Mobile Positioning for Location Dependent Services in GSM Networks

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Abstract. A feasible Mobile Positioning solution is often sought after by network operators and service providers alike. Location-dependent applications create a new domain of services which might not only be of interest to the next generation of mobile users but also create new potential revenue streams. Applications vary from emergency services and tracking to location-based information services, location-based billing and location-dependent advertising. Due to the shortcomings of location-related information present in GSM networks, and the lack of positioning functionality in most of the commonly sold mobile devices, a straightforward solution for mobile positioning does not currently exist. This research intends to propose cellular positioning methods which do not require any significant changes to the network or the mobile device itself, which are feasible and cost effective, and which provide sufficient accuracy for certain categories of location-based services. These techniques are based on the proper analysis of signal measurement data, probabilistic geometric computation of location areas likely to represent the user's location, and the correlation of this data with information obtained from path loss models used in the design and planning of a mobile radio network.

1 Introduction

Being small, handy and increasingly utile, the mobile phone has become the core device of mobile society. The addition of novel applications and capabilities make it even more personal and trusted, and thus a regular part of everyday life. The popularity of mobile phones and the number of mobile device users is continuously increasing, and at the same time mobile phone manufacturers are striving to introduce new feature-packed devices to hopefully attract potential new customers. These new features include device, internet and intranet connectivity. Consequently, consumers will gain access to content and services at any time and from virtually any geographic location. One must also not forget the emerging multimedia-enriched services where the user experience is enhanced through images, audio and even video content. However, what makes mobile devices fundamentally different from other computers is their inherent mobility [8].

Location based services offer a huge number of possibilities for the definition of new services for 2G and 3G wireless networks. For some applications it is sufficient to determine the cell of the mobile terminal but other services such as emergency calls or navigation systems require a more accurate position determination framework.

Unfortunately, the GSM Network itself lacks positioning functionality since historically it was not designed to carry any location or telemetry information. One can consider the option of integrating with a separate positioning technology [2], but there are huge costs involved in upgrading a substantial part of the network's base-stations with Location Measurement Units (LMUs) to be able to support technologies such as Enhanced Observed Time Difference (E-OTD) or Time of Arrival (TOA) [9]. Also, the limitations of technologies such as Global Positioning System (GPS)

and Assisted GPS (A-GPS) (for instance, the requirement of an open space for at least three satellites to be visible from the mobile terminal, the relatively long time for position fix, and the power required for the GPS receiver) make the technology inappropriate for commercial applications such as Localised Information Services. Apart from all this, technologies such as GPS or E-OTD are still missing from most common mobile handsets on the market.

Thus, the user's location must be determined from data that is inherently present in the cellular network, which although not originally intended for mobile positioning, might be able to give enough clues to heuristically locate a mobile phone to an acceptable level of accuracy. This information consists of network parameters such as the Serving-Cell Identity, Timing Advance and Neighbouring Cell Measurements. This research presents and puts in practice cell-based location confinement and approximation algorithms that use techniques such as probabilistic geometry and path loss models. These algorithms are merged together to provide a positioning solution that can furnish a location dependent application with information pertaining the user's position.

2   Probabilistic Geometric Elimination

In the interests of optimizing the efficiency of the network, the amount of spectrum that an operator has, as well as the quality of service for the user, it is necessary for the operator to know which Base Transceiver Station (BTS) is in closest proximity to each subscriber [10]. This is accomplished by handsets monitoring the signal strength and the Base Station Identification Code (BSIC) of the surrounding BTSs, to determine which BTS has the strongest signal, through which any calls or data communication will be routed.

Probabilistic Geometric Elimination groups the techniques that, from the provided network data, geometrically eliminate the areas that are highly improbable to resemble the subscriber's location, and confine the regions that are likely to correspond to the obtained network measurements. Below is an overview of how this collected data contributes to obtain a probable subscriber location area.

2.1   Cell Identity

The simplest approach to cell-based localisation involves identifying the serving cell the mobile phone is using, since the coverage area of that BTS indicates the whereabouts of the user's location. The coordinates of the BTS itself can be used as the first estimation of the mobile's location. Often, most base station sites host more than one BTS and thus each BTS would cover a sector from the whole area around the site, therefore decreasing the probable subscriber location area to a specific sector. The achievable accuracy of the estimated location depends on the size of the cell, which might vary from a few hundred metres to several kilometers.

2.2   Timing Advance

Timing Advance (TA) is a crude measurement of the time required for the signal to travel from the MS to the BTS. In the GSM system, where each mobile station is allocated a specific frequency and time slot to send and receive data, this measurement is essential to make sure that time slot management is handled correctly and that the data bursts from the MS arrive at the BTS at the correct time (in the time slot allocated to them). The computed TA value is then used by the MS to advance transmission bursts so that the data arrives at the correct time slot. The resolution is

one GSM bit, which has the duration of 3.69 microseconds. Since this value is a measure of the round trip delay from the MS to the BTS, half the way would be 1.85 microseconds, which at the speed of light would be approximately equal to 550 meters. Thus, Timing Advance can give an indication of distance from the identified BTS, in steps of approximately 550 meters.

2.3   Network Measurement Reports

The Mobile Station continuously measures signal strengths from both the serving cell (the BTS it is attached to) and also its neighbouring cells. The serving cell supplies the MS with a list of adjacent cell frequencies which it should monitor and in return, the MS provides the results of up to six strongest signal strength measurements. When the signal strength of one of the adjacent cell frequencies is substantially higher than that of the serving cell, *Handover* or *Cell Reselection* takes place. The concept of Cell Reselection is similar to that of the Handover and is essentially the process of selecting another cell to attach to, with the difference that during Cell Reselection the MS is in idle mode while Handover occurs while the MS is engaged in a communication session.

The richer these Network Measurement Reports (NMR), the more clues are available for making a correct guess of the location of the mobile device. This information can be both useful but deceivingly difficult to be interpreted correctly so as to contribute to a greater accuracy over the initial location area obtained by using solely Cell-ID and TA. The received signal strength cannot be directly interpreted into the distance of the MS from the corresponding BTS since radio signals do not get attenuated by air with the same rate as the attenuation of other materials such as buildings and other solid obstructions. Therefore, direct triangulation or trilateration using signal strength is not possible, especially in urban areas.
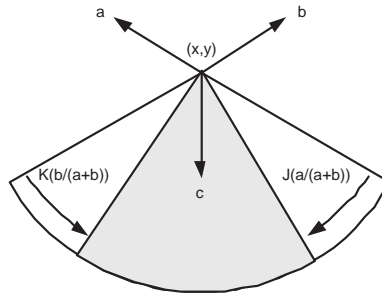

Fig. 1: Deducing a probable location sector from three signal strength measurements originating from the same site.

However, NMR information can be used to deduce angular approximations. The fact that the signal from a particular antenna is being received with a greater strength than others can indicate that the bearing of the MS from the site is close to a certain degree to the azimuth that the antenna is facing. One can also quite confidently assume that signals originating from antennas on the same site (and with the same configuration) will be attenuated equally (since they will encounter the same obstructions and suffer the same path loss). For instance, a site located at coordinates (x, y), which has the common three sector configuration, would typically be associated with three signal measurements a, b, and c, which will contribute to the approximation of a probable location *sector* related that site, as shown in Figure 1. The constants J and K depend on antenna configuration parameters such as its radiated beam width.

By evaluating measurements from each neighbouring site present in the NMR, one can geometrically exclude more areas that are improbable to resemble the location of the MS, and thus the original area obtained from the Cell-ID (and possibly TA) would be cropped down to a smaller one by removing the parts that are highly unlikely to enclose the subscriber's location. This principle will lead to complex geometric shapes which can be used as the initial search space for more complex and computationally intensive techniques that are to follow.

3   Path Loss Analysis

During the planning of wireless networks many path loss predictions for the whole coverage area of each BTS are computed in order to analyse and evaluate the coverage and interference scenario [4]. These path loss predictions are computed using propagation models which generate a 2D array representing the path loss for each pixel in the area around the BTS. The area represented by each pixel in this array depends on the desired granularity of the path loss predictions.

It is quite evident that the accuracy achieved from these models relies on the accuracy of the prediction models used. The three most common propagation models are discussed below.

Hata-Okumura This is an empirical model especially designed for the prediction of path loss in urban areas [6]. Obstacles, environmental features and local effects (shadowing or reflections) are not considered. Indoor coverage, especially in multi-floor buildings cannot be predicted with an acceptable accuracy.

COST 231 Walfisch-Ikegami This is an improved empirical and semi-deterministic model that was developed by the European COST research program [1]. This model gives particular attention to propagation over roof-tops (multiple diffractions in the vertical plane) and leads to higher accuracy in dense urban areas.

Intelligent Ray Tracing (IRT) The idea behind this deterministic model is to describe the wave propagation with rays launched from the transmitting antenna. These rays are reflected and diffracted at walls and similar obstacles [5]. Since propagation modelling through conventional *Ray Tracing* requires a high computational effort, IRT reduces this computation time by preprocessing building databases during which all geometric operations are pre-performed and stored. The main disadvantage with these kind of models is the high level of detail required to be present in the base map and building database.

Once the appropriate model is calibrated to predict to an acceptable accuracy, path loss predictions can be generated. A path loss prediction for each base station for each pixel is computed creating a 2D matrix representing the predicted signal strength of each location (up to a predefined granularity) for each BTS. The correct correlation of the actual measurements obtained from the mobile terminal with the predicted values will make localization of the mobile terminal possible.

3.1   Dominant Cell Prediction

The path loss predictions discussed above can be used to identify the locations where a particular BTS is predicted to be the dominant cell, i.e. its frequency will have the strongest signal and thus it will be most likely selected to be the serving cell. This is often referred to as the *best-server* prediction. However, the best-server does not necessarily indicate all the locations where the BTS might be the serving cell since the handset might not perform *cell reselection* if the signal from the stronger cell does not exceed the current serving cell by a certain threshold, called *cell reselection*

offset. Thus, we propose a variation of the *best-server* prediction which creates a new 2D matrix containing *cell domination levels*, indicating the difference in predicted signal strength between the particular cell and its strongest neighbour. Positive values in this array indicate the level by which the cell exceeds its strongest neighbour, while negative values indicate the level by which the cell is inferior (and therefore it is no longer the best server) to its strongest adjacent cell. Locations that are likely to be served by a particular cell i are those where:

$$D_{i(x,y)} \geq 0 - C_i$$

with $D_{i(x,y)}$ being the cell domination level for cell i at location (x, y) and C_i being the cell reselection offset for the BTS of cell i.

3.2   NMR Correlation

While *dominant cell predictions* help to confine the area where the mobile terminal is probably located, we still need to have a way to select the most probable location within that area. The NMR obtained from the mobile terminal can thus be compared to the predicted signal strengths at each location and the pixel that is predicted to match most to the obtained measurements will have the higher probability of being the actual location of the mobile terminal.
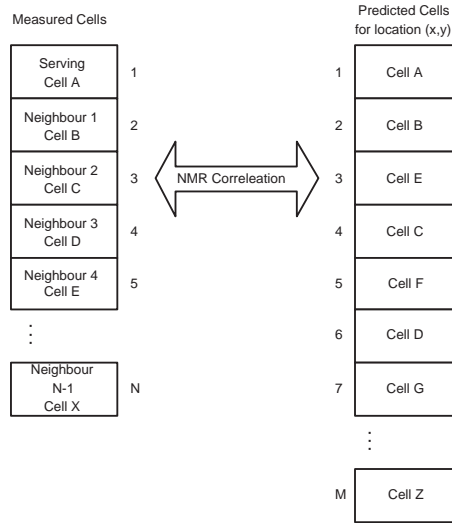

Fig. 2: Correlation of NMR information with predicted signal strengths for a particular location.

Relative Signal-strength Correlation The correlation method proposed by Wolfe et al. [5] involves performing a squared error analysis between the measured signal strengths and predicted signal strengths. This correlation method will produce good results outdoors for the generic case, but it will immediately suffer in urban environments where there are too much obstructions or the subscriber is indoors.

To make up for this problem, we propose a variant of this correlation method which basically involves the analysis of relative strength differences between the measured signal strength of the serving cell and the signal strengths of each neighbour compared with the predicted differences for the same sites. Thus, this variant will have an improved accuracy in locations where there is an approximately uniform signal drop due to situations such as the user being deep in a building.

Cell-placing Analysis The above correlation method does not take into consideration cells which were predicted to have a high signal strength but in fact had no measurement present in the NMR information. Thus, we propose another correlation method which analyses the cell's placing (in the list of cells ordered by their signal strength) and not the actual signal strength. Thus, a cell which is present in the predictions but not in the NMR information will automatically inflict more error to the other cells and decrease the likelihood of that pixel to resemble the mobile terminal's location.

Same-site Analysis Since two antennas on the same site are attenuated by the same obstructions, it can be assumed that the measured signal difference between two antennas residing on the same site will match closely to the predicted signal difference obtained from the path loss model. Thus, if more than one cell from the same site are present in the NMR information, a new probable location area, having the form of a narrow beam, can be generated from locations predicted to have similar signal strength differences between the same antennas. If the NMR information presents more than one site with this characteristic, then it would be also possible to *triangulate* the user's location from *beams* originating from two sites.

4   Quality of Position

Apart from having a positioning system which locates mobile terminals with an acceptable accuracy, it is also important that the system is capable of determining the chances it has to guess the user's position, or in other words, what would be the possible error associated with a particular location approximation [3]. This *Quality of Position* (QoP) would then be very useful for the LBS application, which would then be able to determine if the QoP is appropriate for the service and act accordingly. The methods for calculating the QoP we propose are based on analysing the distance from the approximated location to the vertices of the probable location area.

5   User Experience

Accurate positioning is only half of the story in delivering successful location-based services. One also has to focus on the service itself, the intuitiveness and user friendliness of the user interface, and the value it offers to the customer. There are also a number of customer oriented issues that must not be ignored, such as user-privacy [7].

Thus, it was felt that appropriate attention must also be given to the process of developing and delivering location-based services to the customer, to close the loop between mobile positioning technology and the actual user of the technology. This tight coupling between the user and the technology is especially important in our case since, the actual procurement of location information might have to be triggered or approved by the user himself through his mobile handset. This project also aims to present a prototype location service which abides with these guidelines and aims to provide the user with experience more than just content.

6   Conclusions

This research aims to present an extensive in-depth study of the value of Location Based Services and the technologies that can enable them in conventional GSM networks. A set of cell-based positioning techniques are proposed based on information available from the network and on accurate

path loss models. Part of the project also involves that these techniques are implemented and put on trial through the development of a prototype positioning system. The research will also put a special focus on the development of location based services themselves, user experience and other user-related issues.

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