Seminar

MOBILE BUSINESS

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GSM Positioning Control

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Abstract

You most probably have heard about GSM, a system for mobile communication enabling people to make phone calls, send messages, etc. But that's not all that is possible to do. This document discusses GSM Positioning Control, a system that is based on mobile cellular networks used for GSM. It allows tracking of users and it gives the users the possibility to determine their position, just as with GPS. A range of possible applications is provided by this system. There are different methods, and some even integrate GPS.

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1 Introduction

Development of GSM was started in 1982 as a standard for digital mobile communication. Today—this was not always the case—GSM stands for *Global System for Mobile Communication.*

In our society everyone knows that GSM is something that allows people using a special device (a mobile phone for instance) to make phone calls from about everywhere, send short messages via SMS, and more recently send pictures, etc.

But GSM is not only good for communication: The architecture of the system makes it possible to use GSM for positioning control. There are a lot of possible applications, as we will see later.

Figure 1 gives an overview of positioning systems. The most popular positioning system is probably GPS. The figure shows that GPS and GSM positioning control are not direct competitors, since they are based on different concepts, and there are even applications where GSM and GPS work together, as we will see later in more detail.

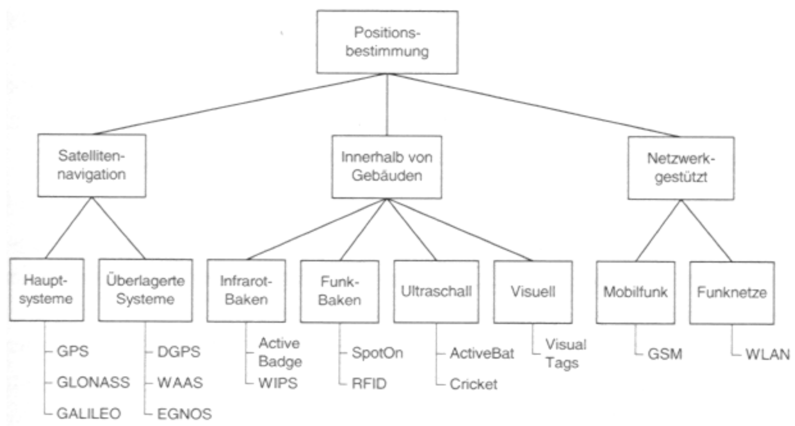

Figure 1: Classification of positioning systems.

We will see that there are several methods to calculate positions with GSM, and comparing the precsion of GPS with the different techniques of GSM positioning control indicates that most of them can't compete with GPS. Now you may wonder why they are used. Well, there is a fundamental difference between GPS and GSM-based positioning control, as we will see later on, which allows applications that are not possible with standard GPS. But there are good news, too: some techniques integrate GPS with GSM, so that we have the precision of GPS and all the advantages provided by the GSM network.

We are going to shortly describe the necessary parts of the GSM network and its architecture, and then discuss positioning control in more detail.

2 GSM Basics

2.1 The Network

The network used for GSM is divided into cells, each of which has its own station for receiving and sending information, called a *Base Station* (BTS). This division is necessary because the power of the electromagnetic signals decreases at least quadratically with the distance, and so the mobile devices would need a huge amount of energy to send information because they could be located very far from the base station if there was only one. The division of the network in cells reduces the distance from a *Mobile Station* (MS)—a cell phone for instance—to the base stations up to a certain maximum (35 km for the GSM network). Figure 2 shows the division of a network into cells.

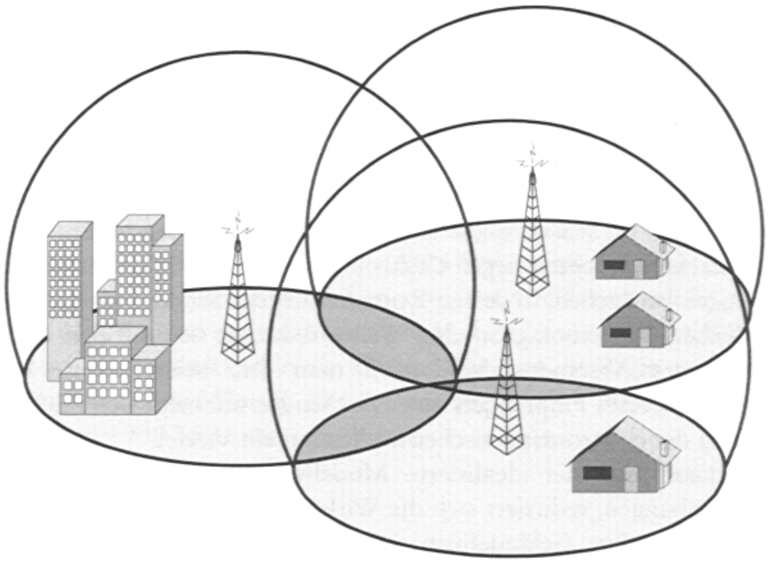

Figure 2: Structure of cellular networks: division into cells.

2.2 The Architecture

As stated above, each cell is controlled by a BTS, and any MS is bound to one BTS. A number of BTSs are controlled by a *Base Station Controller* (BSC), which in turn are governed by *Mobile Switching Centers* (MSC). We don't explain all these components in more detail, since they are not relevant for positioning control. Figure 3 shows the architecture of the GSM network.

The cylindric elements of figure 3 represent special storing registers. Two of them, the *Visited Location Register* (VLR) and the *Home Location register* (HLR) will be

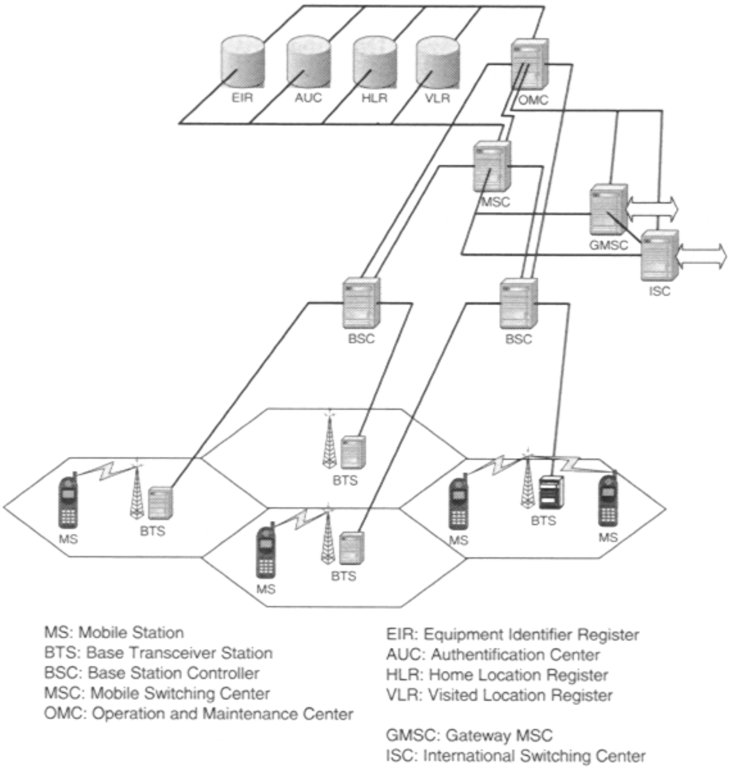

Figure 3: Architecture of the GSM network.

important for us. The network may be divided into several *Service Areas*, each of which has its own MSC. In turn, each MSC has its VLR, but there is only one central HLR for the entire network.

The two location registers store permanent and more importantly temporary data. The temporary records in the registers are created and deleted as users join and leave the corresponding service area. The HLR stores information about users of the corresponding network, as well as some temporary information, such as the location in the network for example. This is what is going to be important for positioning control. The VLR stores only temporary data about users currently in the network.

3 GSM Positioning Control

A fundamental difference of GPS and GSM based positioning control is that in GPS the users don't send any information to the satellites. It is a one-way communication, and it is not possible for any one except the user himself to get the location information.

This is totally different with GSM. As soon as an MS enters the network (i.e. enters the service area of a certain MSC), the relevant information is created in the VLR and is then sent to the HLR. Now the GSM network knows exactly which cell the MS currently is in. This provides the basis for positioning control with GSM, and it is referred to as *Cell of Origin* (COO).

3.1 Mobile Positioning System (MPS)

Network cells can be very big, with a radius varying from a 100 m up to 35 km. This leads to very imprecise location information. Therefore Ericsson has developed the *Mobile Positioning System*, which works with standard GSM and doesn't require changes for the MSs, and only minor adaptations on the network infrastructure are necessary. Additionally, MPS may be powered up with GPS (UL-TOA, A-GPS).

3.2 Applications

A lot of applications are imaginable or already exist:

- retrieve information about hotels, gas stations, restaurants, etc. that are in the proximity,
- taxi companies or other transportation companies may track and coordinate their units,
- cars equipped with GSM devices can be tracked down when they were stolen,
- people can be located for rescueing in emergency situations,
- the GSM network's positioning capabilities can be used in navigation systems,
- local news, information and weather reports, etc.

3.3 Network-based positioning control

3.3.1 Cell Global Identity (CGI)

This is the most basic and imprecise method for positioning control, but it is in widespread use. It can always be used if no better method is applicable. It just indicates the cell a MS is currently assigned to. Since the size of a cell varies from 100 m (in urban environments) to 35 km (in rural environments) it is obvious that for a lot of applications this precision is largely insufficient. But better methods exist.

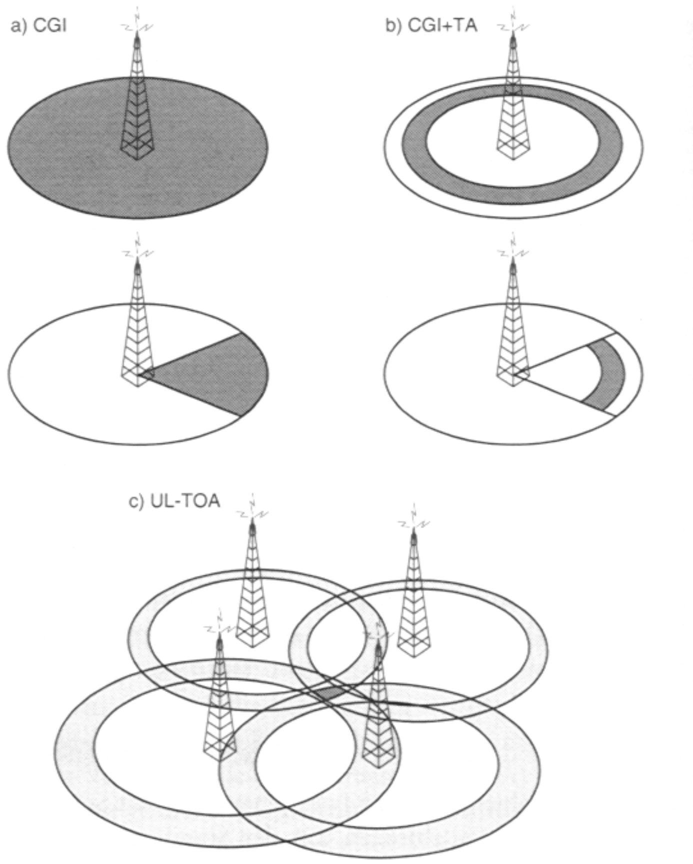

Figure 4: Techniques for positioning with GSM.

3.3.2 Signal Strength

Another relatively easy way to estimate the location of a mobile station is to meter the strength of its signals. Since the strength of the signals decreases (at least quadratically) as the distance increases, it is possible to calculate how far an MS is away from the BTS. But this method has very low accuracy, because signals may be disturbed by buildings, rocks, etc.

3.3.3 Angle of Arrival (AOA)

Sometimes Base Stations have antennas that are capable of determining directions, or have multiple antennas, each of which is responsible for a specific direction. This makes it possible to get a part of the cell where the MS currently is, and this improves the precision substantially. This is expressed by the second picture of part a) of figure 4.

Each of these sectors has its own CGI.

3.3.4 Timing Advance (TA), CGI+TA

Timing Advance is a runtime compensation. Since the timing in GSM must be very precise, the MS must send its data earlier so that it arrives at the correct time at the BTS. The time that the MS must send its data earlier is determined by the BTS and communicated to the MS. The timing advance is related directly to the distance between the MS and the BTS. (Values are between 0 and 63, which corresponds to a runtime of up to 233 μs, which in turn corresponds to the maximum radius of a network cell of 35 km).

The distance from the BTS to an MS is measured in steps of 550 m. This is very useful for determining the position of an MS more precisely than just with CGI, as illustrated in figure 4. The position can now be confined to an arc of a circle.

3.3.5 Uplink Time of Arrival (UL-TOA)

A yet better method for determining positions in a GSM netwok is the Uplink Time of Arrival. It can be used if an MS is the vicinity of at least four BTSs. The runtime of signals from the MS to the BTSs are then used to determine the position up to a precision of 50–150 m by a process similar to the one used by satellite-based systems, that is a triangulation method. In UL-TOA, GPS satellites are used to synchronize the base stations, since no synchronization is foreseen in standard GPS.

3.3.6 Uplink Time Difference of Arrival (U-TDOA)

The principle is the same as with UL-TOA, but instead of using the runtime of the signals, the difference of the runtime of the signals is used to determine the position. So instead of getting an intersection of cirlces, we have an intersection of hyperbolas, as showed in figure 5.

The hyperbolas represent the possible positions where the difference of the runtime of the signals is constant.

3.4 MS-based positioning control

In this family of procedures the MS does the necessary job to calculate the position. This results in yet more precise information, but the MSs need some modifications resp. must be replaced by new devices, that have modified software i.e. enhanced processing logic and/or power) or even better hardware (GPS receivers for instance). This makes the whole thing more expensive and it is the main reason why it is not used very much yet. Two existing methods are E-OTD and A-GPS.

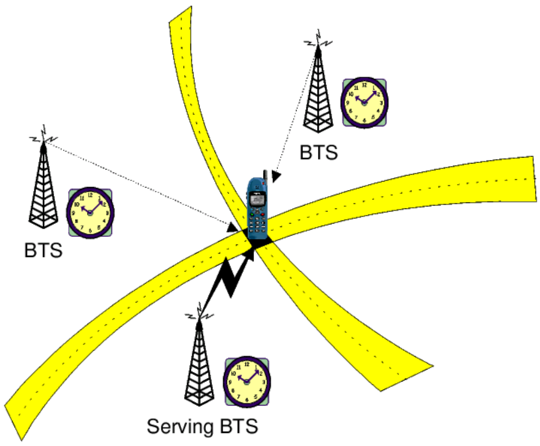

Figure 5: Principle of Uplink Time Difference of Arrival.

3.4.1 Enhanced Observed Time Difference (E-OTD)

E-OTD is very similar to UL-TOA. It is also triangulation method, but it works the other way round, meaning that it is a downlink technique. BTSs regularly send synchronization burts. These, and also common dummy bursts that constantly appear during GSM communication, are used by the MSs to calculate the postition. To achieve this, the signals of three BTSs must be caught. It is not as precise as GPS, but works inside buildings. The hardware of the MS doesn't need to be modified, but software must be enhanced.

The calculation of the position is done as illustrated in figure 6: Te MS calculates the possible position in regard to each of the BTSs. Then it calculates the intersection of the resulting areas, and a confidence ellipse represents the position of the MS.

3.4.2 Assisted GPS (A-GPS)

Assisted GPS makes the task for GPS capable mobile devices a lot easier as with standard GPS, where the device must first find at least three satellites before it can do the calculation of the position (10 steps in standard GPS versus only 3 steps in A-GPS). This takes from 40 seconds to a few minutes and is relatively power consuming. In A-GPS, GPS is integrated in a mobile network and the computation task is now partly done by the network: The network knows everything about the GPS satellites. As we already know, it is also aware of the MS's position (approximately). Now the network can tell the MS which satellites to use by providing it their positions and clock times and can start calculating the position immediately. This greatly improves performance and power consumption. When the MS has calculated its position it communicates it

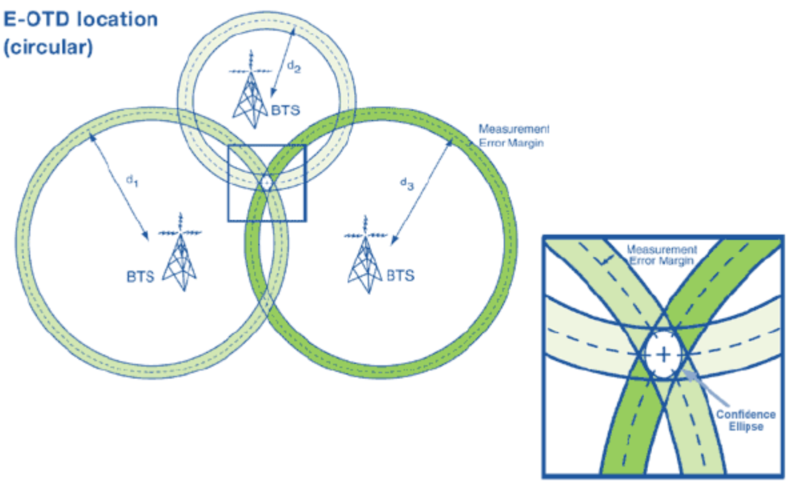

Figure 6: Illustration of how E-OTD works.

to the BTS.

A-GPS gives precision up to 3 m, and it is significantly faster since there is no need to first find satellites. But A-GPS requires that MSs are equiped with GPS receivers and it doesn't work well inside buildings.

3.5 Architecture of MPS

Figure 7 shows the system's architecture.

Additionally, if the MSs are capable to catch GPS signals, the location can be determined even more precisely.

Now the position data that has been determined—regardless of the method (if it has been done by GPS, the MS sends its location information to the base station)—it is send to the *Mobile Positioning Center* (MPC), where they may be accessed via the Internet. This again shows the difference with pure GPS, where only the MS has knowledge of the location.

3.6 Comparison

The following table compares the precision of the several location techniques.

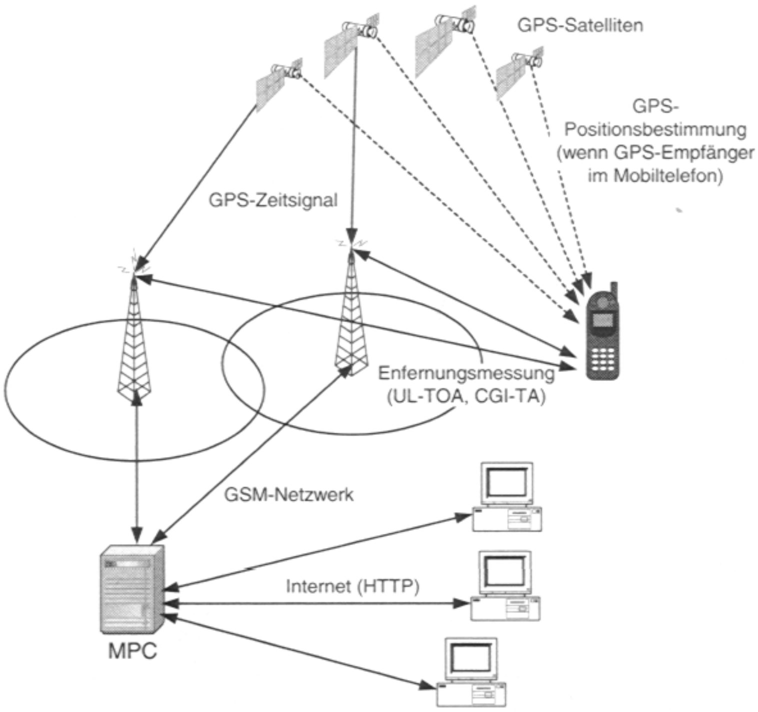

Figure 7: Architecture of MPS.

Technology	**Urban env.**	**Rural env.**
CGI	> 100 m	< 35 km
CGI+TA	> 100 m	circle of arc of 550 m
UL-TOA	˜150 m	˜50 m
U-TDOA	˜50 m	˜80 m
E-OTD	˜200 m	˜60 m
A-GPS	20–30 m	3–10 m

It may seem strange that for some of the techniques the precision is better in rural environments as in urban ones, but this is because in highly agglomerated places, as towns generally are, the signals are biased.

3.7 A Practical Example: E911

The E911 (enhanced 911) is a system for locating callers dialing 911 with their mobile phone. The European Union is working on a similar system, called E112. The system has been released with two phases: Phase I requires that the accuracy of the location be within 1 mile, and Phase II requires the accuracy to be between 100 and 300 meters.

When someone calls 911 with their mobile phone, the call is directed to the nearest public safety answering point (PSAP), and the PSAP then receives the phone number and location of the caller.

The methods used to determine the position in E911 are CGI, U-TDOA, E-OTD and A-GPS.

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