Using Idle Mode E_c/N_0 Measurements for Network Plan Verification

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Abstract— The aim of this paper is to illustrate a feasible method for verification of the quality of the WCDMA network plan using Idle mode E_c/N_0 measurements. Based on the measured average E_c/N_0 of a cell in the Idle mode and in an empty network, the level of other-to-own-cell interference can be estimated. This, on the other hand, enables estimation of the downlink capacity with certain assumptions of the traffic service parameters and of the downlink orthogonality factor. Moreover, this allows mapping of the quality of different cell, and hence can provide an input for topology optimisation process. For a commercial network, the data required for estimation of the quality of a network plan and individual cells can be captured from the network side (temporary E_c/N_0 and DL throughput), thus removing the need of using field measurements for network quality verification. The method has been tested by conducting extensive field measurements with different cell loads, and the capacities of four different cells have been estimated using the proposed method. The outcomes indicate sufficient match between the estimated decrease of E_c/N_0 due to the increase of DL throughput and the actual measured values.

Key words: capacity estimation, field measurements, quality verification, WCDMA.

1. INTRODUCTION

For UMTS FDD (Universal Mobile Telecommunications System Frequency Division Duplex) networks, verification of the network plan is very crucial in the network deployment phase. Operators need to be aware of the attainable capacity of the network prior to the commercial release. A reliable and applicable verification of the changes in the network topology (layout) during the optimization phase is also strongly required. Radio network planning tools (e.g., [1]) provide naturally an assessment of the network functionality and air interface capabilities [2]. Possible implementation constrains of static network simulators can however limit the reliability of simulations [3]. Moreover, using a dynamic tool for topology verification would be rather time-consuming. The evaluation of the quality of the network plan can not be hence entirely relied on simulations. Mutual involvement of numerous contributing factors to the capacity of WCDMA (wideband code division multiple access) network makes the performance evaluation process highly complicated as well.

Moreover, conducting numerous field measurements in various traffic conditions could turn out to be rather complicated. Hence, a method providing an easy way to verify the quality of the network plan is highly desired.

The aim of this paper is to present a method for assessment of the quality of a radio network plan in WCDMA. This method utilizes information provided of the Idle mode E_c/N_0 measurements (provided from standardized measurement of mobile) for establishing an estimate of the maximum average capacity of a cell. In the verification phase, these estimated cell capacities are then compared to actual measured values of E_c/N_0 and throughputs with different loads. Finally, an idea how this method could be utilized in an operational network of topology optimization is provided.

2. CAPACITY EVALUATION METHOD

The maximum downlink throughput in a cell can be defined by the allowed noise rise NR_{DL} (1) due to the increase of load η_{DL} (2) [4]:

$$NR_{DL} = -10log_{10}(1 - \eta_{DL}) \qquad (1)$$

$$\eta_{DL} = \sum_{n=1}^{N} \frac{(E_b/N_0)_n R_n v_n}{W}[(1 - \alpha_n) + i_n] \qquad (2)$$

In (2), E_b/N_0 is the energy per bit to noise spectral density ratio, R is the user bit rate, v is the activity factor, W is the system chip rate, α is the orthogonality factor, and i is the other-to-own-cell interference. From radio network planning point of view, the level of other-to-own-cell interference naturally defines the quality of the radio plan and is hence the main factor to be optimised.

For observing the noise and interference level in a network, standardized E_c/N_0 (energy per chip over interference spectral density) measurements on CPICH (common pilot channel) can be used [5]:

$$E_c/N_0 = \frac{RSCP}{RSSI} \qquad (3)$$

In (3), RSSI (received signal strength indicator) is defined as the whole wideband received power including
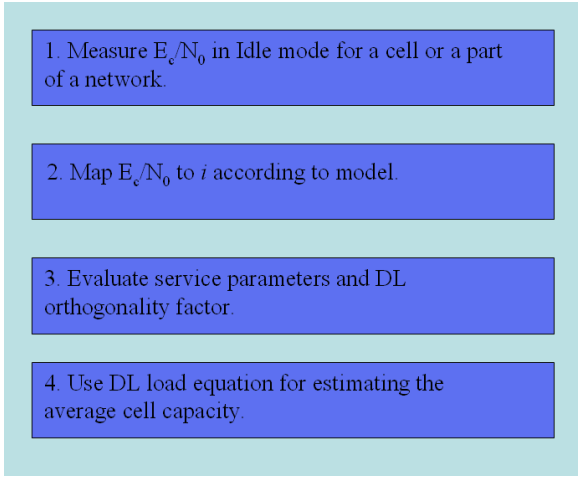
Figure 1. Overall flow of the capacity estimation method.

power from the serving cell and neighboring cells as well as noise power. Correspondingly, RSCP (received signal code power) is the received power of the monitored/serving CPICH. In general, E_c/N_0 provides a convenient indicator of coverage and capacity of a cell (or network), since it takes into account the absolute level of coverage (through RSCP) and interference level (through RSSI).

Downlink noise rise and E_c/N_0 are connected through cell throughput (or requested load). The cell noise level increases as a function of throughput due to raising multiple access interference. Moreover, an increase of load reduces the observed E_c/N_0 level in a cell due to higher level of RSSI. Thus, changes in the noise rise can be directly seen as variations of E_c/N_0 level. It is obvious from the load equation that the less sensitive a cell noise level is for the throughput variations, the higher is the cell capacity due to lower other-to-own-cell interference factor[1].

The overall flow of the capacity evaluation method is depicted in Fig. 1. The fundamental idea in this approach is that the cell capacity is estimated from the Idle mode E_c/N_0 measurements. This average measured value of E_c/N_0 is thereafter used to estimate the average other-to-own-cell interference factor of a cell. As a result, for a certain traffic service parameters and assumption of the orthogonality factor, the cell quality can be defined in terms of average capacity by using standard load equations. Estimation of other-to-own-cell interference level is possible in the downlink already in an empty network (using Idle mode measurements), since downlink interference is present due to transmission of common channels [2]. As the method relies on mapping of a cell capacity according to its average E_c/N_0 there should actually not exist any coverage limitations. In practice, this means that RSCP should preferably be

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[1]Naturally same service parameters and orthogonality is assumed.

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maintained above the level of -100 dBm in order to keep the contribution of thermal noise at minimum level. This way, the capacity estimation does not suffer from reductions of E_c/N_0 due to coverage restrictions.

In order to have a mapping between E_c/N_0 and i, a reference value for E_c/N_0 is needed. A theoretical maximum of E_c/N_0 would be 0 dB, if CPICH is sent with an infinite power. However, in practice, the power of CPICH is limited, and the maximum achievable E_c/N_0 in a cell would be close to -3 dB. Assumption of -3 dB E_c/N_0 presumes that CPICH and P-CCPCH (primary common control physical channel) are send with an equal power. In this method, i is calculated assuming that it is 0 in single cell area (non-overlapping area) and 1 in the possible SHO (soft handover) area (overlapping area). Naturally, assumption of $i=1$ in SHO area does not practically hold true, but this mapping is utilised for making the model as simple as possible. An assumption of a more specific distribution for i would be more sophisticated than this simple approach. However, as the analysis is based on average measured values, also an average value of i is needed instead of exact distribution. Nevertheless, average E_c/N_0 would hence correspond to -3 dB in the single cell and -6 dB in the possible SHO. In practise, as coverage overlapping always occurs, the measured E_c/N_0 levels over a cell should not be lower than -3 dB. As an example, if the measured E_c/N_0 value in the cell area is on average -4.2 dB, this would mean that 40% of the cell area is denoted as overlapping area (i.e., E_c/N_0 at level of -6 dB), and the resulting mean i would correspond to 0.4.

Utilization of the downlink load equation (2) requires still an estimate of the average downlink orthogonality factor ($\overline{\alpha}$) over the cell area. This is one parameter that cannot be improved during network topology optimization with any traditional planning techniques, as it represents characteristics of propagation channel and environment. According to [6], the mean value of α ($\overline{\alpha}$) decreases as a function of distance from the base station:

$$\overline{\alpha}(r) = \frac{1}{1 + kd} \qquad (4)$$

where d is the mobile-to-base station –distance and k is a constant. As observed in [6], $k=2.9$ provides an acceptable fit of the orthogonality model to the simulated outcomes in macrocellular environment (mean delay spread approximately 0.5 μs). Thus, integrating the mean over the whole cell area results in an α depending on the average distance:

$$\alpha = \frac{1}{kD} ln(kD + 1) \qquad (5)$$

where D is the average distance from the base station (BS).

3. MEASUREMENT SCENARIO

For evaluating the performance and accuracy of the proposed capacity estimation method, four different cell types were measured. Based on the Idle more E_c/N_0 measurements, the load curve was estimated. In addition, the measurements were conducted with two different load conditions in order to provide a comparison between the estimated and the measured load curve. The following type of cells were measured and evaluated:

- Cell 1: Urban macrocell with wall-mounted antennas (rather open propagation environment)
- Cell 2: Urban microcell with pipe-mounted antennas (street canyon environment)
- Cell 3: Urban microcell with wall/pipe-mounted antennas (street canyon environment)
- Cell 4: Suburban macrocell with mast installation

Three of these cells were located clearly in urban environment and one in suburban environment. Every cell belong to a 3-sectored site configuration. In addition, all cells were different with respect to antenna installation and propagation environment. Types of antenna installation included wall, pipe, and mast-type of installations. The propagation environment varied naturally between urban and suburban, but also the density and average heights of buildings varied significantly between the measured cells.

The measurement equipment consisted of two mobiles and of a GPS receiver connected to a laptop running an air interface measurement tool. The measurement equipment were placed in a car. The measurement route for all cells was selected in a way that it covered equally locations near the base station and further away at the cell edges. This is actually important for average capacity analysis, since too many samples close to BS might provide an optimistic estimation of the cell capacity. On the other hand, estimating the capacity from the measurement samples from the cell edge would underestimate the average cell capacity. Finally, the measurement route within all cells was sufficiently long in order to increase the statistical reliability of measurement results, and to have measurement samples from as many places as possible. However, any of the measurement route did not cover indoor locations.

In total, three different measurement rounds were conducted for each cell using the same measurement route (three different cell loads). Idle mode measurements were used for estimating i. Moreover, the measurement were conducted with different loads in order to evaluate the accuracy of the load curve estimate. Summarizing different cell loads used in the measurements:

1) Both mobiles measuring only in Idle mode
2) One mobile in Connected mode, the other mobile in Idle mode
3) Both mobiles in Connected mode

Table 1. Average measured E_c/N_0 and downlink throughput values for analysed cells in with all three loads.

Parameter	E_c/N_0 [dB]			Throughput [kbps]		
Cell ID	Idle	DCH	2xDCH	Idle	DCH	2xDCH
Cell 1	-3.85	-4.70	-5.05	0	367	496
Cell 2	-4.82	-5.00	-6.35	0	132	586
Cell 3	-5.10	-5.80	-6.51	0	321	486
Cell 4	-4.70	-5.02	-6.28	0	321	425

During a Connected mode, mobile was downloading a packet with a requested bearer speed of 384 kbps (HTTP and background QoS class).

4. MEASUREMENT RESULTS AND VERIFICATION

The outcomes from the measurement are gathered in Table 1 for all measured cells. The E_c/N_0 as well as the throughput values are average values of both mobiles. The results illustrate how average E_c/N_0 decreases as a function of increasing throughput. Moreover, the observed outcomes indicate that the quality and the resulting capacity of Cell 1 would be the highest based on the smallest E_c/N_0 in Idle mode (-3.85 dB). Notice that even through the quality of the cell would be the highest, another lower quality cell might have higher absolute capacity due to better average downlink code orthogonality. Nevertheless, Cell 3 seems to be the worst one based on Idle mode measurement.

The detailed cell-based results of load curve estimation together with obtained outcomes from the measurements with DCH (dedicated channel) connections are shown in Figs. 2-5. For each cell, average distance from the BS is evaluated that is thereafter used for defining the average orthogonality factor for the cell according to (5). Other service parameters for the load equation were as follows: R=384 kbps, v=1, and W=3.84 Mcps.

The first measured cell was categorised as a macrocell. Fig. 2 shows the load curve analysis for this cell together with measured load points. The first dot (blue) shows the average level of E_c/N_0 from Idle mode measurement. Based on this value, average i would hence correspond to 0.27. Moreover, based on the average distance of the measurement route from the base station (317 m), downlink orthogonality factor was evaluated to be 0.71. The load curve estimated from the Idle mode measurements has some offset with the measurement results and with the actual measurements either with one DCH connection (red point) or with two DCH connections (black point). However, with α=0.54, the line would match exactly to the measured load points (not shown here). It might be hence possible that utilised model for α provides a small error in urban environment. The capacity of the cell would correspond to 1030 kbps (α=0.54), when the maximum cell capacity is based on
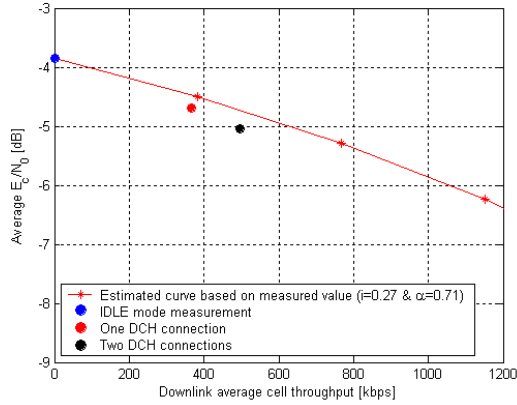
Figure 2. Capacity estimation curves and measurement results for Cell 1 (urban macrocell with wall installation and with rather open propagation environment).

Figure 3. Capacity estimation curves and measurement results for Cell 2 (urban microcell with pipe installation and street canyon propagation environment).

3 dB noise rise (1) (i.e., 50 % load) or, correspondingly, to 3 dB average decrease of E_c/N_0 respect to Idle mode E_c/N_0. The average level of RSCP during the measurement was -66.3 dBm, which is clearly above the thermal noise floor (-100 dBm). Hence, within the measurement route, any coverage constraints were not observed.

The second measured cell was categorised as a microcell. Antennas were installed on top of a building in a pipe, but the height of the surrounding buildings exceeded the antenna installation height. The average distance of the measurement route was 340 m from the base station, which corresponds to $\alpha = 0.7$. With this parameter selection for Cell 2, the estimated capacity is underestimated (Fig. 3). This could be caused by incorrect estimate of the downlink orthogonality factor. Actually, with α=0.85 the load curve would match again exactly the highest measured load point (black point). Note also that having a single DCH connection in a cell should not destroy the code orthogonality totally, since there are not any other DCH connections in the air interface. However, there should be a slight degradation in code orthogonality from P-CPICH and P-CCPCH. Nevertheless, in case of only one DCH connection in a cell, the code orthogonality should be actually very close to 1. With this logic (i.e., $\alpha = 1$), the load curve would actually cross the second load points. By adopting the correction in the orthogonality factor, the estimate of the cell capacity corresponds to 1000 kbps. However, as seen from the estimated value of other-to-own-cell interference (i=0.605), there would be some room from optimisation either for this particular cell, or in the neighboring cells. The measured average level of RSCP was -68.4 dBm, which ensures proper coverage in the measurement route. However, for a microcell, the capacity of 1000 kbps is rather low, and moreover, it seems obvious that the capacity of a cell with antenna pipe
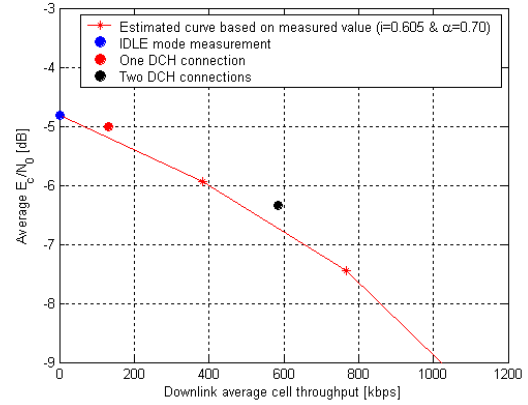
installation suffer compared to, e.g., wall installation.

The third measured cell was categorised as a microcell as well. However, this cell is slightly closer to macrocell, since antennas were installed almost to the roof only slightly below average roof top level. Moreover, antennas were located in 30 m height. The average distance of the measurement route from the base station was 225 m that corresponds to $\alpha = 0.77$. Moreover, the average RSCP was -70.7 dBm within the measurement route. The load curve for the Cell 3 is provided in Fig. 4. Similarly as in case of Cell 2, the estimated capacity is too low for this particular cell. However, increasing the average α to 0.85, the load curve would match exactly the measured point with two mobiles (black point). Furthermore, with a full code orthogonality, measured point of one DCH corresponds exactly to the estimated one. Even thought, the capacity of this cell would be only 870 kbps, which is again rather low for a microcell. However, this was expected due to the lowest measured Idle mode E_c/N_0 measurement (-5.0 dB).

The fourth measured cell was deployed at suburban area having low height residential buildings only. The antennas of the base stations were installed in a mast. The measured Idle mode E_c/N_0 was -4.7 dB. The average distance from the base station was 840 m, and the corresponding orthogonality 0.51. According to the estimation, the average cell capacity would hence correspond to 720 kbps, which is rather suitable for a macrocell. It seems to be obvious that in suburban macrocellular environment, also the model for the orthogonality seems to match more exactly to the measured values. Moreover, with a single DCH connection and $\alpha = 1$, the estimation would match exactly the estimated point. The average RSCP level for the cell was -72.7 dBm.
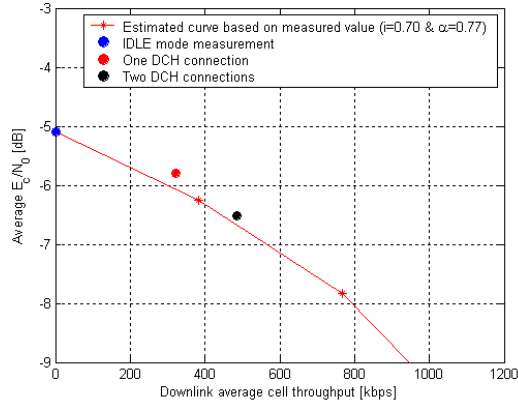
Figure 4. Capacity estimation curves and measurement results for Cell 3 (urban microcell wall/pipe installation and with street canyon propagation environment).

Figure 5. Capacity estimation curves and measurement results for Cell 4 (suburban macrocell with mast installation and with open propagation environment).

5. APPLICATIONS OF THE METHOD

The proposed verification method for the quality of the network plan and conducted verification measurements show rather good match between theory and practice. From a network operator, this paper provides a method how to verify the quality of their network plan and how to estimate cell capacity with certain traffic service parameters. Here, the verification measurements were presented only for a single cell, but the method can be easily utilised also for estimating the capacity and quality of a cluster of cells or a bigger part of a network.

In an operational network, using field measurements as such for this method is not feasible, since it requires a number of samples all over the cell area in order to increase the statistical reliability of the estimation, and to avoid having samples too close or too far from the base station antenna. It requires furthermore knowledge of the corresponding downlink throughput. Therefore, the most suitable solution would be to gather the required information regarding E_c/N_0 values together with corresponding DL throughputs from the network side. This would require a use of periodical measurement events from the mobile stations for the time period required for a estimation of cell average capacity and its quality. The output information from the method regarding the quality of cells could be utilized as an input not only for traditional network topology optimisation but also for the algorithms handling the tilt angles of remote-controlled electrical tilt (RET) antennas.

6. DISCUSSION AND CONCLUSIONS

This paper presents a method for network quality verification through E_c/N_0 measurements. The proposed method utilises the information of the average E_c/N_0 values in the Idle mode for estimating other-to-own-cell i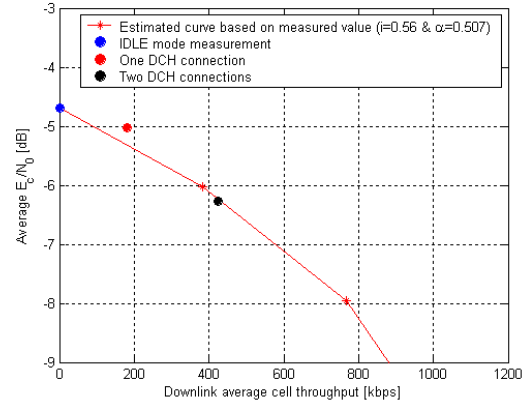nterference level, and furthermore the quality of the cell. As such, method can be also used for mapping the quality of a part of a network or a whole network. The method estimates also the available average downlink capacity with the aid of provided service parameters and an estimate of downlink orthogonality factor. The shown comparisons between the method and the outcomes of measurements provide rather accurate match, and most of the error is merely an offset (originating typically from wrong selection of α). However, the major conclusion it that already the Idle mode E_c/N_0 provides an indicator of the quality of the cell, hence allowing the identification of bad quality cells from the network.

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