Geometrical Transformations as an Efficient Mean for Reducing Impact of Multipath Propagation on Positioning Accuracy

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Abstract

Major challenge in time-biased mobile positioning techniques is a derivation of reliable time of arrival or range measurements. Multipath propagation error corrupts the accuracy of positioning, and therefore adequate techniques need to be deployed. This paper proposes an algorithm for decreasing contribution of multipath propagation on positioning in networks, typical for macrocellular urban deployment in UMTS. Since the whole procedure is based on geometrical transformations, the impact on system performance as well as the implementation complexity is kept at the minimum level. The algorithm constitutes an enhancement to an inexpensive Cell ID+RTT location method, thus the functionality together with performance analysis is presented in the context of this technique. However, it can easily be applied on the top of alternative time-biased cellular positioning methods. Accuracy of enhanced Cell ID+RTT in multipath environment has been simulated with very promising results. Outcomes have showed that nearly 90% of users can be located within 170 m, and correspondingly 67% with the accuracy of 120 m, in the scenario with the highest considered multipath errors and without presence of LOS.

1 Introduction

Estimation of exact time of signal arrival is necessary for accurate mobile positioning. Expected reliability of location measurements must be known for proper application of LBS (location based services). Throughout the years, many techniques for mitigating the effects of multipath propagation in CDMA (Code Division Multiple Access) - based systems have been developed. The most challenging situation occurs when consecutive multipath components arrive at the receiver within the period less than one chip, since then, the traditional RAKE receiver cannot distinguish the individual paths. Naturally, for location estimation methods, an ability of separating the first arriving component is the most important. Moreover, detection whether the first arriving path is LOS (line of sight) or not is crucial for proper location evaluation. The LOS detection problem has not been extensively studied in accessible research. Most of the existing solutions are based on history observation of the range measurements [15], [16]. Similar solution is utilized in a database correlation method [3], when measured power delay profile from detected cell is compared with the profile stored in the database. However, application of these algorithms is complex due to a strong assumption, that a priori knowledge of system’s standard measurement noise or power profile is known. Existing techniques for estimating a multipath delay in CDMA systems generally include DLL (delay locked loop) - based structures, EKF (extended Kalman filter) - based solutions, ML (maximum likelihood) detection, deconvolution methods, and subspace-based algorithms [11]. Traditionally, feedback loops are utilized for delay tracking [7], their main drawbacks include reduced reliability in closely spaced path scenarios and high possibility of loosing the lock when feedback propagation errors are significant. Originally, the extended Kalman filter for delay tracking in a single user CDMA system was proposed in [9], and later on, enhanced to the multi-user scheme. Behaviour of the EKF - based structures in closely spaced path scenarios is much better and a converge process is notably faster than in DLL - based solutions. However, due to extended complexity and high sensitivity to the initial conditions, the application of EKF - based methods is also problematic. The aim of the ML - based algorithms is a cancellation of multipath interference by subtraction from the correlation function of a reference pulse. MEDLL (Multipath Estimating Delay Locked Loop), initially developed for GPS positioning [14] and consecutively adopted for root raised cosine pulse shape used in CDMA - based systems [11], tries to estimate jointly delays, phases, and amplitudes of all multipath components. Complexity of the approach increases meaningfully with the number of paths. The multipath delay can also be estimated by application of deconvolution methods. However, together with inverse filtering the noise is enhanced [8]. The widest known subspace-based algorithms include MUSIC (Multiple Signal Classification) [10,6] and ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) [10]. Due to the high resolution in estimation process of these procedures, the high complexity makes the subspace-based algorithms difficult to implement.

Typically, network designers need to balance complexity and required performance. Therefore, there is a continuous
demand for inexpensive positioning methods providing sufficient performance for most of the location-sensitive applications.

The aim of this paper is to propose a solution for mobile positioning providing a high degree of the accuracy in multipath propagation environment. The technique does not require knowledge of LOS and delays between subsequent multipath components. Information of cellular ranges is obtained by application of Cell ID+RTT (Round Trip Time) [4] method enhanced by FSHO (Forced Soft Handover) algorithm [5]. Naturally, the proposed method can also utilize location information provided by other time-biased cellular location technique, e.g., OTDOA (Observed Time Difference of Arrival) [2]. The whole procedure is based on consecutive RTT measurements for better reliability and geometrical transformations for delivering the most accurate position. The algorithm takes advantage of dense network deployment, high probability of establishing SHO (soft handover) with the nearest sites, and channel variation characteristics. Since almost all calculations take place in the SRNC (Serving Radio Network Controller), the proposed solution does not interfere with the system performance and requires only minor software changes.

2 Performance of the Forced SHO algorithm for Cell ID+RTT location method

Cell ID+RTT has been selected as a referred location technology due to its low deployment costs and satisfied performance for mobiles within SHO. In free propagation conditions, the accuracy of positioning, when the UE is in SHO with three cells, is at the level of 16 m [4]. Previous studies have showed that the UE can be easily forced to three-way SHO (soft handover) for the time instant needed for necessary RTT measurements, thus enabling high accurate positioning for nearly all served mobiles in the network. The availability is limited by hearability of the 3rd pilot. Assuming $E_{\text{N0}} \leq 23 \text{ dB}$ as a reception threshold for CPICH (Common Pilot Channel), in 1 km cell spacing scenario, nearly 90% of mobiles can be forced to three-way SHO (soft handover) for the time instant needed for necessary RTT measurements, thus enabling high accurate positioning for nearly all served mobiles in the network. The availability is limited by hearability of the 3rd pilot. Assuming $E_{\text{N0}} \leq 23 \text{ dB}$ as a reception threshold for CPICH (Common Pilot Channel), in 1 km cell spacing scenario, nearly 90% of mobiles can be forced to three-way SHO (soft handover) for the time instant needed for necessary RTT measurements, thus enabling high accurate positioning for nearly all served mobiles in the network.

Moreover, utilization of standardized messages and procedures requires only slight software changes in the UE.

3 Theory of the proposed algorithm

The overall structure of the algorithm is presented in Fig. 1. The procedure includes FSHO algorithm, repeatable RTT measurements, geometrical calculations, and VM (virtual mapping). Details of the FSHO algorithm are omitted and can be found in [5]. Since all calculations happen in the SRNC, there is no additional signaling introduced in the air interface. The algorithm has been designed for application in 6-sectored network environment, since this configuration provides the best outcomes from the system capacity and positioning point of view [4,12,13].

Initially, the position of the UE is estimated on traditional Cell ID+RTT basis. The original sector ID is remembered, and the value of RTT is examined. If the reported RTT corresponds to the distance less than 15% of site spacing than the accuracy of a single Cell ID+RTT is usually at a good level in dense networks, and thus further action is not needed. For instance, in 1 km site spacing scenario, the accuracy varies as a function of distance between the UE and the serving NodeB from 16 m to 50 m when the UE is from 20 m to 150 m far away from the serving site, correspondingly [4]. Moreover, if the reported RTT corresponds to less than 150 m, the multipath delay is not significant, and thus the reliability of the range measurement is at the sufficient level. Otherwise, the UE is forced to three-way SHO by application of the FSHO algorithm. After successful establishment of the three-way SHO, the SRNC checks if the original sector ID of the UE belongs to outer or inner sectors relatively to the NodeBs of the newly established AS (active set), see Fig. 2. If the original sector ID belongs to the group of outer sectors relatively to the AS of NodeBs, the UE is forced to leave the SHO, and it is successively forced to the three-way SHO with other cells, precisely defined by the SRNC. This step is to ensure that the UE is located somewhere inside the hexagon limited by dashed lines in the Fig. 2, i.e., that the original sector ID of the UE belongs to the group of inner sectors. Subsequently, the RTT is simultaneously measured by all NodeBs in the AS. If any of the reported measurements corresponds to distance 115% larger than site spacing, the measurement is treated as unreliable and for further calculations the maximum possible size of this range is used.

![Figure 1: Overall structure of the proposed procedure.](image-url)
Definition of inner and outer sectors of the UE served by NodeB 1 relatively to NodeB 2 and NodeB 3. Inner sectors: 1 and 2; Outer sectors: 3, 4, 5, and 6.

Figure 3: Maximum possible value of RTT report - 115% of the site spacing.

Points of ranges intersections located closer to the symmetrical centre of the triangle constructed by NodeBs of AS.

The position of the UE is estimated in the intersection point of triangle bisectors constructed on derived points.

Simulation environment

Dedicated simulator in Matlab was implemented for performance examination of the proposed algorithm under various propagation conditions. The network layout consisted of three sites having equal site spacing of 1 km with equal antenna directions. Mobiles were uniformly distributed over the simulation area. Simulations were made based on the assumption that located mobile is forced to three-way SHO. For a randomly selected mobile, RTT measurements from three sites were simulated. Multipath propagation errors in range measurements were modelled in such a manner that each RTT measurement was delayed by a value determined by a function of the UE distance from the corresponding NodeB. Moreover, RTT errors were multiplied by a random variable in order to model channel variations, see Fig. 6.
Three different multipath models were considered with different expected delays in RTT measurements. Subsequent iterations of range measurements are performed for reliability improvement. Selection of the multipath model in each iteration of RTT measurements is made randomly according to the predefined weights. Their values depend on the original propagation environment (in the second iteration), see Table 1, or multipath model selected in the previous iteration round, see Table 2. Weights for multipath model selection are defined in such a manner that probability of choosing different model than in the previous round is kept at low level, approximately 10%, see Table 2. Simulations were performed for 4 and 10 iterations, and presented results of the accuracy constitute an average of 5000 location estimation processes in each case. The procedure of virtual mapping was deployed for 6-sectored configuration with 65° antennas.

### 5 Simulation results

Simulations have showed very promising outcomes of the proposed algorithm. Accuracy results are presented in the form of CDF (cumulative distribution function) in Fig. 7. In scenarios where delays due to multipath propagation are the greatest (Urban A, Urban B), application of the VM can significantly enhance the accuracy. For instance, the mean value of the accuracy decreases from 139 m to 105 m with use of the VM in Urban A environment, when RTT is measured 4 times on each radio link. Similarly, the variance is reduced from 97 m to 73 m in the same propagation scenario. Accuracy of the approach is radically better with higher number of iterations, e.g., in Urban A, the mean value is from 89 m with VM to 105 m without VM, and the variance - from 64 m to 78 m, respectively. Naturally, in environments with smaller multipath delays, the degree of positioning accuracy is much higher, as 90% CERP (circular error probability) in 10 RTT iteration cases decreases from 180 m in Urban A to 150 m in Urban C. Since in Urban C, the accuracy is already at a high level, the increase of the accuracy does not go in pair
with the RTT repetition number. Moreover, from Fig. 7 it can be observed that in scenarios less suffering from multipath propagation, e.g., in Urban C, application of the VM does not enhance the accuracy that much.

The availability of the FSHO algorithm limits the availability of the proposed method due to initial assumption that the located UE is forced to the SHO. Referring to [5], in considered network configuration, over 90% of served mobiles can decode the 3rd pilot, thus they can be forced into three-way SHO.

6 Conclusions and discussions

In this paper a novel algorithm for mobile positioning in multipath propagation environment has been presented and analyzed. Proposed algorithm for mitigation effects of multipath propagation on positioning accuracy together with underlying enhanced Cell ID+RTT location method forms a robust, inexpensive solution for mobile positioning. Since the algorithm does not require knowledge of LOS and also delays between multipath components are not needed, the complexity is kept at very low level. In scenario, most suffering from RTT errors due to multipath propagation (Urban A), 90% of mobiles can be located within 200 m (Fig. 7). The application of the VM algorithm can further enhance the accuracy, as 90% CERP is reduced to 180 m. It was shown that in areas with smaller expected multipath errors in range measurements, the deployment of the VM must be made carefully, see Fig. 8. Other performance factors as the availability and the latency are strictly related to FSHO algorithm [5], as the execution time of the proposed algorithm itself can be neglected.

Further development should include verification of obtained performance outcomes through field measurements as well as the practical implementation.

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