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8

Radio Network Planning

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8.1 Introduction

This chapter presents WCDMA radio network planning, including dimensioning, detailed capacity and coverage planning, and network optimisation. The WCDMA radio network planning process is shown in Figure 8.1. In the dimensioning phase an approximate number of base station sites, base stations and their configurations and other network elements is estimated, based on the operator's requirements and the radio propagation in the area. The dimensioning must fulfil the operator's requirements for coverage, capacity and quality of service. Capacity and coverage are closely related in WCDMA networks, and therefore both must be considered simultaneously in the dimensioning of such networks. The dimensioning of WCDMA networks is introduced in Section 8.2.

In Section 8.3 detailed capacity and coverage planning is presented, together with a WCDMA planning tool. In detailed planning, real propagation maps and operator's traffic estimates in each area are needed. The base station locations and network parameters are selected by the planning tool and/or the planner. Capacity and coverage can be analysed for each cell after the detailed planning. One case study of the detailed planning is presented in Section 8.3 with capacity and coverage analysis. When the network is in operation, its performance can be observed by measurements, and the results of those measurements can be used to visualise and optimise network performance. The planning and the optimisation process can also be automated with intelligent tools and network elements. The optimisation is introduced in Section 8.3.

The adjacent channel interference must be considered in designing any wideband systems where large guard bands are not possible. In Section 8.4 the effect of interference between operators is analysed and network planning solutions are presented.

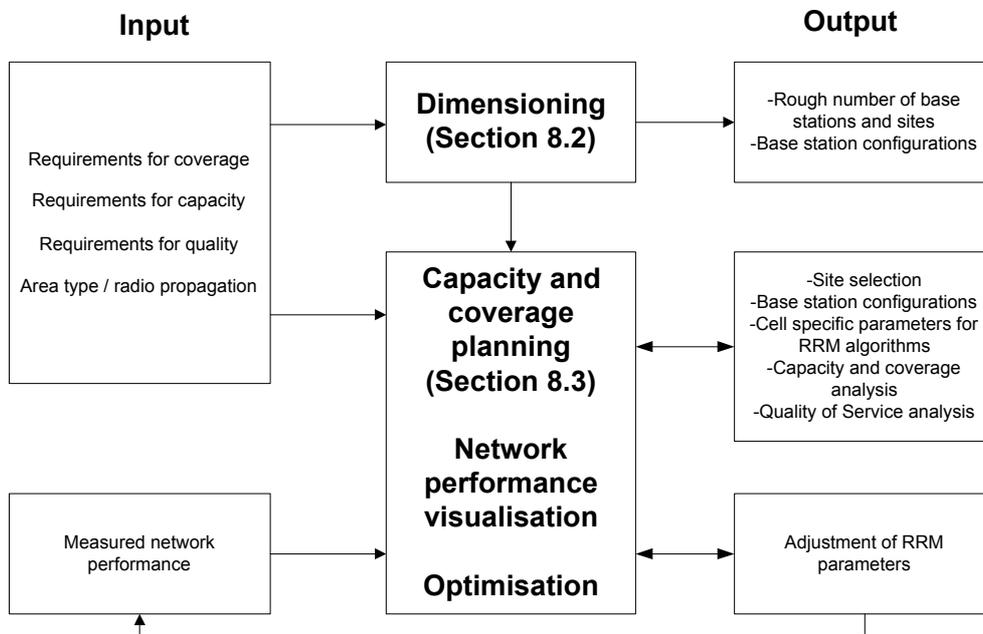


Figure 8.1. WCDMA radio network planning process

8.2 Dimensioning

WCDMA radio network dimensioning is a process through which possible configurations and amount of network equipment are estimated, based on the operator's requirements related to the following.

Coverage:

- coverage regions
- area type information
- propagation conditions

Capacity:

- spectrum available
- subscriber growth forecast
- traffic density information

Quality of Service:

- area location probability (coverage probability)
- blocking probability
- end user throughput

Dimensioning activities include radio link budget and coverage analysis, capacity estimation, and finally, estimations on the amount of sites and base station hardware, radio network controllers (RNC), equipment at different interfaces, and core network elements (i.e. Circuit Switched Domain and Packet Switched Domain Core Networks).

8.2.1 Radio Link Budgets and Coverage Efficiency

The link budget of the WCDMA uplink is presented in this section. There are some WCDMA-specific parameters in the link budget that are not used in a TDMA-based radio access system such as GSM. The most important ones are as follows.

- Interference margin:
The interference margin is needed in the link budget because the loading of the cell, the load factor, affects the coverage: see Section 8.2.2. The more loading is allowed in the system, the larger is the interference margin needed in the uplink, and the smaller is the coverage area. For coverage-limited cases a smaller interference margin is suggested, while in capacity-limited cases a larger interference margin should be used. In the coverage-limited cases the cell size is limited by the maximum allowed path loss in the link budget, and the maximum air interface capacity of the base station site is not used. Typical values for the interference margin in the coverage-limited cases are 1.0–3.0 dB, corresponding to 20–50% loading.
- Fast fading margin (= power control headroom):
Some headroom is needed in the mobile station transmission power for maintaining adequate closed loop fast power control. This applies especially to slow-moving pedestrian mobiles where fast power control is able to effectively compensate the fast fading. The power control headroom was studied in [1]. The performance of fast power control is discussed in Section 9.2.1. Typical values for the fast fading margin are 2.0–5.0 dB for slow-moving mobiles.
- Soft handover gain:
Handovers – soft or hard – give a gain against slow fading (= log-normal fading) by reducing the required log-normal fading margin. This is because the slow fading is partly uncorrelated between the base stations, and by making handover the mobile can select a better base station. Soft handover gives an additional macro diversity gain against fast fading by reducing the required E_b/N_0 relative to a single radio link, due to the effect of macro diversity combining. The amount of gain is a function of mobile speed, the diversity combining algorithm used in the receiver, and the other types of diversity that already exist in the received signal. The total soft handover gain is assumed to be between 2.0 and 3.0 dB in the examples below, including the gain against slow and fast fading. The handovers are discussed in Section 9.3 and the macro diversity gain for the coverage in Section 11.2.1.4.

Other parameters in the link budget are discussed in Chapter 7 in [2]. Below, three examples of link budgets are given for typical UMTS services: 12.2 kbps voice service

using AMR speech codec, 144 kbps real-time data and 384 kbps non-real-time data, in an urban macro- cellular environment at the planned uplink noise rise of 3 dB. An interference margin of 3 dB is reserved for the uplink noise rise. The assumptions that have been used in the link budgets for the receivers and transmitters are shown in Tables 8.1 and 8.2.

Table 8.1. Assumptions for the mobile station

	Speech terminal	Data terminal
Maximum transmission power	21 dBm	24 dBm
Antenna gain	0 dBi	2 dBi
Body loss	3 dB	0 dB

Table 8.2. Assumptions for the base station

Noise figure	5.0 dB
Antenna gain	18 dBi (3-sector base station)
E_b/N_0 requirement	Speech: 5.0 dB 144 kbps real-time data: 1.5 dB 384 kbps non-real-time data: 1.0 dB
Cable loss	2.0 dB

The link budget in Table 8.3 is calculated for 12.2 kbps speech for in-car users, including 8.0 dB in-car loss. No fast fading margin is reserved in this case, since at 120 km/h the fast power control is unable to compensate for the fading. The required E_b/N_0 is assumed to be 5.0 dB. The E_b/N_0 requirement depends on the bit rate, service, multipath profile, mobile speed, receiver algorithms and base station antenna structure. For low mobile speeds the E_b/N_0 requirement is low but, on the other hand, a fast fading margin is required. Typically, the low mobile speeds are the limiting factor in the coverage dimensioning because of the required fast fading margin.

Table 8.4 shows the link budget for 144 kbps real-time data service when an indoor location probability of 80% is provided by the outdoor base stations. The main differences between Tables 8.3 and 8.4 are the different processing gain, a higher mobile transmission power and a lower E_b/N_0 requirement. Additionally, a headroom of 4.0 dB is reserved for the fast power control to be able to compensate for the fading at 3 km/h. An average building penetration loss of 15 dB is assumed here.

Table 8.5 presents a link budget for 384 kbps non-real-time data service for outdoors. The processing gain is lower than in the previous tables because of the higher bit rate. Also, the E_b/N_0 requirement is lower than that of the lower bit rates. The effect of the bit rate to the E_b/N_0 requirement is discussed in Section 11.2.1.1. This link budget is calculated assuming no soft handover.

Table 8.3. Reference link budget of AMR 12.2 kbps voice service (120 km/h, in-car users, Vehicular A type channel, with soft handover)

12.2 kbps voice service (120 km/h, in-car)		
Transmitter (mobile)		
Max. mobile transmission power [W]	0.125	
As above in dBm	21.0	a
Mobile antenna gain [dBi]	0.0	b
Body loss [dB]	3.0	c
Equivalent Isotropic Radiated Power (EIRP) [dBm]	18.0	d = a + b - c
Receiver (base station)		
Thermal noise density [dBm/Hz]	-174.0	e
Base station receiver noise figure [dB]	5.0	f
Receiver noise density [dBm/Hz]	-169.0	g = e + f
Receiver noise power [dBm]	-103.2	h = g + 10*log(3840000)
Interference margin [dB]	3.0	i
Receiver interference power [dBm]	-103.2	j = 10*log(10^((h+i)/10)-10^(h/10))
Total effective noise + interference [dBm]	-100.2	k = 10*log(10^(h/10)+10^(j/10))
Processing gain [dB]	25.0	l = 10*log(3840/12.2)
Required Eb/No [dB]	5.0	m
Receiver sensitivity [dBm]	-120.2	n = m-l+k
Base station antenna gain [dBi]		
Base station antenna gain [dBi]	18.0	o
Cable loss in the base station [dB]	2.0	p
Fast fading margin [dB]	0.0	q
Max. path loss [dB]	154.2	r = d - n + o - p - q
Coverage probability [%]		
Coverage probability [%]	95	
Log normal fading constant [dB]	7.0	
Propagation model exponent	3.52	
Log normal fading margin [dB]	7.3	s
Soft handover gain [dB], multi-cell	3.0	t
In-car loss [dB]	8.0	u
Allowed propagation loss for cell range [dB]	141.9	v = r - s + t - u

Table 8.4. Reference link budget of 144 kbps real-time data service (3 km/h, indoor user covered by outdoor base station, Vehicular A type channel, with soft handover)

144kbps real time data		
Transmitter (mobile)		
Max. mobile transmission power [W]	0.25	
As above in dBm	24.0	a
Mobile antenna gain [dBi]	2.0	b
Body loss [dB]	0.0	c
Equivalent Isotropic Radiated Power (EIRP) [dBm]	26.0	d = a + b - c
Receiver (base station)		
Thermal noise density [dBm/Hz]	-174.0	e
Base station receiver noise figure [dB]	5.0	f
Receiver noise density [dBm/Hz]	-169.0	g = e + f
Receiver noise power [dBm]	-103.2	h = g + 10*log(3840000)
Interference margin [dB]	3.0	i
Receiver interference power [dBm]	-103.2	j = 10*log(10 ^h /(h+i)/10)-10 ^h (h/10))
Total effective noise + interference [dBm]	-100.2	k = 10*log(10 ^h (h/10)+10 ^j (j/10))
Processing gain [dB]	14.3	l = 10*log(3840/144)
Required Eb/No [dB]	1.5	m
Receiver sensitivity [dBm]	-113.0	n = m-l+k
Base station antenna gain [dBi]		
Base station antenna gain [dBi]	18.0	o
Cable loss in the base station [dB]	2.0	p
Fast fading margin [dB]	4.0	q
Max. path loss [dB]	151.0	r = d - n + o - p - q
Coverage probability [%]		
Coverage probability [%]	80	
Log normal fading constant [dB]	12.0	
Propagation model exponent	3.52	
Log normal fading margin [dB]	4.2	s
Soft handover gain [dB], multi-cell	2.0	t
Indoor loss [dB]	15.0	u
Allowed propagation loss for cell range [dB]		
Allowed propagation loss for cell range [dB]	133.8	v = r - s + t - u

Table 8.5. Reference link budget of non-real-time 384 kbps data service (3 km/h, outdoor user, Vehicular A type channel, no soft handover)

384kbps non-real time data, no soft handover		
Transmitter (mobile)		
Max. mobile transmission power [W]	0.25	
As above in dBm	24.0	a
Mobile antenna gain [dBi]	2.0	b
Body loss [dB]	0.0	c
Equivalent Isotropic Radiated Power (EIRP) [dBm]	26.0	d = a + b - c
Receiver (base station)		
Thermal noise density [dBm/Hz]	-174.0	e
Base station receiver noise figure [dB]	5.0	f
Receiver noise density [dBm/Hz]	-169.0	g = e + f
Receiver noise power [dBm]	-103.2	h = g + 10*log(3840000)
Interference margin [dB]	3.0	i
Receiver interference power [dBm]	-103.2	j = 10*log(10 ^h /(h+i)/10)-10 ^h (h/10))
Total effective noise + interference [dBm]	-100.2	k = 10*log(10 ^h (h/10)+10 ^j (j/10))
Processing gain [dB]	10.0	l = 10*log(3840/384)
Required Eb/No [dB]	1.0	m
Receiver sensitivity [dBm]	-109.2	n = m-l+k
Base station antenna gain [dBi]	18.0	o
Cable loss in the base station [dB]	2.0	p
Fast fading margin [dB]	4.0	q
Max. path loss [dB]	147.1	r = d - n + o - p - q
Coverage probability [%]	95	
Log normal fading constant [dB]	7.0	
Propagation model exponent	3.52	
Log normal fading margin [dB]	7.3	s
Soft handover gain [dB], multi-cell	0.0	t
Indoor loss [dB]	0.0	u
Allowed propagation loss for cell range [dB]	139.9	v = r - s + t - u

The coverage efficiency of WCDMA is defined by the average coverage area per site, in km²/site, for a predefined reference propagation environment and supported traffic density.

From the link budgets above, the cell range R can be readily calculated for a known propagation model, for example the Okumura–Hata model or the Walfish–Ikegami model. The propagation model describes the average signal propagation in that environment, and it converts the maximum allowed propagation loss in dB to the maximum cell range in kilometres. As an example we can take the Okumura–Hata propagation model for an urban macro cell with base station antenna height of 30 m, mobile antenna height of 1.5 m and carrier frequency of 1950 MHz [3]:

$$L = 137.4 + 35.2 \log_{10}(R) \quad (8.1)$$

where L is the path loss in dB and R is the range in km. For suburban areas we assume an additional area correction factor of 8 dB and obtain the path loss as:

$$L = 129.4 + 35.2 \log_{10}(R) \quad (8.2)$$

According to Equation (8.2), the cell range of 12.2 kbps speech service with 141.9 dB path loss in Table 8.3 in a suburban area would be 2.3 km. The range of 144 kbps indoors would be 1.4 km. Once the cell range R is determined, the site area, which is also a function of the base station sectorisation configuration, can then be derived. For a cell of hexagonal shape covered by an omnidirectional antenna, the coverage area can be approximated as $2.6R^2$.

8.2.2 Load Factors and Spectral Efficiency

The second phase of dimensioning is estimating the amount of supported traffic per base station site. When the frequency reuse of a WCDMA system is 1, the system is typically interference-limited by the air interface and the amount of interference and delivered cell capacity must thus be estimated.

8.2.2.1 Uplink Load Factor

The theoretical spectral efficiency of a WCDMA cell can be derived from the load equation whose derivation is shown below. The uplink load factor, η_{UL} , can be calculated as a sum of load factors of all N uplink connections L_j in a cell:

$$\eta_{UL} = \sum_{j=1}^N L_j \quad (8.3)$$

The load factor of each connection is derived below. We first define the E_b/N_0 , energy per user bit divided by the noise spectral density:

$$(E_b / N_0)_j = \text{Processing gain of user } j \cdot \frac{\text{Signal of user } j}{\text{Interference from other users}} \quad (8.4)$$

This can be written:

$$(E_b / N_0)_j = \frac{W}{v_j R_j} \cdot \frac{P_j}{I - P_j} \quad (8.5)$$

where W is the chip rate, P_j is the received signal power from user j , v_j is the activity factor of user j , R_j is the bit rate of user j , and I is the total received interference in the base station. Solving for P_j gives

$$P_j = \frac{1}{1 + \frac{(E_b/N_0)_j \cdot R_j \cdot v_j}{W}} I \quad (8.6)$$

Since $P_j = L_j \cdot I$, we obtain the load factor of one connection:

$$L_j = \frac{1}{1 + \frac{(E_b/N_0)_j \cdot R_j \cdot v_j}{W}} \quad (8.7)$$

Additionally, the interference from the other cells must be taken into account by the ratio of other cell to own cell interference, i :

$$i = \frac{\text{other cell interference}}{\text{own cell interference}} \quad (8.8)$$

The uplink load factor can now be written as:

$$\eta_{UL} = (1+i) \cdot \sum_{j=1}^N L_j = (1+i) \cdot \sum_{j=1}^N \frac{1}{1 + \frac{(E_b/N_0)_j \cdot R_j \cdot v_j}{W}} \quad (8.9)$$

The load equation predicts the amount of noise rise over thermal noise due to interference. The noise rise is equal to $-10 \cdot \log_{10}(1-\eta_{UL})$, where η_{UL} is the load factor. The interference margin in the link budget must be equal to the maximum planned noise rise. When η_{UL} becomes close to 1, the corresponding noise rise approaches to infinity and the system has reached its pole capacity. The parameters are further explained in Table 8.6.

The required E_b/N_0 can be derived from link level simulations and from measurements for a predefined multipath fading channel. It includes the effect of the closed loop power control and soft handover. The effect of soft handover is measured as the macro diversity combining gain relative to the single link E_b/N_0 result. The other cell to own (serving) cell interference ratio i is a function of cell environment or cell isolation (e.g. macro/micro, urban/suburban) and antenna pattern (e.g. omni, 3-sector or 6-sector [4]).

The load equation is commonly used to make a semi-analytical prediction of the average capacity of a WCDMA cell, without going into system-level capacity simulations. This load equation can be used for the purpose of predicting cell capacity and planning noise rise in the dimensioning process.

For a classical all-voice-service network, where all N users in the cell have a low bit rate of R , we can note that

$$\frac{W}{E_b / N_0 \cdot R \cdot v} \gg 1 \quad (8.10)$$

and the above uplink load equation can be approximated and simplified to

$$\eta_{UL} = \frac{E_b / N_0}{W / R} \cdot N \cdot v \cdot (1 + i). \quad (8.11)$$

Table 8.6. Parameters used in uplink load factor calculation

	Definitions	Recommended values
N	Number of users per cell	
v_j	Activity factor of user j at physical layer	0.67 for speech, assumed 50% voice activity and DPCCH overhead during DTX 1.0 for data
E_b/N_0	Signal energy per bit divided by noise spectral density that is required to meet a predefined Quality of Service (e.g. bit error rate). Noise includes both thermal noise and interference	Dependent on service, bit rate, multipath fading channel, mobile speed, etc.
W	WCDMA chip rate	3.84 Mcps
R_j	Bit rate of user j	Dependent on service
i	Other cell to own cell interference ratio seen by the base station receiver	Macro cell with omnidirectional antennas: 55%

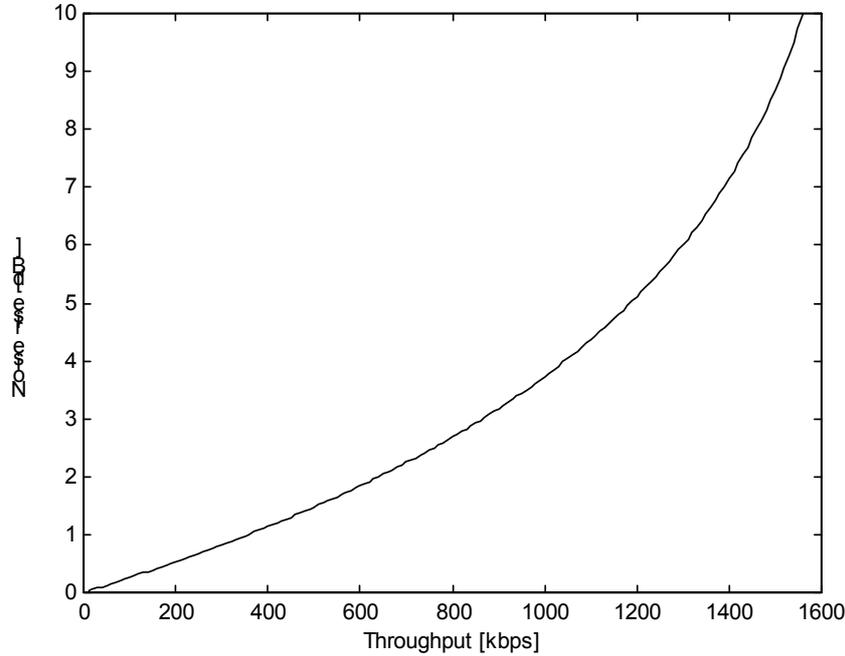


Figure 8.2. Uplink noise rise as a function of uplink data throughput

An example uplink noise rise is shown in Figure 8.2 for data service, assuming an E_b/N_0 requirement of 1.5 dB and $i=0.65$. The noise rise of 3.0 dB corresponds to a 50% load factor, and the noise rise of 6.0 dB to a 75% load factor. Instead of showing the number of users N , we show the total data throughput per cell, of all simultaneous users. In this example, a throughput of 860 kbps can be supported with 3.0 dB noise rise, and 1300 kbps with 6.0 dB noise rise.

8.2.2.2 Downlink Load Factor

The downlink load factor, η_{DL} , can be defined based on a similar principle as for the uplink, although the parameters are slightly different [5]:

$$\eta_{DL} = \sum_{j=1}^N v_j \cdot \frac{(E_b/N_0)_j}{W/R_j} \cdot [(1-\alpha_j) + i_j] \quad (8.12)$$

where $-10 \cdot \log_{10}(1-\eta_{DL})$ is equal to the noise rise over thermal noise due to multiple access interference. The parameters are further explained in Table 8.7. Compared to the uplink load equation, the most important new parameter is α_j , which represents the orthogonality factor in the downlink. WCDMA employs orthogonal codes in the downlink to separate users, and without any multipath propagation the orthogonality remains when the base station signal is received by the mobile. However, if there is sufficient delay spread in the radio channel, the mobile will see part of the base station signal as multiple access

interference. The orthogonality of 1 corresponds to perfectly orthogonal users. Typically, the orthogonality is between 0.4 and 0.9 in multipath channels.

In the downlink, the ratio of other cell to own cell interference, i , depends on the user location and is therefore different for each user j .

In downlink interference modelling, the effect of soft handover transmission can be modelled as having additional connections in the cell. The soft handover overhead is defined as the total number of connections divided by the total number of users minus one. At the same time the soft handover gain relative to the single link E_b/N_0 is taken into account. This gain, called the macro diversity combining gain, can be derived from link/system level simulation analysis and is measured as the reduction in the required E_b/N_0 for each user.

The downlink load factor η_{DL} exhibits very similar behaviour to the uplink load factor η_{UL} , in the sense that when approaching unity, the system reaches its pole capacity and the noise rise over thermal goes to infinity.

For downlink dimensioning, it is important to estimate the total amount of base station transmission power required. This should be based on the *average* transmission power for the user, not the *maximum* transmission power for the cell edge shown by the link budget.

The minimum required transmission power for each user is determined by the average attenuation between base station transmitter and mobile receiver, that is \bar{L} , and the mobile receiver sensitivity, in the absence of multiple access interference (intra- or inter-cell). Then the effect of noise rise due to interference is added to this minimum power and the total represents the transmission power required for a user at an 'average' location in the cell. Mathematically, the total base station transmission power can be expressed by the following equation:

$$BS_TxP = \frac{N_{rf} \cdot W \cdot \bar{L} \cdot \sum_{j=1}^N v_j \frac{(E_b/N_0)_j}{W/R_j}}{1 - \eta_{DL}} \quad (8.13)$$

where N_{rf} is the noise spectral density of the mobile receiver front-end. The value of N_{rf} can be obtained from

$$N_{rf} = -108.2 \text{ dBm} + NF \quad (8.14)$$

where -108.2 dBm is the thermal noise level with 3.84 Mcps, and NF is the mobile station receiver noise figure with typical values of 5–9 dB.

The load factor can be approximated by its average value across the cell, that is

$$\bar{\eta}_{DL} = \sum_{j=1}^N v_j \cdot \frac{(E_b/N_0)_j}{W/R_j} \cdot [(1 - \bar{\alpha}) + i] \quad (8.15)$$

Table 8.7. Parameters used in downlink load factor calculation

Definitions	Recommended values for dimensioning
-------------	-------------------------------------

N	Number of connections per cell = number of users per cell x (1 + soft handover overhead)	
v_j	Activity factor at physical layer	0.67 for speech, assumed 50% voice activity and DPCCH overhead during DTX 1.0 for data
E_b/N_0	Signal energy per bit divided by noise spectral density, required to meet a predefined Quality of Service (e.g. bit error rate). Noise includes both thermal noise and interference	Dependent on service, bit rate, multipath fading channel, mobile speed, etc.
W	WCDMA chip rate	3.84 Mcps
R_j	Bit rate of user j	Dependent on service
α_j	Orthogonality of user j	Dependent on the multipath propagation 1: fully orthogonal 1-path channel 0: no orthogonality
i_j	Ratio of other cell to own cell base station power, received by user j	Each user sees a different i_j , depending on its location in the cell and log-normal shadowing
$\bar{\alpha}$	Average orthogonality factor in the cell	ITU Vehicular A channel: ~60% ITU Pedestrian A channel: ~90%
\bar{i}	Average ratio of other cell to own cell base station power received by user. Own cell interference is here wideband	Macro cell with omnidirectional antennas: 55%

Note: The own cell is defined as the best serving cell. If a user is in soft handover, all the other base stations in the active set are counted as part of the 'other cell'.

In both uplink and downlink the air interface load affects the coverage but the effect is not exactly the same. The difference between the uplink and downlink load curves is described below. The maximum path loss, i.e. coverage, as a function of the load is shown in Figure 8.3 for both uplink and downlink. A 3-sector site is assumed, and the throughputs are shown per sector per carrier. The uplink is calculated for 144 kbps data and the link budget is shown in Table 8.14. An other-cell to own cell interference ratio i of 0.65 is assumed. In the downlink an orthogonality of 0.6 and E_b/N_0 of 5.5 dB are assumed, giving a pole capacity of 820 kbps/cell. The base station transmission power is assumed to be 10 W, and additionally 4 dB cable loss is taken into account. The effect of downlink common channels is included in the downlink calculations, i.e. only part of 10 W is allocated for downlink common channels. The uplink pole capacity in this example is 1730 kbps/cell.

In the downlink the coverage depends more on the load than in the uplink, according to Figure 8.3. The reason is that in the downlink the maximum transmission power is the same 10 W regardless of the number of users and is shared between the downlink users, while in the uplink each extra user has its own power amplifier. Therefore, even with low load in the downlink, the coverage decreases as a function of the number of users.

We note that with the above assumptions the coverage is clearly limited by the uplink for a load below 700 kbps, while the capacity is downlink limited. Therefore, in Chapter 11 the coverage discussion concentrates on the uplink, while the capacity discussion concentrates on downlink.

The capacities presented above depend on the environment and represent only examples. The dependency of capacity and coverage will remain regardless of the assumptions. The effect of the environment on capacities is presented in Section 11.3.1.2.

We need to remember that in third generation networks the traffic can be asymmetric between uplink and downlink, and the load can be different in uplink and in downlink.

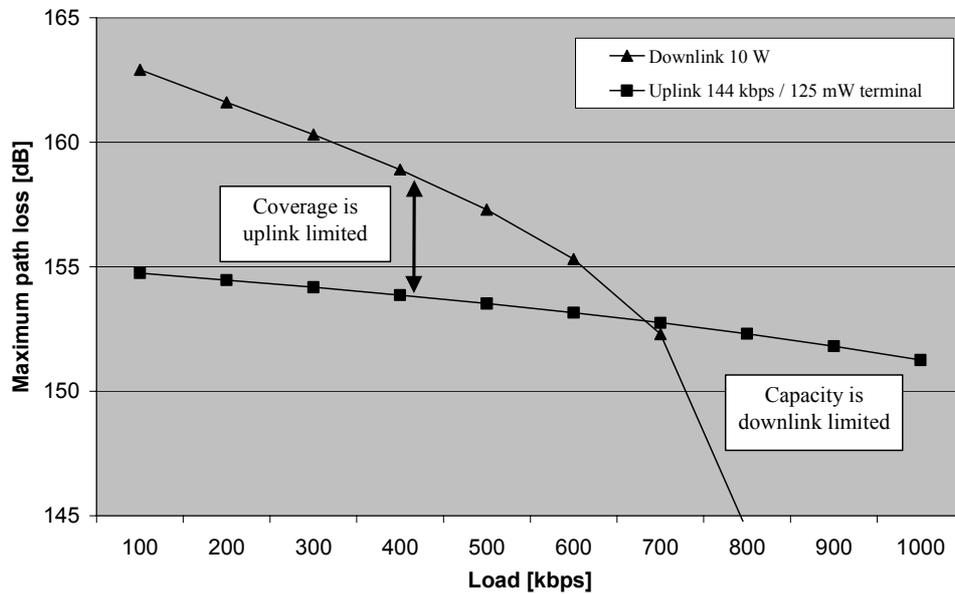


Figure 8.3. Example coverage vs. capacity relation in downlink and uplink in macro cells

In Figure 8.3 a base station maximum power of 10 W is assumed. How much could we improve the downlink coverage and capacity by using more power, such as 20 W? The difference in downlink coverage and capacity between 10 W and 20 W base station output powers is shown in Figure 8.4. If we increase the downlink power by 3.0 dB, we can allow 3.0 dB higher maximum path loss regardless of the load. The capacity improvement is smaller than the coverage improvement because of the load curve. If we now keep the downlink path loss fixed at 153 dB, which is the maximum uplink path loss with 2 dB interference margin, the downlink capacity can be increased by only 10% (0.4 dB) from 680 kbps to 750 kbps. Increasing downlink transmission is an inefficient approach to increasing downlink capacity, since the available power does not affect the pole capacity.

Assume we had 20 W downlink transmission power available. Splitting the downlink power between two frequencies would increase downlink capacity from 750 kbps to 2×680 kbps = 1360 kbps, i.e. by 80%. The splitting of the downlink power between two carriers is

an efficient approach to increase the downlink capacity without any extra investment in power amplifiers. The power splitting approach requires that the operator's frequency allocation allows the use of two carriers in the base station.

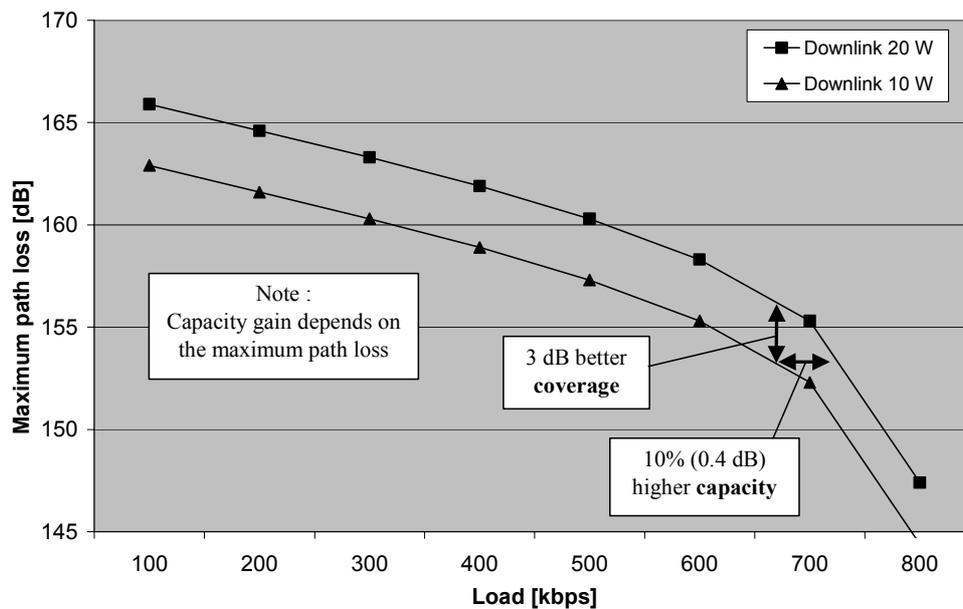


Figure 8.4. Effect of base station output power to downlink capacity and coverage

8.2.2.3 Spectral Efficiency of WCDMA

The spectral efficiency of WCDMA can be defined either by the number of simultaneous calls of some defined bit rates, or, more appropriately in third generation systems, by the aggregated physical layer throughput supported in each cell per 5 MHz carrier, measured in kbps/cell/carrier. Spectral efficiency is a function of radio environment, user mobility and location, services and quality of service, and propagation conditions. The variation can be quite large (e.g. 50–100%). Therefore, most system simulations that attempt to offer some indication of the average spectral efficiency of WCDMA reflect only the results for some predefined cell conditions and user behaviour.

To dimension for mixed traffic, the capacity can be calculated exactly according to Equations (8.9) and (8.12). The general conversion rule between a voice channel and a data channel capacity usage can be based on the individual load factors of each service.

8.2.3 Soft Capacity

8.2.3.1 Erlang Capacity

In the dimensioning in Section 8.2 the number of channels per cell was calculated. Based on those figures, we can calculate the maximum traffic density that can be supported with a

given blocking probability. The traffic density can be measured in Erlang and is defined ([6], p. 270) as:

$$\text{Traffic density [Erlang]} = \frac{\text{Call arrival rate [calls/s]}}{\text{Call departure rate [calls/s]}} \quad (8.16)$$

If the capacity is hard blocked, i.e. limited by the amount of hardware, the Erlang capacity can be obtained from the Erlang B model [6]. If the maximum capacity is limited by the amount of interference in the air interface, it is by definition a soft capacity, since there is no single fixed value for the maximum capacity. For a soft capacity limited system, the Erlang capacity cannot be calculated from the Erlang B formula, since it would give too pessimistic results. The total channel pool is larger than just the average number of channels per cell, since the adjacent cells share part of the same interference, and therefore more traffic can be served with the same blocking probability. The soft capacity can be explained as follows. The less interference is coming from the neighbouring cells, the more channels are available in the middle cell, as shown in Figure 8.5. With a low number of channels per cell, i.e. for high bit rate real-time data users, the average loading must be quite low to guarantee low blocking probability. Since the average loading is low, there is typically extra capacity available in the neighbouring cells. This capacity can be borrowed from the adjacent cells, therefore the interference sharing gives soft capacity. Soft capacity is important for high bit rate real-time data users, e.g. for video connections. It can also be obtained in GSM if the air interface capacity is limited by the amount of interference instead of the number of time slots; this assumes low frequency reuse factors in GSM with fractional loading.

In the soft capacity calculations below it is assumed that the number of subscribers is the same in all cells but the connections start and end independently. In addition, the call arrival interval follows a Poisson distribution. This approach can be used in dimensioning when calculating Erlang capacities. There is an additional soft capacity in WCDMA if also the number of users in the neighbouring cells is smaller.

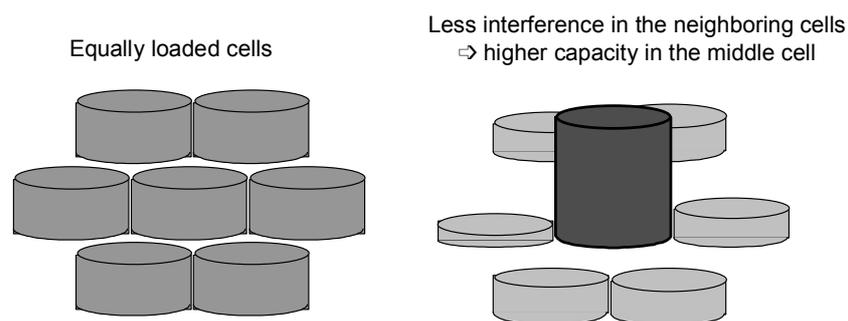


Figure 8.5. Interference sharing between cells in WCDMA

The difference between hard blocking and soft blocking is shown with a few examples in the uplink below. WCDMA soft capacity is defined in this section as the increase of

Erlang capacity with soft blocking compared to that with hard blocking with the same maximum number of channels per cell on average with both soft and hard blocking:

$$\text{Soft capacity} = \frac{\text{Erlang capacity with soft blocking}}{\text{Erlang capacity with hard blocking}} - 1 \quad (8.17)$$

The interference-based admission control strategy is presented in Section 9.5. Such an admission control strategy gives soft blocking and soft capacity.

Uplink soft capacity can be approximated based on the total interference at the base station. This total interference includes both own cell and other cell interference. Therefore, the total channel pool can be obtained by multiplying the number of channels per cell in the equally loaded case by $1 + i$, which gives the single isolated cell capacity, since

$$\begin{aligned} i + 1 &= \frac{\text{other cell interference}}{\text{own cell interference}} + 1 = \frac{\text{other cell interference} + \text{own cell interference}}{\text{own cell interference}} \\ &= \frac{\text{isolated cell capacity}}{\text{multicell capacity}} \end{aligned} \quad (8.18)$$

The basic Erlang B formula is then applied to this larger channel pool (= interference pool). The Erlang capacity obtained is then shared equally between the cells. The procedure for evaluating the soft capacity is summarised below.

1. Calculate the number of channels per cell, N , in the equally loaded case, based on the uplink load factor, Equation (8.9).
2. Multiply that number of channels by $1 + i$ to obtain the total channel pool in the soft blocking case.
3. Calculate the maximum offered traffic from the Erlang B formula.
4. Divide the Erlang capacity by $1 + i$.

8.2.3.2 Uplink Soft Capacity Examples

A few numerical examples of soft capacity calculations are given, with the assumptions shown in Table 8.8.

Table 8.8. Assumptions in soft capacity calculations

Parameter	Value
Bit rates	Speech: 12.2 kbps Real-time data: 16–144 kbps
Voice activity	Speech 67% Data 100%
E_b/N_0	Speech: 4 dB Data 16–32 kbps: 3 dB Data 64 kbps: 2 dB Data 144 kbps: 1.5 dB
i	0.55
Noise rise	3 dB (= 50% load factor)
Blocking probability	2%

The capacities obtained, in terms of both channels based on Equation (8.9) and Erlang per cell, are shown in Table 8.9. The trunking efficiency shown in Table 8.9 is defined as the hard blocked capacity divided by the number of channels. The lower the trunking efficiency, the lower is the average loading, the more capacity can be borrowed from the neighbouring cells, and the more soft capacity is available.

Table 8.9. Soft capacity calculations in the uplink

Bit rate (kbps)	Channels per cell	Hard blocked capacity	Trunking efficiency	Soft blocked capacity	Soft capacity
12.2	60.5	50.8 Erl	84%	53.5 Erl	5%
16	39.0	30.1 Erl	77%	32.3 Erl	7%
32	19.7	12.9 Erl	65%	14.4 Erl	12%
64	12.5	7.0 Erl	56%	8.2 Erl	17%
144	6.4	2.5 Erl	39%	3.2 Erl	28%

We note that there is more soft capacity for higher bit rates than for lower bit rates. This relationship is shown in Figure 8.6.

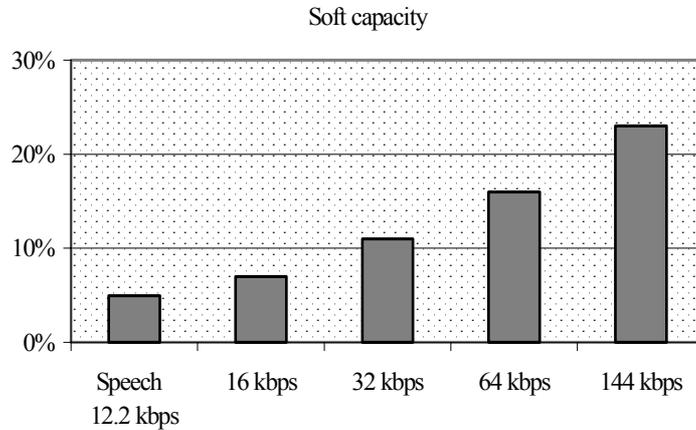


Figure 8.6. Soft capacity as a function of bit rate for real-time connections

It should be noted that the amount of soft capacity depends also on the propagation environment and on the network planning which affect the value of i . The soft capacity can be obtained only if the radio resource management algorithms can utilise a higher capacity in one cell if the adjacent cells have lower loading. This can be achieved if the radio resource management algorithms are based on the interference, not the bit rate or the number of connections.

Similar soft capacity is also available in the WCDMA downlink as well as in GSM if interference-based radio resource management algorithms are applied.

8.3 Capacity and Coverage Planning

8.3.1 Iterative Capacity and Coverage Prediction

In this section detailed capacity and coverage planning are presented. In the detailed planning phase real propagation data from the planned area is needed, together with the estimated user density and user traffic. Also, information about the existing base station sites is needed in order to utilise the existing site investments. The output of the detailed capacity and coverage planning are the base station locations, configurations and parameters.

Since in WCDMA all users are sharing the same interference resources in the air interface, they cannot be analysed independently. Each user is influencing the others and causing their transmission powers to change. These changes themselves again cause changes, and so on. Therefore, the whole prediction process has to be done iteratively until the transmission powers stabilise. Also, the mobile speeds, multipath channel profiles, and bit rates and type of services used play a more important role than in second generation TDMA/FDMA systems. Furthermore, in WCDMA fast power control in both uplink and downlink, soft/softer handover and orthogonal downlink channels are included, which also impact on system performance. The main difference between WCDMA and TDMA/FDMA

coverage prediction is that the interference estimation is already crucial in the coverage prediction phase in WCDMA. In the current GSM coverage planning processes the base station sensitivity is typically assumed to be constant and the coverage threshold is the same for each base station. In the case of WCDMA the base station sensitivity depends on the number of users and used bit rates in all cells, thus it is cell and service specific. Note also that in third generation networks the downlink can be loaded higher than the uplink or vice versa.

8.3.2 *Planning Tool*

In second generation systems, detailed planning concentrated strongly on coverage planning. In third generation systems, a more detailed interference planning and capacity analysis than simple coverage optimisation is needed. The tool should aid the planner to optimise the base station configurations, the antenna selections and antenna directions and even the site locations, in order to meet the quality of service and the capacity and service requirements at minimum cost. To achieve the optimum result the tool must have knowledge of the radio resource algorithms in order to perform operations and make decisions, like the real network. Uplink and downlink coverage probability is determined for an specific service by testing the service availability in each location of the plan. A detailed description of the planning tool can be found in [7].

The actual detailed planning phase does not differ very much from second generation planning. The sites and sectors are placed in the tool. The main difference is the importance of the traffic layer. The proposed detailed analysis methods (see the following sections) use discrete mobile stations in the WCDMA analysis. The mobile station density in different cells should be based on actual traffic information. The hotspots should be identified as an input for accurate analysis. One source of information concerning user density would be the data from the operator's second generation network or later from the third generation.

The planning tool described here differs from the dynamic simulator introduced in Section 10.6.2. The planning tool is a static simulator that is based on average conditions, and snapshots of the network can be taken. The dynamic simulator includes the traffic and the mobility models which make it possible to develop and test the real-time radio resource management (RRM) algorithms. The dynamic simulations can be used to study the performance of the RRM algorithms in realistic environments, and the results of those simulations can be used as an input to this network planning tool. For example, the practical performance of handover algorithms with measurement errors and delays can be tested in the dynamic tool and the results fed into the network planning tool. Testing of RRM algorithms requires accurate modelling of WCDMA link performance, and therefore a time resolution corresponding to power frequency of 1.5 kHz is used in the dynamic simulator. Such a high accuracy makes the dynamic simulation tool complex and the simulations still too slow – using current top-line high speed workstations – for practical network planning purposes. The accurate dynamic simulation tool can be used to verify and develop the more simple performance modelling in the network planning tool. When enough results from large-scale WCDMA networks are available, those results will be used in the calibration of the network planning tool.

8.3.2.1 Uplink and Downlink Iterations

The target in the uplink iteration is to allocate the simulated mobile stations' transmission powers so that the interference levels and the base station sensitivity values converge. The base station sensitivity level is corrected by the estimated uplink interference level (noise rise) and therefore is cell specific. The impact of the uplink loading on the sensitivity is taken into account with a term $-10 \cdot \log_{10}(1 - \eta_{UL})$, where η_{UL} is given by Equation (8.9). In the uplink iteration the transmission powers of the mobile stations are estimated based on the sensitivity level of the best server, the service, the speed and the link losses. Transmission powers are then compared to the maximum allowed transmission power of the mobile stations, and mobile stations exceeding this limit are put to outage. The interference can then be re-estimated and new loading values and sensitivities for each base station assigned. If the uplink load factor is higher than the set limit, the mobile stations are randomly moved from the highly loaded cell to another carrier (if the spectrum allows) or to outage.

The aim of the downlink iteration is to allocate correct base station transmission powers to each mobile station until the received signal at the mobile station meets the required E_b/N_0 target.

8.3.2.2 Modelling of Link Level Performance

In radio network dimensioning and planning it is necessary to make simplifying assumptions concerning the multipath propagation channel, transmitter and receiver. A traditional model is to use the average received E_b/N_0 ensuring the required quality of service as the basic number, which includes the effect of the power delay profile. In systems using fast power control the average received E_b/N_0 is not enough to characterise the influence of the radio channel on network performance. Also, the transmission power distribution must be taken into account when modelling link-level performance in network-level calculations. An appropriate approach is presented in [1] for the WCDMA uplink. It has been demonstrated that, due to the fast power control in the multipath fading environment, in addition to the average received E_b/N_0 requirement, an average transmission power rise is needed in interference calculations. The power rise is presented in detail in Section 9.2.1.2. Furthermore, a power control headroom must be included in the link budget estimation to allow power control to follow the fast fading at the cell edge.

Multiple links are taken into account in the simulator when estimating the soft handover gains in the average received and transmitted power and also in the required power control headroom. During the simulations the transmission powers are corrected by the voice activity factor, soft handover gain and average power rise for each mobile station.

8.3.3 Case Study

In this case study an area in Espoo, Finland, was planned, comprising roughly $12 \times 12 \text{ km}^2$. The network planning tool described in Section 8.3.2 was utilised. The operator's coverage probability requirement for the 8 kbps, 64 kbps and 384 kbps services was set, respectively, to 95%, 80% and 50%, or better. The planning phase started with radio link budget estimation and site location selections. In the next planning step the dominance areas for each cell were optimised. In this context the dominance is related only to the propagation conditions. Antenna tilting, bearing and site locations can be tuned to achieve clear

dominance areas for the cells. Dominance area optimisation is crucial for interference and soft handover area and soft handover probability control. The improved soft/softer handover and interference performance is automatically seen in the improved network capacity. The plan consists of 19 three-sectored macro sites, and the average site area is 7.6 km^2 . In the city area the uplink loading limitation was set to 75%, corresponding to a 6 dB noise rise. In case the loading was exceeded, the necessary number of mobile stations were randomly set to outage (or moved to another carrier) from the highly loaded cells. Figure 8.7 depicts the network scenario, and Table 8.10 shows the user distribution in the simulations.

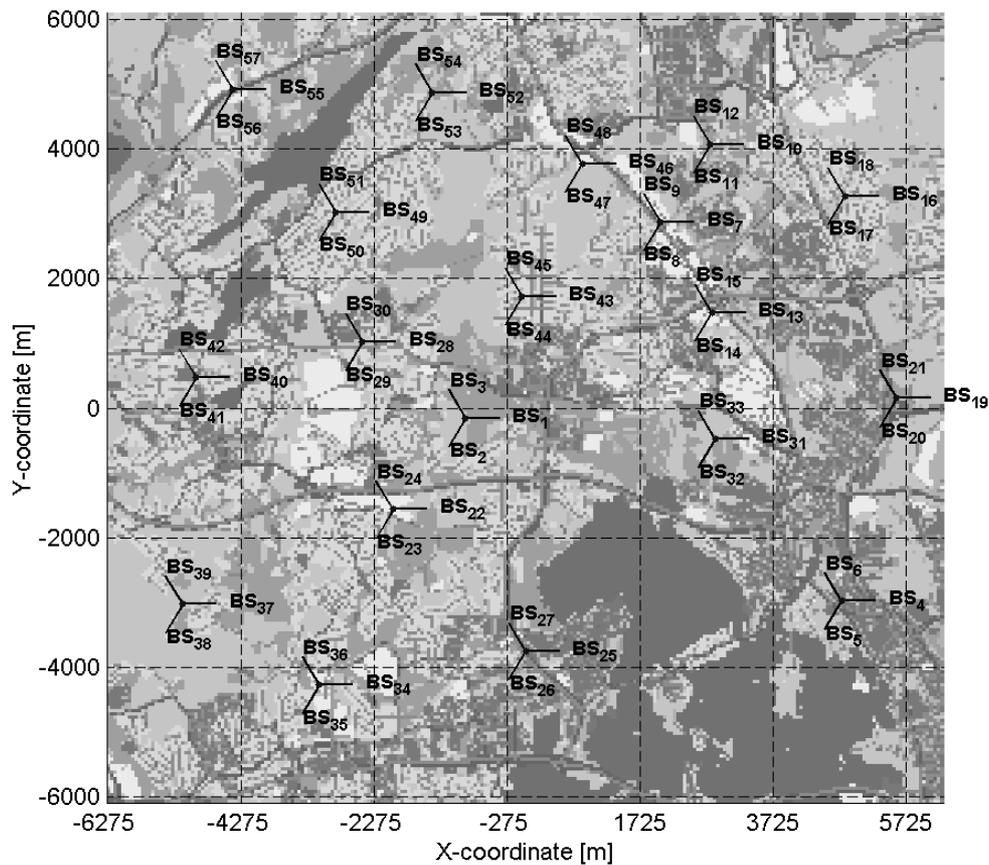


Figure 8.7. The network scenario. The area measures $12 \times 12 \text{ km}^2$ and is covered with 19 sites, each with three sectors

Table 8.10. The user distribution

Service in kbps	Users per service
8 kbps	1735

64 kbps	250
384 kbps	15

Three mobile speed cases were simulated: 3 km/h, 50 km/h and mixed case. In the mixed case half of the users were pedestrian (3 km/h) and the other half moved with a speed of 50 km/h. The other simulation parameters are listed in Table 8.11.

Table 8.11. Parameters used in the simulator

Uplink loading limit	75%
Base station maximum transmission power	20 W (43 dBm)
Mobile station maximum transmission power	300 mW (= 25 dBm)
Mobile station power control dynamic range	70 dB
Slow (log-normal) fading correlation between base stations	50%
Standard deviation for the slow fading	6 dB
Multipath channel profile	ITU Vehicular A
Mobile station speeds	3 km/h and 50 km/h
Mobile/base station noise figures	7 dB / 5 dB
Soft handover addition window	-6 dB
Pilot channel power	30 dBm
Combined power for other common channels	30 dBm
Downlink orthogonality	0.5
Activity factor speech/data	50% / 100%
Base station antennas	65° / 17 dBi
Mobile antennas speech/data	Omni / 1.5 dBi

In all three simulation cases the cell throughput in kbps and the coverage probability for each service were of interest. Furthermore, the soft handover probability and loading results were collected. Tables 8.12 and 8.13 show the simulation results for cell throughput and coverage probabilities. The maximum uplink loading was set to 75% according to Table 8.11. Note that in Table 8.12 in some cells the loading is lower than 75%, and correspondingly the throughput is also lower than the achievable maximum value. The reason is that there was not enough offered traffic in the area to fully load the cells. The loading in cell 5 was 75%. Cell 5 is located in the lower right corner in Figure 8.7, and there is no other cells close to cell 5. Therefore, that cell can collect more traffic than the other cells. The cells 2 and 3 are in the middle of the area and there is not enough traffic to fully load the cells.

Table 8.12. The cell throughput, loading and soft handover (SHO) overhead. UL = uplink, DL = downlink

Basic loading: mobile speed 3 km/h, served users: 1805				
Cell ID	Throughput UL (kbps)	Throughput DL (kbps)	UL loading	SHO overhead
cell 1	728.00	720.00	0.50	0.34
cell 2	208.70	216.00	0.26	0.50
cell 3	231.20	192.00	0.24	0.35
cell 4	721.60	760.00	0.43	0.17
cell 5	1508.80	1132.52	0.75	0.22
cell 6	762.67	800.00	0.53	0.30
MEAN (all cells)	519.20	508.85	0.37	0.39
Basic loading: mobile speed 50 km/h, served users: 1777				
Cell ID	Throughput UL (kbps)	Throughput DL (kbps)	UL loading	SHO overhead
cell 1	672.00	710.67	0.58	0.29
cell 2	208.70	216.00	0.33	0.50
cell 3	226.67	192.00	0.29	0.35
cell 4	721.60	760.00	0.50	0.12
cell 5	1101.60	629.14	0.74	0.29
cell 6	772.68	800.00	0.60	0.27
MEAN	531.04	506.62	0.45	0.39
Basic loading: mobile speed 50 km/h and 3 km/h, served users: 1802				
Cell ID	Throughput UL (kbps)	Throughput DL (kbps)	UL loading	SHO overhead
cell 1	728.00	720.00	0.51	0.34
cell 2	208.70	216.00	0.29	0.50
cell 3	240.00	200.00	0.25	0.33
cell 4	730.55	760.00	0.44	0.20
cell 5	1162.52	780.92	0.67	0.33
cell 6	772.68	800.00	0.55	0.32
MEAN	525.04	513.63	0.40	0.39

Table 8.13 shows that mobile station speed has an impact on both throughput and coverage probability. When mobile stations are moving at 50 km/h, fewer can be served, the throughput is lower and the resulting loading is higher than when mobile stations are moving at 3 km/h. If the throughput values are normalised to correspond to the same loading value, the difference between the 3 km/h and 50 km/h cases is more than 20%. The better capacity with the slower-moving mobile stations can be explained by the better E_b/N_0 performance. The fast power control is able to follow the fading signal and the required E_b/N_0 target is reduced. The lower target value reduces the overall interference level and more users can be served in the network.

Comparing coverage probability, the faster-moving mobile stations experience better quality than the slow-moving ones, because for the latter a headroom is needed in the mobile transmission power to be able to maintain the fast power control – see Section 8.2.1. The impact of the speed can be seen especially if the bit rates used are high, because for low

bit rates the coverage is better due to a larger processing gain. The coverage is tested in this planning tool by using a test mobile after the uplink iterations have converged. It is assumed that this test mobile does not affect the loading in the network.

Table 8.13. The coverage probability results

Basic loading: mobile speed 3 km/h	Test mobile speed:	
	3 km/h	50 km/h
8 kbps	96.6%	97.7%
64 kbps	84.6%	88.9%
384 kbps	66.9%	71.4%
Basic loading: mobile speed 50 km/h	Test mobile speed:	
	3 km/h	50 km/h
8 kbps	95.5%	97.1%
64 kbps	82.4%	87.2%
384 kbps	63.0%	67.2%
Basic loading: mobile 3 and 50 km/h	Test mobile speed:	
	3 km/h	50 km/h
8 kbps	96.0%	97.5%
64 kbps	83.9%	88.3%
384 kbps	65.7%	70.2%

The downlink coverage probability analysis is different from the uplink one. In the uplink direction the limiting factor is the mobile station maximum transmission power. In the downlink direction the limitations are dependent on the used radio resource management algorithms. One limitation in the downlink direction is the total base station transmission power. In addition to that, another limit can be taken into use: the power limit per radio link. Figure 8.9 shows an example downlink coverage analysis for the speech service. It can be seen that if the power per link limitation is selected correctly, the downlink coverage probability can be set to the same value as the uplink coverage probability. Thus, the uplink and the downlink service areas can be balanced. The required powers per link in Figure 8.9 are the average powers and do not include the fast fading margin.

This example case demonstrates the impact of the user profile, i.e. the service used and the mobile station speed, on network performance. It is shown that the lower mobile station speed provides better capacity: the number of mobile stations served and the cell throughput are higher in the 3 km/h case than in the 50 km/h case. Comparing coverage probability, the impact of the mobile station speed is different. The higher speed reduces the required fast fading margin and thus the coverage probability is improved when the mobile station speed is increased.

The presented network planning tool was shown to be useful for taking into account the dependency between capacity and coverage in WCDMA. Also, the coverage areas of different bit rates can be evaluated for the chosen base station sites, and parameters for RRM algorithms can be set.

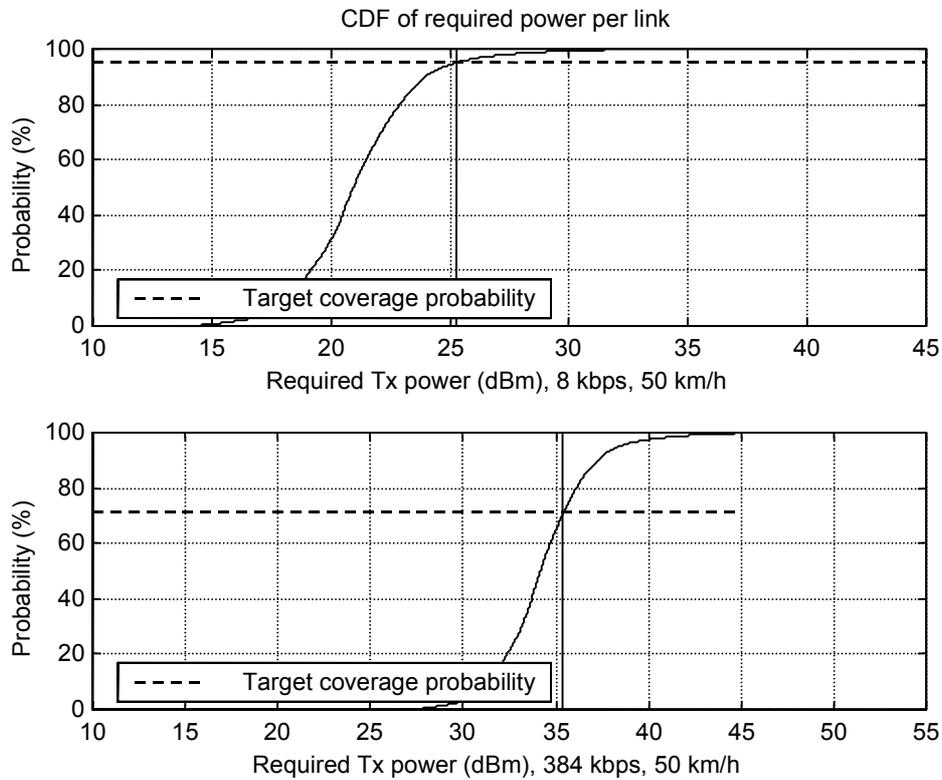


Figure 8.9. An example of the downlink coverage analysis. For the speech service (8 kbps, 50 km/h) the limit for the radio link was set to 25 dBm to achieve the 95% coverage probability. In the case of the 384 kbps and 71% coverage probability requirement the limit per radio link would be 35 dBm

8.3.4 Network Optimisation

Network optimisation is a process to improve overall network quality as experienced by the mobile subscribers and to ensure that network resources are used efficiently. Optimisation includes the analysis of the network and improvements in the network configuration and performance. The transition in Figure 8.1 from detailed capacity and coverage planning to network operation and optimisation is smooth. Statistics of the key performance indicators for the operational network are fed to the network status analysis tool, and the radio resource management parameters can be tuned for better performance. The radio resource management algorithms are described in Chapter 9. An example optimisation parameter is soft handover area optimisation. The network status analysis tool could be an integrated part of the radio network planning tool presented in Section 8.3.3. The traffic growth in the network requires continuous interaction of the planning tool and the operational network.

The capability of the current network to support the forecast traffic growth is analysed, and the radio network plan can be further processed based on actual measured data.

The first phase of the optimisation process is to define the key performance indicators. These consist of measurements in the network management system and of field measurement data, or any other information which can be used to determine the quality of service of the network. With the help of the network management system it is possible to analyse the past, present and predicted future performance of the network.

The performance of the radio resource management algorithms and their parameters can be analysed using the key performance indicator results. The radio resource management algorithms include handovers, power control, packet scheduling, admission and load control.

The network quality analysis is designed to give an operator a view of network quality and performance. The quality analysis and reporting consists of planning the case, field measurements and network management system measurements. After the quality of service criteria have been specified and the data has been analysed, a survey report can be generated. For second generation systems, quality of service has consisted, for example, of dropped call statistics, dropped call cause analysis, handover statistics and measurement of successful call attempts. For third generation systems with a greater variety of services, new definitions of quality of service for quality analysis must be generated.

Automatic optimisation will be important in third generation networks, since there are more services and bit rates than in second generation networks and manual optimisation would be too time consuming. Automatic adjustment should provide a fast response to the changing traffic conditions in the network. It should be noted that at the start of third generation deployment, only some of the parameters can be automatically tuned, and therefore a second generation type optimisation process must still be maintained.

8.4 GSM Co-planning

Utilisation of existing base station sites is important in speeding up WCDMA deployment and in sharing sites and transmission costs with the existing second generation system. The feasibility of sharing sites depends on the relative coverage of the existing network compared to WCDMA. In this section we compare the relative uplink coverage of existing GSM900 and GSM1800 full-rate speech services and WCDMA speech and 144 kbps and 384 kbps data services. Table 8.14 shows the assumptions made and the results of the comparison of coverage. The maximum path loss of the WCDMA 144 kbps here is 2 dB greater than in Table 8.3. The difference comes because of a smaller interference margin and no cable loss. Note also that the soft handover gain is included into the fast fading margin in Table 8.14 and the mobile station power class is here assumed to be 21 dBm.

Table 8.14 shows that the coverage of the 144 kbps data service is only 1.0 dB worse than the speech coverage of GSM1800. Therefore, a 144 kbps WCDMA data service can be provided when using GSM1800 sites, with the same coverage as GSM1800 speech. If GSM900 sites are used for WCDMA and 144 kbps full coverage is needed, an 11 dB coverage improvement is needed in WCDMA. This comparison assumes that GSM900 sites are planned as coverage-limited. In densely populated areas, however, GSM900 cells are typically smaller to provide enough capacity. Section 11.2 analyses the uplink coverage of

WCDMA and presents a number of solutions for improving WCDMA coverage to match GSM site density.

If high-power terminals with a transmission power of 24 dBm are used, the coverage will be 3 dB better than with 21 dBm output power.

Table 8.14. Typical maximum path losses with existing GSM and with WCDMA

	GSM900 / speech	GSM1800 / speech	WCDMA / speech	WCDMA / 144 kbps	WCDMA / 384 kbps
Mobile transmission power	33 dBm	30 dBm	21 dBm	21 dBm	24 dBm
Receiver sensitivity ¹	-110 dBm	-110 dBm	-123 dBm	-116 dBm	-112 dBm
Interference margin ²	1.0 dB	0.0 dB	2.0 dB	2.0 dB	2.0 dB
Fast fading margin ³	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB
Base station antenna gain ⁴	16.0 dBi	18.0 dBi	18.0 dBi	18.0 dBi	18.0 dBi
Body loss ⁵	3.0 dB	3.0 dB	3.0 dB	—	—
Mobile antenna gain ⁶	0.0 dBi	0.0 dBi	0.0 dBi	2.0 dBi	2.0 dBi
Relative gain from lower frequency compared to UMTS frequency ⁷	11.0 dB	1.0 dB	—	—	—
Maximum path loss	164.0 dB	154.0 dB	155.0 dB	153.0 dB	152.0 dB

¹WCDMA sensitivity assumes 5.0 dB base station noise figure and E_b/N_0 of 5.0 dB for 12.2 kbps speech, 1.5 dB for 144 kbps and 1.0 dB for 384 kbps data. GSM sensitivity is assumed to be -110 dBm with receive antenna diversity.

²The WCDMA interference margin corresponds to 37% loading of the pole capacity: see Figure 8.2. An interference margin of 1.0 dB is reserved for GSM900 because the small amount of spectrum in 900 MHz does not allow large reuse factors.

³The fast fading margin for WCDMA includes the macro diversity gain against fast fading.

⁴The antenna gain assumes three-sector configuration in both GSM and WCDMA.

⁵The body loss accounts for the loss when the terminal is close to the user's head.

⁶A 2.0 dBi antenna gain is assumed for the data terminal.

⁷The attenuation in 900 MHz is assumed to be 11.0 dB lower than in UMTS band and in GSM1800 band 1.0 dB lower than in UMTS band.

The downlink coverage of WCDMA is discussed in Section 11.2.3 and is shown to be better than the uplink coverage. Therefore, it is possible to provide full downlink coverage even for bit rates higher than 144 or 384 kbps using GSM1800 sites.

Any comparison of the coverage of WCDMA and GSM depends on the exact receiver sensitivity values and on system parameters such as handover and frequency hopping. That presented in Table 8.14 is an example calculation. Note also that the aim of this exercise is

to compare the coverage of the GSM base station systems that have been deployed up to the present with WCDMA coverage in the initial deployment phase during 2001–2002.

8.5 Multi-operator Interference

8.5.1 Introduction

In this section, the effect on WCDMA performance of adjacent channel interference between two operators on adjacent frequencies is studied. Adjacent channel interference needs to be considered, because it will affect all wideband systems where large guard bands are not possible, and WCDMA is no exception. If the adjacent frequencies are isolated in the frequency domain by large guard bands, spectrum is wasted due to the large system bandwidth. Tight spectrum mask requirements for a transmitter and high selectivity requirements for a receiver, in the mobile station and in the base station, would guarantee low adjacent channel interference. However, these requirements have a large impact, especially on the implementation of a small WCDMA mobile station.

In this section, the Adjacent Channel Interference power Ratio (ACIR) is defined as the ratio of the transmission power to the power measured after a receiver filter in the adjacent channel(s). Both the transmitted and the received power are measured with a filter that has a Root-Raised Cosine filter response with roll-off of 0.22 and a bandwidth equal to the chip rate [8]. The adjacent channel interference is caused by transmitter non-idealities and imperfect receiver filtering. In both uplink and downlink, the adjacent channel performance is limited by the performance of the mobile. In the uplink the main source of adjacent channel interference is the non-linear power amplifier in the mobile station, which introduces adjacent channel leakage power. In the downlink the limiting factor for adjacent channel interference is the receiver selectivity of the WCDMA terminal. The requirements for adjacent channel performance are shown in Table 8.15 and apply to both uplink and downlink.

Table 8.15. Requirements for adjacent channel performance [8]

Frequency separation	Required attenuation
Adjacent carrier (5 MHz separation)	33 dB
Second adjacent carrier (10 MHz separation)	43 dB

A difficult interference scenario where the adjacent channel interference could affect network performance is illustrated in Figure 8.10. This assumes that there are a large macro cell of operator 1 and small micro cells of operator 2. In Figure 8.10 operator 1's mobile is transmitting with high power to a distant macro cell, and at the same time is located very close to one of operator 2's micro cells. It needs to be further assumed that these macro and micro cells are on adjacent frequencies. Part of the transmission of the mobile is leaking to the adjacent carrier and possibly causing interference to the micro cell reception.

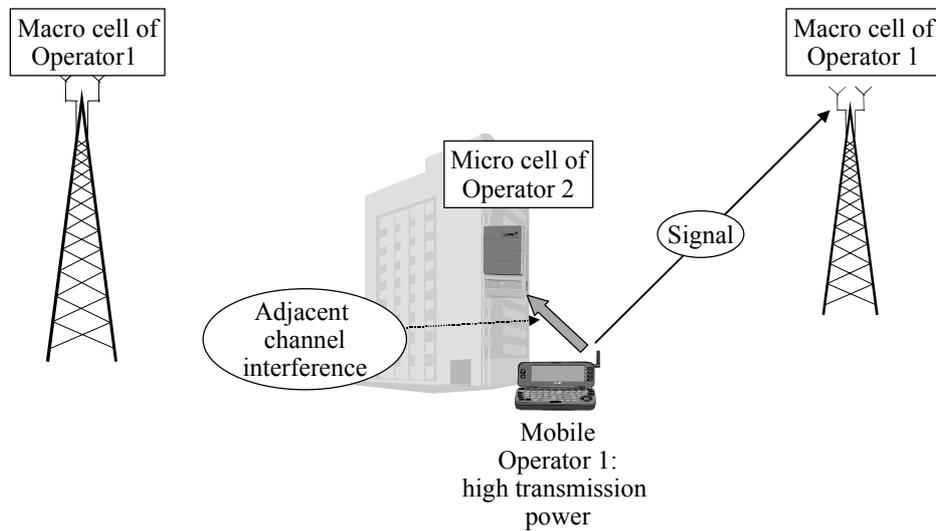


Figure 8.10. Adjacent channel interference in uplink from macro mobile to micro base station

In the following sections the effect of the adjacent channel interference in this interference scenario is analysed by worst-case calculations and system simulations. It will be shown that the worst-case calculations give very bad results but also that the worst-case scenario is extremely unlikely to happen in real networks. Therefore, simulations are also used to study this interference scenario. Finally, conclusions are drawn regarding adjacent channel interference and implications for network planning are discussed.

8.5.2 Worst-Case Uplink Calculations

In this section the worst-case adjacent channel interference scenario is presented. The worst-case adjacent channel interference occurs when a mobile is transmitting on full power very close to a base station that is receiving on the adjacent carrier. A minimum coupling loss of 50 dB is assumed here. The minimum coupling loss is defined as the minimum path loss between mobile and base station antenna connectors. The other assumptions in these worst-case calculations are shown in Table 8.16 and the results in Table 8.17.

Table 8.16. Assumptions in uplink worst-case calculations of adjacent channel interference

Parameter	Value
Minimum coupling loss between mobile and micro cell in Figure 8.10	50 dB
Mobile transmission power	Maximum power 21 dBm
Micro base station noise figure	5 dB

Table 8.17. Results of uplink worst-case calculations

Parameter	Value
Thermal noise level with 3.84 Mcps	-108.2 dBm
Thermal noise level in the micro cell base station receiver	-108.2 dBm + 5 dB = -103.2 dBm
Interference from the adjacent channel	21 dBm - 50 dB - 33 dB (ACIR) = -62 dBm
Noise rise due to adjacent channel interference	-62 dBm - (-103.2 dBm) = 41.2 dB

The adjacent channel interference in the micro cell base station receiver is -62 dBm, which is 41 dB above the thermal noise level in the receiver. Such a high increase in the interference level would clearly affect the uplink coverage area of the micro cell. It is, however, extremely unlikely that this worst-case scenario would happen. It requires that the following conditions are fulfilled at the same time:

- Operator 1's mobile is transmitting with its full power of 21 dBm.
- Operator 1's mobile is located very close to operator 2's micro base station antenna. The minimum coupling loss of 50 dB occurs only if the base station antenna is very low and the mobile can get close to the antenna.
- Operator 1's mobile is transmitting on the adjacent carrier. If there is one carrier between the transmission and the reception, the adjacent channel interference power is attenuated by 10 dB than on the adjacent carrier according to Table 8.16.
- The noise figure of the micro cell base station, including cable losses, is only 5 dB. If the sensitivity is not so good, the base station is less sensitive also to the adjacent channel interference.

Even if there is increased interference in the base station receiver, this does not necessarily lead to any dropped calls in the micro cell. It does lead, however, to a reduced coverage area, though this may not be a problem if the micro cell is not coverage limited.

Since the worst-case scenario discussed above is very unlikely, a simulation approach is used in Section 8.5.4 to study the practical effect of the adjacent channel interference on the WCDMA radio network performance.

8.5.3 Downlink Blocking

We need to note that operator 1's mobile is receiving adjacent channel interference in the downlink from operator 2's micro base station, and its connection will be dropped before that user is able to get extremely close to operator 2's base station. This happens because the selectivity of the mobile receiver is not perfect and the mobile is receiving interference from the micro cell base station on the adjacent carrier. The dropping of the downlink connection can even be considered desirable. It is preferable to drop one connection in downlink than to allow that mobile to interfere with all uplink connections of one cell. The dropping of the downlink connection depends on the maximum power that can be allocated to one connection from the macro cell base station to compensate the increased interference in the mobile reception.

If a mobile experiences adjacent channel interference in the downlink from a nearby base station, it can escape the interference by making an inter-frequency handover to the operator's other WCDMA carrier. Inter-frequency handovers can be used to avoid adjacent channel interference problems in the downlink.

This downlink blocking does not happen where there is interference between UTRA FDD and TDD systems, and therefore more difficult uplink interference situations can occur between FDD and TDD than within the FDD band. Interference between FDD and TDD systems is analysed in Section 12.3.4.

8.5.4 Uplink Simulations

The effect of adjacent channel interference from a macro cell mobile to the micro cell base station is studied in this section with a system simulator, which was presented in [9]. The worst-case calculation for that interference scenario was presented in Section 8.5.2, though that scenario is very unlikely to happen. In the simulation approach the effect of the adjacent channel interference can be analysed with a more realistic approach. The system simulator included macro cells and micro cells and all the mobiles connected to the cells. The minimum coupling loss in these simulations was 53 dB, which is a very low value and occurs only if the mobile can get very close to the base station antenna.

Table 8.18. Important simulation parameters for adjacent channel interference simulations. For other parameters see [10]

Parameter	Value
Minimum coupling loss	53 dB
Macro-to-macro base station distance	1000 m
Micro-to-micro base station distance	180 m
Mobile maximum power	21 dBm
Maximum allowed noise rise in micro cell	20 dB
Maximum allowed noise rise in macro cell	6 dB

The WCDMA nominal channel spacing is 5 MHz with a 3.84 Mcps chip rate. In these simulations the old chip rate of 4.096 Mcps has been used. The chip rate of 3.84 Mcps improves the adjacent channel performance by 0.5–0.7 dB compared to the results shown in this section [11]. In the uplink, all channels are assumed to be traffic channels of 8 kbps speech and no load due to control channels is calculated. In the downlink, the common control channels are modelled and contribute to the base station transmission power. The orthogonality factor was 0.4.

In these simulations the maximum allowed noise rise in the uplink was 20 dB in micro cells and 6 dB in macro cells. The noise rise is the increase in the wideband interference level over the thermal noise in the base station reception. For large macro cells a smaller noise rise is allowed because a higher noise rise decreases the coverage area. In the simulations this maximum loading was iteratively selected so that the predefined maximum noise rise values were not exceeded even if there was interference from the adjacent channel. This approach corresponds to the case where the real-time radio resource management algorithms, such as admission control, load control and packet scheduler, keep the uplink loading within the planned limits, and the coverage area is not affected by the adjacent channel interference. The effect of the adjacent channel interference can be seen as a reduced uplink capacity.

8.5.5 *Simulation Results*

In these simulations the coverage area of the micro and macro cells was kept within the planned limits even if there was adjacent channel interference, and the reduction in the maximum capacity was observed. The capacity loss is shown in Figure 8.11. The capacity is not sensitive to the adjacent channel interference if the attenuation between adjacent carriers (the ACIR) is higher than 20 dB. The minimum requirement for the ACIR is 33 dB: see Table 8.15. With a value of 33 dB the capacity loss in the micro cells is clearly below 1% and in the macro cell below 2%. Macro cell capacity is more sensitive to adjacent channel interference than micro cell capacity. The simulations show that micro cell capacity remains good while macro cell performance suffers more from adjacent channel interference. This is due to the fact that the number of interfering macro cell users is so small that the adjacent channel interference generated by them is negligible. On the other hand, the number of micro cell users is very high, thus they generate high adjacent channel interference to the macro cell base stations.

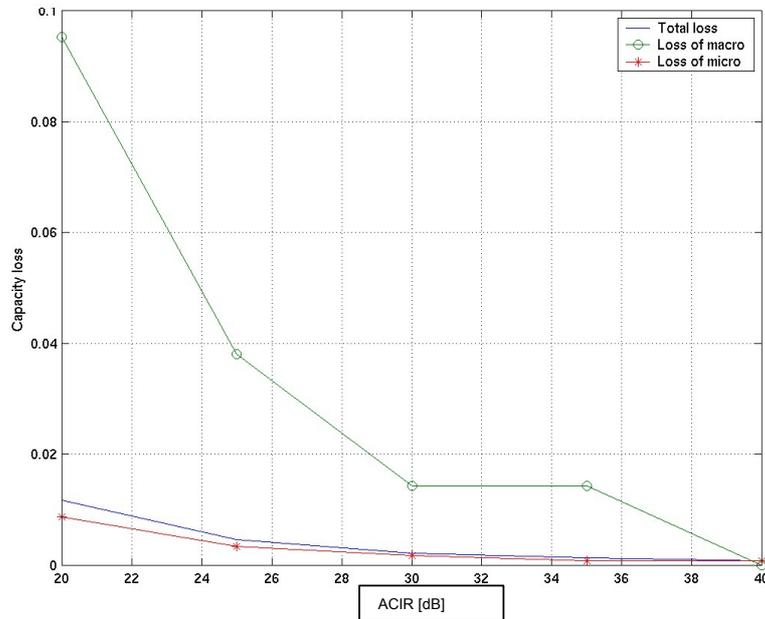


Figure 8.11. Uplink capacity loss due to adjacent channel interference for micro–macro scenario

8.5.6 Network Planning with Adjacent Channel Interference

This section presents a few network planning solutions that make sure that adjacent channel interference does not affect WCDMA network performance.

The selection of the base station antenna location and the antenna patterns affects the minimum coupling loss from the mobile to the base station. If that coupling loss is large, the adjacent channel interference can be avoided. In practice, the antenna should not be located so low that the mobile can easily get very close to the antenna.

It is possible also to reduce the sensitivity of the base station receiver, i.e., increase the noise figure of the base station RF parts. This approach is called desensitisation and can be used to make the base station receiver less sensitive to adjacent channel interference. At the same time the base station receiver also becomes less sensitive to the desired signal and the cell range is reduced. Therefore, this approach is suitable for small cells where coverage is not the problem.

If the operators using adjacent frequency bands co-locate their base stations, either in the same sites or using the same masts, adjacent channel interference problems can be avoided, since the received power levels from the mobiles at both operators' base stations are then very similar. Since there are no large power differences, the adjacent channel attenuation of 33 dB is enough to prevent any adjacent channel interference problems. Also in the downlink the power levels received from both base stations are equal in both operators'

mobiles. Note that co-location solves adjacent channel interference problems in UTRA FDD mode, but with UTRA TDD co-location can cause difficult interference situations. TDD interference scenarios are analysed in Chapter 12.

The nominal WCDMA carrier spacing is 5.0 MHz but can be adjusted with a 200 kHz raster according to the requirements of the adjacent channel interference. By using a larger carrier spacing, the adjacent channel interference can be reduced. If the operator has two carriers in the same base station, the carrier spacing between them could be as small as 4.0 MHz, because the adjacent channel interference problems are completely avoided if the two carriers use the same base station antennas. In that case a larger carrier spacing can be reserved between operators, as shown in Figure 8.12.

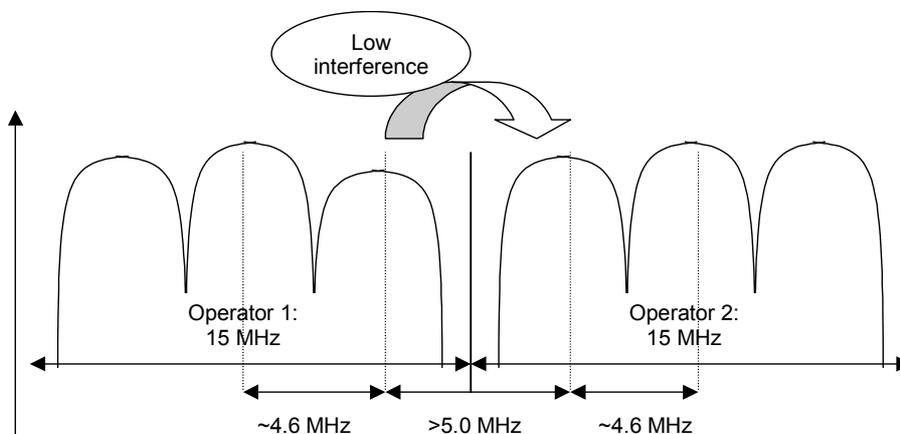


Figure 8.12. Selection of carrier spacings within operator's band and between operators

The network planning solutions to avoid adjacent channel interference are summarised below:

- selection of base station antenna locations
- desensitisation of the base station receiver
- co-location of the base stations with other operators
- adjustment of the carrier spacings
- inter-frequency handovers.

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