4ICT9 Lecture Notes – GPS

1 Network Positioning / Location Based Services

Generally, positioning technologies or methods can be grouped into various categories, including in terms of:

- 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 re-quire 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 methods best fit these requirements. Sometimes combining 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 techniques. 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 reasonable degree of accuracy, such as upgraded software requirements in handsets or additional hardware requirements in mobile networks. Positioning technologies in this category e.g. OTDOA, require huge investments in mobile network infrastructure.

- Investment. This is a major consideration, and will depend on the level of additional service that network provisions 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 must work. The first is 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 initial measurements and reports these back to the network as a Network Measurement Report, which allows the Network calculate the handset position. These modes are shown below.

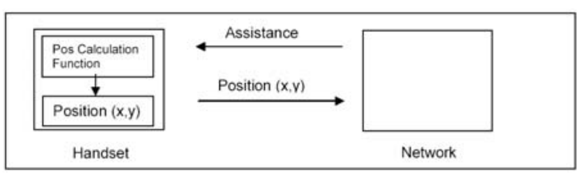

Figure 1: Handset Based mode

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

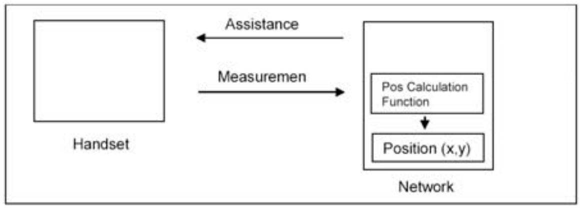

Figure 2: Handset Assisted mode

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. 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).

1.1 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 build-ings or near obstructions. Integrated into a mobile phone based location finding system it will obviously provide an inexpensive method for location finding, as it offers wide-scale coverage, along with inexpensive handsets, which are often bought for other purposes, e.g. making telephone calls.

1.2 Cell-ID (Cell Identity)

The basic positioning finding methods (used typically in GSM networks) are based on the use of cell identification (Cell-ID). 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 with provides the location measurement information for determining the handsets position. This information is available in both the network and at the handset. The Cell-ID is then converted to a geographic position by the operator using knowledge of the network and the coverage database at the serving mobile location centre (SMLC). This positioning method can support all legacy handsets and roaming subscribers. The accuracy level depends on cell size. The figures below show 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 (base transceiver station). TA improves accuracy in bigger cells - such as those that occur in rural areas with a GSM 900 network. With proper software support in the handset (MS), Timing Advance can be used with tri-angulation technique for more accurate location fixes. The table below outlines typical accuracies.

Figure 3: Cell-ID

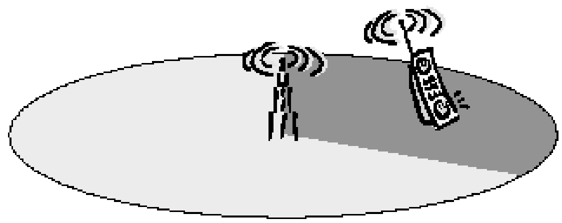

Figure 4: Cell site with sector

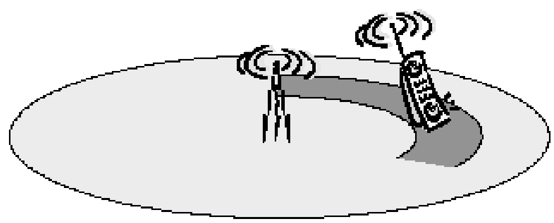

Figure 5: Cell-ID with sector and timing advance

1.3 E-CGI (Enhanced Cell Global Identity)

In the GSM cellular system the handset makes measurements of the operating parameters for visible cells, and sends them to the network for hand-over decisions. These network measurement reports contain the estimated power level, at the handset, from both the serving cell, and the visible neighbouring cells. 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 below. 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.

Unfortunately, the accuracy of E-CGI is only as good as the prediction tool used and the radio environment that the MS operates in. Accuracy is also dependent on cell density, network

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.			

Figure 6: Accuracy of Cell-ID

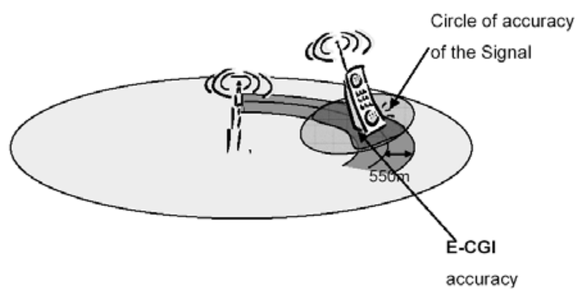

Figure 7: Enhanced Cell-ID

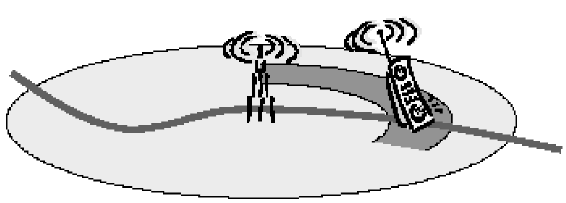

Figure 8: Cell site with sector, timing advance and supplementary information

configuration and environment. Field measurements will improve prediction tool accuracy and there may be alternate methods of augmenting such measurements when more accurate methods, such as A-GPS, are available. This could include requesting a supplemental position estimate and measurement report from an A-GPS handset. Unfortunately, E-CGI performs poorly indoors and in rural areas with low BTS density.

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

Figure 9: Accuracy of E-CGI

1.4 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. This technique relies on the relatively new technology of an-tenna 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). 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. Some preliminary simulation work has been done 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. Field trials in London, for the Angle of Arrival technique, suggests that AOA is unviable for urban location estimation.

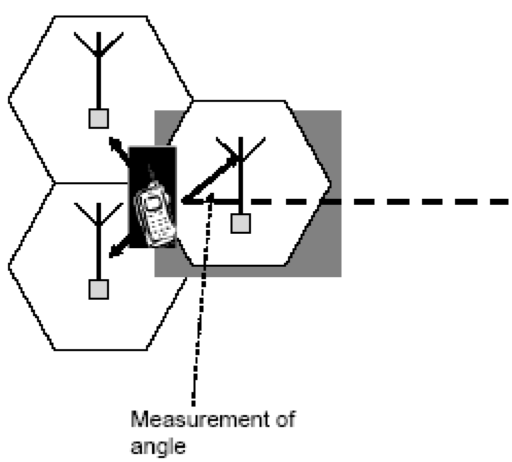

Figure 10: AoA

1.5 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 bandpass the frequencies with maximum Signal-to-Noise Ratio (SNR) can further reduce the probability if timing error. Initially Knapp et al. proposed a Maximum Likelihood (ML) receiver, and more recently Gardner et al. and Izzo et al. 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 cites accuracy with the FCC requirements, which is less than 125m for 67% of the time.

1.6 Time Difference of Arrival (TDOA)

TDOA measures the relative arrival time at the MS of signals transmitted from three Base Station (BS), at the same time (or known offset). It is one of the leading candidates for location systems. The relative arrival times at three BSs of one MS can be measured (see below). Again, the maximum timing resolution depends on the sampling rate at the receiver. Precise synchronisation of BS's will be required for this method.

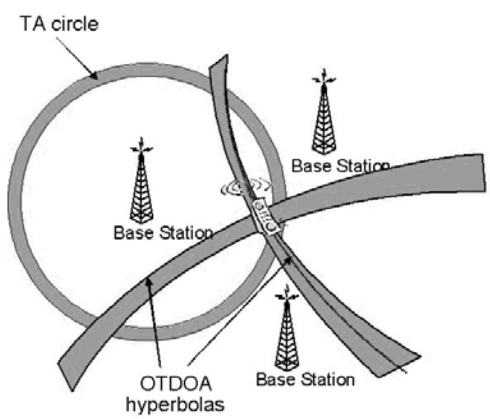

Figure 11: TDoA

The estimate can be made from the intersection of two hyperboloids each defined by the equation:

$R_{i,j} = \sqrt{(X_i - x)^2 + (Y_i - y)^2} - \sqrt{(X_j - x)^2 + (Y_j - y)^2}$ 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 Equations in x and y have been proposed and compared by Chan et al.. Preliminary field trials in Helsinki on a GSM900 network gave location estimate accuracy of less than 200m for 67% of the time.

1.7 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. 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. 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). LCS is location service signaling which is the means by which the handset responds to network interrogation about its whereabouts 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, that are placed in fixed positions and have the capability to perform E-OTD measurements and return them to the SMLC. E-OTD accuracy is outlined below, 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) has some outstanding technical issues to be resolved before performance can be considered as good as E-OTD in GSM.

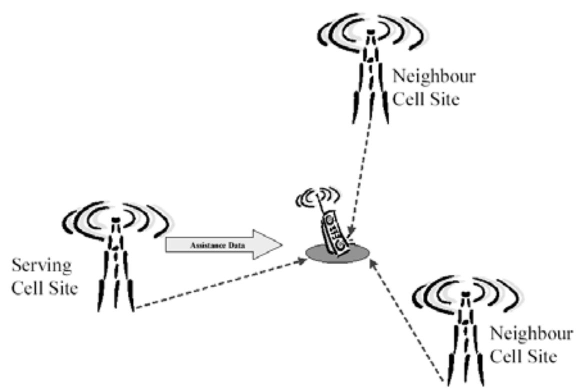

Figure 12: Enhanced-OTD

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

Figure 13: Accuracy of Enhanced-OTD

1.8 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. 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 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. For instance, A-GPS can provide position estimates:

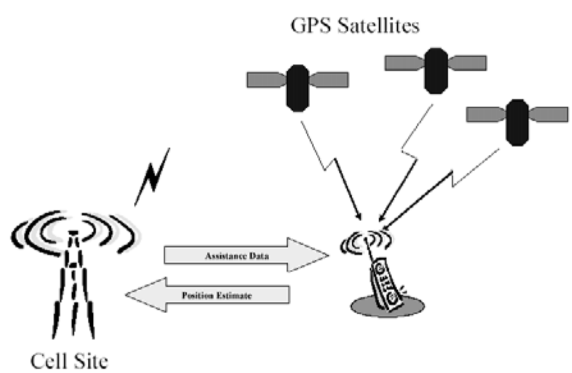

Figure 14: A-GPS

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

Figure 15: Accuracy of A-GPS

- Under foliage.
- In-car.

- Most, if not all, outside environments.
- Many indoor environments.

A-GPS also provides good vertical accuracy and velocity estimates. GPS assistance data signalling to the MS may take 10s, but once received by the handset, assistance data ican be 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.

It currently seems likely that European GSM networks will offer positioning based on CGI/Cell-ID, CGI/Cell-ID +TA and then UTDOA.

UTDOA is a TDOA based scheme where the uplink energy transmitted by an MS is used to make a location determination. If the MS was in the dedicated mode, carrying subscriber traffic prior to the beginning of the location process, the energyassociated with this subscriber traffic can be used to locate the MS. If the MS was placed in the dedicated mode by the MSC specifically for location determination purposes, either the SDCCH or TCH can be used for U-TDOA location purposes