Pilot correlation positioning method for urban UMTS networks

Jakub Borkowski and Jukka Lempiäinen
Institute of Communications Engineering, Tampere University of Technology
P.O. Box 553, FI-33101 TAMPERE, FINLAND
Tel. +358 3 3115 5137, Fax. +358 3 3115 3808
{jakub.borkowski, jukka.lempiainen}@tut.fi

Abstract – The aim of this paper is to present a novel mobile positioning method for urban deployment of UMTS network. Proposed technique is entirely network-based, thus not involving any modifications in the terminals. The method presented in this paper utilizes information accessible in the SRNC describing the visible pilot RSCP measurements of a particular UE. Least square method is used for selecting the most similar situation from the set of pre-measured pilots strength samples stored in location server in the network. The performance of the method has been examined by intensive measurement campaigns carried out in Elisa UMTS network in Tampere, Finland. Field trials have provided very promising results, since on the average, the position of the user can be estimated with the accuracy at the level of 190 m for 90% of measurements and 90 m with 67% CERP.

1. Introduction

Operators considering deployment of a location technique in their networks must choose between expected performance and associated costs. The best performance of mobile positioning in terms of the accuracy and reliability provides AGPS (assisted Global Positioning System) method [1]-[2]. Thus, in long-term deployment, almost certainly, this technique will be in common use. However, ordinary terminals currently being released for UMTS (Universal Mobile Telecommunication System) networks are not equipped with GPS receivers. Therefore, there is still room for solutions for mobile positioning with very high degree of applicability. Moreover, due to limited indoor availability of the GPS, deployment of the AGPS technique is often considered in hybrid solution with a cellular positioning method, which provides service for indoor users. Thus, cellular location techniques can be further utilized in hybrid approaches with the AGPS. The crucial requirement of these, cellular location methods, constitutes a possibility of direct deployment in current UMTS networks, without a need for users to change or update their terminals or for operators to introduce complex changes to the network equipment.

Multipath propagation significantly corrupts the accuracy in most of the cellular positioning techniques. Most challenging situation for time-biased location systems is a closely spaced scenario. Arrival of consecutive multipath components at the UE (User Equipment) within the time instance shorter than a resolution of the RAKE receiver, which is duration of one WCDMA (Wideband Code Division Multiple Access) chip – 0.26 µs, causes invalid estimation. The area of research, focusing on extraction of reliable time of arrival measurements from erroneous reports has been widely explored. Most popular approaches include DLL (delay locked loop) - based solutions [3], EKF (extended Kalman filter) structures [4], derivatives of ML (maximum likelihood) estimation [5], deconvolution methods [6], and subspace-based algorithms [7]. However, implementation of the referred algorithms, reducing the negative impact of multipath propagation, significantly increases the total complexity of the system. Relatively inexpensive solution for robust positioning in the presence of multipath has been presented in [8]. The ECID+RTT (Enhanced Cell ID + round trip time) technique forces the UE to SHO (soft handover) [9] for the time instant needed for realization of the RTT [15] measurements from the NodeBs in the active set. Moreover, the geometrical pseudo ranges provided by RTT measurements are processed by uncomplicated geometrical transformations and Virtual Mapping algorithm, described in [8]. The drawback of this method is a requirement of software update in the terminals, in order to support the forced SHO procedure, which naturally decreases its degree of applicability in the current market. Other set of approaches to the positioning problem in urban environments is based on a database consisting of a history of measurements. Based on a priori knowledge of a particular measurement in the entire network, the position of the UE is estimated in the region corresponding to the sample with the highest degree of correlation with the report. For GSM (Global System for Mobile Communications), a method utilizing database with pre-measured signal strength samples has been proposed in [10] and further intensively evaluated, e.g., in [11]. Logically, collecting measurement samples for needs of the database can be avoided in these techniques by use of a predicted data, as presented in [12], where satisfying outcomes have been achieved, as 90% CERP (circular error probability) is below 200 m. Whereas in UMTS, DCM (database correlation method) [13] has been developed for urban positioning, which employs the measurement of multipath delay profile from the strongest cell. Moreover, the complementary used RTT information limits the area of possible estimates. Good results have been achieved by testing the method in dense network scenarios - 95% of users can be located with the error smaller than 140 m in the network with 210 m average site spacing distances. However, the key disadvantage of this...
method is that the impulse response measurements are not standardized, thus triggering the requirement of software changes in the terminals. Moreover, reporting of such measurements to the location server is also not standardized, thus the degree of applicability of the DCM method is not at a satisfying level.

In this paper, an effective positioning method for urban environment will be proposed and evaluated by field measurements. The proposed technique is entirely based on standardized measurements and procedures, therefore the deployment costs are significantly minimized. PCM (pilot correlation method) requires a database with stored pre-measured samples over the network coverage area. Samples include the most likelihood results of RSCP (received signal code power) measurements of visible pilots in every area of the service coverage. Database is created automatically from log files of the measurement tool. Thus, there is no need for additional effort related to database formation, because the radio conditions must be measured during network deployment and optimization process.

2. Pilot correlation method

The planned area of service coverage is divided into small regions (positioning regions). Size of the positioning regions is tuned according to the desired accuracy for planned location sensitive applications. For each positioning region, the most probable situation of CPICHs (Common Pilot Channels) visibility with corresponding results of RSCP measurements is stored. During typical functionality of the network, in the Cell_DCH or Cell_FACH state the UE continuously measures the RSCP of visible pilots and reports them in the Measurement Report messages [14] to the SRNC (Serving Radio Network Controller). Therefore, the required information for positioning is already in the network. When the Location Request is sent to the SRNC/SMLC (Serving Mobile Location Centre), simply, the latest Measurement Report stored in the SRNC from the particular mobile is selected and transferred to the SMLC for further processing. If the latest available Measurement Report in the SRNC was received relatively long time ago, the information needs to be updated by paging the UE, which is being located. Similar procedure is performed when the referred UE is in the Idle mode. Then, the SRNC executes the paging procedure in order to make the UE to enter the Cell_FACH state for a time instant required to send a message containing RSCP measurements of the pilots to the SRNC. Thus, there is no additional specific signaling introduced in the air interface and most importantly, the method can be applied to regular UEs without any hardware or software update. The overall procedure of the operation is presented in Fig. 2. Naturally, the Location Request can also be originated from the terminal itself. The database required for the PCM operation is located in the SMLC. When the selected Measurement Report is forwarded from the SRNC, the corresponding vector containing scrambling codes and measured RSCP of visible pilots is compared with all samples stored in the database. The least square method is applied to compute the deviation between stored, pre-measured samples, and the actual measurement, Eq. 1,

$$S_{LMS} = \sum_{i=1}^{N} (s_i - m_i)^2 = \sum_{i=1}^{N} \Delta_i$$

where, vectors representing stored sample and reported measurement are indicated by $s_i$ and $m_i$, correspondingly. Deviation is computed for all fields included in the vector ($N$) and it is applied for all samples stored in the database. The positioning region, which corresponds to the stored sample having the highest resemblance with the measurement, constitutes the location estimate. The position of the user is always mapped in the middle point of the positioning region thus minimizing the estimation error. The selected location is forwarded to the SRNC. Implemented software for the need of the positioning system generates automatically a database from log files of the field measurement tool. Due to crucial requirements of intensive radio measurements before any commercial launch of the network, creation of the database does not involve significant extra effort. Under regular operation of the positioning method, the database should be updated from time to time (e.g., 6-12 months) due to propagation changes caused by modification of the urban scenario. Logically, the database can also be generated from predicted values by radio network planning tool.
3. Measurement scenario

The pilot correlation method was deployed for testing purposes in the Elisa UMTS network in the urban environment of Tampere city, as presented in Fig. 1. Sites were mainly deployed in 3-sectored manner with 400 m mean spacing distances. The average base station antenna height was slightly higher than the typical rooftop level, which was approximately 15 m thus forming a light macrocellular environment. Within the area of around 2 km$^2$, over 300 positioning regions were distinguished. For collecting samples for a need of the database, a measurement tool consisting of laptop PC with Nemo Outdoor software connected to the test mobile phone (Nokia 7600) and the GPS receiver (Garmin 35) was utilized. Evaluation of the accuracy of the proposed method was performed by setting a mobile user with the same measurement equipment moving along 3 different routes, Figs 3a, 4a, and 5a. During each route, the location of the user was estimated over 2000 times. In every case, the reported accuracy constituted a deviation between the reported position and the indication of the GPS receiver.

4. Measurement results

In the first stage, the deviation of the estimated location from the GPS-reported position of a single user moving along the route, as depicted in Fig. 3a, was evaluated. The cumulative distribution function in Fig. 3b presents achieved accuracy of the approach. The precision of the positioning higher than 130 m for 90% of measurements and 70 m for 67% of measurements fulfils the emergency - 911 requirements for the network-based solutions with big margin and simultaneously it is sufficient for most of the LBS (location-based services). The mean value of the accuracy is slightly below 95 m and the standard deviation is 68 m. Subsequently, the performance of the proposed technique was examined in more complex routes over the whole area of the service coverage, as illustrated in Figs. 4a and 5a. Routes were driven in different days with different interference level in the network. Thus, a danger of wrong correlation estimates was potentially higher. Performed evaluation provided very positive results, since the 90% CERP is maintained at the level of 195 m in the case of the route 2 (see Fig. 4b) and 180 m in the case of the route 3 (see Fig. 5b). The degree of 67% CERP is maintained at the level of 90 m for both routes 2 and 3. Due to more narrow urban canyons in these more dense routes, the
GPS error was significantly higher than in the route 1, thus contributing to the overall accuracy decrease of the proposed method. Therefore, it is advisable to use a DGPS (differential GPS) in the database creation process in order to produce the most accurate database.

Other performance factors including the availability and latency also do not pose problems in the entire functionality of the system. The positioning technique is available for all mobiles within the service area. Since the proposed method does not include complex procedures or heavy computation, the latency of the whole positioning process can be neglected.

5. Performance comparison

The accuracy of the pilot correlation method in comparison with other techniques for mobile positioning is illustrated in Fig. 6. The accuracy of the PCM is approximately at the same level as the ECID+RTT method. However, the PCM is much more applicable, since deployment of the ECID+RTT technique requires slight software changes in terminals enabling forced SHO procedure [9]. In turn, the PCM is entirely network-based, thus not requiring any modifications in the terminals. Fig. 6 also illustrates the accuracy, which can be achieved by one of the simplest approaches for mobile positioning – a mobile-based technique utilizing multiple RSCP measurements. Naturally, for many location-sensitive applications the estimation accuracy provided by the multiple RSCP technique is already at the sufficient level. However availability of more accurate positioning measurements, e.g., by utilization of the PCM, can significantly widen the scope of offered location-based services, while keeping the implementation complexity at the very low level.

6. Further development

The attainable accuracy of the PCM method is naturally limited by definition of the positioning region, thus a direct improvement will include a definition of sub-positioning regions within the existing ones.

Further development of the PCM will include development of an algorithm sensitive for the degree of correlation. The procedure will forward the consecutive measurements properly weighted for correlation calculation in case when the degree of correlation is low. Moreover, it is believed that supplementing the stored samples in the database with most common RTT measurements data for each positioning region could significantly improve the overall performance in larger cities. Therefore, this extension to the PCM method will be analyzed and tested by field measurements.

7. Conclusions and discussion

Pilot correlation method for UMTS urban environment was introduced. Key advantage of the proposed method for mobile positioning is the high level of applicability, since it can be deployed without any modifications in the terminals. Considering rapidly increasing coverage and number of subscribers in UMTS networks worldwide, the presented method provides operators a solution for immediate deployment without significant investments. The proposed method utilizes a database with stored a priori measured RSCP of visible pilots in the network area. The position of the UE is estimated in the region characterized by a minimum deviation between measured RSCP by the UE and the stored sample in the database. The accuracy of the proposed approach was evaluated by intensive measurement campaigns carried out in the Elisa UMTS network deployed in the urban environment of Tampere, Finland. It was shown that the accuracy for
67% of measurements is maintained in the range of 70 m - 90 m, while for 90% of measurement the accuracy varies from 130 m to 195 m. Obtained results of the accuracy fulfill the safety requirements for network-based solutions and naturally constitute reliable positioning information for various commercial location-based applications. Due to the uncomplicated procedure of positioning the overall latency does not introduce any limits in potential applications.

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