Radio Network Planning Process and Methods for WCDMA

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Abstract - This paper describes the system dimensioning and the radio network planning methodology for a third generation WCDMA system. The applicability of each method is demonstrated using examples of likely system scenarios. The challenges of modeling the multiservice environment are described and the implications to the system performance simulations are introduced.

Keywords: WCDMA, dimensioning, radio network planning, static system simulation, dynamic system simulation

I. INTRODUCTION

As the launch of third generation technology approaches, operators are forming strategies for the deployment of their networks. These strategies must be supported by realistic business plans both in terms of future service demand estimates and the requirement for investment in network infrastructure. Evaluating the requirement for network infrastructure can be achieved using system dimensioning tools capable of assessing both the radio access and the core network components. Having found an attractive business opportunity, system deployment must be preceded by careful network planning. The network planning tool must be capable of accurately modeling the system behaviour when loaded with the expected traffic profile. The third generation cellular systems will offer services well beyond the capabilities of today's networks. The traffic profile, as well as the radio access technology itself form the two most significant challenges when dimensioning and planning a WCDMA based third generation system. The traffic profile describes the mixture of services being used by the population of users. There are also specific system functionalities which must be modelled including fast power control and soft handover. In order to accurately predict the radio coverage the system features associated with WCDMA must be taken into account in the network modeling process. Especially the channel characterization, and interference control mechanisms in the case of any CDMA system must be considered. In WCDMA network multiple services co-exist. Different services (voice, data) have different processing gains, E_b/N_0 performance and thus different receiver SNR requirements. In addition to those the WCDMA coverage depends on the load characterization, hand over parameterization, and power control effects. In current second generation systems' coverage planning processes the base station sensitivity is constant and the coverage threshold is the same for each base station. In the case of WCDMA the coverage threshold is dependent on the number of users and used bit rates in all cells, thus it is cell and service specific.

The WCDMA planning process can be divided into three phases: initial planning (dimensioning), detailed radio network planning and network operation and optimization. Each of these phases requires additional support functions like propagation measurements, Key Performance Indicator definitions etc. In a cellular system where all the air interface connections operate on the same carrier the number of simultaneous users is directly influencing on the receivers' noise floors. Therefore, in the case of UMTS the planning phases cannot be separated into coverage and capacity planning. In the case of the post second-generation systems data services start to play an important role. The variety of services requires the whole planning process to overcome a set of modifications. One of the modifications is related to the quality of service (QoS) requirements. So far it has been adequate to specify the speech coverage and blocking probability only. Also more and more one has to consider the indoor and in-car coverage probabilities. In the case of UMTS the problem is slightly more multidimensional. For each service the QoS targets have to be set and naturally also met. In practice this means that the tightest requirement shall determine the site density. In addition to the coverage probability the packet data QoS criteria are related to the acceptable delays and throughput. Estimation of the delays in the planning phase requires good knowledge of the user behaviour and understanding in the functions of packet scheduler.

Common features between second and third generation coverage prediction also exist. In all the systems both of the links have to be analyzed. In current systems the links tend to be in balance whereas in the case of third generation one of the links can be higher loaded than the other, and thus either one of the links could be limiting the cell capacity or coverage. The propagation calculation is basically the same for all standards, with the exception that different propagation models could be used. Another common feature is the interference analysis. In the case of WCDMA this is needed for the loading and sensitivity analysis, in the case of TDMA/FDMA it is essential for frequency allocation. In order to fully utilize the WCDMA capabilities, a thorough understanding of the WCDMA air interface is needed from the physical layer to the network modeling, planning and performance optimization.

In this paper the pre-operational phase of the WCDMA planning process, as depicted in Figure 1 in detail, is discussed. Section II is concentrating on the initial planning issues. The WCDMA link budget is introduced and it is demonstrated how different services and their QoS requirements impact on the site density estimate. In Section III a static radio network simulator is introduced. The methodology required in the coverage and capacity estimation for WCDMA is described for both uplink and downlink. Topic of Section IV is to demonstrate the accuracy of dimensioning: an example area is dimensioned and the average site distance is determined. The dimensioning result is compared with the outcome of a static network simulation. In Section V the analysis methods of the static simulator are verified. The verification was performed with a dynamic system simulator. The paper is concluded in Section VI.

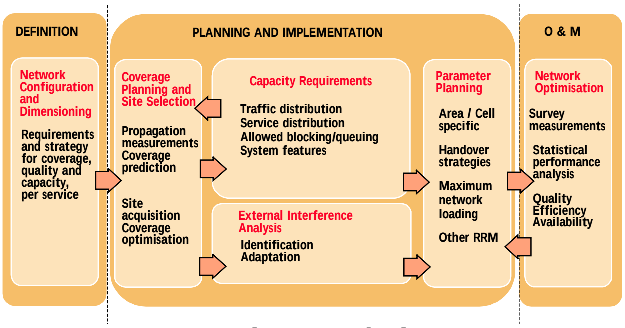

Figure 1. WCDMA Radio Network Planning process.

II. INITIAL PLANNING, SYSTEM DIMENSIONING

Initial planning (i.e. system dimensioning) provides the first and most rapid evaluation of the network element count as well as the associated capacity of those elements. This includes both the radio access network as well as the core network. This paper focuses upon the radio access part solely. The target of the initial planning phase is to estimate the required site density and site configurations for the area of interest. Initial planning activities include radio link budget (RLB) and coverage analysis, capacity estimation, and finally, estimation for the amount of base station hardware and sites, radio network controllers (RNC), equipment at different interfaces, and core network elements. The service distribution, traffic density, traffic growth estimates and QoS requirements are essential already in the initial planning phase. In the initial planning phase the quality is taken into account in terms of blocking and coverage probability. RLB calculation is done for each service, and the tightest requirement shall determine the maximum allowed isotropic path loss.

A. WCDMA specific items in the radio link budget

In this section the WCDMA uplink and downlink budgets are discussed. To estimate the maximum range of a cell a RLB calculation is needed. In the RLB the antenna gains, cable losses, diversity gains, fading margins, diversity gains etc. are taken into account. The output of the RLB calculation is the maximum allowed propagation path loss which in return determines the cell range and thus the amount of sites needed. There are a few WCDMA specific items in the link budget if one compares to the current TDMA based radio access system like GSM. These include interference degradation margin, fast fading margin, transmit power increase and soft handover gain.

The interference degradation margin is a function of the cell loading. The more loading is allowed in the system, the larger interference margin is needed in uplink, and the smaller is the coverage area. The uplink loading can be derived as follows, for simplicity the derivation is performed with service activity $v = 1$.

To find out the required uplink transmitted and received signal power for a mobile station MS_k connected to a particular base station BS_n, the basic CDMA E_b/N_0 equation is used. The usual, slightly theoretical, assumption is that I_{oth}, the interference received from the MSs connected to the other cells is directly proportional (proportionality constant i) to I_{own}, the interference received from the MSs connected to the same BS_n as the desired MS. Assume that the MS_k uses bit rate R_k, its E_b/N_0 requirement is ρ_k and the CDMA modulation bandwidth is W. Then the received power of the k-th mobile, p_k, at the base station it is connected to, must be at least such that

$$\frac{W}{R_k}\left(\frac{p_k}{I_{own} - p_k + I_{oth} + N}\right) = \frac{W}{R_k}\left(\frac{p_k}{I_{own} - p_k + iI_{own} + N}\right) \geq \rho_k, \quad k = 1,\dots,K_n \qquad (1)$$

where K_n is the number of MSs connected to BS_n, $N = N_0 W = N_f \kappa T_0 W$ is the noise power in the case of an empty cell, N_f is the receiver noise figure, κ is the Boltzmann constant and T_0 is the absolute temperature.

The inequalities in (1) are slightly optimistic because it is assumed that there is no interference from the own signal. In reality this is not exactly true in multipath propagation conditions. Equation (1) is however still chosen to avoid taking multipath interference into account twice. I.e., the E_b/N_0 requirements determined from link level simulations are presented so that N_0 means only noise and multipath interference is visible in higher E_b/N_0 requirement to a certain BER performance. Solving the inequalities as equalities means solving for the minimum required received power (sensitivity), p_k:

$$p_k\left(1 + \frac{\rho_k R_k}{W}\right) = \frac{\rho_k R_k}{W}(1+i)I_{own} + \frac{\rho_k R_k}{W}N \quad \Rightarrow$$

$$p_k = \frac{1}{1 + \frac{W}{\rho_k R_k}}(1+i)I_{own} + \frac{1}{1 + \frac{W}{\rho_k R_k}}N, \quad k = 1,\dots,K \qquad (2)$$

If the Equations in (2) are summed over the mobile stations connected to BS_n then

$$\sum_k p_k = \left[\sum_k \frac{1}{1 + \frac{W}{\rho_k R_k}}(1+i)\right]\sum_k p_k + \left[\sum_k \frac{1}{1 + \frac{W}{\rho_k R_k}}\right]N \Rightarrow$$

$$\sum_k p_k(1+i) = \frac{\left[\sum_k \frac{1}{1 + \frac{W}{\rho_k R_k}}(1+i)\right]N}{1 - \left[\sum_k \frac{1}{1 + \frac{W}{\rho_k R_k}}(1+i)\right]} \qquad (3)$$

since $I_{own} = \sum_k p_k$. If loading is defined as

$$\eta = \sum_k \frac{1}{1+\frac{W}{\rho_k R_k}}(1+i) \tag{4}$$

this loading definition can be enhanced to include sectorisation gain, ζ, and service activity, ν:

$$\eta = \sum_k \frac{1}{1+\frac{W}{\rho_k R_k \nu_k}}(1+i\cdot\zeta) \tag{5}$$

In [12] the uplink loading is estimated using equation

$$\eta = \frac{1}{W}\cdot \sum_{j=1}^{m} R_j \cdot \nu_j \cdot \rho_j (1+i) \tag{6}$$

where m is the number of services used. The difference between Equations (5) and (6) are due to the fact that (6) does not include sectorisation gain and that in the derivation starting from Equation (1) the denominator is I_{own} - p_k + iI_{own} +N rather than I_{own} + iI_{own} +N, which is only the case when $p_k << I_{own}$.

The downlink dimensioning is following the same logic as the uplink. For a selected cell range the total base station transmit power ought to be estimated. In this estimation the soft handover connections must be included. If the power is exceeded either the cell range ought to be limited, or number of users in a cell has to be reduced. For downlink the loading (η_{DL}) is estimated based on

$$\eta_{DL} = \sum_{i=1}^{I}\left[\frac{\rho_i R_i \nu_i}{W}\left((1-\alpha_i) + \sum_{n=1, n\neq m}^{N}\frac{Lp_{mi}}{Lp_{ni}}\right)\right] \tag{7}$$

where Lp_{mi} is the link loss from the serving BS m to MS i, Lp_{ni} is the link loss from another BS n, to MS i, ρ_i is the *transmit* E_b/N_0 requirement for the MS i, including the SHO combining gain and the average power raise caused by fast power control, N is the number of base stations, I is the number of connections in a sector and α_i is the orthogonality factor depending on multipath conditions (α = 1: fully orthogonal).

The term $\sum_{n=1, n\neq m}^{N}\frac{Lp_{mi}}{Lp_{ni}}$ defines the iDL.

Direct output of the downlink RLB is the single link power required by a user at the cell edge. The total base station power estimation must take into account multiple communication links with average ($\overline{Lp_{mi}}$) distance from the serving base station. Furthermore, the multicell environment with orthogonalities α_i should be included in the modeling. More on the downlink loading and transmit power estimations can be found in [13]. In the RLB calculation in uplink direction the limiting factor is the mobile station transmit power, in downlink direction the limit is the total base station transmit power. When balancing the uplink and downlink service areas both links must be considered.

The interference degradation margin to be taken into account in the link budget due to a certain loading η (either in uplink or downlink) is

$$L = 10\cdot\log_{10}(1-\eta) \tag{8}$$

Fast fading margin or power control headroom is another CDMA specific item in the RLB. Some margin is needed in the mobile station transmission power for maintaining adequate closed loop fast power control in unfortunate propagation conditions like the cell edge. This is applicable especially for pedestrian users where the E_b/N_0 to be maintained is more sensitive to the closed loop power control. The power control headroom has been studied more in [6] and [7]. Another impact of the fast power control is the transmit power increase. In the case of a slowly moving mobile station the power control is able to follow the fading channel and the average transmitted power increases. In own cell this is needed to provide adequate quality for the connection and does not cause any harm, since increased transmit power is compensated by the fading channel. For neighbouring cells however this means additional interference. The transmit power increase *(TxPowerInc)* is used to reduce the reuse efficiency according to Equation (9). In Equation (4) i should be replaced with term $TxPowerInc\cdot i$ in case the mobile station transmit power increase is significant.

$$F_r = \frac{1}{1+TxPowerInc\cdot i} \tag{9}$$

Soft handover gain is discussed already in [3]. Handovers – soft or hard – provide gain against shadow fading by reducing the required fading margin. Due to the fact that the slow fading is partly uncorrelated between cells, and by making handovers the mobile can select a better communication link. Furthermore, soft handover (macro diversity) gives an additional gain against fast fading by reducing the required E_b/N_0 relative to a single radio link. The amount of gain is a function of mobile speed, diversity combining algorithm used in the receiver and channel delay profile. More about the SHO gain can be found in Section II C.

B. Receiver sensitivity estimation

In the link budget the BS receiver noise density is estimating the noise level over one WCDMA - carrier. The required receiver SNR contains the processing gain and the loss due to the loading. The loading used is the total loading due to different services on the carrier in question. The required signal power (S) depends on the SNR requirement, receiver noise figure and bandwidth.

$$S = SNR\cdot N_0\cdot W \tag{10}$$

where

$$SNR = \rho\cdot\frac{R}{W\cdot(1-\eta)} \tag{11}$$

and $N_0\cdot W = N_f\cdot\kappa T_0 W$ (12)

where N_f is the receiver noise figure, κ is Boltzmann constant, T_0 is the absolute temperature and η is the loading. In some cases the basic noise/interference level is further corrected with the man made noise term.

C. Shadowing margin and soft hand over gain estimation

The next step is to estimate the maximum cell range and cell coverage area in different environments/ regions. The RLB is estimating the maximum allowed isotropic path loss, from that value a slow fading margin, related to the coverage probability, has to be subtracted. When estimating the coverage probability the propagation model exponent and the standard deviation for the log-normal fading must be set. If the indoor case is considered the indoor loss is from 15 dB to 18 dB and the standard deviation for log-normal fading margin calculation is set to 10 - 12 dB. In the case of outdoor coverage typical standard deviation value is 7 to 8 dB. Typical propagation constants range from 2.5 to 4. Traditionally the area coverage probability used in the RLB is for single cell case [1]. The required probability is 90% to 95% and typically this leads to 7 - 8 dB fading margin, depending on the propagation constant and standard deviation of the log-normal fading. The Equation (13) estimates the area coverage probability for single cell case:

$$F_u = \frac{1}{2}\left[1 - erf(a) + \exp\left(\frac{1-2\cdot a\cdot b}{b^2}\right)\cdot\left(1 - erf\frac{1-a\cdot b}{b}\right)\right] \quad (13)$$

Where $a = \frac{x_0 - P_r}{\sigma\cdot\sqrt{2}}$ and $b = 10\cdot n\cdot\log_{10}\frac{e}{\sigma\cdot\sqrt{2}}$, P_r is the received level at cell edge, n is the propagation constant, x_0 is the average signal strength threshold and σ is the standard deviation of the field strength..

In real WCDMA cellular networks the coverage areas of cells overlap and the mobile station is able to connect to more than just one serving cell. If more than one cell can be detected the location probability increases and is higher than determined for a single isolated cell. Analysis performed in [2] indicates that if the area location probability is reduced from 96% to 90% the number of base stations is reduced by 38%. This number indicates that the concept of multiserver location probability should be carefully considered. In reality the signals from two base stations are not completely uncorrelated, and thus the soft handover gain is slightly less than estimated in [2]. In [3] the theory of the multiserver case with correlated signals is introduced:

$$P_{out} = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} e^{-x^2/2}\left[Q\left(\frac{\gamma_{SHO} - a\cdot\sigma\cdot x}{b\cdot\sigma}\right)\right]^2 dx \quad (14)$$

where P_{out} is the outage at the cell edge, γ_{SHO} is the fading margin in the case of soft handover, σ is the standard deviation of the field strength and for 50% correlation $a = b = 1/\sqrt{2}$. With the theory presented for example in [1] this probability at the cell edge can be converted to the area probability. In the WCDMA link budget the SHO gain is needed. The gain consists of two parts: combining gain against fast fading and gain against slow fading. The gain against slow fading is dominating and it is specified as:

$$G = \gamma_{single} - \gamma_{SHO} \quad (15)$$

If we assume 95% area probability, n = 3.5 and the standard deviation is 7 dB the gain will be 7.3 dB - 4 dB = 3.3 dB. If the standard deviation is larger and the probability requirement higher the gain will be more.

Table 1. Example of a WCDMA RLB.

	UL		DL	
Transmitter power	125.00	a	1372.97	mW
	20.97	$b=10\log_{10}(a)$	31.38	dBm
Tx antenna gain	0.00	c	18.00	dBi
Cable/body loss	2.00	d	2.00	dB
Transmitter EIRP (incl. losses)	18.97	e=b+c-d	47.38	dBm
Thermal noise density	-174.00	f	-174.00	dBm/Hz
Receiver noise figure	5.00	g	8.00	dB
Receiver noise density	-169.00	h=f+g	-166.00	dBm/Hz
Receiver noise power	-103.13	$i=10\log_{10}(W)+h$	-100.13	dBm
Interference margin	-3.01	j	-10.09	dB
Required Ec/Io	-17.12	$k=10\log_{10}(E_b/N_o/(W/R))-j$	-7.71	dB
Required signal power [S]	-120.26	l=i+k	-107.85	dBm
Rx antenna gain	18.00	m	0.00	dBi
Cable/body loss	2.00	n	2.00	dB
Coverage probability outdoor (requirement)	95.00		95.00	%
Coverage probability indoor (requirement)	0.00		0.00	%
Outdoor location probability (calculated)	85.62		85.62	%
Indoor location probability (calculated)	32.33		32.33	%
Limiting environment:	outdoor		outdoor	
Log normal fade constant outdoor	7.00		7.00	dB
Log normal fade constant indoor	12.00		12.00	dB
Propagation model exponent	3.50		3.50	
Log normal fade margin	-7.27	o	-7.27	dB
Handover gain (inc. any macro diversity combining gain at cell edge)	0.00	p	2.00	dB
Slow fade margin	-7.27	q=o+p	-5.27	dB
Indoor loss	0.00	r	0.00	dB
TPC headroom (fast fade margin)	0.00	s	0.00	dB
Allowed propagation loss	147.96	t=e-l+m-n+q+r-s	147.96	dB

D. Cell range and cell coverage area estimation

Once the maximum allowed propagation loss in a cell is known, it is easy to apply any known propagation model for the cell range estimation. The propagation model should be chosen so that it optimum describes the propagation conditions in the area. The restrictions of the model are related to the distance from the base station, the base station effective antenna height, the mobile antenna height and the frequency. One typical example for macro cellular environment is Okumura-Hata. Equation (16) presents an example Okumura-Hata path loss model for an urban macro cell with base station antenna height of 25 m, mobile antenna height of 1.5 m and carrier frequency of 1950 MHz [4].

$$Lp = 138.5 + 35.7\cdot\log_{10}(r) \quad (16)$$

After choosing the cell range the coverage area can be calculated. The coverage area for one cell in hexagonal configuration can be estimated with:

$$S = K \cdot r^2 \qquad (17)$$

Where S is the coverage area, r is the maximum cell range and K is a constant, depending on the network topology. The number of sectors is typically from 1 to 3. In the case of WCDMA reasonable values are up to 6 sectors. In the case of 6 sectors the estimation of the cell coverage area becomes problematic, since a six-sectored site does not necessary resemble a hexagon. A proposal for the cell area calculation at this stage is that the equation for the omni case is used also in the case of 6 sectors and the larger area is due to a higher antenna gain. The more sectors are used the more careful soft handover overhead has to be analysed to provide an accurate estimate. In Table 2 some of the K-values are listed.

Table 2. K-values for the site area calculation.

SITE CONFIG.	1 omni	2-sectored	3-sectored	6-sectored
K	2.6	1.3	1.95	2.6

E. Capacity and coverage analysis in the initial planning phase

Once the site coverage area is known the site configurations in terms of channel elements, sectors and carriers, and site density (cell range) has to be selected so that the supported traffic density can fulfil the requirements. An example dimensioning case can be seen in Section IV. The WCDMA RLB is slightly more complex than the TDMA one. The cell range depends on the number of simultaneous users (number of channels/users in terms of interference margin, see Equation (6)). Thus the coverage and capacity are connected and already in the very beginning the operator should have knowledge and vision of the subscriber distribution and growth since it has a direct impact on the coverage. Finding the correct configuration for the network so that the traffic requirements are met and the network cost minimised is not a simple task. The number of carriers, number of sectors, loading, number of users and the cell range all have an impact on the result.

III. DETAILED PLANNING PROCESS

A. Introduction to a static radio network planning simulator

In this study the simulator first introduced in [9] 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 different terminal speed and uses a different service (bit rate, activity factor, which both can be different for uplink and downlink). Therefore each mobile station gets assigned an individual E_b/N_0 requirement imported from link level simulations. The simulator itself consists of basically three parts – initialisation, combined uplink and downlink analysis and post processing phase. Following the initialisation part, round after round in the main part of the tool, both the uplink and downlink for all mobile stations are analysed and after the iterations have fulfilled certain convergence criteria, in the final step, the results of the uplink and downlink analyses are post processed for various graphical and numerical outputs. On top of these results, for selected areas (which also can consist of the whole network) area coverage analyses for UL and DL dedicated channel as well as for common channels (common pilot CPICH, broadcast control channel BCCH, forward access and paging channel FACH and PCH on the P-CCPCH and S-CCPCH) can be performed. In case a second carrier is present in the network area, either used by the same operator or by another operator adjacent channel interference (ACI) can be taken into account. Only in case the second carrier is assigned to the same operator, load can be shared according different strategies between the carriers (IF-HO).

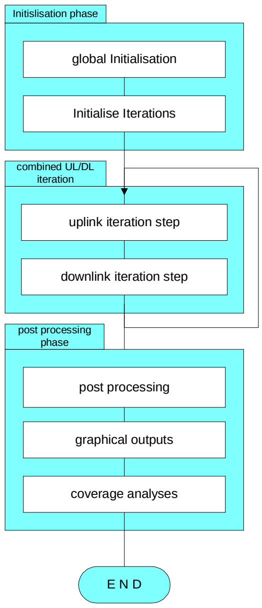

Figure 2. Static simulator overview.

B. Initialisation Phase

In the global 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. In the following step, requirements coming from the link level simulations are assigned to base stations and mobile stations. After some initialisation tasks for the iterative analysis – setting default transmit powers and network performance - the actual simulation can start.

C. Combined uplink and downlink analysis

C1. Uplink iteration step

The target in the uplink iteration is to allocate the mobile stations' transmit powers so that the (interference+noise)-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 gains and average power raise due to fast transmit power control. The impact of the uplink loading on the base station sensitivity (noise rise) is taken into account by adjusting it with (1-η). η can be defined by Equation (5).

After the average transmit powers of the mobiles have been estimated they are compared to the maximum value allowed and mobiles exceeding this limit are trying IF-HO if allowed or are put to outage. Now the interference analysis can be performed again and the new loading and base station sensitivities are calculated until their changes are smaller than specified thresholds. Also in case the uplink loading of a cell exceeds specified limits, mobile stations are moved to another carrier if allowed (IF-HO). Otherwise they are put to outage.

C2. Downlink iteration step

Similarly to the uplink the goal of the downlink iteration is to assign the base station transmit powers for each link (including SHO connections) a mobile station is having until all mobile stations receive their signal with the required carrier-to-interference-ratio, C/I, defined by Equation (18).

$$targetCI = \frac{EbNo_{MS}}{W/R} \tag{18}$$

where $EbNo_{MS}$ is the received E_b/N_0 requirement of the MS depending on terminal speed and service. The actual received $(C/I)_m$ of MS m is calculated using MRC according Equation (19) by summing the C/I values of all links k, k=1...K mobile station m is having.

$$\left(\frac{C}{I}\right)_m = \sum_{k=1}^{K} \frac{p_{km}/Lp_{km}}{(1-\alpha_k)(P_k - v_m p_{km})/Lp_{km} + I_{oth,k} + N_m} \tag{19}$$

where P_k is the total transmit power of the base station to which link k is established, Lp_{km} is the link loss from the cell k to the mobile station m, α_k is the cell specific orthogonality factor, p_{km} is the power allocated to the link 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 and it is not known a priori whether a link can be established or not. In case either certain link power limits or the total transmit power of a base station is exceeded mobile stations are performing IF-HO if allowed or taken out randomly from the network.

In a further step for each mobile station it is checked whether the received E_c/I_0 value is above a user defined threshold so that the mobile station can reliably measure the base station and synchronise to it. Also here if the threshold given is exceeded, the mobile station tries IF-HO or is put to outage. A flow chart for the detailed iteration steps can be seen from Figure 3.

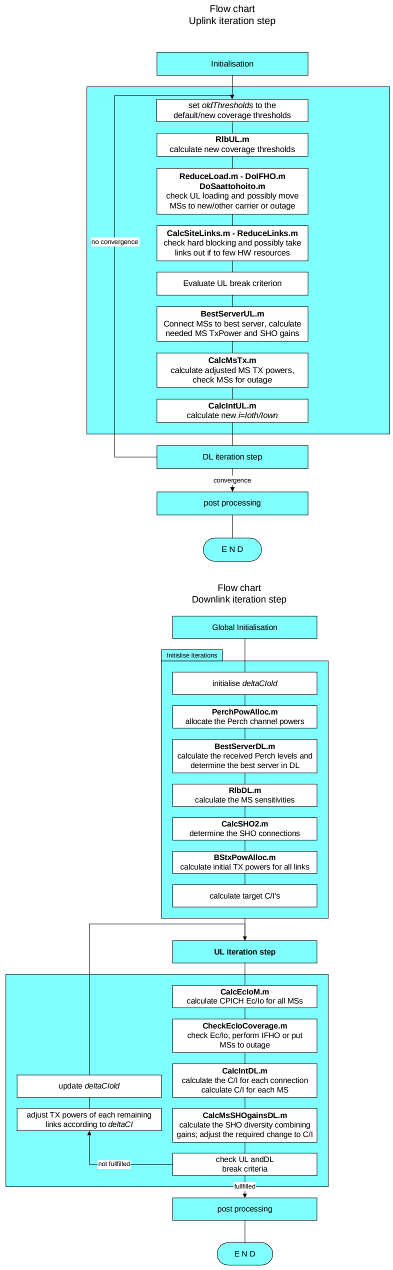

Figure 3. Flowcharts for the UL and DL iteration steps.

C3. Adjacent channel interference calculations

The adjacent channel interference influence due to the two possible carriers – either from own network or from a competitive operator's network in the same area - is taken into account by filtering this interference with a channel separation dependent filter. In both directions UL and DL the adjacent carrier filtering is implemented as a two-fold process. In UL, one filter for the mobile stations has been implemented indicating its out of band radiation (*acpFilterUL*). This filter is used to indicate how much power the mobile station is leaking into the other carriers receiving band (*Adjacent Channel Leakage Ratio, ACLR*). For the base station in the uplink another filter (*aciFilterUL*) has been implemented. This filter is indicating the selectivity of the base station's receiver in multicarrier situation, i.e. how big portion of the adjacent channel power is received by the base station as adjacent channel interference power (*Adjacent Channel Protection, ACP)*. Also this filter setting depends on the carrier separation. The adjacent channel interference situation in UL is depicted in Figure 4. In the simulations these two filters are combined to a single filter by Equation (20):

$$acFilterUL = -10 \cdot \log_{10}\left(10^{-\frac{aciFilterUL}{10}} + 10^{-\frac{acpFilterUL}{10}}\right) \quad (20)$$

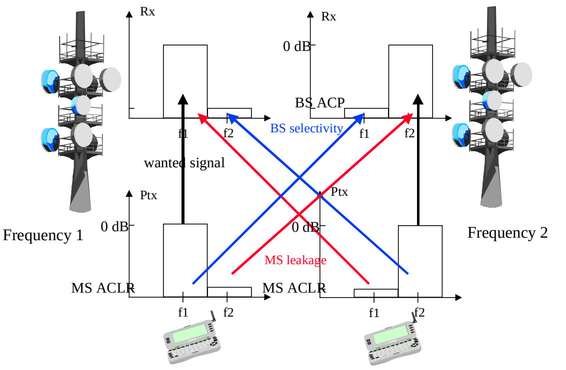

Figure 4. UL adjacent channel interference situation.

Adjacent channel interference (I_{ACI}) is taken into account when calculating the UL load according to Equation (21).

$$\eta = \frac{I_{own} + I_{oth} + I_{ACI}}{I_{own} + I_{oth} + I_{ACI} + N} \quad (21)$$

Also in the downlink similar type of filtering is introduced as in the uplink. One filter for the base stations has been implemented indicating the out of band radiation of the base station (*acpFilterDL*). This filter is used to indicate how much power the base station is leaking into the other carriers receiving band (*ACLR*). The filter setting depends on the separation between the carriers. For the mobile station another filter has been implemented (*aciFilterDL*). This filter is indicating the selectivity of the mobile station's receiver in multicarrier situation, i.e. how much of the adjacent channel interference power is received by the mobile station (*ACP*). Also this filter setting depends on the carrier separation. The adjacent channel interference situation in DL is depicted in Figure 5. In the simulations these two filters are combined to a single filter by Equation (22):

$$acFilterDL = -10 \cdot \log_{10}\left(10^{-\frac{aciFilterDL}{10}} + 10^{-\frac{acpFilterDL}{10}}\right) \quad (22)$$

Adjacent channel interference (I_{ACI}) in DL is taken into account when calculating the C/I of a single link a MS is having according to Equation (23).

$$\left(\frac{C}{I}\right)_m = \sum_{k=1}^{K} \frac{p_{km}/Lp_{km}}{(1-\alpha_k)(P_k - v_m p_{km})/Lp_{km} + I_{oth,k} + I_{ACI} + N_m} \quad (23)$$

where variables are as defined after Equation (19), I_{oth} is interference from other cells on same carrier and I_{ACI} is adjacent channel interference.

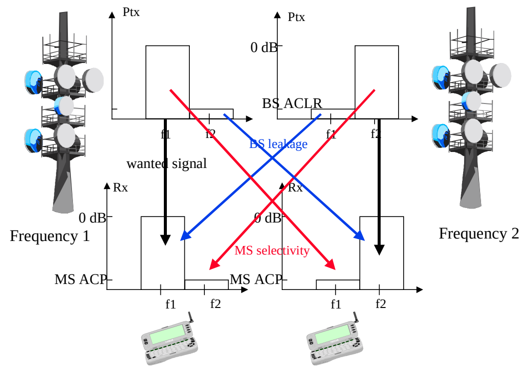

Figure 5. DL adjacent channel interference situation.

D. Predicting the network coverage

In all estimations of area coverage probability (UL, DL DCH, CPICH, BCH, FACH, PCH) it is assumed that the interference situation is stable. This means that a certain traffic distribution has been assumed and the detailed UL and DL iteration has been run. A test mobile is then run through all pixel of the interesting area and all other MSs which could be served are contributing to the interference. The test mobile is not influencing on the interference situation, therefore the other to own cell interference ratio will not change and also the total transmit power of the serving BSs are constant.

UL DCH coverage

In UL direction now it can be estimated whether or not this additional mobile station using a certain bit rate and having a certain E_b/N_0 requirement could get the service in the chosen geographical location. This means, if the maximum allowed transmit power of the test MS is enough to fulfil the E_b/N_0 requirement at the BS receiver. The needed transmit power for the MS is calculated with Equation (24) and compared to the maximum allowed.

$$P_{TX,MS} = \frac{N_0 \cdot Lp}{v \cdot (1-\eta) \cdot \left(1 + \frac{W}{R \cdot \rho \cdot v}\right)} \quad (24)$$

Area coverage probability finally is defined as the proportion of the chosen area where the additional MS really gets the wanted service under that stable interference situation. The weakness in this approach is that in reality an additional mobile station would change the interference situation, for example some other mobiles could go to outage but in the case of low bit rate services this effect can be neglected.

DL DCH coverage

In downlink direction the coverage probability calculation is based on the transmit power limits per radio link. The main focus is to check pixel-by-pixel, whether or not there is enough transmit power per link from base stations in the active set, if there would be a

MS in the pixel, using a given service (bit rate) and having a given speed. Also here it is assumed that the total transmit powers of BSs do not change from what was left after UL/DL iteration, i.e. it could be assumed that the influence of the test MS is replaced by the closest original MS. In iteration however there may or may not have been a MS in the pixel. The coverage probability then again is defined as the amount of pixels from the whole area where the service was possible.

CPICH coverage

In radio network planning the CPICH transmit power should be set as small as possible but ensuring that the best cell and neighbour cells can be measured and synchronised and the CPICH can be sufficiently used as the phase reference for all other DL physical channels. Typically this means that 5% - 10% of the total BS power is used for CPICH. For each pixel in the chosen area the E_c/I_0 in that pixel is calculated according Equation (25).

$$CPICHecio = \frac{P_{CPICH}/Lp}{\sum_{i=1}^{numBSs} P_{TX,i}/Lp_i + I_{ACI} + N_0} \qquad (25)$$

where P_{CPICH} is the CPICH power of the best server, Lp is the link loss to the best server, $P_{TX,i}$ is the total transmit power of BS i, Lp_i is the link loss to BS i, I_{ACI} is adjacent channel interference, N_0 is the thermal noise of the default MS and *numBSs* is the number of base stations in the network. The achieved E_c/I_0 is then compared to a user given threshold and the CPICH coverage defined as the ratio of pixels where the threshold is exceeded compared to all pixels. The weakness of this modeling for the CPICH E_c/I_0 coverage is that it is done only for the best server. In an operating network however, all neighbour cells must also be measured and therefore all neighbour cells' CPICH E_c/I_0 should be analysed, too. This could be overcome however by e.g. adding a threshold to the required CPICH E_c/I_0. Descriptions of other static simulators can be found for example in [18], [19].

IV. EXAMPLE DIMENSIONING CASE AND VERIFICATION OF DIMENSIONING WITH STATIC SIMULATIONS

This section is containing an example use case for the initial planning phase in case of a green field macrocellular operator. In this example case only one network evolution phase is considered, in the real radio network planning case the traffic growth should be more carefully considered. In this work three cases have been analysed. First case is 8 kbps speech only, mobile station speeds 3 (50% of MSs) and 120 km/h (50% of MSs). Second case is dimensioning speech and circuit switched data (64 kbps), speech mobiles moving 50 km/h, data terminals 3 km/h. The last case is 144 kbps data only, terminals moving with 20 km/h. More details related to the case can be found in [14]. The study consisted of two parts. In the first part the operator's macrocellular network is dimensioned, i.e. the cell range is estimated with given input parameters. This study is based on the assumption that the traffic and the QoS information are available from the operator. In the second phase the network is planned for the estimated site distance (1.5*R) and the WCDMA analysis is performed for the radio network. As depicted in Figure 1 this use case is concentrating on the first half of the radio network planning process: the network dimensioning, network configuration definition and coverage/capacity planning.

In the first phase the dimensioning task is to generate certain traffic and QoS requirements for the above mentioned three cases and to dimension the cases accordingly. The radio network was dimensioned for an urban area of 13 x 13 km^2. The propagation model used was Okumura-Hata with an area correction factor of 0 dB. The traffic and QoS requirements for all the three cases are in Table 3.

Table 3. The traffic and QoS requirements and other dimensioning parameters.

	SPEECH	SPEECH AND 64 KBPS CS DATA	144 KBPS PACKET DATA
Subscribers	60000	60000, 12000	24000
Average traffic/subscriber	0.060 Erl	0.040 Erl , 0.025 Erl	3 kbps
Blocking	2%	1%	-
Coverage probability	95%	95%/70%	80%
Data activity	50%	50%	100%
Assumed soft capacity	20%	10%	10%
SHO overhead	40%	40%	40%
Maximum uplink loading	60%	65%	65%
MS/BS transmit power	24/43 dBm	24/43 dBm	24/43 dBm
Common channel overhead	10%	10%	10%
Antenna gain MS/BS	0/17 dBi	0/17 dBi	0/17 dBi
Cable/body loss	3/0 dB	3/0 dB	3/0 dB
MS speed	3 km/h 120 km/h	50 km/h, 3 km/h	20 km/h
Std for the log normal fading	7 dB	7 dB	7 dB
Peak to average ratio for total BS power calculation	4 dB	4 dB	4 dB
Average orthogonality	50%	50%	50%
i and iDL	55%	55%	55%
BS antenna height	30 m	35 m	35 m

In the dimensioning process both the capacity and the coverage have to be considered. The cell range is determined not only by the RLB, but also on the capacity requirements. From the selected cell range the coverage area for the site can be estimated by Equation (17). Once the site coverage area is known the supported traffic density can be estimated. The selected site density must be such that the traffic density requirement and the coverage requirement in terms of coverage probability are met. In the following table the dimensioning results are collected. In the example case the cell range has been solely based on the uplink results. In uplink direction the target loading as specified by Equation (6) is limiting the number of channel elements per cell. As it can be seen already in the dimensioning results, the base station transmit power is actually limiting in all of the cases. In order to meet the capacity requirements either cell range, number of sectors or number of carriers should be changed. In this case only one carrier was used.

Table 4. Dimensioning results.

	SPEECH	SPEECH AND 64 KBPS CS DATA	144 KBPS PACKET DATA
Selected cell range	2.08 km	1.98 km	1.52 km
Uplink loading	0.32 3 km/h 0.29 120 km/h	0.40 speech 0.18 data	0.65 data
Service limiting the cell range	Speech 3 km/h	64 kbps data	144 kbps data
Number of channel elements per cell required to meet the capacity based on UL	30 3 km/h 30 120 km/h	42 speech 6 data	855.6 kbps throughput ~ 6 data channels
Number of channel elements per cell supported by DL	21 3 km/h 19 120 km/h	27 speech 6 data	5 data
Required number of 3-sectored sites (based on UL)	20 (60 cells)	22 (67 cells)	37 (112 cells)

In the second phase of the work the dimensioning results in terms of number of cells and the cell range were used in the corresponding static simulator runs. The items with **bold** font in Table 3 and Table 4 were used as inputs for the simulation. The site distance used in the static simulator has been estimated with D = 1.5*R where R is the cell range obtained from the RLB in dimensioning. In this study the network scenario was based on a regular grid, and the network area consisted only of urban area type. The static simulator described in Section III was used in this study. The E_b/N_0 requirements and the traffic distribution used in the simulation were the same as were used during dimensioning. In the dimensioning phase only the antenna gain is used. In the simulations the antenna radiation pattern is also required and an antenna with 65° horizontal beamwidth was selected. The 65° antenna was selected because it is widely used already in 2G networks with three sectored configurations. Furthermore, according to [11] the 65° provides the optimum performance for the used network configuration. In all the simulations the antenna gain was always 17 dBi. The soft handover addition window was set to –6 dB. In Figure 6 there is an example of the network scenario. The system features used in the simulations are from [10] and the ITU vehicular A channel [5] has been assumed for the channel delay profile.

According to the simulations in the speech case the dimensioning is too pessimistic for the uplink capacity. Based on the simulations the network could support 72 speech users versus the 60 proposed by dimensioning. The main difference is because of the interference statistics. The other to own cell interference ratio has relative large standard deviation (0.27, minimum value only 0.11) and thus there are cells which can carry more traffic than Equation (6) is proposing. With the help of the results in Table 5 it can be concluded that current dimensioning is correctly limiting the downlink capacity. According to the simulations with 65° antenna the downlink should serve 46 users, the dimensioning is proposing 40. The simulated coverage probability is slightly higher than the requirement, and thus the site distance in reality could be slightly increased.

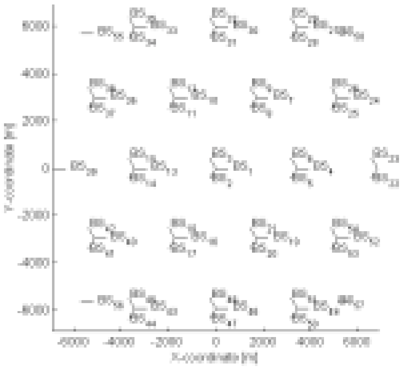

Figure 6. Example of a network scenario. Mixed traffic case.

In the mixed traffic case the uplink dimensioning result was proposing 42 channel elements for speech users and 6 for data users to meet the traffic requirement. The UL simulation result is slightly different from the dimensioning result. The reason for this is partly that it is very difficult to control the simulation run so that the ratio of the data users and the speech users would be exactly as required. The initial requirement was that the data users are 17% of the total users. After the static simulator run the percentage was 16%. In the case of UL there are in average 37 speech users instead of 42, but on the contrary there are 8 data users instead of 6. Therefore one can claim that the uplink dimensioning result is well in line with the simulation results. The power amplifier dimensioning for the DL (based on [13]) shows a clear downlink limitation. The uplink 48 users cannot be served in downlink direction with the assigned 20 W maximum base station transmit power. When the number of users in the dimensioning was reduced to 27 speech and 6 data users the dimensioning estimates the total TX power of 17 W including 10% common channel overhead. Values used for the power calculation were iDL (= $\sum_{n=1,n\neq m}^{N} \frac{Lp_{mi}}{Lp_{ni}}$, see [13]) 55% and peak to average ratio for Lp_{mi} of 4 dB. The downlink is limiting also according to the network simulations. According to the simulation downlink analysis the network can support 25 speech users and roughly 5 64 kbps data users simultaneously, the base station total transmit power being 19 W to 20 W depending on the selected scenario. In the mixed traffic case the dimensioning of the base station total transmit power follows extremely well the simulations. In terms of coverage probability the dimensioning is slightly pessimistic. According to the simulations the data coverage probability is always better than the required 70%. Since the data service is limiting the cell range the speech coverage probability is always better than the required 95%.

In the data case the dimensioning was proposing 855.6/144 = 5.94 simultaneous users (assuming 10% soft capacity, and iDL = 55%). This result is very close to the simulated case, but also in this case the uplink dimensioning is slightly pessimistic. In the downlink dimensioning with iDL = 55%, orthogonality 50% and 4 dB peak to average ratio the BS transmit power for the 5 users is roughly 19 W, including common channels (10% overhead) and 40% soft handover probability. A similar number is also achieved with the static simulations. In the data case the coverage probability is up to 8% higher than required. The difference in decibels of coverage probability of 80% and 88% is 2 to 3 dB, depending on the exact parameter values that have been used in the estimations, see [1]. In coverage limited case this has an impact on the required number of sites. All simulation results are collected in Table 5.

Table 5. Simulation results. Only the average results (averaged over all the cells) are included.

	SPEECH	SPEECH AND 64 KBPS CS DATA	144 KBPS PACKET DATA
Antenna 65°, site distance D = 1.5*R			
Number of users UL	35 3 km/h 36 120 km/h	37 speech 8 data	7
Number of users DL	23 3 km/h 23 120 km/h	25 speech 5 data	5
UL coverage probability	96.3% 3 km/h 98.8% 120 km/h	97.6% 74.4%	87.5%
Other to own cell interference	0.65	0.62	0.75
Loading	0.58	0.67	0.62
BS transmit power/W	19.34	18.95	19.10

In Figure 7 there is an example of the dominance and coverage analysis plot for speech services, test mobile speed 50 km/h. In the dimensioning the used requirement for speech was 95%.

For mixed traffic (speech and 64 kbps) case the probabilities are 98% and 70% respectively. Since data services are limiting the range the actual coverage probability for speech was higher, i.e. 98%. Similar analysis for the RT data gave 68% coverage probability. In the dimensioning the used requirement was 70%.

The results presented here demonstrate that in macrocellular environment the downlink dimensioning is essential, due to the fact that with the assumptions of the macrocellular environment and Vehicular A channel conditions the network is downlink limited.

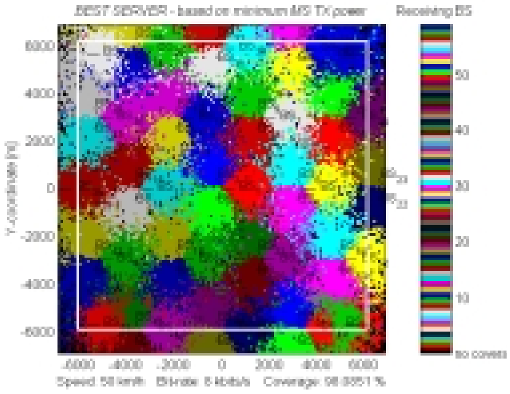

Figure 7. Example result of the mixed traffic case. The coverage probability for speech services.

Uplink dimensioning alone gives too optimistic capacity predictions for the network. Furthermore, the modeling proposed for the dimensioning is verified with static network simulations. The comparison of the simulation results and the dimensioning results show good agreement.

V. COMPARISON OF A STATIC TO A DYNAMIC NETWORK SIMULATOR

The scope of this section is to demonstrate that the accuracy of the static simulator is adequate for radio network planning purposes.

A. Introduction to the dynamic simulator

Typically the system level simulators operate with the resolution determined by the feature that changes interference situation most often. In WCDMA the fast closed loop power control operating with 1.5 kHz frequency is the algorithm having the highest frequency, and therefore, 1.5 kHz frequency is used in the system simulator used in the comparison. Conventionally, the information obtained from the link level tool is linked to the system simulation by using a so-called *average* value interface describing the BLER performance by average E_b/N_0 requirements. The average value interface is not accurate if there are fast changes in the interference due to, e.g. high bit rate packet users. This kind of approach suits well for static snap-shot simulations, but cannot be used when simulating systems with fast power control and high bit rate packet data. With the presented dynamic simulator however, a so-called *actual* value interface (AVI) is used that provides accurate modeling of fast power and high bit rate packet data [16].

In the dynamic simulator the users are making calls and transmitting data according to the traffic models. The call generation process for real time services, such as speech and video, is made according to a Poisson process [15], [17]. For speech, voice activity and discontinuous transmission have to be considered. For circuit switched data services, the traffic model is a constant bit rate model, with 100 % of activity.

The calculation of interference is an essential process of the system simulator. The better the interference modeling is, the more accurate results can be obtained. The total interference power $I_{bs(k)}$ received by a base station k is calculated as follows:

$$I_{bs(k)} = \sum_{\substack{n=1 \\ n\neq m}}^{N} \left[Lp_{n,k} \cdot \frac{\sum_{i=1}^{J} g_{i,n,k}}{\sum_{n=1}^{J} \hat{g}_{i,n,k}} \cdot p_{ms(n)} \right] \qquad (26)$$

where N is the total number of active mobile stations in the system and m is index for the observed user. $Lp_{n,k}$ is path loss (attenuation due to distance and slow fading) between the base station k, and the mobile station n. $\sum g / \sum \hat{g}$ is the multipath fading normalized to having long term average equal to one and J is the number of multipath components. $p_{ms(n)}$ is the transmission power of the mobile n. After the interference calculations, the uplink signal-to-noise ratio SNR_{UL} can be calculated for the user m connected to the base station k as

$$SNR_{UL(m,k)} = \sum_{i=1}^{J} \frac{G \cdot p_{ms(m)} \cdot a_i^2}{I_{bs(k)} + N} \qquad (27)$$

where G is the processing gain, a_i is amplitude attenuation of path i and J is the number of allocated RAKE fingers. In (27) it is assumed that the received signals are combined coherently with maximal ratio combining. In downlink the effect due to orthogonal codes has to be considered. Because of the multipath propagation perfect orthogonality cannot be assumed. For optimal maximal ratio combining, the downlink signal-to-noise-ratio SNR_{DL} for a user m can be calculated as

$$SNR_{DL(m)} = \sum_{k=1}^{M} \left(\sum_{i=1}^{J_k} \frac{G \cdot p_{bs(m,k)} \cdot a_{k,i}^2}{I_{ms(m)} - P_{bs(k)} \cdot a_{k,i}^2} \right) \qquad (28)$$

where $I_{ms}(m)$ is the total interference power received by the mobile station m, M is number of base stations in the active set, $p_{bs(m,k)}$ is the transmitting power for the observed user from the base station k, $P_{bs}(k)$ is the total power transmitted from the base station k, $a_{k,i}$ is amplitude attenuation of the channel tap i and J_k is the number of allocated RAKE fingers from base station k.

In the dynamic simulator following items were measured: Bad quality calls, defined as calls having an average frame error rate FER exceeding a threshold (usually 5% for speech). The minimum call duration is set to 7 seconds in order to increase the confidence of the averaging. Statistical data of these calls are recorded such as coordinates, start and end time and the call duration. Dropped calls, i.e. calls that have consecutive frame errors that exceed a threshold (usually 50 frame errors). Usually dropped calls are considered as severely poor quality calls. So bad quality and dropped calls can be taken as one measure whose percentage is referred to the number of started calls after the warm-up period. Power outage – for speech, this is taken from active terminals including those that are in DTX. Therefore it is slightly distorted due to the other half of the users that are in DTX. So the actual outage for terminals that are actively "talking" is higher. Rough value is twice than that of the output. There is no discrepancy for data. E_b/N_0 targets is taken from all active terminals including those in SHO. So all factors regarding the channel and diversity are taken into account. Finally SHO probability histogram of the number of branches per user was collected.

From the static simulator for all UL and DL connections the histogram of the transmit powers and their cumulative distribution function are taken. Moreover the p-th percentiles Q_p for 0, 50, 75, 90, 95 and 100% are extracted. Statistics showing the number and type of SHO connection were gathered. For the whole simulated area the estimated active set size (AS size) is collected (based on the CPICH levels.) In each simulated case also the UL loading level was stored.

In the final comparison the total traffic per cell, UL power distribution [dBm], DL total/link power distribution [dBm], SHO statistics, SHO areas, cell dominance areas, and not served mobiles (static) versus dropped and bad quality calls (dynamic) were of interest.

B. Comparison results

In this section some of the comparison results are collected. Main conclusion is that the cells level results (for example loading) are in good agreement with both the simulation methods. In Figure 8 the number of links is depicted cell by cell. It can be seen that the number of links per cell follows the same trend.

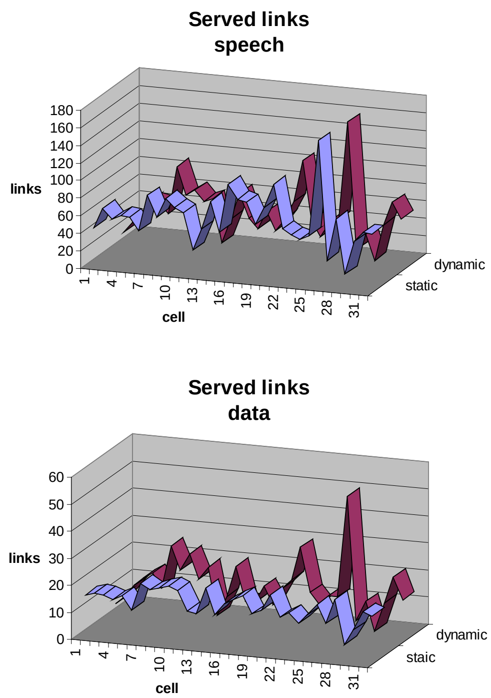

Figure 8. Number of links per cell for static simulator and dynamic simulator cell by cell.

In the following figure the difference of the cell dominance areas as seen by the two different simulators is depicted. It can be stated that the difference is minor. In 90-95 % of all the pixels both simulators propose same dominant cell.

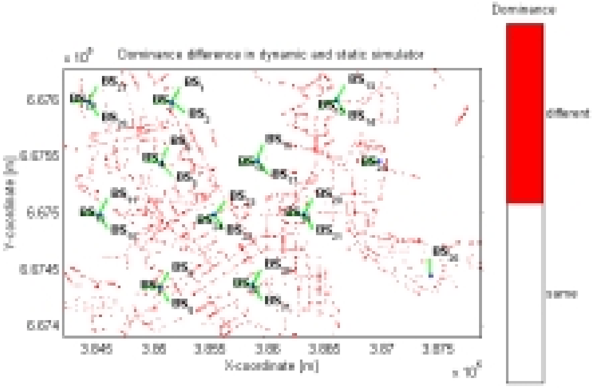

Figure 9. Dominance difference in speech case.

The uplink power distribution statistics are collected for speech and data case in Table 6. The maximum values do not differ significantly, but some of the percentile-values are well apart. This could indicate different power distribution shapes for the two simulators. This cannot be avoided due to the different nature of the simulators.

Table 6. UL Power distribution difference.

	MIN	Q50	Q75	Q90	Q95	MAX
Speech case						
Static s.[dBm]	-44	-10.38	-1.37	5.81	10.95	20.39
Dyn. s. [dBm]	-49	-14.5	-7	0	4.5	20
diff [dB]	-5	-4.12	-5.63	-5.81	-6.45	-0.39
Data case						
Static s.[dBm]	-41.79	-0.08	7.1	13.59	15.77	20.03
Dyn. s. [dBm]	-44	-3	6	15	19	20
diff [dB]	-2.21	-2.92	-1.1	1.41	3.23	-0.03

In downlink direction the transmit power statistics were collected. The comparison results are collected in Table 7. The difference in downlink direction has similar trend as in uplink.

Table 7. DL Power distribution difference.

	MIN	Q50	Q75	Q90	Q95	MAX
Speech case						
Static s.[dBm]	8.25	13.58	16.12	18.37	18.98	24.14
Dyn. s. [dBm]	-1	12.5	16.5	20	21.5	24
diff [dB]	-9.25	-1.08	0.38	1.63	2.52	-0.14
Data case						
Static s.[dBm]	18.91	24.01	24.8	25.57	25.83	26.29
Dyn. s. [dBm]	7	25	25.5	25.7	25.8	26
diff [dB]	-11.91	0.99	0.7	0.13	-0.03	-0.29

The (downlink) link power distributions for the two simulators in speech case are depicted in Figure 10. The shapes of the distributions are close to each other. In case of data the variance is larger.

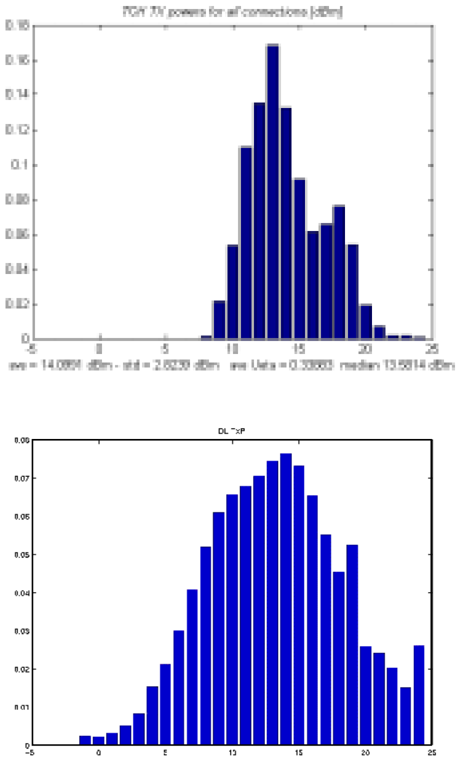

Figure 10. Link power distributions. Top figure for the static simulator (ave Ueta = average UL loading).

Another important result is the soft handover behaviour in the simulators. In Table 8 soft handover statistics from the data simulations have been collected.

Table 8. Handover comparison – 64 kbps CS data case.

	HANDOVER TYPE			SHO
	1-way	2-way	3-way	OVERHEAD
static sim.[%]	83.7	14.9	1.4	17.7
dyn. sim. [%]	72	23	5	33

In addition to the soft handover overhead the difference in active set sizes were investigated. These results are depicted in Figure 11.

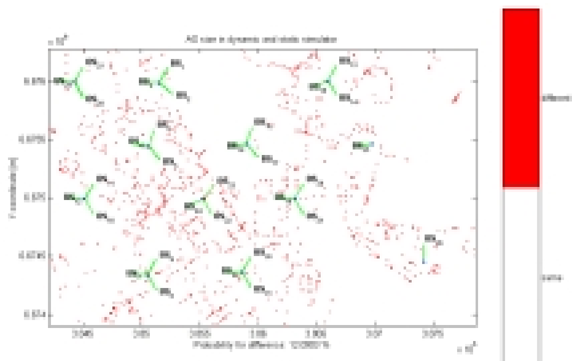

Figure 11. AS size difference in speech case.

In a radio network planning phase it is important to identify the outage areas of the network. In this study the outage prediction of the static radio network simulator was compared to the result from the dynamic simulator. Main conclusion of this case is that the problems have the tendency to be distributed roughly in the same locations for either static tool or dynamic one. The number of problematic calls cannot be directly compared to each other.

VI. CONCLUSION

In this work the radio network planning process and methods for WCDMA networks were introduced and verified. Accuracy of the tools is essential to provide an operator with reasonable information of the required network topology and hardware requirements. In this work initial planning phase (dimensioning) methods were introduced. Furthermore the dimensioning results were compared with results proposed by static simulator. The comparison of the static simulation results and the dimensioning results show good agreement. In general it can be stated that the proposed dimensioning methods perform with reasonable accuracy in cases where the traffic distribution is such that the network can serve several simultaneous users in each cell. In case of high bit rate services the network performance is strongly dependent on the location of the mobile users and the general interference situation, therefore it can be stated that also the proposed dimensioning modeling will perform with degraded accuracy. In case of high bit rate services with low number of connections the proposed methods would underestimate the required BS power too much giving only a long-term average. One way to overcome this problem would be to use the worst case parameter values (cell edge) for the most demanding services.

Further, it has been demonstrated that static radio network planning simulator is giving a realisation of the network, which is close to the network analysed by the fully dynamic simulator. Generally the tools are resulting in similar picture of the network. The uplink and downlink power distributions as well as the cell loading levels and supported links per cell are following the same trends. Problem zones in the network (dropped/bad quality calls, outage etc.) occur in the same locations in both analyses. Handover probabilities, active set sizes and dominance areas are almost the same in both tools. Nevertheless, a static tool is suitable for network planning. Dynamic simulator however is superior for benchmarking of radio resource management algorithms and for analysing of the dynamic phenomena in the networks. The reason is not only in the computation complexity of the dynamic one but also in the fact that the dynamic tool is "not calibrated", i.e. that the call drop rate is dependent on dropping criteria and thus the number cannot be taken as exact absolute value. The number could be just compared with different simulation with the same dropping criterion.

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