the other positioning methods. In the traditional software-oriented hybrid location determination method, during the execution cycle, many operations must be executed to locate MS position, hence is not proper to be used in FPGA and RISC processors.

In the proposed method, two BSs must be implemented, any of them responsible for one or more operation, while in TDOA method at least three BSs are required to estimate the MS location. Using less number of antenna arrays compared with another positioning methods, is a privilege in our proposed method.

The proposed algorithm use the parameter of a hyperbola which can be defined by a set of all points in the plane, the difference of whose distance from two fixed points (the foci) in the plane is a positive constant equal to 2a, and this parameter can be easily calculated as:

$$a = \frac{R_1 - R_2}{2} = \frac{ct_{12}}{2} \tag{3.12}$$

Also the parameter c defines half of the distance between the two foci which define the positions of the two base stations, this parameter can be calculated from:

$$c = \frac{D}{2} \tag{3.13}$$

$$b = \sqrt{c^2 - a^2} \tag{3.14}$$

The parameter *b* can be calculated by approximating its value using an iterative CORDIC like square-root computing element as will be illustrated later .Such approximation is done to avoid the use of power and square root operation in below equation.

The proposed algorithm work with two cases and every case has three main hardware-oriented steps:

• Step 1: Vector circular rotation

• Step 2: Vector hyperbolic rotation

• Step 3: Vector length incrementation

Case 1: Alpha 1 on and Alpha 2 off

The proposed hardware oriented algorithm starts with vector circular rotation with α_1 using the measurements provided by AOA to find $\sin(\alpha_1)$, $\cos(\alpha_1)$. Assuming that the base station provides AOA measurement as it is shown Figure 13. A vector 1 is circularly rotated by the AOA value. The vector circular rotation is implemented using an iterative hardware oriented technique as it is shown Figure 13.

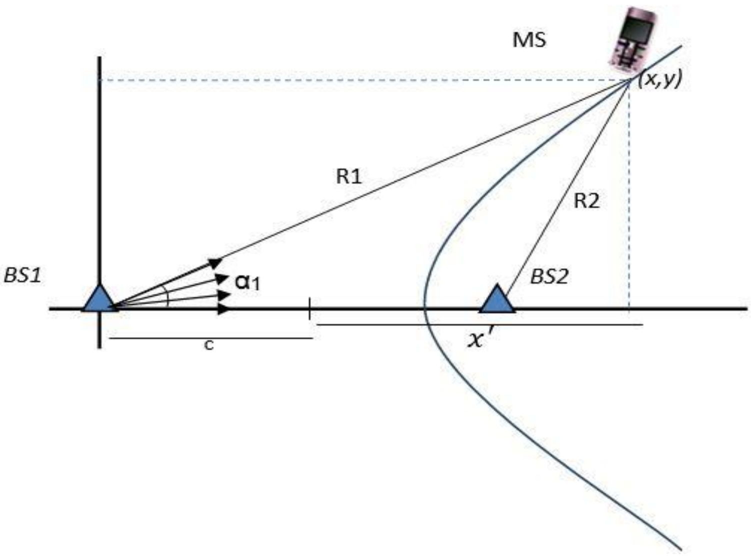

Figure 13. Circular Vector Rotation with AOA

The circular rotation matrix M can be written as:

$$M = \begin{bmatrix} cos\sigma & \pm sin\sigma \\ \mp sin\sigma & cos\sigma \end{bmatrix} \tag{3.15}$$

Where σ is the step rotation angle in radians. Taking the sin function as:

$$\sin\sigma = 2^{-k} = v \tag{3.16}$$

And knowing that:

$$cos^2\sigma + sin^2\sigma = 1 \tag{3.17}$$

The cos function can be written as:

$$\text{Cos}\ \sigma = \sqrt{1 + sin^2}\sigma = \sqrt{1 + 2^{-2k}} \tag{3.18}$$

Now, we can show that:

$$= \sqrt{1 - 2^{-2k}} \leq 1 - 2^{-2k-1}$$

By squaring both sides:

$1-2^{-2k} \leq 1-2.2^{-2k-1}+2^{-4k-2}$

$=1-2^{-2k}+2^{-4k-2}$

Hence,

For k ≥ 4 one gets $2^{-4k-2} \leq 2^{-18} \leq 10^{-5}$.so for an accuracy of Ɛ=10^{-5}, cos(α) can be approximated as:

$$\cos\sigma = 1-2^{-2k-1} = 1-2^{-(2k+1)} = 1-u \qquad (3.19)$$

Therefore, a vector 1 (x,y) can be recursively rotated using matrix (3.14), and the new coordinates of its head each rotation, are as follows:

$$\begin{bmatrix} x_{i+1} \\ y_{i+1} \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} . \begin{bmatrix} x_i \\ y_i \end{bmatrix} \qquad (3.20)$$

So, for the vector 1, the rotation equations are:

$$x_{1,i+1} = x_{1,i} + x_{1,i}\, u - y_{1,i}\, v, \qquad (3.21)$$

$$y_{1,i+1} = y_{1,i} + y_{1,i}\, u + x_{1,i}\, v, \qquad (3.22)$$

With initial values $x_{1,0} = 1$, $y_{1,0} = 0$. since the step rotation angle is σ_i, the accumulated angle will be:

$$\sigma_{i+1} = \sigma_i + 2^{-k} \qquad (3.23)$$

The stop condition for the rotation is

$$\Delta\alpha_1 = \alpha_1 - \sigma_{i+1} \leq \varepsilon \qquad (3.24)$$

And the last iteration values are $x_{1,i+1} = \cos(\alpha_1)\,, and\ y_{1,i+1} = \sin(\alpha_1)$, and the rotation loop is control by:

While $\Delta\alpha_1 = (\alpha_1 - \sigma_{i+1}) > \varepsilon$

Rotate vector (1)

END

Now, the proposed technique implements step 2 and 3 in parallel as it shown in Figure 14, therefore, it will be called parallel vector hyperbolic rotation and vector incrementation. To perform hyperbolic rotation, The TDOA measurement provided by the MS results in to hyperbolic curve that passes through the MS. The parameters of the hyperbolic function (a, c and b) are determined using equations (3.12), (3.13) and (3.14), respectively. It is obvious that the computations of (a) and (c) can be implemented using only simple shift operations. However, the computation of (b) parameter requires some mathematical operations that are difficult to implement in hardware. Therefore, a CORDIC like iterative computation is used such that,

$$x_{2,i+1} = x_{2,i} + x_{2,i}\, u - y_{2,i}\, v, \quad (3.28)$$

$$y_{2,i+1} = y_{2,i} + y_{2,i}\, u + x_{2,i}\, v, \quad (3.29)$$

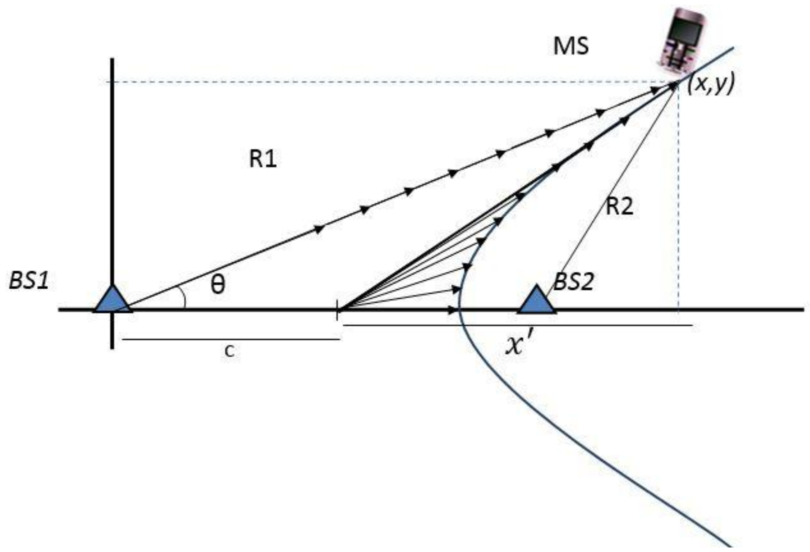

Figure 14. Parallel Vector Hyperbolic Rotation and Vector Length Incrementation With α1

Initially, the coordinates values are set $x_{2,0} = c$ and $y_{2,0} = a$, and the iterative procedure continues until the stopping condition is reached where $y_{2,i}$ becomes nearly close to zero. After evaluating the hyperbolic parameters, the vector hyperbolic rotation and vectors length incrementation will be started to find the intersection point which represents the MS as shown in Figure 14. The procedure will starts with hyperbolic rotation for vector (2) to calculate real coordinate of (x), the initial values are $x_{2,0} = a$ and$y_{2,0} = 0$.

Hyperbolic rotation for vector (2)

The hyperbolic rotation matrix *M* can be written as:

$$M = \begin{bmatrix} \cosh\sigma & \sinh\sigma \\ \sinh\sigma & \cosh\sigma \end{bmatrix} \quad (3.29)$$

Where

$$\text{Sinh } \sigma = 2^{-k} \quad (3.30)$$

$$\text{Cosh}^2 \sigma - \text{Sinh}^2 \sigma = 1 \quad (3.31)$$

Cos function can be written as:

$$\text{Cosh } \sigma = \sqrt{1 + sinh^2 \sigma} = \sqrt{1 + 2^{-2k}} \quad (3.32)$$

Now, we can show that:

$$= \sqrt{1 + 2^{-2k}} \leq 1 + 2^{-2k-1}$$

By squaring both sides:

$$1 + 2^{-2k} \leq 1 + 2.2^{-2k-1} + 2^{-4k-2}$$

$$= 1 + 2^{-2k} + 2^{-4k-2}$$

Hence,

For k ≥ 4 one gets $2^{-4k-2} \leq 2^{-18} \leq 10^{-5}$.so for an accuracy of $\mathcal{E}=10^{-5}$, cosh(α) can be approximated as:

$$\text{Cosh } \sigma = 1 + 2^{-2k-1} = 1 + 2^{-(2k+1)} = 1 - u \quad (3.33)$$

Finally, the parametric equations of hyperbola are:

$x = a\,cosh\;\sigma$ (3.34)

$y = b\,sinh\;\sigma$ (3.35)

To calculate real coordinate of (x), the initial values are $x_{2,0} = a$ and $y_2 = 0$.

$x_{2,i+1} = x_{2,i} + x_{2,i}\,u - y_{2,i}\,v$, (3.36)

$y_{2,i+1} = y_{2,i} + y_{2,i}\,u + x_{2,i}\,v$, (3.37)

The resultant $x_{2,i+1} = a\;cosh\;\sigma$ can be used for real x coordinate of the rotated vector, But the resultant $y_{2,i+1} = a\,sinh\,\sigma$ is not the real y coordinate of the rotated vector this is because equation (3.21), where b should be used to find real y coordinate.

Now, to calculate real coordinate of (y), the initial values are $x^{/}_{2,0} = b$, and $y^{/}_{2,0} = 0$. the resultant $y^{/}_{2,0} = b\;sinh\,\sigma$ can be used for the real y coordinate of the rotated vector.

$x^{/}_{2,i+1} = x^{/}_{2,i} + x^{/}_{2,i}u - y^{/}_{2,i}\,v$, (3.38)

$y^{/}_{2,i+1} = y^{/}_{2,i} + y^{/}_{2,i}u + x^{/}_{2,i}\,v$, (3.39)

Vector length incrementation is used parallel with Vector hyperbolic rotation to estimate x and y coordinate for MS, and used function such as:

For vector (1)

$x_{1,i+1} = x_{1,i}$ + Si 2^{-k} cos α_1 (3.40)

$y_{1,i+1} = y_{1,i}$ + Si 2^{-k} sin α_1 (3.41)

Where S is the sign of increment, Si is a sign parameter (i.e. Si= +1).

While Δx =(c+$x_{1,i}$-$x_{2,i}$) > ε

Rotate vector (2)

While Δy = (y'_2-y_1) > ε

If Δy= (y'_2-y_1) > ε

Increment Vector (1)

End while

End while

Case 2: Alpha 1 off and Alpha 2 on

The proposed hardware oriented algorithm start case 2 with vector circular rotation with α_2 using the measurements provided by AOA to find sin(α_2) and cos(α_2). Assuming that the base station provides AOA measurement as it is shown Figure 15, a vector 3 is circularly rotated by the AOA value. The vector circular rotation is implemented using an iterative hardware oriented technique as it is shown Figure 15. So, for the vector 3, the rotation equation is:

$$x_{3,i+1} = x_{3,i} + x_{3,i}\, u - y_{3,i}\, v, \qquad (3.21)$$

$$y_{3,i+1} = y_{3,i} + y_{3,i}\, u + x_{3,i}\, v, \qquad (3.22)$$

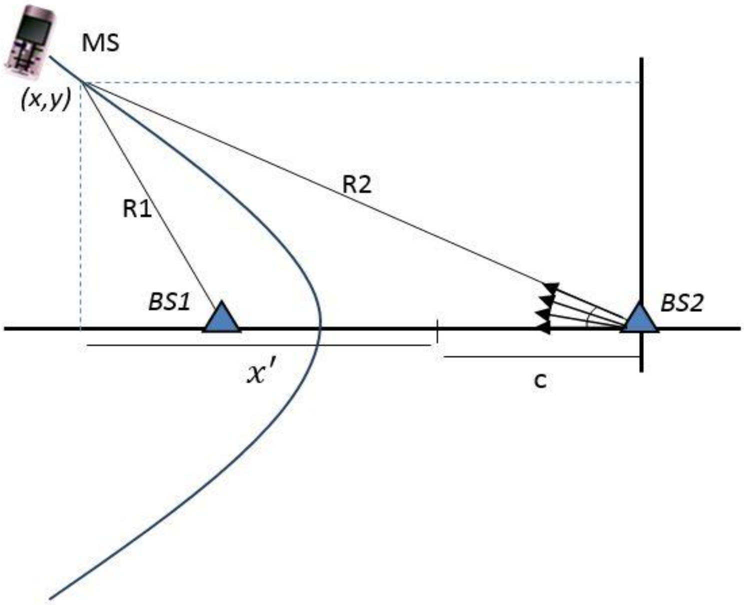

Figure 15. Parallel Vector Rotation with α2

With initial values $x_{3,0} = 1,\ y_{3,0} = 0.$ since the step rotation angle is σ_i, the accumulated angle will be:

$$\sigma_{i+1} = \sigma_i + 2^{-k} \tag{3.23}$$

The stop condition for the rotation is:

$$\Delta\alpha_2 = \left(\alpha_2 - \frac{\pi}{2}\right) - \sigma_{i+1} \leq \varepsilon \tag{3.24}$$

And last iterated $x_{3,i+1} = \cos(\alpha_2)$, and $y_{3,i+1} = \sin(\alpha_2)$, and the loop rotation is control by:

While $\Delta\alpha_2 = (\alpha_2 - \sigma_{i+1}) > \varepsilon$

Rotate vector (3)

END

Now, the proposed technique implements step 2 and 3 in parallel as it shown in Figure 16.

Vector length incrementation is used parallel with Vector hyperbolic rotation to estimate x and y coordinate for MS, and used function such as:

For vector (3)

$x_{3,i+1} = x_{3,i} + \text{Si}\ 2^{-k} \cos \alpha_2$ (3.40)

$y_{3,i+1} = y_{3,i} + \text{Si}\ 2^{-k} \sin \alpha_2$ (3.41)

And the same procedure is applied to do hyperbolic rotation for vector (2) as mentioned before.

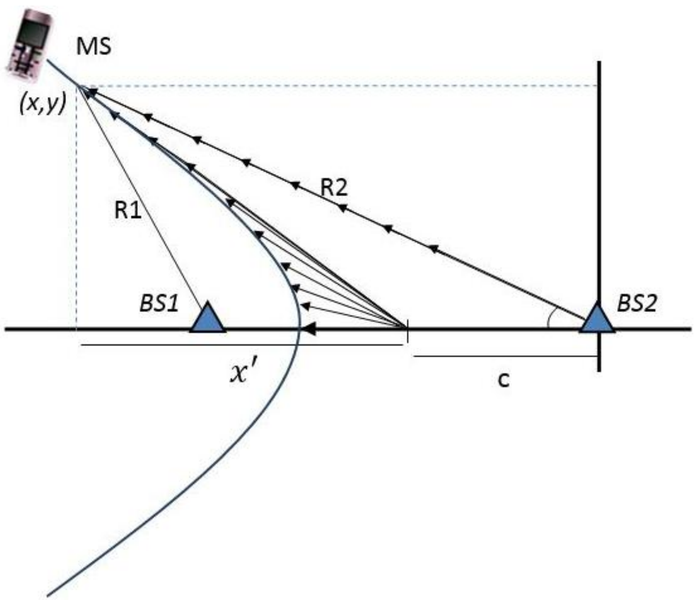

Figure 16. Parallel Vector Hyperbolic Rotation and Vector Length Incrementation with α2

While $\Delta x_2 = (c + x_{2,i} - (D + x_{3,i})) > \varepsilon$

Rotate vector (2)

While $\Delta y_2 = (y'_2 - y_3) > \varepsilon$

Increment Vector (3)

End while

End while

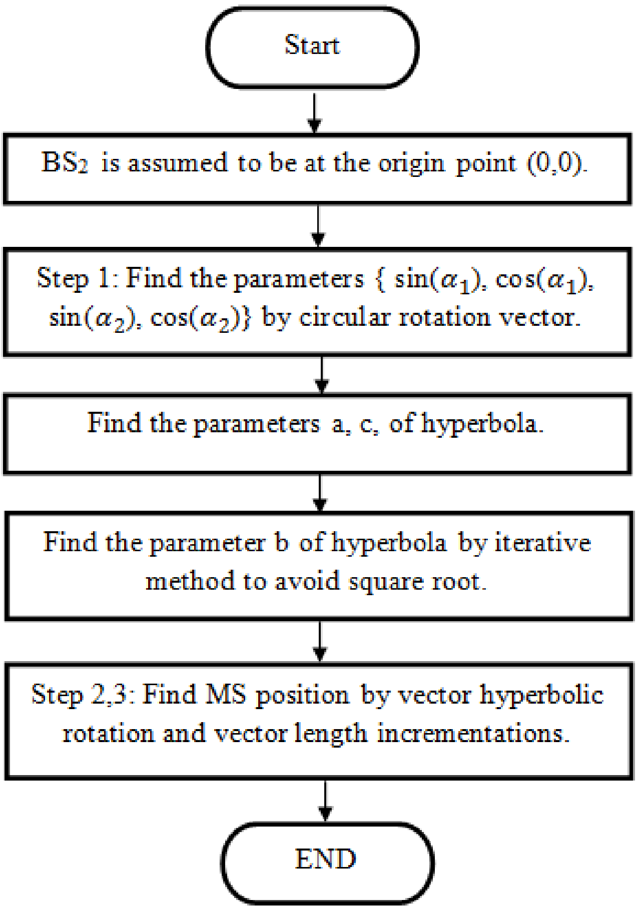

Figure 17. The General Scheme for the Proposed Algorithm

From the above equation it clearly that no trigonometric or complex calculation are used. Only, simple add, subtract and shift operations are used which are the necessary requirements for simple hardware implementation.

Chapter 4

SIMULATION AND ANALYSIS OF RESULTS

This chapter explains the simulation and results that was obtained in this project. The computational cost of the proposed method in comparison with the hardware oriented algorithms was done. The errors in estimation of the proposed technique was computed and compared with the hardware oriented algorithms.

The proposed algorithm simulation was executed in MATLAB 7 package. MATLAB 7 was used initially to observe the working of the traditional methods like angle of arrival and time difference of arrival algorithms. The errors, and the computational costs of these traditional methods were estimated using MATLAB 7.

In the proposed algorithm (HTDA) which utilizes the techniques of angle of arrival and time difference of arrival techniques, the mobile location estimation is evaluated in the coverage area. In the proposed method (HTDA) it is seen that only simple addition, subtraction and shift operations are used. This method also completely avoids the usage of trigonometric equations or complex calculation which is easily to implement in simple hardware oriented and highly likely to be implemented in the FPGA which is considered as future work for these thesis.

The detailed simulation model and the simulation results of computational cost estimation and estimation errors are as explained below.

4.1 Simulation Model

For the simulation purposed and accurate results generation, the mobile station position locations are randomly distributed between (0,0), (D,0) and (0,D) where D is assumed to be the distance between the two deployed BSs which equal to 1 km. As shown in Figure 18, for smooth results the estimation trail is repeated for 10,000 random MS position, and then the error and computational cost computed as an average for 10,000 estimation trails.

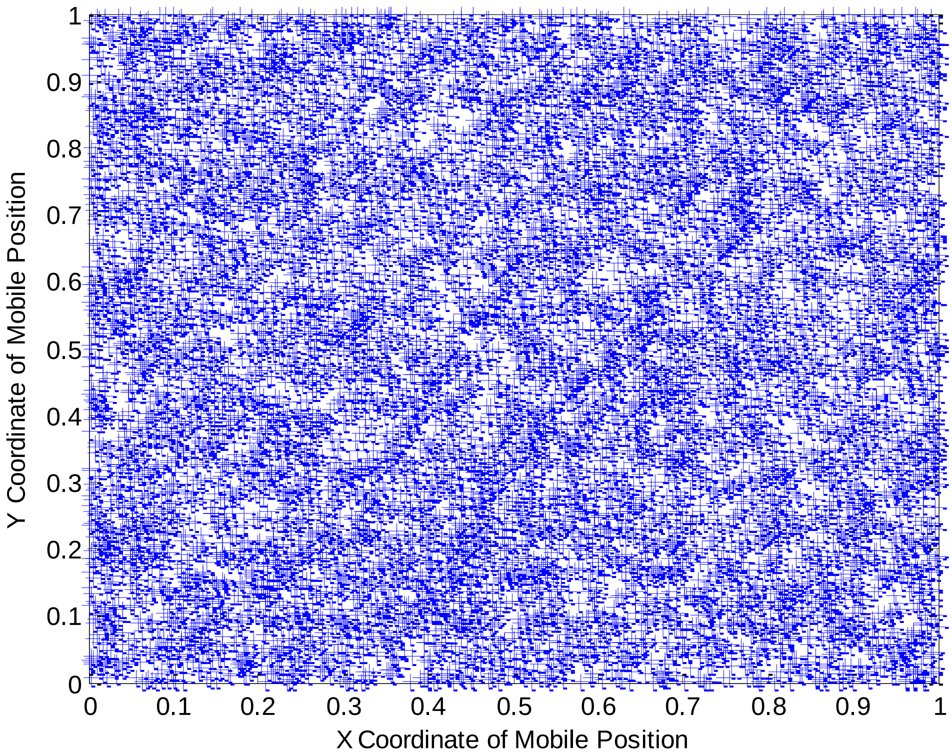

Figure 18. Random Distribution for Mobile Position

4.2 Simulations for Computational Cost

The corresponding weight multiplied by the number of operations will compute the computational cost [36]. The overall computational cost for every step size of 20 bit accuracy and precision in the proposed algorithm (HTDA) is tabulated in Table 1.

Table 1.Weights of Operations

Operation	Relative Weight
Addition	1
Subtraction	1
Shift	1
Multiplication	40
Division	40
Square Root	100
Sin	404
Arcsine	404
Cos	404
Tan	1448
Arc tan	1448

Table 1, describes the overall computational cost for every step size of 20 bit accuracy in the proposed Hybrid algorithm (HTDA).

The computational cost of the proposed algorithm (HTDA) was then compared with the traditional methods like time difference of arrival algorithm and angle of arrival algorithm. The comparison of the computational cost is depicted in Figure 19.

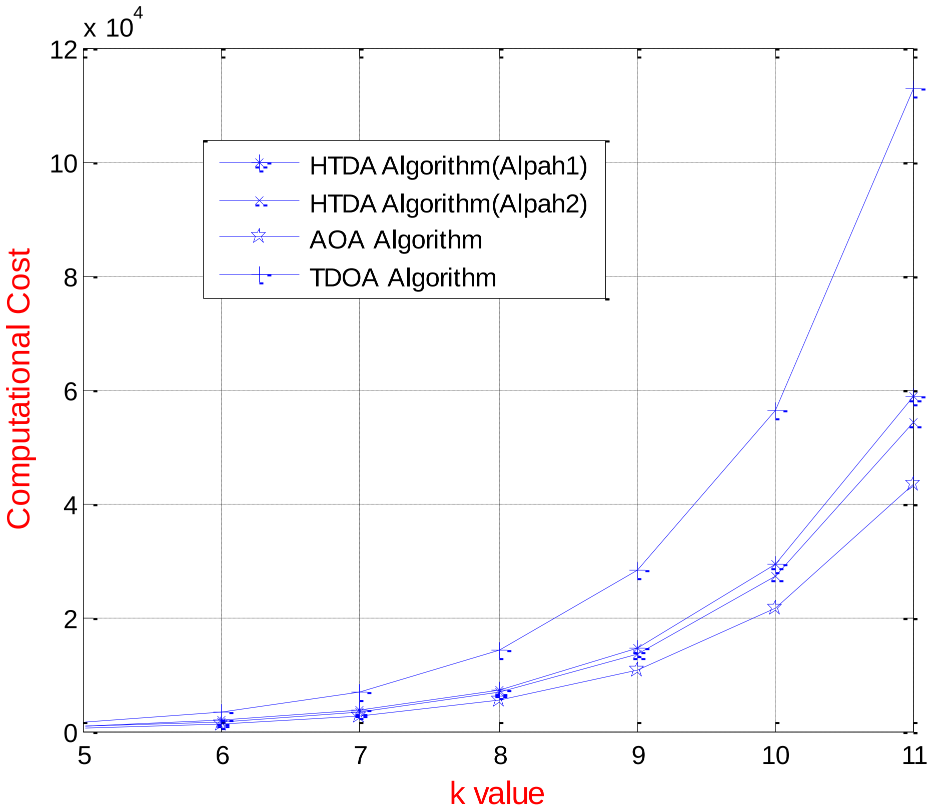

Figure 19. Computational Cost for the Proposed Algorithm with (α1,α2) in Comparison with AOA and TDOA Algorithms

From the Figure 19, it is seen that the computational cost of the proposed algorithm (HTDA) with (α_1, α_2) outstrips the traditional algorithm for the 'K' value of 7 and more or less close to K=8 where the computational cost for traditional algorithm equal 3861. For one processor clock, a minimum of one operation or maybe it will be processed with a fewer number of operations. Thus the operation will be processed with a fewer clock cycles and hence the proposed algorithm will execute at higher speed. As seen from the Table 1, the proposed technique's weight of operation increases as the value of K is increased which intern will decrease the step size. The computational cost of the proposed algorithm (HTDA) will increase for higher values of 'K' i.e. For values of K greater than 7. As seen from the Figure 19, the proposed algorithm (HTDA) has very little computational cost in both cases (α_1, α_2) when compared to other hardware oriented techniques like time difference of arrival method while the accuracy of the proposed algorithm (HTDA) equivalent the accuracy of TDOA algorithm. The computational cost of AOA algorithm is less than TDOA and the proposed (HTDA) algorithms but, it has less accuracy from TDOA and the proposed algorithms. The proposed algorithm exhibits a moderate computational complexity taking into consideration the superior performance of the proposed algorithm in term of error (which is equivalent to TDOA). The presented algorithm (HTDA) in both cases (α_1, α_2) in this thesis can be considered as a low complex version of TDOA algorithm as shown in Figure 19, Thus this adds up to an advantage of this algorithm that it can be easily implemented in FPGA which will be much handier.

Comparing the proposed method (HTDA) in both cases (α_1, α_2) with traditional AOA and TDOA methods, the computational cost for the K value to 5 (step size of 2^{-5}) is lesser. The time taken to run the algorithm and estimate the position location of the target will depend on the step size. The processing and execution time taken to estimate the position location of the mobile station is illustrated in Table 2, and it's done by using CORE 2 Duo processor.

Table 2. CPU Execution Time for the Proposed Hybrid (HTDA)

K value	CPU time (sec) α1	CPU time (sec) α2
5	2.505095	2.519398
6	2.887424	2.730622
7	3.952449	3.602659
8	5.859154	5.099851
9	9.710372	8.601830
10	17.671779	14.568515
11	32.953674	27.884087

In addition, the proposed algorithm (HTDA) requires only two BSs to perform algorithm the estimation process while, three BSs are required in TDOA algorithm. Using two BSs facilitate the estimation process without restricting the cell to hexagonal shape as TDOA algorithm. Using three BSs with hexagonal cell shape introduce some complex mathematical operation that is omitted in the proposed (HTDA) algorithm. If we look to Figure 19, the average computational cost for the proposed algorithm only with (α_1, α_2), it seen that the computational cost has approximately posses same amount for all step value of k.

4.2 Simulation Results for Errors in Location Estimation

As mentioned in chapter 1, for all wireless communication users (in particular to cell phones) there is a mandatory rule from federal communication commission (FCC) to mend the quality and reliability of all emergency services like 911. A similar mandatory rule is abided by European commission for emergency services like E112. Looking at these commissions, their common motto is to ensure public safety by estimating the position location with maximum accuracy and with acceptable errors. This conventional error which is accepted by the commission is calculated for the proposed (HTDA) algorithm and it is compared with the standard algorithms like angle of arrival and time difference of arrival.

It is noted that the hardware oriented angle of arrival technique has higher percentage of errors which intern leads to lower accuracy and precision. In the Figure 20, it is observed that the proposed algorithm (HTDA) has very less errors in both cases (α_1, α_2) when compared with the AOA hardware oriented method.

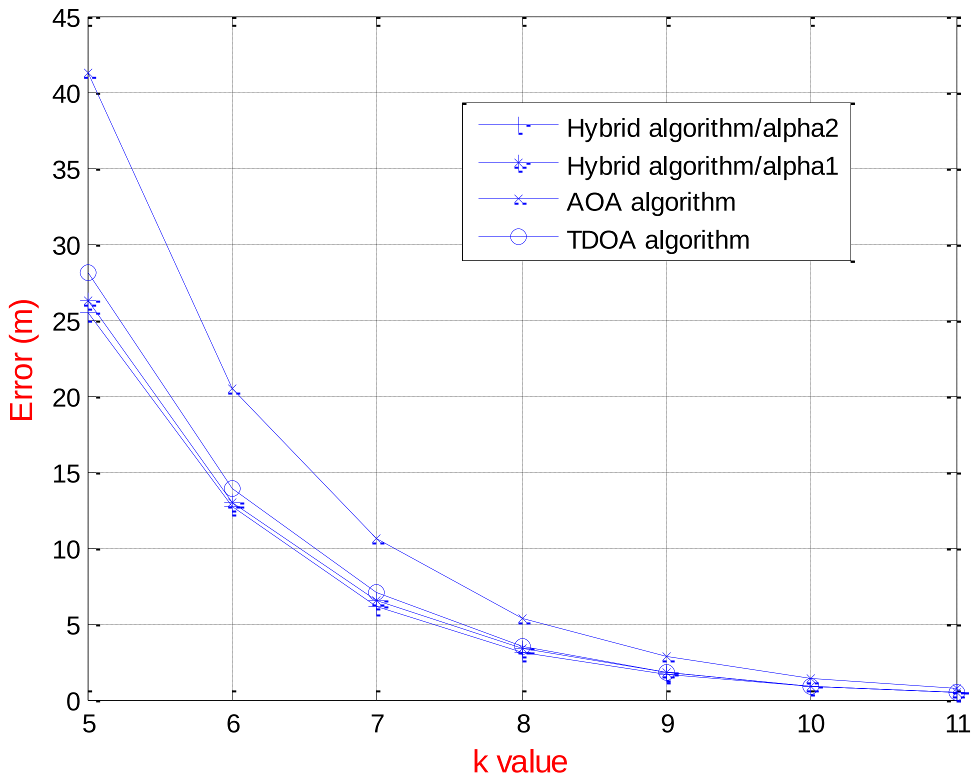

Figure 20. Comparison of Errors for the Proposed (HTDA) with α1, α2 and Hardware Oriented Techniques

But looking into the Figure 20, one can observe that time difference of arrival technique and the proposed algorithm (HTDA) in both cases (α_1, α_2) possess the same amount of errors. The errors in the proposed algorithm are equivalent when compared with the time difference of arrival technique. This is illustrated in Figure 20, which shows the comparison of errors for time difference of arrival method and the proposed algorithm in both cases (α_1, α_2).

In the above Figure 20, it is seen that in the proposed algorithm (HTDA) the error with α_1 is about 25 meters but, with α_2 is about 24 meters in the worst step i.e. for a step size of 2^{-5} in term the MS position location are randomly distributed for 10,000 estimation trails. The estimated error can be drawn closer to zero by decreasing the step size of the proposed (HTDA) algorithm. Thus for every step size that is discussed it is seen that the proposed hybrid (HTDA) technique is more accurate than hardware oriented Angle of arrival method and equivalent the performance for Time difference of arrival. Table 3, shows comparison the proposed and the traditional algorithm computational cost and error with AOA and TDOA algorithms. As the trigonometric operations are eliminated and it uses only simple operations the proposed algorithm has higher accuracy and precision to estimate the position location from AOA method. Thus this method can be suitably implemented in FPGA.

Table 3. Comparison the Proposed and the Traditional Method Computational Cost and Error with AOA and TDOA Algorithms

k value	AV HTDA Error(α1)	AV HTDA Error(α2)	AV AOA Error	AV TDOA Error	AV HTDA Cost(α1)	AV HTDA Cost(α2)	AV AOA Cost	AV TDOA Cost	AV Traditional algorithm Cost
5	25.25584	24.67946	41.15597	27.79131	867.18	810.46	857.724	1663.377	3861
6	12.9933	11.83991	20.50802	14.03186	1744.34	1688.41	1330.534	3425.408	3861
7	6.164333	6.576247	10.52623	7.037046	3498.87	3401.62	2675.95	6949.082	3861
8	3.371953	3.049814	5.272605	3.503656	7013.97	6826.53	5366.971	13991.87	3861
9	1.677029	1.620798	2.617623	1.776359	14036.17	13677.9	10748.71	28077.91	3861
10	0.811071	0.873892	1.305298	0.886242	28079.18	27380.68	21512.37	56251.52	3861
11	0.415777	0.420084	0.653918	0.439588	56168.86	54783.31	43040.56	112599	3861

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this thesis, a new algorithm is proposed (HTDA) which will help us in estimating the position location in cellular networks. The proposed algorithm avoids all kinds of trigonometric operations or complex calculation and uses only simple operations in addition, subtraction and shift operations. These factors make the proposed algorithm compatible enough to be implemented in simple hardware oriented and highly likely to be implemented in the FPGA which is considered as future work by the author.

This algorithm is an improvement over the existing hardware oriented algorithms like angle of arrival and time difference of arrival method. The proposed algorithm(HTDA) makes use of angle of arrival and time difference of arrival methods to emerge as a much efficient technique for estimating the position location. The mobile station that is located within the line of sight between the one smart antenna can be efficiently estimated for their position location with higher accuracy and precision by running this proposed algorithm in any one of these algorithms.

Another important aspect that plays a vital role in the mobile systems is cost. The proposed method is completely cost effective when compared to the time difference of arrival method. This is because the execution functions and instructions of the mobile systems are minimized. The number of processing instructions is substantially reduced due to the use of reduced instruction set computer (RISC). This RISC uses minimum set of instructions to execute the approximation of position location. As seen in the previous chapter it is observed that the proposed method (HTDA) has very less computational cost (for step size of 2^{-5}) when compared to time difference of arrival technique.

The simplicity of the proposed algorithm is relatively high because it utilizes only simple operations in addition, subtraction and shift operators to estimate the position location. It also avoids the trigonometric functions or complex calculation which makes the execution of the algorithm faster.

The proposed technique is no short of a hybrid method which combines the angle of arrival and time difference of arrival method. The accuracy that was obtained is pretty much high and it is more than sufficient in satisfying the federal commission standards. The proposed algorithm has very less computational cost than time difference of arrival methods for hall range for values of K.

5.2 Future Work

The future work of this project is to implement the algorithm in the FPGA. This can definitely be implemented in the FPGA as it does not use trigonometric functions. In the case of traditional methods trigonometric functions are used and thus making it complicated for implementation.

The proposed algorithm to be used in mobile phone tracking purposes is also considered in the author's future work. The estimation of position location of the mobile station in three dimensional spaces can be done by enhancing this algorithm.

The proposed algorithm is intended to be integrated with global positioning system by the author.

REFERENCES

[1] Stefan, S., Moritz, N., & Alistair, E. (2006). *Foundations of location based services*, lecture note on LBS, university of Zurich.

[2] Liu, F., & Yang, Z. (2009). Study on applications of LBS based on electronic compass. In *Wireless Communications, Networking and Mobile Computing, 2009. WiCom'09. 5th International Conference on* (pp. 1-4). IEEE.

[3] Farrell, J. A., & Barth, M. (1999). *The Global Positioning Systems & Inertial Navigation*. McGraw-Hill. ISBN 0-07-022045-X.

[4] Choi, W. J., & Tekinay, S. (2003). Location based services for next generation wireless mobile networks. In *Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual* (Vol. 3, pp. 1988-1992). IEEE.

[5] Tayal, M. (2005). Location services in the GSM and UMTS networks. In Personal Wireless Communications, 2005. ICPWC 2005. *2005 IEEE International Conference on (pp. 373-378)*. IEEE.

[6] McMahon, M., & Steketee, C. (2006). Investigation of proposed applications for LBS enabled mobile handsets. *In Mobile Business, 2006. ICMB'06. International Conference on (*pp. 26-26). IEEE.

[7] Michelena, E. D., & Gutman, S. I. (2002). An automatic meteorological data collection system that is installed at Global Positioning System monitoring stations. *In OCEANS'02 MTS/IEEE* (Vol. 4, pp. 1930-1934). IEEE.

[8] Rappaport, T. S., Reed, J. H., & Woerner, B. D. (1996). Position location using wireless communications on highways of the future. *Communications Magazine, IEEE*, *34*(10), 33-41.

[9] Kayton, M., & Fried, W. R. (1997). *Avionics navigation systems*. John Wiley & Sons. ISBN 0-471-54795-6.

[10] Ficco, M., & Russo, S. (2009). A hybrid positioning system for technology-independent location-aware computing. *Software: Practice and Experience*, *39*(13), 1095-1125.

[11] Leick, A., Rapoport, L., & Tatarnikov, D. (2015). *GPS satellite surveying*. John Wiley & Sons. Inc, Hoboken, New Jersey: ISBN 0-471-05930-7.

[12] El-Rabbany, A. (2002). *Introduction to GPS: the global positioning system*. Artech House., INC. ISBN 1-58053-183-1.

[13] Munoz, D., Lara, F. B., Vargas, C., & Enriquez-Caldera, R. (2009). *Position location techniques and applications*. Academic Press. ISBN 13:978-0-12 374353-4.

[14] Webster, J. G., & Eren, H. (Eds.). (2014). *Measurement, Instrumentation, and Sensors Handbook: Spatial, Mechanical, Thermal, and Radiation Measurement* (Vol. 1). CRC press. LLC.1999, ISBN 3-540-64830-5.

[15] Tetley, L., & Calcutt, D. (2007). *Electronic navigation systems*. Rout ledge. 3rd edition. Lightning Source UK; ISBN 0 7506 5138 5.

[16] Mirjana, I., Simic Predrag, V. Pejovic. (2008).”Mobile Networks A compression of three methods to determine Mobile station location in cellular communication systems”; *John Wiley & Sons, Ltd*; European Transactions on Telecommunications EUR. Trans. Telecoms; DOI: 10.1002/ett1333. Available at www.interscience.wiley.com

[17] Laitinen, H., Lähteenmäki, J., & Nordström, T. (2001). Database correlation method for GSM location. In *Vehicular Technology Conference, 2001. VTC 2001 Spring. IEEE VTS 53rd* (Vol. 4, pp. 2504-2508). IEEE.

[18] Kaemarungsi, K., & Krishnamurthy, P. (2004). Modeling of indoor positioning systems based on location fingerprinting. In *INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies* (Vol. 2, pp. 1012-1022). IEEE.

[19] Fang, S. H., Lin, T. N., & Lin, P. (2008). Location fingerprinting in a décor-related space. *Knowledge and Data Engineering, IEEE Transactions on, 20*(5), 685-691.

[20] Baumann, J., Zimmermann, D., Layh, M., & Landstorfer, F. M. (2006). Accuracy Estimation of Location Determination Based on Database Correlation. In *Vehicular Technology Conference, 2006. VTC-2006 Fall. 2006 IEEE 64th* (pp. 1-5). IEEE.

[21] Figuera, C., Mora-Jiménez, I., Guerrero-Curieses, A., Rojo-Álvarez, J. L., Everss, E., Wilby, M., & Ramos-López, J. (2009). Nonparametric model comparison and uncertainty evaluation for signal strength indoor location.*Mobile Computing, IEEE Transactions on*, *8*(9), 1250-1264.

[22] Rappaport, T.S. (1996). *Wireless communications: principles and practice* (Vol.2). New Jersey: prentice hall PTR.

[23] Sayed, A. H., Tarighat, A., & Khajehnouri, N. (2005). Network-based wireless location: challenges faced in developing techniques for accurate wireless location information. *Signal Processing Magazine*, *IEEE*, *22*(4), 24-40.

[24] Xiang, Z., Song, S., Chen, J., Wang, H., Huang, J., & Gao, X. (2004). A wireless LAN-based indoor positioning technology. *IBM Journal of research and development*, *48* (5.6), 617-626.

[25] Kitasuka, T., Hisazumi, K., Nakanishi, T., & Fukuda, A. (2005). Positioning Technique of Wireless LAN Terminals Using RSSI between Terminals. *International conference on pervasive systems and computing, PSC,* Las Vegas, Nevada, CSRA Press, pp 47-53.

[26] Youssef, M., & Agrawala, A. (2004). Continuous space estimation for WLAN location determination systems. In *Computer Communications and Networks, 2004. ICCCN 2004. Proceedings. 13th International Conference on* (pp. 161-166). IEEE.

[27] Jeehong, K., & Lee, C. G. (2006). Location and position recognizing method by wireless Ethernet signal strength in indoor. In *Industrial Technology, 2006. ICIT 2006. IEEE International Conference on* (pp. 670-674). IEEE.

[28] Bensky, A. (2007). *Wireless positioning technologies and applications*. Artech House., INC.; ISBN-13: 978-159693-130-5.

[29] Arias, J., Zuloaga, A., Lázaro, J., Andreu, J., & Astarloa, A. (2004). Malguki: an RSSI based ad hoc location algorithm. *Microprocessors and Microsystems, 28*(8), 403-409.

[30] Michel, J. F., & Vossiek, M. (2008). Wireless sensor network approach for robust localization of mobile nodes with minimal complexity. *e & i Elektrotechnik und Informationstechnik*, *125*(10), 341-346.

[31] Lewis, F. L. (2004). Wireless sensor networks. *Smart environments: technologies, protocols, and applications*, 11-46. John Wiley, New York; ARO Research Grant DAAD 19-02-1-0366; pp: 1-18.

[32] Raghavendra, C., Krishna, M., Sivalingam, L. & Taieb, Z. (2004). "*Wireless sensor networks*"; ISBN: 1-4020-7883-8.

[33] Mao, G. (Ed.). (2009). *Localization Algorithms and Strategies for Wireless Sensor Networks: Monitoring and Surveillance Techniques for Target Tracking: Monitoring and Surveillance Techniques for Target Tracking*. IGI Global.

[34] Aiello, R., & Batra, A. (Eds.). (2006). *Ultra wideband systems: technologies and applications*. Newnes.Inc. ISBN 13: 978-0-7506-7893-3.

[35] Exel, R., & Loschmidt, P. (2009). High accurate timestamping by phase and frequency estimation. In *Precision Clock Synchronization for Measurement, Control and Communication, 2009. ISPCS 2009. International Symposium on* (pp. 1-6). IEEE.

[36] Muller, J. M., & Muller, J. M. (2006). *Elementary functions*. Birkhũser Boston.

APPENDIX

Appendix A: Confidence Interval

For sample size equal to 10, with 95% confidence level, we can say the MS located in this interval. Confidence interval upper and lower boundaries are shown in Table 4.

Table 4. Confidence interval for 10 samples

K	Mean value	Variance (S^2)	Standard Deviation	Lower Boundary	Upper Boundary
5	15.2391	240.1876	15.4980	4.1533	26.3250
6	10.8715	80.9897	8.9994	2.4341	17.3088
7	5.2290	31.3093	5.5955	1.2265	9.2315
8	1.8207	0.7892	2.8884	1.1852	2.4562
9	1.0125	0.5015	1.5062	0.9500	1.1047
10	0.6060	0.2769	0.5262	0.2296	0.9824
11	0.2378	0.0200	0.1413	0.1367	0.3389

The confidence interval results for different k values are illustrated in the table above.

As an example in the following, we will calculate the confidence interval for k=7. The confidence interval for the samples can be calculated using this formula:

$$\bar{Y} - t_{\frac{a}{2}}, n-1\ \frac{s}{\sqrt{n}} \leq \mu \leq \bar{Y} + t_{\frac{a}{2}}, n-1\ \frac{s}{\sqrt{n}}$$

Where $\bar{Y}$ is the sample mean and:

$$\bar{Y} = \frac{\sum_{i=1}^{10} = y_i}{10} = 4.6472$$

Where$y_1, y_2, \ldots\ldots, y_n$ represents a sample of size n.

S is standard deviation and $s = \sqrt{S^2}$ where:

$$S^2 = \frac{\sum_{i=1}^{10}(y_i - \bar{Y})^2}{n-1} = 8.6829$$

So:

$S = \sqrt{8.6829}$*= 2.9467*

Since $t_{\frac{0.05}{2}, 9} = 2.262$, using the confidence interval, the boundaries can be calculated. So we have:

$$4.6472 - (2.262).\frac{8.6829}{\sqrt{10}} \leq \mu \leq 4.6472 + (2.262).\frac{8.6829}{\sqrt{10}}$$

Therefore:

2.683128 ≤ μ ≤ 10.8581