Critical Analysis and Modelling of Location Finding Services

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Abstract

This report gives an overview of all the location-finding technologies used for estimating the position of user equipment (handset) in a wireless communication network. It outlines the most common traditional location tracking method, Global Positioning Service (GPS). It then contrasts this against new methods of location technologies which are available using the most common wireless network in the world, Global System for Mobile Communication, (GSM). The objective of the research is to critically assess the location-finding techniques used in providing location services, which will involve mathematical modelling and experimentation. These will then be presented, along with an extensive literature search, to illustrate the expected results against actual measurements.

This report also shows the results of an experiment that carried out using Enhanced Cell Identity with Timing Advance incorporating triangulation model, and the range of experiments which will be used in the future.

1 Introduction

1.1 Introduction

There has been a great increase in interest in location-based services in the recent years. This might include locating or tracking a mobile device used by, for instance, field service engineer, a company vehicle or field sales personnel, and so on. The location information can then be used to send local services depending on the current physical location. An important element of this is to implement a system that fits the requirements of the location service. The key objective of this research is to analyse differing models for location finding for mobile devices, and to analyse their performance. Each model will then be assessed through practical experiments, or where there is a lack of currently available equipment, through mathematical modelling.

The research question is:

> … whether it is possible to define a range of models for location-tracking services in mobile devices, and to determine their expected location performance for a given specification.

This will be assessed:

> … by defining real-life experiments, and determining the expected performance. These will then be compared with field-trail experiments, and against published work.

The critical analysis will be:

> … the models will be critically assessed for their expected and actual performance, against theory, field trails and published material, for various physical locations. Possible applications for the differing technologies will be investigated, and recommendations made on the key judgements that would be made on deciding on the best location-finding technology.

The target degree for this research is an **MPhil**.

1.2 Background

This research is funded by Justfone Limited, which is a software development company specialising in wireless application development and services. The research has grown from a TCS programme, and investigates differing models for location finding services.

1.3 Location Technologies

There are number of technological alternatives for locating the position of user equipment, including terminal-based and network-based solutions. As an introduction, the basic techniques are discussed in this section. The location technologies are typically grouped as network-centric, where the mobile phone network is used to locate the device, or station-centric, which requires additional stations, such as satellites or additional radio transmitters, to provide the location.

1.3.1 Global Positioning System (GPS)

GPS is handset based, and consists of 24 satellites, which circle the Earth in a particular constellation so that several satellites fall within line of sight of any GPS receiver on Earth. A wireless subscriber must have a handset with specially equipped with GPS circuitry, which acts as a GPS receiver. When a location request is made, the GPS-enabled handset determines the phone's latitude and longitude based on the satellite's broadcast (Figure 1.1). The main benefit of GPS is its high level of accuracy. Unfortunately, GPS-enabled handsets are more expensive than GPS-free handsets. GPS must also have a clear line-of-sight between the device and the satellite. Thus, its performance deteriorates in built-up urban areas.

1.3.2 Assisted Global Positioning System (A-GPS)

This is a handset-based technology that is an enhanced version of conventional GPS. Assisted-GPS uses GPS chipset in the mobile handset, together with some assistance data sent over the mobile network to locate the subscriber.

1.3.3 Differential Global Positioning System (D-GPS)

Similar to A-GPS, this is handset-based but requires a reference station (either ground-based or geosynchronous) to reduce the location data error, hence, it provides highly accurate location fix.

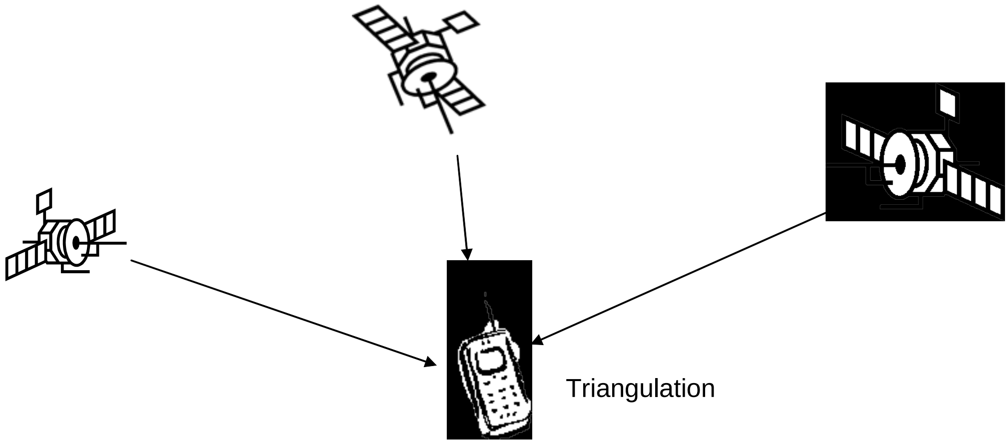

Figure 1.1: GPS

1.3.4 Cell Identity (Cell-ID)

This is the simplest form of positioning technology, and is network centric. It is also known as mast-based location. The mobile network always knows the location of a registered mobile handset to location area level, and when a call is in progress it knows which of the cells within the area that is communicating with that handset. The cell centre is used as an estimate for user location. Figure 1.2 outlines its operation. The cell size will obviously define the resolution. Hence the accuracy level for GSM 1800 (where cell sizes are smaller) is better than accuracy level compared with GSM 900. The 3rd Generation of mobile phones, UMTS, will obviously provide better results then GSM 1800 since it operates at 2000 MHz and has smaller cell size. This research will look at identifying the sizes of these cells at differing locations.

1.3.5 Time-of-arrival (TOA)

This positioning method is based on measuring the time differences in the arrival time of a signal sent by the mobile handset to three or more location measurement units (LMUs) attached to base stations, as illustrated in Figure 1.3. Using a combination of these time differences and a knowledge of the exact position of each LMS, allows the position of the mobile handset to be computed using triangulation. The LMUs are normally co-located with the base stations. This technology works across all types of handsets and its usability is high, as it can be used both indoors and outdoors. However, TOA requires significant investment in mobile network infrastructure.

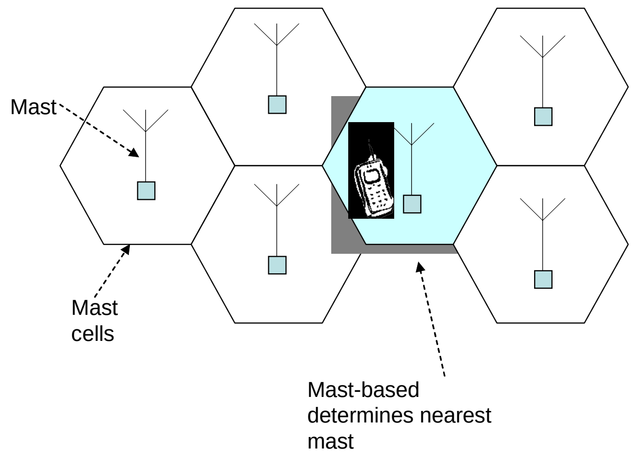

Figure 1.2: Mast-based location

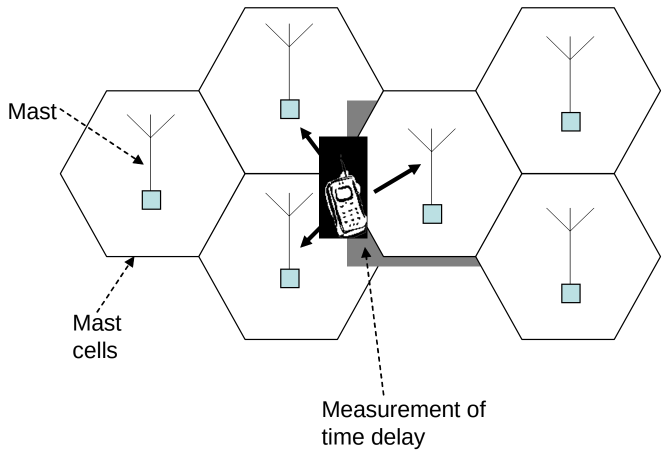

Figure 1.3: Time-of-arrival

1.3.6 Angle of Arrival (AOA)

This method locates a wireless subscriber by determining the angle at which the signal is arriving from the subscriber's handset, as illustrated in Figure 1.4. One problem with AOA is the cost of implementation and maintenance. The advantage of AOA is that it is nearly always available, indoors and outdoors, and provides location data across all mobile handsets.

1.3.7 Location Pattern Matching (LPM)

This is also known as Multipath Fingering. Its main technique is to analyse the signal bounced off solid objects to build up a pattern (fingerprint), which is stored in a central database. When a handset transmits, the signal is received at various antennas sites and then transmitted to a mobile switch. The network then attempts to match the characteristics of the transmission with the fingerprints in the database to define a location. The advantage of LPM is that a wireless subscriber can use any handset. This technique is also effective in urban environments that include tall buildings and other obstructions. Also, only one cell or mast is required to locate and track signals from a handset. The major disadvantage is the time required to build the fingerprints database. Also the fingerprint database has to be recalculated frequently as patterns may change.

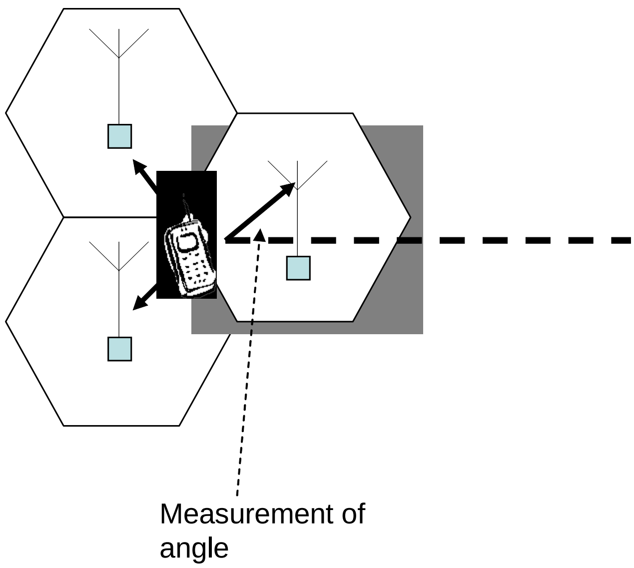

Figure 1.4: Angle-of-Arrival

1.3.8 Observed Time Difference (OTD)

This is a network-centric technology that relies on measuring the differences in arrival time of signals sent out by several cellular base stations (BTSs), at the mobile handset and at a nearby fixed reference, or location measurement unit (LMU). Triangulation then allows user position to be estimated.

1.3.9 Enhanced Observed Time Difference (E-OTD)

This is also known as Cambridge Positioning Systems (CPS), and is basically an enhanced version of OTD. It relies on the subscriber's handset to perform location-based data calculation, in addition to LMUs, thus gives more accurate location fixes. The main disadvantage of this system is that software modification in the handset is required for enhanced measurement process.

1.4 Time plan

An outline of the stages to complete the research are:

- **Complete literature review**.
- **Define of location models**. This investigates the main location models, which include: Assisted Global Position Service (A-GPS); Cell-ID; Time-of-arrival (TOA); Observed Time Difference (OTD) and Angle of Arrival (AOA).
- **Definition of experiments for location services**. This will define how each experiment for each location service model will be carried out and how theoretical results will be compared.
- **Experiment definitions**. This will involve setting up experiments, which will determine the resolution of location services, as compared with the models for each type of location systems. The GPS model will be used for bench marking other location services models.
- **Conference paper and IEE Review paper**. This will be published in a leading IEEE/ACM, once the data from all location services models has been gathered and conclusion reached. The research will also generate some of the most extensive reviews of location-finding techniques, thus an IEE will be written which covers these areas.

2 Position Technologies

2.1 Introduction

The aim of this chapter is to outline, in more detail, some of the key techniques using in location-finding technologies. Mobile phone technology has passed through three main phases:

- **First generation** (1G). First generation mobile phones (1G) had very low transmission rates (typically just a few KB/s).
- **Second generation** (2G and 2.5G). These are devices improved this to give several hundred KB/s. 2G/2.5G networks use GSM.
- **Third generation** (3G). These devices give almost workstation network bandwidths (in MBps), which allows full multimedia transmissions. 3G networks are called UMTS (Universal Mobile Telecommunications System) which differs from the existing GSM network.

2.2 Location Estimation Techniques

Generally, positioning technologies or methods can be grouped into various categories, such as in terms:

- Performance. Technologies grouped in terms of their performance, are based on the accuracy of the positioning method that give different level of accuracy and hence aim for different sectors of market. For example, fleet managers do not require high level of accuracy so most basic positioning methods such as Cell-ID, Cell-ID + TA are enough. However, emergency services, such as mountain rescue or ambulance services, require more accuracy and hence E-OTD positioning method best fits its requirements. Sometimes combing and deploying two or more location technologies give more accurate results. These positioning technologies can be grouped under complexity and are commonly known as hybrid.

A-GPS, Cell-ID + TA are typical examples.

- Complexity.
- Implementations requirements. In some situations some sort of extra implementation is required for positioning technology to work and to achieve some degree of accuracy level, such as software requirements in handsets, hardware requirements in mobile networks. Positioning technologies under this category such as OTDOA requires huge investments in mobile network infrastructure.
- Investments. This is a major factor, and will depend on the amount of additional services that the network can provide for in the future, and their required level of accuracy.

According to the current GSM specifications, there are basically two modes of operation under which the few positioning technologies such as E-OTD, OTDOA, A-GPS work [1]. First, is the handset-based mode, where the position calculation function is carried out in the handset and then sent back to the network. Second is the handset-assisted mode, where the handset makes only measurements and reports these back to the network as a Network Measurement Report, which calculates the handset position. These modes are shown Figure 2.1 and Figure 2.2.

The estimation of position technologies is based on accuracy of the positioning method. Other factors, which are important, are, for example, complexity of the system and the investment needed on the network side and possibly in handsets.

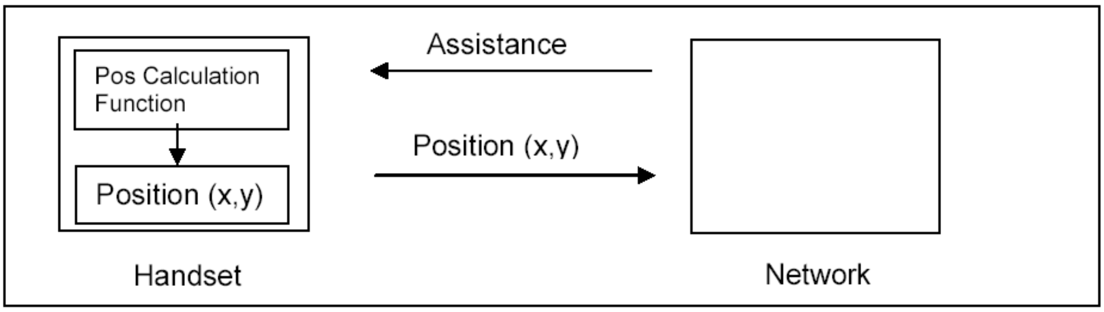

Figure 2.1: Handset based mode

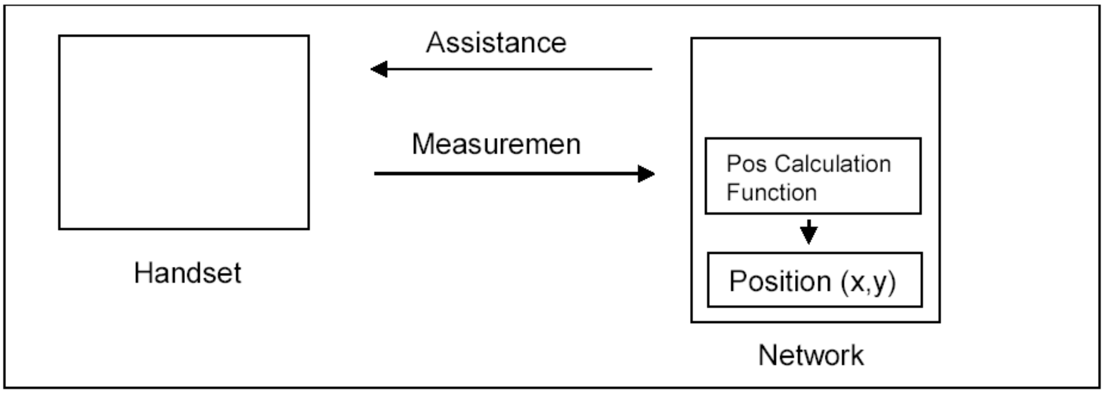

Figure 2.2: Handset assisted mode

The following are the various techniques that can be used to calculate, or at least estimate, an unknown location of a mobile handset using wireless networks[1]. The techniques include:

1. GPS (Global Positioning System)
2. Cell-ID (Cell Identity).
3. AOA (Angle of Arrival).
4. TOA (Time-of-arrival).
5. OTD (Observed Time Difference).
6. A-GPS (Assisted – Global Positioning System).

2.3 GPS (Global Positioning System)

This technique is a highly accurate method, but is often expensive to implement on a wide-scale basis. It also has limited coverage in urban areas, especially within buildings or near obstructions. Mobile phone based location finding will obviously provide an inexpensive method for location finding, as it has wide-scale coverage, along with inexpensive handsets, which are typically bought for other purposes, such as making telephone calls.

[1] Rappaport et al [2] provides a useful and comprehensive reference.

2.4 Cell-ID (Cell Identity)

The basic positioning finding methods (used typically in GSM networks) are based on the use of cell identification (Cell-ID) [1]. Cell-ID can be used alone, or together with timing advance (TA) and network measurement reports (NMR). In the Cell-ID positioning method, the cell that the handset is registered to is the location measurement of the handset's position. This information is available in the network and at the handset. The Cell-ID is then converted to a geographic position using knowledge of the operator's network, such as coverage database at the serving mobile location centre (SMLC). This positioning method can also support all legacy handsets and roaming subscribers. The accuracy level, of course, depends on cell size. Figure 2.3 and 2.5 are typical examples of omni-directional and sectored cells.

In some cases, Timing Advance (TA) can be used to improve performance. TA is a measure of the MS (mobile station) range from BTS[2] (base transceiver station), to a resolution of 550m and improves accuracy in bigger cells like in GSM 900. With a proper software support in the handset (MS), Timing Advance can be used with triangulation technique for more accurate location fixes. Table 2.1 outlines typical accuracies.

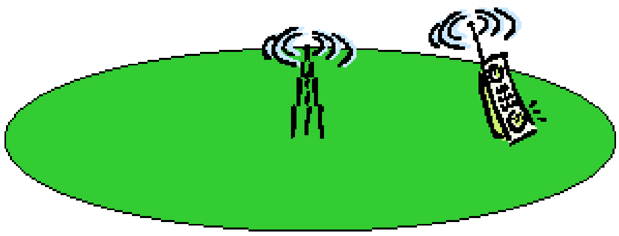

Figure 2.3: Cell-ID [1]

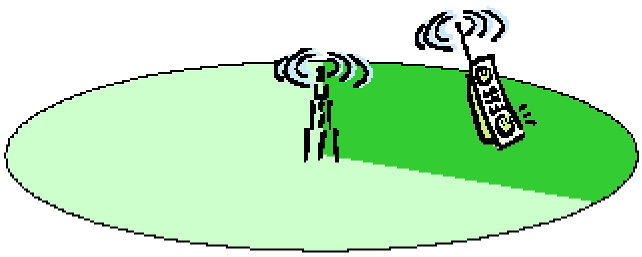

Figure 2.4: Cell site with sector [1]

[2] The Base Transceiver Station (BTS) is a mast with antenna

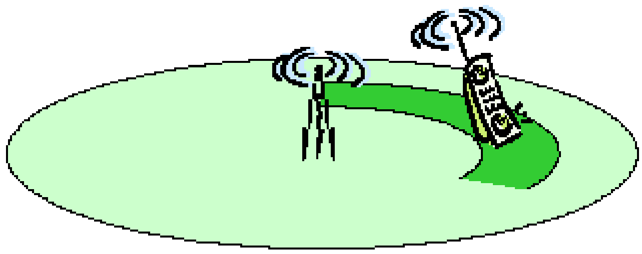

Figure 2.5: Cell-ID with sector and timing advance [1]

Table 2.1: Accuracy of Cell-ID [1]

Technology	*Rural*	*Suburban*	*Urban*	*Indoor*
Cell ID	1-35km Typical: 15km	1-10km Typical: 5km	Macrocells: 500m-5km Typical: 2km Microcells: 50-500m Typical: 200m	10m-50m (if pico cells are used)
Cell ID + TA	TA gives no major improvements in accuracy, but it is good to check whether the handset is connected to the nearest cell, rather than the strong signal.			

2.4.1 E-CGI (Enhanced Cell Global Identity)

In the GSM cellular system the handset makes measurements of its operating conditions, and sends them to the network for hand-over decisions. These *network measurements reports* contain the estimated **power level**, at the handset, from the serving cell, and the cells on the neighbour list. The power level measured at the handset can be used to estimate the BTS-MS distance, based upon simple propagation models and/or network planning tools. This is illustrated in Figure 2.6 and Figure 2.7.

Power measurements from adjacent sectors of the same cell site can provide an estimate of the angle of the MS from the site. Pattern recognition algorithms can be used with multiple measurements reports to give improvements in accuracy.

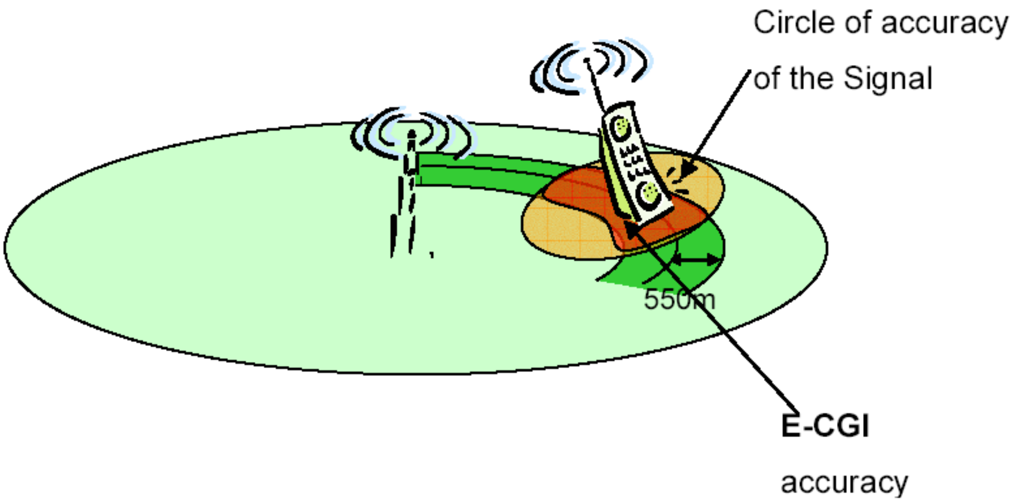

Figure 2.6: Enhanced Cell-ID [1]

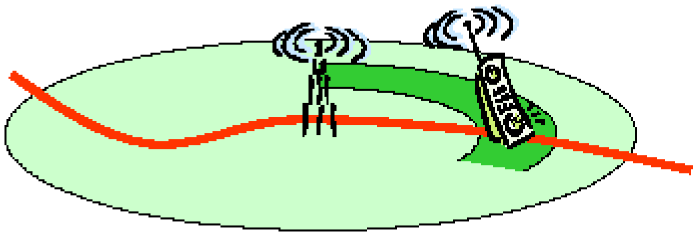

Figure 2.7: Cell site with sector, timing advance and supplementary information [1]

Unfortunately, the accuracy of E-CGI is only as good as the prediction tool used and the radio environment that is available. Accuracy is also dependent on cell density, network configuration and environment. Field measurements will improve prediction tool accuracy and there may be methods of collecting such measurements when more accurate methods, such as A-GPS, are available. This could include requesting a position estimate and measurement report from an A-GPS handset. Unfortunately, E-CGI performs poorly indoors and in rural areas with low BTS density.

Table 2.2: Accuracy of E-CGI [1]

Technology	*Rural*	*Suburban*	*Urban*	*Indoor*
E-CGI	250m-35km	250-2.5km	50-550m	Highly variable

2.5 AOA (Angle of Arrival)

The Angle of Arrival method calculates the relative angles of arrival at Mobile Station MS of three Base Stations (BTS), or the absolute angle of arrival of the MS at two or three BS (Figure 2.8). 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 differences across the array (*phase interferometry*) or by measuring the power density across the array (*beamforming*) [2]. Once the measurement has been made the location can be calculated by simple triangulation.

It may be impractical to have an antenna array at the MS due to size, alignment and array separation problems. Lei et al. [8] have carried out some preliminary simulation work with a mobile antenna array receiver which suggests, if it is physically viable, that it is possible to implement such a system. Antenna arrays at the Base Station BS are planned for 3rd Generation of mobile networks, such as for UMTS, to provide directional transmission to improve network capacity.

A field trial in London, for Angle of Arrival technique, by Owen et al. [10] suggests that AOA is unviable for urban location estimation.

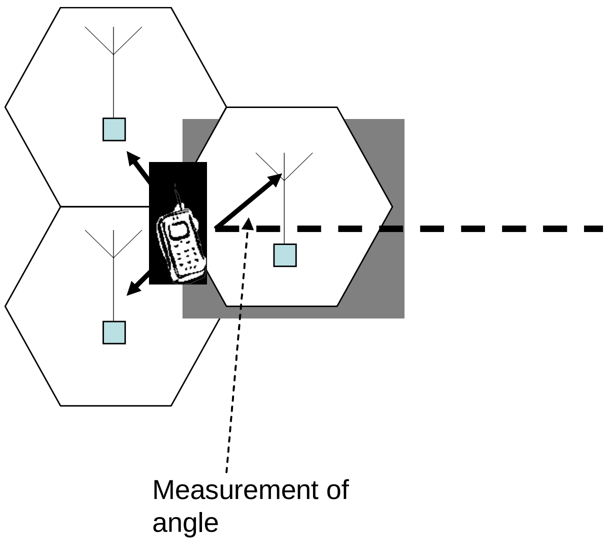

Figure 2.8: AOA

2.6 TOA (Time-of-arrival)

The Time-of-arrival TOA technique works by Mobile Station MS bouncing a signal back to the Base Station (BS) or vice versa. The propagation time between the MS and BS can be calculated at half the time delay between transmitting and receiving the signal. Again, the MS location can be calculated by the interception of circles from three such sets of data using least squares to minimise the error.

With the introduction of wide bandwidth digital systems, timing information becomes relatively easy to obtain by correlation of a known pilot sequences at the receiver. The maximum time resolution depends on the sampling rate at the receiver. Pre-filtering the signal to band-pass the frequencies with maximum Signal-to-Noise Ratio (SNR) can further reduce the probability if timing error. Initially Knapp et al. [11] proposed a Maximum Likelihood (ML) receiver, and more recently Gardner et al. [12] and Izzo et al. [13] proposed variations on this receiver architecture to exploit the cyclic nature of the signal.

A major drawback of the TOA approach is that a duplex transmission is required. Cedervall [14] cites accuracy with the FCC requirements, which is less than 125m for 67% of the time.

2.6.1 Time Difference of Arrival (TDOA)

TDOA measures the relative arrival time at the MS of signals transmitted from three Base Station (BSs), at the same time (or known offset). It is now considered the leading candidate for any future location system. Also, the relative arrival times at three BSs of one MS can be measured (Figure 2.9). Again, the maximum timing resolution depends on the sampling rate at the receiver. Precise synchronisation of BSs will be required for this method. The estimate can be made from the intersection of two hyperboloids each defined by the equation:

$$R_{i,j} = \sqrt{(X_i - x)^2 + (Y_i - y)^2} - \sqrt{(X_j - x)^2 + (Y_j - y)^2} \qquad (2.1)$$

where: (x, y) represents the fixed coordinates of BS.
n and $R_{i,j}$ represent the propagation distance corresponding to the measured time difference $\tau_{i,j}$.

Iterative and empirical Methods for solving the set of Equation (2.1) in x and y have been proposed and compared by Chan et al. [15]. Encouraging preliminary field trials in Helsinki [16] on a GSM900 network give location estimate accuracy of less than 200m for 67% of the time.

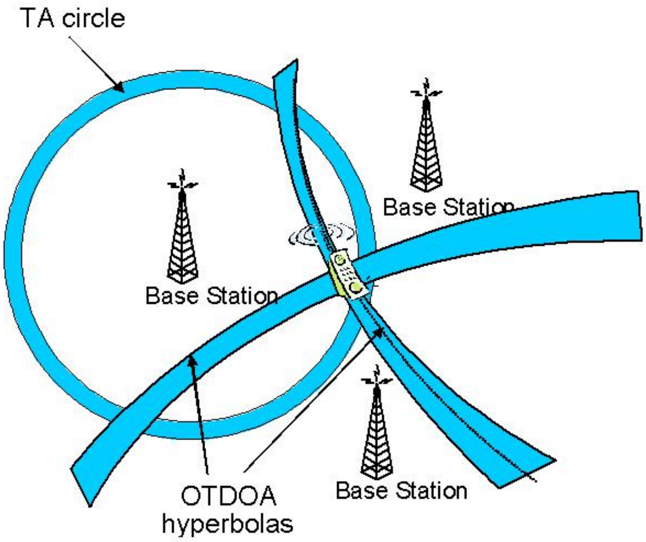

Figure 2.9 TDOA

2.7 E-OTD (Enhanced - Observed Time Difference)

E-OTD is a time-based method, whereby the handset measures the arrival time of signals transmitted from three, or more, BTSs (Figure 2.10). The time measurement capability of E-OTD is a new function on handsets. In MS-assisted E-OTD, the timing measurements made by the handset are then transferred to the SMLC using standardised LCS signalling[3]. The measurements returned are related to the distance from each BTS to the MS and the position of the MS is estimated using triangulation. In MS-based E-OTD, the position calculation function is in the handset and the position is returned to the SMLC.

The position of each BTS must be accurately known (within 10m, recommended)

[3] LCS is location service signaling which is the way that handset respond to network interrogation about its where about

to perform triangulation and estimate the position of the handset. The transmission times of each BTS must also be accurately known to perform E-OTD. If the network is not synchronised, BTS transmission time must be measured using a network of Location Measurement Units (LMUs). LMUs are essentially modified mobiles, optionally with a GPS receiver, placed in a fixed position with the capability to perform E-OTD measurements and return them to the SMLC.

E-OTD accuracy is outlined in Table 2.3, and is dependent on cell density, cell plan, multipath, interference, noise, LMU performance, and cell site position accuracy. Fortunately, accuracy does not degrade much indoors and E-OTD performs well in high BTS density areas. Conversely, E-OTD has poor performance in low BTS density areas.

The E-OTD method in UMTS (Observed Time Difference of Arrival – Idle Period Down Link-OTDOA-IPDL) still has technical issues to be solved before performance can be considered as good as E-OTD in GSM.

Table 2.3: Accuracy of Enhanced-OTD [1]

Technology	*Rural*	*Suburban*	*Urban*	*Indoor*
E-OTD	50m-150m	50-150m	50-150m	Good

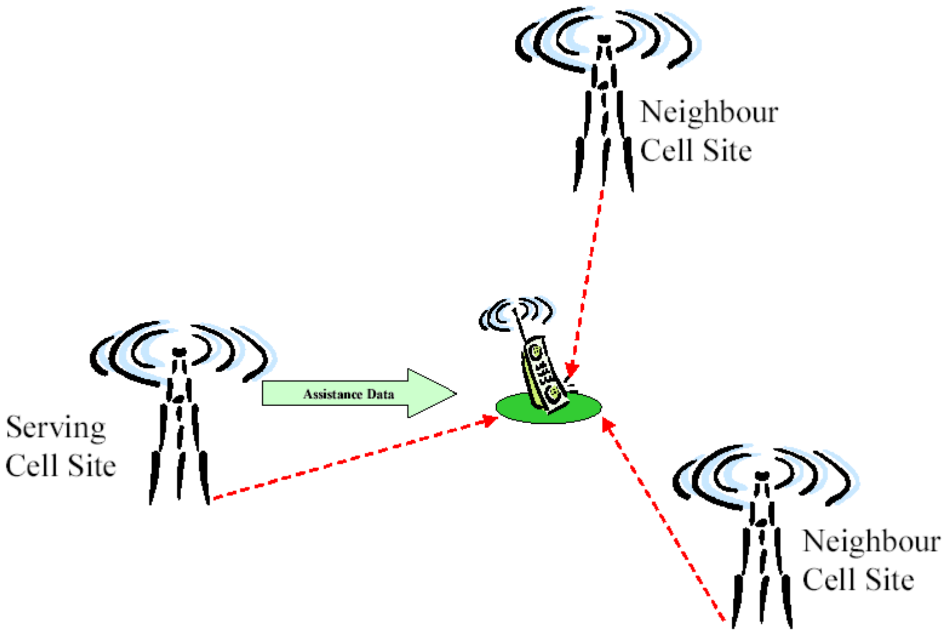

Figure 2.10 [1]

2.8 A-GPS (Assisted – Global Positioning System)

A-GPS is a time-based method, whereby the handset measures the arrival time of signals transmitted from three, or more, GPS satellites (Figure 2.11). Adding GPS functionality has a high impact on the handset with new hardware and software required. Most implementations of A-GPS have a low impact on the network, requiring only support at the SMLC.

In general, the information normally decoded by the GPS receiver from the satellites is transmitted to the MS through the radio network, bringing improvements in time-to-first-fix[4] and battery life – as the handset no longer needs to search for and decode the signals from each available satellite. Removing the need to decode the satellite signals also enables detection and time-of-arrival estimation over multiple parts bringing improvements in sensitivity, that is, A-GPS can provide position estimates:

[4] This is the initial time for the first location measurement.

- Under foliage.
- In-car.
- Most, if not all, outside environments.
- Many indoor environments.

A-GPS also provides good vertical accuracy and velocity estimates. Signals of GPS assistance data to the MS may take 10s, but once received by the handset, assistance data is useful for up to 4 hours.

There are two implementations of A-GPS. MS assisted, whereby the measurements are passed back to the network for position calculation and MS based, whereby the position is calculated in the handset. A-GPS is Radio Access Network independent so there is consistent performance in UMTS. Additionally, performance of A-GPS in UMTS is expected to improve.

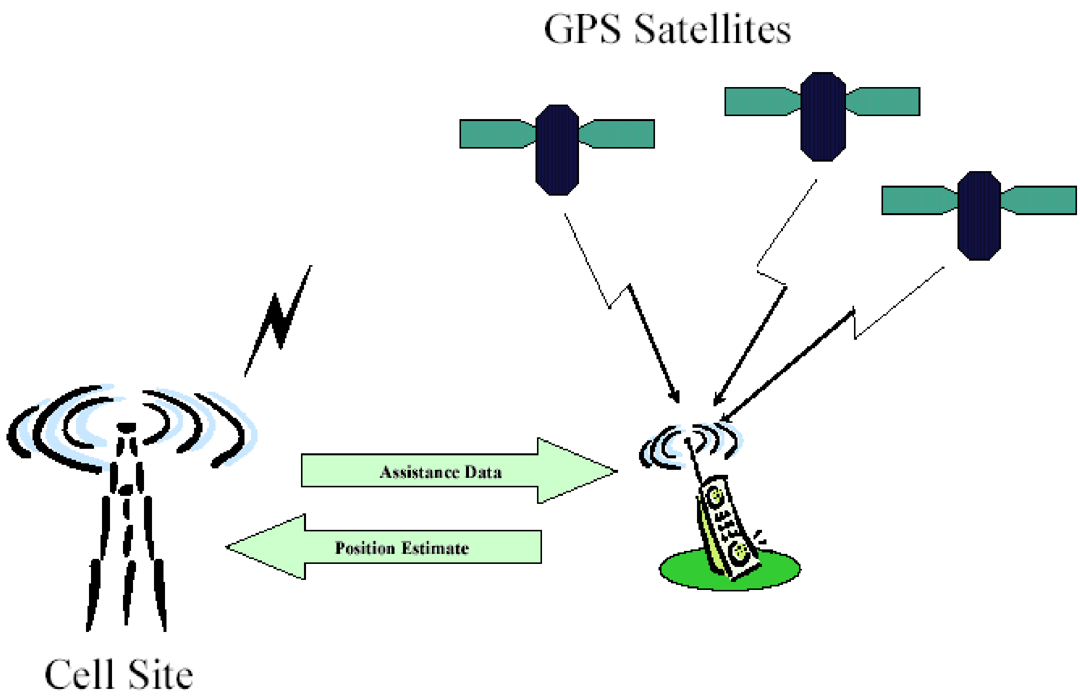

Figure 2.11 [1]

Table 2.4: Accuracy of Assisted-GPS [1]

Technology	*Rural*	*Suburban*	*Urban*	*Indoor*
A-GPS	10m	10-20m	10-100m	Variable

3 Critical Analysis

3.1 Introduction

The aim of this chapter is to analyse different methods that are mostly deployed for location tracking technologies.

3.2 Signal Strength Analysis

As GSM networks were developed, signal strength analysis was one of the first methods to be proposed as it was the simplest to implement. The technique works by measuring the signal strength of signals from at least three base stations (BSs) at the MS, or by measuring the signal strength of the MS at least 3 BSs. The signal strength measurements are related to the MS-BS separation distances. The MS location then can be calculated by the approximate intersection of three circles of known radius by using least squares to minimise the error, as illustrated in Figure 3.1.

There are fundamental problems associated with the signal strength measurements:

- **Fading**[5]. The fading profile of received power requires that the mobile device is not stationary and that some form of averaging is required. Figel et al [3] suggests that long-term median averaging can yield estimates that vary by as little as 0.5dB with individual estimates varying by 40dB.
- **Signal strength**. The signal strength measurements must be converted to distance measurements. Figel et al. proposed qualifying each BS with a contour map of signal strength measurements, however with the large number of Base Stations (BSs) this would now be unrealistic. More recently Hata [4] derived widely accepted empirical formulae from actual data, however, these do not account for

[5] Fading involves varying signal strengths such as with a contour map that can be made from varying signal strengths for each base station

local variations caused by the actual terrain.

Previous results suggest location estimate accuracy of less than 500m (Song [5]) and about 350m (Figel et al. [3]). More recently, with further processing of the estimations, accuracies of about 60m (Hellebrandt et al. [6]) and less than 270m (Salcic [7]) have been reported from the simulations.

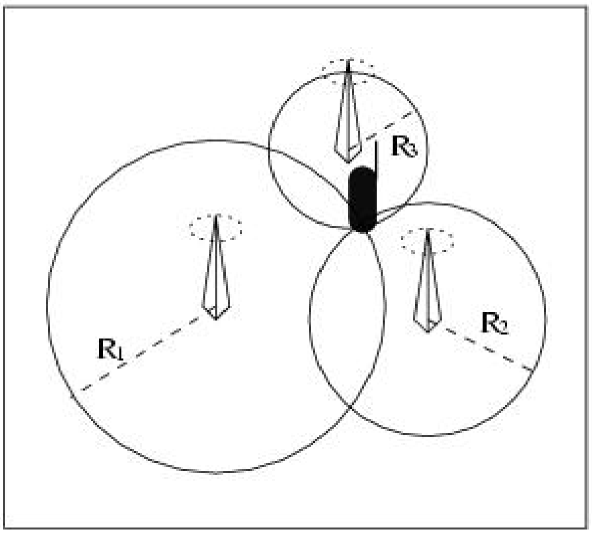

Figure 3.1:

3.3 Hybrid Techniques

Hybrid techniques use more than one type of location finding technology, specifically Angle of Arrival (AOA) and Time-of-arrival (TOA), or signal strength hybrid this has the advantage in that it communicates with only one Base Station (BS), as shown in the diagram in Figure 3.2. Yost et al. [17] suggest a TDOA-TOA hybrid would improve location estimate accuracy. An understanding of the relationship of the accuracy of each technique to different environments will help to combine the measurement types optimally.

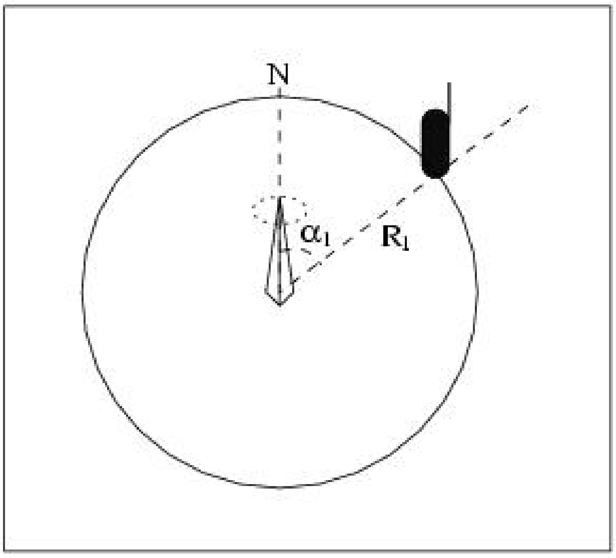

Figure 3.2:

3.4 Main Obstacles to Location Estimation

There are several key obstacles associated with location estimation which will have to be overcome. Interference, of course, can be an important role in the quality of the location-service. This can take the form of multiple paths for the radio signal, or from other radio devices. They can also be affected by local scatter patterns, which are caused by local geographical objects, such as buildings and trees.

3.4.1 Hearability of Remote Base Station (BS)

In most techniques, non-serving base stations[6] are involved. The *hearability* of signals to or from these BSs may cause some measurements to be impractical, when the MS is close to its serving BS. This especially occurs if the communications are power controlled, which causes the SIR[7] (for the remote signal) to be high. It may thus be impossible to collect the required measurements from the remote BSs in a short enough time [18]. Results summarized in CellScope [19] support this hypothesis.

Motorola propose a power-up function at the MS [20], whereas Cedervall pro-

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6 These are base stations that your mobile can see but not registered with.

7 The SIR defines the ratio between the strength of the signal and the strength of the interference.

poses slotted transmission at the BS [14]. Cedervall use a Time-of-arrival (TOA) approach and simulates location accuracies to less than 125m for 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.

3.4.2 Multi-path Conditions

Multi-path effects are caused by the air interface and local scatterers (reflections off geographical features) which results in a received signal made up 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[8] can be implemented to capture these rays. Multi-path will have an effect on Angle of Arrival (AOA) measurements (particularly at the MS) as a large angle spread may be observed at the receiver. Typical values are 360° for indoor, 20° for urban and 1° for rural environments [21].

3.4.3 Non-Line-of-Sight (NLOS) Conditions

The problem of non-line-of-sight (NLOS) communication is fundamental, as timing, signal strength, and, especially AOA information, will be inaccurate, as the path is not a straight one. Results from a study by Silvetoinen et al. [22] indicate change in propagation distances of 400 to 700m will be typical of 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 analysing measurement statistics as proposed by Wylie et al. [23]. Certainly to simulate a realistic scenario, a dynamic LOS/NLOS channel must be modelled.

3.4.4 Geometric Dilution of Precision (GDOP)

In certain situations, GDOP will have a significant effect on the accuracy of the system, particularly in highway cells where the BS arrangement may be linear. Pent et al

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[8] A RAKE receiver is a device invented by Price and Green in 1958 where the multiple signals appear as fingers of a garden rake head.

[24] and Lee [25] propose methods to measure the GDOP and demonstrate the effect on their simulated results. In theory it will be possible to reject certain measurements using GDOP analysis.

3.5 Location Estimation Enhancement Techniques

Several methods have been proposed to improve the location estimation techniques, and have been proposed to make use of extra data sets [5, 15]. Optimal solutions can be found by using weightings proportional to the confidence in a set of data, such as:

- The effect of data on the location estimate from far-away BSs or GDOP-poor BSs could be reduced.
- With Time-of-arrival (TOA), it may be possible to restrict the error range to a positive sign, as TOA methods cannot underestimate the time delay. Morley et al. [26] show that adding this further constraint to the least squares solution can significantly reduce errors. It may be possible to extend this idea to Time Difference of Arrival (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. A soft decision method could be implemented.

There are several ways in which the estimation procedure can be improved when multiple sets of location estimates in time are available. Both Hellebrandt et al. [6] and Pent et al. [24] successfully use velocity estimation 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. A technique used in urban locations has been simulated with success by Caffrey et al. [27].

3.6 Current Location Estimation Systems

The FCC in the US has defined many of the guidelines on which current mobile networks have been developed. For this type of network, TeleSentinal [9] has been developed, an AMPS[9] compatible system which uses AOA information arriving at two BSs, to calculate the MS location. Trials indicate that its accuracy exceeds the FCC requirement. The system does require additional hardware to be provided (or bought) by the mobile network operator and BSs must be constantly recalibrated to assure that the AOA information is correct.

In the UK, Cursor Systems [28] have developed a GSM-compatible method based on TDOA of signals from both the BSs at the MS and additional sensors, which are placed at known locations. Different network operators can work on one network of sensors. This system also claims to meet the US FCC requirements, However, as the US legislation does not apply in Europe, the same motivation is not present to network operators to pay for these solutions.

[9] Analogue Mobile Phone System is the analogue equivalent of the GSM network, and is still extensively used in the US.

4 Experimentation

4.1 Introduction

The purpose of this chapter is to define an experiment for one of the location technologies discussed earlier, so that its expected and actual performance can be assessed against theory, field trials and published material.

4.2 Range of experiments

So far, only one experiment is defined to evaluate its accuracy. This experiment was carried out using GSM 900[10] mobile network and it makes exclusive use of a GSM parameter - Timing Advance - which is only available in the handset and used by serving BTS to receive timing frame from the MS, on-time.

4.2.1 Timing Advance

The radio interface in GSM uses a combination between frequency (FDMA) and time (TDMA) multiplexing. The frequency division in GSM 900 allocates 125 frequencies in each direction for GSM. The uplink[11] frequencies are between 890 and 915MHz and the downlink[12] frequencies are between 935 and 960MHz. The carrier frequencies are separated with 200 kHz on each side. These frequencies are allocated in pairs, so that each uplink/downlink pair is separated with exactly 45 MHz. Each of the carrier frequencies are divided into eight logical channels, using TDMA, and a TDMA frame contains one time-frame from each of the eight channels, and lasts 4.615 ms. The time-frames from each channel lasts 0.577 ms. The total bit-rate for all eight channels is 270.833 Kbit/s, whereas the bit-rate for each channel is 22.8 Kbit/s.

In order to get the TDMA scheme to work, the time frames from each mobile sta-

[10] GSM 900 is the standard network used in the UK

[11] Uplink is MS to BTS

[12] Downlink is BTS to MS

tion must be synchronized when received by the BTS, as shown in the diagram in Figure 4.1.

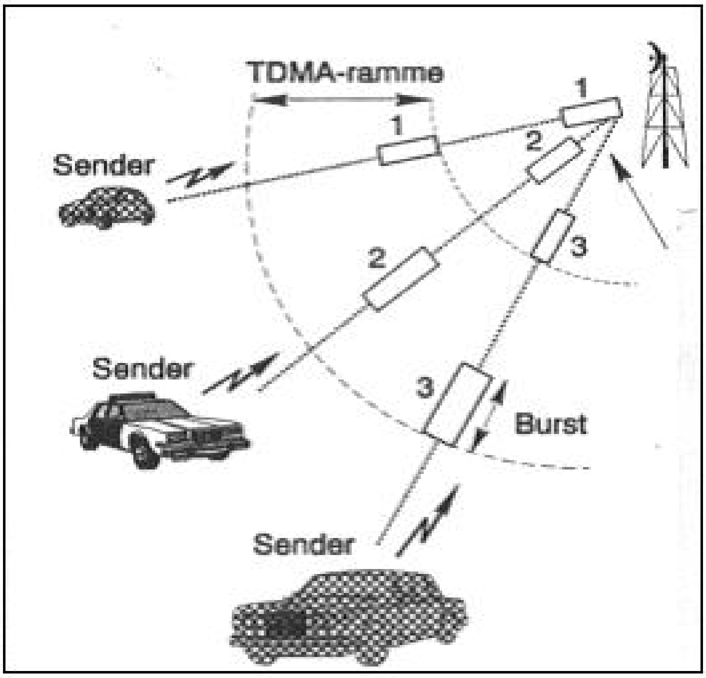

Figure 4.1: The synchronisation of TDMA frames

The Timing Advance (TA) implements synchronization [33], and the degree of synchronization is measured by the BTS on the uplink. This is achieved by checking the position of the training sequence, which is mandatory in all frames transmitted from the MS. From this, the BTS calculates the Timing Advance and sends it back to the MS in the first downlink transmission. From the TA value received from the BTS, the MS can determine when to send the frame, so that it can arrive at the BTS in synchronism. The values of the TA is continuously calculated and transmitted to the MS during the lifetime of a connection.

The TA can take values from 0 to 233μs. These values are coded by six bits, where [33] 0 is defined to be no timing-advance, and 63 to be the maximum timing advance. This gives a time-difference of 233/63 = 3.70μs.

These measurements of TA can be used to calculate distance directly. Since 1 bit of the TA represents a difference of 3.70μs of the signal BTS - MS - BTS, and the refraction index of air is approximately 1 [34], the distance per bit of TA is:

$$3.70\mu s.c.\frac{1}{2} = 3.70.3\times10^{8}.\frac{1}{2} = 550m \qquad (4.1)$$

Since the TA is rounded to the nearest bit-period during calculation, the actual BTS-MS distance, d, is:

$$550.\left(TA - \frac{1}{2}\right) \le d < 500.\left(TA + \frac{1}{2}\right), TA > 0 \qquad (4.2)$$

$$0 <= d < 225,\ TA = 0$$

The TA is calculated on the first arrived propagation path, which has a significant reception power level, and not on the maximum received power level. Therefore, we can assume that the TA represents the Line Of Sight signal in most situations [35].

4.3 Currently conducted experiment

Objective: The objective of this experiment is to measure the level of accuracy provided by Cell-ID with Timing Advance, using triangulation. A similar technique is discussed in Section 3.2 in which the MS uses the signal strength (RxLevel) from at least three BSs to measure its current location. This experiment uses Timing Advance (TA) instead of RxLevel[13] to locate its current position.

Equipment: In order to carry out this experiment, the following equipments are used:

1. Nokia Handset 7210 with NetMonitor[14].
2. GPS receiver (Benefon).
3. Microsoft MapPoint 2002.

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13 RxLevel is the received signal level.

14 NetMonitor is an administrative software tool for Nokia mobile phones that is mainly used for monitoring network and phone parameters. It has to be activated before use which, in this case, appears as an extra menu.

Procedure: In order to carry out this experiment, exact location of at least three neighbouring Base Stations (BSs) is required in terms of their grid references. For this, some support from the mobile network would be helpful but not necessary.

1. A suitable location is picked up where the experiment is to be carried out. This is done by using NetMonitor in Nokia 7210 where RxLevel from each neighbouring Base Station (BS) is checked to make sure that it is enough for MS to camp (register) on to the mobile network.
2. The current exact location of the MS is measured using the GPS receiver, Benefon. This position is to be used as a reference on the map since GPS gives the highest level of accuracy of all mobile location technologies i.e. accuracy of few meters.
3. Using NetMonitor in Nokia 7210, Timing Advance (TA) value in the MS for the current serving Base Station (BS) is recorded. Same procedure is then repeated for other two neighbouring Base Stations (BSs) by forcing MS to do a handover.
4. Using the distance calculation equation given in Section 4.2, distance from each Base Station (BS) is calculated and drawn on the MS MapPoint 2002. It is also summarised in the table 4.1 below. The MapPoint diagram is shown in Figure 4.2.

The calculated results for the three base stations are summurised in Table 4.1.

Cell-ID	**OS Grid**	**TA**	**Distance (Km)**	**BCCH**
28393	E357070 N6329040	4	1.925 – 2.475	45
4121	E365510 N632220	12	6.325 – 6.875	105
22747	E361450 N626975	10	5.225 – 5.775	49

Table 4.1: Calculation results of Timing Advance for three Base Stations.

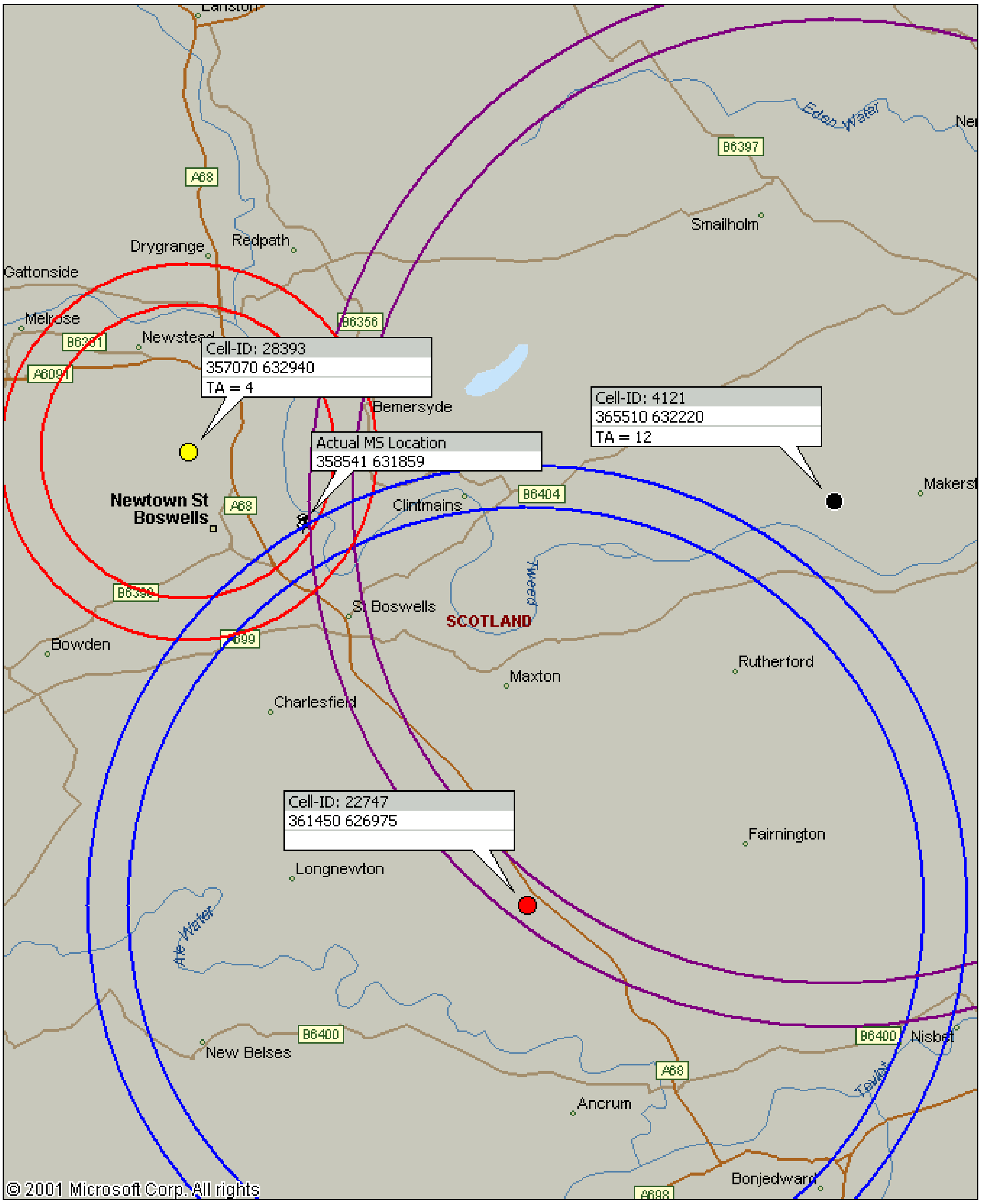

Figure 4.2: Concentric circles for each BS showing distance from MS

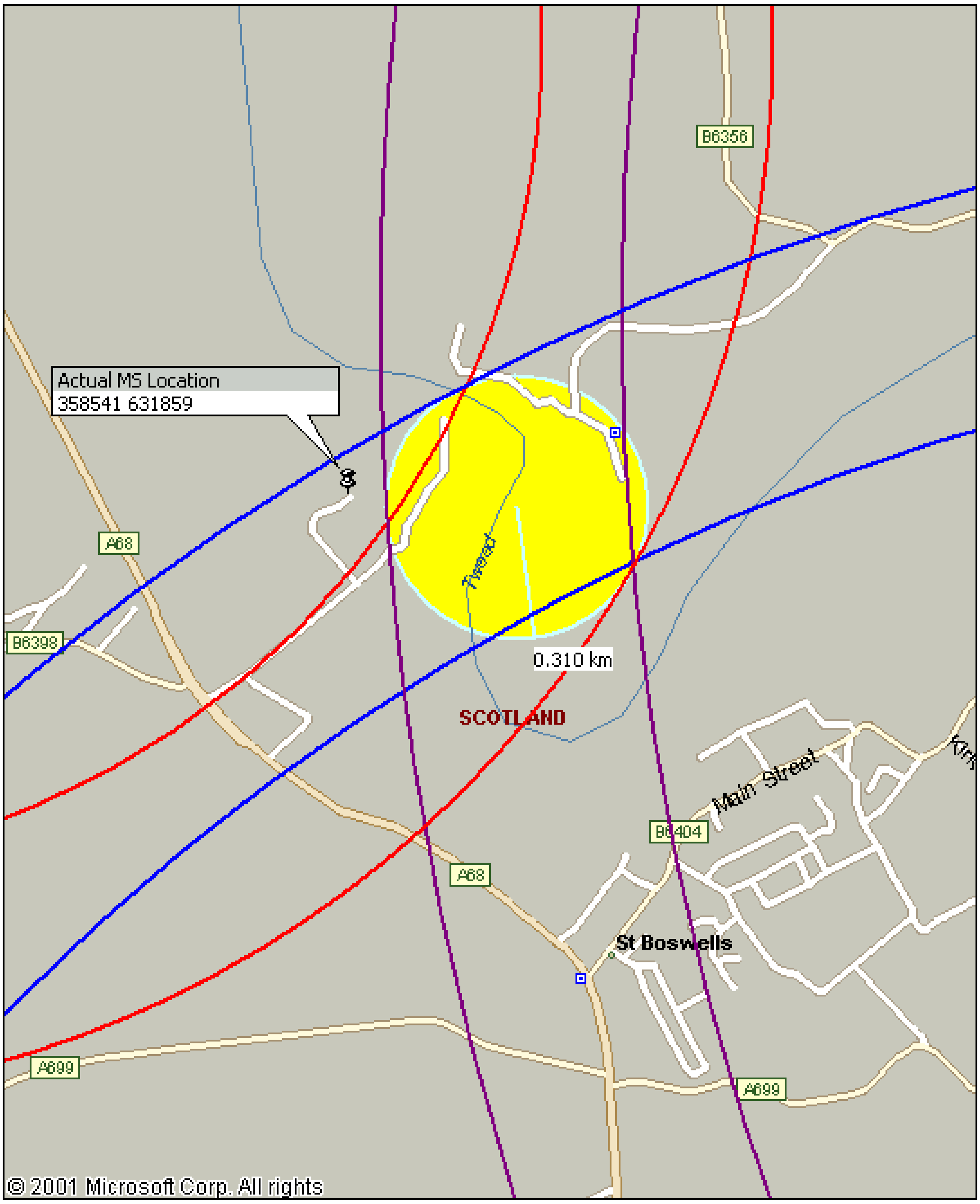

Figure 4.3: MS is marked with push-pin symbol

4.4 Discussion of results

In Figure 4.2, the two concentric circles are a set of minimum and maximum distance from each base station. Since each time slot, when converted to distance value, represents 550 meters, the mobile station can possibly be either at the start of the time slot or can be right at the end (see Section 4.2.1 and Figure 4.1). Hence, the distance between the two concentric circles is 550 meters. According to the Figure 4.3, MS location area is shaded and has a radius of 310 meters. Hence this provides a resolution accuracy of 310 meters.

The experiment shows good results which are comparable to theoretical accuracy described by Figel et. Al. [3] and Hata [4], although both of them incorporate signal strength measurements instead of Timing Advance. These experiment also have some degree of inaccuracy (see Figure 4.3) but this could be due to the fact that the information provided by mobile network regarding exact location of their mobile mast deliberately introduced some error to avoid information being used publicly. Assuming mast locations are accurate, the inaccuracy level can be improved by combining signal measurements and timing advance values from each Base Station.

5 Time Plan

5.1 Introduction

The purpose of this chapter is to show the detailed time plan for the next 12 months.

5.2 Detailed plan

The main tasks include:

Task 1: Experiment 1: Completed.

Task 2: Experiment 2: This experiment will use simple a timing advance function, in a sectored and omni-directional cell, to improve accuracy of generic cell-id location technology.

Task 3: Experiment 3: This experiment will use a triangulation method, similar to described in Chapter 4 in this report, but combining extra GSM parameters like timing advance, receiving power level, and so on, to improve level of accuracy.

Task 4: Experiment 4: This experiment will test the accuracy provided by Assisted Global Positioning Service (A-GPS). A GPS location fix will be used as a benchmarking tool.

Task 5: Model Creation: An Enhanced Observed Time Difference (E-OTD – Section 2.7) model will be created and simulated results from this model will be compared with GPS results.

Task 6: IEE paper: Paper will be submitted to IEE Journal in Communication Engineering[15] (ISSN 1479-8352). This will mainly be a review paper, and will critically assess location-finding technologies.

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[15] IEE Communication Engineer: Provides an in-depth coverage of new work at a level which will be informative and accessible to engineers active in areas of communications, including the design, development, operations and application of systems for communication and information networking.

Task 7: Conference paper: IEEE GLOBECOM 2004 [36], Texas, Dec 2004. Submission deadline: 1 March 2004.

Task 8: Final Experiment: If E-OTD is available in the UK at that time, this experiment will be carried out and results will be compared with simulated results obtained from Task 5.

Task 9: Literature search will be continued throughout the whole period.

Task 10: Write-up phased.

The following diagram outlines the time scales involved.

	Task	October 2003				Nov 2003				Dec 2003					Jan 2004				Feb 2004				Mar 2004					Apr 2004			
		6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	9	16	23	1	8	15	22	29	5	12	19	26
1	Experiment 1																														
2	Experiment 2																														
3	Experiment 3																														
4	Experiment 4																														
5	Model																														
6	IEE paper																														
7	Conf paper																														
8	Final ex.																														
9	Lit. search																														
10	MPhil thesis																														

	Task	May 2004					June 2004				July 2004				Aug 2004			
		3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23
10	Thesis																	
11	Viva																	

6 Conclusions

The purpose of this research is to critically analyse location-finding technologies for the wireless communication networks. The experiment that has been carried out in Chapter 5 shows good results which are comparable to theoretical accuracy described by Figel et. Al. [3] and Hata [4], although both of them incorporate signal strength measurements instead of Timing Advance. Experiment results do have some degree of inaccuracy (see Figure 4.3) but this could be due to the fact that the information provided by mobile network regarding exact location of their mobile mast deliberately introduced some error to avoid information being used publicly. Assuming mast locations are accurate, the inaccuracy level can be improved by combining signal measurements and timing advance values from each Base Station.

Traditional GPS location service provides highest level of accuracy than any other mobile network. However, in various practical applications this level of accuracy is not required. Table 6.1 provides a summary of an outline comparison between the technologies. The literature search has identified the mathematics involves in defining the location of the mobile device. Each of the technologies has their own strengths and weaknesses, and each type has a potential application.

Technology	Performance		Implementation Requirements				Cost
	Urban	**Rural**	**Handset**	**Network**	**Antennas**	**Satellite**	
GPS	Moderate	High	GPS compliant handset	SW modification required	None	Required	GPS handset
TOA	Moderate	Moderate/ Poor	SW required	HW/SW modification	>=3	None	Cost of network infrastructure
AOA	Moderate	Moderate	None	HW/SW modification	>=2	None	Cost of network infrastructure
LPM	Moderate/ High	Moderate	SW required	SW modification	>=1	None	Investment in signal database

Table 6.1:

7 References

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