A Novel Approach to WCDMA Radio Network Dimensioning

Birgitta Olin, Henrik Nyberg and Magnus Lundevall
Ericsson Research
Ericsson AB
Stockholm, Sweden
Birgitta.Olin@ericsson.com

Abstract— **In this paper a novel dimensioning approach for WCDMA radio networks is suggested. It is derived to handle real-time services on dedicated channels, but can easily be augmented to include best-effort traffic on the high-speed downlink shared channel. The method facilitates calculation of transmit power distributions based on detailed link gain statistics, enabling fast, yet accurate, estimation of *e.g.* network design and cost. It is shown that good agreement with detailed dynamic simulations can be achieved.**

Keywords- dimensioning;WCDMA;HSDPA

I. INTRODUCTION

The purpose of radio network dimensioning is to estimate the required number of radio base stations needed to support a specified traffic load in an area. The outcome of the dimensioning procedure is used in radio network design processes to get an early indication of network size and cost. The dimensioning phase is later followed by a planning phase during which more specific information is collected, enabling a more detailed analysis.

Standard WCDMA dimensioning methods use calculations that utilize expressions aimed at determining power levels (*e.g.* average power) for both capacity and coverage estimates corresponding to a fixed number of users in each cell. Margins are added to compensate for traffic variations and randomness of the radio environment, *e.g.* shadow fading. See *e.g.* [1], [2], [3] and [4]. A more refined approach is the snapshot based simulation technique that mainly targets network planning, see *e.g.* [5]. In the snapshot approach, a number of independent samples of the network state are generated using assumed steady-state distributions for traffic and radio links. Appropriate performance statistics is collected in order to draw conclusions about coverage and capacity given the current network layout. The static snapshot simulations are sometimes complemented by short dynamic simulations in order to better take certain dynamic mechanisms into account, see *e.g.* [5]. Full dynamic simulations are usually considered too cumbersome for dimensioning and planning since the search for suitable cell sizes might require a large number of time consuming simulations with different network configurations.

The approach described in this paper covers and integrates several aspects of downlink and uplink coverage and capacity. The method differs from the standard dimensioning approach in the fundamental aspect that simultaneous distributions of user positions, traffic intensities and inter-cell interference are included explicitly throughout the calculations. In this, shadow and multipath fading are also taken into account. Additional refinements can be made in order to take antenna diversity, soft handover (HO) and softer HO into account. Instead of obtaining approximate average power levels, we thus get comparatively accurate estimates of distributions for the different quantities that are important for dimensioning purposes. Since the power distributions, in particular the tails, provide valuable information about the system, the proposed method will yield a better understanding of the system and its ability to serve the offered traffic than methods based on averages. For instance, a distribution for the cell carrier transmit (TX) power can be used to determine how often the network suffers from base station power outage.

High speed downlink packet access (HSDPA) is a WCDMA release 5 feature that provides a high speed downlink shared channel (HS-DSCH) that is shared by several users, see *e.g.* [6]. Dimensioning methods for this access are of great importance. Since the HS-DSCH employs adaptive coding and modulation rather than fast power control, new aspects must be taken into account in the dimensioning process. Different approaches have been suggested. An interesting, albeit simplified, analytical approach for HSDPA dimensioning is discussed in [7]. Snapshot based techniques for HSDPA network planning are discussed in [5]. We briefly describe how the proposed method can be extended to include the HS-DSCH.

II. MODELS AND ASSUMPTIONS

The basic quantity for dimensioning is the instantaneous link quality, that is the received carrier to interference (plus noise) ratio (C/I). The downlink (DL) or uplink (UL) C/I, denoted by $\gamma_b(x)$ for a link between an arbitrary position *x* and a cell *b,* is given by

$$\gamma_b(x) = p_b(x) \cdot g_b(x) / (I_b(x) + N) \qquad (1)$$

where $p_b(x)$ is the (instantaneous) transmit power assigned to the link, $g_b(x)$ is the corresponding link gain, $I_b(x)$ is the received interference and *N* is thermal noise. Equation (1) is valid for both the UL and the DL, but the interference term depends on the direction (the noise level might as well). The interference for the UL is

0-7803-8521-7/04/$20.00 (C) 2004 IEEE

$$I_b(x) = \sum_{x' \neq x} p_b(x') \cdot g_b(x') \tag{2}$$

where the summation goes over all other present user positions. For the DL, the interference is

$$I_b(x) = P_{\text{cell},b} \cdot \alpha_b(x) \cdot g_b(x) + \sum_{b' \neq b} P_{\text{cell},b'} \cdot g_{b'}(x) \tag{3}$$

where $P_{\text{cell},b}$ is the carrier TX power in cell b and where the sum goes over all cells $b' \neq b$. The factor $\alpha_b(x)$ is the "non-orthogonality" factor, modeling the impact of intra-cell interference due to loss of orthogonality to the other cell b links. The total cell power is given by

$$P_{\text{cell},b} = P_{\text{CCH},b} + \sum_{x} p_b(x) + P_{\text{HS-DSCH},b} \tag{4}$$

in which $P_{\text{CCH},b}$ is the power assigned to the common control channels (CCHs) in cell b and $P_{\text{HS-DSCH,b}}$ is the power assigned to the HS downlink shared channel. Without HSDPA, the last term in (4) is zero.

The gain $g_b(x)$ comprises antenna gain, propagation loss, shadow fading and multipath fading. It depends on the distance and angle between position x and cell b, and random factors associated with shadow and multipath fading.

The notation $\bar{g}_b(x)$ is used for the link gain without multipath fading ("average gain"). In the following, cell numbering is done individually for each position x with respect to the ranking of the average link gains, *i.e.*

$$\bar{g}_1(x) \geq \bar{g}_2(x) \geq \bar{g}_3(x) \geq \ldots. \tag{5}$$

Thus for position x, the cell with the highest average link gain is denoted by 1, the second highest by 2, etc.

A. *Model assumptions*

For dedicated channels (DCHs), it is assumed that for each service s, a required C/I level $\gamma(s)$ can be specified. Fast power control assigns transmit power to the active links (between the user equipment (UE) and various cells) in order to satisfy the C/I requirement if possible (power limitations might apply). For HS-DSCH, the transmit power is fixed. The achieved link quality is then given by equation (1).

For each position x, power is assigned to the link with the highest average gain $\bar{g}_1(x)$. In case of soft HO, power is assigned to the n links (n different cells) with the n highest average link gains. In the following, soft HO with at most two links (*i.e.* $n \leq 2$) is assumed. The assumed HO rule is that a UE has active links to the two best cells if

$$\bar{g}_2(x) / \bar{g}_1(x) \geq T \tag{6}$$

for some HO threshold T.

The power assigned to the CCHs is assumed to be proportional to the common pilot channel (CPICH) power.

In addition, some standard assumptions are used for the radio environment and the traffic distribution. That is, a homogenous radio environment is assumed. Parameters associated with propagation loss, shadow fading and multipath fading are the same for all cells. User positions are mutually independent and uniformly distributed over the area considered. The number of users in the area of each service is assumed to be Poisson distributed (blocking and other user access restrictions are not regarded). The network is built up by sites in a uniform hexagonal pattern, *i.e.* equally sized cells.

III. WCDMA WITHOUT HS-DSCH

The proposed dimensioning procedure uses an iterative loop in its search for an appropriate network cell size, see Fig. 1. Before the loop is entered the cell size is set to an initial value. Given the cell size, the coverage with respect to CCHs, DL code power and UE power is checked. Provided that these steps yield acceptable performance, the total cell output power is estimated and checked. The cell size is altered until a sufficiently good solution is found.

A. *Input data*

To estimate the power distributions some input data must be prepared. First, a large number of user positions are sampled randomly in an area with a specified radio environment. The area is then covered by cells, and for all selected positions, path gain values associated with all cells in the area are derived. The reason for studying a large number of randomly chosen positions instead of working directly with the gain distribution is the complex nature of the gain values and their mutual dependencies. No resampling will be necessary when changing cell sizes, as long as the gain has a form that can be rescaled and the UEs are uniformly distributed over the area.

At most two soft HO links are considered here. The data necessary for each sampled position x will then be $g_1(x)$ and $g_2(x)$ (corresponding to the ordered average gains $\bar{g}_1(x)$ and $\bar{g}_2(x)$), and the corresponding sums of the link gains to the

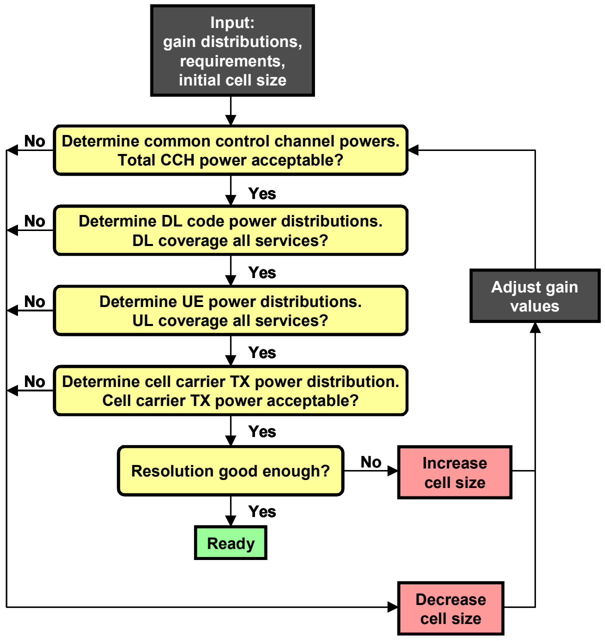

Figure 1. Basic dimensioning loop.

lower ranked cells, *i.e.*

$$g_{\mathrm{sum},1}(x)=\sum_{b\geq 2} g_b(x) \text{ and } g_{\mathrm{sum},2}(x)=\sum_{b\geq 3} g_b(x).$$

In addition, the corresponding average gains $\overline{g}_1(x)$, $\overline{g}_2(x)$, $\overline{g}_{\mathrm{sum},1}(x)$ and $\overline{g}_{\mathrm{sum},2}(x)$ are needed.

B. Common control channels

When assigning TX power to the downlink common control channels, the power required for the common pilot channel (CPICH) is determined first. Then, the power levels of the other common control channels are set based on knowledge about their relative required strength compared to the CPICH.

The required CPICH power for position *x,* corresponding to the E_c/N_o requirement γ_{CPICH}, is estimated by

$$P_{\mathrm{CPICH}}(x)=\gamma_{\mathrm{CPICH}}\cdot\left(\hat{P}\cdot\left(1+\frac{\overline{g}_{\mathrm{sum},1}(x)}{\overline{g}_1(x)}\right)+\frac{N_{\mathrm{DL}}}{\overline{g}_1(x)}\right) \tag{7}$$

where $\hat{P}$ is the expected peak cell output power and N_{DL} is the DL thermal noise. The average CCH power needed for coverage of *x* is obtained by

$$p_{\mathrm{CCH}}(x)=P_{\mathrm{CPICH}}(x)\cdot F_{\mathrm{mean}} \tag{8}$$

where F_{mean} is a factor comprising the C/I requirements and expected activity factors of the common control channels. The actual average CCH power $\overline{P}_{\mathrm{CCH}}$ is estimated as the CCH power yielding coverage of a sufficiently high percentage of the samples. The level of the CCH power is acceptable if the actual average CCH power is below a given threshold.

C. Code power

Downlink coverage is investigated by examining the code power distribution, that is the distribution of the power assigned to DCHs in the DL direction. Given the estimated gain value distributions described by the input data, the code power distributions for different services are obtained as the output powers that yield required C/I values.

The code power distribution is estimated using equations (1), (3), an averaged version of (4) and the gain samples. An iterative scheme is used with an initial guess of the average cell TX power. For users not in HO, the code power corresponding to position *x* and service *s*, $p_1(x,s)$, is estimated by

$$p_1(x,s)=\gamma_{\mathrm{DL}}(s)\cdot\widetilde{I}_1(x) \tag{9}$$

in which $\gamma_{\mathrm{DL}}(s)$ is the target C/I for service *s* and $\widetilde{I}_1(x)$ is the interference plus noise divided by the strongest gain value. Applying equation (3) for the strongest cell, the scaled interference can be written as

$$\widetilde{I}_1(x)=P_{\mathrm{cell},1}\cdot\alpha_1(x)+\overline{P}_{\mathrm{cell}}\cdot\frac{g_{\mathrm{sum},1}(x)}{g_1(x)}+\frac{N_{\mathrm{DL}}}{g_1(x)} \tag{10}$$

where the cell output power levels in all other cells are approximated by the mean cell power $\overline{P}_{\mathrm{cell}}$. The output power of the selected cell, $P_{\mathrm{cell},1}$, is in this stage approximated by the mean cell power as well. In the first step of the iteration, a suitable initial guess of $\overline{P}_{\mathrm{cell}}$ is used.

For samples in HO positions, it is assumed that the total C/I is the sum of the C/I values on the links in the active set. Assuming equal output powers on both links, the code power for a sample in HO is

$$p_1(x,s)=p_2(x,s)=\frac{\gamma_{\mathrm{DL}}(s)}{1+\widetilde{I}_1(x)/\widetilde{I}_2(x)}\cdot\widetilde{I}_1(x) \tag{11}$$

where $\widetilde{I}_1(x)$ is given by (10) and $\widetilde{I}_2(x)$ is the scaled interference on the second strongest link, *i.e.*

$$\widetilde{I}_2(x)=P_{\mathrm{cell},2}\cdot\alpha_2(x)+\frac{P_{\mathrm{cell},1}\cdot g_1(x)+\overline{P}_{\mathrm{cell}}\cdot g_{\mathrm{sum},2}(x)}{g_2(x)}+\frac{N_{\mathrm{DL}}}{g_2(x)} \tag{12}$$

The approximation $P_{\mathrm{cell},1}=P_{\mathrm{cell},2}=\overline{P}_{\mathrm{cell}}$ is used in (12) to simplify numerical calculations. Finally, the code powers are adjusted with respect to the code power limits $p_{\max}(s)$, *i.e.*

$$p(x,s)=\min\left(p_1(x,s),p_{\max}(s)\right). \tag{13}$$

Once the code power samples have been calculated, the average cell output power is updated according to

$$\overline{P}_{\mathrm{cell}}=\overline{P}_{\mathrm{CCH}}+\sum_s\left(\overline{p}(s)+\overline{p}_{\mathrm{H}}(s)\cdot F_{\mathrm{H}}\right)\cdot n(s)\cdot d(s) \tag{14}$$

in which the sum goes over the services *s* that are present, $\overline{p}(s)$ is the mean code power (over all samples *x*) and $\overline{p}_{\mathrm{H}}(s)$ is the mean power for the samples in HO for service *s*, *n(s)* is the mean number of service *s* users per cell (given by cell size, user density and relative service mix), F_{H} is the fraction of samples in HO and *d(s)* is the activity (or DTX) factor. The code power estimation is iterated until the average cell power stabilizes. The code power distribution for service *s* is then estimated by the empirical distribution of the calculated code power samples, *i.e.*

$$F_s(y)=M_s(y)/M \tag{15}$$

where $M_s(y)$ is the number of samples with a power $p(x,s)$ less than or equal to *y*, and *M* is the total number of samples. Coverage is checked for each service *s* by the condition that at most a fraction f_s of the users exceed a specified level $p_{\mathrm{lim},s}$:

$$F_s(p_{\mathrm{lim},s})\geq 1-f_s. \tag{16}$$

D. UE power

Uplink coverage is checked by examining the UE power distribution. This distribution is obtained in the same way as the code power distribution. In the uplink the C/I equation (1) is combined with the UL interference given by (2) and the target C/I for service *s*, $\gamma_{\mathrm{UL}}(s)$. Receiver antenna diversity is taken into account by modeling the combined C/I as a function of the C/I values for the antenna branches. The UL coverage is checked by a condition similar to equation (16).

E. Carrier power

The DL code power calculations are only valid if the cells do not suffer from power shortage. Hence, the cell carrier TX power distribution, which is the distribution of the sum of the powers assigned to the dedicated channels and the common control channels, must be included in the process. To obtain the cell TX carrier power distribution, code power distributions are convolved and then shifted according to the common control channel setting. To produce an estimate that accurately mimics the cell power distribution, we include the effects of macro diversity, TX increase and the effects of traffic variations. In the following, we consider the single-service case. The extension to multiple services is straightforward.

The carrier power, P_{cell}, is given by equation (4). The corresponding carrier power distribution function is then given by

$$\mathbf{P}(P_{\mathrm{cell}} \le y) = \sum_{n_{\mathrm{H}}=0}^{\infty} \sum_{n_{\mathrm{NH}}=0}^{\infty} F_{n_{\mathrm{H}},n_{\mathrm{NH}}}(y) \cdot w(n_{\mathrm{H}}, n_{\mathrm{NH}}) \qquad (17)$$

where $F_{n_{\mathrm{H}},n_{\mathrm{NH}}}(y)$ is the carrier power distribution function given n_{H} users in HO and n_{NH} not in HO, and where the weight $w(n_{\mathrm{H}}, n_{\mathrm{NH}})$ is the probability of such a combination. The total number of users in a cell is assumed to be Poisson distributed. Since HO is assumed to depend on the gains only, the number of users not in HO respectively in HO are independent and Poisson distributed, *i.e.*

$$w(n_{\mathrm{H}}, n_{\mathrm{NH}}) = \frac{m_{\mathrm{H}}^{n_{\mathrm{H}}}}{n_{\mathrm{H}}!} e^{-m_{\mathrm{H}}} \cdot \frac{m_{\mathrm{NH}}^{n_{\mathrm{NH}}}}{n_{\mathrm{NH}}!} e^{-m_{\mathrm{NH}}} \qquad (18)$$

where m_{H} and m_{NH} are the expected numbers of users in HO respectively not in HO. These quantities are given by the (current) cell size, user density and F_{H}, *i.e.* the estimated fraction of users in HO. The carrier power density (corresponding to $F_{n_{\mathrm{H}},n_{\mathrm{NH}}}(y)$) given n_{H} and n_{NH} users, is calculated as the density of the sum of $n_{\mathrm{H}} + n_{\mathrm{NH}}$ stochastically independent code powers plus a fixed CCH power, *i.e.*

$$f_{n_{\mathrm{H}},n_{\mathrm{NH}}}(y) = f_{\mathrm{H}}^{*n_{\mathrm{H}}} * f_{\mathrm{NH}}^{*n_{\mathrm{NH}}}(y - P_{\mathrm{CC}H}) \qquad (19)$$

where f_{H} and f_{NH} are the conditional code power densities (note that they depend on n_{H} and n_{NH}) and where f^{*n} means the *n*-fold convolution of the function *f* by itself (f^{*0} is Dirac's delta). The code powers are given by equation (9) and (11), so the code power distributions (and consequently corresponding densities) can be estimated as in the preceding section by equation (15). The difference now is that the average carrier power in the strongest cell ($P_{\mathrm{cell},1}$ in (10) and (12)) is estimated using equation (14) but with the given values of n_{H} and n_{NH} rather than the average numbers. For the other cells, the overall average carrier power according to equation (14) is used. Thus, new code power densities must be estimated for each combination of n_{H} and n_{NH}. To limit the computational effort, a subset of "interesting" (n_{H}, n_{NH}) combinations is chosen for the summation in equation (17). A useful method is to apply a random sampling scheme over a large subset of combinations.

Note that the carrier power distribution is calculated as if the code powers are independent when the number of users is given. In fact, this is an approximation but it usually works well since the code power variance is normally dominated by stochastic link gains that are uncorrelated between different users.

Power shortage is checked by the condition that

$$\mathbf{P}(P_{\mathrm{cell}} \le P_{\mathrm{cell,max}}) \ge 1 - q \qquad (20)$$

where $P_{\mathrm{cell,max}}$ is the maximal cell power and q is a specified power outage risk.

IV. WCDMA WITH HS-DSCH

The method proposed above can be extended to include best effort data on the HS-DSCH. The power available for the HS-DSCH is given by the cell carrier power consumption needed to handle the services on DCHs and the common control channels. Via C/I calculations for the different positions, it is possible to derive a bitrate distribution that can be used when estimating HS-DSCH coverage and throughput. The method makes it possible to use detailed HS-DSCH link modeling including variable multipath fading. The focus is to estimate the bitrate experienced by the user being served, which is a relevant measure for coverage checking. This measure corresponds to the potential cell HS-DSCH throughput when round-robin scheduling is applied.

A. Power assigned to HS-DSCH

The HS-DSCH and DCHs share the power not assigned to the CCHs, but DCHs have priority over the HS-DSCH.

B. Link quality and bitrate estimation

The bitrate per UE position sample is estimated to obtain the bitrate distribution. Equations (1) and (3) are used to calculate C/I samples which in turn are used to estimate the bitrate samples that yield the estimated bitrate distribution. For equations (1) and (3), the power assigned to the HS-DSCH must be specified.

Adaptive coding and modulation can be taken into account by sampling several gain samples per link in order to capture the multipath fading variation. For each sampled UE position, a number of gain value samples are generated with different but correlated multipath fading components (correlation depending on UE speed). The corresponding C/I values are used to get instantaneous bitrate samples (corresponding to coding, modulation and BLER) that are averaged for each UE.

C. Cell level performance

The HS-DSCH bitrate distribution is estimated from the UE bitrate samples obtained in the bitrate estimation step. Coverage is checked by the condition that the UE bitrate is at least at a specified level with a sufficiently high probability.

V. CALCULATIONS VERSUS SYSTEM SIMULATIONS

We have compared calculated power distributions and dimensioning results with those derived from detailed dynamic system simulations for three different cases. In the first example we wanted to estimate the maximal conversational video traffic load that a given network can handle. The offered load is normalized with the load that yields a total dropping and blocking rate of 10%. In this example it was the cell carrier power that was the limiting factor rather than insufficient coverage. The maximal normalized load was determined to 0.82 by the dimensioning loop. For loads higher than that, the risk of power outage was too high. In Fig. 2 (top), calculated cell carrier TX power distributions (dashed lines) are compared with distributions derived from dynamic system simulations (solid lines) for different load levels. Admission and dropping functions were disabled in the dynamic simulations. In general, there is a good fit between the calculated and simulated distributions, particularly between the tails which hold important information about the system quality. When the admission and dropping functions are disabled the video quality deteriorates rapidly when the cell runs out of TX power. Activating admission and dropping functions prevents this. Fig. 2 (bottom) shows dropping and blocking rates extracted from system simulations (with admission and dropping functions activated). The simulations indicated a normalized capacity in the range 0.8-0.9, depending on accepted blocking and dropping probabilities. The carrier power limit was assumed to be 20 W.

The second and third examples include best-effort services mapped onto the HS-DSCH. In the second example, we determine a network deployment that can provide the required quality for a specified user density and traffic load per user. The required quality is specified by maximal frame error rate for the speech service and good enough bitrate coverage for the best-effort service. Fig. 3 (left) depicts normalized bitrate distributions that are derived from calculations and system simulations for the cell size determined by the dimensioning loop. As can be seen, the system simulations verify that the requirement to cover 90 % of the area with a normalized bitrate of at least 0.16 is fulfilled. Moreover, the bitrate distribution derived from the calculations show good resemblance with that extracted from system simulations. Finally, for the same area and the same network, the normalized bitrate distributions for a heavily loaded pure best-effort HSDPA scenario were derived. These are shown in Fig. 3 (right). In this case the bitrate distribution corresponds to that of round-robin scheduling and the mean bitrate indicates the expected system throughput.

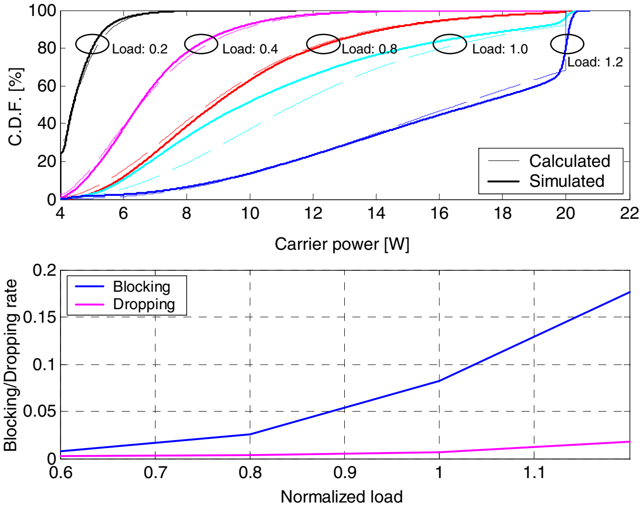

Figure 2. Carrier power distributions (top) and blocking/dropping rates (bottom).

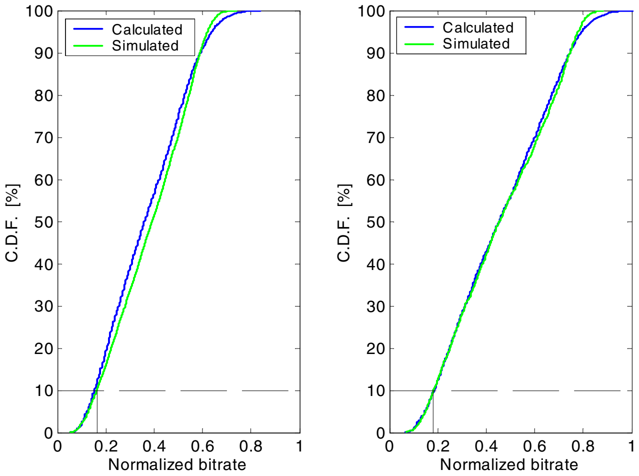

Figure 3. Normalized bitrate. Left: mixed best-effort and voice. Right: best-effort only.

VI. CONCLUSIONS

We have described a novel method for WCDMA radio network dimensioning, including the high-speed downlink shared channel. It comprises a unified treatment of uplink and downlink coverage and capacity. The examples in this paper, comparing the method with detailed system simulations, indicate that good agreement can be achieved.

REFERENCES

[1] K. Hiltunen, R. De Bernardi, "WCDMA downlink capacity estimation", VTC 2000 (spring).

[2] K. Hiltunen, N. Binucci, "WCDMA downlink coverage: interference margin for users located at the cell coverage border", VTC 2002 (spring).

[3] K. Hiltunen, M. Karlsson, "A novel WCDMA uplink capacity and coverage model including the impact of non-ideal fast power control and macro diversity", VTC 2003 (spring).

[4] H. Holma and A. Toskala, Eds., *WCDMA for UMTS,*. John Wiley & Sons, New York (2000).

[5] U. Türke, M. Koonert, R. Schelb, C. Görg, "HSDPA performance analysis in UMTS radio network planning simulations", VTC 2004 (spring).

[6] *High Speed Downlink Packet Access (HSDPA) Overall Description; Stage 2 (Release 5).* 3GPP Technical Report 25.308 v5.4.0, March 2003.

[7] D. Avidor, S. Mukherjee, "Downlink dimensioning for the HSDPA standard", *Proceedings of the 2002 International Symposium on Wireless Personal Multimedia Communications (WPMC)*, Honolulu, USA.