# Location Techniques for UMTS Radio Networks

## Presentation of Research Activities

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*Abstract* – **The objectives in ongoing research related to mobile positioning are inexpensive solutions providing high accuracy of position estimation. Cell ID+RTT hybrid positioning method is identified as an inexpensive technique providing good availability, applicability, and satisfying accuracy. This paper presents results of studies and analysis of Cell ID+RTT. A static radio network simulator has been used to evaluate the availability of the considered positioning method. The best availability of accurate location estimates is provided by 6-sectored/65° topology scenario, mainly due to higher proportion of areas with higher degree of accuracy (soft and softer handovers). In order to improve the availability, and thus to enhance the overall accuracy, the UE can be forced to SHO for the time instant needed for RTT measurements. Initial simulation outcomes have showed that position of nearly 90% of users can be estimated with high accuracy (16 – 20 m in free propagation environment) by utilizing the proposed algorithm.**

## I. INTRODUCTION

Mobile positioning has attracted meaningful attention during the last decade. The trend has been triggered by safety requirements issued by government authorities (the U.S Federal Communication Commission) and, simultaneously, by commercial factors, since positioning provides enormous market opportunities for location-sensitive applications. The concentration now turns into the technical solutions providing accurate and reliable location information available for all users in the network.

Currently three location methods have been included in the Third Generation Partnership Project (3GPP): Cell ID, observed time difference of arrival with idle period downlink support (OTDOA-IPDL), and assisted GPS (AGPS) [1]. Moreover, many other positioning methods have been designed and proposed for future releases of Universal Mobile Telecommunications System (UMTS), which mainly constitute availability enhancements to OTDOA (time alignment IPDL (TA-IPDL) [2], positioning elements IPDL (PE-IPDL) [3]-[4], and Cumulative Virtual Blanking (CVB) [5]. Other network-based approaches for location estimation include angle of arrival (AOA) [4], [6]-[7], Cell ID+RTT [8]-[9], E-CGI, AOA+RTT [10], and OTDOA+AOA [11]. Moreover, satellite-based methods utilizing GALILEO data (Assisted GALILEO) or combination of GPS and GALILEO data (AGPS + Assisted GALILEO) are under investigation [12].

The referred solutions for mobile positioning naturally differ in applicability, availability, reliability, and accuracy. Typically, methods implying high deployment costs provide satisfying performance of positioning. Therefore, network operators have to decide between price and accuracy.

In this paper, it will be shown that even inexpensive location methods can provide user location information with accuracy sufficient for most of the location applications. Cell ID+RTT hybrid method has been selected for detailed analysis due to its applicability, availability, and satisfying accuracy. Moreover, the utilization of forced SHO algorithm [13] with conjunction of the Cell ID+RTT method significantly improves the availability of “accurate” Cell ID+RTT positioning.

## II. THEORY OF CELL ID+RTT

The simple location method included in 3GPP, Cell ID, is typically implemented as network-based method, and thus it does not require any changes to the terminals. The accuracy of Cell ID positioning depends merely on the size of the serving sector or on the size of common area of the sectors when user equipment (UE) is in softer or soft handover (SHO). In order to improve the accuracy, the serving radio network controller (SRNC) requests round trip time (RTT) measurements from the corresponding NodeB(s) or, if implemented, from a location measurement unit (LMU). RTT constitutes of the time difference between beginning of the transmission of a downlink dedicated physical channel (DPCH) frame and the beginning of the reception of the corresponding uplink frame. Based on the time of propagation, the distance of the UE from the corresponding NodeB can be estimated. Current oversampling methods allow RTT to be reported with 1/16 chip resolution, which corresponds to 5 m accuracy. If the UE is in SHO, all NodeBs included in the active set (AS) can perform RTT measurements. Since in SHO, UMTS network is naturally synchronized, the multiple RTT measurements can contribute to improvement in accuracy without the need of the network synchronization.

The coverage area of Cell ID+RTT is divided into three areas with different degree of attainable accuracy. These are single sector coverage area (single RTT report), softer handover (two sector IDs and single RTT report), and SHO (two or more Cell IDs and RTT reports). The size of the single sector coverage area depends strictly on the sectoring scheme and cell spacing. Single sector coverage area is limited, not only by softer handovers, but also by soft handovers that in some scenarios can occur between sectors. The phenomenon of having soft handover connections between neighboring sectors appears in dense macrocellular scenarios if horizontally narrow antennas are deployed at the NodeBs (Fig. 1), since these (such as 33° antennas) provide relatively weak signal of the main beam direction. It is illustrated in Fig. 1c that due to SHO connections between sectors in 6-sectored/33° topology with 1 km cell spacing, the sector service area is much narrower than in 6-sectored/33° scenario with 2 km cell spacing (Fig. 1d). Instead, when wider antennas are used, e.g., 65° in 6-sectored scenario (Fig. 1b), the coverage area of the sector is defined only by softer handovers together with the sectorization scheme. [8]-[9]

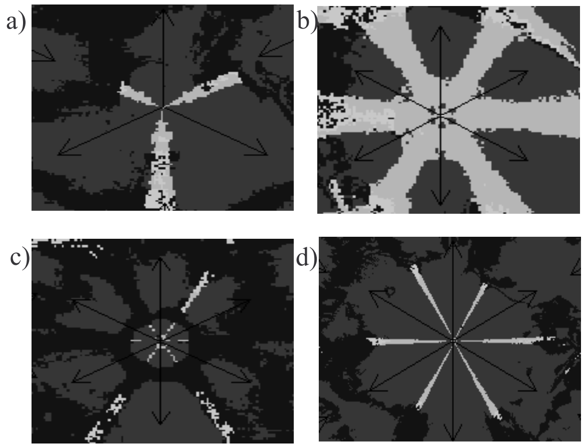

*Figure 1: Soft (dark gray) and softer handover (light gray) areas between sectors, a) 3-sectored/65° 1 km cell spacing, b) 6-sectored/65° 1 km cell spacing, c) 6-sectored/33° 1 km cell spacing, d) 6-sectored/33° 2 km cell spacing.*

The *accuracy* of Cell ID+RTT in single sector coverage area can be evaluated from the following equation:

$$accuracy = 2 \cdot \pi \cdot d \cdot \frac{\alpha}{360^0} \tag{1}$$

where $d$ is a distance from the serving NodeB and $\alpha$ *is* the angle of single sector coverage area defined as:

$$\alpha = \frac{360^0}{number\_of\_sectors} - max(\beta,\gamma) \tag{2}$$

where $\beta$ and $\gamma$ stand for the outspread angle between softer and soft handover, correspondingly.

The single sector coverage area ($\alpha$) in 6-sectored scenarios can be expressed by a single linear equation as in (3) with a small error (1°-2°). However, the single sector coverage area in 3-sectored scenarios is very topology specific, and thus cannot be encapsulated into a single equation. The problem is wider presented in [9].

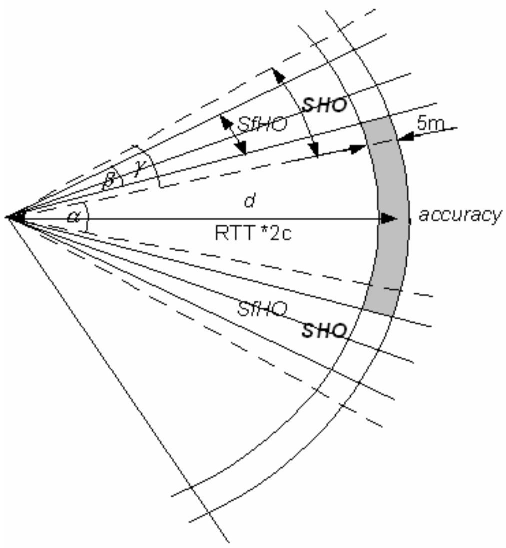

*Figure 2: Single Cell ID and single RTT situation.*

$$\alpha = 60° - \left( 0.56 \cdot BW - 14.5° + \begin{cases} -0.6 \cdot BW + 39.6° : cell\_sp = 1km \\ 0 : cell\_sp > 1km \end{cases} \right) \tag{3}$$

In (3), $BW$ is the antenna beamwidth and $cell\_sp$ is the cell spacing.

In softer handover, the attainable accuracy is much better than in a single sector coverage area, since the angle $\beta$ of the softer handover area is typically much smaller than the angle of a single sector coverage area ($\alpha$).

$$accuracy = 2 \cdot \pi \cdot d \cdot \frac{\beta}{360^0} \tag{4}$$

In SHO, the accuracy of Cell ID+RTT is on the highest level. In this state, the accuracy depends additionally on the geometry of the network and the AS size. Naturally, with higher AS size, a better accuracy can be achieved. The best scenario within two-way SHO can be achieved when lines between the UE and the NodeBs of AS cross each other at the right angle ($\alpha$=90°). In turn, the most pessimistic case is when $\alpha$=180° meaning that the UE and corresponding NodeBs are located at the same line. The accuracy can be expressed as in (5). [8]-[9]

$$accuracy = 2\sqrt{2d_1^{\,2} + 3d_1 l + \frac{5}{4}l^2 - 2(d_1^{\,2} + \frac{3}{2}d_1 l + \frac{l^2}{2})\cos\beta} \tag{5}$$

Where $\beta$ is expressed as:

$$\beta = \alpha - 180° + arccos\left( \frac{(d_1 - d_2)((d_1 + d_2) + 2l) + c^2}{2c(d_1 + l)} \right) + arccos\left( \frac{(d_2 - d_1)((d_2 + d_1) + l) + c^2}{2c(d_2 + \frac{l}{2})} \right) \tag{6}$$

The theoretical attainable accuracies are gathered in Table 1 for 3-sectored/65°, 6-sectored/65°, and 6-sectored/33° with 0.75, 1.0, and 1.5 km cell spacings. It has been assumed that UE is located in the middle of the cell range. Moreover, free propagation environment has been assumed.

Table 1: Theoretical accuracies of different topology scenarios.

| *Scenario* | *Type of Area* | *Accuracy cell sp. = 750 m* | *Accuracy cell sp. = 1000 m* | *Accuracy cell sp. = 1500m* |
|---|---|---|---|---|
| 3-sectored/65° | Single Cell ID+RTT | 229 m | 440 m | 720 m |
| | Softer handover | 33 m | 43 m | 65 m |
| | SHO | 16 m – 99 m | 16 m – 99 m | 16 m – 99 m |
| 6-sectored/65° | Single Cell ID+RTT | 82 m | 165 m | 248 m |
| | Softer handover | 72 m | 96 m | 144 m |
| | SHO | 16 m – 99 m | 16 m – 99 m | 16 m – 99 m |
| 6-sectored/33° | Single Cell ID+RTT | 147 m | 160 m | 360 m |
| | Softer handover | 13 m | 17 m | 26 m |
| | SHO | 16 m – 99 m | 16 m – 99 m | 16 m – 99 m |

## III. SIMULATION ENVIRONMENT

A radio network planning tool has been used to evaluate network performances under different network configurations. Basically, the simulations consisted of two different parts – coverage predictions together with capacity and performance analysis utilizing Monte-Carlo simulation approach.

Since macrocellular network was under research, for the pilot coverage predictions, COST-231-Hata propagation model was used with a radio propagation slope of 35 dB/dec. The base station antennas were set to 25 m and the mobile station antennas to 1.5 m. The prediction model was also adjusted with an average area correction factor of -6.7 dB to correspond to a light urban or suburban environment. 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). The digital map included basic terrain types (water, open, and forest) and buildings of different heights in a raster format. The average roof top level was well below 25 m.

The radio network simulation tool uses Monte-Carlo technique for capacity and performance analysis. In Monte-Carlo process, a large number of randomized snapshots is taken of the network performance over time. 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. In the beginning of a snapshot, the base station and mobile station powers are initialized to the level of thermal noise power (affected by noise spectral density, receiver noise figures, and noise bandwidth). In the initialization phase, also mobile-dependent standard deviations (STD) of slow fading are calculated. STD of slow fading is a zero-mean and has a log-normal distribution, which is added to the path loss between base station and mobile station. After that, the transmission powers for each base station and mobile station are calculated iteratively in such a manner that uplink and downlink $E_b/N_0$ requirements for each connection are satisfied. After a snapshot, all statistics (such as noise powers, required transmission powers etc.) are gathered, and results from an individual snapshot are added to the results.

During a snapshot, mobile is connected to a sector antenna, which provides the best energy per chip over the total wideband interference ratio, $E_c/N_0$ in the common pilot channel (CPICH). When a connection to best server has been established, all other candidates sector are examined to see whether they satisfy the requirement to be in AS of a mobile. To be added, the level of the $E_c/N_0$ from candidate sector must be sufficient, and moreover, it has to be within the SHO window). The allowable transmission powers should also not be exceeded if a candidate sector is added to a mobile's AS.

The network layout consisted of 19 sites in a hexagonal grid having equal site spacing. Base station antenna directions were 0°, 60°, 120°, 180°, 240°, and 300°. The simulation area is depicted in Fig. 3. WCDMA-specific simulation parameters are shown in Table 2.

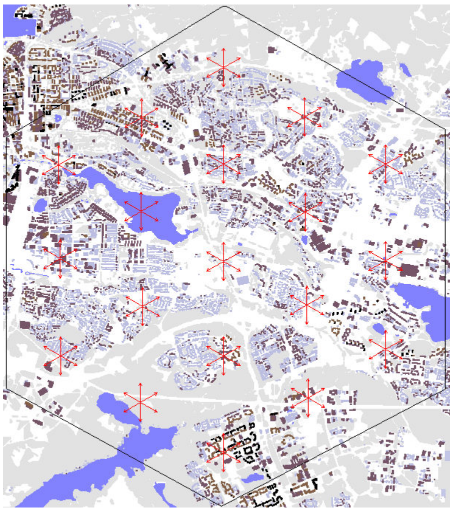

Figure 3. Simulation area.

Table 2: WDMA – specific simulator parameters.

| **Parameter** | **Value** | **Unit** |
|---|---|---|
| Maximum BS TX power | 43 | dBm |
| CPICH | 30 / 33 | dBm |
| SCH | 27 / 30 | dBm |
| CCCH | 30 / 33 | dBm |
| DL $E_b/N_0$ | 8 | dB |
| UL $E_b/N_0$ | 5 | dB |
| BS noise figure | 5 | dB |
| MS noise figure | 8 | dB |
| MS dynamic range | 70 | dB |
| Required $E_c/N_0$ | -15 | dB |
| SHO window | 5 | dB |
| STD of slow fading | 9 | dB |
| UL noise rise | 6 | dB |
| DL code orthogonality | 0.6 | |
| Voice activity factor | 0.5 | |

The impact of UTRAN parameters (SHO window, $E_c/N_0$ requirements, CPICH power) on the size of different accuracy areas has been analyzed in [8]. It has been observed that minimum $E_c/N_0$ requirement does not have a meaningful impact on the availability of Cell ID+RTT at the range from -15 to -18 dB. However, a lower threshold degrades the service probability significantly. In turn, the size of the SHO window affects the overall performance of studied location technique. Naturally, due to wider window, there appear a considerably growth in areas with higher degree of accuracy, i.e., softer handover and SHO, and simultaneously, a decrease of service probability in the transmit power limiting scenarios is not significant. Simulation results in [8] returned a set of parameters providing balance between network performance and availability of Cell ID+RTT: SHO window 5 dB and $E_c/N_0$ –15 dB.

## IV. SIMULATION RESULTS

Simulations were carried out in order to evaluate the distribution of the areas with different degree of accuracy for the chosen 6-sectored topology scenarios in light urban macrocell environment. Figs. 4-12 present a comparison of positioning performance by means of availability, accuracy, and radio network performance for all considered network topologies with different cell spacings when concluded set of parameters was selected. The availability has been presented for two CPICH power scenarios; left bars correspond to CPICH 33 dBm, and right ones to lower pilot power allocation scheme of 30 dBm.

The obtained outcomes (Fig. 4-12) shows that 6-sectored/65° configuration offers the widest availability of softer and soft handover (e.g., for 1 km cell spacing scenario, nearly 40% SHO and 40% softer handover) areas, and thus it provides the best overall performance for Cell ID+RTT. However, simultaneously, when wider antennas are deployed in 6-sectored scenarios, the number of failure connections is on very high level, indicating poor performance from radio network planning perspective. The balance between network performance and availability of "accurate" positioning can be realized by changing the power allocation scheme, i.e., by decreasing pilot power to 30 dBm, and thus increasing available power for user plane data. The service probability is then significantly enhanced while areas with higher degree of accuracy are maintained on almost unchanged level (e.g., for 1 km cell spacing scenario, only 2-5% less SHO and 1% less softer handover areas, Fig. 7).

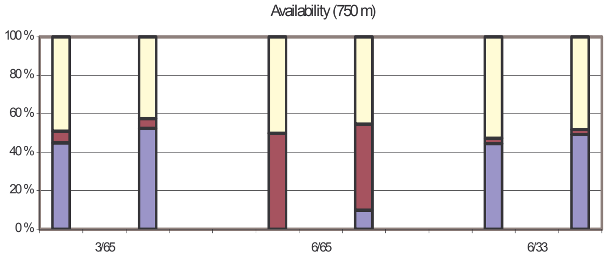

*Figure 4: Availability of Cell ID+RTT for 750 m cell separation scenarios. For each topology case, results are presented for higher (left bar) and lower (right bar) CPICH power allocation scheme.*

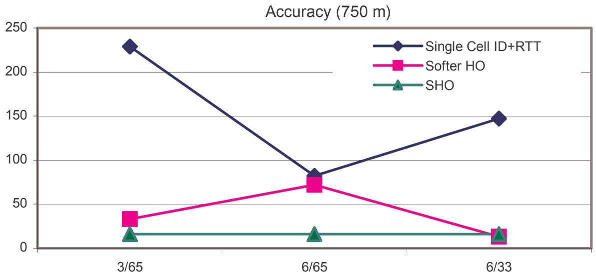

*Figure 5: Attainable accuracy of Cell ID+RTT in 750 m cell separation scenarios.*

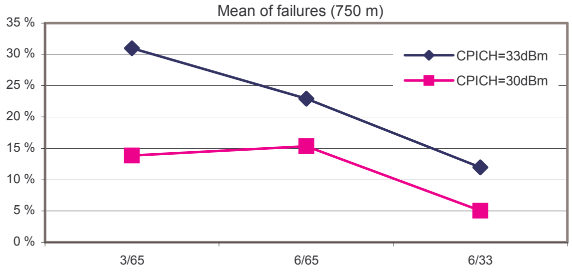

*Figure 6: Comparison of mean of failures in 750 m cell separation scenarios.*

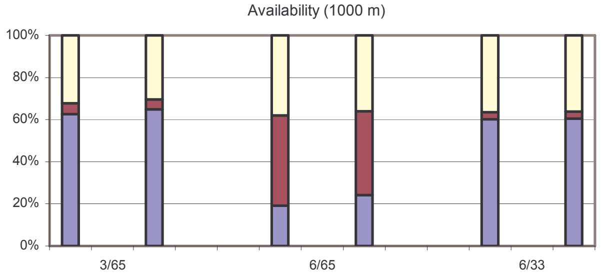

*Figure 7: Availability of Cell ID+RTT for 1000 m cell separation scenarios. For each topology case, results are presented for higher (left bar) and lower (right bar) CPICH power allocation scheme.*

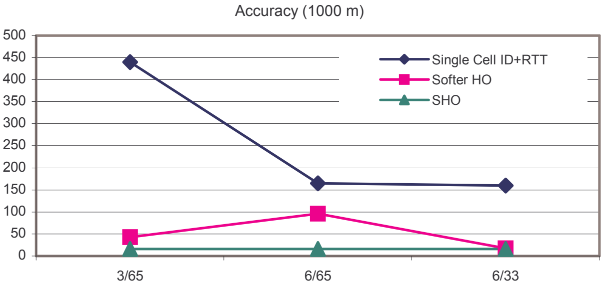

*Figure 8: Attainable accuracy of Cell ID+RTT in 1000 m cell separation scenarios.*

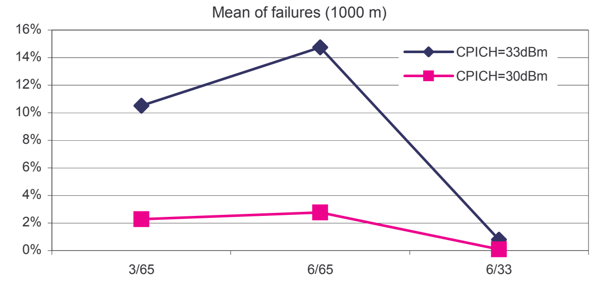

*Figure 9: Comparison of mean of failures in 1000 m cell separation scenarios.*

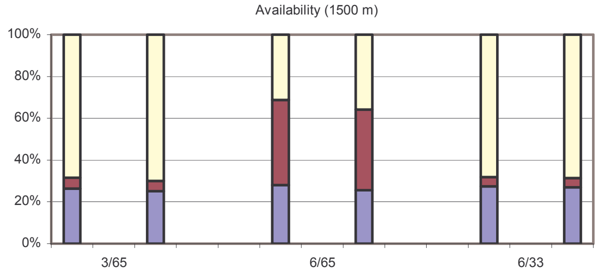

*Figure 10: Availability of Cell ID+RTT for 1500 m cell separation scenarios. For each topology case, results are presented for higher (left bar) and lower (right bar) CPICH power allocation scheme.*

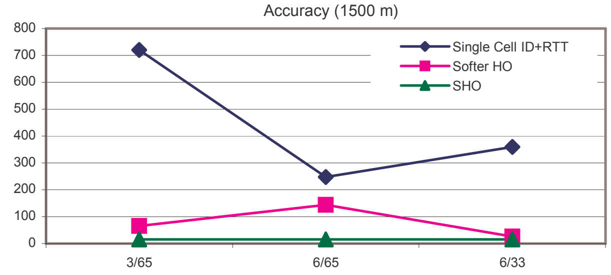

*Figure 11: Attainable accuracy of Cell ID+RTT in 1500 m cell separation scenarios.*

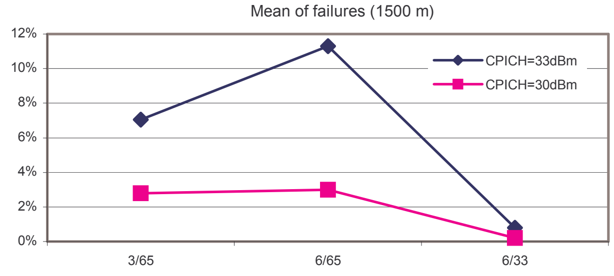

*Figure 12: Comparison of mean of failures in 1500 m cell separation scenarios.*

## V. FORCED SHO ALGORITHM

Since even in the best topology scenario from positioning and radio network planning point of view, approximately 25% of users (1 km cell spacing scenario) is under the coverage of a single sector where accuracy is quite low. Application of forced soft handover algorithm can significantly enhance the availability of "accurate" Cell ID+RTT positioning by introducing the terminal to SHO for the time instant needed for necessary measurements.

Forced handovers for GSM, supporting the corresponding Cell ID+TA (Timing Advanced) location method have been analyzed in [14]-[15] and 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 even with forced handover algorithm was not good enough. Moreover, the important drawback of this method was interruption of communication during location procedure, since soft handovers are not supported in GSM. In UMTS, firstly, the resolution of single RTT measurement can be up to 5 m (with 1/16 oversampling), and secondly, soft handovers allow a continuous transmission during location evaluation.

The proposed forced SHO algorithm for enhancing Cell ID+RTT [13] takes advantage of signaling messages and procedures standardized in 3GPP [16], which reduce the complexity and requirement for hardware and software changes. Traditionally, a cell is added into AS, when measured $E_c/N_0$ on CPICHs of the monitored set is greater than T_ADD for a fixed period of time (time-to-trigger) [17]. The adding range T_ADD is calculated according to the best server of the AS:

$$T\_ADD = Best\_Server\_AS + T\_ADDH \qquad (7)$$

where *T_ADDH* is a fixed hysteresis for adding threshold.

In the proposed algorithm, the SHO window is widened by changing the value of T_ADDH until at least three pilots from different sites will fulfill the adding criteria (Figs. 13 and 14). The main part of the algorithm is implemented in the UE (Fig. 14). It is triggered by an appropriate *Measurement Control* message sent by SRNC/RRC (serving radio network controller/radio resource control) on downlink DCCH. The algorithm changes the value of T_ADD until three measured pilots from different sites fulfill the criteria. Then, the *Measurement Report* carrying the list of these NodeBs is sent back to the SRNC, which subsequently triggers the *Radio Link Addition* procedure (Fig. 13).

In order to establish the new radio link(s), first the CPHY-RL-Setup-REQ needs to be sent by the SRNC to NodeB(s) to configure the new physical connections. This stage is denoted as *Radio Link Addition* in Fig. 13. After receiving *Active Set Update Complete* message, the SRNC requests RTT measurements from all NodeBs in the AS. All reported RTTs are then mapped onto a coverage map in the SRNC, and finally LCS response is sent back to the network or to the higher layers of the UE. Network is restored to the entire state by sending standard SHO *Measurement Control* message by SRNC/RRC, which forces the UE to start the regular SHO update procedure. The most expecting after-effect is the *Radio Link Removal* procedure. After termination of the radio link(s) reception (UE/L1), the UE acknowledges with an *Active Set Update Complete* message. The last step of removal procedure is executed by CPHY-RL-Release-REQ message sent from

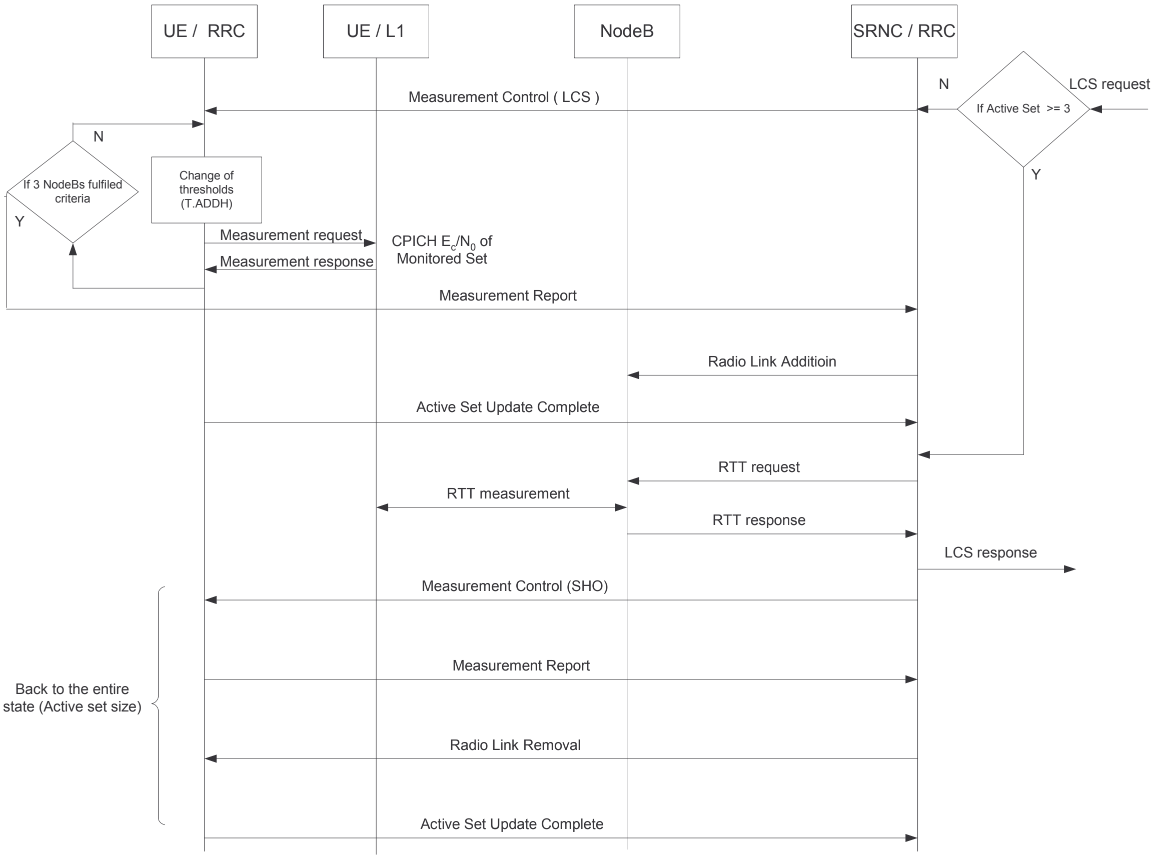

*Figure 13: The overall procedure of dynamic forced SHO algorithm.*

SRNC/RRC to the physical layers of NodeB and RNC in order to release the radio link(s) (not included in Fig. 13).

Naturally, the SHO window cannot be increased to the infinite size, since in some locations $E_c/N_0$ of the 3rd pilot can be under an absolute detection level. Therefore, in initial stage of the algorithm operation, the minimum allowed value of T_ADDH (limitADD) has to be derived based on $E_c/N_0$ measurements on hearable pilot channels. The latency of the whole algorithm should not be significant, and thus the higher level of interference during existence of the additional radio links is expected to have only a small decrease in the network capacity.

Simulations were used to evaluate the availability of the algorithm in a macrocellular UMTS network for light urban environment. The proposed positioning solution is available for all mobiles in the network, which can decode at least three pilot signals from different sites. Since quality terminals can receive pilots from a signal with $E_c/N_0$ higher than about –23 dB, this value has been assumed as a reception threshold according to [18].

The initial simulation results show that 6-sectored/65° configuration offers the widest availability of the enhanced Cell ID+RTT, since nearly 90% of mobiles can decode the 3$^{rd}$ pilot anytime (Fig. 15).

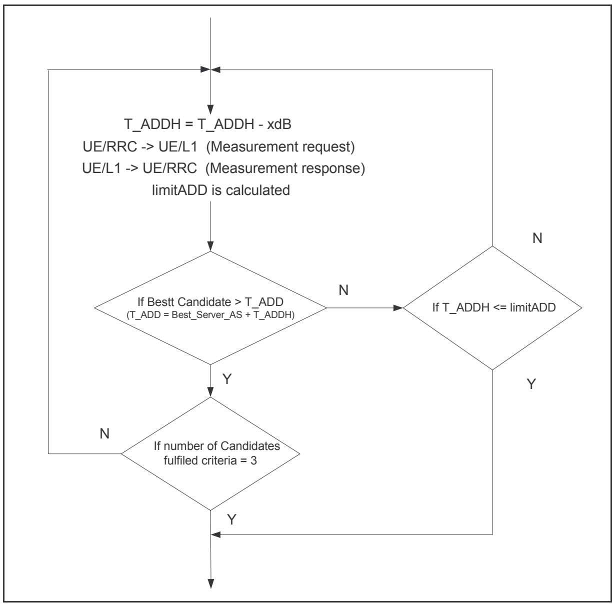

*Figure 14: Part of the forced SHO algorithm implemented in the UE.*

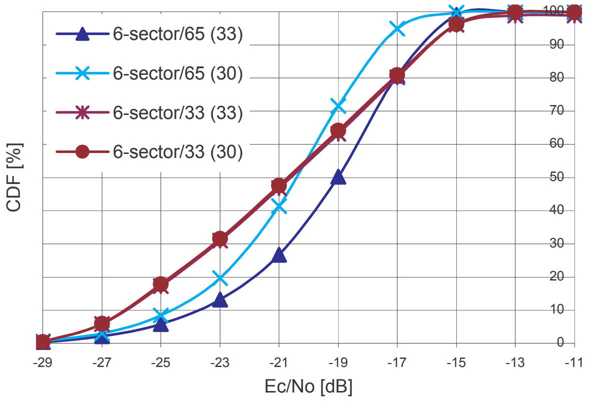

*Figure 15: Hearability of the 3rd pilot. Considered scenarios are highly loaded with 1 km cell separation. Values in brackets stand for the CPICH power in dBm.*

## VI. CONSLUSIONS AND DISCUSSION

This paper has analyzed the performance of Cell ID+RTT hybrid positioning method. The theoretical analysis of geometry showed that the accuracy of the considered location method depends heavily on the network topology (cell spacing) and base station antenna configuration (sectoring and antenna beamwidth) together with mobile location, and varies from 16 m to over 700 m as a function of these parameters. Since the best accuracy of positioning can be achieved in softer and soft handovers, the availability of these areas was simulated under different network topologies.

The simulation results showed that the availability of "accurate" Cell ID+RTT positioning is on the highest level with 6-sectored/65° network topology, mainly due to higher proportion of soft and softer handover areas (e.g., for 1 km cell spacing scenario, nearly 40% of SHO and 40% of softer handover areas). This affects also the expectable overall accuracy, which is naturally better if horizontally wider antennas (such as 65° in 6-sectored scenario) are deployed at the base stations. This result differs from the optimal 6-sectored/33° configuration when positioning methods are not considered in the network [19]-[21].

Changing the power allocation scheme, i.e., decreasing CPICH power to 30 dBm makes high loaded and dense network uplink noise limited with very low level of mean of failures. Simultaneously, areas with high degree of accuracy are maintained on almost unchanged level (e.g., for 1 km cell separation scenario: 2-5% less SHO and 1% less softer handover areas).

In order to provide superior accuracy for Cell ID+RTT, all mobiles should be within SHO. However, this would cause enormous degradation of the downlink capacity. Therefore, forced SHO algorithm has been proposed, which introduces the mobile in to a SHO for the time instant needed for necessary RTT measurements. Therefore, according to simulations, the position can be estimated with high accuracy (16 – 20 m in free propagation environment) for, on average, 90% of served mobiles. Moreover, since the proposed algorithm utilizes standardized procedures, the complexity of the system together with impact on networks and terminals is reduced to minimum. Simultaneously, the higher level of interference during maintenance of additional radio links is expected to have an inconspicuous impact on the downlink system capacity.

## ACKNOWLEDGMENT

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