THE IMPACT OF THE BASE STATION SECTORISATION ON WCDMA RADIO NETWORK PERFORMANCE

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Abstract - The 3rd generation cellular systems will offer services with higher bit rates compared to today's networks and therefor for an operator it is of utmost importance to exploit all possible resources to improve the capacity of the radio network. One attractive possibility, already used in most of the 2nd generation networks, is to increase the sectorisation at the base stations, i.e. using 3 or even up to 6 sectors per site. In this paper we demonstrate with simulations and some theoretical derivation how the sectorisation of the base stations influences on the performance (capacity and quality of service) of a WCDMA radio network. In addition the simulator and the modelling of the 3rd generations fast power control and soft handover are presented.

I. INTRODUCTION

The scope of this paper is to demonstrate the impact of the higher order sectorisation on the performance of a capacity limited WCDMA macro-cellular network. The sectorisation is widely implemented also in the current FDMA/TDMA networks, typical configuration being a three sectored solution. One can claim that in the 2nd generation systems the antenna selection is not as critical as it is in the case of WCDMA. The sector overlapping will cause interference leakage from one sector to another, but with loose frequency reuse pattern this is not causing problems in terms of degraded quality of service. Furthermore, if the slow frequency hopping is applied in the network, the interference situation is effectively averaged and capacity is not reduced. The common problem for 2nd and 3rd generation systems in case of wrong antenna selection is related to handover. The sector overlapping will cause the handover probability to increase. In the case of the hard handover new parameterisation of the hand over algorithm can alleviate the problem. In the WCDMA system with soft handover the increased soft handover probability will reduce the system capacity in terms of hard blocking. In addition to that the increased interference leakage from the overlapping cells will directly reduce the system capacity. In this paper it is demonstrated that in the case of higher order sectorisation in a WCDMA system the correct antenna selection is crucial.

The influence of the sectorisation on the performance of a WCDMA radio network can be seen in multiple ways: Firstly, due to the narrower beam of the sector antennas, less interferers are received. Furthermore, the higher gain of the sector antennas allows to reduce the base station transmit power leaving the power amplifier and therefore allowing more users to be served with a fixed maximum total power. Finally, the power is radiated more concentrated to the desired users, reducing the interference radiated to the other users. This improves their C/I value and decreases again the needed transmission power at the base station. Another effect, the increased cell range due to the higher antenna gain was not studied here, because the cell ranges have been selected so, that the loading of the cell was the limiting factor. The biggest disadvantage of higher sectorisation is the control of the cell overlapping. The overlap is increasing the overhead due to soft handover and therefore must be controlled so that it stays below an acceptable level.

This paper has been divided into following parts. In Chapter II the used simulator is introduced and the parts it consists of are described. Furthermore, importing of the results of link level simulations for modelling the fast transmit power control and the soft handover are included. In Chapter III the simulations are introduced and the scenarios and the parameters used in the simulations are presented. Chapter IV gathers the simulation results and compares the sectorisation gain to values obtained from a theoretical derivation. Finally in Chapter V some conclusions are drawn.

II. DESCRIPTION OF THE SIMULATOR

In this study the simulator introduced in [1] was used. It is of static nature and needs as inputs a digital map, the network layout and the traffic distribution in form of a discrete user map. Each of the users can have a different speed and using a different service (bit rate, uplink and downlink activity factor). Therefore each mobile station gets assigned an individual E_b/N_0 requirement imported from extended link level simulations. The simulator consists of basically four parts – initialisation, uplink analysis, downlink analysis and post processing phase. In the initialisation phase, the network configuration is read in from parameter files for base stations, mobile stations and the network area. Some system parameters are set and propagation calculations are performed. Uplink and downlink are then analysed separately by means of iterative processes and in the final step, the results of the uplink and downlink analyses are post processed.

A. Introduction to the uplink iteration

The target in the uplink iteration is to allocate the mobile stations' transmit powers so, that the interference levels and thus the base station sensitivity values converge. The average transmit powers of the mobile stations to each base station are estimated so that they fulfil the base stations E_b/N_0 requirements. The average mobile stations' transmit powers are based on the sensitivity level of the base station, service (data rate) and speed of the mobile station and the link losses to the base stations. They are corrected by taking into account the activity factor, the soft handover (SHO) gains and average power raise due to fast transmit power control (TPC). The latter two ones are imported in form of look up tables based on extended link level simulations and SHO analyses [2] and [3]. Influence of the fast TPC can be seen in an increase of the average transmit power and in the headroom (fast fading margin) an MS needs above the average transmit power to follow the fast fading. SHO gains in contrary help to alleviate the situation by reducing the average needed transmit power and the headroom. The impact of the loading on the sensitivity is taken into account by adjusting it with (1-η). For an isolated cell, η is defined by (1) as

$$\eta = \frac{1}{W} \cdot \sum_{j=1}^{K} \varepsilon_j \cdot \nu_j \cdot \rho_j \qquad (1)$$

where W is the chip rate, ε_j is the E_b/N_0 requirement, ν_j is the activity factor and ρ_j the data rate of user j, j=1…K and K is the number of users in a cell [4].

After the transmit powers of the mobiles have been estimated they are compared to the maximum allowed value and mobiles exceeding the maximum are put to outage. Now the interference analysis is performed again and the new loading and base station sensitivities are calculated until their changes are smaller than specified thresholds. In case the loading of a cell exceeds the specified limit, mobile stations are moved to another carrier if the needed spectrum is available. Otherwise they are put to outage.

B. Introduction to the downlink iteration

Similarly in the downlink iteration the base station transmit powers for each link including SHO connections are assigned until all mobile stations receive their signal with the required carrier-to-interference-ratio, C/I, defined by Equation (2).

$$targetCI = \frac{EbNo_{MS}}{W/R} \qquad (2)$$

where $EbNo_{MS}$ is the received E_b/N_0 requirement of the MS depending on speed and service, W is the chip rate and R is the data rate. The actual received $(C/I)_m$ of MS m is calculated according Equation (3) by summing the C/I values of all links k, k=1...K mobile station m is having.

$$\left(\frac{C}{I}\right)_m = \sum_{k=1}^{K} \frac{p_{km}/L_{km}}{(1-\alpha)(P_k - v_m p_{km})/L_{km} + I_{oth,k} + N_m} \qquad (3)$$

where α is the cell specific orthogonality factor, P_k is the total transmit power of the base station to which link k is established, L_{km} is the path loss from the cell k to the mobile station m, v_m is the service activity factor, p_{km} is the power allocated to from base station k to mobile station m, $I_{oth,m}$ is the other cell interference and N_m is the background and receiver noise of MS m.

The initial transmit powers are adjusted iteratively according the difference between the achieved and the targeted C/I value until convergence is achieved. The process requires iteration, since the C/I at each mobile station is dependent on all the powers allocated to the other mobile stations. Also in case the total transmit power of a base station is exceeded mobile stations are taken out randomly from the network.

III. SIMULATION DESCRIPTION

The networks used in this study consisted of one centre site surrounded by two tiers of sites on a regular hexagonal grid. Various different scenarios (number of sectors * beamwidth) were simulated. The most common scenarios, sites with omni directional cells, 3 sectored sites using 90° and 65°

antennas and 6 sectored sites using 33° antennas are discussed closer in this abstract. For the other combinations only some results are presented. In Figure 1 an example for the network scenarios for the 6-sectored configuration is depicted. The distance of the sites was in all cases 3 km. It was chosen so that the service probability was bigger than 95% in all cases and the network was capacity

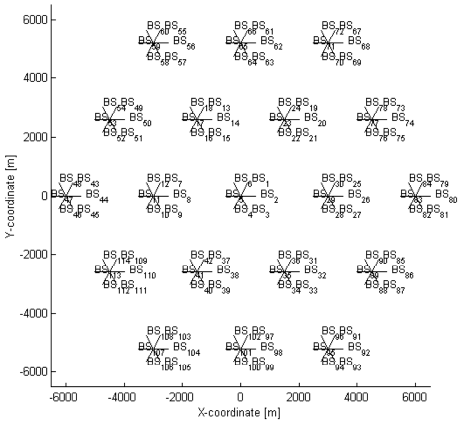

Figure 1. Example of the network scenario for the 6 sector configuration.

Applied path loss model was Okumura-Hata for urban environment overlaid with a slow fading having a standard deviation of 7 dB. The channel used in the simulations was the Vehicular A channel as specified in [5]. The user profile used in the simulations was a homogenous distribution of speech users (8 kBit/s) with a speed of 50 km/h. It should be noted that the capacity however is strongly dependent on the service and the speed (see e.g. [2] and [6]). The coverage probability was required to be more than 95%. To take a base station into the active set a simple SHO algorithm introduced in [7] was applied. All base stations whose received Perch power level was within a given addition window below the strongest received level were included. The other basic WCDMA system features are taken from [8]. All the simulation parameters are collected to Table 1.

All scenarios have been simulated with 3 different mobile station distributions to improve the statistical reliability. For the relative high number of speech users which can be served 3 distributions proved to be enough. In case of mobiles using higher bit rates less users can be served and more runs should be simulated. The initial number of mobiles was set so high, that the network was overloaded. Then appropriate number of mobiles has been removed until the required uplink loading was achieved or the total base station transmit power was not exceeded.

Table 1. Parameters used in the simulation.

Base station maximum transmit power	43 dBm
Mobile station maximum transmit power	24 dBm
Mobile station minimum transmit power	-46 dBm
Shadow fading correlation between base stations	50%
Standard deviation for the shadow fading	7 dB
Channel profile [8]	ITU Vehicular A
Mobile station speed	50 km/h
MS/BS noise figures	7 dB / 5 dB
Soft handover addition window	-3 dB
Perch power	30 dBm
Combined power for other control channels	30 dBm
Orthogonality	50%
Service activity factor	67%
Uplink loading limit	50%

IV. SIMULATION RESULTS

The first result that was checked during the simulation was the coverage probability for speech users. Figure 2 is presenting an example of the coverage probability estimation together with a plot of the cell dominance areas for the 3-sector case.

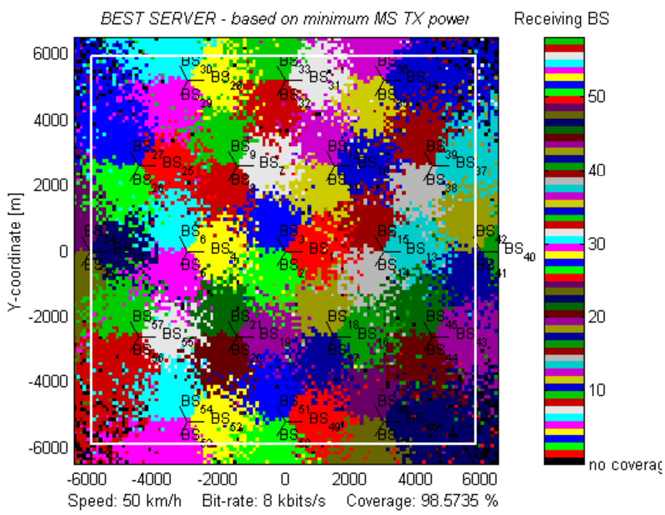

Figure 2. The cell dominance areas and coverage probability for the 3 sector case.

The numbers for the other cases are collected to Table 2. It can be seen that in all cases the coverage probability was higher than required 95%, increasing as the number of sectors increases.

Table 2. Service probabilities.

#SECTORS, BEAMWIDTH (°)	COVERAGE PROBABILITY
1 sector, omni ant.	96.6 %
3 sectors, 90° ant.	97.6 %
3 sectors, 65° ant.	98.6 %
6 sectors, 33° ant.	99.6 %

As measure for the capacity in all of the cases the number of users per cell and per site was of interest. The results are collected in Table 3.

Table 3. The number of users per cell and per site.

		users/cell		users/site	
		UL	DL	UL	DL
1 sect	omni	59.2	43.0	59.2	43.0
3 sect	90 deg	50.7	35.5	152.2	106.4
3 sect	65 deg	56.7	42.6	170.1	127.9
3 sect	33 deg	55.7	40.3	167.0	120.8
4 sect	90 deg	46.0	30.7	183.9	122.7
4 sect	65 deg	53.2	39.9	212.8	159.7
4 sect	33 deg	50.9	35.7	203.5	142.8
6 sect	90 deg	39.4	24.5	236.7	147.1
6 sect	65 deg	46.4	32.4	278.6	194.2
6 sect	33 deg	49.6	36.3	297.4	218.0

With the help of Table 3 one can see that the number of users per sector is decreasing as the sectorisation is increasing. The amount of users per site however is increasing but not proportional to the number of sectors, because the overlap in the sectors is leaking interference from one sector to the other. Another result from Table 3 is that for each number of sectors an optimum beamwidth exists. Optimum being when the number of users is at maximum.
Another quantity of interest was the percentage of overhead due to SHO connections. The SHO overhead indicates the additional required amount of hardware and in case the number of channel units is limited it is increasing the hard blocking probability. As last figure of merits the other to own cell interference ratio, i, was collected. Both results, i and SHO overhead, are shown in Table 4.

Table 4. SHO overhead and Ioth/Iown.

		SHO overhead	i = Ioth/Iown
1 sect	omni	23%	58%
3 sect	90 deg	34%	88%
3 sect	65 deg	27%	66%
3 sect	33 deg	26%	70%
4 sect	90 deg	42%	109%
4 sect	65 deg	31%	76%
4 sect	33 deg	33%	86%
6 sect	90 deg	53%	146%
6 sect	65 deg	42%	105%
6 sect	33 deg	32%	90%

From Table 4 it can be seen that due to the increasing amount of sectors the number of SHO connections and therefore the overhead is getting bigger. Simultaneously the amount of interference leaking into neighbouring cells increases, but with proper choice of the antenna beamwidth also these effect can be controlled to acceptable level. For the two most typical cases (3 sectors / 65° antenna and 6 sectors / 33° antenna) it is important to notice that there is only an increase of 5% in SHO overhead going to the higher sectorisation. If the antenna beamwidth had been kept constant, the number would have been 15% higher. This indicates that in the 6 sector case the SHO areas have to be planned even more carefully than in 3 sectored case. The smallest interference leakage occurred for the 3 sectors / 65° antenna base station. With 66% it was in the order of the omni case, other scenarios had higher values of about 90%. This applies also to the 6 sectors / 33° case indicating that even smaller beamwidth should be selected.
Finally the sectorisation gain, ξ, then was estimated as the average number of simultaneous users relative to the average number of users of the omni site configuration according to Equation (3).

$$\xi = \frac{number\ of\ users\ of\ sectored\ site}{number\ of\ users\ of\ omni\ site} \qquad (3)$$

The estimated numbers for ξ in uplink and in downlink are collected in Table 5. These simulation results were then compared to theoretically derived numbers from Equation (4), which represents the ratio of total received power to the power from the within the sector.

$$\xi = N_S \cdot \int_{-\pi}^{\pi} p(\vartheta)\cdot G(\vartheta)\, d\vartheta \Bigg/ \int_{-\varphi/2}^{\varphi/2} p(\vartheta)\cdot G(\vartheta)\, d\vartheta \qquad (4)$$

where G(ϑ) is the antenna gain in direction ϑ, p(ϑ) is the received power in front of the antenna in direction ϑ, $\varphi = 2\pi/N_s$ is the sector width in radians with N_S as the number of sectors. The numerical evaluation of Equation (4) with the antennas used in the simulations for a sectorisation up to 10 sectors can be seen in Figure 3.

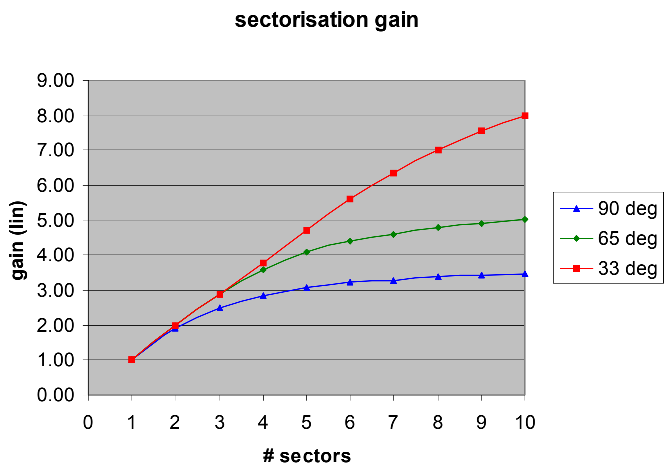

Figure 3. Theoretical sectorisation gains according Equation (4).

The theoretical numerical values for the simulated cases are collected also to Table 5.

Table 5. The simulated and theoretical sectorisation gains.

		sectorisation gain			
		UL	DL	mean	theory
1 sect	omni	1.00	1.00	1.00	1.00
3 sect	90 deg	2.57	2.47	2.52	2.51
3 sect	65 deg	2.87	2.97	2.92	2.90
3 sect	33 deg	2.82	2.81	2.81	2.90
4 sect	90 deg	3.11	2.85	2.98	2.86
4 sect	65 deg	3.59	3.71	3.65	3.59
4 sect	33 deg	3.44	3.32	3.38	3.79
6 sect	90 deg	4.00	3.42	3.71	3.22
6 sect	65 deg	4.70	4.51	4.61	4.40
6 sect	33 deg	5.02	5.07	5.04	5.60

Ideally, with sectorisation one would expect an increase of the capacity proportional to the number of sectors. But due to overlap of the sectors the gain in capacity however is smaller than this expected value. Also the environment is playing an important role. If there are obstacles in the vicinity of the antenna, the side lobe levels of the antennas are increased and the main beams are broadened [9]. Both effects increase the amount of interference, which is radiated/received to/from other sectors, thus reducing the sectorisation gain.
The real sectorisation gains in these simulations for 3, 4 and 6 sector case were 2.9, 3.7 and 5.0, respectively compared to the ideal ones of 3, 4 and 6. The simulated results however were close to the results obtained from the theoretical Equation (4) (2.9, 3.6 and 5.6).

V. CONCLUSIONS

This paper investigated the influence of the base station sectorisation, meaning the number of sectors and the beamwidth of the used antennas, on the performance of a 3rd generation capacity limited network. It has been shown that the higher sectorisation is giving higher capacity but the increase is not proportional to the number of sectors. The overlap in the antenna radiation patterns as well as the influence of the environment on the shape of the patterns makes it difficult to control the interference leakage into neighbouring sectors and thus reduces the capacity of the network. By careful selection of the antenna beamwidth however, the effect can be kept small and almost ideal sectorisation gains can be achieved. The paper also demonstrated, that by the same careful selection the increase of the soft handover areas can be kept at an acceptable level so that the additional overhead due to more SHO connections, possibly resulting in hard blocking and also reducing the system capacity, is small enough. The control of the SHO areas requires however also careful selection of the soft handover parameters. In the simulations a simple SHO algorithm, using a relative small addition window of -3 dB was used. In addition with the higher sectorisation, the orientation of the sectors, i.e. the bearing of the antennas must be selected even more carefully because the more sectors will be applied the more of them are pointing to each other. All of the above mentioned conclusions indicate, that the network performance can be significantly improved by the higher sectorisation but the more sectors are applied the more careful the network planning has to be done.

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