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Low Cost Positioning and Efficient Fallback in GSM and UTRAN Networks

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Abstract - There is a need for mid-range precision positioning techniques to serve applications for the mass market and legacy handsets. A method is presented throughout this paper that significantly surpasses the accuracy of pure cell identifier based positioning, without the need to modify handsets or radio network components. Measurements that are already available in radio networks, like reception power levels, are used to find the most probable location of a subscriber while optimizing a two-dimensional cost function. Application of this method to the GSM and presented field trial results clearly show its benefit.

1 Introduction

Positioning of mobile users in a wireless cellular network has become an important issue in recent years. On the one hand, it is required by law in case of emergency calls in some countries. On the other hand, location based services are regarded as an important commercial application of mobile telecommunication networks. There are many positioning methods available today, most of which demand the installation of additional hardware, such as a GPS receiver in the mobile phone or additional measurement units on the network side. Applications usually have different requirements on the accuracy of the user's position. Navigation or guidance services need a high precision estimate of the position that implies the use of some satellite based systems. But there are many existing or upcoming applications for mobile phones, which are based on information about the position of the user, that do not require the high accuracy of a satellite based system. In case a mean accuracy of about 100–300 meters can be achieved, applications like friend finder, fleet management, parcel tracking, or finding the nearest facility of a certain kind become possible. Then, simple cell identifier based techniques are usually not suitable due to an insufficient positioning accuracy.

Therefore, there is a need for mid-range precision positioning techniques to serve applications for the mass market and legacy handsets. Positioning methods based on the cell identification and taking into account additional measurements constitute one class of such techniques. In [1] an algorithm is presented that utilizes measurements of the propagation delay and reception power of serving and neighbouring base stations in addition to the cell identifier information. The serving cell information and the propagation delay measurement are used to restrict the possible area of the subscriber location. During positioning of a user the measured reception power levels are compared with predictions provided by radio network planning tools. This class of methods yields a greatly improved accuracy, when compared with pure cell identifier based techniques.

Furthermore, they still need no hardware extensions to the network or to the handset. Although the investment for such technique is rather limited, the operation and maintenance effort should not be neglected. The mobile network operator has to provide signal strength prediction data for the whole network. This is a tremendous amount of data that need to be kept up-to-date. In case of regular tuning or modification of the network, the processing has to be redone every time to update the database.

The method presented throughout this paper works similarly to the mentioned technique but does not require the provision of field strength prediction data. It results in a similar performance with less effort on the operation and maintenance side. It is therefore well suited for numerous commercial applications. Additionally, it is also a good choice as a complement for satellite based positioning techniques. The latter ones like GPS usually need a fallback since the performance is often insufficient in dense-urban or indoor environments even if assistance data are used. The time to fix either becomes unacceptably long or fixes are not possible at all.

2 Positioning of Users

The presented positioning technique uses the measurements provided by mobile stations to the network, including the round trip time and the reception power levels data. The method is applicable for both 2G and 3G technologies, as it is based on the standardized measurements. It can be realized as a network or mobile based technique (either independent or network assisted).

The method uses two separate sets of data: network data, required to build a framework for handling positioning requests, and measurement data, specific for each separate location estimate. The network data comprise the coordinates, the transmitted power and frequency, the antenna type, height and azimuth of each transmitter. The measurements data usually include the round trip time to the serving transmitter and the received signal levels from the serving and neighbouring transmitters. For actual positioning, the method uses the pathloss distance and round trip time distance distributions. The former is based on the Okumura-Hata and COST-231 models (see [3], [4]), whereas the latter uses the theoretical relationships linking distance and propagation delay.

The split of the needed data into two groups is reflected in the architecture of the positioning algorithm. One set of procedures deals with the off-line preparation of the network database. The coefficients of the propagation and round trip time distributions are calculated and assigned to each transmitter in function of the radio frequency used and the physical properties of the surrounding area (e.g. microcell in urban environment). Additionally, the serving area of each transmitter is estimated based on the position and configuration data of other transmitters. The other set of steps constitutes the on-line part executed whenever a mobile user is to be located. It starts with retrieval of the most recent measurements from the network and it may also be necessary to query the mobile station. Then, the position is calculated in an iterative process of the cost function optimization.

3 Description of Method

The mobile user's position obtained by the proposed approach is a solution to a two-dimensional optimization problem over an area in the vicinity of the serving antenna. The cost function used in this case relies on a statistical assessment of the distance between a mobile station and surrounding transmitters. For each cell in the network this distance can be estimated by means of measured round trip times and received power levels.

Let us denote the probability density function of the distance related to the round trip time t by $f(\cdot|t)$ and the one related to the received power level r by $g(\cdot|r)$. Naturally, both

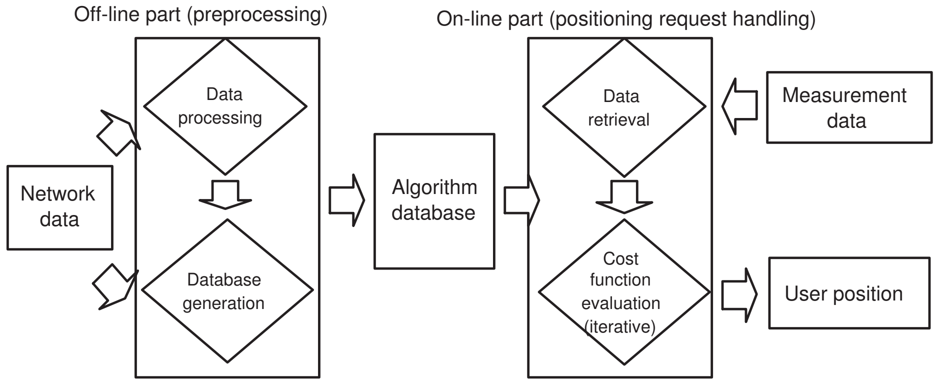

Figure 1: Positioning process flowchart

functions depend on the propagation conditions as well as transmitter's settings (for details see Subsections 3.1 and 3.2), thus they are defined for each cell separately. Let us further assume that $t_i, i = 1, \ldots, n$ stand for measured round trip times and $r_j, j = 1, \ldots, m$ for received power levels. Here n, m represent the numbers of transmitters having the round trip time and received power level available. Then, the cost function c of a mobile user's position $\boldsymbol{x}$ can be defined in the following way

$$c(\boldsymbol{x}) = \sum_{i=1}^{n} \log f\left(d(\boldsymbol{x}, \boldsymbol{x}_i^t)|t_i\right) + \sum_{j=1}^{m} \log g\left(d(\boldsymbol{x}, \boldsymbol{x}_j^r)|r_j\right) ,$$

where d is a distance function, while $\boldsymbol{x}_i^t$ and $\boldsymbol{x}_j^r$ are respective antennas' positions. Figure 2 depicts how it might look like in practice. The origin of the coordinate system is placed at the position of the serving antenna. Light colour denotes areas where the mobile user is more likely to be located. It can be seen that surrounding antennas are placed in areas where the colour is dark — the probability of user's position is low there.

The cost function can also be seen as the log-likelihood of a position on the plane. Hence, the most probable mobile user's position is the one maximizing c. The optimum can be found by any of nonlinear optimization techniques, e.g. the Nelder-Mead simplex method [2]. In fact, this is the method of choice because it evaluates the cost function exlusively at visited points on the plane and does not require the knowledge of its partial derivatives the computation of which would be too expensive both analytically and numerically. Moreover, the method is resistant to any strange behaviour of the function being optimized and usually finds its global optimum.

3.1 Round Trip Time Distance

Results of the round trip time measurement sent over radio interfaces are encoded as integers and they correspond to discretized values of distance between the mobile station and transmitter's antenna. This measurement is subject to various errors connected with propagation conditions (e.g. line/non-line of sight) and measuring equipment's inaccuracy, which shall be reflected in the model by a suitable choice of dispersion parameter per cell.

Let us denote by d_{rtt} the distance equivalent to the increase of round trip time by 1, and by r_{rtt} the ratio of the time period corresponding to d_{rtt} to the standard deviation of the measurement. Then, under assumption of uniformity of user's distance to the antenna over the whole cell, the probability density function of the round trip time distance distribution can be specified as follows

$$f(d|t) \sim \frac{r_{\mathrm{rtt}}}{d_{\mathrm{rtt}}} \left(\Phi\left((t + \tfrac{1}{2} - \tfrac{d}{d_{\mathrm{rtt}}}) r_{\mathrm{rtt}} \right) - \Phi\left((t - \tfrac{1}{2} - \tfrac{d}{d_{\mathrm{rtt}}}) r_{\mathrm{rtt}} \right) \right) ,$$

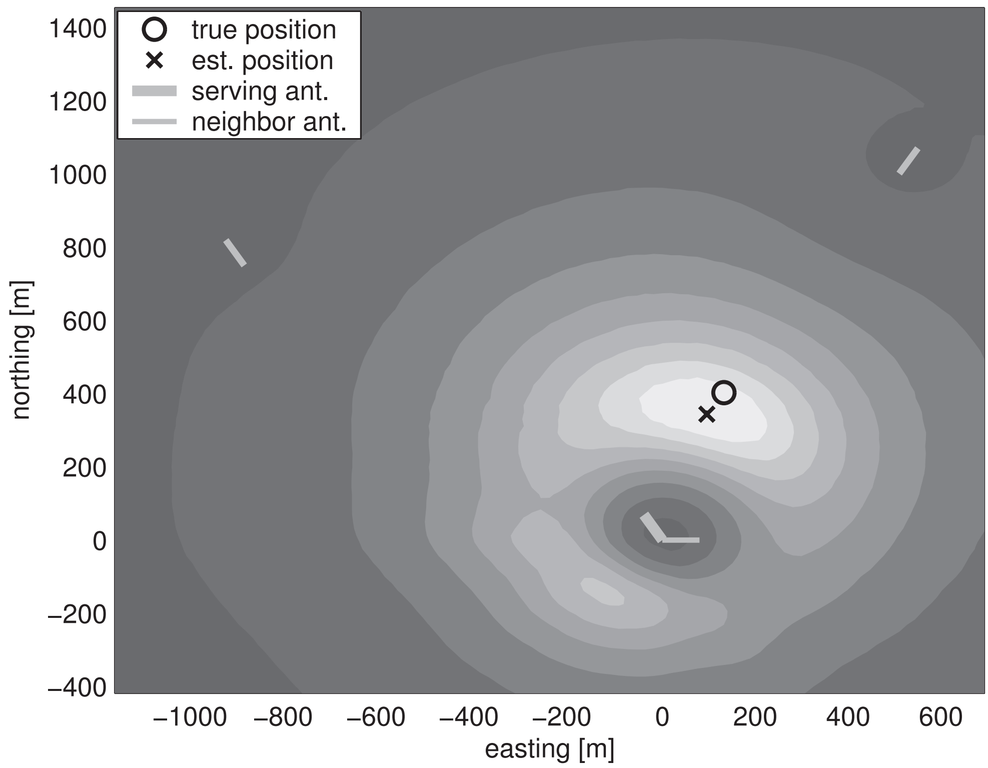

Figure 2: Example of cost function

where Φ stands for the normal cumulative distribution function. The importance of this part of the cost function depends mainly on the actual round trip time measurement's accuracy and granularity.

3.2 Pathloss Distance

On the basis of received power levels, which are essential in assessing the distances to neighbouring cells' antennas, respective pathloss values can easily be calculated the distance relation of which is already well known in theory. The most widely used approach is described by the equation

$$p = -10\beta + 10\alpha \log_{10} d \,,$$

where p stands for the pathloss in dB, while α and β are model coefficients. Both α and β reflect the impact of propagation conditions and transmitter's antenna specific settings (e.g. height over ground, transmission power, radiation pattern, frequency band) on the pathloss behaviour. In the probabilistic approach, it is often assumed that p is a median of the normal distribution with dispersion parameter σ_{pl} interpreted as slow fading component of the model.

Supposing that the mobile user's distance to the antenna is uniformly distributed, the pathloss distance can be modeled by a log-normal distribution with parameters μ and σ of the form

$$\mu = \frac{\log 10}{10\alpha}(p + 10\beta) + \sigma^2 \,, \qquad \sigma = \frac{\log 10}{10\alpha}\sigma_{\mathrm{pl}} \,.$$

Figure 3 depicts examples of density functions of such approach for several pathloss values.

This figure shows one important thing — a relatively small change in pathloss value brings about a significant change in distance assessment. That is why, in order to compensate the uncertainty, it is beneficial to have several pathloss values available in the cost function, preferably obtained for antennas located on different sites.

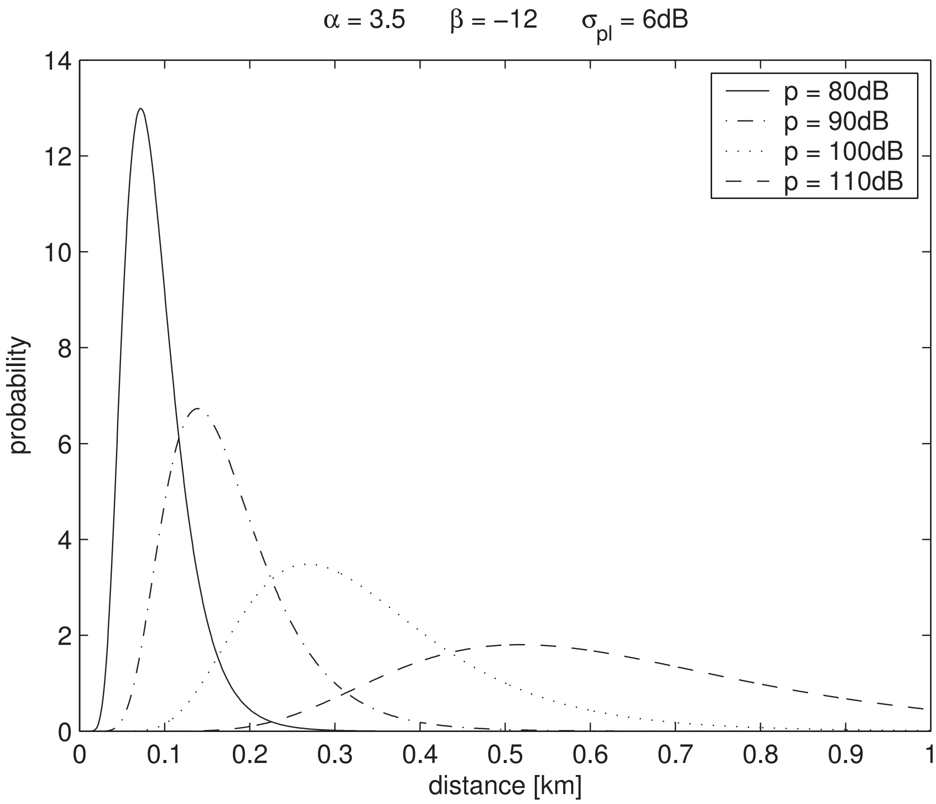

Figure 3: Example of pathloss distance models

4 Applications

The proposed method is suitable for all networks providing both round trip time and received power level measurements mentioned earlier. They are, for instance, Timing Advance and RXLEV in GSM networks. In case of the FDD mode in UTRAN networks, the Round Trip Time, UE RX-TX time difference, and RSCP or pathloss measurements can be used.

Focusing on the application in GSM networks, one has to be aware that the timing advance is rather a coarse measure of distance, since in this case $d_{\mathrm{rtt}} \sim 550$m. However, the overall performance turns out to be satisfactory in comparison with other known positioning techniques. In particular, it occurs to be only slightly worse than that of the method presented in [1], which uses received power level predictions instead of propagation models.

information used	dense urban	urban	rural
cell ident. + TA	305	305	545
cell ident. + TA + pathloss	105	210	415

Table 1: Comparison of method average accuracy [m]

In Table 1 the average accuracy of the proposed method is compared against the one of the method based on cell identification and timing advance information only (often referred to as CI-TA). The given results were obtained for various field trials conducted in GSM networks. The benefit of using pathloss models is clear, especially in urban areas, where more pathloss values are available for positioning. However, it has to be pointed out that timing advance information is used in different ways in these solutions. In CI-TA the estimate of mobile user's position is located on the azimuth of the serving antenna the distance to which is calculated as the product of $d_{\rm rtt}$ and reported timing advance value. Furthermore, the presented solution reaches an accuracy of about 100 meters in dense urban areas, where it is comparable even with satellite based methods. In fact, it can be successfully used as a fallback for those approaches since they often fail in badly conditioned environments.

The method proves to be very robust, i.e. measurement errors do not affect strongly positioning results. This is because uncertainties connected with individual measurements usually compensate each other and the use of probabilities in the cost function makes the decision about the user's position very fuzzy.

The computational complexity of the proposed technique cannot easily be assessed because an optimization method is used to obtain the mobile user's position. However, practical tests show that setting the convergence criterion properly (e.g. 1 meter tolerance) makes the optimization process end up after 30 steps on average. On every step the cost function is evaluated from 1 to 4 times depending on its local shape. Hence, the computational effort can be kept low without loss in accuracy.

5 Conclusions

This paper presents a positioning technique, which does not require any changes or add-ons to handsets or radio network, and is therefore able to work with low cost and legacy handsets. Especially for consumer applications, the achieved accuracy is quite sufficient and much higher than that of cell identification based methods. Additionally, the technique is well suited as a fallback for satellite based positioning since the best performance is reached in dense urban environments, where satellite based methods often fail. Therefore, it is applicable to the biggest portion of the market of location based services providing an excellent performance-to-cost ratio.

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