Optimization aspects for cellular service performance and mobile positioning in WCDMA radio networks

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***Abstract*— The aim of this paper is to evaluate the impact of selected topology planning aspects on performance of WCDMA cellular network and mobile positioning techniques. The assessment is based on field measurements and simulations. Capacity improvement is illustrated for the network topology when antenna down tilt, sectoring, and repeaters are considered. In turn, two network-based location methods (CID+RTT and PCM) are selected for evaluation of the accuracy in a radio environment optimized for the maximum capacity. Presented results yield for a compromise if both, radio capacity and the CID+RTT, are aimed to be maximized through antenna down tilting and sectoring. On the other hand, topology optimization through repeater deployment improves the positioning accuracy as well. Considered topology optimization methods affect the PCM accuracy when the underlying database is intended to operate in a non-optimized topology, however the mean value of the accuracy is still on an appropriate level.**

Keywords- *optimization, positioning, topology, radio network planning*

INTRODUCTION

Evolution of offered services consuming more bandwidth often creates bottlenecks in radio interface, typically in urban areas that attract extended number of subscribers. Undoubtedly these scenarios create challenging tasks for network planners aiming at maximizing network coverage and capacity while keeping implementation costs at a minimum possible level. Radio network planning objectives can be achieved by exploitation of optimization techniques including antenna down tilting, repeaters deployment, or sectoring [1]. Resulting topology modifications directly influence the performance of offered value-added services for subscribers, in particular, LCS (location services). Naturally, the degree and direction of the influence depends on the underlying location technique that estimates the actual position. For instance, the accuracy of majority of cellular positioning techniques is sensitive to the shape of the cell dominance areas, cell overlapping, multipath propagation, and LOS (line-of-sight) availability. The influence on radio capacity and positioning performance is significant in CDMA (Code Division Multiple Access)-based networks, as relatively small topology changes have crucial impact on the radio conditions. Prior studies have illustrated impact of numerous capacity enhancements methods [2]-[3], however the influence on the performance of cellular positioning techniques has not been widely researched.

In this paper, selected topology optimization methods (antenna down tilting, sectoring, and repeater deployment) are analyzed by simulations and filed measurements performed in UMTS (Universal Mobile Telecommunications System) network. Conducted analyses illustrate impact of considered optimization aspects on radio capacity and accuracy of selected mobile positioning methods for UMTS.

II. TOPOLOGY OPTIMIZATION ASPECTS

A. Antenna down tilting

Antenna down tilting is an efficient method for directing antenna radiated power to the intended cell area. Down tilting method can be either MDT (mechanical) or EDT (electrical). MDT is carried out by physically turning the antenna element towards the ground, whereas in EDT antenna pattern is shaped by changing phase differences between antenna array elements. Advantage of EDT is the capability to down tilt also the side lobes of the antenna, without relative widening of antenna pattern that MDT causes. Antenna down tilt raises the signal level at the intended cell area, while interfering radiation towards neighbouring cells is reduced. Secondary effects of antenna down tilt are, e.g., reduced cell overlapping, smaller SHO (soft handover) overhead, possible coverage degradation in cell border areas, and increased amount of SfHO (softer handover) in MDT. In [2], capacity improvement between non-tilted and optimally tilted network was studied in macro cellular environment with different practical site and antenna configurations.

B. Repeater deployment

Repeaters (RF-signal amplifiers) have been typically used to extend the coverage of a macro cell, to provide coverage to areas that are shadowed by obstacles. However, repeaters are found to be useful also in capacity- and interference-limited networks to increase the downlink throughput of the cell by reducing the required BS (base station) transmit power [4]. Repeater has two antennas: donor and serving antenna. The donor antenna is pointed to the direction of the mother BS antenna for the reception of the signal to be amplified. In turn, the serving antenna is oriented towards the intended traffic on the coverage area of the repeater. Repeater has adjustable amplification ratio (repeater gain). Cost-efficiency and short deployment time are the key motivating aspects, when optimizing a cellular network by deploying repeaters. Network operators could use repeaters as an aid in providing additional coverage or capacity for short- or long time purposes. Although repeaters are able in certain scenarios to reduce the required transmit power of the users, the noise amplification property limits the performance of the repeater with high gain settings. This is problematic especially in the UL (uplink), when repeater decreases the BS receiver sensitivity by increasing the received BS noise levels. In addition, interfering signals from the other users are amplified by the repeater unit.

C. Sectoring

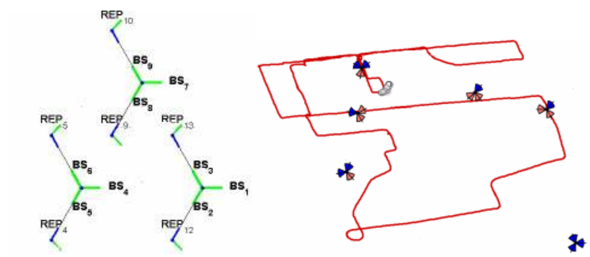
Sectoring is known to be an efficient method for increasing capacity cellular systems [5], but achieving maximal capacity improvement requires properly selected down tilting and antenna configuration [2]. In order to keep the sector overlapping at appropriate level, antennas should be selected in accordance with the sectoring scheme. Namely, horizontal beam width should be adequately narrowed while adding sectors to the site. Moreover, this results in expanded coverage due to higher antenna gain and increased capacity due to reduced interference between sectors and reduced SfHO overhead. Typical configurations are 3- and 6-sectored sites with antenna horizontal beam width of 65° and 33°, respectively. Also other configurations are commonly used, e.g., 4-5 sectors, or mixed 33°/65° when updating 3-sectored 65° sites to 6-sectored.

III. Positioning Techniques

Cellular network-based positioning techniques provide location information for LCS without involvement of the GPS (Global Positioning System). Moreover, in network-based methods, the position is estimated in the network equipment with minimum impact on the terminal implementation. Two developed network-based cellular location techniques were selected for detailed analysis.

A. CID+RTT (Cell identification + round trip time)

CID+RTT positioning is based on the serving sector information and physical layer measurements. The technique is described in detail in [6]-[7]. Its accuracy mainly depends on the size and shape of the dominance area and NLOS (non LOS) probability. Moreover, the positioning accuracy is affected SfHO and SHO probability. For terminals in these areas, multiple Cell ID information and single RTT (SfHO) or multiple RTT reports (SHO) decrease the estimation ambiguity [6]. Generally, the accuracy of the CID+RTT for terminals within single cell dominance or SfHO area [7]:



(a) (b)

Fig. 1. (a) - Fragment of the simulation layout for CID+RTT accuracy assessment. Green lines illustrate site and repeater antenna orientations;

(b) - Fragment of the network illustrating measurement route and sites with modified MDT configuration. Antennas, whose MDT angle was changed, are indicated as red.

$$Accuracy = \sqrt{RTT\_error^2 + CellID\_error^2}. \qquad (1)$$

In (1), *RTT_error* is the RTT measurement inaccuracy caused by NLOS propagation and hardware limitations. In turn, *CellID_error* is defined as follows:

$$CellID\_error = (d + RTT\_error) \cdot \pi \cdot \frac{\alpha}{360^0}, \qquad (2)$$

where, d illustrates the real distance between the terminal and the serving BS and α is the outspread angle of the cell dominance or SfHO area. Since RTT is measured on each active RL (radio link), the estimation accuracy for terminals in SHO is defined by *RTT_error* on each RL as well as by the performance of applied numerical optimization methods.

ECID+RTT (Enhanced CID+RTT) technique is an extension of the basic CID+RTT method. The technique improves the accuracy of the CID+RTT by forcing the positioned terminal to SHO. Moreover, the ECID+RTT has better performance in multipath environment [8].

B. PCM (pilot correlation method)

The PCM positioning exploits a database with collection of pre-measured RSCP (received signal code power) over the entire coverage of the intended positioning service. The location is estimated in the network by correlating the reported RSCP measurement from the positioned terminal with the samples stored in the previously created database. The information about the received levels of CPICHs (Common Pilot Channels) is crucial for proper network functionality. Therefore, typically the positioning process does not require any extra signaling as the valid RSCP measurements are already in the network. In other cases, the UE (User Equipment) is paged in order to obtain valid RSCP report. The PCM is comprehensively presented in [8].

The accuracy of the PCM is limited by the resolution of the database. Moreover, network topology influences the estimation accuracy, since typically dense site locations allow for more clear differentiation between various regions defined in the database.

IV. Simulation Environment and Measurement Scenario

The impact of selected topology aspects on the accuracy of introduced positioning methods was assessed by simulations and measurements.

A modified, Matlab-based static simulator NPSW (Network planning strategies for WCDMA) was used for CID+RTT performance assessment. Simulation layout consisted of 19 sites (3-setored) constructed over the hexagonal grid with equal, 1 km site spacing. The positioning accuracy was evaluated in three topology scenarios with different EDT angle on the BS antennas, 0º, 3º, and 7º. Additionally, the accuracy was assessed in the scenario with 24 repeaters, Fig. 1a. All sites were configured with 65º horizontally wide antennas. The antenna height for all sites and repeaters was 25 m. Propagation was modeled by COST-231-Hata model with shadowing represented by a log-normal random variable with 8 dB standard deviation. Sites and repeaters were places in a flat area and a single environment class with correction factor of -10 dB. Repeaters were placed 500 m from the donor BS in the main beam of the antenna. Repeaters were configured with a fixed gain of 60 dB. Repeater antennas (65º horizontal beam width) had 7º EDT. Simulations were conducted for 500 terminals randomly distributed over the simulation area. NLOS propagation was modeled according to the model introduced in [9]. Namely, for UE-BTS distances (*d*) larger than 250 m, *RTT_error* was modeled by the equation:

$$E(d) = (A \cdot d) \cdot y\,. \qquad (3)$$

In (3), A is a proportional coefficient that equals 0.35 while y is a lognormal variate defined as $Y = log(y)$ is a Gaussian random variable with σ_y=2.2 dB. The model is valid only for d > 250 m. For terminals located closer to the serving BS, the range error was modeled by a random variable, which mean value was defined as $0.25 \cdot d$ and σ_y=1.8 dB. The accuracy was calculated according to (1) and (2) based on the outspread angle (α) estimated from the simulation results. For terminals located in 2- or 3- way SHO area, the accuracy was defined as a difference between the convergence point of the numerical method 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 [10].

Impact of topology optimization on the PCM accuracy was evaluated by field measurements performed in an urban UMTS network. For the assessment in all considered configurations a single PCM database was used, which was created from measurements conducted in the network where most of the sites were down tilted (denoted as *nominal configuration*). The positioning accuracy was evaluated in three different topology configurations: in the *nominal configuration*, in the scenario where all MDT were removed (Fig. 1b), and in the repeater scenario with different repeater gain adjustments. The network consisted of multiple conventional 3-sectored sites with approximately 400 m spacing distances. The average BS antenna height was 20 m, slightly exceeding the rooftop level. In a scenario with repeater, two gain settings were considered (65 dB and 70 dB). Repeater donor antenna was installed in LOS conditions with the mother cell in approximately 300 m distance. Repeater donor and serving antennas were placed in 10 m height. The database consisted of over 300 positioning regions defined within 1 km^2 network coverage. Single entry in the database was created from the region of the average size of 100 m x 50 m. In order to illustrate impact of the considered optimization aspects on the PCM accuracy, the same database was used for all evaluations. The accuracy was evaluated based on samples collected by test mobile over the measurement route. The routes were defined in a manner to cover most of the areas affected by the down tilted sites (Fig. 1b) and in scenario with repeater – the area of mother and adjacent cells. During each measurement route, over 500 position estimates were performed. The accuracy was defined as a difference between the estimated position and the GPS indication.

Impact of considered optimization aspects on the network capacity was evaluated by static simulations. Influence of down tilting and sectoring on cell capacity was studied by simulations with hexagonal configuration of 19 cells. Simulations were performed by NetAct Planner tool. The antenna height was configured as 25 m, while site spacing was defined as 1.3 km**.** Antenna horizontal beam width for 3-sectored scenarios was 65° and for 6-sectored scenarios 33° and 65°. Capacity gains for different scenarios were calculated based on the service probability of 12.2 kbps speech users. Other simulation parameters can be found from [2], [11]. In turn, impact of optimization by repeater deployment on the radio capacity was assessed using the same topology configuration as for the evaluation of the impact on the positioning performance. Repeater gain was set to the constant value of 65 dB. Two repeater serving antenna configurations were studied - without MDT and with 6° MDT on the repeater serving antennas. The traffic hot spots were located at the cell edges where the signal level from the base stations was at minimum level. The traffic density in the circular hot spots (radius 150 m) was defined by using a hot spot density factor (HSDF). HSDF value 1 represents a homogenous traffic distribution, whereas HSDF of 6 means that the traffic density in the hot spot is six times the density in the surrounding areas. Capacity gain was defined as the improvement in the average cell throughput compared to the repeater off case. Flat terrain was included for the Monte Carlo–based simulations (with COST-231-Hata propagation model).

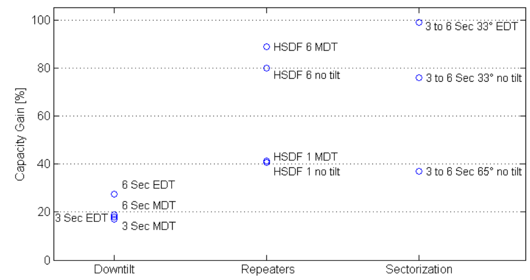


Fig. 2. Capacity improvement relative to the reference scenario in considered optimization methods for macro cellular planning.

V. Radio Capacity – Results and Analysis

Capacity gains for different optimization methods are shown in Fig. 2. Capacity gains for down tilt were defined from simulations using optimal down tilt angle settings shown in [2]. In 3-sectored scenario capacity gain respect to non-tilted network with MDT and EDT are 17.0% and

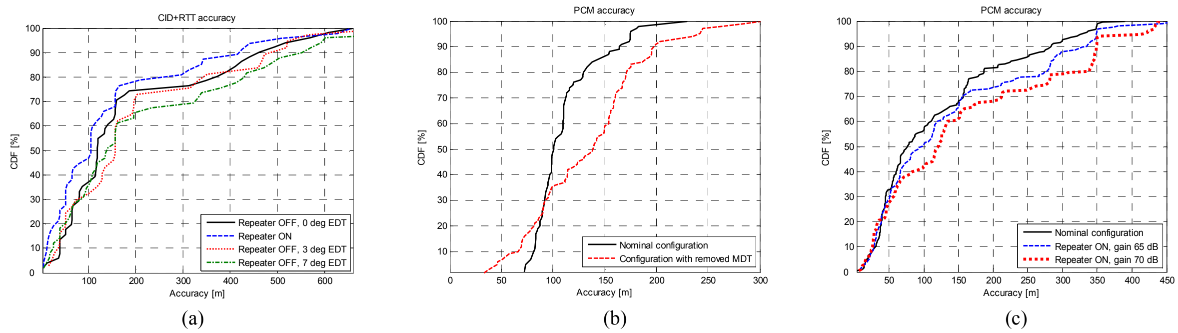


Fig. 3. Impact of considered optimization methods on the accuracy of positioning; (a) - Comparison of the CID+RTT accuracy in various down tilt and repeater scenarios; (b) – Comparison of the PCM accuracy in considered down tilt configurations, (c) – Comparison of the PCM accuracy in different repeater configurations.

18.1%, respectively. For 6-sectored scenario with MDT and EDT the capacity gains are 18.8% and 27.5%, respectively. The presented values for achieved capacity gain while down tilting antennas are relatively low because of the selected reference scenario. For instance, comparison of scenarios with antenna height of 45 m would result in capacity gains up to 50%. Capacity gains from sectoring are calculated for one site, hence high gain values are expected when doubling the number of sectors in a site. Adding three antennas to a 3-sectored site without changing antennas with narrower horizontal beam width (65°) gives capacity gain of only 37% due to very high SfHO probability caused by excessive sector overlapping. More optimized configuration is to use 33° antennas, which provides 76% capacity gain without down tilting and 99% capacity gain in EDT scenario.

The impact of repeaters on the network capacity was simulated with different HSDF. The results with HSDF of 6 (hot spot traffic density is six times higher than in the surrounding areas) show a significant improvement in the DL performance. Actually, this is observed even with the homogenous traffic distribution (HSDF = 1). The averaged BS TX (transmit) power is reduced by 6 dB with a throughput-based DL capacity gain of 75%, when HSDF of 6 is used. In case of homogenous traffic distribution, the corresponding averaged DL TX power reduction is 4.8 dB with a capacity gain of 38%. No significant change in the UL TX power levels is observed. When MDT of 6° is added to the repeater serving antennas, the achieved capacity gain is increased from 75 % to 80 %, thereby indicating a slight improvement in the network capacity [12]. Similar observations have been made in [4].

VI. Mobile Positioning – Results and Analysis

A. Antenna down tilting

The accuracy of the CID+RTT is directly influenced by the size of the cell dominance areas, site spacing distance, and SfHO/SHO probability. Therefore, in the scenarios with increased EDT aiming at minimizing inter-cell interference through reducing cell overlapping, the CID+RTT accuracy decreases as well. In the analyzed scenarios, the SHO probability decreases while EDT is increased - from 30.9% (0º) to 25.3% (3º) and 21.7% (7º). At the same time the probability of 3-way SHO that provides the best CID+RTT accuracy is reduced as well, from 7.9% (0º EDT) to 5.6% (3º EDT) and 4.2% (7º EDT). The outspread angle (α) of the sector dominance and SfHO area is 90º and 30º correspondingly for all considered scenarios. The resulting accuracy reduction due to smaller cell overlapping is illustrated in Fig. 3a. Namely, in the configuration without EDT, the mean accuracy is 190 m and standard deviation - 173 m, while in configurations with 3° and 7° EDT, the mean accuracy drops to 207 m and 220 m. Adequately, standard deviation of the accuracy for 3° and 7° EDT scenarios increases to 183 m and 210 m. Moreover, antenna down tilting is also not preferred from the ECID+RTT perspective, as forcing the UE to SHO with 3 cells can be challenging for locations in a clear cell dominance area.

Topology modifications, such as antenna down tilt or repeater deployment are considered to have minor impact on the PCM positioning performance as long as the database is updated according to the topology modifications. Figs. 3b and 3c illustrate an influence of discussed optimization methods on the PCM accuracy while database is not updated. Propagation changes caused by removal of MDT in selected sites (Fig. 1b) affect reduction of mean accuracy from 111 m (nominal configuration) to 168 m (scenario with removed MDT), as illustrated in Fig. 3b.

B. Repeater deployment

The functionality of the CID+RTT is essentially changed when repeaters are deployed. Namely, delays introduced by the repeaters need to be taken into account when reported RTT information is translated to the range distance. Additionally, for terminals served by the repeater, positioning based on the CID information should be adequately modified to include repeater serving antenna geographical coordinates and repeater antenna characteristics. From performed analysis, the outspread angle (α) of the repeater serving area is 110º, while α for cell dominance and SfHO area remains unchanged. In the repeater scenario, mean CID+RTT accuracy is improved from 190 m to 154 m (Fig. 3a).

Expectedly, deployment of the repeater reduces the accuracy of the PCM that uses database intended to operate in a nominal network configuration. The reduction is proportional to the increase of the repeater gain. However, the error increase is not significant. Namely, the mean accuracy in the nominal configuration is reported at the level of 118 m, while in repeater configurations – 137 m (65 dB gain) and 158 m (70 dB gain), see Fig. 3c.

C. Sectoring

The accuracy of the CID+RTT is directly influenced by the size of cell dominance areas, thus sectoring has impact on the positioning performance. Site antenna configuration with higher number of sectors causes smaller dominance areas, which directly improve the performance of the CID-based estimation. The accuracy of the CID is also enhanced due to increased overlapping between sectors if SfHO regions are properly defined in CID+RTT estimation process. Moreover, deployment of 6-sectored sites with horizontally wide antenna (65º) increases cell overlapping that positively affects the positioning based on the RTT measurements. According to [6], the overall accuracy of the CID+RTT is improved by over 50% in 6-sectored topology due to 40% SHO probability and decreased estimation ambiguity in the cell dominance area.

Positioning based on the PCM benefits from the topology evolution towards higher order sectoring schemes as well. The resolution of the database with stored RSCP samples can be increased due to more diverse visibility of pilots over the same coverage area. Enhanced resolution of the database naturally translates into better positioning accuracy.

VII. Conclusions and Future Work

Selected optimization aspects were illustrated and assessed from radio network performance and location techniques perspective. Conducted study revealed that for optimization aiming at emphasizing cell dominance areas by, e.g., down tilting or sectoring, results yield for a compromise between network capacity and CID+RTT or ECID+RTT performance. For instance, with increased EDT angle on all sites in the considered scenario the mean CID+RTT accuracy is reduced from 190 m (0º) to 207 m (3º) and 220 m (7º) due to reduced SHO overhead. At the same time, the radio capacity is improved by 17% - 27.5%. Similarly, 6-sectored site configuration suggests usage of horizontally narrow antennas in order to maximize radio capacity. However, the CID+RTT accuracy increases with cell overlapping, hence the preferred topology configuration consist of 6-sectored sites with 65º beam width antennas. On the other hand, optimization through repeater deployment positively affects the radio capacity as well as the CID+RTT accuracy. A major cause of this improvement is more frequent presence of reference points (sites and repeaters) for positioning. Thus, the accuracy in a scenario with repeaters corresponds closely to the regular topology with very dense site locations. Namely, the CID+RTT accuracy is improved to 154 m while depending on the HSDF configuration, the radio capacity is improved from 37% to 80%. Naturally, positioning in the network equipped with repeaters requires additional intelligence on the network side that recognizes terminals served by the repeater and performs appropriate corrections to the position estimation process.

Conducted study revealed that the performance of the PCM is sensitive to the topology optimization. However, in practical topology modification tasks, the PCM database does not have to be necessarily updated when the LCS performance requirements are not very strict, as the accuracy is still on a decent level. For instance, the mean accuracy is reduced from 118 m to 137 m when the repeater is deployed (65 dB gain) and to 168 m when MDT configuration is changed. Generally, discussed optimization aspects should improve the PCM accuracy due to increased variety of radio conditions allowing reduction of the database resolution. Naturally, in order to achieve the accuracy improvement, the underlying database needs to be updated according to all performed topology modification

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References

[1] J. Lempiäinen, M. Manninen (ed.), UMTS Radio Network Planning, Optimization and QoS Management. Dordrecht: Kluwer Academic Publishers, 2003.

[2] J. Niemelä, T. Isotalo, and J. Lempiäinen, "Optimum Antenna Downtilt Angles for Macrocellular WCDMA Network," *EURASIP Journal on Wireless Communications and Networking,* Num. 5, Dec. 2005, pp. 816-827.

[3] P. Lähdekorpi, J. Niemelä, J. Borkowski, J. Lempiäinen, "WCDMA Network Performance in Variable Repeater Hotspot Traffic Cases", *in Proc. of 6th IEE Int. Conf. on 3G & Beyond*, 2005

[4] M. Rahman, P. Ernström, "Repeaters for Hotspot Capacity in DS-CDMA Networks", *IEEE Trans. Vehicular Techn.*, 2004, Issue 3, vol. 53, pp. 626-633.

[5] Jaana Laiho-Steffens, Achim Wacker, Kari Sipilä and Kari Heiska, "The Impact of the Base Station Sectorisation on WCDMA Radio Network Performance", *in Proc. of IEEE Vehicular Techn, Conf.*, 1999, pp. 2611-2615.

[6] J. Borkowski, J. Niemelä, J. Lempiäinen, "Performance of Cell ID+RTT Hybrid Positioning Method for UMTS Radio Networks", *in Proc. of 5th European Wireless Conf.*, pp. 487-492, 2004.

[7] J. Borkowski, J. Itkonen, J. Lempiäinen, "Impact of UMTS Topology Layout on Cell ID+RTT Positioning Accuracy", *in Proc. of 15th IST Mobile Summit,* 2006.

[8] J. Borkowski, J. Lempiäinen, "Practical Network-based Techniques for Mobile Positioning in UMTS", *EURASIP Journal on Applied Signal Processing*, to appear in special issue on Wireless Location Technologies and Applications, 2006.

[9] J. Borkowski, J. Lempiäinen, "Novel-mobile-based positioning techniques for UMTS", *in Proc. of 9th IEEE Int. Symposium on Wireless Personal Multimedia Comm.,* 2006.

[10] Powell, M. J. D., "A Fortran Subroutine for Solving Systems of Nonlinear Algebraic Equations," Numerical Methods for Nonlinear Algebraic Equations, P. Rabinowitz, ed., Ch.7, 1970.

[11] J. Niemelä and J. Lempiäinen, Impact of the Base Station Antenna Beamwidth on Capacity in WCDMA Cellular Networks, *in Proc. IEEE 57th Vehicular Techn. Conf.*, 2003, vol.1, pp. 80-84.

[12] P. Lähdekorpi, "Effects of Repeaters on UMTS Network Performance", Master of Science Thesis, Tampere University of Technology, March 2006.