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Mobile Location Estimation Approaches

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Chapter 1

Introduction

The location procedure allows the mobile system to keep the user's location knowledge, more or less accurately, in order to be able to find him, in case of an incoming call, for example. Location registration uses this information to bring the user's service profile near its location and allows the network to provide him rapidly with his services (e.g., the visitor location registration, functions in GSM, etc.).

The location of a cellular telephone can be estimated using radio signals transmitted or received by the mobile station.

Some location estimation methods, such as GPS (Global Positioning System), are based on signals transmitted from satellites. With these technologies the MS (Mobile Station) formulates its own position which is relayed to a central site.

Other methods rely on terrestrial communication by using a cellular network as the transport mechanism for relaying the location estimate. As an alternative to these approaches, cellular networks can be used as the sole means for providing location services, where the MSs are located by measuring the signals traveling to and from a set of cellular BSs (Base Station).

For a fair comparison of the location techniques, several aspects must be considered. First of all, the performance of a technique can be measured in terms of location accuracy and response delay. Due to the nature of mobile communication signals, accuracy is actually given by a probability distribution in each propagation environment. Secondly, the implementation of different techniques requires various amounts of software and hardware changes to mobile handsets and network. Of course, these changes create costs. Finally, if extensive modifications to the handset are needed, location service may be available only for new handsets.

The remainder of this report is organized as follows: in Chapter 2 we present the existing location estimation methods, and we provide a performance comparison of these methods. After reviewing relevant literature, we will discuss the main practical limitations to location estimation in the Chapter 3. Current location estimation systems and a discussion of issues specific to 3G (third Generation) systems are given in Chapter 4. Finally, some concluding remarks are presented in Chapter 5.

Chapter 2

Location Estimation Methods

Several cellular location techniques have been developed recently. Some of these methods have been implemented in trial systems and some commercial products have already been introduced. The location techniques for cellular handsets proposed so far will be presented in the following.

2.1 Cell identification (Cell Id)

The cell Id is the simplest method for determining the location of a mobile. It relies on the hypothesis that the geographical coverage of a cell corresponds to that predicted by radio coverage studies. When an active mobile is connected to a base station, the mobile is assumed to be located geographically within the area predicted to be best served by this base station. Reliable positioning therefore requires accurate maps of the BS coverage area. It is possible to refine positioning using RTT measurements[1] taken by the BS. Using this measurement, the base station can work out the distance to the mobile, with a theoretical accuracy of about 80 m. This makes it possible to restrict the area of inaccuracy. Although the information is of little use for a cell served by an omnidirectional antenna, it can offer improved accuracy in the case of "sectored" cells served by several antennas. A method is needed to identify the cell that best represents the geographical position of the mobile. For example, the mobile may be asked which is the best cell for reception, or statistical processing of the cells used by the mobile can be carried out. The latter solution would allow further refinement of the positioning accuracy by determining in which zone of the cell the mobile is located. Cell Id positioning method can be either terminal or network based.

The advantage of methods based on cell coverage is the fact that no special development is required to the mobile itself. The main difficulty with these methods lies in correctly predicting the geographical coverage of the cells, as the "best" BS will not always be the one that is physically closest. The reliability and accuracy of the positioning obtained depend on the precision of the radio predictions.

[1] measures the time between the transmission of a frame from BS to the MS and the reception of the corresponding frame.

2.2 Network-based approach

In network-based architectures the network receivers signals from the mobile unit and performs the necessary operations to estimate the mobile unit's location. The signal measurements are used to determine the length and/or direction of the radio paths, and then the MS position is computed from geometric relationships.

2.2.1 Signal Strength Analysis

Signal strength analysis was the first method to be proposed for location estimation. This technique consits in measuring the strength of signals from at least three BSs at the MS or by measuring the signal strength of the MS at at least three BSs. The signal strength measurements are related to the MS-BS separation distances. Since a measurement of signal provides a distance estimation between the MS and BS, the MS must lie on a circle centered at the BS [1]. The MS location then can be then calculated by the approximate intersection of three circles of known radius by using least squares to minimize the error as shown (Figure 2.1).

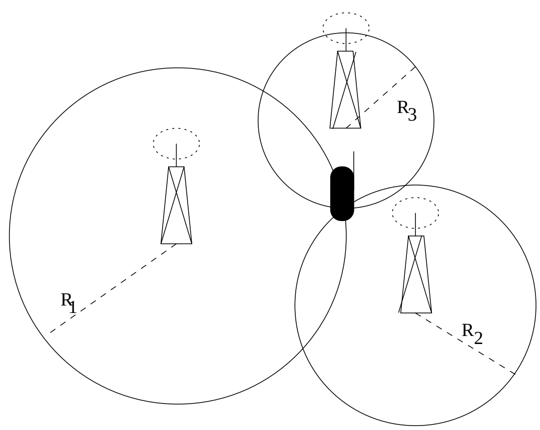

Figure 2.1: Location estimation for the signal strength techniques

An important characteristic of radio propagation is the increased attenuation of the radio signal as the distance between the transmitter and receiver increases. When there is a line of sight (LoS) between the BTS and the MS, the distance for a given signal strength can be obtained from the line of sight model equation:

$$\triangle P(dB) = 10.\alpha.log(\frac{f}{c}) - 10.\beta.log(4\pi d) \tag{2.1}$$

Where $\triangle P$ is the difference between transmitted and received signal strength, f is carrier frequency (Hz), c is the light speed (m/s), d is the distance in meters, α is a frequency factor and β is terrain factor. These factor constants are empirically determined [1] [1].

An accurate distance estimation have been described in [2], it uses the mean, the standard deviation and the median of the corresponding signal strength values for each of the base stations.

There are fundamental problems associated with signal strength measurements. Firstly, the fading profile of received power requires that the mobile is not stationary and that some form of averaging is required. In [1] it was suggested that long term median averaging can yield estimates that vary by as little as 0.5dB with individual estimates varying by 40dB. Secondly the signal strength measurements must be converted to distance measurements. Qualifying each BS with a contour map of signal strength measurements was proposed in [1], however with the large number of BSs this would now be unrealistic. More recently, widely accepted empirical formulae from actual data was derived in [2], however these do not account for local variations caused by the actual terrain.

2.2.2 Angle of Arrival (AoA)

Angle of Arrival is another technology employed in some network -based systems. This technique works by calculating the relative angles of arrival at an MS of three BSs or the absolute angle of arrival of the MS at two or three BSs.

The angle of arrival method would require the installation and interconnection of additional antennas, in order to determine the direction from which the signals sent by the mobile station are being received. This technique relies on the relatively new technology of antenna arrays which provide the direction finding capability to the receiver. The angles can be calculated by measuring phase difference across the array (phase interferometry) or by measuring the power spectral density across the array (beamforming). Once the measurements have been made the location can be calculated by simple triangulation (as shown in Figure 2.2).

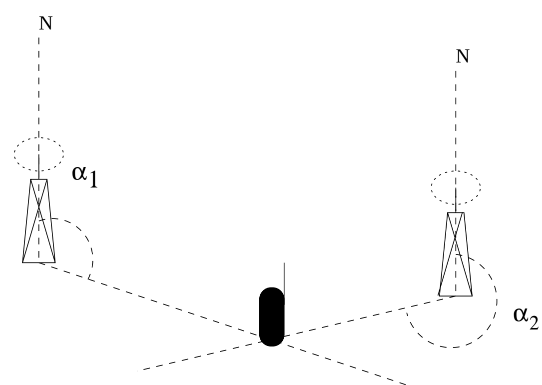

Figure 2.2: Location estimation for the AoA technique

AoA systems use phased-array antennas to compute the angle at which signals transmitted from a wireless phone arrive at the base station. The system computes the caller's location using the actual position of two or more receiving cell sites and the signal's angle of arrival at these base stations [36].

In the absence of a LoS signal component, the antenna array will lock-on to a reflected signal that may not be coming from the direction of the MS. Even if a LoS component is present, multipath will still interfere with the angle measurement. The accuracy of the AoA method diminishes with increasing distance between the MS and BS due to fundamental limitations of the devices used to measure the arrival angles as well as changing scattering characteristics.

For macrocells, scattering objects are primarily within a small distance of the MS, since the BSs are usually elevated well above the local terrain [4] [5]. Consequently, the signals arrive with a relatively narrow AoA spread at the BSs. In [4], the authors have modeled this situation by assuming a ring of scatterers about the MS, with the BS situated well outside the ring as shown in Figure 2.3.

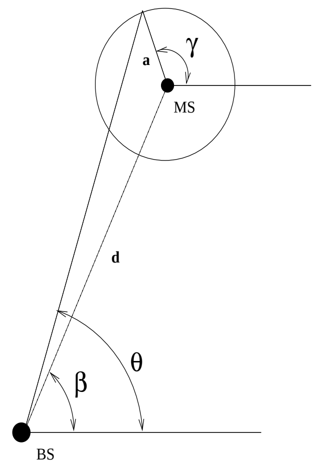

Figure 2.3: The scattering model for propagation in macrocells. The MS is a distance d from the BS and is surrounded by a scattering ring of radius a.

For microcells, the BSs may be placed below roof top level. Consequently, the BSs will often be surrounded by local scatterers such that the signals arrive at the BSs with a large AoA spread. Thus, while the AoA approach is useful for macrocells it may be impractical for microcells.

2.2.3 Time-based Techniques

Time-based techniques are those based on estimating the ToAs (Time of Arrival) of a signal transmitted by the MS and received at multiple BSs or the TDoAs (Time Difference of Arrival) of a signal received at multiple pairs of BSs.

The essential ingredient for the time-based approaches are high resolution timing measurements. However, it should be noted that LoS propagation conditions are still necessary to achieve high accuracy for the time-based methods. The problem of non-LoS (NLoS) propagation is addressed in Section 3.3.

Several methods have been proposed as means of forming time estimates in mobile systems including phase estimation, pulse transmission, and spread spectrum techniques. Phase estimating systems employ phase detectors from which ToA information is obtained, and requires synchronization at three or more BSs. ToA or TDoA information can be obtained from wideband pulse transmission using correlation techniques [6] [7].

Finally, with spread spectrum signaling, the ToAs or TDoAs can also be determined through the use of a correlation techniques, as will be discussed in Section 2.5. Spread spectrum ranging has been investigated in the literature and is the principle behind GPS [8].

2.2.3.1 Time of Arrival (ToA)

In the ToA approach, the distance between a MS and BS is measured by finding the one way propagation time between a MS and BS. Geometrically, this provides a circle, centered at the BS, on which the MS must lie. By using at least three base stations to resolve ambiguities, the MS's position is given by the intersection of the circles.

ToA technique works by the MS bouncing a signal back to the BS or vica vers. The propagation time between The MS and BS calculated at half the time delay between transmitting and receiving the signal. Again the mobile station location can be calculated by the interception of circles from 3 such sets of data using least squares to minimize the error. With the introduction of wide bandwith digital systems timing information becomes relatively easy to obtain by correlation of a known pilot sequence at the receiver. The maximum time resolution depends on the sampling rate at receiver. Prefiltring the signal to bandpass the frequencies with maximum SNR (Signal to Noise Ratio) can further reduce the probability of timing errors. Initialy Knapp et al. [9] proposed a maximum likelihood receiver. More recently Gardner et al. [10] and Izzo et al. [11] proposed variation on the receiver architecture to exploit the cyclic nature of the signal.

To obtain the location estimate from the raw time of arrival data, the following function is formed:

$$F(x) = \sum_{i=1}^{N} \alpha_i^2 . f_i^2(x) \tag{2.2}$$

where the α_i are weights reflecting the reliability of the signal received at BS_i. The location estimate is determined by minimizing the function given in ??.

2.2.3.2 Time Advance (TA)

The cell wise location determination of a mobile station is already in use, via the Cell Identity method presented in Section 2.1. Each cell has a radio base station serving it, so the cell has a known location. In TA [12], a TDMA[2] cell knows the time it takes for its signal to reach a mobile device. This knowledge is required because multiple devices share the air interface at the same frequency using different time slots. To ensure the signal from a distant device does not stray outside its time slot, a timing advance signal is sent to the mobile station. The timing advance signal can be converted into a distance with a precision of 550 meters, thus providing a location that looks like a doughnut. In urban areas this may be acceptable, especially if directional antennae are taken into account. Precision in rural areas will be poor.

2.2.3.3 Time Difference of Arrival (TDoA)

Usually the mobile unit can not be synchronized accurately enough to directly obtain the time used by the signal to travel between a mobile unit and a base stations. One solution to get around the synchronization problem is to use differences in the time delays of several base stations instead of absolute times. Time differences are used in the time differences of arrival. Precise synchronization of BSs will be required for this method.

TDoA works by measuring the relative arrival times at MS of signals transmitted from three BSs at the same time (or known offset). Likewise the relative arrival times at three BSs of one

[2] A digital cellular telephone communications technology that divides each cellular channel into three time slots in order to increase the amount of data that can be carried.

MS can be measured. Again the maximum timing resolution depends on the sampling rate at the receiver.

As shown in Figure 2.4, the estimate can be made from the intersection of two hyperboloid each defined by the following equation:

$$R_{ij} = \sqrt{(X_i - x)^2 + (Y_i - y)^2} - \sqrt{(X_j - x)^2 + (Y_j - y)^2} \tag{2.3}$$

Where (X_n, Y_n) represents the fixed coordinates of BS_n and R_{ij} represents the propagation distance corresponding to the the difference in the time delays between the mobile unit and base stations i and j, (x, y) are the coordinates of the mobile unit. Iterative and empirical methods for solving the set of equation ?? in x and y have been proposed and compared in [13].

This approach becomes difficult if the hyperbola or circles do not intersect at a point due to time measurements errors.

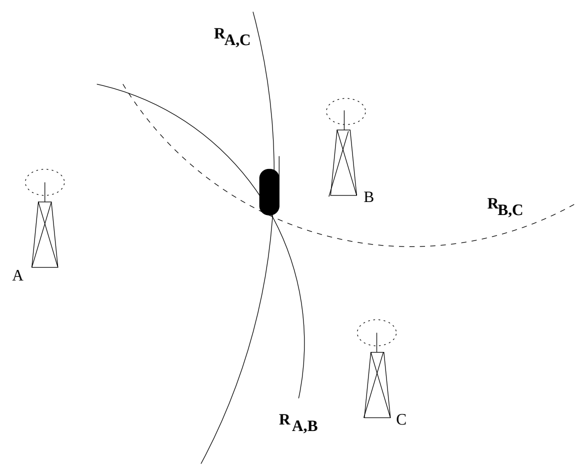

Figure 2.4: Location estimation for the TDoA technique

TDoA is now considered the leading candidate for any future location system. The TDoA method is succefully applied in the GSM system. Encouraging preliminary field trials in Helsinki [14] on a GSM 900 give location estimate accuracy of <200m 67% of the time. If measurements corresponding to more than three base stations are available in either ToA or TDoA methods, the incompatibility problem mentioned in conjunction with the AoA method, can arise. In such case special heuristics have to be applied to obtain a location estimate. When the signal is transmitted from the base station to the MS and the position is estimated in the mobile station, the method is reffered to OTD (Observed Time Difference).

2.2.4 Triangulation

The triangulation method uses measurements of the time taken by signals coming from several base stations. If the position of two base stations is known accurately, and it is possible to measure the difference in time that the signals transmitted by these stations take to reach the mobile station - the observed time difference, that is, the time difference observed on the system clock as received from the two base stations - it is then possible to work out a locus (hyperbola) for which this time difference is constant and equal to that measured by repeating this operation and taking the intersection of the hyperbola defined in this way [13].

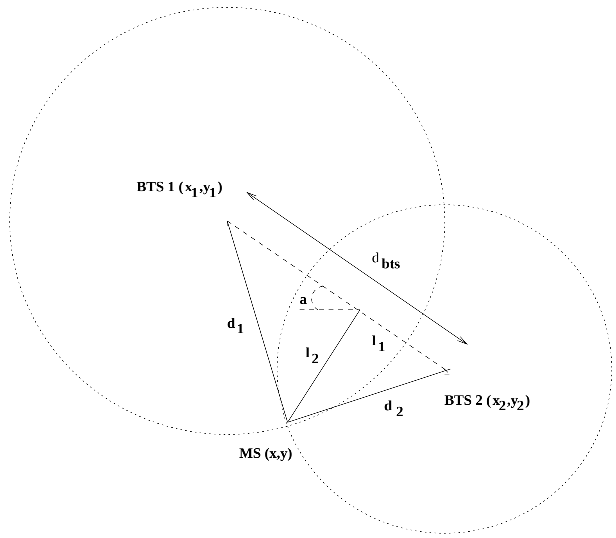

Figure 2.5: Finding coordinates using triangulation

The triangulation location technique uses the geometric properties of triangles to compute object locations. In the following we present a geometric solution for calculating the coordinates of the MS.

The coordinates (x_1,y_1) and (x_2,y_2) for each of the BTSs is known as shown on Figure 2.5. In addition the mean distances d_1 and d_2 is known. From the Figure 2.5 we see:

$$d_{bts} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

$$l_1 = d_1 + d_2 - d_{bts}; \qquad l_2 = \sqrt{d_2^2 - l_1^2}$$

$$\sin(a) = \frac{y_2 - y_1}{d_{bts}}; \qquad \cos(a) = \frac{x_2 - x_1}{d_{bts}}$$

We can call the point where l_1 and l_2 meets P, and obtain:

$$x_p = x_2 - l_1.\cos(a); \qquad y_p = y_2 - l_1.\sin(a)$$

Thus, the most probable position of the MS have two solutions:

$$x = x_p - l_2.\sin(a) = x_2 - l_1.\cos(a) - l_2.\sin(a)$$

$$y = y_p + l_2.\cos(a) = y_2 - l_1.\sin(a) + l_2.\cos(a)$$

and

$$x = x_p + l_2.\sin(a) = x_2 - l_1.\cos(a) + l_2.\sin(a)$$

$$y = y_p - l_2.\cos(a) = y_2 - l_1.\sin(a) - l_2.\cos(a)$$

which correspond to the two intersections of the circles in Figure 2.5.

2.2.5 Representing position based on probability

Regardless of which technique is used to find the distance between the different Base Stations to the MS, the result will be a probability distribution.

In [15], the probability distribution of the signal strength measurements is calculated as the sum of the distribution in the radio channel, and the measurement error in the MS.

This distribution assigns a value to the probability that the distance will be a certain value.

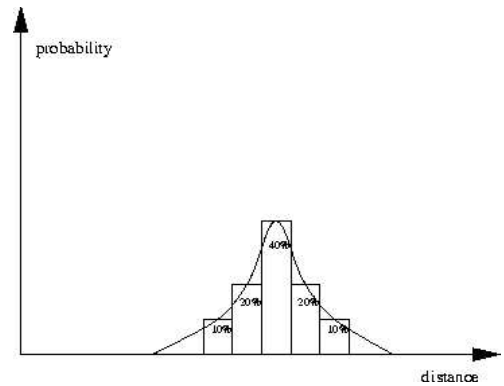

Figure 2.6: Discrete probability distribution.

The probability distribution assigns a probability to each possible distance. To simplify the examples and the calculation, discrete probability distributions will be used. If a measurement of the distance between a MS and a BTS resulted in the distribution in Figure 2.6, the probable location of the MS would be as in Figure 2.7.

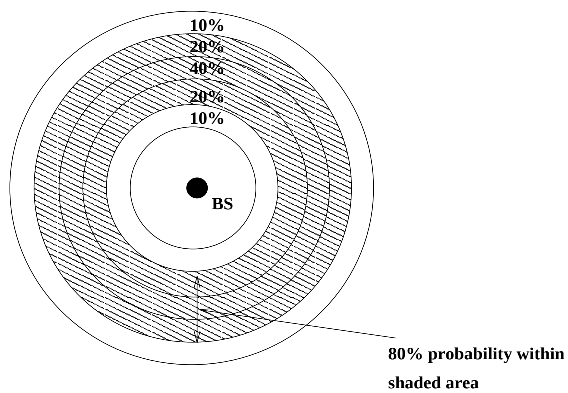

Figure 2.7: Location probability with one BS

The Figure 2.7 shows the most probable locations for the MS will be within the area between two concentric circles concentered with BTS. This will be the best possible result when measurements for only one BTS are available. Information about the area can easily be transmitted by giving the position of the BTS and the radii of the inner and outer circle.

Thus the probabilities of each intersection can be found by multiplying the probabilities for each of the intersecting areas. On Figure 2.8 we can see that each intersection consists of two small "squares".

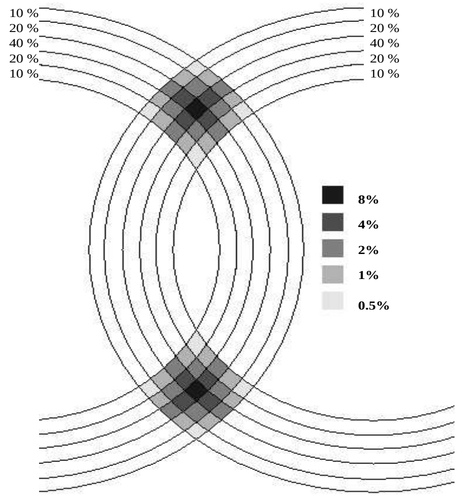

Figure 2.8: Location probability with two BSs.

The probability for the MS to be located within one square will then be the half of the product of the probabilities for the intersecting areas.

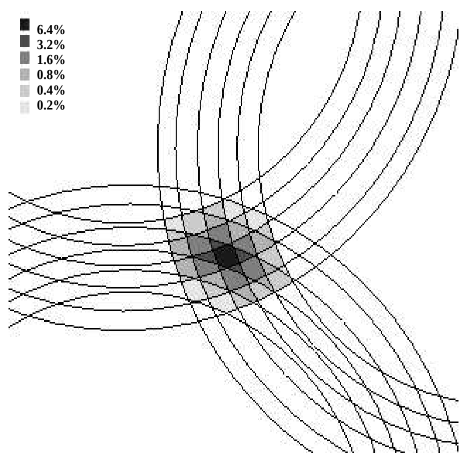

Figure 2.9: Location probability with three BSs.

Figure 2.9 shows the similar result for three BTSs. The area is now broken up into a mosaic of smaller areas of different shapes, each with an assigned probability, calculated from formula ??:

$$Pr\{A \cap B \cap C\} = Pr\{A\}.Pr\{B\}.Pr\{C\} \tag{2.4}$$

2.2.6 Hybrid techniques

Hybrid techniques using more than one of the above have been suggested, specially a AoA and ToA signal strength hybrid which has an advantage in that communication with only one BS is required as depicted in Figure 2.10. In [16] a TDoA-ToA hybrid was suggested to improve location estimate accuracy. An understanding of the relationship of the accuracy of each technique to different environments will help to combine the measurements types optimally. Analysis of the geometric dilution of precision (GDoP) (see Section 3.4) for each technique is essential.

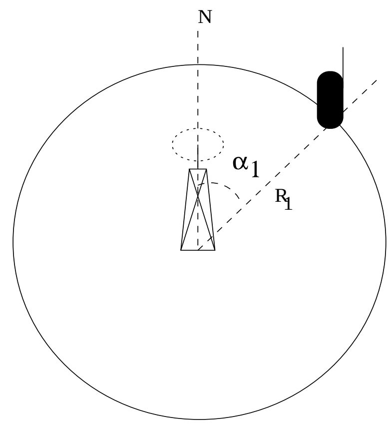

Figure 2.10: Location estimation for the hybrid AoA-ToA/signal strength technique

2.3 Hand-set based approach

In mobile-based architectures the mobile unit performs the necessary measurements of downlink signals to infer its own location without any uplink communication. In order for this to be possible the network has to broadcast some assistance data, such as the locations of the base stations.

Hand-set based techniques rely on a modified handset to calculate its own position. One such technique is to use a Global Positioning System (GPS) receiver embedded in the handset. In addition to self-location, these techniques also require a return data path to report the location to the network.

2.3.1 Satellite positioning systems (GPS)

Satellite-based location systems, and among them especially GPS which is a constellation of 24 medium orbit satellites used for global coverage of the earth, achieve the most accurate positioning today [17].

Terrestrial mobile networks offer the possibility of transmitting support information (e.g., ephemeries, time references or even differential corrections) to these satellite receivers. Using this support data, positioning time (time-to-fix), accuracy and sensitivity are improved considerably.

Until recently the accuracy of plain GPS location was about 100 meters. More sophisticated equipment used prelocated reference points in the so called differential GPS scheme to obtain accuracy of approximately one meter [15].

Advantages of the GPS system include world wide availability, and high accuracy. However, GPS is applicable only in areas where there is a simultaneous line-of-sight to several satellites. These rules out the use of conventional GPS systems, for instance, under dense foliage, between high buildings or mountains and indoors. In addition, the time to acquire a synchronization lock on the GPS satellites, can take anywhere from 30 seconds to 15 minutes, depending on the prior knowledge of the receiver and satellite locations.

Moreover, this method requires a relatively expensive satellite receiver (processing & radio) to be integrated into the mobile.

2.3.2 Network Assisted GPS positioning (A-GPS)

There is a less power-consumption alternative: "Assisted GPS", in which some of the positioning parameters are obtained in advance through GPS receivers installed as fixed elements of the communications network. This technique simplifies case-by-case calculating and reduces the time needed to identify a position to a matter of seconds.

In assisted GPS location estimation systems, the shortcomings of a GPS receiver are taken care of by using a local reference station containing a GPS receiver, as shown in Figure 2.11. The location reference station has a satellite-quality clock contrary to a commercial GPS receiver clock. In wireless communication systems, a base station is ideal for integration with local reference stations. The base station estimates certain components of the range measurement and broadcasts the corrections to the mobile station.

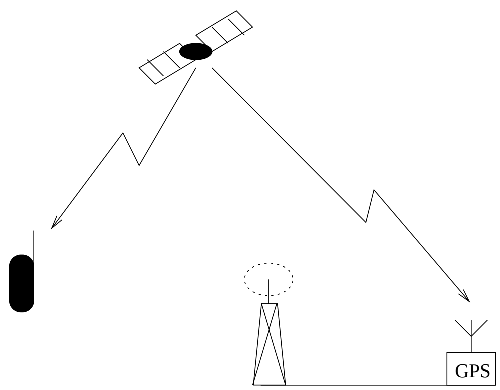

Figure 2.11: GPS technology in a base station corrects mobile station GPS data. The GPS in the base station always has a line of sight with the GPS satellites.

Because the base station location is known, it can find the error and correct the mobile station position. For mobile station to base station distances of 500 meters, the range of error is within two to three meters. Placing a base station (integrated with a local reference station) on top of a tallest building partially mitigates the multipath effect.

The basic idea in assisted GPS is to establish a GPS reference network or a wide-area differential GPS network with receivers that have clear views of the sky and can operate continuously. This interference network is also connected with the mobile network. At the request of a mobile station or network-based application, the assistance data from the reference network is transmitted to the mobile station to increase performance of the GPS sensor. If implemented properly, the assisted-GPS method should be able to reduce the sensor start-up time, increase the sensor sensitivity and consume less handset power than conventional GPS.

2.4 Database correlation

Since all the location techniques have their limitations, for example an unsatisfactory performance in some propagation environments, it is an attractive option to use all available data to obtain an optimal locationestimate. Combining cell identification, signal level, angle of arrival, time difference of arrival, and GPS techniques would yield much better accuracy especially compared to the worst cases of each individual technique. Moreover, this kind of an approach can handle the varying amount of information provided by old handsets, new handsets, handsets equipped with a GPS receiver.

2.4.1 Database Correlation Method (DCM)

This method is based on correlation of received signal information with database information. The mobile phone forwards the cellular and/or satellite-based signal information to the location server. The mobile terminal contains a communications functionality (e.g., SMS) for transmitting the required signal information up to an application server. The application server passes the signal information and any other relevant information forward to the location server. The location algorithm at the location server yields an estimate of the mobile terminal coordinates with the help of the signal information and additional information stored in the database. The additional information include digital maps, system information (e.g., base station coordinates) and a priori measured or calculated calibration data. Location server returns the estimated location back to the application. Depending on the application, the coordinates are used by the application server or they are returned back to the mobile terminal. The application may also be part of the location server in which case a separate application server is not needed.

In GSM, the signal information might include the cell Id, signal levels, timing advance, and OTDs. If the RTDs are available, they can be used as well. The location is estimated by comparing the signal information to known signal information stored in a database. In the comparison, simple correlation-type algorithms or more advanced pattern matching algorithms [18] can be used.

The proposed technique requires that a large database of measured or predicted signal information is established and maintained. The effort for this can be reduced by covering, in the first phase, only the most critical areas, for example the city centres. On the other hand, if the location server is connected with a teleoperator's network planning system, the database maintenance could be carried out in parallel with the network planning activity.

2.5 Performance comparison of location methods

The performance of location techniques depends on a number of factors. The sensitivity of the techniques of the different factors is evaluated in the Table 2.1.

The correlation method is assumed to use only the information that can be measured by existing handsets (cell ID, signal levels, timing advance, and OTDs) and no base station synchronicity is assumed. It should be noted that different implementations of a given technique, for example handset based vs. network based implementation, lead to various amounts of modifications. Software modifications to the handset are needed if it has to send any measured data to the network. The cell identification, angle of arrival, and TDoA techniques can be implemented without any

	Multipath propagation	Satellite visibility	Distance measurement accuracy	Number of base stations	Temporal & spatial variations
Cell ID	no	no	no	no	no
Signal level	small	no	no	large	large
AoA	large	no	no	small	small
Time Difference	large	no	large	large	no
Correlation	no	no	no	large	large
GPS	large	large	small	no	no

Table 2.1: Sensitivity of location performance on different factors

modifications to the handsets if the location estimation is done in the network. However, the TDoA technique may benefit from software modifications. Handset-based GPS needs no modifications to the network, but here we assume a network-assisted GPS that has certain advantages as described above. New hardware to BSs is needed in the AoA technique (antenna arrays) and the time-based techniques TDoA and E-OTD (synchronization).

2.6 Location estimation enhancement techniques

Several methods have been proposed to improve the location estimation techniques and to make use of extra data sets [21] [22]. Optimal solutions can be found by using weightings proportional to the confidence in a set of data. For instance the effect of data on the location estimate from far away BSs or GDoP poor BS's could be reduced.

Because location systems based on TDoA and AoA each offer advantage under varying conditions, systems that combine both technologies were developed.

Another method proposed for ToA is to restrict the error range to a positive sign (ToA methods cannot underestimate the time delay). Morley et al. [19] show that adding this further constraint to the least squares solution can significantly reduce errors. It may be possible to extend this idea to TDoA if one postulates that a TDoA measurement between a close and a far BS will tend to be an overestimate as a far BS is more likely to suffer from NLoS. This method was extended to an advanced positioning technique for GSM networks called Enhanced Observed Time Difference (E-OTD).

E-OTD involves measuring the propagation time of signals received by the mobile terminal, between the base station serving the radio cell in which the terminal is located and at least two other adjacent base stations. Then the results are compared. Since the coordinates of the base stations are known, the position of the terminal can be calculated either in the terminal itself or in the network by means of triangulation (described in Section 2.2.4).

E-OTD requires upgrading of the functions of the mobile terminal. Its accuracy is in the order of 150 meters. Under ideal conditions, it is even capable of precisely identifying positions to within a few meters [20].

There are several ways in which the estimation procedure can be improved when multiple sets of location estimates in time are available. In [16] velocity estimation has been successfully used on previous estimates to constrain the current location estimate. This smoothing process is sometimes referred to as dead reckoning. If geographical information is available or in urban areas where BSs are arranged at block corners it is possible to adjust location estimates to fall on roads.

2.7 Conclusion

In this chapter, we have given an overview of the proposed methods to estimate the location of mobile stations in different systems such as GSM, UMTS, etc. Each of them can be applied efficiently in one or more of these systems by giving a very close approximation of the mobile location.

However, many obstacles remain to be resolved to reach a very close estimation of the mobile location. These obstacles will be the subject of the next chapter.

Chapter 3

Main obstacles to location estimation

Sources of error in location systems include hearability of remote *BSs,* multipath propagation, non line of sight conditions and the multiple access interference which will be presented in this chapter. It is important to mitigate these impairements to improve the location accuracy.

3.1 Hearability of remote BS's

In most techniques non-serving *BSs* are involved. The hearability of signals to or from these *BS's* may cause some measurements to be impractical when the *MS* is close to its serving *BS*. Especially if the communications are power controlled the SIR[1] (for the remote signal) will be high. It may be impossible to collect the required measurements from the remote *BSs* in a short enough time. A power up function at the *MS* was proposed [23], slotted transmission at the BS proposed in [37]. Using a ToA approach he simulates location accuracies less than 125m 80% of the time. These will both have a significant effect on the capacity of the network but may be worth further study. Another important technique to consider is interference cancellation whereby known signals that are present can be removed from the received signal, thus reducing the apparent SIR.

3.2 Multipath conditions

Multipath effects are caused by the air interface and local scatterer (reflections off geographical features) which results in a received signal made of several different copies of the same transmitted signal at different time delays, magnitude and phase. In modern systems the communication channel is estimated and a RAKE receiver can be implemented to capture these rays. Multipathing will have an effect on AoA measurements (particularly at the MS) as a large angle spread may be observed at the receiver. Typical values are 360^o for indoor, 20^o for urban and 1^o for rural environments [24].

[1] Signal to Interface Ratio.

3.3 Non-Line of Sight conditions (NLoS)

The problem of non-line of sight communication is fundamental. Timing, signal strength, and especially AoA information will be inaccurate. Results from a study in [25] indicate change in propagation distances of 400-700m will be typical for an MS experiencing NLoS conditions. In TDoA timing errors may cancel out to a certain degree assuming similar NLoS properties to each BS. It seems feasible that the NLoS propagation errors may be predictable by analyzing measurement statistics as proposed in [26]. Certainly to simulate a realistic scenario a dynamic LoS/NLoS channel must be modelled.

3.4 Geometric Dilution of Precision (GDoP)

Geometric Dilution of Precision is caused by Suboptimal BS Layout In certain scenarios the GDoP will have a significant effect on the accuracy of the system. Specifically Highway cells where the BS arrangement may be linear. In [27] and [28] methods to measure the GDoP were proposed, a demonstration of the effect on simulated results was given. In theory it will be possible to reject certain measurements using GDoP analysis.

3.5 Lack of Bandwidth

The Lack of Bandwidth is one of practical limitation and challenges conditions that degrade position estimates, considering that it reduces ability to resolve multipath and make accurate time estimates. The bandwidth of a given position location system impacts location accuracy giving that lower bandwidth has lower time resolution and low time resolution makes TDoA less accurate.

Inability to resolve some multipath components may make AoA less accurate. From signal processing theory, for good performance, the Time-Bandwidth Product should be greater than the value one.

3.6 Conclusion

Achieving accurate location of a mobile system remains a challenge considering the sources of error in location estimation, in particular the effect of buldings in urban areas.

Alternative location methods are under development and several trials and tests have been carried for the current mobile systems. In the next chapter we present the current location estimation systems.

Chapter 4

Current location estimation systems

Location estimation can be accomplished in all wireless systems. Variations of TDoA, AoA and their hybrid have been developed. GSM bandwidth of 200 kHz, wider than AMPS, makes TA, ToA, TDoA and E-OTD potentially more accurate. The TA feature of GSM is a good candidate for a fallback location estimation method. CDMA wide bandwidth of 1.25 MHz increases the accuracy of location technologies. CDMA is time referenced with a GPS unit and is the most accurate timing estimation.

It is unlikely that any one system will be able to provide accurate mobile positions under all circumstances. The final solution to this problem is a more pragmatic combination of several location methods working together. ToA is expected to make significant contributions to such a solution. Standardisation is focused on time-difference methods (E-OTD, ToA) and the use of GPS.

In this chapter we study the application of the different mobile location methods to the third generation mobile systems.

4.1 CDMA System

The CDMA uplink is composed of access channels and reverse channels, each of which may provide signals for radiolocation. The reverse traffic channel is only active when a call is in progress, so its use for location is limited. For applications such as fleet management, location updates may be needed even when a MS is not transmitting on the reverse traffic channel. For these applications, the radio signals to be used for radiolocation must come from the access channel, which is only used by the MS to respond to pages and orders from the BS, make call originations, send data burst messages, or to send registration messages. The use of autonomous access channel transmissions has the advantage of not consuming system resources by the BS to process and transmit to the MS, as is the case for an ordered registration. Hence, autonomous registration updates could provide the signals used for mobile location when the MS is idle.

All cellular systems suffer from co-channel interference. In cellular CDMA, users share the same frequency band with different spreading codes. One of the primary impediments to high capacity in CDMA cellular systems is the near-far effect, where the signals from the different MSs are received with unequal power at a BS making it difficult to recover the weaker users [29] [30].

It has been shown that multiple access interference greatly affects the coarse timing acquisition of spread spectrum signals [50, 51]. Power control schemes can be used to combat the near-far effect, that attempt to ensure that each user's signal is received with equal power at the BS [31] [32].

4.2 Location methods in third generation

In 3G mobile systems essentially the same kind of techniques can be used as in the 2G generation systems such as GSM [33]. However, the signal bandwidth is typically larger in 3G systems and consequently, better accuracy can be achieved in distance measurements. For example, WCDMA (Wideband Code Division Multiple Access) is one of the techniques to be included in the global 3G standards [34]. The bandwidth of the signal is of the order of 5 MHz which is large compared to the 200 kHz bandwidth of the GSM signal. The distance measurement capability is directly proportional to bandwidth and therefore a clear advantage over GSM exists. However, the distance measurement accuracy is not always directly proportional to the accuracy of the coordinate solution. For example: the good distance measurement capability is not useful if the direct signal path does not exist due to a large obstacle, such as a building.

In addition to the potential for improved location accuracy, another advantage is that 3G systems are designed to support packed mode communications. This enables flexible and cost-effective transmission of the messages and commands related to the location procedure. In GSM, the SMS service is used which is too slow for many applications and allows only a limited amount of information to be transferred. There are also some difficulties to tackle as listed in [35]. One obstacle to be faced in WCDMA systems is the hearability problem. The problem occurs when the mobile is close to one BS and the strong signals of this BS prevent the MS of receiving signals from other BSs. The same problem occurs also in uplink: the faraway BSs are not able to receive signals from the MS. The so called Idle Slot Forward Link method (IS-FL) has been proposed to solve the hearability problem [33]. In this method, each BS periodically "turns off" for a short time during which the MSs are able to receive signals from other base stations. Also temporarily increased power or multiuser detection could be used to solve the hearability problem [18].

Another disadvantage is that the BSs are not synchronized in the FDD (Frequency Division Duplex) operating mode, which seems to be the technique to be used at least in the first phase of the 3G networks. Networks based on the synchronized TDD (Time Division Duplex) operating mode are foreseen to evolve later. In FDD mode a method for measuring the relative time differences of the base stations shall be included as is the case in GSM, which makes the implementation of the location system more complicated.

4.2.1 UMTS and location estimation

Universal Mobile Telecommunications System (UMTS), is projected as the broadband wireless multi-media system of the future, utilizing spread spectrum technology CDMA. The wideband nature of the FDD facilitates the high resolution in position location. The duration of one chip (3.84Mcps) correspond to approximately 78 meters in propagation distance. If the delay estimation operates on the accuracy of samples/chip then the achievable maximum accuracy is approximately 20 meters. There are other inaccuracies that will cause degradation to the positioning but 20 meters can be considered as best possible positioning performance. UMTS specifies that it will provide location information for mobiles to an accuracy of 50m. With GPS assistance may be even 10 meter accuracy is possible.

Chapter 5

Conclusion

In this report the theory and current status of mobile location technology have been examined. There are several ways to determine a cell-phone user's position, however, no method that is superior to all others has been found yet. GPS is the most commonly discussed option. Signal attenuation, angle of arrival (AoA), time of arrival (ToA), time difference of arrival (TDoA), enhanced observed time difference (E-OTD), and time advance (TA) are used to locate unmodified cellular telephones. All these technologies are based on knowing the location of reference points and then relating them to the location of the mobile station. Signal attenuation has not received as much attention as the other methods. AoA and TDoA are the most discussed methods. AoA was first developed for military and government organizations, because it operates with no modification of mobile devices and was later applied to cellular signals. It is based on the estimation of mobile station signal angle at the base stations and requires an array of antenna elements.

The time-based methods ToA, TDoA and observed time difference (OTD) work on the basis of time a signal takes in propagating from one place to another (from a mobile station to base stations in case of ToA, and from the base stations to the mobile station in case of OTD). Because TDMA systems know how much time signals take to reach mobile stations, the information is exploited for location estimation.

TDoA requires that multiple base stations listen to hand-over access bursts and triangulate the position of the mobile device. This has the advantage of workingwith existing GSM mobiles, but needs substantial investment in supporting infrastructure.

With E-OTD, the handset listens to bursts from multiple base stations and measures the observed time differences. The measurements are used to triangulate the position of the mobile device. E-OTD requires handset modifications, but less positioning infrastructure support than ToA.

The accuracy of the mobile location estimation is mainly limited by the wild conditions of the propagation channel and the multiple access schemes. In particular, the non-line of sight conditions, the multipath and the number of possible averages, limit seriously the expectations aroused by the UMTS bandwidth.

For handset modification, the GPS-assisted method is the most desired. However, millions of handsets are in operation already. Hence, there is high motivation to develop unmodified handset methods.

List of Abbreviations

A-GPS Assisted GPS

AMPS Advanced Mobile Phone System

AoA Angle of Arrival

BS Base Station

BTS Base Transceiver Station

CDMA Code Division Multiple Access

DCM Database correlation Method

E-OTD Enhanced Observed Time Difference

FCC Federal Communications Commission

FDD Frequency Division Duplex

GDoP Geometric Dilution of Precision

GPRS General Packet Radio Services

GPS Global Positioning System

GSM Global System for Mobile communication

LoS Line of Sight

MS Mobile Station

NLoS Non Line of Sight

OTD Observed Time Difference

RSS Received Signal Strength

RTT Round Trip Time

SIR Signal to Interface Ratio

SMS Short Messages Service

TA Time Advance

TDoA Time Difference of Arrival

TDMA Time Division Multiple Access

ToA Time of Arrival

UMTS Universal Mobile Telecommunications System

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