Effective Use of GSM for Accurate Positioning

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Cellnet/British Telecom (BT) has been active in the area of GPS/GSM location and application research for over five years. Cellnet/BT have undertaken considerable development and field trials of various GSM methods for location positioning, which have resulted in several patent registrations. Recent R&D projects undertaken by the Mobility engineering team at BT Labs. include MOSA (Mobile Social Alarm) and City Guide using GPS positioning data to deliver value-added applications and services for both the general public and business users. A critical factor to the successful development of innovative value-added services is co-operation with partners, to promote and evolve open standards for GSM location.

KEY WORDS

1. Communications. 2. Positioning. 3. Integration.

1. INTEGRATION OF GPS AND GSM. There are a variety of methods and applications for location of GSM (Global System for Mobiles) handsets, all of which either need GPS in some form or would benefit from its availability. GPS appears in GSM location systems either directly as a positioning device or as a clock providing synchronisation. Applications for GSM location have varying user requirements. The location methodologies themselves vary in their strengths and weaknesses. These considerations have led operators and manufacturers to specify solutions that combine different location methodologies for different environments and applications. Typically these involve both GPS in the network for synchronisation as well as GPS in a proportion of handsets and vehicles.

Whilst much of the momentum for GSM location systems came from US Federal Communications Commission (FCC) requirements, these are distinct from the requirements for commercial location systems because there is no absolute need to be able to locate all legacy handsets to 125 m for commercial services. The various location applications can be divided into 3 groups of services with the following accuracy requirements: coarse location of all handsets, low-cost location to $\sim$ 125 m of selected (all in US) handsets, precise location $\sim$ 10 m of niche handsets.

The technical issues associated with the integration of GPS into terminals for 10 m location include development of appropriate antennas, integration of additional chipsets into terminals, power consumption and GPS service coverage. New highly-integrated chipsets have been developed to address these issues along with state-of-the-art development of miniaturised ceramic antennas.

Technical issues associated with the integration of GPS clocks into the network include maintenance/reliability of the clocks, satellite visibility and timing of existing outdoor base-station units. These issues are addressed by the development of GPS clocks that combine precise GPS time with relative time measurement of groups of neighbouring base-stations along with aggregation of secondary clock sources to provide continuity.

2. MARKET REQUIREMENTS.

2.1. *FCC Mandate*. Much of the work in researching methods for locating GSM handsets began in 1995/1996 with the FCC's requirement in the US for wireless operator's to be able to provide mobile handset location information to the emergency service call centres (PSAPs). After an initial investigation into the feasibility of providing this information, a mandate was issued stating that all wireless technologies should support location of emergency calls to 125 m, 67 percent of the time by Oct 2001. Interpretation of the mandate is still being discussed to clarify whether all handsets need to be located in the case of an emergency call to 125 m RMS or 67 percent of located handsets have to be located to within 125 m. A major issue has been the support of existing handsets, which it was argued should not apply to second generation (GSM and CDMA) handsets because of the low numbers deployed to date. Lack of clarity on this issue, has meant the choice of technology suitable for GSM in North America has been dominated by the need to locate legacy handsets to 125 m. This has made support of locating legacy handsets in North America a fundamental requirement ahead of the installation and other aspects of the system that may be required by commercial applications.

2.2. *Commercial Services*. Research into commercial services needs has indicated that the wireless location services market will increase over the next five years to be worth $7bn/annum in revenues in the US. It has also shown that the performance requirements for the various services proposed vary depending upon the service. The accuracy requirements for the various services are normally divided into 3 tiers:

- 1–10 km for basic fleet management; area number calling,
- 125 m for location sensitive billing, direction services, capacity planning, network optimisation, roadside assistance, distress calls, stolen vehicle tracing, taxi/fleet management,
- 10 m for vehicle navigation, surveying.

Other performance issues that vary between services are: impact on network load, ability to charge for the service, ability to work in idle mode, response time, cost of delivery and capacity. Cellnet/BT view GSM location as complementary to GPS location, once standards are achieved within GSM. With the commercial support of organisations such as Nokia, Motorola and Alcatel, the technology developments and integration necessary within the GSM networks will improve the accuracy in both urban and rural areas.

Cellnet operates a number of first generation location services; these include Call Saver and 999 (112) emergency calls. In November 1997, Cellnet launched the first of a new generation of value-added services. Traffic Line provides customers with real-time motorway traffic information. The service is delimited to where the service user initiates a 1200 (Traffic Line) call by identifying the originating cell and thus providing only traffic information for the driver in the immediate area. Cellnet and BT have undertaken further location services trials, MOSA (Mobile Social Alarm) uses the combination of a standard GSM handset and GPS receiver with a SOS assistance button. The service has been piloted with a number of local authorities e.g. health visitors and social workers where employee safety and security are of utmost importance. Further work has been undertaken recently by BT and Cellnet in conjunction with the Home Office to define and develop a common standard interface in the UK, for the conveyance of mobile originated 999 (112) emergency calls with GPS or GSM location data. This will allow the BT 999 operator assistance points to forward location data (Grid Reference) to the emergency authority initially by manual methods but ultimately by electronic communications.

From the research undertaken, the commercial opportunity for the development of specific location services and revenue generation opportunities can differ greatly, depending upon the current and desired market position. For example, network operators in the UK do not currently charge customers for the 2–3 million 999 (112) calls generated on mobile phones each year. However, to support and enhance the service with location data requires additional investment, the dilemma is who should pay for this added value: the network operator, customer, Home Office or the recipient? The USA operators have indicated that a 911 call with location data attached will attract a $6 per month fee.

3. POSITIONING METHODS. Various positioning methods to meet market requirements have been studied by the GSM standards bodies. These methods, in many cases, rely on GPS as an absolute time source and/or precise frequency reference in the network, and as a positioning device in the handset or vehicle.

3.1. *Cell sector/power measurement/timing advance*. This is a coarse method (1–10 km) that meets the requirement for location of existing handsets by the network at low cost. This can be achieved with modifications to the switch only.

3.2. *Observed Time Difference* (*E-OTD*). This is a synchronisation-based method of location that enables compatible handsets to be located at low cost in idle and active mode to 125 m accuracy. It requires the handset to measure the Observed Time Difference of frames from surrounding base stations, and the network to measure the relative frame emission times from the base stations. The handset position may be calculated from these measurements and the locations of the base stations. The calculation can either be performed in the network or in the handset. The relative frame emission times of the base stations can be calculated by subtracting the absolute frame emission times from each other. The absolute frame emission times can be measured very accurately at each base station by GPS clocks time stamping and reporting the frame emissions from other base stations periodically.

Alternatively, relative timing devices at known locations (a proportion of base station sites) can be deployed to monitor surrounding base stations and make relative frame time measurements similar to handset OTD measurements. The measurements from these relative timing devices may then (theoretically) be linked with measurements made by other devices assuming that their deployment has been planned to ensure coverage of overlapping cells with direct line-of-sight.

In practice, use of a combination of absolute time and relative time is recommended. In this case, relative time devices will be deployed at macro-cells along with absolute time GPS clocks. The relative time device will measure neighbouring cells and the macro-cell relative to absolute GPS time. This then provides an absolute frame time report for each of the cells visible by the relative time device at the macro-cell. This method combines the efficiency of deployment of the relative time method with the high accuracy, robustness and simplicity of calculation achievable with the absolute time measurement approach.

A potential major benefit of the E-OTD method of location is for the system to allow handsets to self locate in idle mode. This requires the network to broadcast to the handsets the positions of the base stations and the current frame emission time differences between base stations. To make this benefit possible, it is necessary to synchronise the base station frequencies in order to reduce the rate at which the relative frame emission times change and consequently the rate at which the network is required to broadcast this information to the handset. GPS is the most practical way to provide precise frequency synchronisation to the base stations.

GPS synchronisation clocks have been specially developed to meet the need for GSM location allowing base station deployment of precise time and frequency across the network. The clocks have been integrated with GSM relative time difference measurement and to provide compact, low cost, robust timing boards designed to be integrated within base stations or be deployed as external units at macro-cell sites.

3.2. *Time of Arrival* (*TOA*). This is an alternative synchronisation-based method of location capable of achieving 125 m accuracy. It works like E-OTD in reverse in that it measures at the base stations the time of arrival of transmissions from the handset instead of the handsets measuring the time of the base stations' transmissions. It requires the time of arrival of the handset transmissions to be measured at three or more monitoring base stations. This is achieved by making absolute time measurements at each base station using GPS clocks.

The major operational difference between TOA and E-OTD is that TOA supports legacy handsets, which is important for E911 in North America. However, it also requires monitoring equipment to be deployed at every base station to measure the absolute time of arrival of the handset transmissions. Furthermore, it requires the network to participate actively in making handset specific measurements for every location request. To implement this system, GPS clocks will be deployed at every base station as part of a monitoring device co-located at the cell site with the base station equipment.

3.3. *GPS*. GPS is a very well established positioning system and is currently deployed in vehicles as well as handheld dedicated devices for navigation. It can achieve better than 125 m accuracy even with Selective Availability (SA). It has coverage where there is a clear view of the sky, unlike TOA and E-OTD which work without a view of the sky but require 3 base stations to be receivable. The complementary nature of GPS's wide coverage and E-OTD's coverage into areas without view of the sky (urban/indoor), make these technologies an ideal combination.

Automotive GPS is available now, using robust low-cost GPS receiver boards. The high level of integration achieved with state-of-the-art chip sets, giving the benefits of low cost, small size and low power consumption, makes the use of GPS in premium handsets a next step. The inclusion of GPS as part of ASIC cell libraries, with GPS code designed to run on an integrated ARM processor means that GSM smart phones with integrated GPS will become available over the next 2 years from a number of manufacturers. A major enabling technology in this process of integrating

GPS into GSM handheld devices has been the breakthrough in miniaturised GPS antennas. With the development of ceramic loading methods, GPS antennas have been reduced in size by a factor of six to create small enough devices for inclusion in mobile handsets with the high performance necessary for GPS reception.

4. NETWORK ASSISTED GPS.

Differential GPS is a well-established technique for improving GPS positioning accuracy down to the centimetric level. It utilises correction data collected and sent by a fixed GPS receiver at a known position to a mobile receiver to improve positioning accuracy. GSM provides a ready-made communications mechanism for sending such augmentation data to the network of mobile receivers. GPS augmentation data can be used for more than increasing positioning accuracy; it can also overcome many of the potential weaknesses faced by GPS when integrated into portable devices. These are:

- Coverage problems can be reduced by using augmentation data to assist the GPS receiver to position itself from weaker satellite signals. The augmentation data enables the receiver to make timing measurements on the satellites without needing to decode the navigation messages. The timing measurements may then be sent back to the network for location calculation or the augmentation data may include information necessary for the handset to locate itself from the measurements.
- Power consumption problems can be reduced by the handset sending back data for the network to perform the calculation of position. It can also be reduced by the GPS receiver only being powered for a short period of time to collect a sample of received GPS data to be processed in conjunction with GPS data received in the network.
- Initialisation can be an issue with unassisted GPS as it must first receive all the satellite data. Sending the satellite data directly from the network to the handset GPS receiver solves this.

Augmentation is clearly very powerful, but it requires fixed GPS receivers to be deployed in the network at regular intervals to generate the augmentation data. Furthermore, network assisted GPS is very valuable but has a cost associated with the air-time needed to transmit the data; therefore it is not a substitute for unassisted GPS or the other positioning technologies, but can co-exist and be used in specific applications.

5. CONCLUSION.

GPS is key to the GSM location technologies that provide accuracy better than 1 km. The solutions are complementary and will all benefit from GPS clocks at macro-cells. GSM positioning based on synchronisation of the network will become universally available (TOA/E-OTD). GPS will be integrated into handheld GSM devices, and increasingly in vehicles, to provide precise positioning for certain applications with back up from GSM synchronisation-based positioning. GPS in the network and in the terminal will be the ultimate solution for high value applications utilising the benefits of GPS at macro-cells together with GSM bi-directional communication capabilities.