The Impact of the Radio Network Planning and Site Configuration on the WCDMA Network Capacity and Quality of Service

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Abstract – The 3rd generation cellular systems will offer services with higher bit rates compared to today's networks and therefore for an operator it is of utmost importance to exploit all possible resources to improve the capacity and Quality of Service of the radio network. The scope of this paper is to demonstrate with simulations how careful radio network planning can improve the network capacity and quality of service (QoS). Furthermore, it is demonstrated how the site configuration expansions can support the network capacity growth. Example results of omni-, three-, four- and six sectored site configuration simulations are presented including four different antennas and various different tilts. Furthermore a test case is shown to demonstrate the effect of a mast head amplifier (MHA) in the WCDMA uplink.

I. Introduction

In the case of WCDMA networks the detailed planning is itself an optimisation process. In the case of the 2nd generation the detailed planning concentrated strongly on the coverage optimisation. The 3rd generation planning is more interference and capacity analysis than only coverage area estimation. During the course of the radio network planning the base station configurations need to be optimised, the antenna selections and antenna directions and even the site locations need to be tuned as much as possible in order to meet the QoS and the capacity and service requirements with minimum cost. The results presented in this paper show how means of radio network planning can be used to meet those requirements and to improve the network performance. The structure of the paper is as follows: In Section II the simulator and the scenarios as well as the simulation parameters are introduced. Section III contains the simulation results including coverage probabilities, the number of simultaneously served users, the other to own cell interference ratio and the overhead due to soft handover (SHO) for the various configurations. Finally, Section IV concludes this paper.

II. Simulator and Scenario Description

The main difference in the planning of the 2nd and 3rd generation systems is the importance of the traffic information layer. For each required service type (bit rate, data/speech activity for uplink and downlink direction) the QoS targets need to be met. The simulator used in this study requires a traffic distribution map as input. The traffic distribution is given as a user map, where users can have different bit rates, speeds and thus different Eb/No requirements. The simulation consists of four parts: initialisation, uplink iteration, downlink iteration and post processing of the analysis results. Main task in the initialisation is the calculation of the link losses from each base station to each position in its calculation area.

A. Uplink iterations

The target in the uplink iteration is to allocate the mobile stations' transmit powers to each base station 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 impact of the loading on the sensitivity is taken into account by adjusting the sensitivity with (1-η). For an isolated cell, η is defined by (1) as

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

where W is the chip rate, ε_j is the E_b/N_0 requirement, v_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. 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. If the maximum MS transmit power is exceeded the MS is directly put to outage.

B. Downlink iterations

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).

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

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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.

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

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 static simulator and the modelling used in the simulations are described in more detail in [1, 2, 3, 4].

C. Network scenarios and simulation parameters

The system features used in the simulations are from [6], except the chip rate was modified to 3.84 Mchip/s. For the multipath channel profile the ITU vehicular A channel from [5] was assumed. In the test scenario the Shinjuku area in Tokyo has been used, assuming all users to be indoors. The 13.5 km^2 area was covered with 10 sites. The selected antenna installation height was 50 meters, the propagation loss was calculated with the Okumura-Hata model, with average correction factor of –4.1 dB. In the simulations, omni-, three-, four- and six-sector configurations have been used, the site locations were kept fixed. The network scenario with six-sector implementation can be seen in Figure 1.

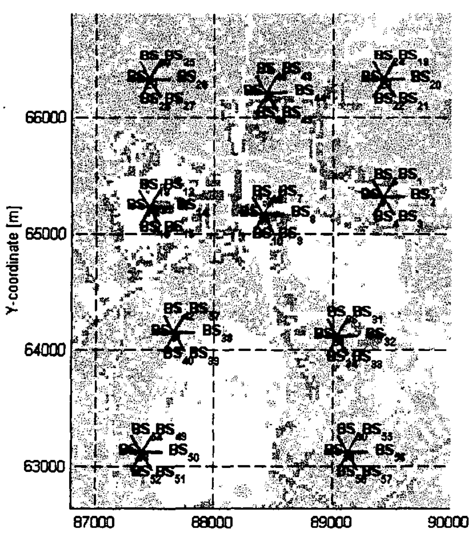

Figure 1. Example of network scenario for the six sectored case.

5 different antennas were used in the simulations with 3 dB beam widths of 120°, 90°, 65°, 33° and additionally an omni antenna. The gains of all antennas was set to 15 dBi and for the SHO addition window a value of –4 dB was used, i.e. all sectors whose Perch are received within –4 dB of the strongest Perch are included into the active set. Other relevant parameters applied in the simulations are collected in Table 1.

Table 1. Simulation parameters.

Chip rate	3.84 Mchip/s
Base station maximum transmit power	43 dBm
Mobile station maximum transmit power	24/27 dBm
Mobile station dynamic range	65 dB
Shadow fading correlation between base stations	50%
Indoor loss	15 dB
Standard deviation for the shadow fading	12 dB
Channel profile	ITU vehicular [5]
Mobile station speed	3 km/h
MS/BS noise figures	8 dB/5 dB
Soft handover addition window	-4 dB
Perch power	30 dBm
Combined power for other control channels	30 dBm
Orthogonality factor in DL	50%
BS antennas	33°/65°/90°/120°/omni 15 dBi
MS antennas	Omni / 0 dBi
Cable losses	2 dB (4 dB)

A service mix of voice users (8 kbit/s), circuit switched data users (64 kbit/s) and packet data users (144 kbit/s) was assumed. The exact traffic information used in this work is presented in Table 2. All simulations have been done with 3 different mobile station distributions and the results presented in Section III are averages over all distributions.

Table 2. The traffic information used in the studies.

Service in kbit/s	Service activity UL	Service activity DL	Users per service
8 kbit/s	50%	50%	720
64 kbit/s CS data	100%	100%	240
144 kbit/s packet data	10%	100%	180

III. Simulation Results

This study consists of three cases. In the first analysis case the impact of the antenna tilting was of interest. Various antenna tilts are simulated to find the optimum. In the second part the influence of the usage of MHA in uplink was studied. For each sectorisation simulations with and without MHA are compared. In the third part the capacity improvement as a function of sectorisation and antenna selection is illustrated. In Table 3-5 the results in terms of other to own cell interference, served users, SHO overhead and UL coverage probability are collected. An example plot for the coverage analysis can be seen in Figure 2.

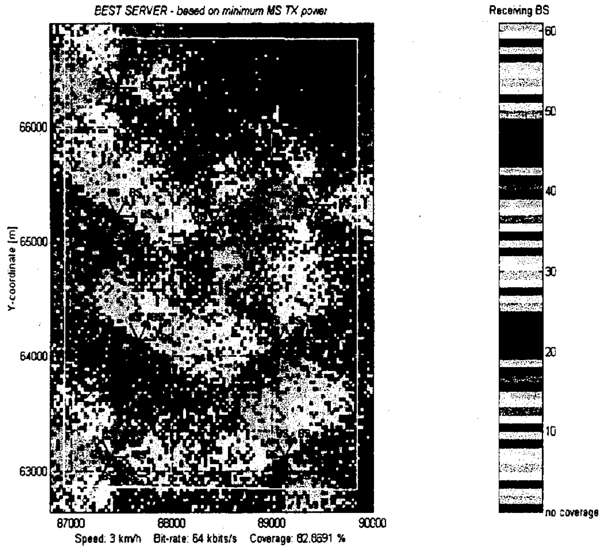

Figure 2. Example of the dominance areas and the coverage probability analysis. The test mobile speed was 3 km/h and the used service 64 kbit/s circuit switched data. Antenna tilt 10°

In the antenna tilting study the electrical tilting was applied and with the help of the results it can be seen that an optimum tilt angle can be found: the capacity and the coverage probability both have to be considered. The results of this study are collected in Table 3.

Table 3. Examples of the impact of the antenna tilt on the network capacity. MHA in use. MS maximum transmit power 24 dBm. In DL in case the base station maximum transmit power is exceeded the connections were randomly put to outage.

Antenna tilt	Other to own cell interference ratio, i	Served users	Soft handover overhead	UL coverage probability (outdoor to indoor) for 8/64/144 kbit/s
OMNI CASE				
0°	0.79	239	28%	70 / 32 / 40%
THREE SECTORED CASE, 65° antenna				
0°	0.88	575	40%	86 / 59 / 62%
4°	0.75	624	39%	91 / 71 / 72%
7°	0.59	697	36%	92 / 76 / 76%
10°	0.37	856	30%	90 / 75 / 74%
14°	0.38	787	32%	81 / 62 / 61%
FOUR SECTORED CASE, 65° antenna				
0°	1.09	604	41%	92 / 70 / 71%
4°	0.94	707	30%	95 / 81 / 81%
7°	0.72	833	26%	96 / 84 / 83%
10°	0.47	959	21%	94 / 82 / 81%
14°	0.50	886	26%	86 / 69 / 68%
SIX SECTORED CASE, 33° antenna				
0°	1.15	880	48%	93 / 76 / 76%
4°	1.03	946	49%	96 / 83 / 83%
7°	0.88	1037	45%	96 / 85 / 84%
10°	0.73	1054	41%	95 / 83 / 82%
14°	0.58	930	33%	86 / 70 / 69%

In these simulations the optimum tilting angle is from 7° to 10°. The relative high optimum tilt angle can be explained by the big antenna installation height (50m). From the Table 3 figures it can be seen the trend that by down tilting the antennas the other to own cell interference ratio i is going down as the tilting is increased. This is because the antenna main beam is not delivering so much power towards the other base stations and therefore most of the radiated power is going to the area that is intended to be served by this particular base station. At the same time the network could also serve more users than without tilting the antennas. There is always some optimum value for the tilting, which depends on the environment, site and user locations and the antenna radiation pattern. If the tilting angle is too much the service area could go down and the base station is not able to serve as big area as without excess tilting. This is seen from the numbers of uplink coverage probability that has also some optimum value. Due to antenna radiation pattern side lobes and nulls there could be some variations of i and coverage probability as a function of tilting angle.

In the second part of the study the usability of a low noise masthead amplifier (MHA) is demonstrated. The MHA is used in the uplink direction to compensate for the cable losses and thus reducing the required mobile stations' transmit powers. The three- and four-sectored scenarios have been simulated with the 65° antenna and the six-sectored case applied the 33° antenna. In all cases the antenna tilt used was 7° and the maximum MS power was 27 dBm. The MHA simulation results are collected in Table 4.

Table 4. The impact of the MHA. MS maximum power 27 dBm. Antenna tilt 7°. In DL in case the base station maximum transmit power is exceeded the connections were randomly put to outage.

	Other to own cell interference ratio, i	Served users in UL	Served users in DL	UL coverage probability (outdoor to indoor) for 8/64/144 kbit/s
THREE SECTORED CASE, 65° antenna				
no MHA	0.60	1038	807	93 / 78 / 78%
with MHA	0.61	1064	746	95 / 82 / 82%
FOUR SECTORED CASE, 65° antenna				
no MHA	0.73	1089	884	96 / 86 / 85%
with MHA	0.73	1107	846	98 / 89 / 89%
SIX SECTORED CASE, 33° antenna				
no MHA	0.88	1124	1052	97 / 87 / 86%
with MHA	0.90	1132	1021	98 / 90 / 90%
no MHA, cable losses 4 dB	0.88	1109	1057	95 / 83 / 82%
with MHA, cable losses 4 dB	0.90	1132	1016	98 / 90 / 90%

The results of Table 4 indicate that by using a MHA the performance in uplink can be improved also in WCDMA systems. In all the cases the number of users that can be served in uplink has been increased due to the increased sensitivity. Also the coverage probability is bigger when deploying a MHA. In the six-sectored case, the influence of MHA has also been bigger when assuming bigger cable losses in ul (4 dB instead of 2 dB). Table 4 however also shows that the scenarios are downlink limited and having more MSs on the uplink actually decreases the downlink performance. In all the cases the downlink capacity was smaller when using a MHA in uplink. The reason could be that if more users can be served in UL, the transmit powers in DL are increased due to more SHO connections and thus reducing DL capacity.

In the third analysis case, which illustrates the capacity improvement as a function of the sectorisation, each base station has been simulated as omni-site and as a site with three, four or six sectors. Furthermore, by simulating the scenarios with antennas having different beam widths, the importance of correct antenna selection for a sectored configuration is emphasised with help of some examples. For all scenarios the MHA was in use, the maximum MS transmit power was 24 dBm and antennas were not tilted. The results related to the sectorisation study are in Table 5.

Table 5. The impact of the antenna selection in the sectorisation case. MS maximum power 24 dBm, MHA in use. No antenna tilt.

Antenna 3 dB beam width	Other to own cell interference ratio, i	Served users	Soft handover overhead	UL coverage probability (outdoor to indoor) for 8/64/144 kbit/s
OMNI CASE				
omni	0.79	240	28%	70 / 32 / 40%
THREE SECTOR CASE				
120°	1.33	441	39%	85 / 50 / 59%
90°	1.19	461	35%	87 / 55 / 62%
65°	0.88	575	34%	86 / 59 / 62%
FOUR SECTOR CASE				
120°	1.72	489	54%	90 / 62 / 68%
90°	1.49	510	51%	92 / 67 / 72%
65°	1.09	604	41%	92 / 70 / 71%
33°	0.92	691	40%	88 / 65 / 64%
SIX SECTOR CASE				
120°	2.18	593	64%	95 / 75 / 79%
90°	1.97	627	59%	96 / 80 / 82%
65°	1.43	758	55%	96 / 80 / 81%
33°	1.15	880	48%	93 / 76 / 76%

In the case with the omni sites, the coverage is very poor and only 240 users could be served. Already in uplink the network is heavily overloaded. There are almost equally amount of MS going to outage because of to high load and because of the MS running out of power. In all the sectored cases the uplink outage reason is the MS not having enough power however the downlink is even more limiting and more mobiles are going to outage. Table 5 clearly indicates that with higher sectorisation, more mobiles can be served. Another observation that can be made from Table 5 is that for each sectorisation case the selection of the antenna beam width is important. To achieve the highest number of served users it is very crucial to effectively control the interference and soft handover overhead. If the overlap in the sectors is too big, interference is leaking to the other sector directly reducing it's capacity. Another effect of the antenna beam being too wide is the waste of hardware resources and increased downlink transmit powers due to too big soft handover overhead. In the simulations, the 65°-antenna was optimum for the three sectored case and the 33°-antenna was best for the four- and six-sectored scenario. Similar trends have been observed also in [7].

IV. Conclusions

With the results in Table 3 to Table 5 it can be concluded that with rather simple radio network planning means (antenna tilting and correct antenna selection for each scenario) the interference can be controlled and the capacity of the network improved. In the antenna tilting study the electrical tilting was applied and with the help of the results in Table 3 it can be seen that an optimum tilt angle can be found. In the simulations presented in the study each of the base stations was optimised in a similar manner. In reality the base stations antennas are not installed at equal height and thus the optimisation of the base stations should be performed site by site. In this paper it has also been demonstrated that the MHA is also feasible in the WCDMA networks, however the benefit is rather small when the system is strongly downlink limited and thus the uplink sensitivity improvement is not so beneficial. The results in Table 4 also indicate, that the QoS can be improved in the uplink direction in lightly loaded networks. In all of the simulated cases the coverage probability was increased when the MHA was in use. How much of the uplink capacity improvement can be utilised in the downlink direction in case of MHA depends naturally on the current downlink loading situation and the admission and load control strategies implemented in the network. The results of this study also clearly show that the higher sectorisation offers more capacity to the network but to achieve this the antenna selection is very crucial to effectively control the interference and soft handover overhead. For each sectorisation case an optimum beamwidth exists.

Acknowledgements

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