Database Correlation Method for GSM Location

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Abstract

Cellular location methods based on angle of arrival (AOA) or time difference (e.g. E-OTD) measurements assume line-of-sight propagation between base stations and the mobile station. This assumption is not valid in urban microcellular environments. We present a Database Correlation Method (DCM) that can utilize any location-dependent signals available in cellular systems. This method works best in densely built urban areas. An application of DCM to GSM, using signal strength measurements, is described and trial results from urban and suburban environments are given. Comparison with AOA and E-OTD trials shows that DCM is a competitive alternative for GSM location in urban and suburban environments.

1. Introduction

Cellular location techniques have received a lot of attention recently. This is due to the great number of new value-added services that can be realized using location technology. Also, the requirement set by the United States Federal Communications Commission (FCC) to locate emergency calls according to certain accuracy criteria by October 2001 has been a driver for the development of location methods. Several techniques have been tested in trials and also in commercial networks. However, it is difficult to estimate which of the competing techniques is the best in terms of accuracy, or which of them fulfil the FCC requirement. This is due to the fact that the accuracy of each location method can not be presented by a single number but by a statistical error distribution, and a large amount of experimental data must be collected in order to find the distribution. Furthermore, the accuracy of any cellular location method is dependent on the network density as well as radio propagation effects.

Most of the proposed methods aiming at higher accuracy than simple cell identification are based either on signal time delay or angle of arrival measurements. Angle of arrival (AOA) technique requires antenna arrays at base stations [1], which makes it expensive to implement in current networks and impractical in microcell sites. GSM standardization includes two methods based on cellular signal timing measurements: uplink Time of Arrival (TOA) and downlink Enhanced Observed Time Difference (E-OTD) [2]. Also these methods require new hardware to the network, and E-OTD requires modifications to handsets as well. Another drawback of these methods is the narrow bandwidth of GSM signals, which does not allow highly accurate signal timing measurements.

In general, the performance of AOA and signal timing based methods is not optimal in densely built urban environments. With these methods, the location of the mobile station (MS) is calculated under the assumption of line-of-sight propagation between the base stations (BSs) and the MS. This assumption is not valid in city centers where high buildings often block the line of sight and signal propagates with less attenuation along street canyons than through the buildings. Moreover, severe multipath propagation characteristic to these environments makes it difficult to detect the angle of arrival or time of arrival of the direct component i.e. the resolution of these measurements is not as good as in more open propagation environments. Consequently, these methods can not fully exploit the dense cellular network of urban environments.

Some location methods, e.g. Enhanced Signal Strength method and Location Fingerprinting [3] have been designed to obtain optimal performance in urban environments. Such methods are important because many foreseen location applications will be used in urban environments and the accuracy requirement in such an environment is typically higher than in an open rural environment. In this paper, we present a new method [4], referred to as the Database Correlation Method (DCM), which can be implemented in GSM using the signal strength measurements performed by all GSM handsets. A common feature of all cellular location methods that are

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designed to perform well in urban environments is that they can not rely on the assumption of line-of-sight propagation. As opposed to Location Fingerprinting, DCM is an approach that requires no new hardware at BS sites because it takes advantage of the measurements available in the system. The difference between Enhanced Signal Strength method and our DCM trial is that we have obtained the signal strength database through measurements instead of computations.

2. Database Correlation Method

2.1. Generic location method

DCM is a general location method that can be applied to any cellular or WLAN network. The key idea is to store the signal information seen by a MS, from the whole coverage area of the location system, in a database that is used by a location server. The database should contain signal information samples, called fingerprints, with a resolution comparable to the accuracy that can be achieved with the method, and this resolution may vary in different environments. Depending on the particular cellular system, the signal fingerprints could include signal strength, signal time delay, or even channel impulse response. Any location-dependent signal information that can be measured by the MS is useful for the DCM technique. Also, it is possible to use measurements performed by the network as well as by the MS. When the MS needs to be located, the necessary measurements are performed and transmitted to the location server. The location server then calculates the MS location by comparing the transmitted fingerprint and the fingerprints of the database. The architecture of a DCM location system is illustrated in Figure 1. It is highlighted that DCM can be implemented in any wireless system, the MS only needs to be able to transmit a location-dependent fingerprint to the location server. This fingerprint may consist of signals measured from GSM, UMTS, WLAN, or GPS system also. The location server must be powerful enough to process all location requests in a reasonable time. In a large-scale implementation, this may require distributed processing.

The major effort in applying DCM is the creation and maintenance of the database. The signal fingerprints for the database can be collected either by measurements or by a computational network planning tool. Measurements are more laborious but produce more accurate fingerprint data. Also a combination of measured and computed fingerprints can be used. The compensation for the effort to build the database is an optimal location accuracy in environments where the assumption of line-of-sight propagation is not valid, e.g. in dense urban and indoor environments. The only assumption is that the database contains up-to-date data. However, minor changes in the

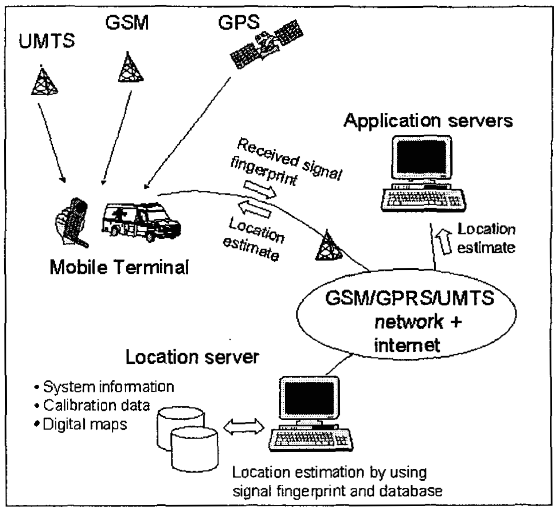

Figure 1. Architecture of DCM system.

network or propagation environment, e.g. new buildings, will only be seen as lowered location accuracy if the database is not updated. Also, it should be noted that similar information that is contained in the DCM database is also needed in network planning. Therefore, the creation and maintenance of the database also support network planning.

2.2. Application to GSM

The essential location-dependent parameters defined in GSM standard are Location Area Code (LAC), serving cell ID, timing advance (TA), and the measured signal strength of the serving cell and its neighbors. In dedicated mode (call on) all these parameters are known to both the MS and the network (signal strength measurements from up to 6 neighbor cells are reported from the MS back to the network). However, in idle mode only the LAC is known to the network. The MS, on the other hand, continuously makes signal strength measurements and also knows the cell ID of the strongest cell. Thus, in order to locate an idle-mode MS using these parameters, the MS must be able to transmit the available parameters to the location server. GSM handsets with the capability to send these measurements through SMS are already available.

LAC, cell ID, and TA, which is known with a resolution of 554 m in dedicated mode only, can be used for rough positioning. For more accurate positioning, it is possible to use signal strength measurements to estimate the distance between the MS and each BS, based on some path loss model. However, this is an unreliable way to measure distance since signal strength variations caused by shadowing will introduce large errors in distance estimates. Especially in urban environments it is seldom possible to obtain an accurate relation between signal strength and MS-BS distance. A better way of using signal strength measurements is to take advantage of previously measured signal strength contours in location determination. This idea has been presented over 30 years ago in [5], where it is emphasized that instead of instantaneous signal strength, the median of samples collected over a sufficiently long period should be used to avoid the effects of fast fading. In GSM, signal strength values in idle mode are averages over a period of at least 5 seconds [6], which is sufficient to smooth out fast fading if the MS is in slow motion. Even if the MS is stationary, the 200 kHz bandwidth of GSM assures that signal strength samples from adjacent locations vary considerably less than in the case of a single-frequency carrier wave. In a fixed position, variations on the order of 10 dB are common, but over 20 dB variations can be seen if a strong signal path, e.g. a line-of-sight path, is suddenly obstructed. Therefore, the algorithm that uses signal strength values for positioning should not be sensitive to such variations.

We have used a simple correlation-type algorithm for finding the best match between the fingerprint to be located and the fingerprints of the database. A difference between the fingerprint to be located and each fingerprint of the database is calculated as

$$d(k) = \sum_i (f_i - g_i(k))^2 + p(k)$$

where f_i is the signal strength of the request fingerprint on the i^{th} Broadcast Control Channel, $g_i(k)$ is the signal strength of k^{th} database fingerprint on the same channel, and the summation is taken over channels that are found in both fingerprints. Each channel that is found in only one of the fingerprints contributes to the penalty term $p(k)$. The coordinates of the database fingerprint that minimizes this difference are returned as the location result. It should be noted that the database search can be limited, based on LAC and cell ID, to a relatively small area. Also other types of algorithms, e.g. pattern matching, could be used.

3. Location trial

We have performed a location trial in two environments: a densely built urban environment (the center of Helsinki, Finland) and a suburban environment (the campus area of Otaniemi in Espoo, Finland). The trial area was approximately 3 km^2 in urban and 1.4 km^2 in suburban environment. In both cases, measurements were performed with a standard GSM phone, which was attached to the dashboard inside a car and connected to a laptop PC. Part of the urban measurements was performed on foot. In all measurements, the phone was in idle mode. The street grid of the trial area was covered once in order to create the database, by collecting on the average two measured fingerprints per second. Reference coordinates for the measured fingerprints were obtained by mouse-clicking marker points on the laptop PC each time the car stopped, started moving, turned, or passed a street corner. Between the marker points, reference coordinates were calculated assuming that the car moved with constant velocity. It was estimated that the errors in reference coordinates caused by the non-constant velocity and inaccurate marker coordinates should be below 20 meters.

During the measurements, the speed of the car was kept below 45 km/h in order to keep the distance the MS moves in 5 seconds, which is approximately the period over which the signal strength is averaged, reasonable. It was observed that lower speed leads to better location accuracy. Furthermore, when inserted in the database, the coordinates for a measured fingerprint were taken to be the reference coordinates of an earlier sample to compensate for the averaging time. We also tried averaging the fingerprints of the database with various grid spacings. If the grid spacing is not too large, averaging has no effect on location accuracy, but reduces the amount of fingerprints in the database and thus processing speed for one location request.

In addition to the measurements forming the database, we drove test routes through the trial area in order to evaluate the location accuracy of our method. In the urban area, three test routes of total length 15 km and in the suburban area one 1.5-km long test route were driven. The lengths of all test routes and the numbers of fingerprints collected are summarized in Table 1. Again, the reference coordinates for a sample fingerprint were taken from an earlier sample to compensate for the delay caused by averaging. This simulates the positioning of a stationary MS. Obviously, such compensation can not be done if a moving vehicle is to be located or tracked in real time. In this case, a tracking algorithm can be used to estimate the current location, but in a one-shot location the averaging delay causes an error proportional to the speed of the vehicle. However, this is true for any cellular location method due to the unavoidable delays in measurements, signaling, and location calculation.

Table 1. Test route lengths and numbers of collected fingerprints.

test route	length	fingerprints
urban 1	1450 m	389
urban 2	8600 m	3604
urban 3	4550 m	1240
suburban	3500 m	766

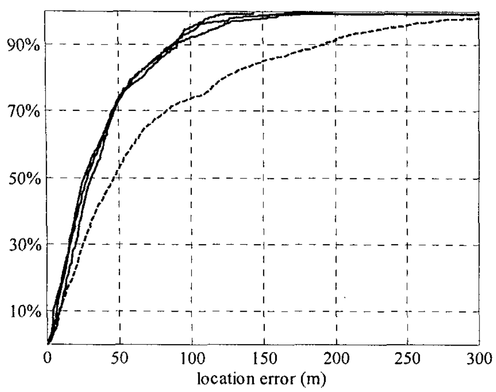

Figure 2. Cumulative location error distribution in urban test routes (solid curves) and suburban test route (dashed curve).

4. Trial results

The cumulative distributions of location error along the test routes are shown in Figure 2. It is seen that the error distribution in the urban test routes does not vary much, but there is a clear difference between urban and suburban accuracy. There are two factors that cause the higher accuracy in the urban environment: denser network and building shadowing. In an urban microcellular environment, the difference in signal strength values on different sides of a (heavy) building is so large that it exceeds random variations caused by e.g. antenna orientation or body shadowing. The signal propagates along street canyons and, as a consequence, the location error is typically directed along the street.

A comparison with the published results from AOA [1] and E-OTD [7,8] trials is shown in Table 2. The results from the two suburban E-OTD trials differ somewhat surprisingly, but the more accurate results [8] are very close to the AOA results [1]. Nevertheless, it can be observed that DCM can be as accurate in an urban environment as AOA or E-OTD in a suburban environment. Although we have no data from an urban AOA trial and only one urban E-OTD trial reference (see Table 2), it seems likely that these methods will not achieve higher accuracy in an urban environment than in a suburban environment. Thus we expect that in an urban environment, better accuracy can be achieved with DCM. In a suburban environment, DCM may provide less accurate, but still acceptable results.

Table 2. Comparison of DCM, AOA [1], and E-OTD [7,8] trial results. 67th and 90th percentiles are shown in all except the last row.

Trial	67%	90%
DCM urban	44 m	90 m
E-OTD urban [7]	141 m	237 m
DCM suburban	74 m	190 m
AOA suburban [1]	45 m	89 m
E-OTD suburban [7]	125 m	231 m
E-OTD suburban [8]	50 m (69%)	100 m (97%)

5. Conclusions

DCM can be seen as a complementary location method for AOA, E-OTD and GPS that perform well in open area i.e. rural and suburban environments. It works best in densely built urban and indoor environments, where these other methods encounter severe problems due to obstructed line-of-sight propagation paths. The accuracy of DCM is better than that of AOA or E-OTD in urban environments and acceptable for many applications in a suburban environment also. However, the costs of applying DCM are lower than for these two methods, since no modifications to the cellular network are needed. The only major cost comes from the construction and maintenance of the database. However, the database can be utilized in network planning and monitoring also.

With DCM, it is possible to use any location-dependent measurements available in the system. Therefore it would be possible to enhance the accuracy of E-OTD in urban environments using DCM. Also, DCM can be used for accurate positioning in WLAN (indoor) and UMTS (urban and indoor) systems.

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