Enhanced Performance of Cell ID+RTT by Implementing Forced Soft Handover Algorithm

Jakub Borkowski, Jarno Niemelä, 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
Email: {jakub.borkowski, jarno.niemela, jukka.lempiainen}@tut.fi

Abstract—The objectives in ongoing research related to mobile positioning are inexpensive solutions providing high accuracy of position estimation. Cell ID+RTT is identified as one of the most available and applicable location technique for UMTS. The technique provides high degree of accuracy, but only for users within SHO. The aim of this paper is to present an algorithm for RTT measurements. Simulation outcomes have showed that application of the proposed algorithm increases the availability of “accurate” Cell ID+RTT estimates (16–20 m in free propagation environment) for nearly all served users in the network, simultaneously improving overall accuracy to 40 m for 90% of measurements. The proposed solution should not have a negative impact on the network performance due to reduced complexity to minimum and small latency of the procedure.

Keywords - Cell ID+RTT, mobile positioning SHO, UMTS.

I. INTRODUCTION

Mobile positioning has recently gained a meaningful attention mainly due to safety requirements issued by the government authorities and, simultaneously, by numerous commercial factors. There are many standardized location techniques for UMTS (Universal Mobile Telecommunication System) included in the 3GPP (Third Generation Partnership Project) [1]. Moreover, numerous other solutions for mobile positioning together with enhancements to the existing methods have been proposed [2]-[3]. Typically, techniques implying high deployment costs provide satisfying performance, while low cost solutions do not satisfy current requirements. One of the inexpensive solutions for mobile positioning, Cell ID+round trip time (RTT) has been studied in [4]. It has been shown that even low cost techniques can provide performance at sufficient level for most of the location-sensitive applications. However, for more sophisticated services, higher accuracy and availability are strongly desired. In order to provide a superior accuracy for Cell ID+RTT, all terminals should be within a three-way soft handover (SHO). However, this configuration would cause significant degradation of the downlink (DL) capacity [5]. Therefore, by forcing a user equipment (UE) to SHO only for the time instant needed for necessary RTT measurements, the high positioning accuracy becomes available for nearly all served mobiles in the network.

Forced handovers for GSM (Global System for Mobile Communications), supporting the corresponding Cell ID+timing advance (TA) location method, have been analyzed in [6]-[9]. The accuracy improvement was clearly shown. However, according to the poor resolution of TA in GSM – 550 m, the overall performance of Cell ID+TA with forced handover algorithm was not good enough. Furthermore, a significant drawback of this method was an interruption of communication during location procedure, since soft handovers are not supported in GSM. In UMTS, the resolution of a single RTT measurement can be up to 5 m (with 1/16 oversampling), and moreover, soft handovers allow a continuous transmission during location evaluation.

In this paper, it will be proposed an algorithm for enhancing the availability of “accurate” Cell ID+RTT positioning by forcing the terminal into SHO for a time instant required for RTT measurements. The proposed enhancement takes advantage of existing messages and procedures standardized in 3GPP [10]-[11], thus reducing the complexity and requirements for hardware and software changes.

II. PERFORMANCE OF CELL ID+RTT

Theoretical analyses of Cell ID+RTT have showed that the accuracy of the selected positioning method strongly depends on the network topology (cell spacing) and base station antenna configuration (sectoring scheme and antenna beamwidth), and varies from 16 m to 450 m as a function of these parameters [4]. It has been presented, that coverage area of Cell ID+RTT can be divided into three areas with different degree of attainable accuracy. Naturally, when the UE is in a three-way SHO, its position can be estimated with high accuracy – 16 - 20 m, since RTTs can be simultaneously measured by all NodeBs included in the active set (AS). The outcomes [4] have showed that the availability of the “accurate” Cell ID+RTT positioning is at the highest level with 6-sectored/65° network configuration, mainly due to higher proportion of soft and softer handovers areas (e.g., in the best configuration of 1 km cell spacing scenario, nearly 35% of users are in SHO and 40% in softer handover). Simultaneously, on average 25% of users are under single sector coverage area, and thus their position might not be estimated with sufficient accuracy (Fig. 1). The Fig.1, representing the availability analysis, is organized in such a manner that for each value of the energy per chip to total interference ratio (E/N_d) requirement, a corresponding set of bars matches the availability calculated for three SHO window cases, namely, 3 dB, 4 dB, and 5 dB.
...with equal antenna directions. Consisting 6 sites in a hexagonal grid having equal cell spacing 200 terminals randomly distributed over network are a cell spacing scenario. The overall accuracy was calculated for CERP (circular error probability) is within 120 m for 1 km 6-sectored arrangement at the base stations would also lead to availability of areas with different degree of Cell ID+RTT accuracy. Results are presented for 6-sectored/65° scenario with 1 km cell spacing.

Figure 1. Availability of areas with different degree of Cell ID+RTT accuracy. Results are presented for 6-sectored/65° scenario with 1 km cell spacing [4].

Naturally, deployment of horizontally wide antennas (65°) in 6-sectored arrangement at the base stations would also lead to high expectable accuracy, as illustrated in Fig. 2, as 90% CERP (circular error probability) is within 120 m for 1 km cell spacing scenario. The overall accuracy was calculated for 200 terminals randomly distributed over network area consisting 6 sites in a hexagonal grid having equal cell spacing of 1 km and 1.5 km with equal antenna directions.

Figure 2. Overall accuracy of Cell ID+RTT positioning.

III. THEORY OF PROPOSED SOLUTION

The position of the UE can be estimated with the sufficient accuracy when at least three RTTs can be simultaneously measured. Therefore, the UE has to be in SHO with three cells or more. Traditionally, a cell is added into AS, when measured $E_b/N_0$ on common pilot channel (CPICH) of the monitored set is greater than $T_{ADD}$ for a fixed period of time (time-to-trigger) [12]. The SHO adding range ($T_{ADD}$) is calculated according to the best server in the AS:

$$T_{ADD} = Best\_Server\_AS + T_{ADDH}$$

where $T_{ADDH}$ is a fixed hysteresis for adding threshold.

In the proposed algorithm, the SHO adding range, and thus the SHO window related to the particular user is widened by changing the value of $T_{ADDH}$ until three pilots from different sites will fulfill the adding criterion. The main part of the algorithm is implemented in the UE (Fig. 3b). In the first step of the algorithm, $E_b/N_0$ of hearable CPICHs of the monitored set are examined with the adding range calculated based on the value of $T_{ADDH}$ as for the standardized SHO operation. Consecutively, the algorithm iteratively decreases the value of $T_{ADDH}$ with a 0.5 dB step and after each decrement checks if the $E_b/N_0$ of measured CPICH fulfills the adding criteria and is the corresponding site not already included in the AS. Thus, the SHO window is increased only for the particular UE. The procedure is terminated when three pilots transmitted by the different sites accomplish the criterion. In the scenarios when the 3rd pilot is not available, the algorithm exits when $T_{ADD}$ reaches the minimum allowed value ($T_{ADD\_min}$). The value of the $T_{ADD\_min}$ constitutes a minimum pilot reception threshold. Since quality terminals can decode pilots from a signal with $E_b/N_0$ as low as –23 dB, this value has been assumed as the minimum value of the adding range ($T_{ADD\_min}$) [13]. Simultaneously, it has been assumed that 2nd pilot is available over the entire network. Therefore, in the situation that $T_{ADD\_min}$ is reached, i.e., the 3rd pilot is not available, the UE is forced to a two-way SHO for the time instant needed for RTT measurements.

The overall procedure of the forced SHO algorithm is presented in Fig. 3a. If the UE is initially in a three-way SHO, the RTT request to all NodeBs in the AS is sent immediately. Moreover, the accuracy improvement by forcing the UE to SHO is not needed when the UE is near the serving NodeB, since the accuracy of a single Cell ID+RTT is already at an acceptable level. Therefore, the UE-NodeB range is initially measured and if the RTT corresponds to distance lower than 150 m, the algorithm is not used, and the position of the UE is estimated on the traditional Cell ID+RTT basis. The accuracy of a single RTT when the UE is at the distance of 150 m from the serving NodeBs corresponds to 99 m and 57 m (in 6-sectored/65° scenario), and to 95 m and 16 m (in 6-sectored/33° scenario) for single sector ID and softer handover, respectively [4].

The part of the algorithm implemented in the UE is triggered by an appropriate Measurement Control message sent by a radio resource control layer of a serving radio network controller (SRNC/RRC) on DL dedicated control channel (DCCH) [10]. After termination of the procedure implemented in the UE, the Measurement Report carrying the list of NodeBs, which can be added to the AS, is sent back to the SRNC on uplink (UL) DCCH activating the Radio Link Addition procedure (Fig. 3a) [11]. In order to establish new radio links between the UE and reported NodeBs, first the SRNC/RRC configures the radio links on the physical layer in the corresponding NodeBs. This stage is denoted as the Radio Link Addition Request. Subsequently, the SRNC/RRC sends the message to the UE/RRC, which configures the UE physical layer to begin reception (not included in Fig. 3a). After successful termination of the Radio Link Addition procedure, the Active Set Update Complete message is sent and the SRNC requests RTT measurements from all NodeBs in the newly established AS.

In order to improve the reliability of RTT-based positioning in multipath propagation environment, the SRNC might request multiple RTT measurements from a single DCCH, and consequently selects the shortest range of each radio link. Selected measurements of reported RTTs are then mapped onto a coverage map in the SRNC, and the position of the UE is...
estimated. Finally, location services (LCS) response is sent back to the network or to the higher layers of the UE.

Network is restored to the initial state by sending the standard SHO Measurement Control message by the SRNC/RRC, which forces the UE to start the regular SHO update procedure. The most expecting aftereffect is the SRNC/RRC, which forces the UE to start the regular SHO standard SHO back to the network or to the higher layers of the UE. The total number of mobiles in one snapshot is Poisson distributed and the locations of mobiles are statistically determined. Hence, the locations as well as the number of mobiles vary from snapshot to snapshot giving an estimate of the mean performance of the network after numerous of snapshots. The traffic distribution was defined homogenous and consisted only of speech users (12.2 kbps). The network layout consisted of 19 sites (for availability analyses) and 6 sites (for accuracy analyses) deployed in a hexagonal grid having equal cell spacing of 1 km and 1.5 km with equal antenna directions. The lower number of base station was selected for the accuracy calculations, since the distribution of the considered areas remains similarly for each site.

IV. SIMULATION ENVIRONMENT

A static simulator was used for the performance assessment of the proposed algorithm under different network configurations typical for macrocellular deployment of UMTS. For the pilot coverage predictions, COST-231-Hata propagation model was utilized with a radio propagation slope of 35 dB/km. The prediction model was adjusted with an average area correction factor of –6.7 dB to correspond to a light urban or suburban environment. The base station antennas were set to 25 m and the mobile station antennas to 1.5 m. The propagation model included also a function to model diffractions over terrain irregularities. Morphological and topographic information of the simulation area was defined by a high-resolution digital map (5 m x 5 m), which incorporates basic terrain types (water, open, and forest) and buildings of different heights in a raster form. The average roof top level was well below 25 m.

Evaluation of the accuracy in locations where the 3rd pilot is unavailable requires also clear definition of softer and soft handover areas. Therefore, Monte-Carlo simulations were used for distribution analyses of the considered areas. In a Monte-Carlo process, a large number of randomized snapshots is taken of the network performance. The total number of mobiles in

![Diagram](image-url)  
**Figure 3.** a) The overall procedure of the forced SHO algorithm; b) Part of the forced SHO algorithm implemented in the UE.

V. SIMULATIONS AND ANALYSES

A. Availability

The proposed positioning solution is available in the network for all mobiles, which can decode at least three pilot signals from different sites. Since quality terminals can decode pilots from a signal with E/N0 as low as –23 dB, this value was assumed as a minimum reception threshold [13].

The availability of the 3rd pilot was simulated under various network configurations. Three different base station configurations were compared with 1 km and 1.5 km cell spacing arrangements and different CPICH power allocation schemes. The obtained results in Fig. 4 show that 6-sector configuration with CPICH 33 dBm, when horizontally wide antennas (65°) are deployed, offers the best availability of the enhanced Cell ID+RTT. In this configuration, 90% (for 1 km cell spacing arrangement) of terminals can receive a decodable 3rd pilot, as illustrated in Fig. 4. Moreover, due to lower level of interference in larger cell spacing scenario, the hearability of the 3rd pilot is greater; on average 95% of mobiles can be forced to SHO (see Fig. 4b).
B. Accuracy

The accuracy improvement of the Cell ID+RTT positioning method due to deployment of the algorithm was analyzed. When the UE is forced to SHO, the accuracy of the positioning is approximately 16 m (assuming free propagation environment and 5 m resolution of a single RTT). In the situations when the UE is not forced to SHO, i.e., the distance from the serving NodeB is smaller than 150 m or the $E_c/N_0$ of the 3rd pilot is below the reception level, the location of the UE is estimated based on the principles of the traditional Cell ID+RTT.

Simulations were made for 200 randomly distributed mobiles over the network area consisting of 6 sites in 6-sectored/65° and 6-sectored/33° configuration. Obtained outcomes present very positive evaluation of the algorithm, since almost all served users can be located with the accuracy better than 40 m (see Fig. 5). Since the availability of the 3rd pilot (Fig. 4) is the main contributor to the overall accuracy, the 6-sectored/65° scenarios present the best results also in terms of the accuracy.

C. Latency

The evaluation of the latency of the whole algorithm is presented in Table 1. The overall latency should not exceed 2 seconds assuming the maximum allowed time (800 ms) for $E_c/N_0$ measurements by the UE. Moreover, the configuration that initially the UE is served by one NodeB, and that only one set of RTT measurements is executed in the final stage of the algorithm. By taking into account additional RTT measurements for better reliability of positioning, the latency naturally increases. However, the increase of the overall latency is not significant, since each set of RTT measurements does not exceed 100 ms [15]. Moreover, all values of the expected delays are assumed based on the standardized maximum delay requirements [14]-[16]. Therefore, in practical implementations, the latency can further be reduced.

D. Signalling load and additional interference

Due to relatively fast execution time of the algorithm, the higher level of interference during the existence of the additional radio links is expected to have neglected impact on the system capacity. The highest peaks of interference would be introduced when trying to force the UE to SHO when signal from the best server is clearly dominating. However, the additional radio links are not established when the UE is located very near the serving NodeB ($\leq 150$ m), since then the accuracy of a single RTT is already at reasonable level. Moreover, the proposed algorithm widens the SHO window of the UE, which is being currently located, thus only the particular UE is forced to SHO. Analyses of capacity reduction in CDMA-based network due to wider SHO window [17] have shown that larger SHO window does not cause enormous introduction of interference. Therefore, it is assumed that, when simultaneously multiple mobiles under the coverage of the same sector are forced to SHO, the increase of interference level is not significant.

The proposed procedure makes use of the standardized signaling messages and procedures, and requires only minor software changes in the UE. The introduced signaling load in the air interface does not differ much from that of the
TABLE I. THE WORST CASE DELAY BUDGET FOR THE FORCED SHO ALGORITHM.

<table>
<thead>
<tr>
<th>Interface / Network element</th>
<th>Procedure</th>
<th>Estimated delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand-alone SHO algorithm</td>
<td>RTT measures</td>
<td>100 ms</td>
</tr>
<tr>
<td></td>
<td>Processing</td>
<td>5 ms</td>
</tr>
<tr>
<td>SRRC – NodeB</td>
<td>Core RTT measurement delay (Measurement Control)</td>
<td>30 ms</td>
</tr>
<tr>
<td>Mod3 – UE</td>
<td>Air interface propagation delay and handover (Measurement Control)</td>
<td>10 ms</td>
</tr>
<tr>
<td>UE</td>
<td>RTX messages</td>
<td>100 ms</td>
</tr>
<tr>
<td></td>
<td>Processing</td>
<td>5 ms</td>
</tr>
<tr>
<td>UE – NodeB</td>
<td>Air interface propagation delay and handover (Measurement Request)</td>
<td>30 ms</td>
</tr>
<tr>
<td>Konekite – SHOC</td>
<td>Core RTT transmission delay (Measurement Request)</td>
<td>10 ms</td>
</tr>
</tbody>
</table>

Radio link additions

<table>
<thead>
<tr>
<th>Interface / Network element</th>
<th>Procedure</th>
<th>Estimated delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRRC – NodeB</td>
<td>Processing</td>
<td>7.260 sec + 640 ms</td>
</tr>
<tr>
<td>Mod3 – UE</td>
<td>Core RTT measurement delay (Radio Link Additions – Active Set Update)</td>
<td>30 ms</td>
</tr>
<tr>
<td></td>
<td>Air interface propagation delay and handover (Radio Link Additions – Active Set Update)</td>
<td>10 ms</td>
</tr>
<tr>
<td></td>
<td>Acknowledgement and Handover</td>
<td>10 ms</td>
</tr>
<tr>
<td>UE – NodeB</td>
<td>Air interface propagation delay and handover (Acknowledgments)</td>
<td>30 ms</td>
</tr>
<tr>
<td>Konekite – SHOC</td>
<td>Core RTT transmission delay (Acknowledgments)</td>
<td>5 ms</td>
</tr>
</tbody>
</table>

Final stage

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Estimated delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTT measures, measurement operation</td>
<td>100 ms</td>
</tr>
<tr>
<td>SHOC</td>
<td>Position estimation</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>

ACKNOWLEDGMENT
Authors would like to thank European Communications Engineering (ECE) Ltd for helpful comments concerning simulation parameters and simulation environment, Nokia Networks for providing NetAct Planner tool, FM Kartta for providing the digital map, and the National Technology Agency of Finland for funding the work.

REFERENCES
[15] 3GPP TS 25.133, “UMTS; Requirements for support of radio resource management (RRM),” Ver. 6.5.0, Rel. 6.