LOCATION USING ESTIMATED IMPULSE RESPONSES IN A MOBILE COMMUNICATION SYSTEM

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ABSTRACT

Mobile station location is typically done using techniques based on time of arrival measurements like network assisted GPS and observed time difference of arrival. Other methods are based on network available information like cell-id, cell-sector, timing advanced and received-signal-strength.

In this paper, we present a novel method for mobile station location using estimated channel impulse responses (CIRs). The CIR is estimated and used in the demodulating process of wideband mobile communication systems like GSM and UMTS. The method is expected to yield better accuracy than other available methods in areas where significant multipath propagation is present.

1. INTRODUCTION

Location of mobile stations (MSs) has received a lot of attention lately. It is commonly believed that a great number of new value-added services can be realised using location technology. The proposed applications are many with functions ranging from traffic navigation, route finding, location-billing, localised news, weather and commercials. People visiting new areas can be made aware of their location relative to nearby hotels, shops and restaurants for instance.

The United States' Federal Communications Commission decision to mandate location-processing capabilities for Emergency-911 calls, increased development in this area substantially. The US network operators are now concentrating on two main technologies to meet the FCC deadline of December 1, 2001 (recently postponed from October 1, 2001). One is based on Global Positioning System (GPS) pseudorange measurements, and the other is based on propagation time measurements between the MS and the base station (BS). The methods developed are now commonly called network assisted GPS (A-GPS) [1] and observed time difference of arrival (OTDOA)[1] [2] respectively. An excellent comparison of these methods is given in [3].

Other location methods are based on network available information like cell-id, cell-sector, timing advanced and received signal strength [4]. Hybrid methods using different selections of these parameters often referred to as enhanced cell-id methods, have also been investigated. Some of these methods are operational yielding value-added services to network operators.

The main disadvantage of A-GPS and OTDOA systems are that they assume line of sight (LOS) propagation between the BS and the MS. This assumption is not valid in city centers where LOS often is blocked by high-rise buildings. In addition the accuracy of these systems is significantly degraded by the multipath propagation caused by signals bouncing off buildings or other elevated topological features. Particularly in street-canyon environments these effects seem to have a significant influence on the performance of location systems.

In mountainous areas characterised by narrow valleys and few base stations both A-GPS and OTDOA performance may degrade severely. In valleys where parts of the sky are blocked GPS signals are obstructed yielding problems for the positioning process [5]. The OTDOA method requires signaling with three or more base stations and this is rarely the case in such areas. Consequently developers have started to look into other methods of providing location capabilities in these areas and particularly in so-called dense urban environments.

Location fingerprinting techniques have received more attention among developers lately in order to address some of the problems related to non line of sight and multipath propagation [4]. In particular a method referred to as the Database Correlation Method is showing promising results [6]. The main idea of location fingerprinting is to map location sensitive parameters of measured radio signals along streets of interest. A database is established and a moving MS can compare its measurements with the ones in the database. In this way the location of a mobile can be estimated. In [6] the parameters used for comparison is the received signal strength as measured by the MS from several nearby BSs.

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[1] The terms time difference of arrival (TDOA) and enhanced observed time difference (E-OTD) are also used for the OTDOA method.

We introduce a new method using the channel impulse response (CIR) for location purposes. The CIR is estimated both by the MS and by the BS and used in the demodulation process in wideband communication systems like GSM [7] and UMTS [8]. Hence no new hardware is required in the MS or at the BS except for a location server containing the database.

2. LOCATION USING ESTIMATED IMPULSE RESPONSE

2.1. System overview

The general idea is to store maps of multipath profiles (MPs) for the whole coverage area. The solution space is thus limited to roads already mapped by a channel sounder. A possible architecture of the proposed location system may look like figure 1. It seems natural in a real system to put the computational load on a location server also containing the database at the BS. Estimating the MPs on the downlink is also possible requiring the location database to be available for the MS in the vehicle (on a CD for example). The results presented in this paper are generated from post-processing of uplink CIR measurements.

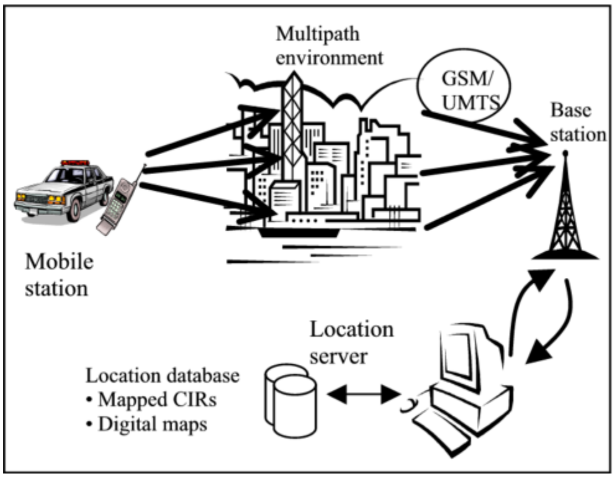

Figure 1. Possible architecture of the proposed location system

2.2. Physical background

Reflections on the radio channel between a receiver and a transmitter give rise to multipath propagation. The CIR, as estimated in wideband receivers, gives an indication of the number of multiple propagation paths as well as their relative delay and strength. The MP at a particular location is normally not unique, for example if there are no reflections due to flat terrain. In most part of, and in particular in areas of interest for this application (e.g. urban and mountainous areas), reflections are present and yield characteristic MPs [9].

The phase of our measured signal will rotate 360 degrees for every one wavelength (15 cm) of radial movement at 2 GHz. This is definitely below our accuracy requirements, which is more in the order of ten meters. The phase information is thus removed in order to save storage space and processing power.

2.3. Estimating the multipath profiles for the database

We have collected MPs along a route of movement. Each profile is coupled with its location and stored in a database. Later a MS moves along the same route, the CIRs are measured and the MPs are estimated in the same manner. A comparison process takes place with the previously collected MPs in the database, yielding location estimates along the route.

The CIR is estimated in GSM during the training sequence and in UMTS by using the pilot sequence in the dedicated physical control channel (DPCCH) standardised for the wideband code division multiple access (WCDMA) radio interface to carry layer 1 control information [8].

We have used two forms of averaging when post-processing the measured data. The MS is placed on a vehicle and any movement is registered by an odometer. The vehicle moved in the forward direction only. When building the database the streets were divided into 1-dimensional cells with a length of 4 meters. All the measured CIRs within one cell were averaged to yield a MP for this cell. Hence we have a 1-dimensional solution space. A junction (although not treated in this paper) would result in a natural extension of this framework. A T-junction for instance would be seen as three 1-dimensional solution spaces yielding position fixes along the most probable street (thus including the possibility of a U-turn).

Hence spatial averaging is used to estimate the MPs for the database. The radio environment is thus mapped to yield one MP for each of the 4 meter cells.

2.4 Estimating the mobile station location

The MS estimates the MPs by time averaging the measured CIRs. The CIRs are collected into 0.5 second timeslots and averaged, thus yielding two MPs per second. All of the MPs are then compared successively with every element in the database. No filtering is performed thus all locations have the same probability for a match.

In order to perform the MP comparison we need to define a metric of similarity. This is often called a cost-function and the one we have used is presented below. Time is represented by the discrete parameter t_k where $k \in [1, K]$, thus $t_{k=1}$ is the start time and $t_{k=K}$ is the stop time of the MP estimation process as performed by the MS. The 0.5 second averaging time of the MS is thus the time between to samples i.e. $t_{k+1} - t_k = 0.5s$.

Distance, or the equivalent term location, is represented by the discrete parameter n where $n \in [1,N]$, thus $n=1$ is the start location and $n=N$ is the end of the route.

The distance between n and $n+1$ is thus the 4 meters of spatial averaging as we described earlier.

We express the difference between the MPs to be located and the ones in the database at time instant t_k and location n as

$$d(t_k, n) = \left\| \boldsymbol{i}(t_k) - \boldsymbol{b}(n) \right\|$$

where $\boldsymbol{i}(t_k)$ is the measured MP at time instant t_k of the MS to be located and $\boldsymbol{b}(n)$ is the MP at location n stored in the database. Collecting the scalar function $d(t_k,n)$ for $n \in [1,N]$ into a vector and multiplying with minus one yields our cost-function

$$\boldsymbol{p}(t_k) = -\,[\,d(t_k,1) \;\; d(t_k,2) \;\ldots\; d(t_k,N)\,]$$

where $\boldsymbol{p}(t_k)$ expresses mathematically how well an MP estimated at time t_k matches with the MPs in the database. A global maximum will occur on the cost-function $\boldsymbol{p}(t_k)$ corresponding to the location of the most similar MP. At every time instant t_k we thus choose the position n of the maximum of the cost-function $\boldsymbol{p}(t_k)$ as our location estimate.

This simple decision process is chosen to give an indicator of the potential accuracy of this location method. Surely clever filtering and intelligence can be added to yield a more robust system.

3. MEASUREMENTS

Measurements are performed by the channel sounder designed and implemented by SIEMENS AG. A detailed mathematical and technical description is given in [10]. The channel sounder is designed to perform outdoor CIR measurements in the 1800 MHz range. The CIR bandwidth and sampling period was set to 10 MHz and 5.12 ms respectively. The channel sounder thus provided approximately 195 CIRs pr second to be stored on files.

As a comparison the UMTS bandwidth is 5 MHz and the DPCCH estimates the CIR 16 times in every 10 ms frame yielding a total of 1600 CIRs pr second.

The measurement campaign was carried out in the Munich urban area in the typical street-canyon environment of Schellingstrasse. The average height of buildings in this street is about 16 meters. The measurement route was about 320 meters and the vehicle drive pattern was typical for a relative narrow urban street with traffic lights and pedestrian crossings. The velocity ranged from 0 to 30 km/h with an average of about 17 km/h.

The channel sounder consists of a receiver with a 120 degrees sectorised antenna situated 21 meters above the ground. The transmitter was set up in a vehicle with an outside antenna at the output. The transmitter antenna was mounted 2,1 meter above the ground. The measured I and Q channel CIRs and the odometer readings had a common time reference. The coupling between location (measured by the odometer) and the CIRs (measured by the channel sounder) was performed by post-processing the data. The odometer had a resolution of 1 centimetre and was a highly accurate Peisler-wheel.

The same street was driven three times while performing CIR measurements. The starting point was the same. Three independent series of the same route were stored as files. Each series consists of about 13500 measured CIRs. Later when post-processing the data as explained in section 2.3 and 2.4 one series was chosen as the database and another represented the moving MS to be located. In this way the true position of the MS to be located was known and could be used to estimate the position error.

4. RESULTS

Calculating the cost-function $\boldsymbol{p}(t_k)$ and choosing the position corresponding to maximum for every time instant t_k, as described in section 2.4, yield figure 2. The solid line in this figure represents estimated position. It is a typical example of the positioning process using fingerprinting methods. The systematic behaviour of the error around 150 meters results when MPs in one area are relative similar to MPs in another area. The cost-function $\boldsymbol{p}(t_k)$ unfortunately has a maximum at the wrong location in such cases. The difference of levels between the incorrect highest top and the correct top is normally relative small but still sufficient to yield significant errors using our relative simple location algorithm. In some cases similar MPs in two different areas lead to big ripples of the graph between the correct and the incorrect location.

The big dip in the solid line of figure 2 as can be seen around 270 meters is an example of an estimated MP at one time instant being most similar to a MP at a totally wrong location. This measurement error may be caused by temporarily shadowing of the transmitted signal (by a passing bus for example) or measurement noise (sampling) effects. It is also possible that the MPs at these two locations truly are very similar increasing the probability of making an incorrect decision.

We have calculated the cumulative distribution function of the total error from three different runs with the described algorithm. Series nr 1 was used as database against series nr 2 and 3 in addition series nr 2 was used as database against series nr 3. The results are depicted in figure 3 showing an error of less than 19 meters in 67% of the cases and an error less than 94 meters in 95% of the cases.

It has to be stressed that our measurement route is not long enough to exclude some influence of border effects on the statistics.

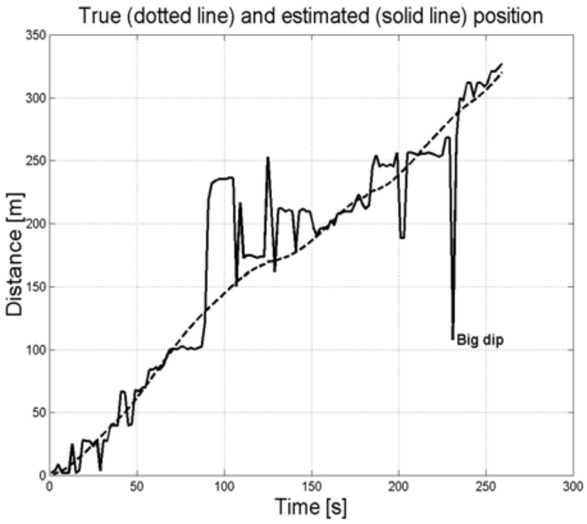

Figure 2. Location estimation along a route of movement in dense urban environment of Munich.

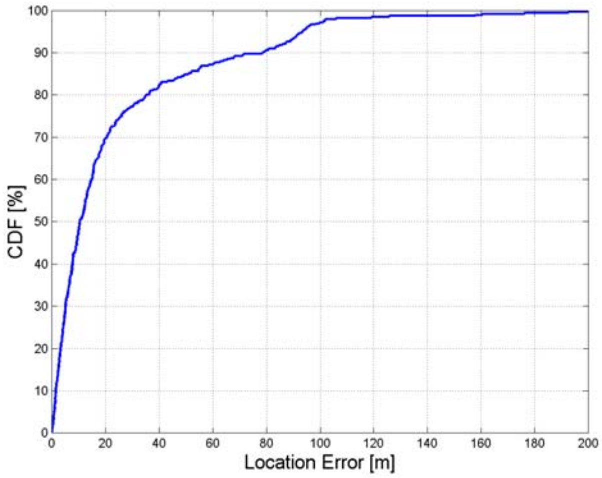

Figure 3. The cumulative distribution function of the location error in dense urban environment of Munich.

5. CONCLUSIONS

We have performed channel impulse response measurements several times along a route in Munich urban area. The measurements are post-processed to yield a database of multipath profiles. The multipath profiles in the database are compared with profiles from another measurements run. The result is a system yielding location estimates along the route of movement.

The accuracy of this method is primarily a function of the reproducibility and uniqueness of the estimated multipath profiles. Clearly, if our choice of location dependent parameters yields a great amount of variation for a specific location, the estimate for this location will be degraded. Estimating locations also become more difficult if the location dependent parameters are very similar at different locations. Hence a large-scale sensitivity analysis with this in mind has to be carried out.

The main advantages of the proposed location system are its potential to yield relatively high accuracy compared to other methods and that it requires signalling from one node only. The main disadvantage is that the solution space will be limited to roads already mapped.

We have a limited solution space for our location processing. The route we used is just 320 meters. The probability of an error is thus reduced, using the described algorithm, compared to a full-scale system. We believe that by developing clever algorithms based on robust pattern recognition techniques, filtering (e.g. Kalman filtering) and some intelligence, the system will be able to cope with more realistic scenarios without increasing the error.

6. REFERENCES

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