# A Mobile Location Service Demonstrator Based on Power Measurements

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***Abstract-*** **Coupled with the unprecedented development of mobile communications, location services have been under study for a number of years. In this paper, a GSM mobile location service demonstrator based on power measurements is presented. The choice of this procedure is justified because the main interest here was to minimise the impact of the service deployment on the operator's network. The procedure have been tested under real GSM networks in different environments and some accuracy measurements have been obtained.**

Keywords – GSM, location, demonstrator

## I. INTRODUCTION

Coupled with the unprecedented development of mobile communications, location services have been under study for a number of years. The interest in mobile location determination was motivated because there are a number of possible services that can be offered to society, companies and individuals: fleet management, route guidance, context sensitive information (restaurants, gas stations, shops, etc.), hot spot detection for proper network planning or location dependent billing are only some examples.

Several physical principles are on the basis of feasible solutions to the wireless position location problem. Many location methods can be proposed from these principles, covering a wide range of demands in terms of complexity, changes in current cellular networks and accuracy. Location strategies based on power level measurements, time delay measurement, mobile speed measurement, cell identification information, angle of arrival, GPS and combinations of these strategies are relevant examples.

In terms of mobile location system deployment two different approaches can be followed: a service transparent to the network operator, where the terminal provides the necessary information to the LSC (Location Service Centre) and the centre executes the location procedure, or a service transparent to the terminal, where the network operator captures all the location-sensitive information and it is transferred to the LSC, which processes it in a similar way than in the previous case. The former implies no changes in the network and the later implies no changes in the terminals. Of course, mixed strategies are also possible.

In this paper a mobile location service demonstrator based on power measurements is presented. The choice of this procedure is justified because the main interest here was to minimise the impact of the service deployment on the operator's network, so that any changes in hardware or software at the base station should be avoided. In the implementation presented in this paper, the mobile terminal is able to capture neighbour cells information, pack this information in one or several SMS (Short Message Service) and send this SMS to the suitable LSC, where some network related information is stored. This functionality is, for example, supported by SIMToolkit phase 2 terminals. It is worth noting that this opens the possibility to offer location sensitive services with low investment and without additional delays in service launching. Despite the accuracy one can expect from power level measurements is limited compared to other location methods because of the heavy random fluctuations typical in mobile environments, there are some improvements one can include in the location algorithms in order to set the accuracy to an acceptable level for many applications.

The rest of the paper is organised as follows. In Section 2 the location method considered is detailed and some possible location algorithms are described. In Section 3, the architecture of the developed demonstrator is described, identifying the main elements and the procedures followed. Section 4 collects some sample results obtained through field trials carried out over real GSM networks in different environments. Finally, Section 5 captures some conclusions from these experimental trials.

## II. LOCATION METHOD

On one hand, a GSM mobile terminal measures the received power from different base stations by taking advantage of the period between the transmission burst and the reception burst. With a 480ms periodicity the mobile reports the power levels (quantized to 64 levels) measured for the serving cell and up to 6 neighbour cells using the SACCH [1]. This information can be delivered by different methods to a LSC: in a network operator approach a SMS is a feasible solution in case the mobile terminal is able to capture "Measurement Report" message (for example a SIMToolkit terminal), whereas in a terminal transparent approach these measurements are available at the cell site and can be monitored and stored for further evaluation by the network operator with the aid of commonly used protocol analyzers.

On the other hand, let assume that the LSC stores a propagation database with geographical references, with the average received powers from any base station within a certain spatial resolution in the service coverage area. In Section 3 we deal with the feasibility that all these information are available as well as cost and generation procedures in the present demonstrator.

The mobile location algorithm can be applied once the former information are available in a central processing unit (i.e. the LSC). Signal strength location algorithms are quite simple. The location algorithm will basically compare the received power levels measured by the mobile with the expected values kept in the database and choose the most similar one. Of course, additional refinements can be introduced. Then, the latitude and longitude or the information related to the user position is forwarded to the mobile terminal. More specifically, the algorithm has the following parts [2].

a) Minimum mean square error algorithm

Assume that for every coordinate **x**=(x, y) defined within a certain resolution in a coverage area, the average power vector $\mathbf{P_x}$ received from the surrounding cells (each one identified by its beacon frequency) is available. Let define the received power vector measured by the mobile station at time t from different base stations, $\mathbf{P_R(t)}$. We can write these vectors as:

$$\mathbf{P_x} = \begin{bmatrix} BCCH_1 & P_1 \\ BCCH_2 & P_2 \\ . & . \\ . & . \\ BCCH_N & P_N \end{bmatrix} \qquad \mathbf{P_R(t)} = \begin{bmatrix} bcch_1 & p_1(t) \\ bcch_2 & p_2(t) \\ . & . \\ . & . \\ bcch_M & p_M(t) \end{bmatrix} \quad (1)$$

Within the coverage area N may vary from 1, typically in rural environments, up to 10, 11 or even more in urban areas. Although usually M=N, in a real network the number of cells a mobile can hear in a given moment may differ from the expected number. $P_i$ i=1..N are long term average values, while $p_i$ i=1..M are usually shorter term average values. In case $\mathbf{P_R(t)}$ corresponds to a GSM "Measurement Report" message, the reported values have already been averaged to some extent, because in the 480 ms period the mobile has been able to capture several samples from each beacon frequency.

Similarly to [3], the mobile is guessed to be located at point **x**, which minimises the MMSE (Minimum Mean Square Error) estimation of the current position. We also include possible discrepancies between both vectors as sources of error, thus contributing to the total error. That is, in case the mobile reports a vector component ($bcch_j$, $p_j(t)$) not present in $\mathbf{P_x}$, a term, $[p_j(t)]^2$ is added to the error. The same is applied for beacon frequencies present in the database and missing in the reported values.

b) Data smoothing

Due to deep fading in received powers, the reported measurements vector may suffer significant changes in the short term. So, despite the reported values have already been averaged because in 480 ms the terminal is able to obtain several samples of the received power coming from a given base station (the higher the number of base stations it is able to listen to the lower the number of samples it is able to take), further averaging is required. A linear regression is a feasible solution as well as considerations about the distance the mobile is able to cover between consecutive information samples.

c) Available Timing Advance (TA) information is considered to further refine the positioning. Only those points stored in the LSC database where the distance to the serving base stations is such that it would provide the same TA than the one reported by the mobile terminal, would be candidates to be the mobile estimated position. Additionally, it can be considered that the higher the difference between reported and stored TAs, the lower the probability to be located at such point should be. Consequently, the algorithm is modified according to:

$$E' = E\left[1 + K \times (TAd)^{\alpha}\right] \qquad (3)$$

where E is the MSE taking into account power levels, K and α are parameters to be adjusted, TAd is the TA difference between reported and stored values (we note that TA is an integer number from 0 to 63) and E' is the final error. Another variant is to consider the contribution of TAd as independent of the power error contribution, so that:

$$E' = E + K \times (TAd)^{\alpha} \qquad (4)$$

## III. DEMONSTRATOR ARCHITECTURE

The architecture of the demonstrator is shown in Figures 1 and 2. Since at the time of developing the demonstrator SIMToolKit supporting "Provide Network Information" command was not available yet, we used a GSM modem with a portable PC instead. The GSM modem supports "Cell Environment Description" command, which provides RxLev, ARFCN and BSIC from the serving and neighbour cells. So, we note that there is no conceptual difference between the adopted solution for demonstration purposes and the envisaged one for mass market implementation purposes. The GSM modem is controlled by a Visual C++ application running in a portable PC. A variable number of measurements will be collected before the mobile to be located sends one or several MO-SMS (Mobile Originated SMS) to the LSC, so that accuracy statistics will allow devising the possibilities to correlate different samples. For simplicity reasons another GSM modem is installed in the server side, as Figure 2 shows. The interface is responsible to proper configure the GSM modem and to provide the received SMS as inputs to the location algorithms. The location algorithms run to obtain an estimated position of the mobile user. Once a position has been decided a MT-SMS (Mobile Terminated SMS) containing the latitude and longitude is sent back to the mobile. We note that SIMToolkit would be able to show this information in the mobile terminal display. In our demonstrator it is plotted on the PC screen. Moreover, a GIS (Geographical Information System) application is installed at the LSC, so that the mobile position is also plotted on a map, allowing the real time tracking of the mobile terminal.

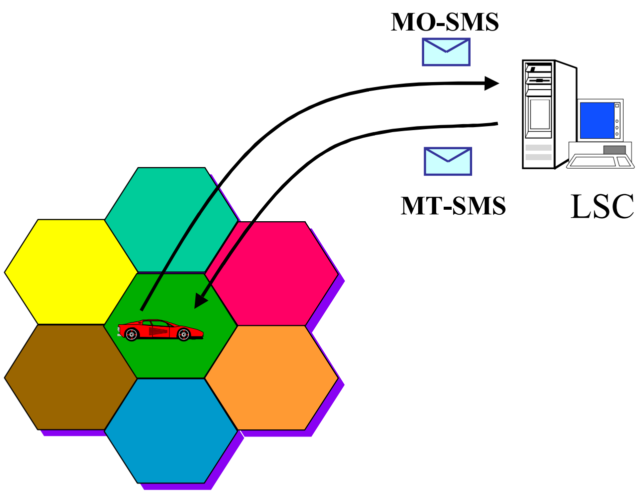


Figure 1. Architecture for the location service demonstrator.

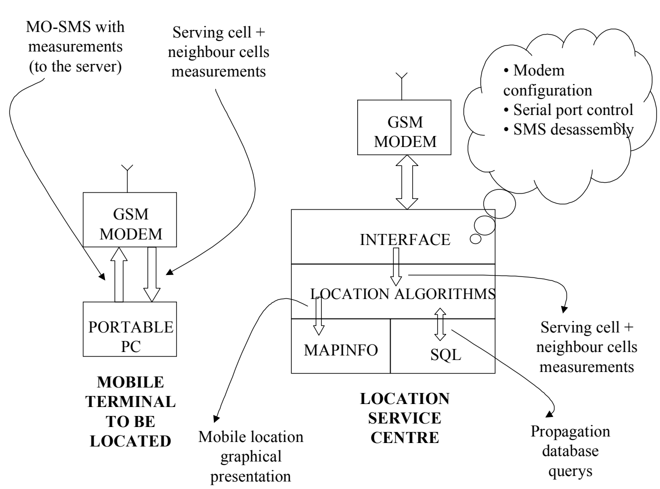


Figure 2. Location Service Centre configuration.

Location algorithms make use of a propagation database, stored in SQL format. A measurement campaign was carried out, covering a rural and suburban area near Barcelona, approximately 60×30 Km. Measurements were repeated at different speeds and with different sampling periods in order to devise a measurement procedure accurate and simple at the same time. The measurement equipment was a portable PC with a test and monitor software installed and a GPS receiver in order to record the position were the measure was being taken. The samples were averaged along a certain space and time in order to generate the coverage database, which was loaded in the SQL. Since the number of samples averaged out for every coverage point was in general high, no significant differences were found for different speeds on the collection path, so that the database could be generated simply driving through the roads at a suitable speed for the traffic conditions. Figure 3 presents the database representation, where adjacent points in the SQL are separated 100 m for the rural scenario.

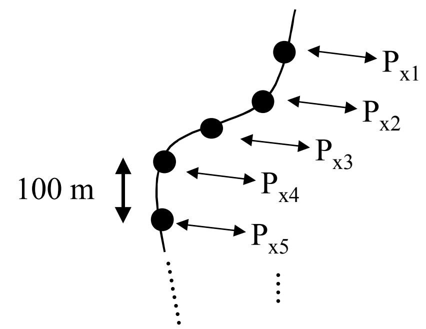


Figure 3. Representation of the database generation.

## IV. FIELD TRIALS

The presented location demonstrator has been tested in different conditions and scenarios: a) The above mentioned rural and suburban area near Barcelona, approximately 60×30 Km, as the initial proof of concept validation trial, b) downtown Barcelona city, approximately 10×10 Km, and c) an intensive campaign over long distance routes around several highways and main motorways in the Mediterranean side of Spain (i.e. from the French border to Valencia area, about 500 Km, a route that suffers heavy truck traffic for orange and other goods exportations). It is worth mentioning that the cost associated to database generation may be very low with the help of strategic partners. In particular, several autonomous and remotely controlled measurement equipments were installed in a fleet covering the interest area and it was not necessary to set up ad-hoc driving tests.

In order to obtain some accuracy statistics, about 2000 location requests from the LCS were triggered for each analysed scenario. A GPS receiver was also connected to the GSM terminal, so that the GPS coordinates were added to the mobile response to the location request. Thus, the LCS was able to compare the estimated position by the developed location procedure with the estimated position by the GPS. The difference between both estimates is reflected in the following as the positioning error, and is taken in the following as the main parameter of interest in the field trial campaign.

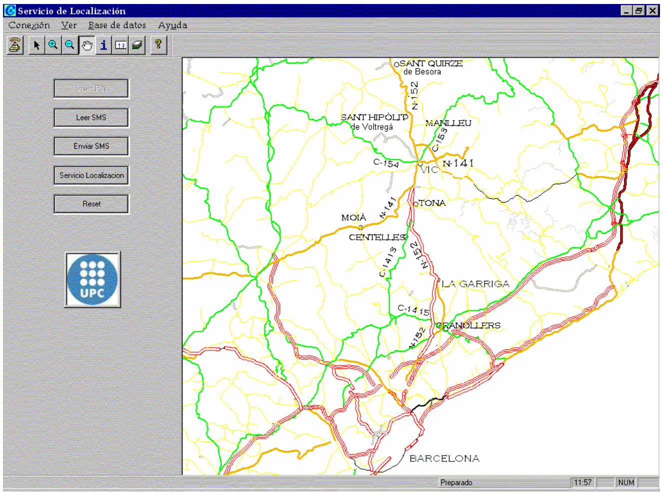

Figure 4. LCS control screen for rural and suburban field trial.

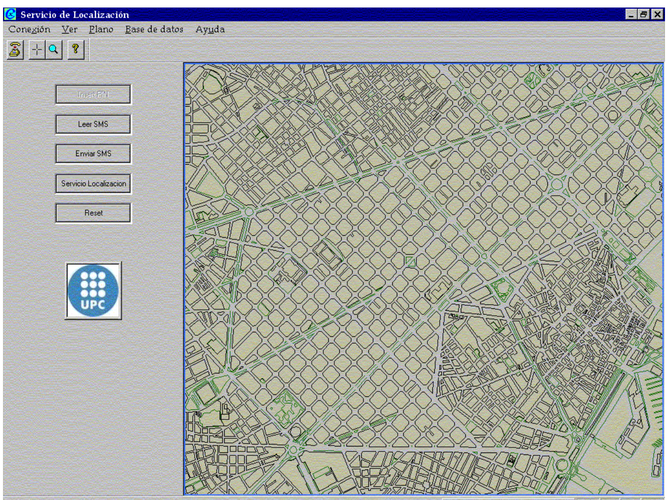

Figure 5. LCS control screen for downtown field trial.

Figure 6 presents in the y-axis the probability that the error between the real and the estimated position is less or equal to the value of the x-axis (i.e. the cumulative density function of the positioning error). It can be clearly observed that the Timing Advance information results very valuable in improving the location accuracy. If the TA difference is not taken into account (i.e. k=0, so that only a MMSE estimation is performed with respect to power measurements), 70% of the tests carried out revealed errors of less than 500 m and only only 90% of the cases are below 2000 m. If the TA difference between the candidate location point in the database and the measurements reported by the mobile under test are taken into account, the shape of the plot is remarkably improved. In particular, as reflected also in Figure 6, the percentile 90% provides accuracies better than about 500 m.

Another interesting performance measurement is to obtain the accuracy as a function of the number of base stations the mobile terminal is able to listen to, so that it may indicate the impact of the coverage the operator is providing on the service performance. Figure 7 reflects that when only one base station can be heard the accuracy degrades, whereas for two or more base stations the results can be significantly improved. In particular, for a scenario with more than 3 BTSs around, the 90% percentile of the positioning error is close to 250 m.

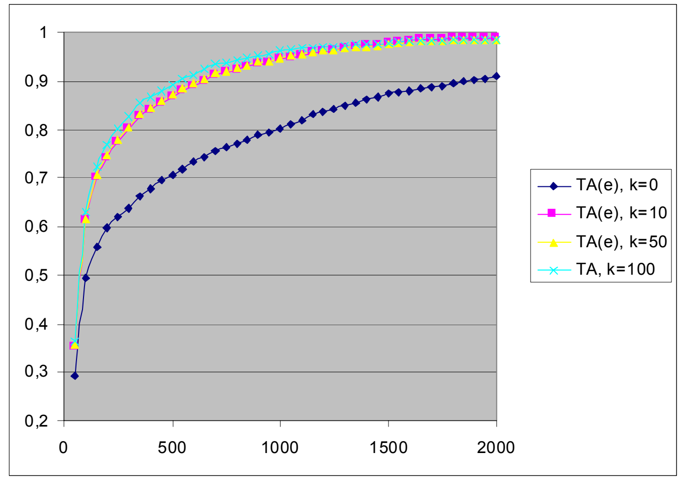

Figure 6. CDF of the positioning error

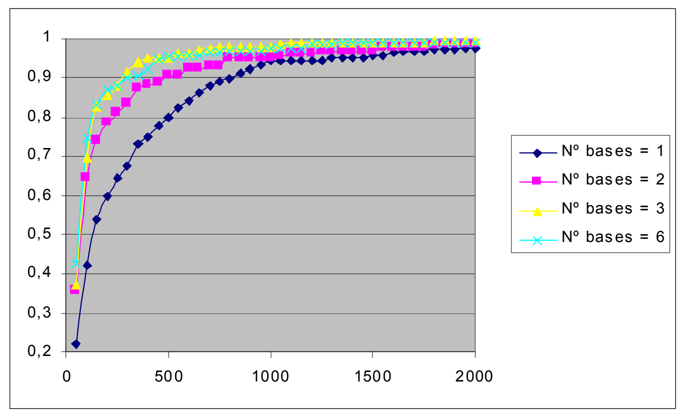

Figure 7. CDF of the positioning error depending on the number of BTS

## V. CONCLUSIONS

A mobile location procedure based on power measurements has been presented in this paper. The main characteristic of this ready to use methodology is its simplicity and the low cost of investment for deployment. The location method has been tested by means of a demonstrator running on a real GSM network. Accuracy results have been obtained, showing the importance of the Timing Advance information to improve the performance. It is envisaged that the assessed accuracy suffices for many practical applications.

## VI. REFERENCES

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