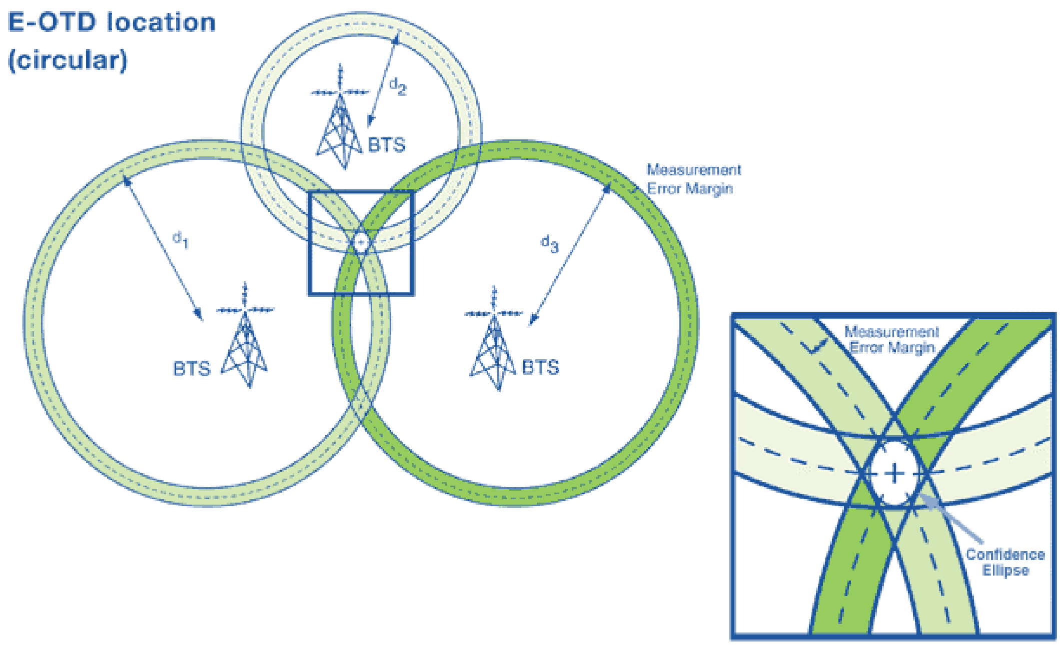
Location services and accuracy

An analysis for field work applications



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1. Introduction

Location services provide location-specific information to users and assist them in case of need by exploiting the ability to locate in real time users and resource and combine this information on spatial information about their surrounding. These services are based on wireless technology and are be deployed for mobile phones and PDA's.
This document focuses on the step of evaluating and determining the geographic resolution and accuracy targets for the location-based information services. First the Location based concept and market are presented, together with the efforts that drive this concept to reality.
Then the document provides descriptions of various location-based applications, which may be considered as possible drivers for the deployment of position enabling mechanisms. The described services may be considered for independent deployment, or collective deployment in various service bundles. What location-based applications all have in common is a requirement to determine the position of a target handsets, but this determination can be carried out with various degrees of accuracy, depending on the service.
To meet the different accuracy requirements of the different location-based applications there are different technological possibilities. The document reviews the different possible location determination technologies. It then relates technological possibilities of locating the handsets with the accuracy requirements demanded by the services.

1.1 LBS background

All mobile applications are based on the ability to provide remote access to data sources from mobile devices (mobile Internet). What distinguishes Location-based Services (LBS) from a pure extensibility service (such as email access from a handset) is how critical location information is to the added value to the user. Services that add value by using the location component are called location-based services. LBS are information services based on the position of the user in space, which is provided by a telecom operator, by a GPS enabled handset, or a combination of both. Location based services include emergency services, car and personal navigation, point-of-interest search, track and trace, field service management, location-based entertainment, and many others. Carriers can use location information to develop new revenue sources and to differentiate their portfolio. Organization can take advantage of location information to increase efficiency, improve service level and customer satisfaction, and reduce operations costs. Location-based services are projected to rise more than 100-fold in the next four years, making it one of the fasted growing sectors in the mobile field. [4]
Location Services may be considered as a family of services that depend on knowledge of the geographic location of mobile stations. Location information may be requested by applications, which may be referred to as "clients". Applications may reside external to the network, within a network, or may reside in a mobile handset [2].

1.2 LBS market

There is a general consensus amongst analysts that LBS will be amongst the most used mobile services, and that they will generate a significant part of mobile data revenues. The ARC group[1], for instance, predicts that location-based services will be the most used mobile service by 2005 (see Figure 1).

2000	2003	2005
Personal information managers	Personal information managers	**Location-based services**
Entertainment	Entertainment	Personal information managers
Financial services	**Location-based services**	Entertainment
Browsing	Financial services	Financial services
Location-based services	Browsing	Browsing
Shopping/m-commerce	Shopping/m-commerce	Shopping/m-commerce
Intranet	Intranet	Intranet

Figure 1 Most used services (Source: The ARC Group).

Market research firm IDC[2] estimates that almost 50% of European subscribers will use LBS by 2005, underlying a potential user basis close to 150 million users. Even in the most conservative of the estimates, LBS will become a larger market than traditional GIS in the medium term. The Strategies Group[3] predicts that LBS will surpass the GIS market size in the period 2002-2004. In general, LBS market estimates fall in the range US$ 9– US$ 20 Billion for Europe in 2005.

1.3 The drivers of LBS

One of the main drivers of LBS development is the US regulation for wireless emergency services (e911). The FCC (Federal Communication Commission) rules require carriers to provide location information automatically to 911 call centres on calls from mobile phones[4]. The requirements are different for handset based and network based solutions. In the first case, the implementation must ensure accuracy of 50 m for 67 % of calls (150 m for 95 % of calls), while for network-based solutions the accuracy is 100 m for 67 % of calls (300 Meters for 95 % of calls). The Commission recognises the different capabilities of handset based Location Determination Technologies (LDT), and network based LDT. In the first case, devices will need to be equipped with, for instance, GPS receivers that ensure higher accuracy. However, GPS enabled handsets are still at the developments stage and will not be available in volumes in the short term. [4]
Network based LDT does not require handset modifications and can operate with legacy devices, although the accuracy is lower. The Commission's mandate will boost the deployment of LDT, especially network based LDT, far faster than the market would achieve without regulatory intervention. Since operators are major players in the implementation of e911, a net result of the FCC mandate will be the implementation and availability of LDT within the operators' infrastructure, thus paving the road for all commercial location-based services.
Another major driver of LBS is the inherent relationship between mobility and position. The sheer number of mobile users especially in Europe and Asia has translated this relation into a market opportunity. Although essentially all GIS applications are location-based applications, the availability of data communication protocols in all handsets makes it attractive to develop information services for a wide range of devices and users. The introduction of the wireless application protocol (WAP[5]) represented a first step in wireless data communication. In spite of the known limitations of the protocol, and of its poor market penetration, essentially all new handsets are data capable and within 2001 the largest share of handsets in use will be data enabled (see Figure 2).

[1] www.the-arc-group.com
[2] www.idc.com
[3] www.strategisgroup.com
[4] www.fcc.gov/911/enhanced/
[5] www.wapforum.org

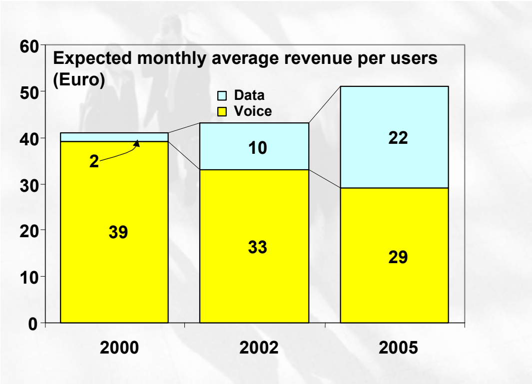

Figure 2 Operators expect revenues from voice to decrease over time, and revenues from data services to increase. Forrester Research projects revenues from data services to about 45% of total operators revenues in 2005. LBS will be a substantial part of these revenues.

The third major driver for the development of LBS is the need of operators to differentiate their offerings and to generate revenues from channels other than voice. In the recent past, operators have witnessed a constant decrease of margins in fixed networks, due to competition and network capacity increase (see Figure 2). A similar pattern is expected for mobile communications. This implies that operators have to exploit other revenues channels, and location represents an asset in the hands of operators that can be translated into revenues [4].

2 LBS services

LBS usually refers to the combination of one or more of the following types of services:

1. **Information services**, which provide information about objects close to the user (in terms of distance, travel time or other). Examples are: locate my position, locate an address, locate an ATM, check traffic conditions on the highway on my route, find a parking lot nearby, take me to the theatre, find the cables and maintenance schedule for this section of the network, make a reservation at a nearby restaurant, etc.
2. **Interaction services**, which are based on the interaction between mobile users/objects and do not require a "mobile internet" component or a content sources. Examples are: Where is my nearest colleague? Where are my children? Where is the shipment now? Where is my car? Where is the closest emergency car to an accident?
3. **Mobility services** that support smart mobility and revolve around navigation capabilities. Examples are: How do I get from A to B? What is the quickest reroute to avoid this traffic jam? When to leave to catch the next train/tram?

LBS are both horizontal (services suitable for consumers and business, such as route information) and vertical services (specific for type of business, such a field service engineer management). These service classes are general, and apply to the consumer and professional market.

2.1 Public Safety Services

2.1.1 Emergency Services

In the US specification of emergency location services are already available. They prescribe the possibility to locate a 911 call from a fixed and mobile phone, with the request to operators to disclose this information to emergency services. The accuracy requirements are the following:

- *For network-based solutions: 100 meters for 67% of calls, 300 meters for 95 percent of calls;*
- *For handset-based solutions: 50 meters for 67% of calls, 150 meters for 95 percent of calls.*

The network should be sufficiently flexible to accommodate evolving enabling mechanisms and service requirements to provide new and improved services.

2.1.2 Emergency Alert Services

Emergency Alert Services may be enabled to notify wireless subscribers within a specific geographic location of emergency alerts. This may include such alerts as avalanche warnings, pending floods or accidents that interrupt circulation. No legal or administrative requirements currently exist for Emergency Alert Services anywhere in the world.

2.2 Tracking Services

2.2.1 Fleet and Asset Management Services

Fleet and Asset Management services allow the tracking of location and status of specific service group users. Examples may include a supervisor of a delivery service who needs to know the location and status of employees, parents who need to know where their children are, or a natural park administrator that wants to know where are the visitors to his park. The service may be invoked by the managing entity, or the entity being managed, depending on the service being provided.

Fleet Management may enable an enterprise or a public organization to track the location of vehicles (cars, trucks, etc.) and use location information to optimise services.

Asset management services, for example, may range from asset visualization (general reporting of position) to stolen vehicle location and geofencing (reporting of location when an asset leaves or enters a defined zone). The range of attributes for these services is wide.

For Fleet and Asset Management services, a distinction may be made between the manager of the fleet/assets in charge of tracking, and the entities being tracked (service group users, etc). The tracking service may make use of handsets with possible specialized functions (Web browsers, etc) to allow for tracking and specific methods for communicating with the managing entity. A managing entity would be able to access one or several managed entities' location and status information through a specified communication interface (Internet, Interactive Voice Response, Data service, etc). The managing entity would be able to access both real-time and recent location and status results of managed entities.

The network shall provide the capability to provide the location and timestamp. In cases where the service group user's mobile station is not registered (i.e. inactive, out of coverage) the last known location information and timestamp may optionally be provided.

2.2.2 Traffic Monitoring

Mobiles in automobiles on freeways anonymously sampled to determine average velocity of vehicles. Congestion, average flow rates, vehicle occupancy and related traffic information can be gathered from a variety of sources including roadside telematic sensors, roadside assistance organizations and ad-hoc reports from individual drivers. In addition average link speeds can be computed through anonymous random sampling of MS locations.
Depending on the capabilities of the location method, traffic behaviour can only be determined if a vehicle location is sampled at least twice within a finite predetermined period.
Traffic monitoring technology is at the basis of innovative road taxes schemes such as the proposed road-pricing scheme currently under evaluation in the Netherlands[6]. Location technology and on-board wireless connections are being considered as a means to exercise road taxes based on type of road, time of travel etc.

2.3 Enhanced Call Routing

Enhanced Call Routing (ECR) allows subscriber or user calls to be routed to the closest service client based on the location of the originating and terminating calls of the user. In addition to routing the call based on location, ECR should be capable of delivering the location information to the associated service client. For example, this capability may be needed for services such as Emergency Roadside Service. This could be used for the purpose of dispatching service agents for ECR service clients that can make use of this information.

2.4 Location Based Information Services

Location-Based Information services allow subscribers to access information for which the information is filtered and tailored based on the location of the requesting user. Subscribers may initiate Service requests on demand, or automatically when triggering conditions are met.

2.4.1 Navigation

The purpose of the navigation application is to guide the handset user to his/her destination. The destination can be input to the terminal, which gives guidance how to reach the destination. The guidance information can be e.g. plain text, symbols with text information (e.g. turn + distance) or symbols on the map display. The instructions may also be given verbally to the users by using a voice call. This can be accomplished through carrying a GSM mobile phone that has location technology capabilities down to a few meters. Less granularity impedes the applicability of this functionality.

[6] www.roadpricing.nl

2.4.2 City guides

City Guides would enable the delivery of location specific information to city visitors or residents. Such information might consist of combinations of various services including historical site location, providing navigation directions between sites, facilitate finding the nearest restaurant, bank, airport, bus terminal, restroom facility, etc.

2.4.3 Cell Broadcast

The main characteristic of this service category is that the network automatically broadcasts information to terminals in a certain geographical area. The information may be broadcast to all terminals in a given area, or only to members of specific group (such as members of a specific organization). The user may disable the functionality totally from the terminal or select only the information categories that the user is interested in.
An example of such a service may be localized advertising. For example, merchants could broadcast advertisements to passers-by based on location / demographic / psychographics information (for example "today only, 30% off on blue jeans"). Similar services would include weather and traffic alerts.

2.4.4 Mobile Yellow Pages

Mobile Yellow Pages services provide the user with the location of the nearest point of interest. The result of the query may be a list of service points fulfilling the criteria (e.g. Banks with ATM within walking distance). The information can be provided to the users in text format (e.g. bank name, address and telephone number) or in graphical format (map showing the location of the user and the bank).

2.5 Service requirements and location accuracy

The accuracy that can be provided with various positioning technologies depends on a number of factors, many of which are dynamic in nature. As such the accuracy that will be realistically achievable in an operational system will vary due to such factors as the dynamically varying radio environments (considering signal attenuation and multipath propagation), network topography in terms of base station density and geography, and positioning equipment available.

The accuracy for LBS can be expressed in terms of a range of values that reflect the general accuracy level needed for the application. Different services require different levels of positioning accuracy. The range may vary from tens of meters (navigation services) to perhaps kilometres (fleet management). The majority of attractive value added location services are enabled when location accuracies of between 25m and 200m can be provided.

Table 1 illustrates a set of LBS services and the requirements in terms of location accuracy (horizontal and vertical) as well as some other basic parameters required by the service.

Table 1 Examples of LBS services and their requirements (including horizontal and vertical accuracy) adapted from [2].

Service Category	Horizontal Accuracy	Vertical Accuracy	Response Time	Periodic Location Reporting	Notes
Public Safety Services					
Emergency Services	Network based: 100m (67%) 300m (95%) Handset based: 50m (67%) 150m (95%)	n/a now 5-15m futures?	< 5 sec.	Required Period TBD suggest 1-10 minutes	Horizontal accuracy is required by the US 911 emergency regulation. A similar regulation is in evaluation in Europe.
Emergency Alert Services	125 m (10 m future?)	n/a now 5-15m future?	< 5 sec.	Required Period TBD suggest 1-10 minutes	
Tracking Services					
Fleet Mgment.	125m	n/a	5 sec.; can be much higher	Required (1-10 minutes)	
Asset Mgment	10m-125m	n/a 5-15m future?	between 5 sec. (critical tracking) to no requirements at all	Required (1-10 minutes)	May require specific terminals, such as SIM boxes
Person Tracking	10m-125m	n/a 5-15m future?	5 sec to several minutes	Required (1-10 minutes)	May require specific terminals, such as SIM boxes
Pet Tracking	10m-125m	n/a 5-15m future?	5 sec to several minutes	Required (1-10 minutes)	Requires specific terminals, such as SIM boxes
Traffic monitoring					
Traffic Congestion Reporting	10-40m Hi- res. req'd for proximity to lanes and road network	May be req'd for over-passes	5 sec.	Required (1-2 minutes)	High bandwidth req on network due to concentration of transmission in proximity of congestion
Enhanced Information provision					
Routing to nearest POI	10m-125m	n/a	5 sec.	Not required	
Roadside Assistance	10m-125m	n/a	5 sec.	Not required	
Navigation	10m-20m	n/a	5 sec or less for dynamic navigation assistance	Required: every few seconds	Route planning requirements are much inferior than navigation
City Sightseeing	10m- 500m	n/a	< 30 sec.	Not required	
Environmental monitoring	10m- 500m	n/a	< 30 sec.	Not required	
Field work support	10m- 500m	n/a	< 30 sec.	Not required	
Localized Advertising	125m	n/a	Not sensitive	Not required	
Mobile Yellow Pages	125m	n/a	< 30 sec.	Not required	

3 Location determination technology

GPS is the standards location determination technology (LDT) at present. A new range of LDT's are now being introduced that exploit the network of radio stations of the operators' infrastructure to locate a handset with increasing accuracy. Most network based LDT's are enhancements of the existing location capabilities of wireless networks. In fact, any wireless communication is based on the ability to locate and track the position of mobile phones so that communication can be established between handsets that change position. At present LDT's fall in two main classes: terminal based and network based [4].
Terminal based solutions include traditional GPS and E-OTD (Enhanced Observed Time Difference). While GPS relies on the signals of a network of satellites, E-OTD uses data received from the base stations in an operators' network to estimate the position of the handset. E-OTD requires new handset capabilities and handset software. The position calculations can be done either in the handset or in the network. The accuracy is in the range of few meters up to 50 meters, and is far less dependent from the operational environment (indoor, urban canyons, sky obscuration) than GPS. The main drawback of terminal based solutions is that they require new handsets.
Network based solutions include Cell-ID and enhanced Cell-ID (such as TOA – uplink Time Of Arrival). Cell ID uses the coverage area of a base station to locate the user. This information is already built in the network and works with existing terminals. Accuracy depends on the cell density, which can be low in rural areas.
Cell-ID can achieve reasonable performance only in urban areas, with accuracy in the range of 100-500 meters. In rural areas the accuracy can be as low as few kilometres. Enhanced Cell-ID, such as TOA, increases the Cell-ID accuracy by triangulating the position detected by at least three cells. TOA and E-TOA work in a similar way, but the key difference is that TOA supports legacy terminals. On the other hand, TOA requires an upgrade of virtually every base station, which is a significant investment for operators. This will not be the case for UMTS networks, which will include accurate location capabilities as a standard in the network. Thanks to the higher density of base stations compared to GSM networks, UMTS will achieve accuracy levels in the range of (several) meters.
In the short to medium term (2002-2003), and before UMTS is deployed, Cell-ID and enhanced versions of it will be the main location determination technology available. Operators will make a slow transition between these technologies and more accurate versions, partly because of the investments necessary and partly because of the need to stabilize LDT technology and introduce interoperability standards and position roaming protocols [4].
In order to make a technological choice there are some considerations to the operator, like the signalling load, handset complexity, capacity, subscriber tie-in to operator, privacy risks among others. But, to the subscriber, all methods can be made to look the same.

3.1 Network based methods

3.1.1 Cell ID based

Cell ID stands for the cell that the handset is connected to. It's the location 'measurement' provided by the network. It works since the operator's know to which Base Station the phone is connected to, and they know the physical location of their cell sites (Figure 3). Cell ID positioning has been possible since cellular networks were first deployed and any handset that is connected to the network can be positioned in this way. Another advantage of this technology is that Cell ID can support all legacy handsets and roamers. However, the accuracy is dependent on cell density. The larger the number of the cells and the smaller the cells more accurate will be the positioning. As a first approximation, in most European countries, where cell coverage is almost complete, 50% of population (and thus of mobile users) can be located with accuracy higher than 700m [8].

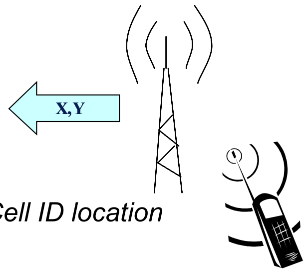

Figure 3 Concept of Cell ID location

3.1.1.1 Timing Advanced

Timing Advance (TA) is a GSM specific parameter. It is a measure of the round trip time between the Base Transceiver Station (BTS) and the Mobile Station (MS). It is used to ensure the bursts from the MS arrive at the BTS at the correct time (see Figure 4).

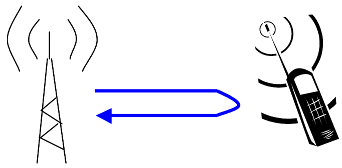

Figure 4 Concept of the Timing advanced Technology.

The resolution of TA is 1 GSM bit, equivalent to 3.69µs. Since it is a round trip measure, the resolution for one leg is 1/2 bit = 1.85µs or 550 metres. Further enhancements can be achieved with directional cells that cover a known sector of the full cell. Finally, additional information, such as the fact that a user is currently travelling on a highway, can be used to complement cell location information and further increase accuracy (Figure 5) [8].
Actual Cell coverage maps can improve Cell ID positioning. The centre of coverage area will frequently be more accurate that cell site position. In most cases TA does not bring significant improvements in positioning accuracy over Cell ID. The real improvement from Timing Advance is to spot when MS is no longer using the 'nearest' cell (e.g. connected to umbrella cell, or neighbour cell). The migration to UMTS will be smooth, once in UMTS, the cells will be smaller and there is an analogy in the TA (also in UMTS is Round Trip Time). The round trip time is reported in 1/16 chip resolution (~5m). However, Timing Advance and Round Trip Time will suffer from variable receiver chain delays in the MS or user equipment.

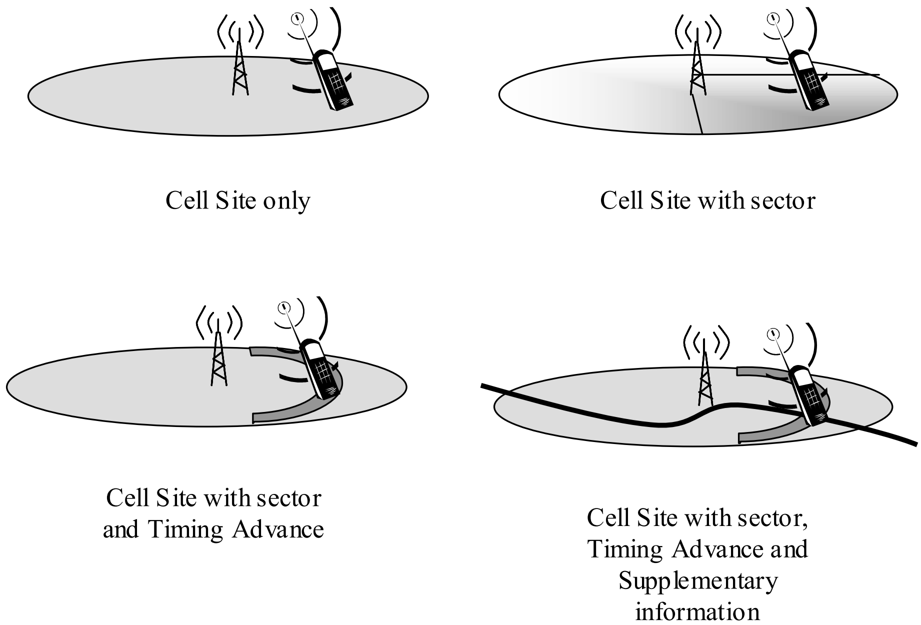

Figure 5 graphical comparisons between the Cell ID technology possibilities.

3.1.2 Triangulation methods

3.1.2.1.1 Pathloss methods
Enhanced - Cell Global Identity (E-CGI)

In all cellular systems the handset will make measurements on the air interface in order to facilitate hand-over decisions. In GSM these 'measurement reports' contain estimated power level measurements from the serving cell and the cells on the neighbour list. The power level detected at the handset (RxLev) can be used to estimate the BTS - handset distance. The most commonly used method is the pathloss model based on the Hata-Okumura model [7]. This relates distance to pathloss, and if the other parameters are known then a distance can be estimated from the measured power.

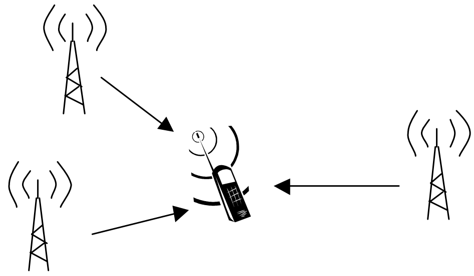

Figure 6 Positioning can be performed by comparison or measured power with a prediction tool database or triangulation using pathloss models.

The 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 measurement reports to give improvements in accuracy [8].

3.1.2.1.2 Uplink Time Of Arrival

Uplink Time Of Arrival (TOA) is a timing based method in GSM. The signals from the handset are detected at geographically dispersed receivers (Figure 7). TOA Live Monitoring Units are usually co-located at BTS sites. It works through the measurement of the time of arrival of the received signals, which is related to a propagation delay and the position of the handset is estimated by triangulation.

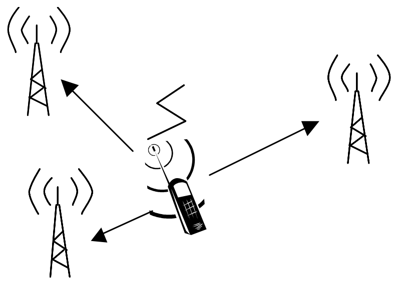

Figure 7 Time of arrival measures the received signals in the Station, originated on the handset and determines the location by triangulation.

TOA supports legacy handsets and it gave theoretical performance compliant with original E911 requirements in the US: "…carriers are required to have the capability to identify the latitude and longitude of the mobile units making 911 calls within a radius of no more than 125 meters, using Root Mean Square calculations (which roughly equate to success rates of approximately 67 percent)…"[7]
The method is based on the fact that a handset is 'forced' by the network to make a handover request and access bursts from handset are then measured by TOA Location. Regarding the Measurement Units TOA (LMUs), they are typically deployed at BTS sites.

[7] www.fcc.gov/911/enhanced/

$$TOA = T_L + T_P + T_T + T_E \quad \begin{cases} T_L & \text{LMU reference time} \\ T_P & \text{Propagation Delay from handset to LMU} \\ T_T & \text{Transmission time from handset} \\ T_E & \text{Errors in measurement (noise, interference, multipath receiver chain delays etc…)} \end{cases}$$

Although TOA technology supports legacy handsets, TOA requires significant network improvements and there is also a built in capacity limit for the TOA system (it will work fine for e.g. emergency requirements but it would be problematic for commercial services). Another disadvantage is that the performance is dependent on traffic in network, and decays with saturated networks. Furthermore, uplink TOA is always Handset Assisted and there is no standardised analogy in UMTS [8].

3.2 Handset based

3.2.1 Enhanced Observed Time Difference (E-OTD)

Enhanced Observed Time Difference (E-OTD) is a time based method, whereby the handset makes time of arrival measurements from signals transmitted by three or more BTS's (see Figure 8). Propagation delay measured is related to the distance from BTS to the handset.

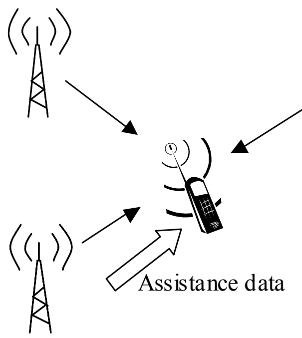

Figure 8 E-OTD concept

E-OTD requires extra functionality in the handset. Signals from the broadcast control channel, part of the GSM standard transmission, are detected at the handset and also assistance data is sent to the handset for the E-OTD. This includes, for instance, reference base stations and their coordinates. Some advantages and disadvantages of this technology are showed in Table 2.

TOA measurements are made at the handset through the following operations:
$TOA = T_H + T_P + T_T + T_E$, where T_H is the handset clock reference, T_P is the Propagation Delay from BTS to Handset, T_T is Transmission time of signal from BTS, and T_E is the Errors in measurement (noise, interfence, etc…).

Results from two BTS's are combined to give a TDOA (Time Difference of Arrival) equation: $TDOA = TOA^1 - TOA^2 = (T_H^1 - T_H^2) + (T_P^1 - T_P^2) + (T_T^1 - T_T^2) + (T_E^1 - T_E^2)$. If base stations are synchronised, then $(T_T^1 - T_T^2)$ will cancel out. If the network is not synchronised, then $(T_T^1 - T_T^2)$ must be measured - therefore, require E-OTD LMUs (Location Measurement Units), which are modified mobiles that perform E-OTD time measurements at a fixed and known position. By measuring two or more TDOAs, isodistance curves from pairs of BTS's can be plotted, resulting in an estimate of the position where the handset is located [8].

Table 2 Advantages and disadvantages of the Enhanced- observed time difference technology.

E-OTD	
Advantages	Disadvantages
Minor modification to handset functionality	High impact on Network Infrastructure - cost, deployment
Good positioning performance in high BTS density areas	Planning, maintenance.
Good indoor coverage	Penetration starts at 0%
Compared to TOA, E-OTD LMUs are much simpler and can be deployed at 1 per 3-5 BTS's.	Uncertain performance in UMTS
	Poor performance in low density BTS areas

3.2.2 Conventional Global Positioning System

Conventional GPS is a navigation system that utilises transmissions from a constellation of US government satellites. The system has been around since 1978 and is widely used in many non-military applications. Like TOA and E-OTD, GPS is a time based positioning method. GPS technology works based on GPS satellites that continuously transmit a bit stream, containing satellite id, GPS time and the almanac data (tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite transmits almanac data showing the orbital information for that satellite and for every other satellite in the system). The receiver searches for satellites, then decodes the information transmitted, which enables it to perform the positioning.
When a GPS receiver is turned on it has a 3D search space to traverse for satellite acquisition and demodulation. In order to decode signals from satellites, there must be little or no blockage (which can become a problem in Urban areas or cloudy skies). Typical of GPS is the need to perform a series of measurements before being able to determine the position. The time required for these measurements changes significantly between cold start (first time a position is required) and hot start (for sequential measurements. Typical start-up times are:

- Cold Start - 12 minutes (2 minutes if Almanac assumed);
- Warm Start - ~1 minute, position, time, almanac;
- Hot Start - ~15 seconds; last fix <1 minute old.

Three Satellites gives a 2D position estimate, and if four or more satellites are reachable a 3D position can be estimated.
Conventional GPS is accurate, within meters, but has no indoor coverage. It has also slow time to fix unless it is permanently tracking satellites, which in turn may require significant power consumption which can be a serious limitation for handsets [8].

3.2.3 Assisted GPS

To solve the inherent restrictions with conventional GPS, Assisted GPS (AGPS) was proposed. AGPS is based upon providing GPS satellite information to the handset, via the cellular network (see Figure 9). A-GPS gives improvements in:

1. the time to first fix (cold start)
2. the battery life
3. sensitivity (thus allowing partial indoor coverage)
4. cost..

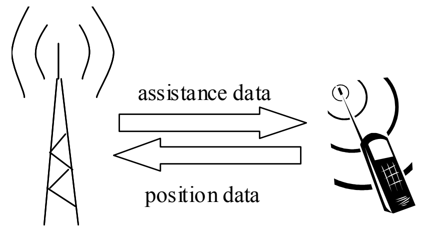

Figure 9 Concept of the AGPS functionality.

AGPS sensitivity is much improved compared to GPS, so this technology is still available even with foliage blocking or body blocking, also in car, most outside environments and many indoor environments, what is big improvement compared to conventional GPS. A-GPS is enabled by Radio Access, so it is Network independent, which allows consistent accuracy. Some advantages and disadvantages are showed in

Table 3 [8].

Table 3 Pros and Cons from the A-GPS technology solution.

A-GPS	
Advantages	Disadvantages
Low impact on Network Infrastructure	Major modification to handset functionality
Excellent outdoor performance	Penetration starts at 0%
Good evolution path to UMTS	Improved yet variable indoor coverage

The Global Positioning System (GPS) embedded in a handset is the most accurate method for locating users. However, stand-alone GPS handset solutions provide inadequate response times and do not work when satellites are obscured, for example, inside buildings or in tunnels. AGPS shares the performances of GPS, but requires network assistance, which comes at a costs for the operators.

3.2.4 Other features

Given that the location estimate is the best possible within the bounds of required response time, location can be better described with a statistical distribution rather than a single point. It may be possible to provide information on the confidence that can be associated with a location estimate. This may be used by location services to decide if a position update should be requested, for example, if the reported accuracy falls below a threshold determined by the network operator for a specific service.
It may also be possible to determine velocity (speed and heading) information from a single location request. (i.e. the response to a single request may provide the results of multiple positioning). When delivered with a location estimate, the confidence region parameters, speed and heading may allow an application to improve the service delivered to the MS user. Some examples are given below [2]:

(a) Confidence Region: Simple measure of uncertainty that specifies the size and orientation of the ellipse in which an MS is likely to lie with a predetermined confidence (e.g. 67%). The size of the confidence region may be used by the network operator or the application to request an updated location estimate.

(b) Speed: enables congestion monitoring, and average travel time estimates between locations.

(c) Heading: the location estimate of a vehicle may be improved to identify the appropriate side of the highway. This may enable the provision of traffic information that relates only to the user's direction of travel.

4 Geo-accuracy and location services

Accuracy is the difference between actual location and estimated location. Different accuracy levels determine the suitability of the information for a give service. Table 4 illustrates the relationship between services and accuracy levels.

Table 4 Examples of location services based on decreasing accuracy requirement (adapted form [2])

· **Location-independent**	**Stock prices, sports reports**
· Regional (up to 200km)	Weather reports, localized weather warnings, traffic information (pre-trip)
· District (up to 20km)	Local news, traffic reports
· Up to 1 km	Vehicle asset management, targeted congestion avoidance advice
· 500m to 1km	Rural and suburban emergency services, manpower planning, information services (where are?)
· 100m (67%) · 300m (95%)	U.S. FCC mandate (99-245) for wireless emergency calls using network based positioning methods
· 75m-125m	Urban SOS, localized advertising, home zone pricing, network maintenance, network demand monitoring, asset tracking, information services (where is the nearest?)
· 50m (67%) · 150m (95%)	U.S. FCC mandate (99-245) for wireless emergency calls using handset based positioning methods, field work support, environmental monitoring
· 10m-50m	Asset Location, route guidance, resource location, fieldwork support, field measurement.

The accuracy that can be provided with various positioning technologies depends on a number of factors, many of which are dynamic in nature. As such the accuracy that will be realistically achievable in an operational system will vary due to such factors as:

- the dynamically varying radio environments (e.g. signal attenuation and multipath propagation);
- network topography in terms of base station density and geography
- positioning equipment available;
- weather conditions and morphology of the surrounding environment.

Accuracy may be independently considered with respect to horizontal and vertical positioning estimates. In general, vertical accuracy is a parameter only for GPS based solutions. For this reason, most LBS services are not based on this assumption.

4.1 Issues: prices and availability

To make sense of the large investments linked to precise location, operators need to assess the relationship between quality of service, that increases with accuracy, and revenues potential of the better service. This has to be balanced against the costs of implementing accurate LDT, both for network operators and for users.

In the recent past two positions seemed to emerge. Existing operators are still cautions about the revenue potential of LBS and tend to focus as much as possible on the simplest possible LBS technology. The rationale is that if a service can be deployed with inaccurate and inexpensive location technology, then it is better to start in this way to gain experience and user feedback and then decide to upgrade to higher quality of service. This policy tends to revolve around Cell ID which is inexpensive and suitable for the legacy pool of handsets. Although it cuts out the most innovative services, it does allow operators to start low-scale without massive investments. This approach is especially suitable for large operators, which have a dominant position and a large installed basis.

At the other extreme there are the new entrants, such as young 2G or 2.5G operators and new operators that have acquired 3G licences. For them the choices are more complicated, since they need to grow and gain users by differentiating on data services rather than engaging on price battles with larger ones. For them, quality of service and differentiation are essential. Those operators that have identified LBS as a differentiator tend to privilege the higher end of LDT capabilities, such as GPS or assisted GPS solutions. In addition, UMTS networks are going to be built from scratch, with the launch of services that will take place with limited coverage. Since network completion will require several years, users will be offered the opportunity of roaming to another complementary UMTS network or to an older

2.5G network to ensure full coverage in any case. In this process, location roaming (see below) will represent a difficult technical challenge. For this reason handsets equipped with GPS receivers (and the versions with assistance) are receiving a growing attention, since they will be able locate the handset without the need of the network [5]. The impacts on the infrastructure and handsets are discriminated for the different LDT's in Table 5.

Table 5 Impacts of different location determination technologies on infrastructures and handsets (Adapted [9]).

LDT	Coverage	Impact on infr.	Impact on handset	Network costs	Handset costs	Total costs
Cell ID	Network coverage	Low	No impact	Low	None	**Low**
E-CGI	Network coverage	Medium	Low	Medium	Low	**Medium**
E-OTD	Network coverage; good urban/indoor; poor rural	High	Medium	High	Medium	**High**
GPS	Poor urban and indoor; good rural	Low	High	None	High	**Medium**
Assisted GPS	Good rural, urban and indoor	High	High	High	High	**High**

In this environment, location information will only gradually become attractive to third parties over the next several years (see Figure 11).

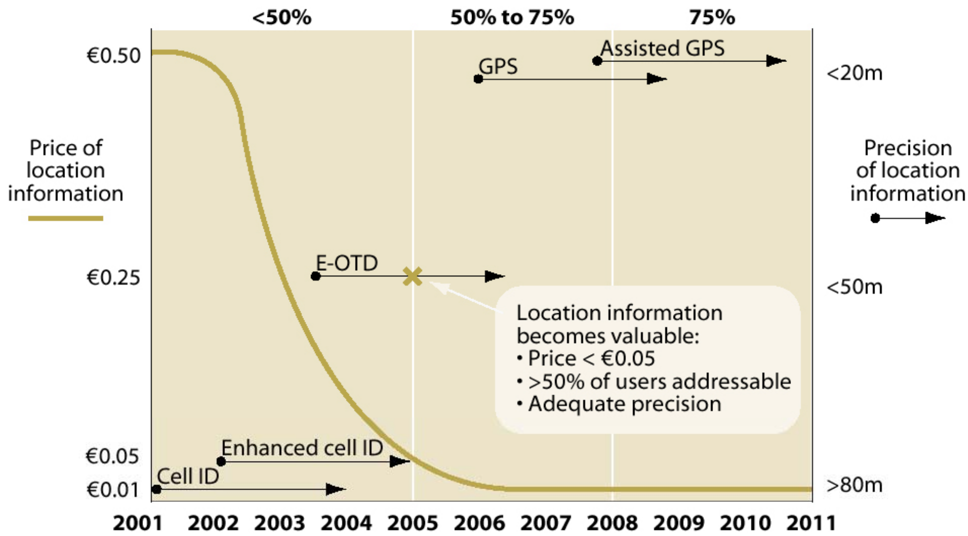

Figure 10 Availability, Precision and Price (from [6]).

Valuable services like store locators with turn-by-turn directions will need more resolution then Cell-ID-based solutions can provide. But most operators won't offer E-OTD technology, which will deliver better precision, until UMTS goes live starting in 2003. Operators will start offering location information at exorbitant prices, aiming to defend their own services and establish a premium for third parties. With only a few users, premium pricing makes sense for operators looking to maximize revenue. But as services proliferate and more and more users become addressable, operators will lower costs to drive volume. this will lead prices to drop from today's € 0.50 to an acceptable € 0.05 by 2005 and even lower by 2001 - €0.01 or nothing at all depending on the accuracy and type of service [6].

5 LBS for field work

5.1 Accuracy and field work

Many filed work services can be deployed in LBS environment, such as, “finding places in the vicinity” or “accessing background information on specific locations”. But different services have different accuracy requirements, so they can be enabled through different location determination technologies. Table 6 shows examples of fieldwork applications.

Table 6 Examples of LBS services and their requirements applied to fieldwork.

Service Category	Horizontal Accuracy	Vertical Accuracy	Response Time	Periodic Location Reporting	Notes about the service
File Safety Services					
Emergency Services	Network based: 100m (67%) 300m (95%) Handset based: 50m (67%) 150m (95%)	n/a now 5-15m future?	< 5 sec.	Required Period TBD suggest 1-10 minutes	A typical service from this category is the “Help” button, where a SOS alert with the location is sent to the authorities.
Push Emergency Services	125 m	n/a now 5-15m future?	< 5 sec.	Required Period TBD suggest 1-10 minutes	From the area managers to the users in the area, to warn them about dangerous situations (e.g. severe weather conditions)
Example of tracking Services					
People position – users of area position.	125m-Cell ID	n/a	5 sec.; can be much higher	Required (1-10 minutes)	
Wild Animals Tracking	10m-125m	n/a 5-15m future?	5 sec to several minutes	Required (1-10 minutes)	May require specific terminals, such as SIM boxes
Example of enhanced Information provision					
Routing to nearest reference location	10m-125m	N/a	5 sec.	Not required	(e.g. from current position to measurement station)
Navigation	10m-20m	n/a	5 sec or less for dynamic navigation assistance	Required: every few seconds	Route planning requirements are much inferior than navigation
Information filter	125m-(Cell ID)	n/a	< 30 sec.	Not required	When information is asked to the service, the response should be filtered through the location.

6 Conclusions

Location accuracy, in terms of the ability to precisely locate a user/handset/terminal, determines the range and variety of services that can be deployed. With low accuracy, the choice of suitable services is limited (e.g. weather forecasts or local news) and the ability to generate revenues is correspondingly limited. As accuracy increases, the range of possible services widens, up to the point at which with location technologies such as assisted GPS virtually all LBS services can be implemented in a commercial way.

Accuracy has two sides. First, it determines if a service can be deployed or otherwise; second, it determines the quality of the service. The services that are strictly dependent on accuracy, that is the services that below certain accuracy make little practical and commercial sense, are rather limited. The vast majority of services can be deployed for a range of accuracy levels, with the quality of service increasing with better location capabilities.

For services that demand accuracy in the range of meters, GPS, assisted GPS or beacon networks are necessary. The lack of them would prevent the deployment of the service. For most other services, however, the service can be deployed with various degrees of accuracy, which in turn determine its quality. Services such as person location, friend finder, nearest POI, advertising, dating etc. can be deployed with rather simple LDT. The improvements in accuracy would determine a clear improvement in quality of service, but not the possibility of deploying the service.

On the contrary, emergency services, panic button, find and rescue, personal door-to-door navigation and the like require precise location determination. If the location cannot be determined with accuracies in the range of 10-100m the service itself becomes of little or no use.

GPS appears to be the best solution for the location determination in the fieldwork context.

Table 7 enables a comparison between the different technological solutions in terms of functionality, accuracy and advantages and disadvantages.

Table 7 Summary of the different technology solutions.

Technology	How it works	Accuracy	Advantages	Disadvantages
Basic Cell ID	The network tracks that base station delivers the best reception to a phone. It determines that the phone is somewhere within that coverage Cell, but not precisely where.	Depends on cell size: 150m (typical city) to 2 km (typical rural area)	• No new handsets required • Cheapest of all technologies for operators	• Poor precision
Network-enhanced cell ID	The network uses additional information from wireless signals (e.g. timing advanced) to calculate where the phone is within the cell	Up to 50% improvement over basic cell ID	• Boosted precision, especially in rural areas • No new handsets required	• Requires homogenous network infrastructure for operators to contain costs
E-OTD	Mobile signal passes from base station to phone with special chip and then to fixed location known to operator. Location is triangulated among these 3 points.	5 to 50 m	• Highest accuracy of non-GPS solutions	• High network investment – costs for the operator • Requires new handsets
GPS	Orbiting GPS satellites send positioning signal to phone equipped with GPS chip, which calculates, it's own location	1 to 10 m	• High accuracy	• Only outdoor use • New handsets required with expensive chip sets and high battery consumption
Assisted GPS	GPS location information works with enhanced cell id technology or E-OTD. This allows GPS accuracy and indoor usage and pinpoints vertical location as well	Same as GPS, but allows for similar precision within building	• High accuracy	• Requires same high network investment as E-OTD • Requires even more expensive handsets than basic GPS.

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