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3rd generation access network considerations

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Author(s)

Josef Noll, Frank Aanvik, Knut Baltzersen, Geir Olav Lauritzen, Joar Løvsletten, Axel Meiling, Frédéric Paint, Kalle Passoja, Bjørn Harald Pedersen, Magne Pettersen and Stein Svaet

Subject headings

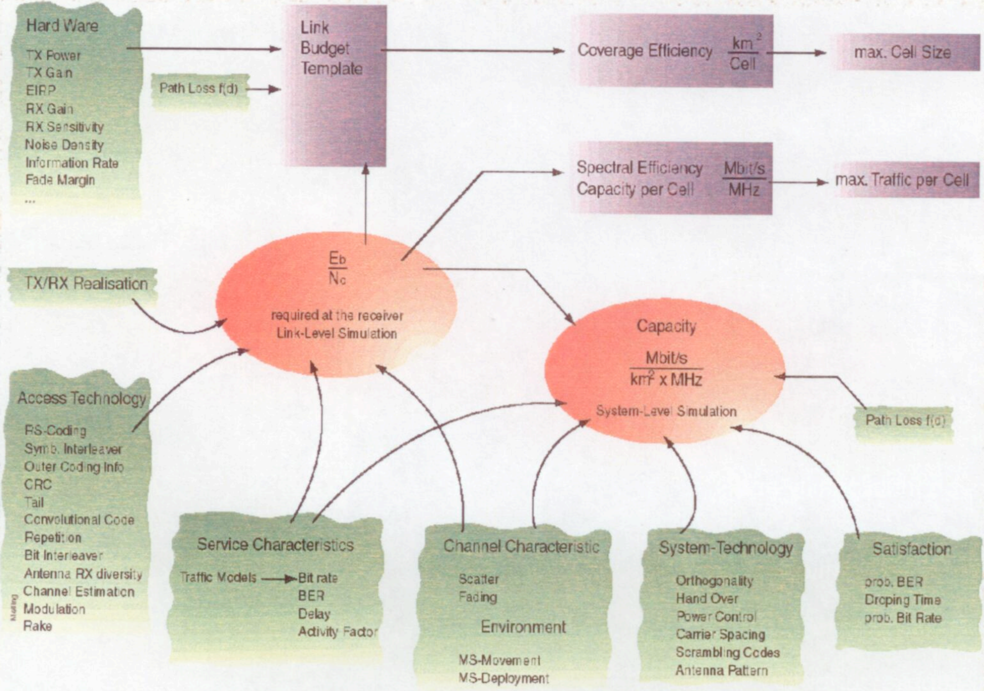
UMTS, Access Network, Planning.

Abstract

This report presents access network issues for third generation systems (3G). UMTS is the 3G system defined by ETSI, and the UMTS terrestrial radio access scheme, UTRA, is a proposal to ITUs IMT 2000 family of air interfaces. The radio access is based on CDMA, while the access network, in the first phase, will be a GSM/GPRS network. UMTS defines service capabilities but not the services. Examples of service capabilities are 144 kbit/s up to 500 km/h and 2 Mbit/s up to 10 km/h. The report analyses the functionality of systems under evolution like GSM and DECT compared to UMTS, reviews the technologies, and performs a capacity and market analysis.

Title (Norwegian)

Vurderinger av tredje generasjon aksessnett


Hard Ware
TX Power
TX Gain
EIRP
RX Gain
RX Sensitivity
Noise Density
Information Rate
Fade Margin
...
Path Loss f(d)
Link Budget Template
Coverage Efficiency km²/Cell
max. Cell Size
Spectral Efficiency Capacity per Cell Mbit/s / MHz
max. Traffic per Cell
TX/RX Realisation
Eb/Nc
required at the receiver
Link-Level Simulation
Capacity
Mbit/s / km² x MHz
System-Level Simulation
Path Loss f(d)
Access Technology
RS-Coding
Symb. Interleaver
Outer Coding Info
CRC
Tail
Convolutional Code
Repetition
Bit Interleaver
Antenna RX diversity
Channel Estimation
Modulation
Rake
Service Characteristics
Traffic Models
Bit rate
BER
Delay
Activity Factor
Channel Characteristic
Scatter
Fading
Environment
MS-Movement
MS-Deployment
System-Technology
Orthogonality
Hand Over
Power Control
Carrier Spacing
Scrambling Codes
Antenna Pattern
Satisfaction
prob. BER
Droping Time
prob. Bit Rate

FDD-Results

			Pedestrian		Vehicular	
			UL	DL	UL	DL
Speech						
	Bit-Rate	kBit/s	8	8	8	8
	maximum Range	m	1020	910	5900	7350
	Spectrum efficiency	(kBit/s)/MHz/cell	123	125	90	71
	Simultaneous Users	Erlang	154	157	112	89
	Eb/No	dB	3,3	6,1	5,4	7,9
LCD-MM						
	Bit-Rate	kBit/s	384	384	384	384
	maximum Range	m	450	520	2800	3900
	Spectrum efficiency	(kBit/s)/MHz/cell	269	461	192	177
	Simultaneous Users	Erlang	3,5	6	2,5	2,3
	Eb/No	dB	1,3	1,1	2,9	3,2
UDD-HM						
	Bit-Rate	kBit/s	384	384	384	384
	maximum Range	m	500	520	2600	3900
	Spectrum efficiency	(kBit/s)/MHz/cell	449	668	216	
	Simultaneous Users	Erlang	91	135	42	
	Eb/No	dB	0,4	0,1	2,4	2,0

7 Work Results[10]

Here are briefly described a few terms, variables and equations that affect the capacity of the CDMA access network. Then the capacity/cell is calculated based on those presented equations and the results are compared to the ETSI simulation results. The differences are later discussed. Finally, two traffic scenarios for Oslo are implemented and we have tried to estimate the number of needed sites and cells.

7.1 Capacity terminology

There are a lot of expressions, units and names, which are connected to the capacity. Many examples from literatures give a new definition, so that there is no consent about the capacity concept. This chapter shows therefore one way to express the capacity concept. These are the main terms, units and expressions:

- The value of bit energy per noise power spectral density is [Skl 98]

  $$\frac{E_b}{N_0}$$

  E_b refers to the energy of one bit in the user's source bit rate. N_0 is the sum of thermal noise spectral density and the interfering power of all the other users at the same carrier frequency. E_b/N_o presents mostly the values that are needed in the receiver to achieve the corresponding quality of service (QoS). The main use is in the link budget template.
- The link budget template comprises all variables of the physical radio link, for example: transmitter power, cable and connector losses, antenna gains, noise figures, bit rates and path losses.
- Coverage efficiency

  $$\left[\frac{km^2}{cell}\right]$$

  is the size of the area covered by one cell [ETSItr 98].

  This term assumes a noise limited system. That means low traffic load in the home and

[10] Meiling Axel, Passoja Kalle et al; 3rd generation access network considerations; Telenor R&D Report, Kjeller 1998

adjacent cells with the result of a low interference level. Estimations can be made using the link budget template.

- **Spectral efficiency** or **capacity per cell** is the total number of user-channel information per MHz and cell. Mbit/s refers to the bit rate that is offered to the user, not to the physical channel rate in the air link. The unit of the spectral efficiency is [Clapt 98]

  $$\left[\frac{Mbit/s}{MHz}\right].$$

- **Capacity** is the connection between the coverage and spectral efficiency. For this term the neighbourhood with its interference has to be taken into account. This term assumes therefore that it is an interference limited system.

  It must be noted that interference in CDMA systems is noise-like and raises the spectral noise density. The reasons are the pseudo-random codes, which are used for the spreading sequences. The unit of capacity is $\left[\frac{Mbit/s}{km^2 \times MHz}\right]$. It has to be noted that Prasad [Pras 98] call this unit spectral efficiency.

- For speech services **Erlang** is usually used instead of Mbits/s.

  Erlang is a unit for traffic intensity. It is defined as [Vil 95]:

  $$A(t) = \frac{1}{T}\int_0^T N(t)dt \quad [Erlang]$$

  with T for the observed time interval and N for the number of used channels. Therefore Erlang shows the average number of simultaneous users. The link between Erlang and offered Mbit/s is as follows:

  $$Erlang = \frac{offered\ bitrate}{speech\ or\ user\ bitrate}$$

7.2 Variables influencing capacity in CDMA

In this chapter we discuss in more detail the factors affecting the capacity and which will later be the basis for capacity calculations. Time variances are ignored in equations, it is assumed that mean values are enough to describe a situation.

CDMA systems are interference limited so if there are more users there will be more interference in a channel which degrades the wanted signal quality. Simplified equation (1) [Gilh 91] gives the ratio of bit energy to interference level, let us call it as E/N ratio.

$$\frac{E_b}{N_0} = \frac{W/R}{\sum_{i=1}^{N_S-1} \chi_i + (I_n/S) + (\eta/S)} \qquad (1)$$

Where:

E_b/N_0 = bit energy/total noise and interference energy needed for certain BER value

W = spread spectrum BW

R = user bit rate

α = (voice) activity factor

χ_i = random variable , which is 1 with probability of α and 0 with probability of 1- α.

N_S = users per sector

I_n = interference density from nearby cells

η = background noise

S = power density of desired signal

W/R = G_p= processing gain

For different E/N ratio the corresponding BER can be determined. This calculation takes various aspects into account, such as modulation technique, coding, diversity etc. Thus, for a given target E/N ratio, we can deduce the maximum number of users if we know the value of the other variables. Here it is assumed that other mobiles are transmitting with the same power level. The total BW means here the BW of one carrier which for UTRA is 5 MHz. The user bit rate means the gross information rate so the bits for error correction, controlling, etc., are also included.

Activity monitoring is an essential part of the CDMA. The activity factor is the amount of call time for which the mobile is active and is transmitting data. Voice activity monitoring is a key factor to improve capacity because it can diminish the level of interference in the cell. During the speech call you are probably not talking all the time and so there is no need to send data forward. Thus, if your mobile is not transmitting when you are not talking the noise level in the cell decreases and there can be more users. In literature, the activity factor for speech varies from 0.4 to 0.6 [Gilh 91][Bra 90].

Interference from other cells also affects the total noise level and thus decreases the number of users. It can be assumed to be on the same level as in the cell under research but it is attenuated because of propagation losses between own and interfering cell. The system capacity is however very sensitive to propagation loss and cell size parameters [Gan 94].

Normally quite high values are used for the path loss coefficient γ in urban environment, for example –3 or –4 meaning that the attenuation is r^{-3} and r^{-4}. The propagation models used in ETSI capacity calculations [ETSIutra 98] for UMTS are for "worst case" propagation losses. Hence they are not necessary the most suitable for this examination because, with those models, the interference from other cells may be too small. However, some articles suggest to use a more piecewise linear model in the micro cell environment in order to calculate the interference from adjacent channels [Gan 94, Rap 90, Mil 92, Harl 89]. So this is quite a controversial issue. Later, in the modelling phase, we have used loss characteristics that are closer to those suggested by ETSI than those suggested in the articles:

$\gamma = 2$ if $1 < r < 200$ m
$\gamma = 3$ if $200\text{m} < r < 2000\text{m}$
$\gamma = 4$ if $r > 2000$ m
where r is the distance between base station and mobile.
$\gamma = 2$ as "mean" loss is quite optimistic because then the loss is the same as in free space. This distance dependent attenuation model results in lower external interference levels than for fixed γ model in larger cell sizes. This is because, in the cell of interest, users are maybe using less power since the attenuation is smaller and the corresponding interference from other cells is more attenuated and so the signal/interference ratio is relatively larger than for a fixed propagation model. In the end, this means that by splitting, for example, a micro-cell into four pico-cells, the capacity increase factor is less than 4.

Equation (1) is still a very simplified formula, which can only roughly estimate the available capacity of the system. In a normal system, there are users with different kinds of demands in terms of bit rates and E/N, which also affects the whole system capacity. In equation (2) [Mach 96], variable data rates with variable bit error needs are taken into account.

$$N_1 \leq \frac{1}{1+\lambda}\left(1+\frac{nG_{p1}}{\alpha_1}\left[\frac{1}{(E_b/N_0)}-\frac{1}{(E_b/N_1)_1}\right]\right)-\frac{\alpha_2 G_{p1} S_2 N_2}{\alpha_1 G_{p2} S_1} \qquad (2)$$

where N_1 = number of users of service type 1

N_2 = number of users of service type 2

λ = interference increase factor (due to adjacent cells)

n = number of sectors

N_t = energy of thermal noise, spurious signals etc

S_1, S_2 = height of the de-spread signal power density for service type 1. and 2.

G_{p1}, G_{p2} = processing gains of service type 1 and 2.

In principle this equation is the same as equation (1). This will be used later in capacity calculations. Some essential factors are still missing. The interference from the other cells needs to be calculated, because it clearly decreases the interference level.

A very important factor is the effective power control [Gilh 91]. If there is not an accurate power control, then some mobiles accessing the same cell can cause too much interference and the signal of the other mobiles in the cell is missed. Hence, only one poorly working mobile may have a strong influence on the capacity of the cell. We assume that channels are orthogonal. There are, however, non-orthogonal channels, then the interference from the other users is increased thus decreasing the performance. The background noise also increases the total noise level and decreases the number of users. This noise is due to thermal noise as well as spurious interference and non-linear transmitters, etc.

7.3 Interference from adjacent cells

On the downlink, the mobile monitors the power transmitted from the BS and it will get power from all the directions with its omnidirectional antenna. So if there is power from more than one BS' then E/N is decreased and so is the capacity. In practice, a mobile can be situated in the border of three different cell areas and thus the mobile can receive power from three different BS with almost equal power-level. This is the worst case, but this situation can be improved with macrodiversity.

The up-link power comes from both the users in the own cell (home cell) and users in other cells. The more users there are, the higher the wanted signal has to be above the thermal noise floor. This correspondingly also affects the neighbouring cells because they are getting more power and so they are more interfered. In [Gilh 91], the up-link and the down-link situations are compared. It showed that the up-link is slightly worse if other variables are the same. The difference is about 5 %. However with antenna diversity the situation can be the other way especially if there is no antenna diversity used in mobiles. Still, the up-link is considered as a limiting direction ("generally accepted that the limiting link is in the reverse direction") [Vit 94,Gilh 91] and also because of the lack of time, we have focused on the up-link direction. On the other hand, orthogonal code channels may limit the downlink and as a result it is not always obvious which is the limiting direction.

The neighbouring cells are assumed to be full meaning that the maximum number of users, in those cells, is reached. In practice, those users are of course more or less spread over the cell area but here we have assumed that the interference power of the adjacent cells is coming from the centre of the adjacent cells. We have taken into account the first, second and third tiers around the own cell. Hence for hexagonal cells, there are six cells in the first tier, twelve in the second and eighteen in the third tier. The interference power from the adjacent cells was noted I/S (equation (1)). One interfering user produces the following interference power in the researched cell [Gilh 91]:

$$\frac{I(r_0, r_m)}{S} = \left(\frac{10^{(\xi_0/10)}}{r_0^{\gamma_0}}\right)\left(\frac{r_m^{\gamma_m}}{10^{(\xi_m/10)}}\right) \qquad (3)$$

There:

r_0 = interfering mobile's distance to desired users cell

r_m = interfering mobile's distance to its own cell site

$\xi_{0,m}$ = Gaussian random variables with zero mean

$\gamma_{0,m}$ = path loss coefficients

We are, here, interested in mean values so in equation (3) we take into account only the mean value of the random variables and this means that the equation can be simplified to be

$$\frac{I(r_0, r_m)}{S} = \left(\frac{r_m^{\gamma_m}}{r_0^{\gamma_0}}\right) \qquad (4)$$

There are only distance variables in this equation and it can be seen that the interference variations are directly related to the attenuation from the interfering mobile to its own site. S was the power of desired signal but, because we assume that cells are of the same kind, the power in the interfering mobile's cell site is equal to S and thus it is minimised. Also, propagation conditions are supposed to be the same in interfering cells as in the research cell. This would mean that γ_m is equal to γ_0 and the formula comes into the form

$$\frac{I(r_0, r_m)}{S} = \left(\frac{r_m}{r_0}\right)^{\gamma_m} \qquad (5)$$

This formula is only for one user but in practice there are rarely only one active mobile cell and so it is not necessarily applicable alone. In the following phase this can be used as a basis.

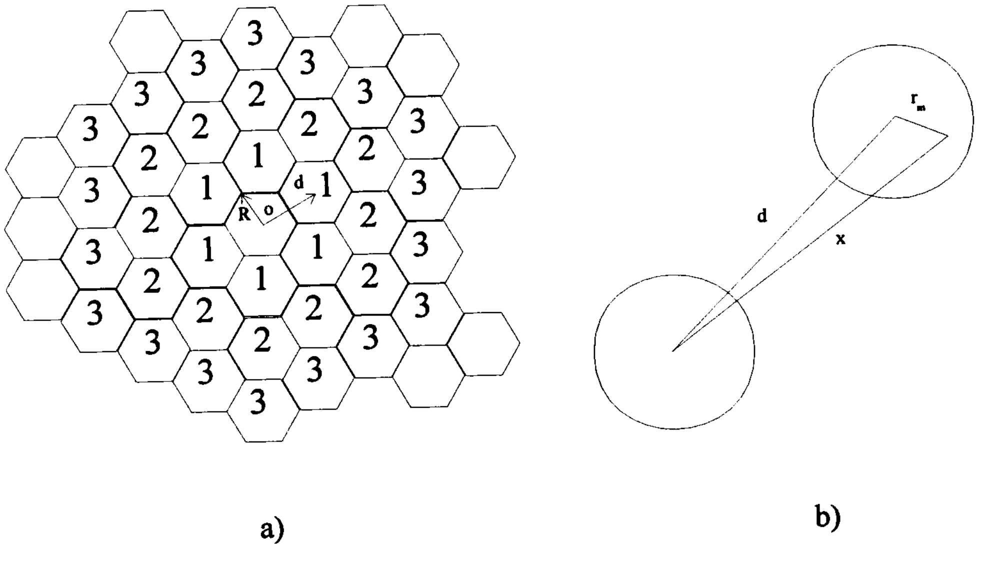


Figure 8: a) Here is the research cell and around of it is described three tiers of cells, b) two cell areas and critical distances between sites and the interfering mobile.

In [Kyo 93] a method for calculating the interference power to a BS from another cell is presented. It is assumed that mobiles are uniformly distributed in a circular cell of radius R. The number of the mobiles in the cell is N and so the density of mobiles is

$$p = \frac{N}{\pi R^2} \qquad (6)$$

Then the total mobile power from a cell with uniform mobile distribution to a base station at distance d (distance between sites) is

$$I(d) = \int \alpha S\left(\frac{r_m}{x}\right)^{\gamma} p dA \qquad (7)$$

Where

$$x = \sqrt{d^2 + r_m^2 + 2dr\cos\theta} \qquad (8)$$

In equation (8) r_m is the distance between an interfering mobile and its own cell site (BS) (Figure 8), and x is equal to r_0 (from equation (3)). Hence equation (8) becomes

$$I(d) = 2\int_0^{\pi}\int_0^{R} \alpha S\left(\frac{r}{x}\right)^{\gamma} \frac{N}{\pi R^2} r dr d\theta = \frac{2\alpha NS}{\pi R^2}\int_0^{\pi}\int_0^{R}\left(\frac{r}{x}\right)^{\gamma} r dr d\theta \qquad (9)$$

This is the power from one cell and thus the power from the corresponding ring is obtained by multiplying with the number of cells in the ring (Figure 8). The Interference increase factor, which describes the relationship between the interference power generated in the other cells and the interference power created by the central cell is

$$\lambda = \frac{I_{tot}}{NS} = \frac{6 * I(d_1) + 12 * I(d_2) + \ldots + n * 6 * I(d_n)}{NS} \qquad (10)$$

Where d_i represents the distance between the BS and ring i.

The interference increase factor (equation (10)) will be used later with equation (2).

The previous equations were for circular shaped cells and the corresponding results are not far from reality. When considering hexagonal cells, the distance between two tiers is not 2R.

Instead the distance between the BS and the first ring, for instance, is

$$d_1 = \sqrt{3}R \qquad (11)$$

The distance to the second ring is supposed to be

$$d_2 = 2\sqrt{3}R \qquad (12)$$

If studied more carefully it can be seen that every ring consists of two groups of cells for which the distance to the BS (in the research cell) is not the same. However, the difference is small and is ignored hereafter.

The integral equation for the interference power has been solved numerically with Matlab and the interference increase factors are presented in Table 1. One can easily see that the differences between propagation losses can have a very significant effect on the capacity of the adjacent cells. If more rings had been considered there would have been even bigger differences, in terms of capacity, between case $\gamma = 2$ and case $\gamma = 5$.

	Interference increase factor						
Number of tiers	$\gamma = 2$	$\gamma = 2.5$	$\gamma = 3$	$\gamma = 3.5$	$\gamma = 4$	$\gamma = 4.5$	$\gamma = 5$
1	1.30	1.03	0.87	0.77	0.70	0.66	0.64
2	1.83	1.29	1.00	0.84	0.74	0.68	0.65
3	2.17	1.43	1.05	0.86	0.75	0.68	0.65

Table 1: Values for interference increase factor as a function of propagation coefficient γ and the number of rings taken into account.

When there are many users, as during the "busy hour", the level of the thermal noise in a channel may be much smaller than the level of the interference power from the other mobiles, and so the E_b/N_t in equation (2.) can be ignored. Thus equation (2.) comes to

$$N_1 \leq \frac{1}{1+\lambda}\left(1+\frac{nG_{p1}}{\alpha_1}\left(\frac{1}{E_b/N_0}\right)\right)-(1+\lambda)\frac{\alpha_2 G_{p1} S_2 N_2}{\alpha_1 G_{p2} S_1} \qquad (13)$$

It must be noted that the effect of the interference from adjacent cells I to the capacity of the research cell can be lowered if the BS has directional antenna (i.e. sectorized cell). Then it "filters out" the interference from the mobiles which are situated outside of the sector of the BS and so, theoretically, the interference can be decreased by 1/n, where n is the number of sectors. It can also be seen, from the previous equation, that λ is not dependent on n but the capacity is almost directly dependent on n. The same effect can be got also by using a directional antenna in the mobile, a frequency reuse increase with highly directional antenna (beamwidth = 30°) may be about 1.3 higher than with an ordinary omnidirectional antenna [Aksu 94].

Consequences due to sectorization are not so straightforward because radiation patterns of antennas are more or less imperfect and there is no sharp separation between sectors. So, in practice, the antenna of the one sector still gets power and interference from the mobiles in other sectors. This effect can be taken into account [Pras 98] when comparing the total interference power received in a sectorized system and the total interference received in a nonsectorized system:

$$n_c = \frac{P_{sectorized}}{P_{non\,sectorized}} = \left(\frac{1}{n}+\frac{2v}{360}\right) \qquad (14)$$

Where:

n_c = "corrected" number of sectors

v = overlap angle of the antenna

This antenna correction will later be used in capacity calculations.

7.4 Power control inaccuracy

Power control is the single most important system requirement for CDMA, since only by control of power of each user accessing a cell can resources be shared equitably among users and capacity maximised. Mobiles receive a pilot signal from the base station and according to the level of the signal, they adjust their own transmitting level so that it is just enough to meet the required BER and not more. In that way, the total interference level in the cell can be kept as low as possible. There is however difficulties in practice because of fast variations in power level. Rayleigh fading may be too rapid to be tracked by power control but variations in relative path losses and shadowing losses may be slow enough to be controlled [Gilh 91]. The effect on the system capacity depends on the effectiveness of the power control. About 20-60 % of capacity reduction can be found in the literature [Gilh 91,Pras 98].

We have used the method suggested in [Vit 93] for which the non-blocking condition is:

$$\sum_{i=1}^{N_S} \alpha_i E_{bi} R + \sum_{j}^{othercells} \sum_{i=1}^{N_S} \alpha_{ij} E_{bij} R + \eta W \leq I_0 W \qquad (15)$$

I_0 = maximum total acceptable interference density

Dividing by $I_0 R$ and defining

$$\varepsilon = E_b / I_0 \qquad (16)$$

equation 15 becomes (by taking new variable Z)

$$Z = \sum_{i=1}^{N_S} \alpha_i \varepsilon_i + \sum_{j}^{othercells} \sum_{i=1}^{N_S} \alpha_{ij} \varepsilon_{ij} \leq (W/R)(1 - \eta / I_0) \qquad (17)$$

Then the blocking probability becomes

$$P_{blocking} = \Pr[Z > (W/R)(1 - \eta / I_0)] \qquad (18)$$

This is however the "ultimate" blocking limit because if it is allowed to degrade the quality of other users then the number of simultaneous active users can be increased. This is one major difference between TDMA and CDMA. In TDMA systems the number of users is always limited and this limit is not connected to the user's link quality. In CDMA this limit is much more flexible.

The number of users/sector is a Poisson random variable with mean value of N_m. The E_b/I_0 –ratio of the mobiles depends on how well the power control works and it is approximately log-normally distributed with standard deviation between 1and 2 dB [Vite 94]. Propagation conditions however degrade the overall performance of power control and so the deviation increases. According to Qualcomm's experiences with CDMA systems the deviation is normally about $\delta = 2.5$ dB.

Probably, the performance in UTRA-based mobiles can be improved; for example with more advanced electronics. But on the other hand, spread spectrum bandwidth in UTRAN is four times larger than IS-95, hence it might degrade the performance for it is obvious that the smaller the bandwidth, the better is the accuracy.

After some mathematics (see [Vit 93]) the blocking condition is

$$P_{blocking} = Q\left[\frac{A - E(Z)}{\sqrt{Var}}\right] \qquad (19)$$

There

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2}\,dt \qquad (20)$$

$$Var(Z) = N_m \alpha \exp\left[2(\beta\delta)^2\right] \qquad (21)$$

$$\beta = (\ln 10)/10 \qquad (22)$$

$$E(z) = N_m \alpha (1+\alpha) \exp\left[(\beta\delta)^2/2\right] \qquad (23)$$

In this model, it is assumed that the mobile's power is controlled all the time. If however, there is a mobile just initiating a call or changing BS there might be more power thus the interference level would be increased.

From equation (19) we can deduce the probability for the amount of time E_b/N_0 is not achieved because of the power control inaccuracy in the cell. This will be used later so that it is determined that 5% of the time the BER is allowed to be poorer than for example 10-3 due to imperfect power control. Then with a blocking probability of 5% we can calculate how many users there can be at a given instant so that the interference power and its variations in the cell will not increase so much that the BER is greater than 5 % of the time. There can be more users in practice than the number assessed by this method, but it also means that the quality of the calls is poorer.

7.5 Coverage limitations

The two environments used here are "Urban pedestrian " and "Urban vehicular." Those are described by ETSI. The first one (Outdoor to indoor and pedestrian test environment [ETSItr 98]) has the following characteristics:

- "Base stations with low antenna height are located outdoors, pedestrian users are located on streets and inside buildings and residences"
- The maximum total TX power for mobile is +14 dBm. Path loss model is

$$L_{pedest} = 40Log(r) + 30Log(f) + 49 \qquad (24)$$

In the vehicular environment the cells are large (radius of few kilometres) and the transmitter power is higher, +24 dBm for the mobile. The path loss model is

$$L_{vehicular} = 40(1 - 4 * 10^{-3}\Delta h) * Log(r) - 18Log(\Delta h) + 21Log(f) + 80dB \qquad (25)$$

In order to find out the coverage, we have used these models, which are the "worst case" models. It is assumed that in urban pedestrian environments sector antennas are used and compared to those coverage calculations done in ETSI with "concept optimised" parameters. In our case there would be more antenna gain in both the up-link and the downlink directions for sector antennas are considered. We also assume that only data rates up to 144 kbit/s are provided in the whole cell area as it is proposed by ETSI (this is naturally dependent on the operator). For the soft handover is used the same gain value as in ETSI calculations. Soft handover can have a significant influence on coverage by increasing it. By changing the values of variables in the ETSI link calculations we find that **the maximum coverage in an *unloaded* cell is 700 m in the urban pedestrian environment**. This result is valid only for sectorized cells, with omni-directional antenna the coverage range is smaller. With loaded cells, those calculations are more complex. But if, by a rough estimation, we assume that the interference level due to other mobiles increases the noise level of about 10 dB, then maximum radius in the cell would be 390 m. This 10 dB increase has been used as a default value in [Gilh 91]. It might be reasonable because if the power level in the spread channel is close to the thermal noise level then that thermal noise clearly diminishes the number of mobiles. On the other hand, if the interference level is much higher then it means that the transmitter level must also be higher. A 5-10 dB increase in the transmitter power does not significantly create more capacity because if the signal level is more than 10 dB above the noise floor then the impact of the noise floor becomes insignificant.

In our scenario we will use a three-layer cell-structure for the network. UMTS forum has suggested that one of these layers would be an "umbrella"-layer, but if the coverage for 144 kbit/s is 440 m or less, then, in practice, this umbrella-function would work poorly. Therefore we have used 10 dB more TX power than in ETSI calculations, which is said to be reasonable because the mobile handling the high bit rates will not be used next to the ear.

This third layer is supposed to serve more vehicular subscribers and we have thus used the propagation models for the urban vehicular environment. ETSI has calculated that the maximum range for an unloaded cell with 144 kbit/s and with "concept optimised" parameters is 3600 m in the up-link direction. With the previous assumption that the interference level is 10 dB over the thermal noise level the loaded coverage range decreases to 1900 m.

With smaller loading and lower bit rates the coverage range values would be naturally higher, but these values have still been used later as the maximum range values of a cell in the capacity calculations.

7.6 Capacity calculations

7.6.1 ETSI simulations vs. Telenor R&D calculations

As in the previous sections is said the modelling of UMTS capacity is quite complicated. It is clear that it is not possible to create as precise models as ETSI has used but there are still some reasons why it is worth trying to calculate capacity on our own. The main reasons are:
There is only one bit rate case at a time in the ETSI simulations. So there is maximum capacity of the cell with speech only or with 64 kbit/s only etc. and not with mixed traffic.
The environments chosen in ETSI simulations are probably different than Oslo for example. Propagation conditions in the ETSI simulations are the "worst case".
Thus, capacity results may be too optimistic. ETSI has not used sectorized antennas for their simulations whereas Telenor Mobil will probably use sector antennas.

There are many variables whose values can be selected to be different and it might be wise to understand also the effects of these variables.

We have only modelled the up-link direction because of the lack of time. Models here are mainly based on equations (2) and (19). A sector-correction factor has been added to equation (19). The sector-correction factor is used a bit differently than in equation (14) because here it is assumed (as in ETSI simulations) that *one sector is one cell.* So the interference increase factor due to the imperfect antenna for the three- sector case is

$$\lambda_{sec/int} = \frac{2v}{120^o} \qquad (26)$$

By taking into account this factor equation (23) becomes:

$$E(z) = N_{sm}\alpha(1+\lambda)(1+\lambda_{sec/int})\exp\left[(\beta\delta)^2/2\right] \qquad (27)$$

The required Eb/No for various environments and for different bit rates and BER are taken directly from ETSI and are used in calculations. Levels are supposed to be so high that the thermal noise level is ignored.

Interference from adjacent cells is taken into account. We consider that three tiers of cells (Figure 8) are interfering. Propagation conditions that are described in ETSI UMTS simulations are not directly used. Instead we calculated, according to ETSI's models, the propagation loss at a distance of 500 m for the urban pedestrian environment and the propagation loss at a distance of 3000 m for the urban vehicular environment. Then we calculated the corresponding path loss coefficient γ supposing that the path-loss equals $r^{-\gamma}$. In pedestrian environment $\gamma = -5.0$ and in vehicular $\gamma = -4.2$. The thermal noise floor is supposed to be 10 dB below the wanted signal level, if it is lower then there will naturally be more capacity.

We have assumed a blocking rate of 2 % for speech channels. For data services, the only QoS requirement is a good quality more than 95% of the time (the same requirement is also for speech). The quality threshold is BER = 10^{-3} for speech and BER=10^{-6} for data services. The mean power control accuracy is 2 dB for speech and 1 dB for data services. This inaccuracy assumption, though maybe incorrect, is based on the assumption that the more information is coming, the more accurately can the right power level be determined. Here we assume that antenna patterns overlap angle would be 10° and that the sector-correction factor is 0.16. This means that the capacity would decrease by 16 %. The overlapping angle is quite low, but due to soft handover the mobiles close to the cell borders are not using as high power as with hard handover [Vit 94] and so it might be reasonable to use a more pessimistic value for the overlap angle. Even this value can be too pessimistic, thus this phenomenon should be still researched.

Calculations are made based on the previously presented equations. So (27) is inserted to (19) and we have used the previously mentioned parameters. Results can be seen in Table 2:. We have compared them with ETSI's results for speech and LCD (long constrained delay) services with various bit rates.

Service	Environment	Source bit rate	E_b/N_0 (dB)	Cell capacity (E/carrier/cell) ETSI (up/down)	Tel. R&D (up)	Spectr. Efficiency (kbits/MHz/cell) ETSI	Tel. R&D
Speech	Pedestrian A 3 km/h	8 kbs	3.3	154/ 157	193	123	154
	Pedestrian B 3 km/h	8 kbs	4.3	129/ 95	148	103	118
	Vehicular A 120 km/h	8 kbs	5.4	112/ 89	142	90	114
	Vehicular B 120 km/h	8 kbs	5.3	115/ 69	144	92	115
LCD	Pedestrian A 3 km/h	64 kbs	2.4	16.4/33.7	14.8	210	190
		384 kbs	1.3	3.5/6.0	2.3	269	177
	VehicularA 120 km/h	64 kbs	3.8	14/12.4	11.9	179	152
		144 kbs	3.1	7.3/7.3	5.5	210	158

Table 2: Comparison between ETSI's results (up-link) and theoretical calculations. A and B in the environment description means different propagation channels described in [ETSItr 98].

The model characteristics for ETSI's results can be seen in [ETSItr 98]. In the E_b/N_0 we have included all overhead (control bits etc.) and the E_b contains all the energy needed to receive one information bit. Turbo codes have not been used in ETSI's simulation. With turbo codes the E_b/N_0 would be lower and the capacity and the coverage higher.
The reader can see that the values for ETSI and Telenor R&D are not the same but that does not mean that the ETSI results are wrong. Those are for more realistic conditions and Telenor R&D models' results are more "theoretical ones". These results can be however used as comparison data for the results in a network planning case and to estimate errors.

- The main reasons for differences between ETSI results may be:

  In the ETSI model, users are not evenly distributed as in the Telenor R&D model, propagation models are more complex. The channel models are also affecting, for example, the performance of power control, whereas in the Telenor R&D model, power control accuracy is fixed.

- Handover, ARQ, random errors etc. are not taken into account in the Telenor R&D model
- High data rates (>144 kbit/s) are possible only close to the sites in the ETSI model. In practice this means that because mobiles are not so close to the adjacent cell then the interference power to nearby cells is lower.
- Needed control channels are ignored.
- Decrease due to the imperfection of transceivers (ACP etc.) is not taken into account (maybe not even in the ETSI calculations).

In order to estimate the capacity in a mixed bit-rate case we have used quite a straightforward method. First of all, speech and simple messaging are supposed to be handled by GSM 900 and 1800 networks. Then all the other data services are handled by UMTS. Rates of 64 kbit/s or more are reduced to be either 64 kbit/s or 144 kbit/s (Table 3). For example 384 kbit/s is reduced to be 6x64 kbit/s.

	Real bit rates		Reduced rates		Needed channels	
Service	Down kbit/s	Up kbit/s	Down kbit/s	Up kbit/s	Down	Up
Speech	8	8	8	8	1	1
Simple message	14	14	8	8	1.75	1.75
Switched data	64	64	64	64	1	1
Medium multimedia	384	64	144	64	2.67	1
High multimedia	2000	128	144	144	13.89	0.89
High interactive MM	128	128	144	144	0.89	0.89

Table 3: Real bit rates vs. reduced bit rates that are used in the calculations.

E_b/N_0 for 144 kbit/s in pedestrian environments is not determined by ETSI and is here iterated by comparing E_b/N_0 values with 64, 144 and 384 kbit/s in different environments. As a result the E_b/N_0 value has taken to be 1.5 dB in pedestrian environments for 144 kbit/s.

In the next phase we have made the calculation in the same way as before. In the urban pedestrian environment we have, however, used three sectors instead of one. The corresponding results are achieved with the "Viterbi"-method because equation (19) was presented by A.Viterbi. Then we have calculated the corresponding cases with equation (2) that was presented by D. Machamer. Therefore, this will be called the "Machamer" method. For the mixed service case equation (2) "Machamer-method" must be usedbut if it is used alone it gives too optimistic capacity results. Therefore, we have first calculated the capacity for one service case with the "Viterbi"-method (equation (19) and (24)) and then we compared the results with those from (2). In the calculations with the "Machamer"-method the interference from adjacent cells has not been taken into account. However it has been taken into account in the "Viterbi"-method. In the same way, the thermal noise floor was ignored in (2.) but taken into account in the "Viterbi"-method so that it will be 10dB below the interference level created by other mobiles. This same approximation was used earlier for coverage calculations. Then the correction factor λ_{method} is calculated and it will be used in (25) and (26). Correction factors are shown in Table. This doesn't include the Erlang-blocking, it is used only for speech in this report.

Service	Environment	Source bit rate	E_b/N_0 (dB)	Cell capacity (E/carrier/cell) Viterbi		Machamer	Method correct. factor	
				λ= 3	λ= 4	λ= n	λ= 3	λ= 4
LCD	Pedestrian A 3 km/h	64 kbs	2.4	15.9	17.1	37.8	0.42	0.45
		144 kbs	1.5	7.7	8.3	21.1	0.36	0.39
LCD	Vehicular A 120km/h	64 kbs	3.8	10.8	11.7	27.7	0.39	0.42
		144 kbs	3.1	4.8	5.2	14.9	0.32	0.35

Table4: Here is compared the maximum bit rates calculated with two different methods.

In equation (2) there is one term for the adjacent cell interference. However it is taken into account (partly) in "Viterbi"-method and so equation (2) must be modified. Thus it becomes:

$$N_1 \le \frac{1}{1+\lambda_{method}}\left(1+\frac{nG_{p1}}{\alpha_1}\left[\frac{1}{(E_b/N_0)_1}-\frac{1}{(E_b/N_1)_{1i}}\right]\right)-(1+\lambda)\frac{\alpha_2 G_{p1} S_2 N_2}{\alpha_1 G_{p2} S_1} \quad (28)$$

And the corresponding maximum number of users for service type 2 is

$$N_2 \le \frac{1}{1+\lambda_{method}}\left(1+\frac{nG_{p2}}{\alpha_2}\left[\frac{1}{(E_b/N_0)_2}-\frac{1}{(E_b/N_1)_{2i}}\right]\right)-(1+\lambda)\frac{\alpha_1 G_{p2} S_1 N_1}{\alpha_2 G_{p1} S_2} \quad (29)$$

Knowing the proportion of the service type 1 and the service type 2 the maximum number of users can be obtained with equations (28) and (29). One must notice that λ_{method} is a method correction factor and that λ is an interference increase factor (due to adjacent cells) as mentioned earlier. When the proportion of the two different services is estimated (from traffic forecasts) in the network, the amount of traffic that a BS can handle can be calculated. These methods will be used later for the calculation of the required number of base stations.

We have only focused on the up-link. The downlink capacity aspects are not discussed in details. In order to estimate the capacity in that case we compared ETSI results for the up-link and for the downlink. Then we have assumed that the capacity relations between the two directions in ETSI simulations would be the same in our implementation. Two code sets were used in ETSI simulations for the downlink, s and so the same assumption was used here.

7.6.2 UTRAN network structure in Oslo in years 2005 and 2007

A network layout is created with regular hexagons. So each cell needs the area of a hexagon and a group of cells with different carriers creates a cluster of N_c cells. We assume that one cluster can use the whole bandwidth reserved for its layer, i.e. if for example 5 MHz is reserved for macro-cell, one macro-cell cluster can use 5 MHz. The distance between the centre and the vertex of the hexagon is R and the distance to the nearest cell with the same carrier frequency is D (= frequency reuse distance). As previously mentioned this cell, with the same frequency, is in a different cluster. The area of the hexagon is [UMTSfor 98]

$$A_{hex} = 2.6R^2 \qquad (30)$$

and.

$$D/R = \sqrt{3N_c} \qquad (31)$$

With equation (31) we can determine the number of cells in one cluster and so the reuse pattern. If we know the attenuation loss in a certain environment, the transmitting power and the needed carrier to interference ratio C/I, we can determine the minimum distance between sites using the same carrier. Moreover given the cell surface we get the value for the variable R and then we also get the value for N_c. Normally, N_c is also the same, as the reuse factor. When we know N_c (or reuse factor) and the bandwidth allocated to a given network layer we can get the available bandwidth/cell and then the available channels/cell. There can also be reuse partitioning so that there would be two different reuse patterns. It is possible to increase the network capacity [Meh 94,pp.35] with this method especially if there are services that have different S/I requirements. In practice, this means that there would be two or more different frequency groups for the same layer. So there might be reuse factors $N_A = 3$ and $N_B = 7$ and if the mobile has a too high S/I for its purposes it can change to the N_A group, and if the S/I is too low it can switch quality to the N_B group. Services with low BER demand such as speech services would use group N_A and services with high BER demand ,such as data services, would use group N_B. As a result the available spectrum would be used more effectively and capacity would be increased.

These previously mentioned procedures are normal for network planning of TDMA based systems (of course this is more or less simplified) such as GSM. Because of the lack of time we will not discuss in more detail GSM network planning, and the parameters for GSM based networks have not been calculated. The working assumption is that a GSM based network could handle speech and short data services and UTRAN would handle the rest of the traffic.

Normally, for CDMA systems, the same frequency is reused in the adjacent cells (reuse factor 1) and so there is no need to do a frequency planning as it is for TDMA systems. However, adjacent cells decrease the capacity of the researched cell very severely as we have noted previously.

The traffic values for different environments are given in chapter four. They are used, in our system modelling, as target values. Based on those values, we have tried to estimate how many cell sites and carriers are needed in different areas in order to provide enough capacity during the "busy hour." For practical reasons, we assume that all BSs use the same transmitting power, otherwise estimations would be too complex. We have also assumed that for speech services the required BER is 10^{-3} and for data services it is 10^{-6} .

For the "Oslo case" we have assumed that antennas are situated above the rooftops; for coverage estimations we have however used ETSI's urban pedestrian model which maybe pessimistic. For the interference from the neighbouring cells is used value $\gamma = 3$. The effect of this is however not so relevant because we have used sector antennas.

The proportion of the total needed 64 and 144 kbit/s is taken from the traffic scenarios in chapter 4. The population density inside ring 1 is assumed to be 70,000 for urban pedestrian and 15,000 for urban vehicular. The numbers of needed channels are in table 6.

From these numbers we have calculated the proportion of services and then we have calculated how many channels can be handled by one cell. These calculations stem from (25) and (26).

		Urban pedestrian, needed and provided capacity			
Direction	**Service (kbit/s)**	**2005medium**		**2007 high**	
		Needed capacity [E/ km^2]	**Maximum provided capacity[E/cell]**	**Needed capacity [E/ km^2]**	**Maximum provided capacity[E/cell]**
Up	8	918	GSM	1117	GSM
Up	64	90.1	11.7	192.5	10.6
Up	144	10.1	1.3	33.1	1.9
Totally needed up	**8**	**1821**		**3252**	
Down	8	918		1117	
Down	64	78.8	8.2	166	7.8
Down	144	103.0	10	245	10
Totally needed down	**8**	**3402**		**6862**	

Table 5: Needed channels (E/km2) and provided channels (E/cell) in urban pedestrian environment reduced to 8, 64 and 144 kbit/s channels. Speech channels are provided by GSM, others with UTRAN.

		Urban vehicular, needed and provided capacity			
Direction	**Service (kbit/s)**	**2005medium**		**2007 high**	
		Needed capacity [E/ km^2]	**Maximum provided capacity[E/cell]**	**Needed capacity [E/ km^2]**	**Maximum provided capacity[E/cell]**
Up	8	98.7	GSM	120	GSM
Up	64	1.7	6.9	3.7	5.5
Up	144	0.3	1.3	1.1	1.6
Totally needed up	**8**	**118**		**169**	
Down	8	98.7		120	
Down	64	1.7	2.0	3.6	1.9
Down	144	2.2	3.0	5.4	3.4
Totally needed down	**8**	**152**		**222**	

Table 6: Needed channels (E/km2) and provided channels (E/cell) in urban vehicular environment reduced to 8, 64 and 144 kbit/s channels. Speech channels are provided with GSM, others with UTRAN.

Based on the maximum number of channels per cell we have calculated how many TRX/km2 are needed for different areas and scenarios. These channels are also considered to be speech channels so that it might be easier to compare with current traffic and network. It should not be possible to physically fragment a channel but we have assumed, for the sake of simplicity, that bit rates such as 1.3*144 kbit/s are possible. Then we have calculated the maximum size of the cell considering there cannot be more traffic than TRX. As previously mentioned, in the urban pedestrian environment there are two similar cell layers and so the "urban pedestrian" traffic/area is divided by two to get the amount of the traffic to be handled by one cell. On top of these two cells there is the umbrella layer which will serve urban vehicular users. The area inside ring 1 is about 2.2 km^2. We have calculated the needed number of cells in that area (Table). We have multiplied with a factor of two in Table the needed number of TRXs because there are two similar "urban pedestrian" layers.

Area	Direction	Scenario	Area (km^2)	Radius (m)	TRX/ (km^2)	TRX inside ring 1, in two layers
Pedestrian	up	2005 m	0.262	550	3.81	8.38 x 2 = 17
	down	2005 m	0.200	480	5.00	11 x 2 = 22
Vehicular	up	2005 m	4.000	2150	0.25	1
	down	2005 m	1.248	1200	0.80	2
Pedestrian	up	2007 h	0.112	360	8.9	19.58x2 = 39
	down	2007 h	0.089	320	11.3	24.86x2 = 50
Vehicular	up	2007 h	1.46	1300	0.80	2
	down	2007 h	0.55	800	1.80	4
Coverage limited case pedestrian			0.13	390	7.59	15.18x2 = 30
Coverage limited case vehicular			3.13	1900	0.32	1

Table 7: Maximum cell sizes within ring 1 for different traffic scenarios assuming that there are two layers to handle pedestrian users and one layer to handle vehicular users.

It is easy to see that the downlink is limiting the cell size. However when we compare the cell radius to the values obtained in the coverage calculations we see that the maximum coverage range is less than the maximum capacity-limited range in 2005 for the urban pedestrian environment. Thus, after having calculated the number of cells needed inside ring 1, the radius of the cell is 390 m instead of 480 m or 550 m. This means more sites but also more capacity.

The area between ring 1 and ring 2 is about 10.7 km^2 and it is here assumed that there would be 15,000 people/km^2 who are in the typical "urban pedestrian" environment and the same number in the "urban vehicular" environment. It is also supposed that there will be two layers providing services for the pedestrian and indoor users as for inside ring 1. There will also be a macro cell layer as for inside ring 1. In Table 1 can be seen the results for this area.

Area	Direction	Scenario	Area (km^2)	Radius (m)	TRX/ (km^2)	TRX between ring 1 and ring 2, in two layers
Pedestrian	up	2005 m	1.19	1170	0.84	9.0 x 2 = 18
	down	2005 m	0.92	1030	1.09	11.7x2 = 23.4
Vehicular	up	2005 m	4.19	2200	0.24	2.6
	down	2005 m	1.46	1300	0.68	7.3
Pedestrian	up	2007 h	0.51	770	1.95	20.9x2 = 41.8
	down	2007 h	0.39	670	2.57	27.5x2 = 55.0
Vehicular	up	2007 h	1.58	1350	0.63	6.7
	down	2007 h	0.57	810	1.76	18.8
Coverage limited case pedestrian			0.13	390	7.59	81.2x2 = 162.4
Coverage limited case vehicular			3.13	1900	0.32	3.4

Table 1: Maximum cell sizes within the area between the ring 1 and the ring 2 in different traffic scenario assuming that there are two layers to handle pedestrian users and one layer to handle vehicular users.

The "ring 2"-case seems to be more coverage-limited than for inside ring 1. We have assumed that the propagation conditions for the pedestrian users will be the same as for the ETSI model where the antenna is at roof top level or below. That model may however be too strict and gives too high attenuation in this area. This naturally affects the needed number of cells and so it may be too pessimistic. On the other hand, if there are more cells then the network will be able to provide high bit rates (≥144 kbit/s) everywhere inside ring 2. So it is important to notice that there is no need to have so many cells and that the number of cells is dependent on the services and also on the wanted QoS.

In Oslo the UTRA network might be the following (inside of ring 2):

- **Year 2005**

  For pedestrian and indoor users there should be a total of about 32 sites with six cells/site (because of the two layers). Then there would be one umbrella layer providing services for the vehicular users with three sites, which probably would be located in the same places as some of the micro-cell sites. Everywhere would be provided with 144 kbit/s in three layers, but if there should be higher data rates everywhere, then there should be more sites in order to get coverage and vice versa. In total, if we assume as for ETSI simulations that two code sets are used for the down-link, there should be about 3200 up-link channels and 6400 down-link channels with 64 kbps available
- Year 2007

  There should be a relatively low increase in the number of sites compared to the increase of the traffic because in the 2005-case many sites were needed in order to get coverage. The network structure would be the same but the number of micro-cell sites would be about 35 and the number of macro cell sites would be about 8 and located in the same places as some of the micro-cell. If we assume as for ETSI simulations that two code sets are used for the down-link, there should be a total of about 3200 up-link channels and 6400 down-link channels with 64 kbps available.

The traffic estimation and the factors mentioned previously in this chapter are the main sources of errors for this work. There is a 10-20 % difference between ETSI's results and Telenor R&D results for 64 kbit/s and 144 kbit/s. Telenor R&D's results are more pessimistic, thus the network scenario may be a pessimistic one. Moreover, the capacity on the downlink has not been studied carefully enough. Hence the ratio between the up-link and the downlink which has been used in ETSI's simulation should not have been used in our calculations. In addition, the coverage for the high data-rate services needs to be studied more thoroughly, for it has a serious impact on the needed number of cell sites estimation. The impact of high data-rate service's coverage is also on the interference. If high data rates are provided everywhere then there will be more interference due to the improper power control. This may occur because when a mobile is moving fast and far from the BS then it is more difficult to get a good power control accuracy than it is for a slow moving mobile close to the BS. So the more unpredictable the propagation conditions are, the more difficult it is to get accurate power control. Since for high data-rate services the power is high, the interference level will be higher than it is for the speech service.

Conclusions

- It is difficult to forecast the traffic in the future. One major factor, which can have a big effect on the forecast values in chapter 4, is whether there will be a vast usage of mobile terminals for remote control or corresponding tasks.
- It might be wise to have a better understanding of coding before implementing UMTS network.
- The traffic will be so asymmetric that it is of paramount importance to get licenses for more than only one unpaired band.

7.7 ETSI Results

The following tables are based on the Evaluation Report for ETSI UMTS Terrestrial Radio Access (UTRA) ITU-R RTT Candidate [ETSIutra 98].

		Indoor		Pedestrian		Vehicular	
		[redacted]	DL	[redacted]	DL	[redacted]	DL
[redacted]		[redacted]		[redacted]		[redacted]	
Bit-Rate	kBit/s	[redacted]	8	[redacted]	8	[redacted]	8
maximum Range	m	[redacted]	900	[redacted]	910	[redacted]	7350
Spectrum efficiency	(kBit/s)/MHz/cell	[redacted]	74	[redacted]	125	[redacted]	71
Simultaneous Users	Erlang	[redacted]	92	[redacted]	157	[redacted]	89
Eb/No	dB	[redacted]	6,0	[redacted]	6,1	[redacted]	7,9
[redacted]		[redacted]		[redacted]		[redacted]	
Bit-Rate	kBit/s	[redacted]	2048	[redacted]	384	[redacted]	384
maximum Range	m	[redacted]	230	[redacted]	520	[redacted]	3900
Spectrum efficiency	(kBit/s)/MHz/cell	[redacted]		[redacted]	461	[redacted]	177
Simultaneous Users	Erlang	[redacted]		[redacted]	6	[redacted]	2,3
Eb/No	dB	[redacted]	1,6	[redacted]	1,1	[redacted]	3,2
[redacted]		[redacted]		[redacted]		[redacted]	
Bit-Rate	kBit/s	[redacted]	2048	[redacted]	384	[redacted]	384
maximum Range	m	[redacted]	350	[redacted]	520	[redacted]	3900
Spectrum efficiency	(kBit/s)/MHz/cell	[redacted]	453	[redacted]	668	[redacted]	
Simultaneous Users	Erlang	[redacted]	82	[redacted]	135	[redacted]	
Eb/No	dB	[redacted]	0,1	[redacted]	0,1	[redacted]	2,0

Table 2: FDD Results

		Indoor		Pedestrian		Vehicular	
		[redacted]	DL	[redacted]	DL	[redacted]	DL
[redacted]		[redacted]		[redacted]		[redacted]	
Bit-Rate	kBit/s	[redacted]	8	[redacted]	8	[redacted]	8
maximum Range	m	[redacted]	950	[redacted]	950	[redacted]	6600
Spectrum efficiency	(kBit/s)/MHz/cell	[redacted]	70	[redacted]	73	[redacted]	148
		[redacted]		[redacted]		[redacted]	
		[redacted]		[redacted]		[redacted]	
[redacted]		[redacted]		[redacted]		[redacted]	
Bit-Rate	kBit/s	[redacted]	2048	[redacted]	384	[redacted]	144
maximum Range	m	[redacted]	200	[redacted]	490	[redacted]	4120
Spectrum efficiency	(kBit/s)/MHz/cell	[redacted]	62	[redacted]	330	[redacted]	201
		[redacted]		[redacted]		[redacted]	
		[redacted]		[redacted]		[redacted]	
[redacted]		[redacted]		[redacted]		[redacted]	
Bit-Rate	kBit/s	[redacted]	2048	[redacted]	384	[redacted]	144
maximum Range	m	[redacted]		[redacted]		[redacted]	
Spectrum efficiency	(kBit/s)/MHz/cell	[redacted]	400	[redacted]	642	[redacted]	320
		[redacted]		[redacted]		[redacted]	
		[redacted]		[redacted]		[redacted]	

Table 3: TDD-Results

The numbers have been evaluated by means of computer simulation. The evaluation is carried out based on the methods and conditions described in [ETSItr 98].

Service characteristics:

- Speech: BER $\leq 10^{-3}$, delay 20 ms and 50% activity factor.
- LCD Data: circuit-switched long delay constrained, BER $\leq 10^{-6}$, delay 300 ms and 100% activity factor.
- UDD Data: packet, connection-less information types.

Calls are generated according to a Poisson process. For circuit switched services, a mean call duration of 120 s is assumed. UDD is a typical WWW browsing service, with burst periods corresponding to the downloading of a WWW document and a certain amount of time for processing the information. Due to this, the average information rate with the 2048 kbit/s service will be only 486.4 kbit/s.

Simulation environment:

- Indoor Office: An office building is assumed where users are moving with 3 km/h speed. The base stations are using omnidirectional antennas. They are deployed in every second office room. Cell radius is 11,6 m and the average cell area is 346 m^2.
- Outdoor to indoor and pedestrian: It is a Manhattan like environment with 200 m block size and users with 3 km/h speed. The base stations are using omnidirectional antennas and are deployed 10 m above ground. Cell radius is about 330 m and call area is 0.1 km^2.
- Vehicular: It is a classic macro cell environment. The speed of the mobile station is 120 km/h and each site is serving 3 sectors. Cell radius for up to 144 kbit/s is 2000 m and the cell area of 10.4 km^2. Above 144 kbit/s the cell radius is 500 m and the area is 0.65 km^2.

To calculate the cell range a coverage analysis is performed with a link budget calculation. The system will be noise limited and running with the lowest load. The range is calculated to provide coverage at the system start-up and ongoing traffic growth.
The System-level simulation is used to get values for the capacity. Speech and LCD traffic are using soft handover. For the UDD packet service the mobile station is simply connected to the strongest base station.
The Quality of Service (QoS) for circuit switched services is achieved if the blocking rate is under 1%, the BER is 95% of session time under the defined threshold and the user does not get dropped. The QoS constraints for the packet service are fulfilled if the user does not get blocked or dropped and if the active session throughput is not below a certain level.

In all the simulations, the base stations are equipped with one 4.096 Mchips/s UTRA/FDD carrier using 5 MHz carrier spacing.
All interference is modelled as additive white Gaussian noise.
The E_b/N_0 is derived from the Link-Level simulation. Fast power control and Rake receivers are included. The E_b/N_0 values are the values that are needed in the receiver to achieve the corresponding BER. They include all overhead for coding and signalling.

TDD has the following exceptions. The base stations are using 2 GHz carrier frequency with 5 MHz spacing and 4.096 Mchips/s chip rate. The duration of a TDMA frame is 10 ms divided into 16 time slots. Only downlink direction has been considered because it is limiting the system capacity. There are different E_b/N_0 values depending on which resource is used. These are the different resources: number of codes per time slot per user, number of users per time slot and number of time slot per user. UDD services are using automatic repeat request (ARQ) together with forward error correction (FEC). For the following reasons no link budget are calculated for UDD services. The ARQ scheme allows retransmission in case of unsuccessful data detection. Therefore no fixed E_b/N_0 values are required to achieve the QoS. However, the range of UDD services is larger than for FDD services.

7.8 Coverage requirements Oslo Ring 1 and 2 with ETSI results

The following table shows the number of cells to cover Oslo Ring 1 and Ring 2 with the specific services. No traffic requirements are taken into account.
The area size within Ring 1 is 2.2 km^2. The area size within Ring 2 is 10.7 km^2 without the area of Ring 1.

		Indoor		Pedestrian		Vehicular	
			DL		DL		DL
Bit-Rate	kBit/s		8		8		8
Cell size max.	km^2		2,1		2,2		140
Cells in Ring 1			2		1		1
Cells in Ring 2			6		5		1
Cell size used in simulation	km^2		0,0035		0,12		10,4
Cells in Ring 1			629		19		1
Cells in Ring 2			3058		90		2
Bit-Rate	kBit/s		2048		384		384
Cell size max.	km^2		0,14		0,7		40
Cells in Ring 1			16		4		1
Cells in Ring 2			77		16		1
Cell size used in simulation	km^2		0,0035		0,12		0,65
Cells in Ring 1			629		19		4
Cells in Ring 2			3058		90		17
Bit-Rate	kBit/s		2048		384		384
Cell size max.	km^2		0,32		0,7		40
Cells in Ring 1			7		4		1
Cells in Ring 2			34		16		1
Cell size used in simulation	km^2		0,0035		0,12		0,65
Cells in Ring 1			629		19		4
Cells in Ring 2			3058		90		17

Table 4: Number of cells to cover Oslo Ring 1 and Ring 2

The values are based on the ETSI results from Table 2.

The cell size used in the simulations are taken from the ETSI base station deployment scheme for the system level simulation [ETSItr 98]. This simulation is used to evaluate the spectral efficiency.

The cell area is calculated for hexagonal cell layout. The link between range r and area A is:

$$A = \frac{3}{2} r^2 \sqrt{3}$$

The table shows only FDD results, however the TDD results are very similar.

7.9 References

[Aksu 94] Aksu A. et al , Other cell interference and capacity of power controlled CDMA in wireless fixed access networks, IEEE .

[Bra 90] Braun H.J. et al, Voice control of the Pan-European digital mobile radio system, CSELT Tech.Rep.,Vol18,No.3, pp183-187,June 1990.

[Clapt 98] Clapton AJ, UMTS-the mobile part of broadband communications for the next century, BT Technol J, Vol 16 No 2 April 1998.

[ETSItr 98] ETSI, Selection procedures for the choice of radio transmission technologies of the UMTS, TR 101 112 V3.2.9,4/98.

[ETSIutra 98] ETSI, Evaluation report for ETSI UMTS terrestrial radio access (UTRA) ITU-R RTT candidate, 9/1998.

[Gan 94] Ganesh R. et al: Traffic capacity of cellular packet CDMA for varying cell size and propagation scenarios, IEEE International Conference on Communication pp805-810 vol.2, 1994.

[Gilh 91] Gilhousen K.S.et al., On the capacity of a cellular CDMA system, IEEE Trans.VehicularTechnology, Vol.40, pp.472-480, May 1991.

[Harl 89] Harlay P., Short distance Attenuation measurements at 900 MHz and 1.8 GHz using low antenna heights for Microcells, IEEE Journal on Selected areas in communicatons, Jan. 1989 pp. 3-11.

[Kyo 93] Kyoung Il Kim, CDMA Cellular engineering issues, IEEE Transactions on vehicular technology, vol. 42, no.3, august 1993.

[Meh 94] Mehrotra, Asha, Cellular radio: analog and digital systems, Artech house, Norwood USA, 1994.

[Pras 98] Prasad R., Universal wireless personal communications, Boston USA, Artech house, 1998.

[Rap 90] Rappaport T.S., Milstein, Effects of path loss and fringe user distribution on CDMA cellular frequency reuse efficiency 2, Proceedings of the IEEE GlobeCom 1990, pp 404.6.1-404.6.7.

[Skl 98] Bernhard Sklar, Digital Communications: fundamentals and applications, Prentice-Hall, 1998.

[UMTSfor 98]UMTS Forum, Minimum spectrum demand per public terrestrial UMTS operator in the initial phase, UMTS Forum secretariat, 1998.

[Vil 95] Villy Bæk Iversen, Data- og Teletrafikteori Lærebok, Instituttet for Teleteknik, 1995.

[Vit 93] Viterbi A.M.,Viterbi A.J., Erlang capacity of a power controlled CDMA System, IEEE journal on selected areas in communications, vol 11.,no 6, august 1993.

[Vit 94] Viterbi A.J. etc, Soft handoff extends CDMA cell coverage and increases reverse link capacity, IEEE journal on selected areas in communications, vol.12, no 8, October 1994.

[Vite 94] Viterbi A. et al, Performance of power controlled wideband terrestrial digital communicatons, IEEE Transactions on Communications, Vol 41, pp 559,-569 4/93.