

Performance of Cell ID+RTT Hybrid Positioning Method for UMTS Radio Networks

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Abstract: Cell ID+RTT positioning method is identified as one of the most available and applicable location technique for UMTS networks. In this paper, the performance of Cell ID+RTT positioning method under different network topologies has been presented. Typical network topologies for urban environment have been simulated with a special attention to the impact of SHO window size, E_c/I_0 requirement, and CPICH power. The results show a slight disagreement between optimum base station site deployment strategy for location services and radio network planning. However, by changing the power allocation (decreasing CPICH power) acceptable outcomes of the network performance have been observed from both points of view.

1. Introduction

The possibility of having knowledge of exact location of a mobile user provides safety and great market opportunities for commerce applications. Currently, three location methods are included in the Third Generation Partnership Project (3GPP) for UMTS. These are Cell ID, Observed Time Difference of Arrival (OTDOA) with Idle Period Downlink (IPDL) support, and Wireless Assisted GPS (AGPS) [1]. Besides those, there are many other proposed techniques for location estimation: Angle of Arrival (AOA), which requires implementation of adaptive antennas [2]-[3], and enhancements of OTDOA, which have been mainly developed to increase hearability of distant pilot signals (e.g., TA-IPDL (Time Alignment IPDL) [4], PE-IPDL (Positioning Elements IPDL) [5], and CVB (Cumulative Virtual Blanking) [6]).

There exist also hybrid techniques, which combine several methods due to better accuracy, reliability, availability, and applicability. Some of them form a combination of standardized method with one of the physical layer measurements, for instance: Cell ID+RTT, E-CGI, and AOA+RTT [7]. Other hybrid techniques use two complete location techniques, e.g., OTDOA+AOA [8].

All referred methods have naturally different features. The most often used balance-example is that expensive methods provide high accuracy and availability, and low cost solutions do not provide so satisfied performance. Therefore, network operators have to decide between price and accuracy.

In this paper, the impact of different network topologies on the performance of Cell ID+RTT (Round

Trip Time) hybrid positioning method has been studied. This hybrid technique has been chosen due to its availability, applicability, and satisfying accuracy. Theoretical accuracy of different network topologies is first evaluated, and subsequent, the distribution of the areas with different degree of accuracy for each topology scenario is studied.

2. Cell ID+RTT

In most of the cases, Cell ID is implemented as a network based method, and thus it does not require any changes in terminals, but only minor software changes in the network. The accuracy of this approach depends strictly on the size of the serving sector. Moreover, in soft or softer handover, an UE reports multiple Cell IDs to SRNC (Serving RNC), and higher accuracy can be achieved.

In order to improve the accuracy, the SRNC requests Round Trip Time (RTT) measurements from the corresponding NodeB(s) or from LMU (Location Measurement Unit, if implemented). RTT constitutes of the time difference between the beginning of the transmission of a downlink DPCH (Dedicated Physical Channel) frame and the beginning of the reception of the corresponding uplink frame. Based on this information, the distance of the UE from a NodeB can be estimated using a certain propagation model. If the RTT measurement is made with 1 chip resolution, the distance of the UE can be estimated with the accuracy of 80 m. However, current oversampling methods allow RTT to be reported with 1/16 chip resolution, which corresponds to 5 m precision.

When the UE is in soft handover, all NodeBs in the active set can perform RTT measurements. UMTS network is then synchronized and a dedicated connection on the DPCH is established between the UE and the NodeBs of active set. The position of the UE is estimated in the intersection of all reported RTTs, and thus the accuracy is significantly enhanced.

3. Accuracy of Cell ID+RTT

In order to evaluate the performance of Cell ID+RTT, coverage area has been divided into three areas with different degree of accuracy (Figure 1):

- a) UE is neither in soft nor in softer handover state – single Cell ID and single RTT are reported.
- b) UE is in softer handover – two Cell IDs and one RTT are reported.

- c) UE is in soft handover – two or more Cell IDs and RTTs are reported.

Also other areas can be defined, e.g., UE simultaneously in softer and in soft handover. However, the accuracy will not change remarkably compared to a soft handover scenario, since the limitation comes from the inaccuracy of RTT measurements rather than from the inaccuracy of Cell ID.

The accuracy in the scenario, where the UE is under coverage of a single cell (Figure 1a), strictly depends on the sectoring scheme and coverage overlapping. In other words, the network topology has a great impact on the accuracy. Single sector service area is limited not only by softer handovers, but also by soft handovers that in some scenarios can occur between sectors (Figures 2, 3a, and 3c). The phenomenon of having soft handover connections between neighbouring sectors appears in dense macrocellular scenarios (e.g., 1 km cell spacing) when horizontally narrow antennas are deployed at the base station.

In Figure 3, it is shown that due to the SHO connections between sectors in 6-sector/33° topology with 1 km cell spacing (Figure 3c), the single Cell ID

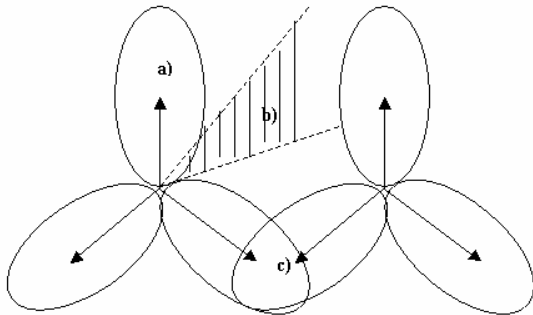


Figure 1: Areas with different degree of accuracy of Cell ID+RTT. a) UE in the coverage of one sector, b) UE in softer handover, c) UE in soft handover.

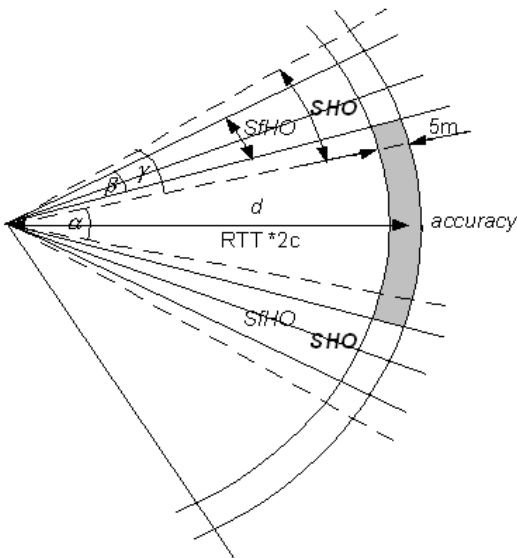


Figure 2: Single Cell ID and single RTT situation.

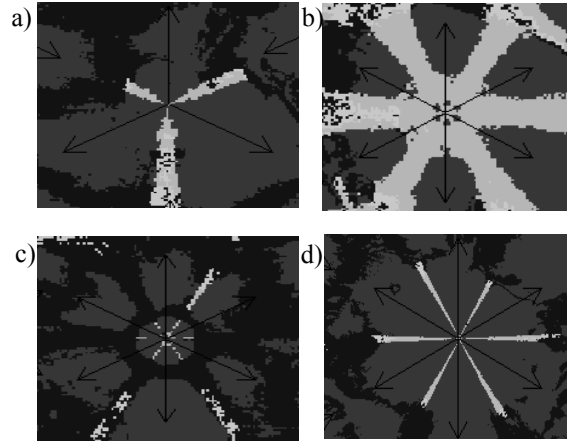


Figure 3: Soft (dark grey) and softer handover (light grey) areas between sectors, a) 3-sector/65° 1 km cell spacing, b) 6-sector/65° 1 km cell spacing, c) 6-sector/33° 1 km cell spacing, d) 6-sector/33° 2 km cell spacing. [9]

area is much narrower than in 6-sector/33° scenario with 2 km cell spacing (Figure 3d). Instead, when wider antennas are used e.g., 65° in 6-sectored scenario (Figure 3b), the single Cell ID area is defined only by softer handovers together with the sectorization scheme. [9]

The accuracy of single Cell ID+RTT can be evaluated from the following equation:

$$accuracy = 2 \cdot \pi \cdot d \cdot \frac{\alpha}{360^\circ} \quad (1)$$

where d is distance from the serving NodeB and α is the angle of the single sector service areas (Equation 2).

$$\alpha = \frac{360^\circ}{number_of_sectors} - \max(\beta, \gamma) \quad (2)$$

where β and γ stand for the outspread angle of softer and soft handover between sectors, correspondingly (Figure 2).

The single sector service area (α) in 6-sector scenarios can be expressed by a simple linear equation with small error (1°- 2°), and assumption that antenna height equals 25 m (Equation (3)). However, the dominance area in 3-sector scenarios is very topology specific, and thus cannot be encapsulated into a single equation. The problem is wider presented in [9]. In the frame of this paper the equation is quoted in order to estimate attainable accuracies within single sector service area in evaluated 6-sectored topologies.

$$\alpha = 60^\circ - \left(0.56 \cdot BW - 145^\circ + \begin{cases} -0.6 \cdot BW + 396^\circ, & cell_sp = 1km \\ 0, & cell_sp > 1km \end{cases} \right) \quad (3)$$

In Equation (3), BW is the antenna beamwidth and $cell_sp$ is the cell spacing

In a softer handover (Figure 1b), two Cell IDs of neighbouring sectors and a single RTT measurement are reported to the SRNC. In this scenario, the attainable accuracy (Equation 4) is much better than in a single Cell ID scenario, since the angle β of the softer handover area is much smaller than the angle of single Cell ID area (α).

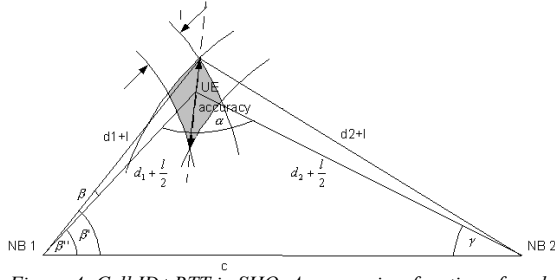


Figure 4: Cell ID+RTT in SHO. Accuracy is a function of angle between joined lines NB1-UE and UE-NB2.

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

In the case of soft handover (Figure 1c), RTT is measured simultaneously and reported by all NodeBs included in the active set. Thus, the accuracy is the best possible to achieve by Cell ID+RTT, since the user location is determined by an intersection of RTT rings measured by different NodeBs. Moreover, the accuracy depends strongly on the geometry of the network and on the size of the active set. The best accuracy is achieved when the lines between the UE and the NodeBs cross each other at right angles ($\alpha=90^\circ$ in Figure 4). The most pessimistic case is when the active set size equals 2, and the UE and NodeBs are located at the same line (denoted as c in Figure 4).

The general equation for the accuracy can be derived as a function of angle α and distances from NodeBs (d_1, d_2) from geometric dependences (Figure 4):

$$accuracy = 2 \sqrt{2d_1^2 + 3d_1l + \frac{5}{4}l^2 - 2(d_1^2 + \frac{3}{2}d_1l + \frac{l^2}{2}) \cos \beta} \quad (5)$$

Where β is expressed as:

$$\beta = \alpha - 180^0 + \arccos\left(\frac{(d_1 - d_2)((d_1 + d_2) + 2l) + c^2}{2c(d_1 + l)}\right) + \arccos\left(\frac{(d_2 - d_1)((d_2 + d_1) + l) + c^2}{2c(d_2 + \frac{l}{2})}\right) \quad (6)$$

Permitted values of angle α and cell spacing c :

$$\alpha = \arccos\left(\frac{(d_1 + \frac{l}{2})^2 + (d_2 + \frac{l}{2})^2 - c^2}{2(d_1 + \frac{l}{2})(d_2 + \frac{l}{2})}\right) \quad (7)$$

Thus:

$$\frac{(d_1 + \frac{l}{2})^2 + (d_2 + \frac{l}{2})^2 - c^2}{2(d_1 + \frac{l}{2})(d_2 + \frac{l}{2})} \leq |1| \quad (8)$$

Finally:

$$\begin{cases} d_1 + d_2 + l \geq c \\ d_1 - d_2 \leq c \end{cases} \quad (9)$$

From Equations (5) and (6), it can be evaluated that when α approaches 90° , the accuracy is better for larger

values of cell spacing c , but when α is closer to 180° , the precision of the position estimation is better for smaller cell spacing.

The equation for β can also be derived without direct dependence on α , thus having the following form using the same permitted values of d_1, d_2 , and c :

$$\beta = \arccos\left(\frac{(d_1 - d_2)(d_1 + d_2) + 2l + c^2}{2c(d_1 + \frac{l}{2})}\right) - \arccos\left(\frac{(d_1 + \frac{l}{2})^2 - (d_2 + \frac{l}{2})^2 + c^2}{2c(d_1 + \frac{l}{2})}\right) \quad (10)$$

The accuracy of three different areas presented in Figure 1 depends mainly on the sectoring scheme, antenna beamwidth, and the cell range. In this paper, the accuracy of Cell ID+RTT is evaluated in three chosen network topologies with 1 km cell separation: 1) 3-sector sites with 65° antennas; 2) 6-sector sites with 65° antennas; and 3) 6-sector sites with 33° antennas. In all considered scenarios, antenna height is kept constant – 25 m.

The attainable accuracy of the defined areas will be examined for the chosen topology scenarios. The value of accuracy has been calculated with assumption of free propagation environment, and that the UE is located in the middle of cell range, i.e., 250 m from the serving NodeB.

Moreover, based on observations, it was assumed that the single sector coverage area for 3-sector/ 65° topology is outspread at 100° and that softer handovers appear in inter-sector areas restricted by the following angles: 10° for 3-sector/ 65° , 22° for 6-sector/ 65° , and 4° for 6-sector/ 33° . Angles of single sector coverage area for 6-sector scenarios have been derived from Equation (3). The accuracies for different network topology scenarios are shown in Table 1.

Topology	Single Cell ID+RTT	Softer handover	Soft handover	
			Best	Worst
3-sector/ 65°	436 m	39 m	16 m	99 m
6-sector/ 65°	163 m	96 m	16 m	99 m
6-sector/ 33°	158 m	17,4 m	16 m	99 m

Table 1: Theoretical accuracies of different topology scenarios.

For soft handover, the accuracy has been evaluated for two geometry cases: the best ($\alpha=90^\circ$) and the worst scenario ($\alpha=180$). Naturally, if the active set size increases, the accuracy of the different geometry scenarios improves significantly. Moreover, the probability of larger active set size increases when α approaches 90° .

4. Simulations

Monte Carlo simulations were utilized in order to evaluate the distribution of the areas with different degree of accuracy for the chosen topology scenarios. Furthermore, the impact of UTRAN parameters (SHO window, E_c/I_0 requirements, CPICH power) on the size of these areas was studied. Simulation area consisted of 19 base station sites of 3-sector (65° antennas) or 6-

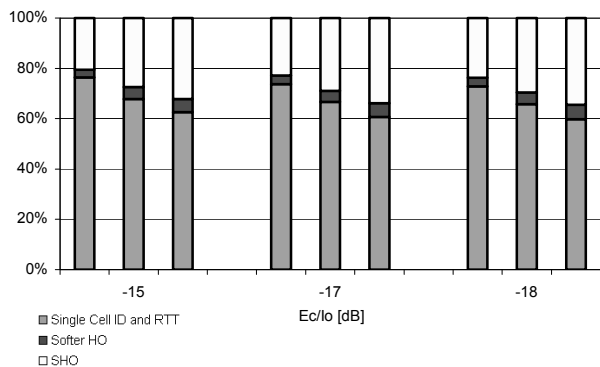


Figure 5: Distribution of areas with defined degree of accuracy, 3-sector/65° topology.

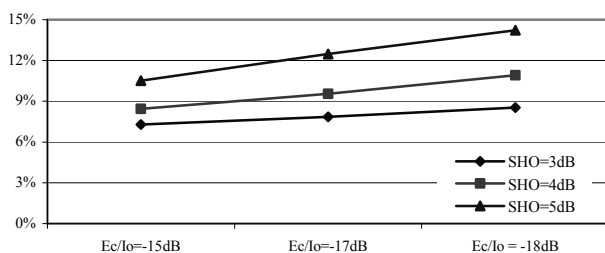


Figure 6: Mean of failures for 3-sector/65° topology.

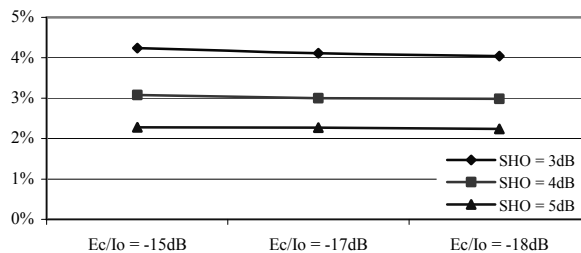


Figure 7: Mean of failures for urban 3-sector/65° topology with lower pilot power (CPICH 30 dBm).



Figure 8: Distribution of areas with defined degree of accuracy, 6-sector/65° topology.

sectored (65° or 33° antennas) configurations. The sites were located in a regular hexagonal grid having equal distances of 1 km. Traffic raster, which contains the number and distribution of the users, was selected to be homogeneous over the simulation area. The user profile consisted only of speech users (12.2 kbps), since packet users were believed not to affect the overall distribution of examined areas. The amount of users was selected in such a manner, that the average uplink load was kept on the same level – 60% in all high loaded scenarios. COST-231-Hata propagation model was chosen for the simulations, propagation slope was constant (35 dB/dec), and an average area correction factor was set to –6.7 dB (light urban/suburban).

Simulations were made for two loaded scenarios. However, since the studied dependences are more expressive in high loaded case, only results of high loaded network are shown in the frame of this paper. The figures are organized in the way that for each value of E_c/I_0 there is a set of bars calculated for different SHO window sizes of 3 dB, 4 dB, and 5 dB, respectively.

The first considered network was 3-sector/65° topology. The results in Figure 5 clearly show that by increasing the SHO window, the change in different accuracy areas is more significant than in different E_c/I_0 scenarios. However, having a lower E_c/I_0 requirement, the service probability is also lower.

The quality of selected topologies with different parameters was observed through the mean number of failure connections in the network.

The mean of failures is greater for SHO window 4 dB and E_c/I_0 -18 dB than for SHO window 5 dB and E_c/I_0 -15 dB (Figure 6). Altogether, more areas with better accuracy in SHO window 5 dB and E_c/I_0 -15 dB

scenario are present. In this topology, a single Cell ID is reported in 60% to 70% of total network coverage area.

The same simulations were made with a lower value of pilot power (CPICH 30 dBm). The overall results show worse performance from location point of view; on average, 1% less softer HO, 2-4% less SHO, and 2-3% more single Cell ID areas. However, the mean of failures is decreased to lower level (2-4%), see Figure 7. The mean of failures behaves differently than in scenarios with higher pilot power, since the network is more uplink noise limited rather than downlink transmit power limited as it is in the scenario of higher CPICH power network. Moreover, the situation when the network with lower CPICH power has higher service probability exists only in dense topologies. In the rural environments (coverage limiting), the low E_c/I_0 (pilot coverage) would become the main contribution to failure, and it might decrease the service probability.

In Figure 8, the results of the simulations of the 6-sector/65° network topology are presented. Naturally, due to implementation of wide beamwidth antennas (65°) for 6-sectored sites, the increase in softer handover areas is significant. Due to remarkable sector overlapping, the attainable accuracy in softer handover areas decreases, since the overlapping areas are overspread at wider angle. Moreover, the level of mean of failures is considerably higher as seen from Figure 9.

With a lower pilot power (30 dBm) in the 6-sector/65° topology, the areas with better accuracy, i.e., soft and softer HO areas are kept on very high level. Only 2-6% less SHO and softer HO areas are obtained (Figure 10) compared to higher pilot scenario. Fortunately, the increase in single Cell ID areas is not significant. On average, there are only 8% more single

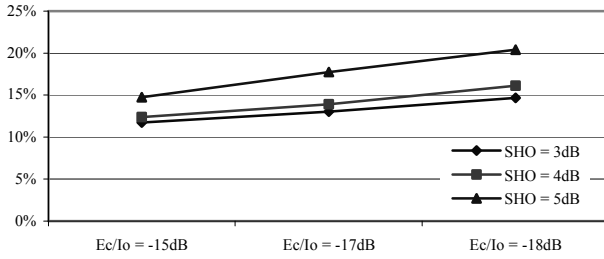


Figure 9: Mean of failures for urban 6-sector/65° topology.

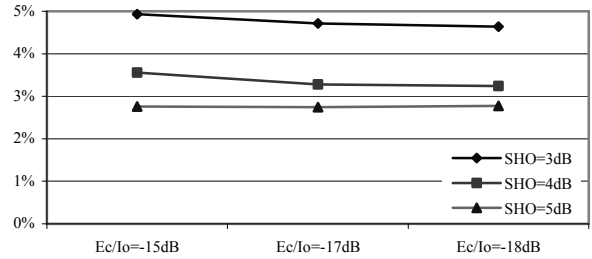


Figure 11: Mean of failures for urban 6-sector/65° topology with lower pilot power (CPICH 30 dBm).

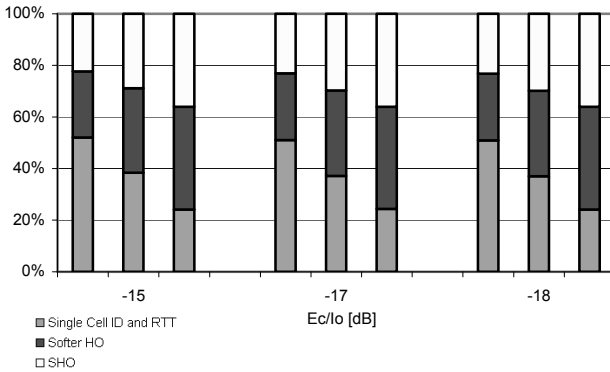


Figure 10: Distribution of areas with defined degree of accuracy, 6-sector/65° topology with lower pilot power (CPICH 30dBm).

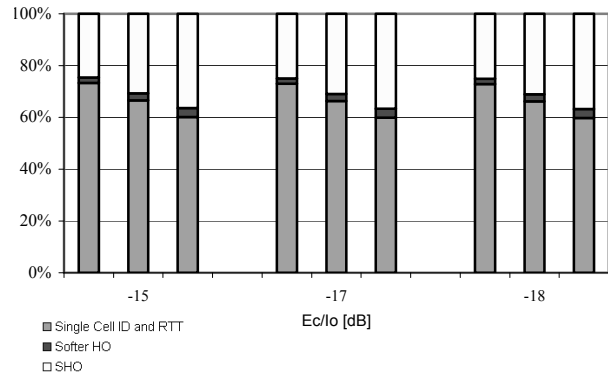


Figure 12: Distribution of areas with defined degree of accuracy, 6-sector/33° topology.

Cell ID areas. The best case (SHO 5 dB, E_c/I_0 -18 dB) provides approximately 20% areas where single Cell ID is reported.

Similarly, changing the value of CPICH to 30 dBm, the 6-sector/65° topology becomes noise limited with lower level of mean of failures (Figure 11).

In 6-sectorised sites with 33° antennas, the probability of SHO is still maintained at high level with almost 100% service probability. The 6-sector/33° topology in high loaded network behaves similar to less loaded scenario. There is practically no difference in the size of defined areas between different E_c/I_0 values (Figure 12). SHO areas are still kept on high level (20%-35%) but single Cell ID is reported from over 60% of the total service coverage area due to the low probability of softer handovers.

5. Discussion and Conclusions

The impact of different radio network topologies on the performance (accuracy and availability) of Cell ID+RTT positioning method has been studied.

Theoretical analysis of geometry shows that the accuracy of the hybrid Cell ID+RTT positioning method depends heavily on the network topology together with mobile location, and varies from 16 m to almost 440 m as a function of these parameters. The best positioning accuracy can be reached in softer and soft handover areas. Thus, availability of these areas was simulated for three different network topologies and for different SHO window, E_c/I_0 , and CPICH power requirements.

E_c/I_0 requirement does not have notable impact on the availability of Cell ID+RTT. However, a lower E_c/I_0 threshold degrades the service probability

significantly. Moreover, the size of the SHO window affects the overall performance of positioning. Naturally, due to wider window, there is a considerable growth in softer and soft HO areas together with decrease in areas, where single Cell ID is reported. Similarly, wider SHO window affects the decrease in the service probability in the transmit power limiting scenarios.

Simulation outcomes showed that good balance between network performance and availability of studied location technique can be maintained by selecting the following values to parameters: SHO window 5 dB and E_c/I_0 -15 dB.

Comparison of network performance from both points of view – positioning and radio network planning – in all considered scenarios is presented in following figures: Figure 12 – Availability, Figure 13 – Accuracy, Figure 14 – Mean of failures. Availability for 3-sector/65° and 6-sector/65° has been presented for two CPICH power scenarios; left bar corresponds to CPICH 33 dBm, and right one, correspondingly, to lower pilot allocation scheme.

The simulation results showed that 6-sector/65° network topology offers the widest availability of softer and soft handover areas and thus it provides the best overall performance for Cell ID+RTT positioning method. This result differs from the optimal 6-sectorised/33° configuration when positioning methods are not considered in the network [10] – [11].

Changing the value of CPICH to 30 dBm makes high loaded and dense networks uplink noise limited with very low level of mean of failures. Moreover, the behaviour of the service probability as a function of E_c/I_0 and SHO window is reverse – the mean of failures is lower for a wider SHO window size and for a lower

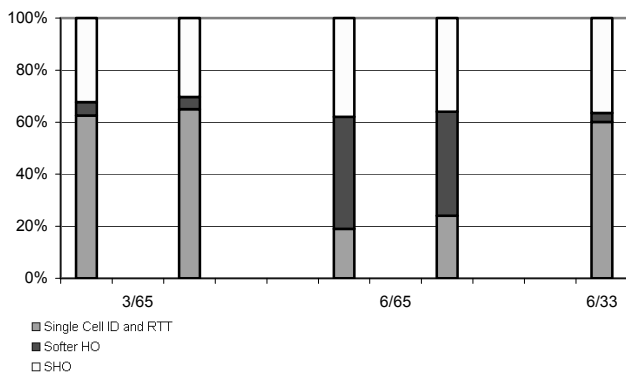


Figure 13: Availability of Cell ID+RTT – conclusions. For 3-sector/65° and 6-sector/65° results are presented for higher (left) and lower (right) CPICH power scenarios.

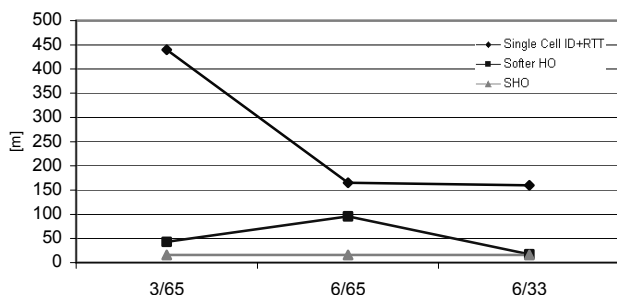


Figure 14: Comparison of accuracy of Cell ID+RTT in considered scenarios.

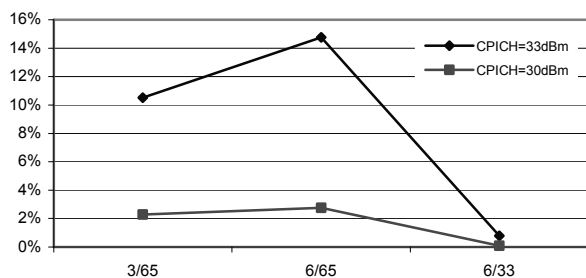


Figure 15: Comparison of mean of failures in considered scenarios.

E_c/I_0 requirement. At the same time, there is only a small decrease in areas with higher degree of accuracy compared to higher pilot scenarios (usually 2-5% less SHO and 1% less softer HO areas). Therefore, by decreasing CPICH power in the 6-sector/65° scenario, the mean of failures decreases from over 20% down to 2%. Simultaneously, the areas with higher degree of accuracy are still kept on high level.

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