INVESTIGATION OF THE MOST SUITABLE LOCATION FINDING TECHNIQUES FOR ISTANBUL IN GSM1800 NETWORK

by

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ABSTRACT

INVESTIGATION OF THE MOST SUITABLE LOCATION FINDING TECHNIQUES FOR ISTANBUL IN GSM1800 NETWORK

Although there isn't yet a successful deployment of a Location Services among the existing worldwide operators, locating the subscriber is still appealing, thus there are many ongoing studies on the topic.

While locating subscriber, an important criteria is the accuracy of the result. However, each application requires different level of accuracy, and not a unique solution may fulfill all these needs at once. This last one makes the location more challenging.

In this work, several already existing techniques, such as CellID, and Signal Strength methods, are applied to field measurements that were done in the real commercial GSM network in Istanbul. Then, a newly emerging method, which is the Database Correlation Method (DCM); is also applied and comparisons are done. This method is not imposing any change for the subscribers terminal, thus this makes it more important and acceptable.

The results obtained by the SS and DCM, are also exposed to the post processing (Kalman Filtering) steps.

Significant improvements in the results are concluded after these processes applied.

ÖZET

İSTANBUL'DA GSM 1800 ŞEBEKESİNDE EN UYGUN YER BULMA TEKNİKLERİNİN ARAŞTIRMASI

Günümüzde, Abonenin Yerini Belirleme Servisleri hiçbir ticari GSM şebekesinde tam olarak başarıyla uygulanamamaktadır. Bu konuda bir çok yeni araştırma ve çalışma yapılmakta ve uygun çözüm standartları geliştirme çabaları sürmektedir.

Yer belirleme uygulamalarında önemli bir kriter, belirlenen yerin hassasiyetidir. Farklı uygulamaların değişik büyüklükteki hatalara, farklı tolerans göstermesi ise işin başka bir boyutudur. Gerek farklı hassasiyet değerleri, gerekse bu değerlerin ancak faklı yöntemlerle ölçülebiliyor olması, yer belirleme tekniklerini ve bunların ticari uygulamalarını zorlaştırmaktadır.

Bu çalışmada gerçek bir ticari GSM şebekesinde yapılan saha ölçümleri eldeki mevcut yöntemler ile incelendikten sonra, literatürde yeni ortaya çıkmaya başlayan Veritabanı Kullanarak İlişkilendirme Yöntemi (DCM) ve Sinyal Seviyesi (SS) Yöntemleri uygulanarak karşılaştırmalar yapılmıştır. Bu yöntem ile hedeflenen mevcut cep telefonları, abonelerinin kullanmakta oldukları cihazlarda bir değişiklik yapmadan kullanması dikkate alınmıştır. Elde edilen sonuçların iyileştirilmesi için ayrıca art işleme yöntemleri de (Kalman Filtresi) değerlendirilmiştir.

Sonuç olarak uygulanan yöntemler sayesinde yer belirleme doğruluklarında kayda değer iyileştirme sağlandığı gözlenmiştir.

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LIST OF SYMBOLS/ ABBREVIATIONS

3GPP	Third Generation Partnership Project
A-GPS	Assisted Global Positioning System
AOA	Angle of Arrival
ARFC	Absolute Radio Frequency Channel
BCCH	Broadcast Control Channel
BSC	Base Station Controller
BSIC	Base station identity code
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CGI	Cell Global Identity
E-112	Enhanced 112
E-911	Enhanced 911
E-OTD	Enhanced Observed Time Difference
E-OTD-C	Enhanced Observed Time Difference Circular
EU	European Union
FCC	Federal Communications Commission
GMLC	Gateway Mobile Location Centre
GMSC	Gateway Mobile Services Switching Centre

GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile telecommunications
HLR	Home Location Register
LCS	Location Service
LMU	Location Measurement Unit
LOS	Line of Sight
MLC	Mobile Location Centre
MPC	Mobile Positioning Centre
MS or MT	Mobile Station / Terminal
MSC	Mobile Services Switching Centre
NLOS	None Line of Sight
OTD	Observed Time Difference
PLMN	Public Land Mobile Network
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RTD	Real Time Difference
RXLEV	Received Signal Level
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module

SMSC	Short Message Service Centre
SS	Signal Strength
STK	SIM ToolKit
TA	Timing Advance
TEMS	Test Equipment for Mobile Systems
TOA	Time of Arrival
UL-TOA	Uplink Time of Arrival
UMTS	Universal Mobile Telecommunications System
VLR	Visitor Location Register
WAP	Wireless Application Protocol
WGS	World Geodetic System

1. INTRODUCTION

From the day one of the communication, the questions who and where have been important. When the mobile communication era started, the question where has been emphasized, and the positioning became more and more important. In the early days, location was important especially for security and emergency purposes [1], [2]. In today world, commercial factors are also driving the wireless location finding technologies to be put in place. Almost for all the mobile operators and the service and application providers, location of the subscribers have become a crucial information for providing mobile customers with the right service, at the right time, in the right location.

Despite the fact that there are numerous drivers for locating the mobile subscribers, there isn't any successfully deployed solution among the GSM operator in Turkey. Another factor negatively affecting the success result is that the presence of many methods using various techniques; however there is no one single solution applicable for all cases. In addition to that, the locating performance isn't still sufficient.

In Turkey, a new driving force for the establishment of the location systems among the GSM operators may appear soon: the European Union standards and integration requirements. The Caution++ project, conducted by European Union's Information Society Technologies (IST), targets to design and develop a novel, low cost and flexible system able to monitor the available resources from the cellular networks of the second and third generation (2G, 3G) and Wireless Fidelity (Wi-Fi) networks [3]. Enhanced 112, started in 2002 in Europe, may be another governmental driver for the locating subscribers [2].

1.1. Objectives

The objective of this thesis is to examine the location techniques that are available in the literature [4]-[24], to do field experiment in the real commercial network, and then enhance the results applying Signal Strength Method and Database Correlation Method (DCM). Then, the obtained results are to be post processed by Kalman filtering.

The software and the tools that will be used during the above processed are also to be developed in Matlab, microsoft office spreadsheet and access programs within the scope of this thesis.

1.2. Thesis Structure

The thesis is organized into 7 chapters:

Chapter 2 gives an overview of the positioning and the accuracy evaluation criteria.

Chapter 3 describes the DCM and post processing techniques.

Chapter 4 express the algorithm and the application developed and used that will be enabling the locating the MT with the proposed models.

Chapter 5 outlines the field measurements done in the real commercial GSM network and the tools used.

Chapter 6 gives deep analysis of simulation and measurement results.

Chapter 7 concludes the thesis studies, and suggests for the possible improvements.

2. OVERVIEW OF POSITIONING

The positioning technologies can be divided into three main categories: Network based technologies, handset based technologies, and hybrid technologies. In this chapter these three categories are briefly discussed, and important capabilities are identified and evaluated.

2.1. Network Based Technologies

Network based technologies have the advantage that they can be used with old mobile terminals. All the required updates for these methods to work, will be in the network. There four methods are Cell-ID (CGI) and TA, Time or Arrival (TOA) / Uplink Time of arrival (UL-TOA), Angle of Arrival (AOA), and Signal Strength (SS).

2.1.1. Cell-ID (CGI) and TA

All the required parameters for this method to work are implemented in the network today. The only update that is needed is a mobile positioning centre that calculates the position estimate [14].

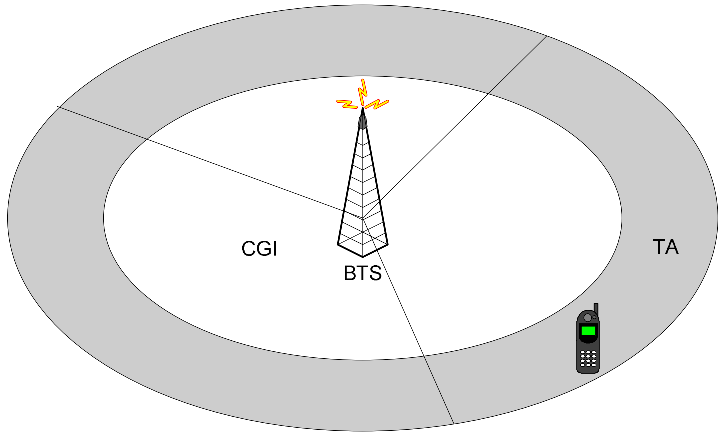

Figure 2.1. CGI with TA method

The single-cell timing advance (TA) positioning method uses the Cell Global Identity (CGI) and the Timing Advance (TA) parameter to determine the location of the MT. The CGI identifies the cell that MT is located in. A cell can be a circular (omni) or a triangular sector. The TA parameter is an estimate of the distance from the MT to the serving BTS. TA values are divided into 64 slots (0-63), each with a radius of 550 m. This means that a MT which is 600 m away from the serving BTS, will have a TA value of 1. By using the TA value, the location of the MT can be constrained further than the cell identity, as the location of the terminal can be narrowed to a circle or a sector in steps of a 550 meters radius from the BTS.

The accuracy of this method varies according to the size of the cell. The radius of a cell may vary from 100 m to 35 km (CGI). In cells that cover a limited geographical area, the accuracy is fairly good, but it decreases fast as the distance between the transmitter and receiver increase. Accuracy will also depend on whether the cell is an omni cell or a triangular sector cell [10].

2.1.2. Time of Arrival (TOA) / Uplink Time of Arrival (UL-TOA)

The uplink time of arrival (UL-TOA) method is quite similar to E-OTD, except that the calculations are performed by the network and not by the MT. This method works by having all BTSs within range listening to a burst from the MT. When a base station receives this burst, it records the time when it was received and sends it to a server. The server gathers the information from multiple BTSs and by comparing the time of arrivals and the BTSs positions, the server can by triangulation calculate the position of the MT [6], [7], [10].

The accuracy of this method varies according to the knowledge of surrounding BTSs, propagation of the received signals and synchronization of the clocks in the network. Since this solution is entirely network based, the investment cost for the operator is high. The number of LMUs needed for this solution is higher (1:1 to 1:2) than the E-OTD method [6], [7], [9].

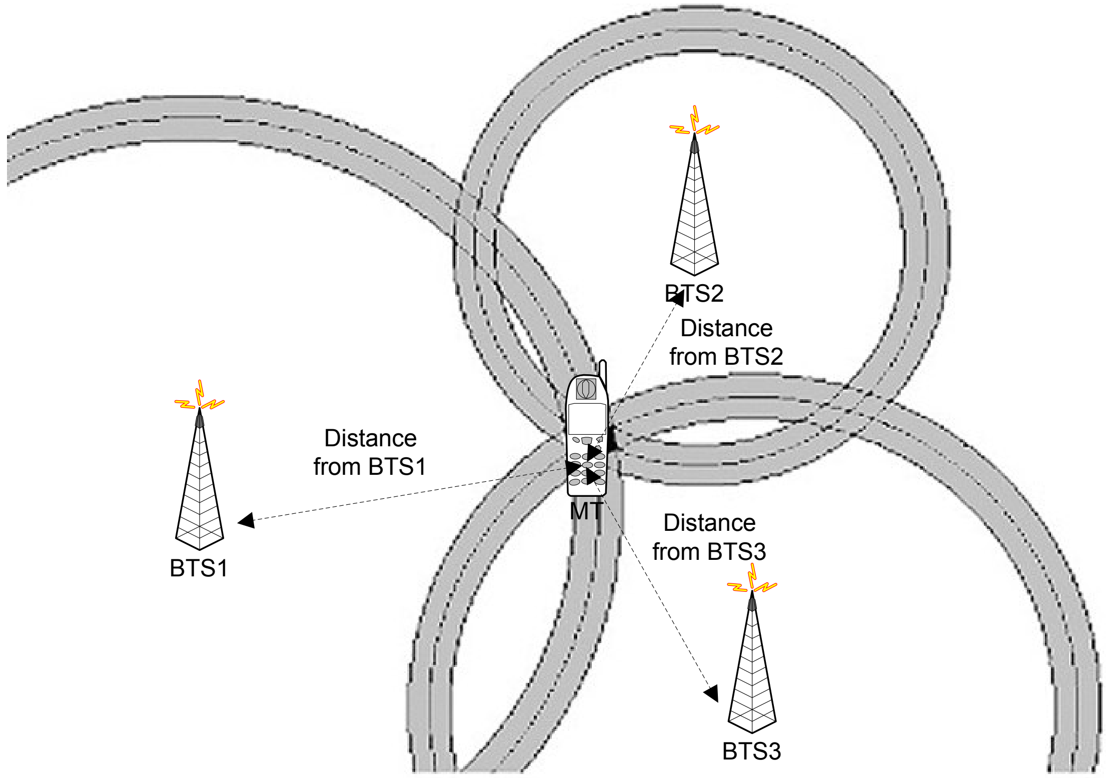

Figure 2.2. Time of arrival (TOA) method

2.1.3. Angle of Arrival (AOA)

The angle of arrival (AOA) method requires the installation of directional antennas or antenna arrays. The method determines location of the MT based on triangulation. The intersection of two directional lines each formed by a radial from a BTS define a unique position for the MT [6], [9], [12], [14]. This method requires the MT to have knowledge of a minimum of two BTSs (or one pair). If available, more than one pair can be used (most common is tree BTSs which yields two pairs).

The accuracy of this method varies according to the knowledge the bearing towards the surrounding BTSs. The method also requires line-of-sight to the involved BTSs for the position estimate to be accurate.

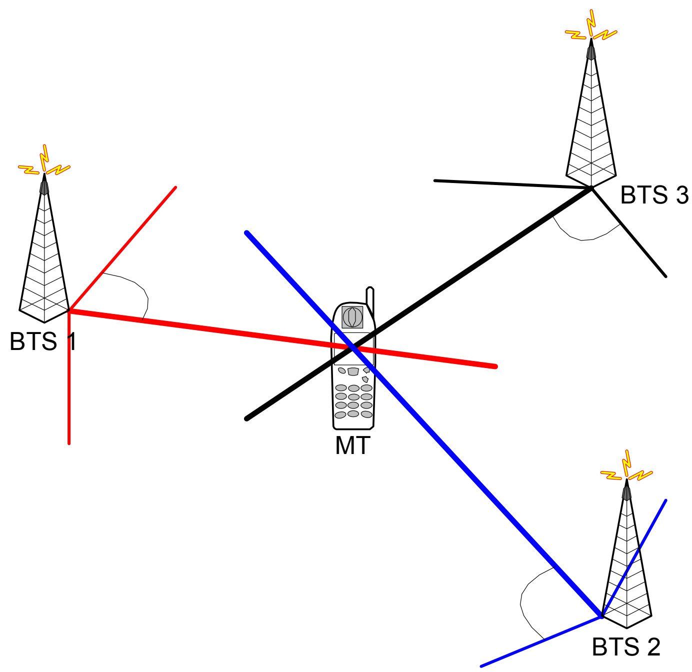

Figure 2.3. Angle of arrival (AOA) method

2.1.4. Signal Strength

One way to improve the positioning accuracy is to utilize information about the signal strength [9], [11]. Depending on the network type and topology, the MT is capable of measuring signal strength values from a number of different sources. For example, in GSM, the MT continuously measures the signal strength of the serving and up to six neighbor cells [9]. In free-space propagation, the signal strength can be assumed proportional to the distance between the signal source and the MT. By using propagation models, the location estimation for the MT can be solved geometrically. However, the line-of-sight (LOS) assumption is often invalid due to the disturbances in the propagation environment. Non line-of-sight propagation environment can also be modeled to some extent, but the results are usually poorer than in case of LOS visibility. In addition, the number of hearable cells affects directly the performance of the signal strength technique. Signals from at least three cells are needed to better solve the location of the MT.

The location of the MT can also be estimated by calculating a weighted average of the cell locations [9]:

$$[X,Y]_{MT} = \frac{\sum_{i=0}^{n} k_{BSi}(x,y)_{BSi}}{\sum_{i=0}^{n} k_{BSi}} \qquad (2.1)$$

Where $[X,Y]_{MT}$ is the estimated location of the MT, n is the number of hearable cells, $(x,y)_{BSi}$ is the location of cell and k_{BSi} is the corresponding signal strength value.

2.2. Handset Based Technologies

Handset based technologies have the best accuracy, but need new or upgraded mobile terminals.

The Assisted GPS (A-GPS) method, use a GPS receiver in the MT to find the MT position. As seen in Figure 2.4, the satellite navigation system developed by the US military makes use of the signals from 27 satellites to calculate the position on earth, both horizontally and vertically with accuracy better than 10 meters [14]. A GPS terminal, wherever it is in the world, needs to be able to see four or more satellites, and when a GPS receiver receives a signal from the satellites, the time of arrival of the signal is used to calculate the receiver’s position.

This method has high accuracy outdoors, but is complicated indoors or certain urban areas because the GPS needs contact with the GPS satellites to function. When a GPS receiver is switched on, it does not know the precise time and location. Thus, it takes some time for the GPS receiver to obtain its position. To solve this problem with the time consuming period to get detailed positioning information in the GPS receiver, assisted GPS (A-GPS) is used.

A-GPS means that for the GPS to “kick-start”, additional data about the MT location is provided by the network or by the MT itself. These two methods are known as network A-GPS and MT A-GPS.

In network A-GPS the information is provided to the MT by the SMLC. In MT A-GPS, additional information can be received by the MT in form of special broadcast messages defined in [14], [20]. This additional information can be CGI for the serving BTS and/or TA. The method can also used with E-OTD to provide additional information about the MT location.

GPS uses a higher frequency band than GSM, and new mobile terminals must be equipped with two antennas (GPS and normal GSM). Because the GPS receiver has high power consumption, the new mobile terminals require higher battery capacity. Thus, the method has high cost for the consumers, who need new mobile terminals to use this method.

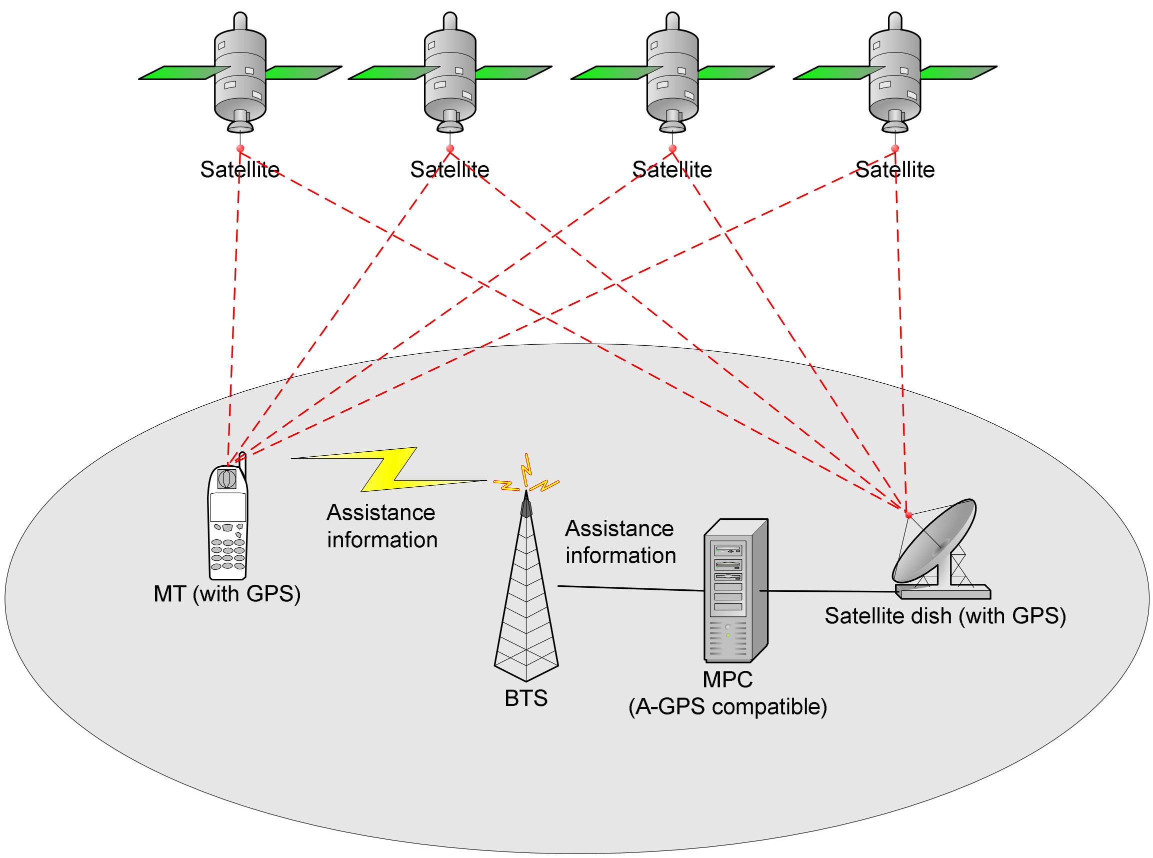

Figure 2.4. Assisted GPS (A-GPS) method

2.3. Hybrid Technology

In this category, upgrades are needed both on the mobile terminals and in the network. The software in the mobile terminals must be upgraded and new elements must be deployed in the mobile network. The E-OTD method belongs to this category.

The Enhanced Observed Time Difference (E-OTD) method is based on the measured Observed Time Difference (OTD) between arrivals of bursts from serving and other BTSs (Figure 2.5). Both normal and dummy bursts can be used. The measured time difference between pairs of base transceiver stations, are referred to as OTD. Because the transmission of frames from the base transceiver stations are not synchronized in the GSM network, the real time differences (RTD) between pairs of base transceiver stations is measured by an LMU.

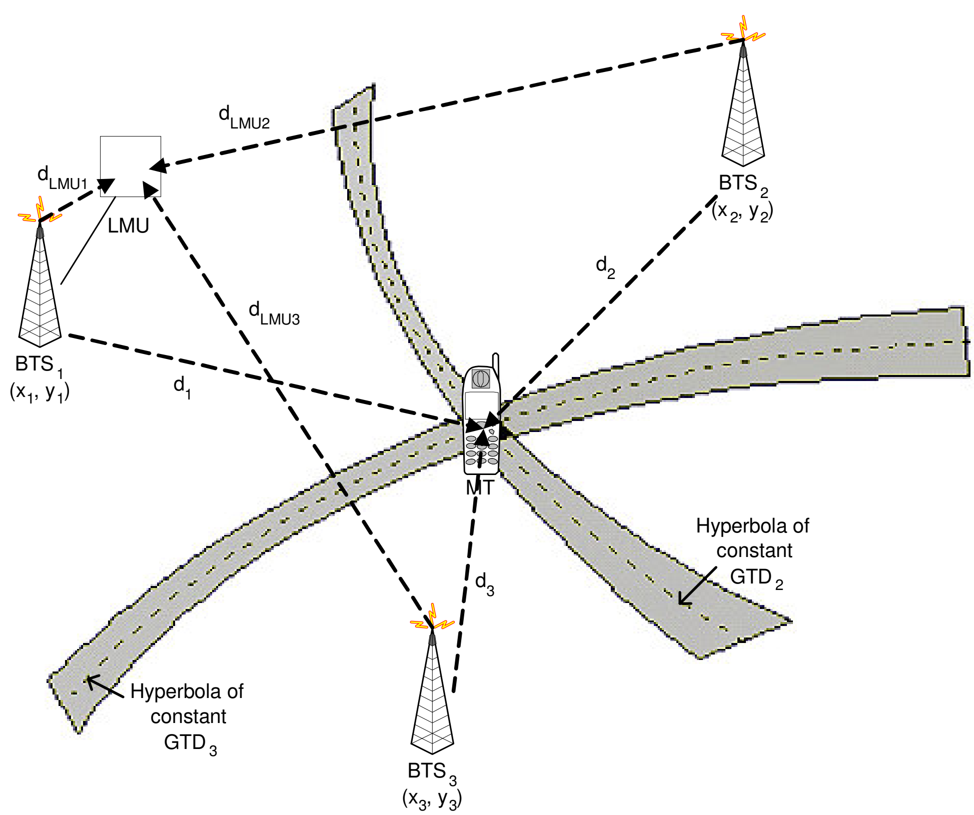

Figure 2.5. The E-OTD method.

In Figure 2.5, di is the length of the propagation paths from the BTSs to the MT and dLMUi is the length of the propagation paths from the BTSs to the LMU. The position of the BTSs is denoted as (xi, yi). The dashed line represents the hyperbolas calculated from the geometric time differences (GTD). The intersection of the hyperbolas gives the location of the MT [15].

2.4. Comparison of Location Technologies

Table 2.1 shows a brief comparison of the different location methods. The data are based on information from different vendors such as Ericsson, Nokia and Cambridge Positioning Systems.

Table 2.1 Comparison of location technologies

Method	**Accuracy**	**Coverage**	**Cost**
CGI + TA	Limited accuracy Guideline estimate: 100-1100 m	Indoor / outdoor: no limitations	In network: MLCs In handset: no cost
TOA / UL-TOA	Better accuracy than CGI + TA, but not as good as A-GPS Guideline estimate: 50-200 m	Indoor / outdoor: no limitations	In network: MLCs and LMUs In handset: no cost
AOA	Guideline estimate: 300 m	Indoor: limited coverage Outdoor: some limitations in case line-of-sight cannot be obtained	In network: directional antennas and MLCs In handset: no cost
Method	**Accuracy**	**Coverage**	**Cost**

SS	Better accuracy than CGI + TA, but not as good as A-GPS Guideline estimate: 50-500 m	Indoor: limited coverage Outdoor: some limitations in case line-of-sight cannot be obtained	In network: LMUs In handset: “no cost”
A-GPS	High accuracy Guideline estimate: 10 – 20 m	Indoor: limited coverage Outdoor: some limitations in case line-of-sight cannot be obtained	In network: MLCs and hardware to provide D-GPS information. In handset: additional HW
E-OTD	Better accuracy than CGI + TA, but not as good as A-GPS Guideline estimate: 50-400 m	Indoor / outdoor: no limitations	In network: MLCs and LMUs (less LMUs than in UL-TOA required and less expensive LMUs) In handset: “no cost” (added SW only)

2.5. Accuracy Criteria

The idea of mobile positioning is to solve the geographical location of a mobile terminal by utilizing radio waves from one or more reference points. Coming sections are looking for the answer of how to express the accuracy of the calculated positions, i.e. calculation of the positioning error [15], [18].

2.5.1. Positioning Error

The term positioning error is generally considered as the Euclidean distance between the estimated location and true location

$$d = \sqrt{(x_t - x_e)^2 + (y_t - y_e)^2 + (z_t - z_e)^2} \quad (2.2)$$

Where $E(x_e, y_e, z_e)$ is the estimated location and $T(x_t, y_t, z_t)$ the corresponding true location. In cellular network positioning, the error in the altitude is often ignored. In addition, the true location might be replaced with the location calculated with the Global Positioning System (GPS) receiver because it is often too time-consuming and sometimes even impossible to determine the true location accurately.

2.5.2. Circular Error Probability

Circular error probability (CEP) is the radius of a circle centered at the true position, containing the position estimate with a certain probability. Usually the radius of the 50% (R50) probability is used, but 67% (R67) and 95% (R95) probabilities are often quoted (Figure 2.6). In case of three-dimensional accuracy, a common measure is Spherical Error Probability (SEP), which also takes the error in the altitude into account.

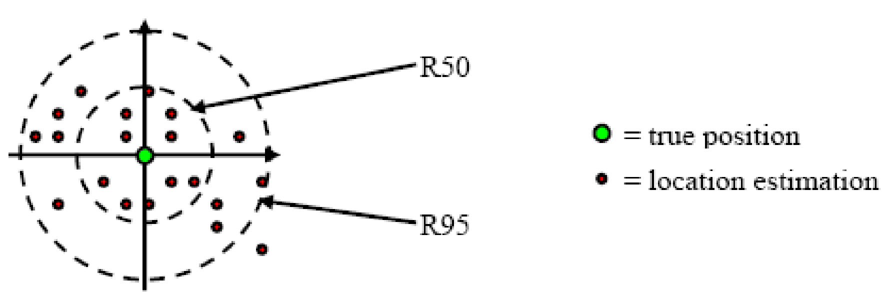

Figure 2.6. Circular error probability.

Actually, R50 equals the median of the positioning error distribution. Half the errors are above the median and half are below the median. A bit similar measure is the arithmetic mean which equals the sum of the positioning errors of the samples divided by the number of samples. The median is a much better measure than the arithmetic mean for highly asymmetrical distributions because it is less sensitive to extreme variations. In mobile positioning, the error distribution is usually distorted and thus, median is usually more illustrative than mean.

2.5.3. Cumulative Distribution Function

Cumulative distribution function (CDF) is often used in visualizing the positioning error. A general impression of the error distribution can be obtained quickly by looking the CDF graph. The X-axis represents the positioning error in meters and the percentage of all samples is depicted in the Y-axis.

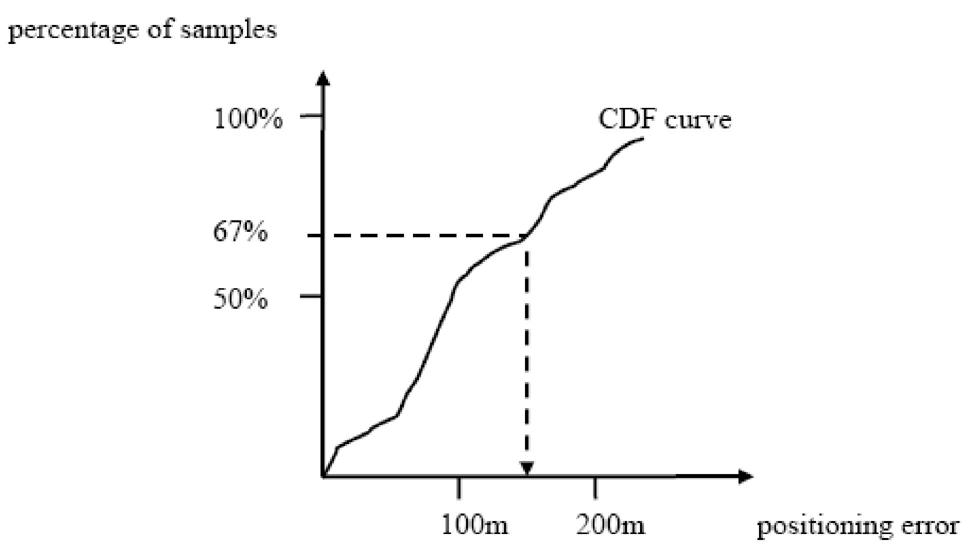

Figure 2.7. Cumulative distribution function.

With the cumulative distribution function, one can find out any desired percentile. For example, in Figure 2.7, it can be seen that 67% of the samples are positioned with an error less then 150 meters. Median, R67 and R95 values can be approximated from the CDF graph.

The accuracy required for E-911 and the accuracy proposed by the E-112 are given respectively in Table 2.2 and Table 2.3.

Table 2.2. Accuracy required for locating mobile terminals in phase II E-911

Solutions	**67% of calls**	**95% of calls**
Handset based	50 m	150 m
Network based	100 m	300 m

Table 2.3. Proposed requirements for location accuracy in E-112

	Indoor	**Urban**	**Suburban**	**Rural**	**Highway/ crossroads**
Caller can provide general information	10 – 50 m	25 – 150 m	50 – 500 m	100 – 500 m	100 – 500 m
Caller can not provide any information	10 – 50 m	10 – 150 m	10 – 500 m	10 – 500 m	10 – 500 m

3. DCM AND POST PROCESSING TECHNIQUES

This section introduces the Database Correlation Method and background information for the two post-processing techniques, Kalman filter and Map-Matching.

3.1. Database Correlation Method

The Database Correlation Method is described in [8], [17], [22] as general location method, which can be applied to any cellular or WLAN network. The key idea is to create a database of reference fingerprints from the whole area of interest. The reference fingerprint is a recorded measurement sample from a certain location in the area. In addition to the location information, the reference fingerprint contains signal information from the cells that were hearable when the measurement was carried out. The positioning is conducted by comparing the signal information of the request fingerprint to signal information of the reference fingerprints and returning the location of the best matching reference fingerprint.

In [22] a method provoked by the Gaussian probability distribution is introduced. The equation is given by

$$P = \sqrt{P_{EXP} * P_{Pen}} = \sqrt{\sqrt[n]{\prod_i e^{-(\frac{f_i - g_i(k)}{\sigma})^2}} * \sqrt[m]{\prod_i e^{-(\frac{f_i - g_i(k_{\min})}{\sigma})^2}}} \tag{3.1}$$

where P_{EXP} is the probability computed for n cells to match the request fingerprint with the k th reference fingerprint and P_{Pen} is the penalty term consisting all the penalty contributions computed for m cells, which do not exist in the reference fingerprint. f_i is the signal strength of the request fingerprint on the i th cell, $g_i(k)$ is the signal strength of the k th reference fingerprint on the same cell and $g_{\min}(k)$ is the weakest signal level in the reference fingerprint. The parameter σ characterizes the deviation between the signal strength values. The reference fingerprint with the highest probability *P* is set to be the best math for the request fingerprint.

3.2. Database Fingerprints

For DCM to work properly, the signal information of the database fingerprints should be location-dependent but not time-dependent. In other words, the measured signal levels of a certain location should remain the same both during the collection of the database fingerprints and during the time when positioning is carried out. However, this is not usually the case.

Two measurements session were done on the decided route. First set of measurements was done when going to Şile, and the second measurement was done on the way back to Ümraniye. In each measurement session 75K sample were logged, means a rich set of fingerprints for the used itinerary.

3.3. Kalman Filtering

The Kalman filter is a recursive solution of the discrete-data linear filtering problem. The word recursive means that the filter uses the information about its previous state during the estimation process of the current state. In mobile positioning, the discrete-data linear filtering problem is the approximated movement of the mobile terminal. With Kalman filtering, it is possible to track the position and speed of the MT and therefore, reduce the positioning error [16], [21].

3.4. Map-Matching

Land vehicle navigation has been one of the main areas of application for GPS device manufacturers. However, the accuracy of the Global Positioning System might vary from a couple of meters to several tens of meters depending on the current propagation environment and satellite visibility.

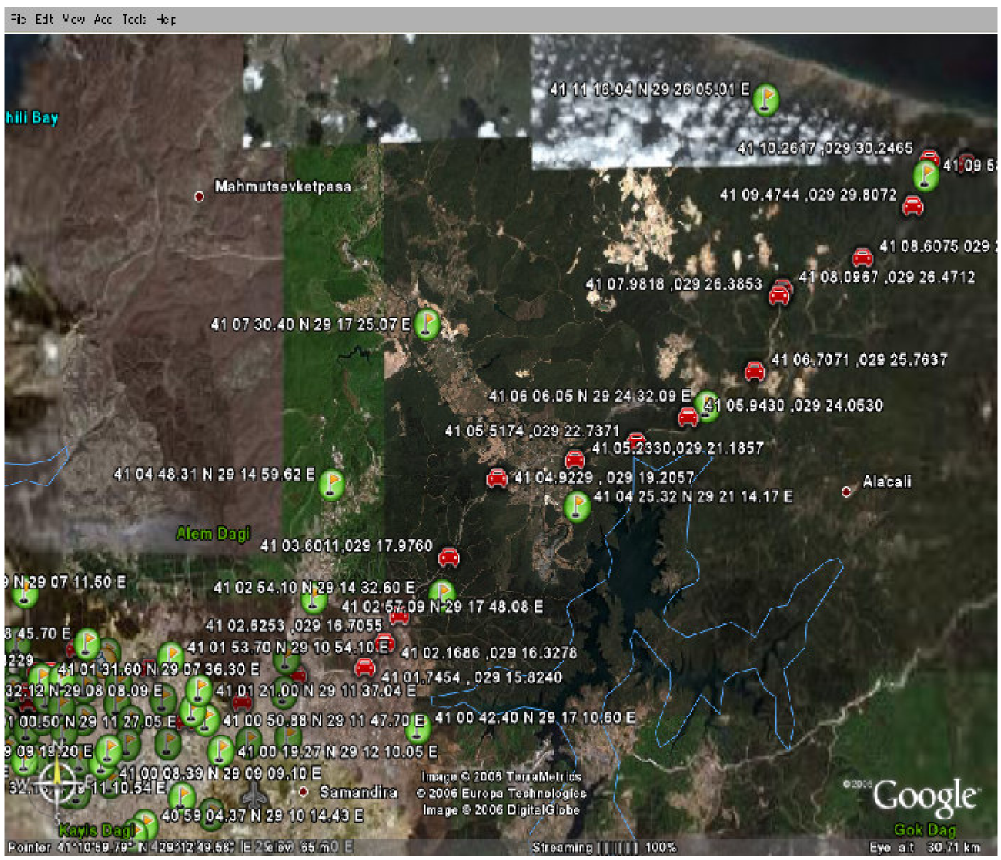

Figure 3.1. Measurements route. Basestations are shown with green icons, and the MT (car) positions with red ones.

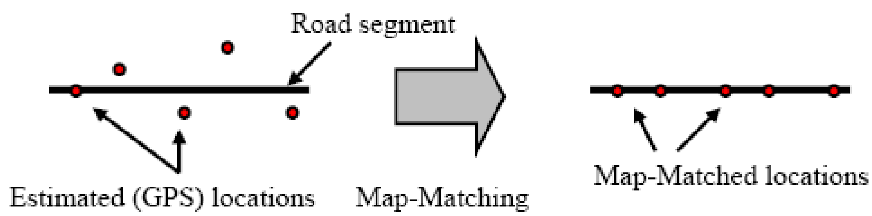

Figure 3.2. The concept of Map-Matching.

Map-Matching aims to reduce the positioning error by matching the traveled GPS-route to the best fitting set of road segments of a digital road map (Figure 3.2) [24].

4. ALGORITHM AND APPLICATIONS

4.1. DCM Algorithm

The database correlation method uses a database built from measurements or predictions. The position of the mobile terminal will then be determined by evaluation of the radio measurements, which are performed by the mobile terminal and/or the base stations. These measurement data are compared to the entries of the database. The corresponding correlation calculations find the best matching database entry and thus lead to a location estimate [22].

4.2. Implementations

A set of applications were developed for the following purposes:

- for parsing the measured data,
- feeding logs into fingerprints database,
- using logs derived from the measurements, implementing the CellID,
- using logs derived from the measurements, implementing the SS,
- running the DCM algorithm.
- applying corrective processes (Kalman filtering).

4.2.1. Parsing The Data

Data parsing is to eliminate the unnecessary data coming from the measurements. Clear data creates fewer burdens on the database and the applications.

4.2.2. Feeding Log into The Fingerprint Database

After parsing operation, data are fed to form the fingerprint database.

The fingerprint database is formed into two set of data. Figure 4.1 and 4.2 show the graphs of data used as fingerprint data bases, obtained by the measurements.

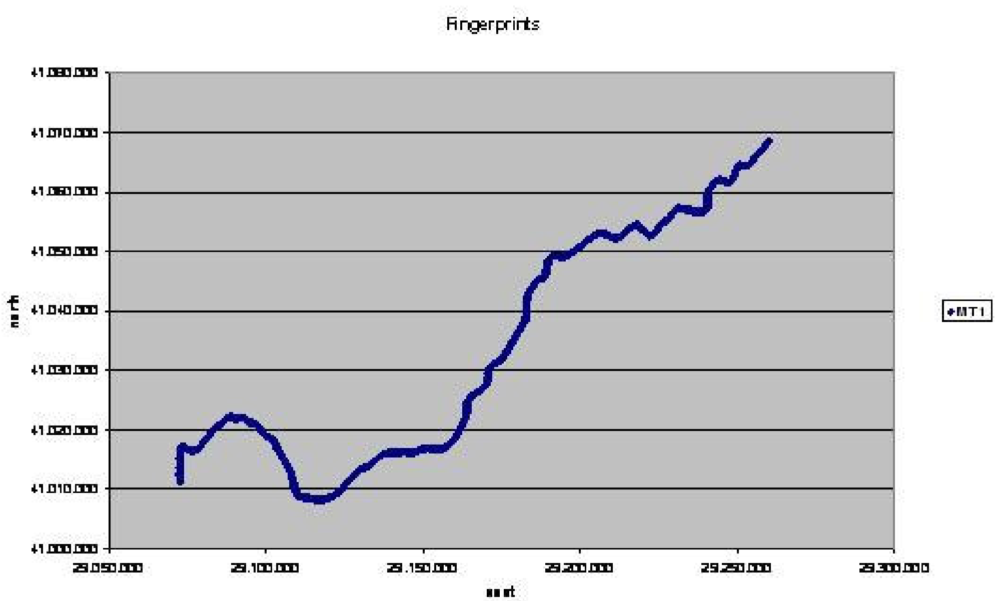

Figure 4.1. Fingerprints data (first of the two data sets of fingerprints)

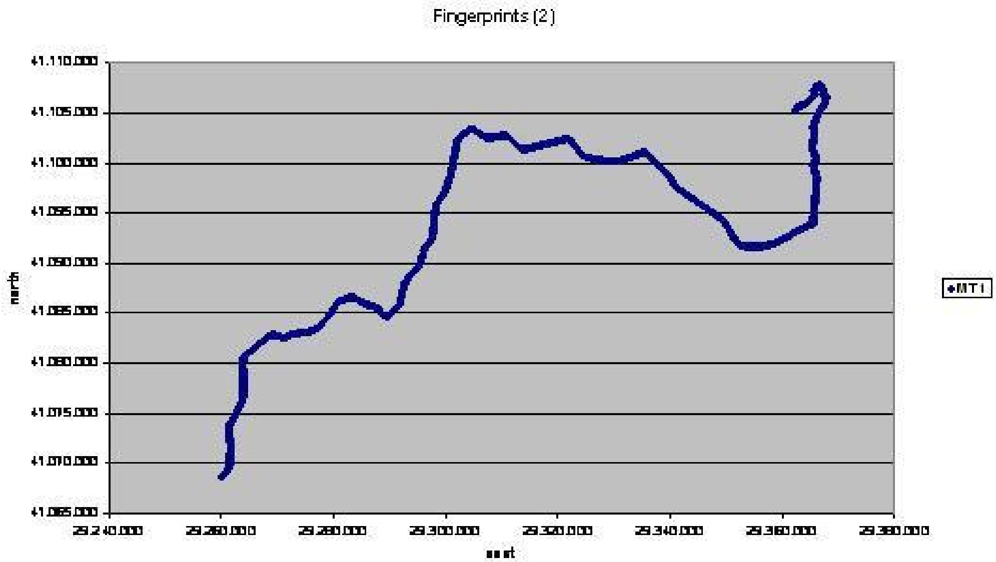

Figure 4.2. Fingerprints data (second of the two data sets of fingerprints)

4.2.3. Computing

Using logs and the database, computing is done for MT positioning with CellID, SS, and the DCM.

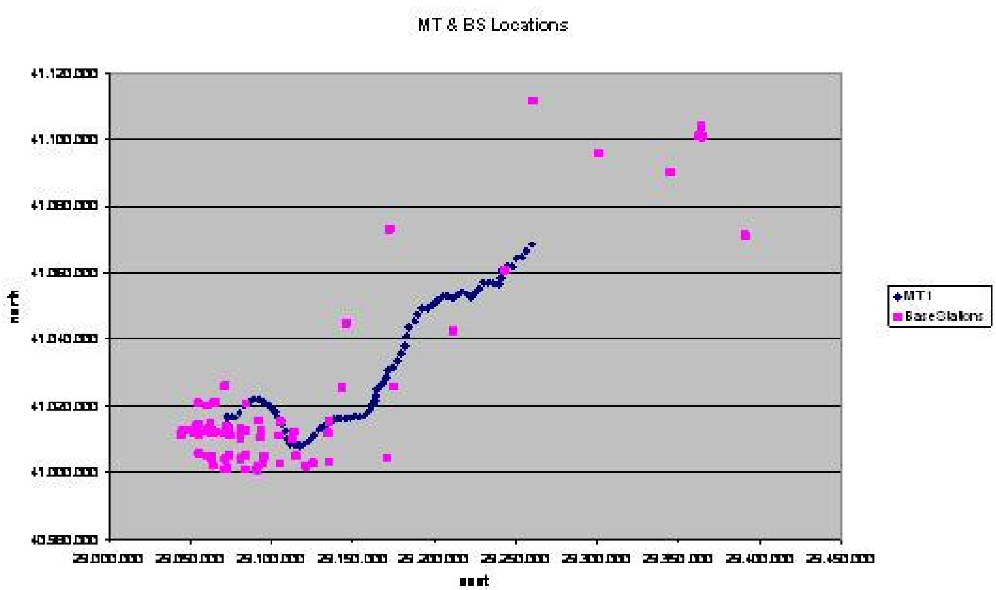

Figure 4.3. Locations of the mobile terminal and base stations

4.2.4. Post Processing

Kalman filtering and the map matching are applied for the better results.

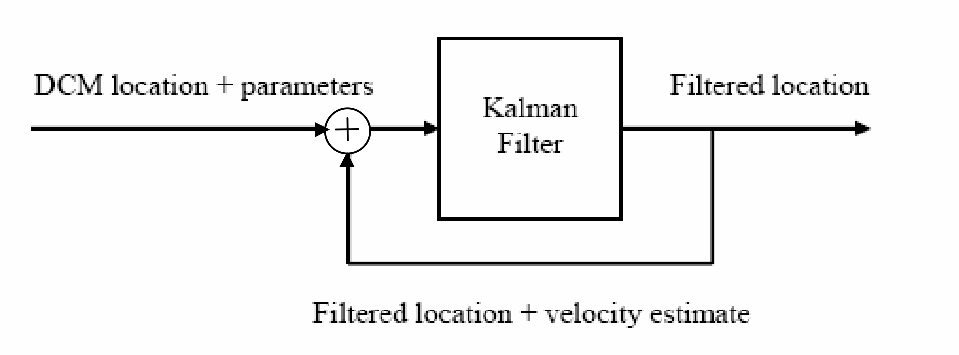

Figure 4.4. Kalman filter in DCM and SS location.

For a portion of the high way, the Map Matching method is applied onto the results obtained after the calculation for the estimation of the mobile terminal's location. The blue dots show the estimated locations of the mobile terminals, and the red squares show the corrected locations after the map matching applied.

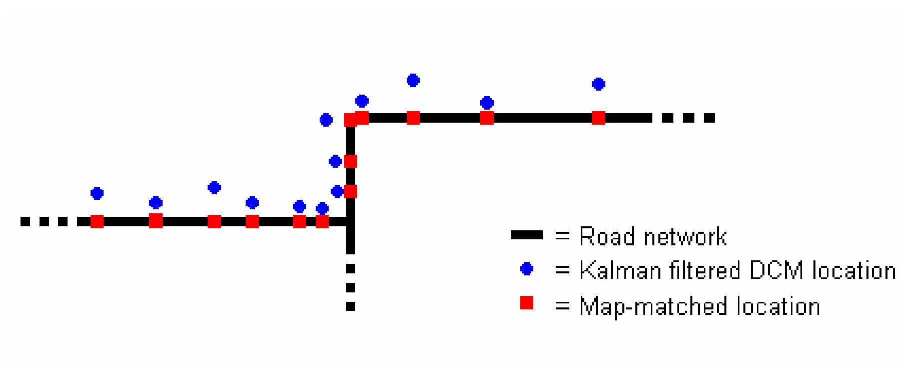

Figure 4.5. Map Matching in DCM location

5. MEASUREMENTS

The implemented DCM algorithm is tested by using terminal measurement data obtained from the commercial GSM 1800 network of Avea. In the coming sections, the completion of these measurements is described in detail.

5.1. Equipment

In this study, the following equipment is used:

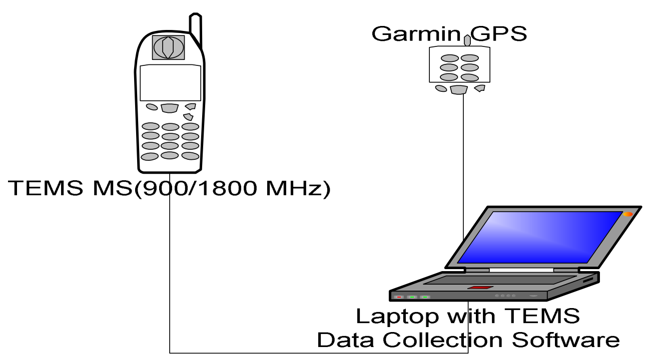

Figure 5.1. Measurement setup

Laptop	:	Toshiba
MT	:	Nokia 6230i
GPS	:	Garmin GPS
TEMS SW	:	TEMS Data Collection and Rout Analysis 6.0

5.2. TEMS^{TM} Product Summary

TEMS Investigation GSM is the real-time air interface test tool for GSM and GPRS network diagnostics. Designed for senior RF engineers and network specialists, TEMS Investigation GSM can be used during all stages of a network's life cycle. The tool allows operators to monitor voice channels as well as data transfer over GPRS, CSD, and HSCSD. It now supports in-building positioning of network data. It also measures radio parameters, assesses speech quality, and decodes air interface messages efficiently and easily. TEMS Investigation is a powerful troubleshooting tool for RF engineers and other personnel working with network performance improvement.

Figure 5.2. Measurement started

Data Collection is the part of TEMS Investigation that interfaces with phones and measurement devices, collects data, and records it in logfiles. It also allows presentation and analysis of a single logfile at a time. Customers familiar with TEMS will note this part is essentially similar to previous versions of TEMS Investigation GSM and TEMS Investigation WCDMA rolled into one.

Figure 5.3. Passing by high traffic road

Route Analysis is an entirely new module that permits presentation and rapid analysis of multiple log files, originating from TEMS Investigation itself or from TEMS Automatic or TEMS Drive Tester. Statistical binning of log file data (by area, time, or distance) is supported.

5.3. TEMS User Interface

The default graphical user interface of TEMS test tool is given in Figure 5.1. The GUI is comprised of five main functions: Worksheet (i.e. workspace), toolbars, navigators, menu bars, and the status bar. The following sections describe respectively each function and its properties.

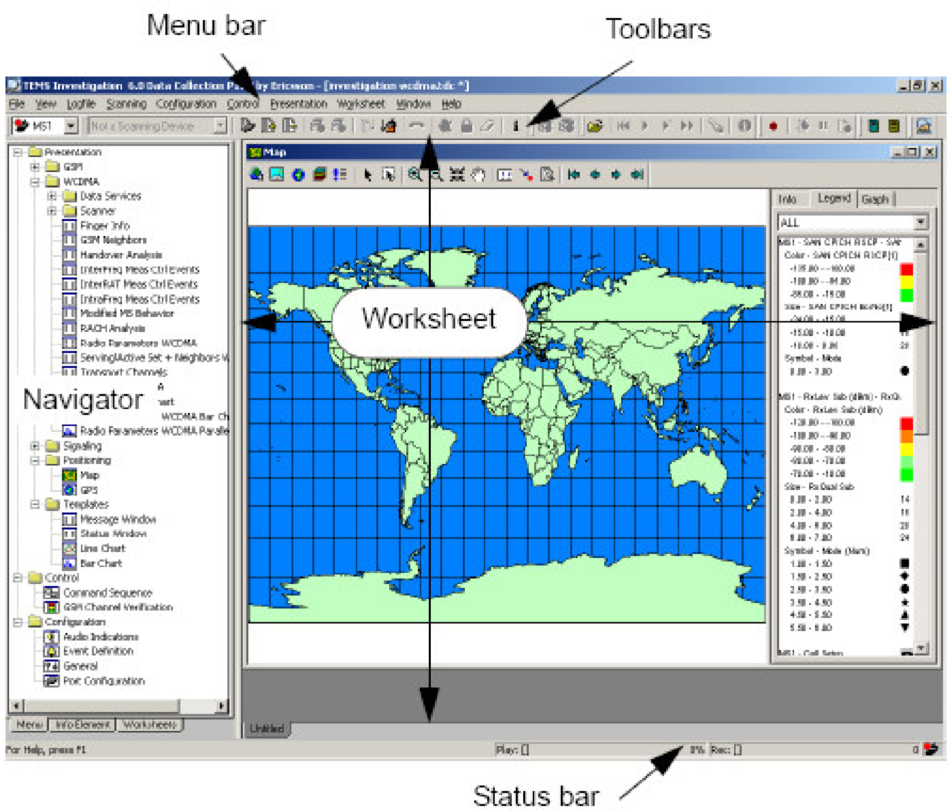

Figure 5.4. TEMS test tool graphical user interface

5.3.1. Workspace and Worksheet

The environment that stores all the windows and settings used in a working session is called the workspace. Settings include information on connected external devices. Only one workspace can be open at a time.

When you start TEMS Investigation Data Collection for the first time, a default workspace is opened. This also happens if you have never saved a workspace. After you have saved a workspace for the first time, the workspace last saved will be opened each time you start the application.

Besides the default workspace, which contains a bit of everything, some further predefined workspaces are supplied in the Application subdirectory.

5.3.2. Toolbars

Through the toolbars all the central functions are accessible. Most of the toolbar buttons are mirrored in the menus.

5.3.3. Navigator

From the Navigator, you can open presentation windows, change the color ranges of information elements, and manage your worksheets.

The Navigator is especially useful for configuring the workspace at the beginning of a session.

5.3.4. Menu Bar

The menus mirror most of the toolbars as well as the Navigator's Menu and Worksheets tabs.

5.3.5. Status Bar

The Status bar displays symbols and short messages that indicate the current status of the application.

5.4. User Modes

TEMS Investigation Data Collection can be run in two different modes, one for testing and recording, and one for replay and analysis:

Drive Testing Mode: The information presented on the screen is obtained from data-collecting devices connected to the PC. In drive testing mode you can record new log files.

Replay Mode: The presented information is read from a log file. In this mode you replay log files for inspection and analysis. You can also use the recording function to copy material between log files.

5.5. Measurements Sessions

Numerous measurement sessions have been done during this study. Early measurements were done especially for training purposes. They also helped to become experienced on the tools. Consequently, these early measurements were discarded.

Three main measurements session were conducted along this study:

1. 1^{st} Session from Umraniye to Şile, during daytime in high traffic,
2. 2^{nd} Session from Şile to Umraniye during late night in low traffic,
3. 3^{rd} Session from Güneşli to Atatürk Airport, then to Eminönü, to Beşiktaş and stopping at Maçka.

5.5.1. 1st Measurement Session

The first session started on 31st of May, 2006, around 17:30. We started the measurements near the Umraniye TEM entrance. The destination was decided to Şile. The route is almost 60Km, and take approximately 2 hour while we did the measurement.

Approximately 75K samples have been taken during this session.

Figure 5.5 shows:

- Red car signs show the places of the car in which the mobile terminal is.
- The green signs with flags show the base stations,
- The route is shown with the red continuous line.

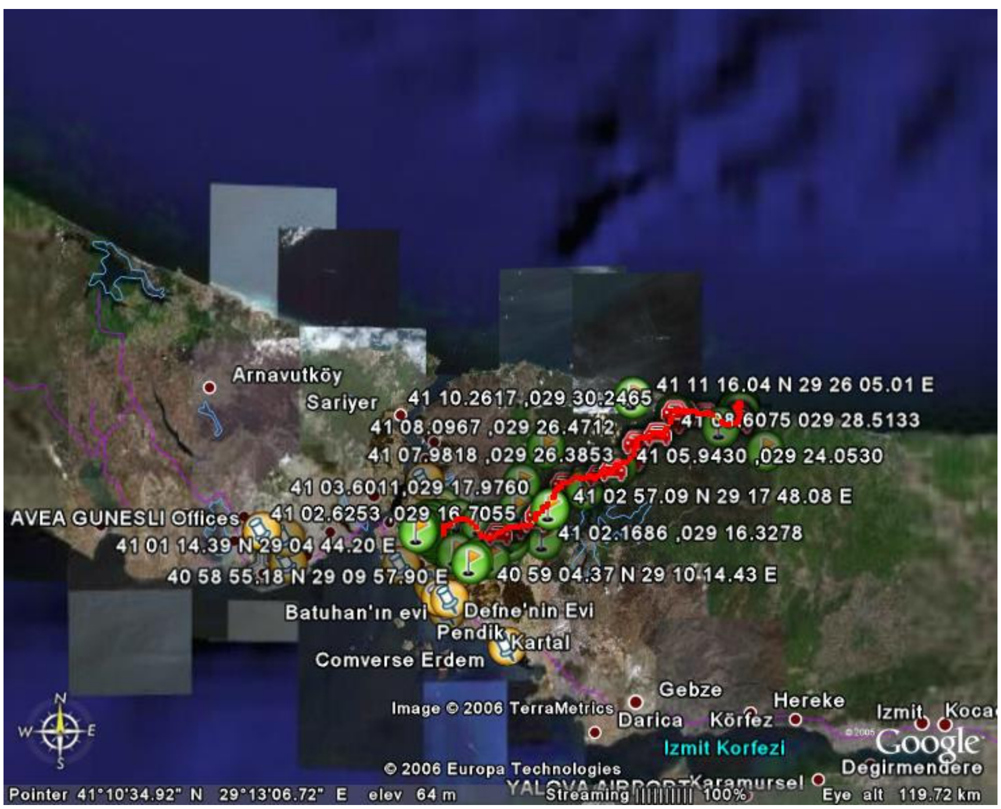

Figure 5.5. 1st Measurement Session from Ümraniye to Şile

Figure 5.6, 5.7 and 5.8 show:

- The customized graphical user interface of TEMS test tool,
- The colorful circles show the place where the measurements were taken. To increase the ease of perception, different colors indicate different signal levels: Green to yellow, colors show signal quality from the best to the weakest,
- Handovers are indicated as hand,
- The location information collected from the GPS and the speed of the mobile terminal (i.e. the car) are given the right upper corner of the GUI.

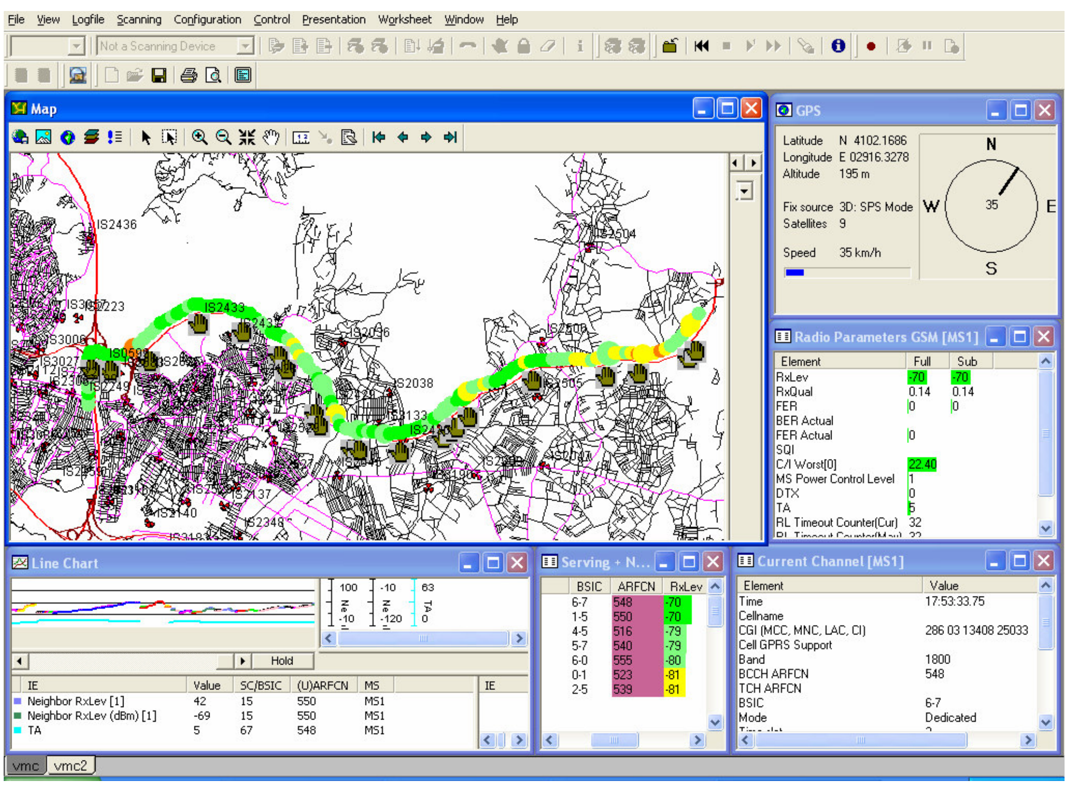

Figure 5.6. Data collection with TEMS, during session1 (1st file)

In order to better analyze the measured data, TEMS test tool offers also the functionalities for replay one by one, or detailed analysis of each measurements steps.

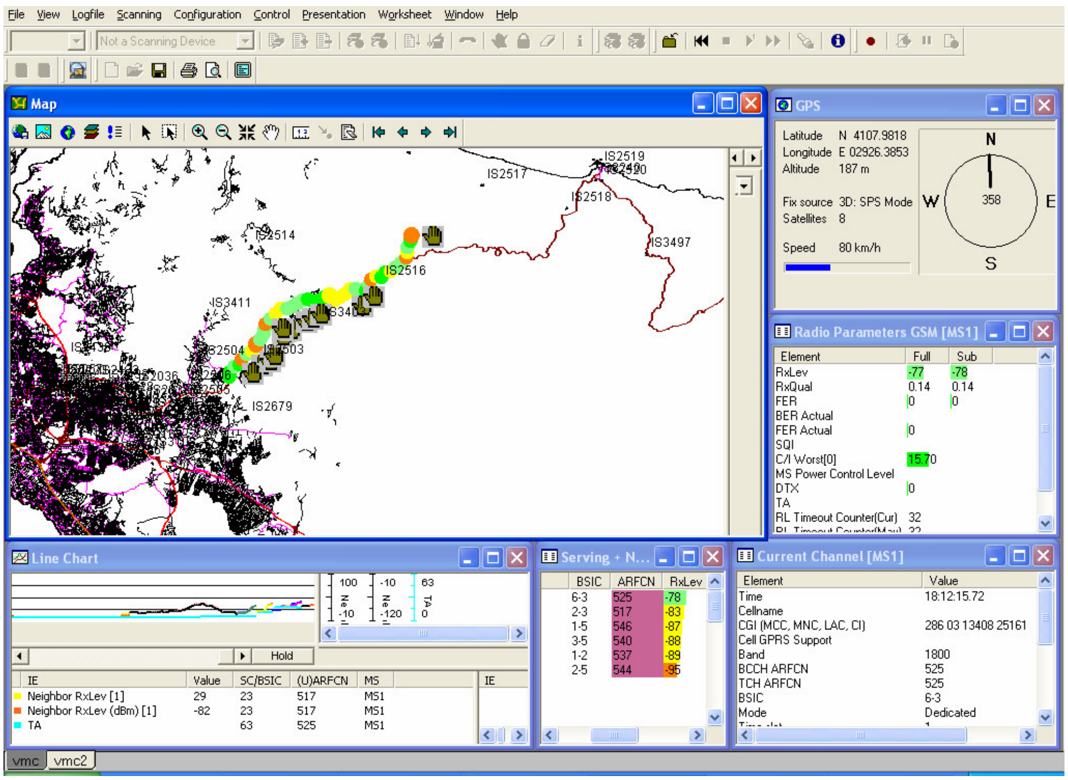

Figure 5.7. Data collection with TEMS, during session1 (2^{nd} file).

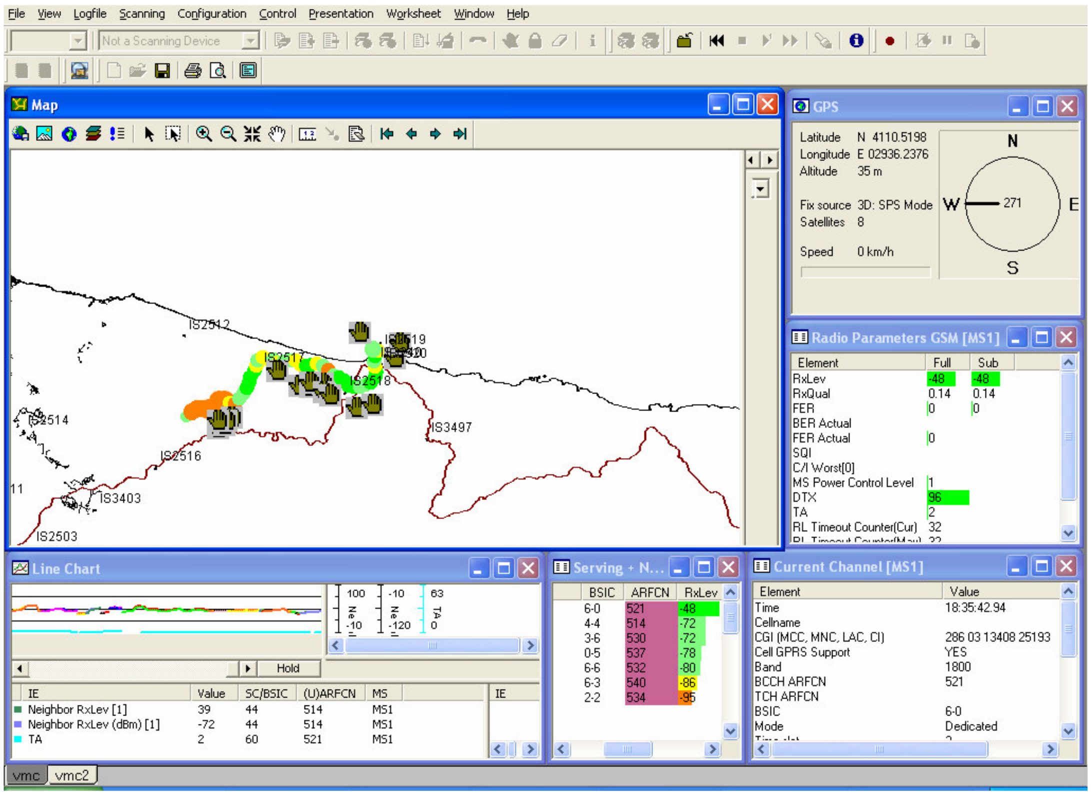

Figure 5.8. Data collection with TEMS, during session1 (3rd file).

5.5.2. 2nd Measurement Session

This session started on 31st of May, 2006, around 21:15, this was the way back to the starting point. The weather conditions were the same, the traffic was slowed down.

Approximately 75K samples have been taken during this session.

5.5.3. 3rd Measurement Session

The third session started on 7th of July, 2006, at around 13:15. We started the measurements near the Gunesli. In order to better investigate the effect of high constructions in a high traffic environment, the destination was decided respectively to

Atatürk Airport, to Eminönü, Beşiktaş up to Maçka. The route is almost 35Km, and took approximately 1 and half hour while we did the measurement.

Approximately 175K samples have been logged during this session.

6. SIMULATION AND MEASUREMENT RESULTS ANALYSIS

In section 6.1, the plan and the purpose of the computer simulations are given. Section 6.2 describes the simulation results and verifies the acceptability of the modeling used in simulation. Verification is assured with results of the simulations by applying the model for the estimation of the location in the existence of two BSs, and more not only in good signal level conditions (where the SNR=63dB) and but also in low signal level conditions, where SNR=11dB.

In Section 6.3, the simulated model will be applied to the values acquired during field measurements. The Kalman Filtering will also be applied to the field measurements in order to investigate its impact. Section 6.4 depicts the effect of Kalman Filter implementation. Section 6.5 explains the DCM, Cell-ID and the SS methods performances. The comparison of all the techniques will be explained in Section 6.6

6.1. Plan and Purpose of the Computer Simulations

In order to verify the computational model to be used, simulations are run according to [26]. To better approximate to the practical mobile operator network coverage and properties, the following scenarios were utilized for computer simulations. Matlab is used as the environment for modeling, calculations, and simulations.

Finding locations when:

- the SNR=11dB and there are two BS,
- the SNR=63dB and there are two BS,
- the SNR=11dB and there are more then two BS,
- the SNR=63dB and there are more then two BS,

The following notations and legends are used throughout the rest of the document:

- BSs are represented with STAR signs,
- MS positions are represented with SQUARE signs,
- Estimation of the MS positions are represented with X signs.

6.2. Simulations Results

In Figure 6.1 and 6.2, the simulations are done for an environment where the MS receives the signals coming from two BSs. The model having these conditions successfully represents the following practical cases:

1. Where the coverage is assured by using only two BS, like the road, high ways (TEM and the road towards the Şile),

2. Where there are very week signals coming by reflections or shadowing (Shadowing effect of big constructions and buildings, like several places around Maçka).

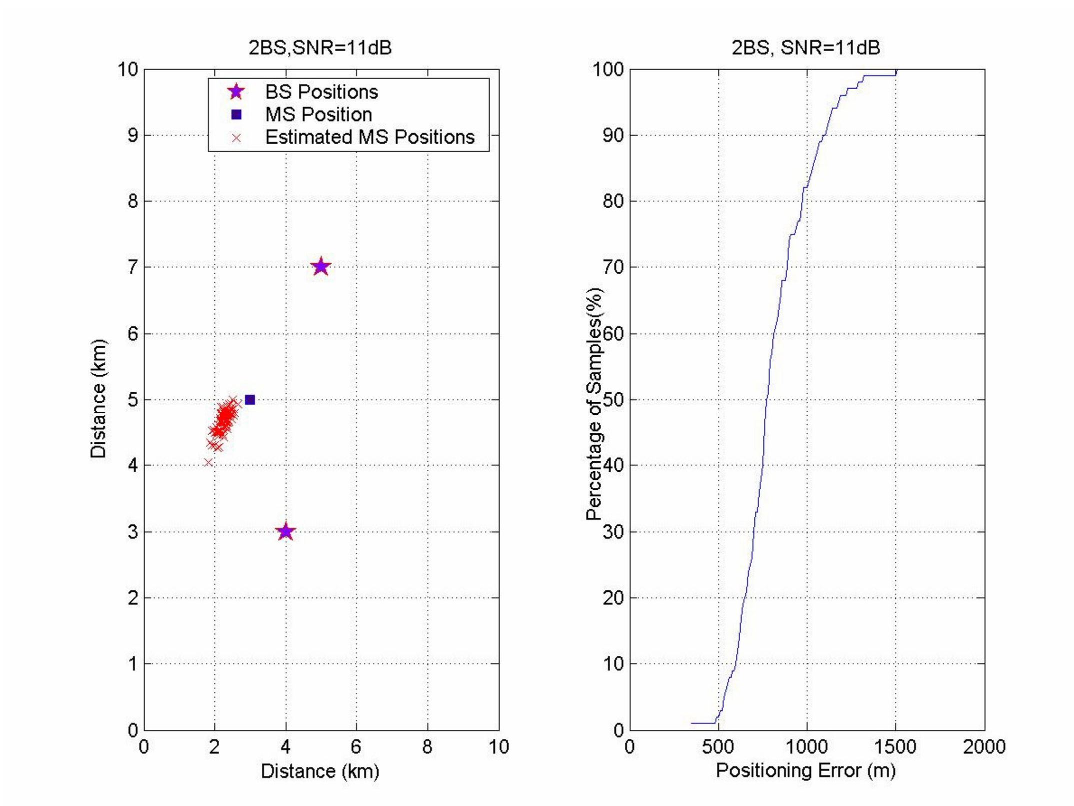

Figure 6.1. Computer Simulations for SNR=11dB and 2 BSs

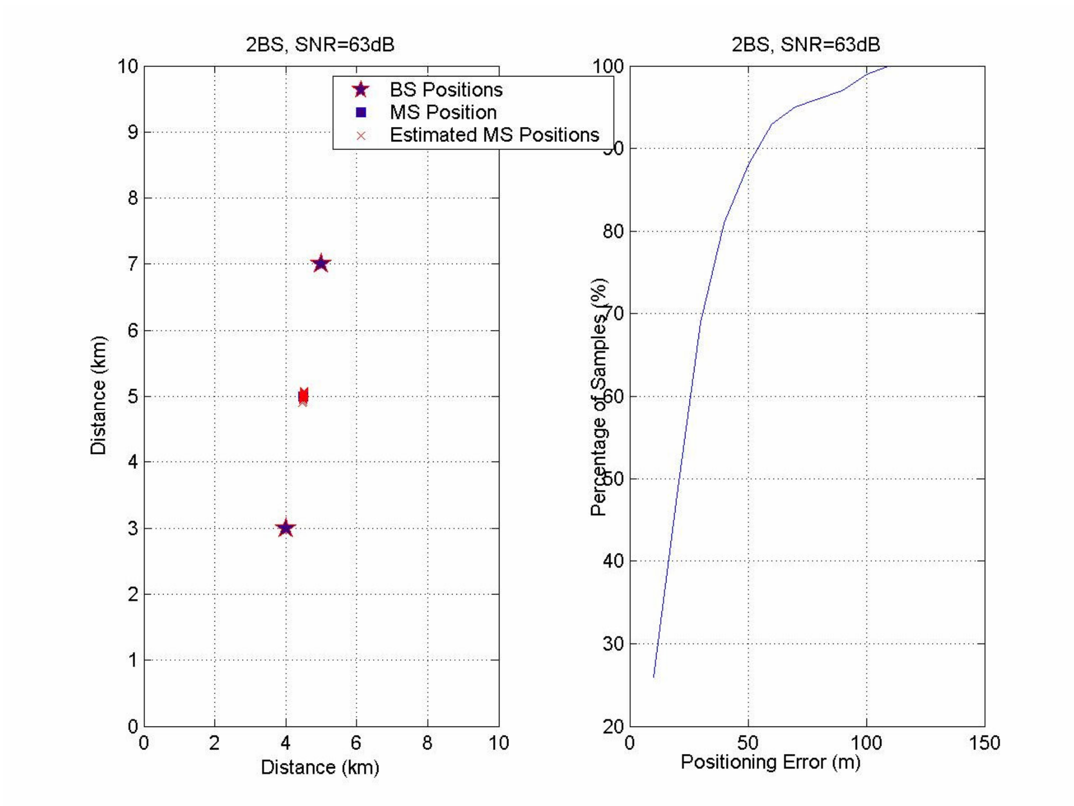

Figure 6.2. Computer Simulation for SNR=63dB and 2 BSs

Figure 6.3 shows the places where there are more then 3 BSs around the MS, but with low signal quality (SNR near to 11dB). The practical case can be encountered in the city centers, where the BSs serve in order to support high GSM services traffic. The accuracy is around 400 meters for 67% of the sample.

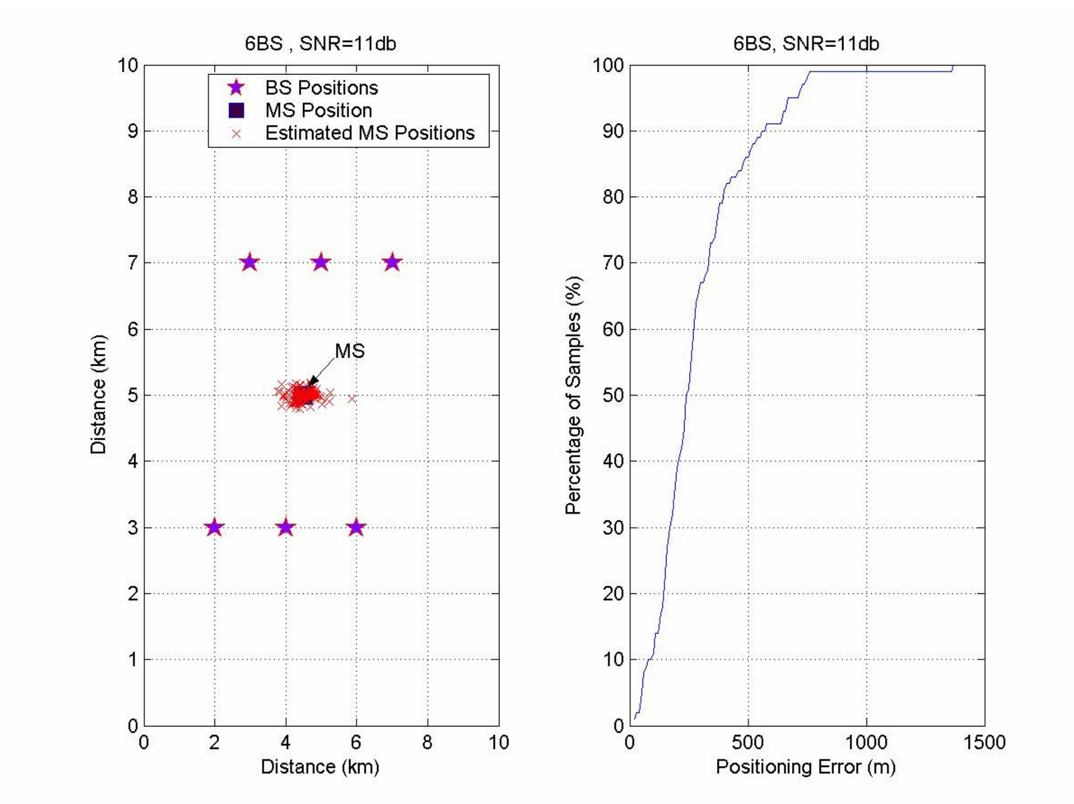

Figure 6.3. Computer Simulation for SNR=11dB and 6 BSs

Figure 6.4 shows the places where there is a good coverage provided at least more then 3 BSs. Although the examples depict 6 BSc, in practical cases 3 BSs yield the same accuracy level. This is the case for most of the large streets or squares in the cities. Accuracy is less then 100 meters for approximately 90% of the samples.

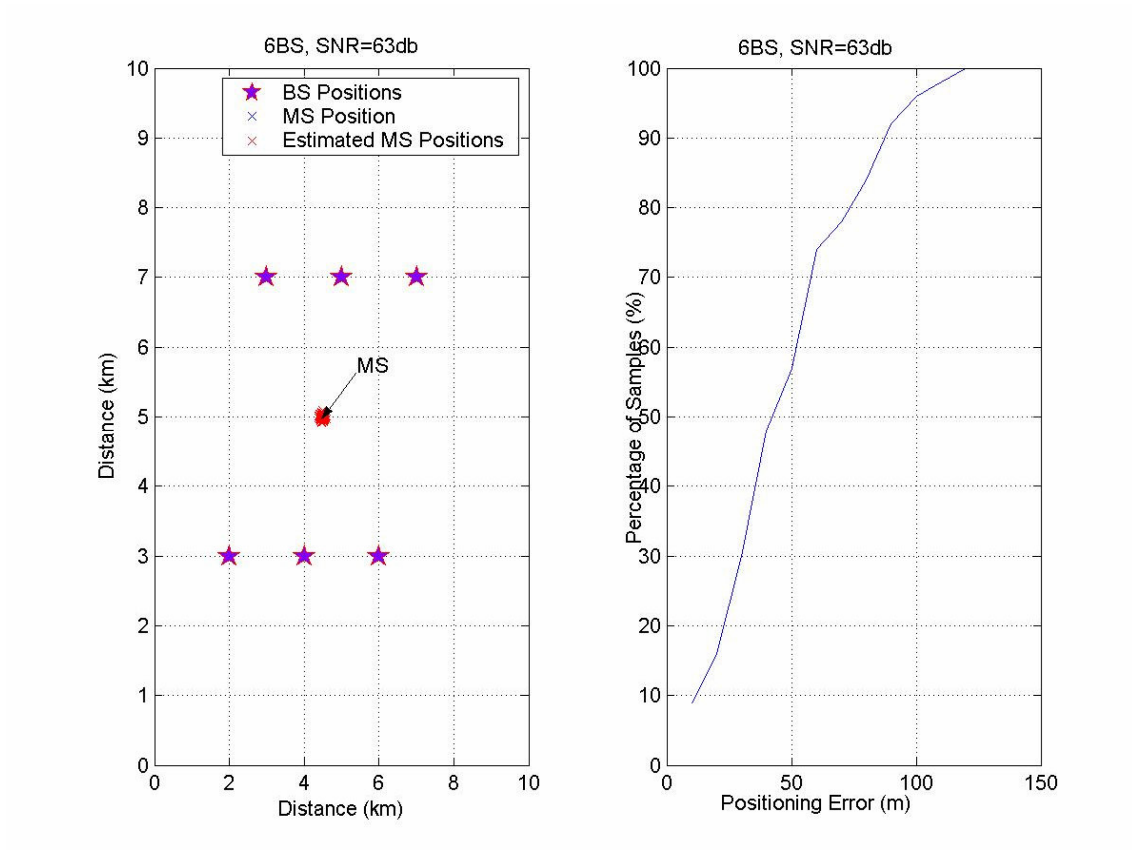

Figure 6.4. Computer Simulation for SNR=63dB and 6 BSs

6.3. Location Estimation for Field Measurements with the Implementation of Simulated Models and Kalman Filtering

After the SS model applied and the estimations are obtained, Kalman filter is implemented to the results.

Kalman filter applied results mostly showed better accuracy than their previous states.

In Figure 6.5, the results are given for one serving and one neighbor BS. The existence of the two BSs is not sufficient for successful location estimation. Although the results of the Figure 6.5 show an accuracy ranking from 200 to 500 meters for 67% of the samples, the below results are specific for the place where MS is.

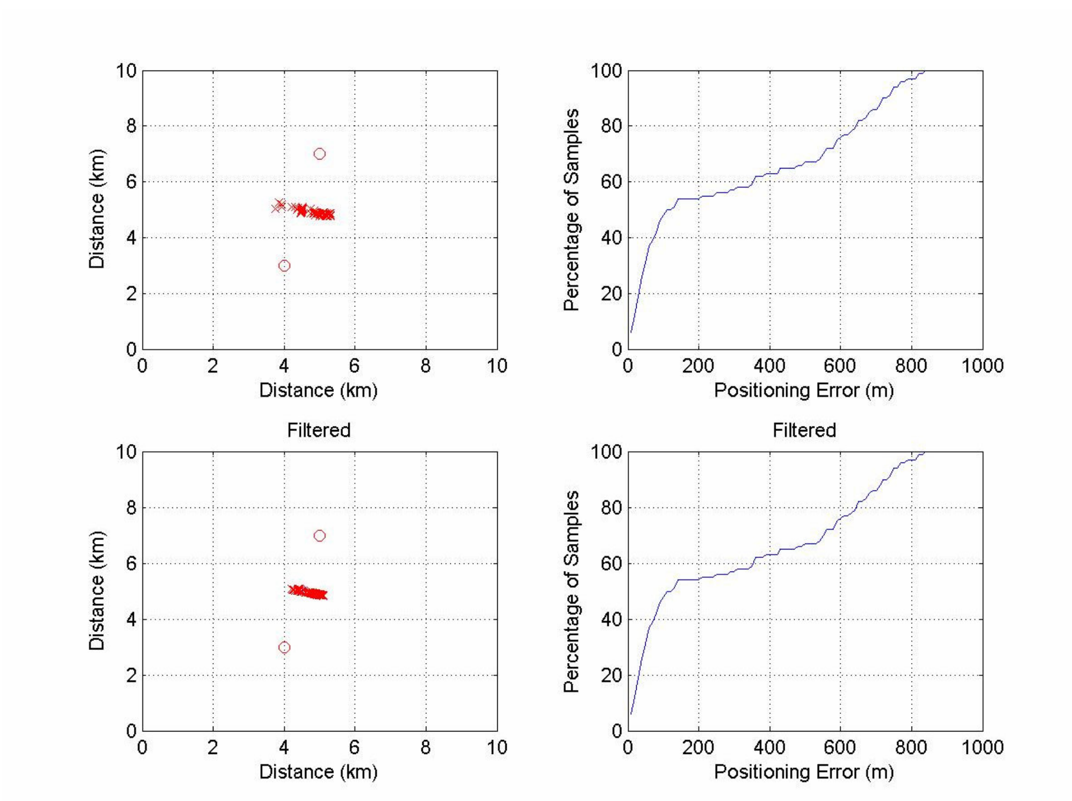

Figure 6.5. Location Estimation for SNR=11dB with one Serving Cell and one Neighbor Cell

Figure 6.6 is a typical example of an MS going along to shoreline of İstanbul. The serving cell is not the closest one to the MS, but any other within the line of sight.

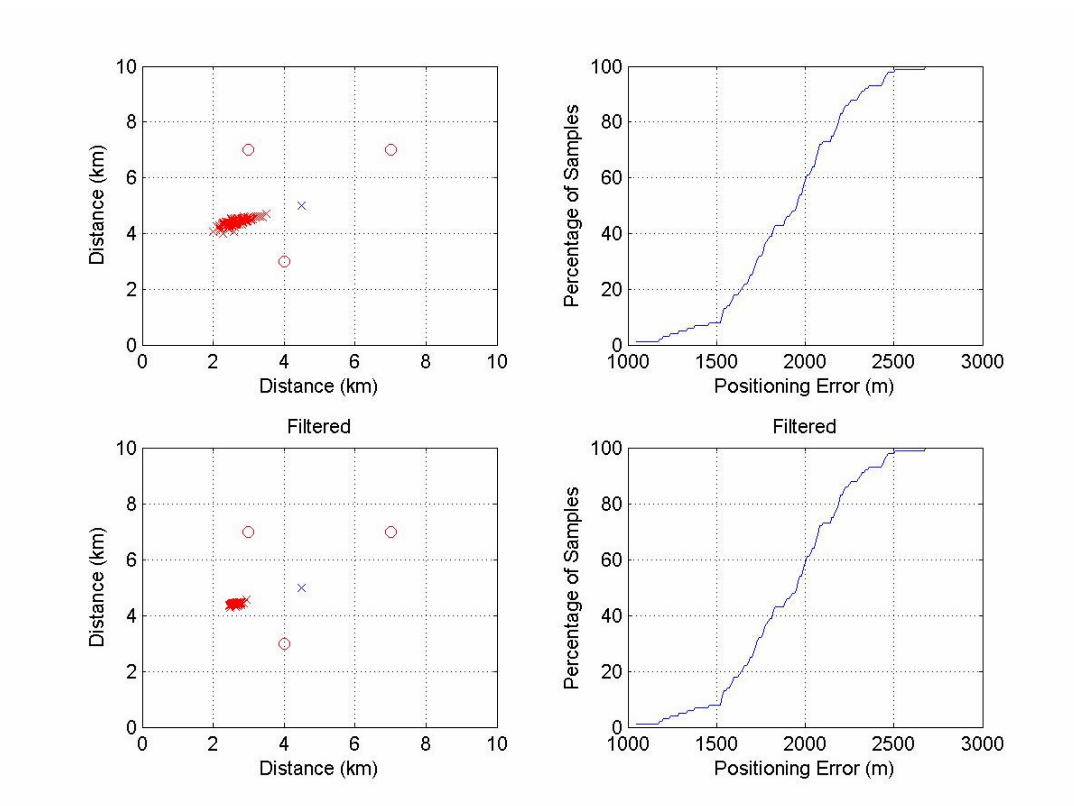

Figure 6.6. Location Estimation for SNR=11dB with one Serving Cell and two Neighbor Cells

Figure 6.7 shows the places where there is a good coverage provided at least more then 3 BSs. Although the examples depict 6 BSc, in practical cases 3 BSs yield the same accuracy level. This is the case for most of the large streets or squares in the cities. Accuracy is less then 100 meters for approximately 90% of the samples. The below examples depict an MS in the Taksim square.

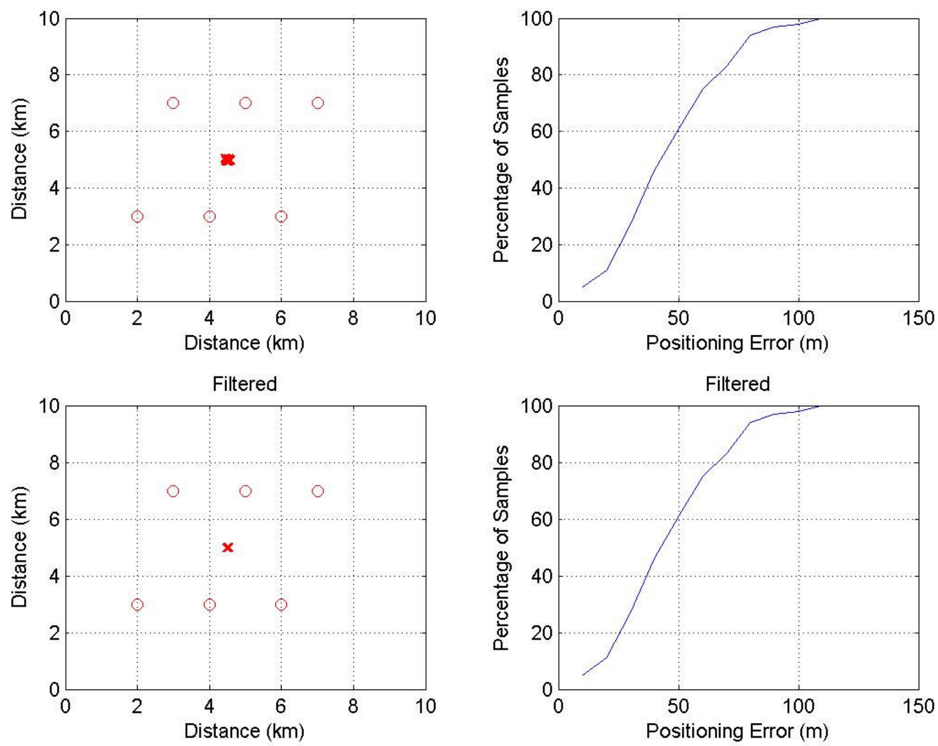

Figure 6.7. Location Estimation for SNR=63dB with one Serving Cell and five Neighbor Cells

6.4. Evaluation of the Postprocessing Effect to the Accuracy Improvements

Table 6.1 Comparisons of the calculated results before after the postprocessing

		Before Postprocessing		Improvements (in meters) with Kalman Filtering only		After Postprocessing with Kalman Filtering	
Base Stations (SC for Serving and NC for Neighbor Cells)	SNR (dB)	Mean (meters)	Standard Deviation (meters)	Mean (meters)	Standard Deviation (meters)	Mean (meters)	Standard Deviation (meters)
SC+2NC	11	1.908,10	324,39	**x**	**X**	1.930,90	98,26
SC+2NC	63	116,48	35,08	**15,2**	**20,48**	101,27	14,59
SC+3NC	11	325,75	199,3	**192,91**	**119,31**	132,84	79,99
SC+3NC	63	54,37	30,04	**37,21**	**19,15**	17,17	10,89
SC+5NC	11	241,79	172,33	**175,78**	**131,95**	66,01	40,38
SC+5NC	63	45,3	22,52	**34,31**	**15,05**	10,99	7,47

To better investigated the post processing effect for the accuracy improvements; the error values are given both before and after the postprocessing applied. In low SNR (around 11 dB), one serving cell and two neighbor cells environment, the accuracy of the positioning is very low. In such cases, the average error is greater than 1900m. The postprocessing technique could not result any improvement in these cases.

One more neighbor cell to the same environment mentioned in the previous paragraph yields better accuracy levels. Despite of low SNR (around 11 dB), location estimations error for an environment with one serving and three neighbor cells is decreased to 325 meters. After postprocessing applied, it is decreased to 132 meters.

The number of the neighbor cells surrounding the MT contributes positively the accuracy, especially when the SNR is low. In an environment with one serving, five neighbor cells with SNR around 11 dB, before postprocessing an error of 241 meters is obtained. After the postprocessing, it is decreased to 66 meters.

As seen in Table 6.1, high SNR (around 63 dB) yields lower error values. With one serving and two neighbor cells the error is around 116 meters, and after postprocessing it is decreased to 101 meters. By the increase of the numbers of the neighbor cell, the error done in location estimations are decreased furthermore, accordingly the postprocessing provides extra improvements for positioning accuracy. For one SC and three NCs, the error values are 54 and 17 meters, respectively before and after postprocessing. Finally for one SC and five SCs, the error values are 45 and 10 meters, respectively before and after postprocessing.

Table 6.2, 6.3, and 6.4 show the improvement of the accuracy in another perspective. Table 6.2 and 6.3 represent the percentage of the samples that the positions are calculated and classified according to the error levels. Table 6.4 compares the accuracy level of the positioning errors calculated before and after the postprocessing with Kalman Filtering. Results are given in percentage in order to better compare the changes.

Table 6.2 Positioning Accuracy results before postprocessing

Before Postprocessing		Percentage of the samples below the error level R<x meters		
Base Stations (SC for Serving and NC for Neighbor Cells)	SNR (dB)	R<50 (m)	R<100 (m)	R<200 (m)
SC+2NC	11	x	x	x
SC+2NC	63	2,0%	29,9%	91,3%
SC+3NC	11	1,4%	11,0%	31,0%
SC+3NC	63	51,7%	91,0%	99,0%
SC+5NC	11	5,9%	17,0%	53,0%
SC+5NC	63	61,0%	97,6%	100,0%

As seen in Table 6.2, the accuracy for positioning of the MS increases thanks to good signal levels received by the MS.

Table 6.3 Positioning Accuracy results after postprocessing

After Postprocessing with Kalman Filter		Percentage of the samples below the error level R<x meters		
Base Stations (SC for Serving and NC for Neighbor Cells)	SNR (dB)	R<50 (m)	R<100 (m)	R<200 (m)
SC+2NC	11	x	x	x
SC+2NC	63	2,4%	32,6%	98,5%
SC+3NC	11	1,9%	14,3%	36,5%
SC+3NC	63	54,3%	94,4%	100,0%
SC+5NC	11	8,8%	21,6%	64,9%
SC+5NC	63	66,9%	100,0%	100,0%

The postprocessing with Kalman Filter shows better results, except where the signal levels are too low and the neighbor cells are not contributing to the quality at the MS side.

Table 6.4 Improvement of the Positioning Accuracy after Postprocessing with Kalman Filter

After Postprocessing with Kalman Filter		Accuracy Improvement		
Base Stations (SC for Serving and NC for Neighbor Cells)	SNR (dB)	R<50 (m)	R<100 (m)	R<200 (m)
SC+2NC	11	x	x	x
SC+2NC	63	0,35%	2,74%	7,18%
SC+3NC	11	0,50%	3,30%	5,45%
SC+3NC	63	2,60%	3,40%	1,00%
SC+5NC	11	2,90%	4,60%	11,90%
SC+5NC	63	5,90%	2,40%	0,00%

As can be seen in Table 6.4, the number of the accurate positioning is increased where the signal levels are low: The effect of the postprocessing with Kalman Filter can also be observed by the increase of the total positioning accuracy.

6.5. Performance Comparisons of DCM, CellID, SS

The Cell ID method is the easiest one to implement in an existing 2G and 2,5G network. It requires low investment, too. Beside its positive characteristics, its major drawback is the low accuracy and relatively unreliable results.

Figure 6.8 and 6.9 describe the accuracy obtained by implementing solely CellID and SS techniques.

The standalone implementation of CellID may serve for only some information services (like nearest taxi station, restaurant finding services) and some entertainment services (like dating). Cell ID technique is far from fulfilling the E-112 proposed accuracy levels.

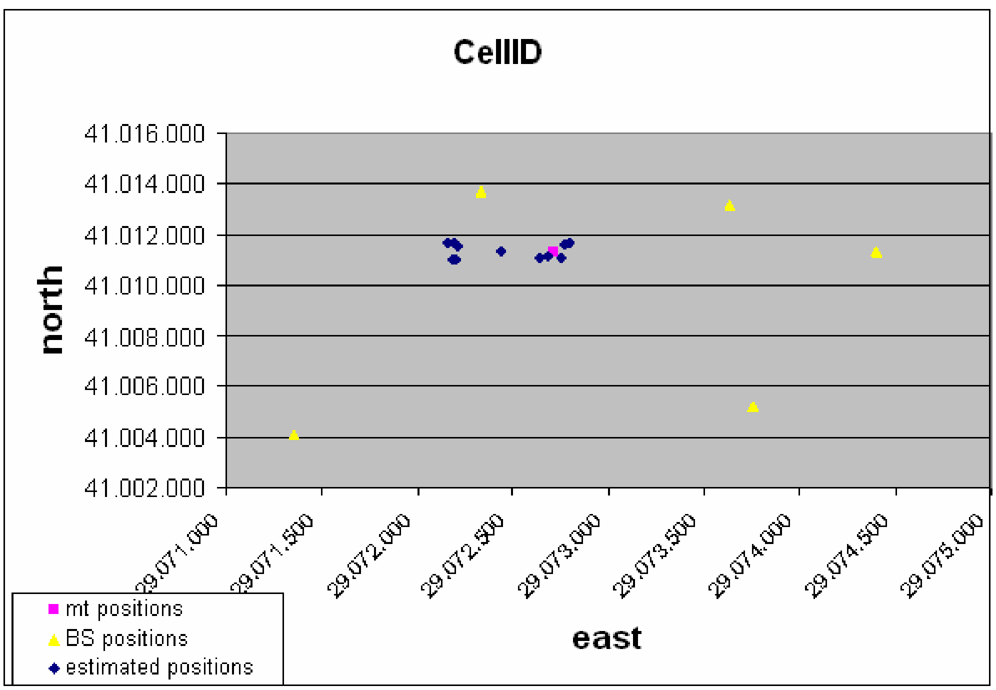

Figure 6.8. Location estimation with Cell ID

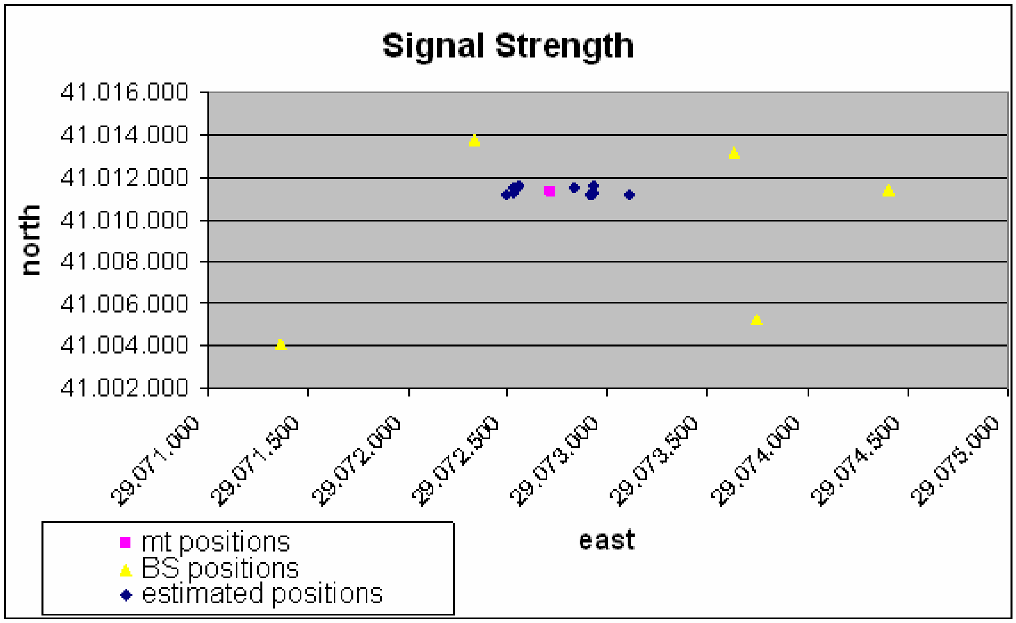

Figure 6.9. Location estimation with Signal Strength

As shown in Figure 6.9, without used in combination with other techniques, SS also may be a low accuracy location finding technique. The SS method, accompanied by modeling and according to the topology and the characteristics of the GSM network, works well in most cases. To increase the accuracy, the best implementation model is to complement with DCM like post processing techniques. The more optimized is the GSM network; the better results may be produced with SS method.

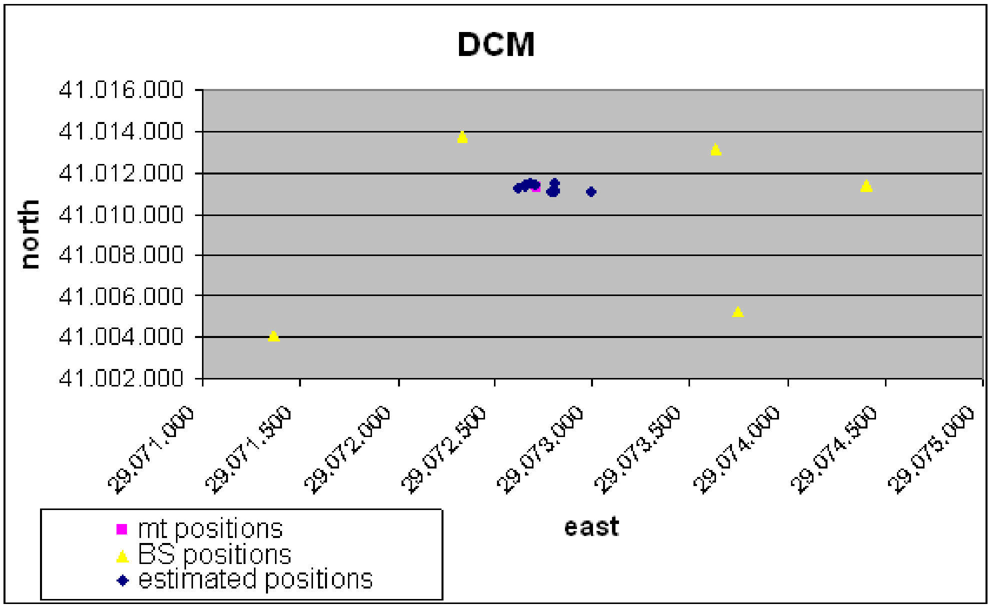

Figure 6.10. Location estimation with DCM

The DCM is not suitable for a standalone solution in a GSM network. In contrast, the DCM is the best fitted when used as a complementary and corrective method when more accurate results are requested.

Another drawback of DCM is that it is requiring high operational efforts and costs. Otherwise, in a dynamic GSM network, the fingerprints may become old; the false results may be produced methodically.

6.6. Performance Comparisons of DCM, CellID, SS with Kalman Filter Implemented

Kalman filtering works well when a continuous observation is required for the MS positions. Kalman filtered results will be converging to the exact position of the MS. Kalman filter especially improves the accuracy by eliminating the faulty estimations caused by reflections.

7. CONCLUSIONS

Taking into consideration all the studied methods mentioned above, it is still impossible to choose only one for geography like Istanbul. For an optimum result, requirements and solutions must be segmented then re-categorized accordingly.

Any off the shelf product will not be matching the required accuracy in the geography. In the city centers Cell ID based location techniques may work with an acceptable accuracy for most of the needs, except for emergency requirements. The optimum solution will be the SS, CellID, DCM and Kalman Filtering techniques working in combinations. Single technique may yield a wide range of accuracy starting from 150m up to several kilometers. Thanks to the combination of the techniques followed by postprocessing method (DCM and Kalman Filter) the accuracy may be increase 5% to 20%.

So far, studies have been targeted to find a method that would use the existing infrastructure of the mobile networks, and the existing mobile terminal of the users, but the obtained results show that the low accuracy problem can not be over come. Therefore, the new solutions are on the way to be as standards in the coming networks and handsets.

The studies have been also concluded that when the handsets involve to the location finding processes the accuracy may be improved easily. Formerly high end handsets become cheaper day over day with extra features on them. The low orbit satellite, their integration to the wireless networks (GSM, GPRS, 3G, and WiFi), and the GPS embedded mobile phones will open soon new challenges to study.

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