Impact of UMTS Topology Layout on Cell ID+RTT Positioning Accuracy

Jakub Borkowski, Jarkko Itkonen, and Jukka Lempiäinen

Abstract—The aim of this paper is to illustrate an impact of UMTS topology layout on the Cell ID+RTT positioning accuracy. The Cell ID+RTT technique was selected for presented analysis, as it is standardized, supported by regular terminals, and does not necessitate any major upgrades of the network hardware. Assessment was performed by static simulations executed on top of selected topology configurations. In addition to common hexagonal layouts, simulations were focused on evaluating the positioning performance on top of the recently proposed modified grid, which has more controlled interference properties. Obtained results yield that topology layout does not have significant impact on the positioning accuracy. However, modified hexagonal configuration provides slightly better support for the Cell ID+RTT positioning than other considered layouts. On average, location of the terminal can be estimated with the accuracy of 298 m in the analyzed modified topology layout and with the accuracy of 333 m in case of the common hexagonal grid when idealistic LOS propagation is assumed. Similarly, in more practical scenarios, i.e., when NLOS and multipath propagation are considered, the modified configuration also performs the best. However, the average overall accuracy is reduced to slightly more than 350 m. Naturally, presented accuracy figures directly depend on the site spacing, as with more dense topology layout, range of positioning errors is reduced.

Key words – Cell ID+RTT, mobile positioning, topology, UMTS.

I. INTRODUCTION

Reducing deployment costs of technology that enables positioning with sufficient accuracy is essential for providing LBS (location-bases services) in a relatively short term. Minimum accuracy of positioning cellular subscribers is defined by FCC (Federal Communication Commission) safety requirements for emergency calls [1] and by demands of majority of location-sensitive applications [2]. Namely, the total mean positioning error for network-based techniques should be kept below 100 m. The most significant challenges in achieving such accuracy level at reasonable system complexity are caused by diverse propagation environment. Major sources of the estimation error include NLOS (non line of sight) with multipath propagation, limited measurement resolution, and geometrical dilution of precision [3].

Cell ID+RTT (cell identification + round trip time) is an exclusively network-based positioning method for UMTS (Universal Mobile Telecommunications System) that is supported by regular terminals and do not require major updates in a network equipment [4]. Questionable accuracy of the basic Cell ID+RTT can be enhanced by multiple RTT measurements performed when the located UE (User Equipment) is in SHO (soft handover) and by other post processing algorithms [5]-[6]. Naturally, each additional component introduced to the positioning system increases the overall complexity that reduces the applicability. In order to select the most feasible positioning system for deployment, the performance should be comprehensively analyzed and confronted with the actual performance demands. Moreover, an impact of the network topology on the positioning performance should be well known, since properly configured topology can positively influence positioning services.

In this paper, the accuracy of the regular network-based Cell ID+RTT positioning method will be analyzed in three different network topology configurations. Moreover, simulation outcomes will illustrate the expected accuracy of the Cell ID+RTT in various propagation environments.

II. NETWORK TOPOLOGY

A hexagonal structure provides the most popular layout for network topology. A traditional hexagonal cell grid can be constructed by omni-directional antennas located in the centre of hexagons [7]. Extending this approach to the most common 3-sectored sites is performed by placing directional antennas in the corner of each hexagon and ensuring constant antenna directions over the network. Considerable attention has been gained by two hexagonal layout modes that are differentiated by antenna directions schemes. Namely, hexagonal topology...
depends on the RTT error and the Cell ID uncertainty. The interference is spread all over the cell boundaries. On the contrary, in the nominal hexagonal topology the antenna main lobes to point towards each other. Hence, controlled radio performance properties by assigning base station antenna to point towards each other. Hence, controlled radio performance properties by assigning base station antenna main lobes to point towards each other. Hence, the high level of interference can be concentrated in selected regions. On the contrary, in the nominal hexagonal topology the interference is spread all over the cell boundaries.

The performance of the modified hexagonal configuration from the capacity point of view has been analyzed in [8]-[9] with initial results indicating potential advantages of the novel topology. Precisely, modified topology provides more controlled radio performance properties by assigning base station antenna main lobes to point towards each other. Hence, the high level of interference can be concentrated in selected regions. On the contrary, in the nominal hexagonal topology the interference is spread all over the cell boundaries.

III. ACCURACY OF CELL ID+RTT

Network-based Cell ID+RTT exploits information about the serving sector and reported RTT measurement. RTT is a standardized NodeB measurement that is performed on DPCCH (dedicated physical channel) and forwarded in the RL (radio link) measurement report to the RNC (radio network controller). NodeB defines RTT by observation of a time difference between the beginning of a DL (downlink) DPCCH frame transmission and reception of the beginning of the corresponding UL (uplink) DPCCH (dedicated physical channel) frame from the first detected path [10]. Reported RTT does not take into account the time offset on the dedicated channel that is introduced by the UE. In order to eliminate this ambiguity, the reported RTT is corrected by subtracting Rx-Tx time difference, which is measured and reported by the UE to the RNC [10]. The Rx-Tx measurement constitutes the time difference between the transmission of the UL DPCCH frame and the first detected path of the DL DPCCH frame.

Generally, the accuracy of the Cell ID+RTT positioning depends on the RTT error and the Cell ID uncertainty. The RTT inaccuracy is mainly caused by NLOS propagation and hardware limitations. In turn, the Cell ID error is defined by a regular size of the cell dominance area (1), Fig. 2. Similarly, for UEs in softer HO, the Cell ID+RTT accuracy is defined adequately. Naturally, the expected accuracy for UEs located in these regions should be at a higher level due to statistically narrower outspread angle ($\alpha$) and thus smaller $\text{CellID\_error}$. Theoretical, based on a single RTT measurement, UE-NodeB distance can be estimated with the resolution of 36 m with 1/2 chip over sampling or, for instance, with the precision of 5 m when 1/16 over sampling is applied. Naturally, the accuracy of the RTT is significantly reduced in NLOS and multipath propagation environment. In order to minimize the Cell ID uncertainty, the position of the UE is always mapped in the middle of the corresponding range arc, which is defined by an erroneous RTT and a width of the dominance area, see Fig. 2. Hence, the overall Cell ID+RTT accuracy can be defined accordingly:

$$\text{Accuracy} = \sqrt{\text{RTT\_error}^2 + \text{CellID\_error}^2}. \quad (2)$$

As RTT is reported from each RL, the accuracy of the RTT-based positioning for UEs in SHO can be potentially higher due to multiple range estimates. Then, the position of the UE is derived from convergence of numerical optimization of corresponding ranges. The positioning accuracy for terminals in such regions depends on the selection of the initial optimization point, on the performance of the numerical algorithm itself, and on the NLOS propagation as well.

IV. SIMULATION ENVIRONMENT

A. Network configuration

A MATLAB-based NPSW (Network planning strategies for WCDMA) static planning tool was modified in order to account evaluation of the positioning performance [11]. The accuracy of the Cell ID+RTT was assessed on top of three different network topology configurations as well as in various propagation environments. Considered network layouts (Fig. 1) were constructed from 19 sites in case of the nominal grids and from 24 sites for the modified hexagonal layout. Sites were configured in a three-sectored manner with 65° horizontal and 2° vertical beamwidth (electronic downtilt) antennas. Average site spacing distance was 1 km. All antennas were defined at a constant altitude of 25 m and were located in a flat area of zero meter ground height and a single environment class with correction factor of -10 dB. Signal propagation was represented by COST-231-Hata prediction model [12]. Moreover, shadowing was modeled by a log-normal distributed random variable with standard deviation of 7 dB. Simulations were conducted for 1000 terminals that...
were Poisson-distributed over the area of 36 km$^2$. In order to represent NLOS propagation, RTT measurements from the serving site were distorted by a positive, distance-dependent additive error. Correspondingly, for terminals in SHO, RTTs were modeled from all RLS that were present in the AS (active set) and NLOS errors were adequately added to each measurement. Limited resolution of the RTT measurements defined by a receiver implementation was not taken into account, as NLOS errors are the most dominant in majority of practical scenarios. For terminals under dominance and softer HO areas, the accuracy was evaluated based on (1) and (2) with corresponding definition of the outspread angle ($\alpha$). In turn, for terminals in 2- or 3-way SHO, the accuracy was defined as a difference between the optimization convergence point and the real position of the UE. Solution of set of equations describing ranges with multiple intersection points was derived by utilization of MATLAB implementation of the trust-region dogleg optimization method [13].

**B. Multipath channel model**

Two different propagation environments were considered with corresponding RTT errors. In addition, the positioning was simulated in the LOS propagation environment in order to provide a direct topology impact on the accuracy. The RTT error due to NLOS propagation was defined by a positive, distance-dependent error. Accordingly, RTT measured by the $i^{th}$ NodeB in the AS was defined as:

$$RTT_i(d) = LOS(d) + 2NLOS(d),$$  \hspace{1cm} (3)$$

where $LOS$ represents the RTT measured in the LOS conditions by the $i^{th}$ NodeB. The RTT suffers from the NLOS bias in both directions (DL and UL). However, as the path length is the same, the final error is not doubled. The positive NLOS bias is essentially correlated with the mean excess delay ($\tau_m$) of the channel based on studies presented in [14]. Moreover, according to the wideband channel measurements cited in [14], the mean excess delay is correlated with the RMS (root mean squared) delay spread ($\tau_{RMS}$) of the channel:

$$NLOS_i(d) = \tau_m(d) = k \cdot \tau_{RMS}. $$  \hspace{1cm} (4)$$

In (4), $k$ is the scaling factor that is derived to be approximately 1 for majority of urban and 2 for suburban environments. Expected value of the delay spread is defined based on model presented in [15]. This statistical model provides an estimate of $\tau_{RMS}$ in a function of the mobile-to-base station distance based on average value of RMS delay spread observed at 1 km distance from the base station. Then, the bias in estimated range due to NLOS can be modeled by (5):

$$NLOS_i(d) = k \cdot \tau_{RMS}(d) = k \cdot T_i(d')^{\epsilon} \cdot x^i. $$  \hspace{1cm} (5)$$

In (5), $T_i$ is a median value of $\tau_{RMS}$ at $d = 1$ km, an exponent $\epsilon$ is defined as 0.5 for urban and suburban propagation environment, and $x$ is a lognormal variable. The variable $x$ is defined by $X = 10\log(x)$, which is a Gaussian-distributed random variable over the terrain at distance $d$ with zero mean and standard deviation $\sigma_x$.

Values of the parameters for the presented NLOS model were defined according to measurement results published in [16] and [17]. Namely, for considered scenario with more favorable radio conditions ($Scenario 1$) $T_i = 0.27$ $\mu$s. In turn, for scenario with more erroneous time measurements ($Scenario 2$), $T_j = 0.98$ $\mu$s. Moreover, for considered environments, standard deviation ($\sigma_x$), was assumed to be 2 dB for $Scenario 1$ and 4 dB for $Scenario 2$. Corresponding example of the NLOS errors in a function of the distance is illustrated in Fig. 3.

**V. SIMULATION RESULTS AND ANALYSIS**

Executed simulations indicate that analyzed topology grids do not have an impact on the outspread angles of typical sector dominance and softer HO areas. Namely, the outspread angles for the sector dominance and softer HO regions are $\alpha = 90^\circ$ and $\alpha = 30^\circ$, correspondingly, see Fig. 4. Naturally, application of horizontally narrower antennas or higher order
sectorization scheme at base stations would decrease the average width of the dominance area and thus improve the overall Cell ID+RTT accuracy [4]. Statistical distribution of softer and SHO areas does not significantly differ in the considered network configurations, see Table 1. However, in the modified hexagonal configuration, considerable increase of 3-way SHO availability was observed. This phenomenon is mainly due to the antenna configuration scheme that defines main lobes to be directed towards each other, Fig 4 (c). Naturally, in 3-way SHO regions the accuracy of the Cell ID+RTT is at a high level as multiple RTTs can be simultaneously measured on each RL.

Comparison of the overall accuracy in the considered topology layouts is presented in Fig. 5. In order to illustrate a direct topology impact on the positioning accuracy, the idealistic LOS situation was also considered, Fig. 5 (a). The observed differences between analyzed grids are not significant. However, in the LOS situation mean accuracy in the modified grid is at the level of 298 m while for the nominal US and European layouts, the mean accuracy equals accordingly, 320 m and 333 m. This improvement is caused by smaller average size of the sector dominance area, Fig. 4. More precisely, in the modified hexagonal grid, the average UE-NodeB distances for UEs in the sector dominance area are statistically smaller than in case of the nominal hexagonal layouts. Therefore, mean values of the Cell ID+RTT accuracy for terminals in the sector dominance area are at the highest level in the modified configuration (339 m) in comparison to the nominal US (352 m) and European (376 m) layouts. Naturally, slightly higher level of the overall accuracy in the modified grid is also caused by higher availability of 3-way SHO areas, in which the position of the terminals can be precisely estimated when no NLOS errors are assumed. In turn, the positioning accuracy for terminals in 2-way SHO state suffers from lack of an explicit solution of the corresponding ranges equations. On average, the terminals in 2-way SHO regions can be located with the accuracy of 315 m in the modified grid and 342 m and 302 m in the US and the European version of the hexagonal configuration. Respectively, this indicates that in case of the European grid, terminals in 2-way SHO are statistically located closer to the AS sites and thus the resulting ambiguity of the optimization convergence is smaller. No considerable differences in the accuracy between considered layouts were observed for terminals located in softer HO areas; on average the estimation error in these regions is kept below 90 m.

In the considered Scenario 1 with NLOS errors in RTT measurements the overall accuracy analyzed on top of the modified grid is improved by 15% in comparison to the nominal European layout, Fig. 5 (b). Mean values of the accuracy for the modified, US, and European hexagonal grids are correspondingly 377 m, 400 m, and 403 m. Indicated impact of topology on the Cell ID+RTT accuracy is expectedly maintained. Naturally, effect of the erroneous RTT measurements can be directly seen in the overall accuracy reduction. The estimation error is significantly worsened for...
terminals in 2- and 3-way SHO state, while the accuracy for terminals under sector dominance in Scenario 1 does not differ much from the LOS conditions. Namely, when RTT can be measured on two RLS, the mean accuracy corresponds to 430 m in the modified grid and to 506 m and 464 m in the nominal US and European grids, see Fig. 6 (a). Similar tendency was observed when three simultaneously measured ranges were reported for the position estimation. Specifically, due to relatively small distances to the AS sites in the modified and nominal US grid, the resulting errors are smaller, Fig. 6 (b).

In Scenario 2, when the errors in RTT measurements are significant, the mean Cell ID+RTT accuracy drops to 486 m in modified grid, to 529 m in the US nominal grid, and to 557 m in the European layout. However, the topology impact remains unchanged.

VI. CONCLUSION AND DISCUSSION

The accuracy of the Cell ID+RTT positioning was assessed by simulations performed in typical topology layouts for UMTS networks. Moreover, the analyses were conducted with different NLOS propagation scenarios. Namely, the accuracy of RTT measurements was reduced by a positive, distance-dependent, additive variable that represented NLOS error. The overall Cell ID+RTT positioning precision depends on the distribution of the sector dominance and SHO areas. Typically, the accuracy is at the highest level for terminals located in softer HO region due to narrow outspread angle and in 3-way SHO areas due to multiple RTT information.

Executed simulations showed that analyzed topologies do not have a significant impact on the Cell ID+RTT accuracy. However, in the modified grid and the US nominal grid, slight increase of 3-way SHO availability was observed since antenna directions are configured such that main lobes point towards each other. In addition, it was illustrated that in the modified hexagonal configuration, sector dominance areas are statistically smaller. Thus, the Cell ID+RTT accuracy evaluated on top of the modified grid provided the best results. Namely, the mean overall accuracy was observed at the level of 298 m for the modified grid, and correspondingly 320 m and 333 m for the nominal US and European hexagonal layouts in the idealistic LOS environment. Similar phenomenon was observed when the positioning was assessed in the NLOS propagation environments. Naturally, with more erroneous RTT ranges, the positioning accuracy was accordingly reduced. In the simulated Scenario 1, the mean overall accuracy was reduced to 377 m in case of the modified grid and approximately to 400 m in the considered nominal hexagonal layouts. However, the topology impact maintained the tendency, as modified hexagonal grid provided the best support for the Cell ID+RTT positioning. Moreover, this topology layout allows for flexible control of interference by assigning proper directions of antenna main lobes together with careful designing of antenna patterns.

Location technique providing estimation accuracy at the illustrated level does not fulfill stated emergency and majority of commercial requirements. Therefore, future studies will focus on analysis of topology impact on other applicable positioning methods including developed enhancements to the basic Cell ID+RTT method. In addition, utilized channel model will also be confronted with measurements of NLOS error that will be conducted in typical urban and suburban environments.

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