2 UPLINK COVERAGE AND CAPACITY ESTIMATION

A natural starting point for a discussion about radio network planning for WCDMA is the uplink link budget.

2.1 Uplink link budget

In Table 1, an uplink link budget is presented. The purpose of the link budget is to estimate the possible uplink cell range. In the coming sections, all the quantities in the link budget are described in more detail. For more information please refer for instance to [1].

Table 1. *Example of uplink link budget for 12.2 kbps speech.*

Service:Speech 12.2 kbps, channel model veh A 120 km/h, suburban environment, in-car		
UE TX power	21 dBm	Class 4
Noise density	-174 dBm/Hz	
Chip rate	3840 kcps	
BS Noise figure	4 dB	Assumption
BS Noise power	-104 dBm	-174+10log(3840000) + 4
Noise Rise	3 dB	Load dependent
Bitrate	12.2 kbps	Speech
Eb/Io	5 dB	Assumption
SIR	-20 dB	5 –10log (3840/12.2)
BSsens	-121 dBm	-104 +3 – 20
UE antenna gain	0 dBi	
Body loss	3 dB	
In-car loss	8 dB	
In-building loss	-	
BS antenna gain	18 dBi	
Feeder loss	3 dB	Zero if antenna amplifier is used
Additional losses	-4 dB	-0+3+8+0-18+3
Shadow fading margin	7 dB	95% coverage, stdv=7
Multipath margin (PC head room)	0 dB	
Soft handover gain	3 dB	
Fading margins	4 dB	7+0-3
Maximum propagation loss	**142 dB**	21-(-121)-(-4)-4

2.1.1 UE transmitted power

There are four different power classes described in the UMTS specifications, see Table 2.

Table 2. *UE power classes according to the specification.*

UE class	**TX power [dBm]**
Class 1	33
Class 2	27
Class 3	24
Class 4	21

It should be noted, that the values in the table relate to a continously transmitting UE, as opposed to e.g. GSM, where the mobile only transmits every 8th timeslot. The difference is 9 dB, meaning that 21 dBm continuous transmission power wise equals 30 dBm transmission every 8th timeslot.

The prevalent UE class will most likely be Class 3 and/or Class 4. It can be anticipated that Class 3 UEs will be used for data communication.

2.1.2 Base station sensitivity

In this section, the WCDMA BS sensitivity is derived. The first step is to calculate the receiver thermal noise floor. As usual the thermal noise density is given by:

$$kT = -174 dBm / Hz$$

where k is the Boltzman constant and T is the room temperature (290 Kelvin)

The noise over the receiver bandwidth (which in WCDMA is equal to the chip rate) becomes:

$$kT + 10\log(3840000) + Nf = -104.15 dBm$$

with an assumed noise figure (Nf) of 4 dB.

An interesting observation is that the receiver noise floor is much higher than in GSM. This is due to the much larger bandwidth of WCDMA.

So far, only thermal noise has been considered. However, in WCDMA it is obvious that interference coming from other users must be taken into account. It is common practice to model this interference by means of a noise rise. A noise rise of for instance 3 dB means that the power of the interference coming from other users is at the same level as the power of the thermal noise, or in other words that the total noise floor seen by the receiver has been doubled. The noise rise is highly dependent on the load in the network and this aspect will be further analyzed in section 2.2. For the time being a noise rise of 3 dB has been assumed in the link budget of Table 1.

As previously mentioned, the large bandwidth required for spreading increases the noise floor, but at the same time, it makes possible to receive and demodulate signals below the noise floor. The required chip-energy-to-interference-ratio *Ec/Io* (or *SIR*) is given by:

$$SIR = Ec / Io = Eb / Io \cdot \frac{R_b}{R_c} = Eb / Io \cdot \frac{1}{PG}$$

or expressed in dB:

$$SIR \ = Ec / Io \ = Eb / Io \ - 10\log(R_c / R_b)$$

Here *Eb* is the required energy per information bit. R_b is the information bit rate and R_c is the chip rate. The ratio R_b/R_c is often referred to as processing gain (*PG*).

For a speech service of 12.2 kbps and an *Eb/Io* of 5 dB the *SIR* becomes:

$$SIR \ = 5 - 10\log(3840 / 12.2) = -20dB$$

which means that the signal can be received 20 dB below the noise floor. Assuming a noise rise of 3 dB, the BS sensitivity becomes:

$$Sens_{BS} = -104 + 3 - 20 = -121dBm$$

Comparing to the sensitivity of a GSM BS this may seem very low, however, one must remember that the signal level must be received continuously as opposed to the GSM case, where the signal is only received every 8th timeslot.

Service data

It is interesting to see that, some of the parameters affecting the BS sensitivity strongly depend on the service. So for instance, the higher the required bit rate, the lower becomes the processing gain the worse gets the BS sensitivity.

In the example in Table 1, a link budget for speech service of 12.2 kbps is presented. Further on, link budgets for higher bit rates will be analyzed. It is important to realize that the bit rates and Eb/Io values referred to are the bit rate of user information excluding overhead such as for instance pilot bits and overhead due to coding. Thus the physical bit rate over the air is much higher than 12.2 kbps.

Related to each service is an Eb/Io value. This is usually provided by the vendor and is strongly dependent on the channel model. There are Eb/Io values given in the 3GPP specification, however these values relate to channel models developed for hardware testing and are not applicable for cell planning purposes. When using different Eb/Io values, it is always important to understand how they are derived. For instance, do they take into account errors in channel estimation and power control? What environments are they applicable for? Is diversity taken into account etc?

There is a relation between the Eb/Io and the bit rate. The required Eb/Io decreases as the bit rate increases. This is due to the fact that Eb/Io includes the power required to send overhead information. The amount of overhead information does not increase proportionally with the information bit rate. Thus, for higher information bit rates the relative power required for overhead information is decreased resulting in an improved efficiency and lowered Eb/Io.

It is worth to emphasize that many of the expected difficulties with the planning of UMTS networks are related to the fact that the system should support different services.

2.1.3 Additional losses

Apart from the loss due to propagation in the air the signal is subjected to various additional losses (or gains). These losses are to a large extent the same as for GSM1800 and will not be explored further in this course.

- Body loss (typically 3 dB)
- UE antenna gain (typically 0 dBi)
- BS Antenna gain (typically 18 dBi for a three-sector site)
- Feeder loss (Typically 3 dB, depends on feeder length If an external amplifier is used before the feeder this loss can be ignored.)
- In-car loss (typically 8 dB). If in-car coverage is desired.
- In-building loss (10-25 dB). If in-building coverage is desired.

2.1.4 Fading margins

Shadow fading margin

The shadow fading margin is applied in order to account for obstacles unforeseen by the prediction algorithms. The margin depends on how large the fluctuation between the predicted value and the real signal strength is. This fluctuation is usually characterized by its standard deviation. A typical figure in an urban rural environment is 7 dB whereas it is higher in suburban- and urban areas.

Also, the higher the desired degree of coverage is, the higher fading margin is required.

Multipath fading margin (PC headroom)

Usually the Eb/Io values are derived assuming an infinite dynamic range for the power control. This means that UE can compensate even for very deep fading dips due to multipath propagation and that no multipath propagation margin is required. This is a fair approximation for UEs that are located not too distant from the BS. However, when the UE reaches the cell border, it will be close to its maximum output power and it cannot fully compensate for fading dips. In order to account for this effect, a margin is required.

The size of the margin is dependent on the channel model. For a channel model with just a single ray (low diversity), a higher margin is required, whereas lower margins are required for channel models with higher diversity. Typical figures might be in the range 0-5 dB.

For fast moving UEs, the power control cannot compensate for fading dips, something that will increase the required Eb/Io. However, it also means that there is no need for a multipath fading margin.

Soft handover gain

Thanks to possibility of performing soft handovers, the required margins for shadow and multipath fading can be somewhat relaxed. This is usually referred to as soft handover gain.

Considering the case of shadow fading, it is well known that the fading patterns from two BSs are partly uncorrelated. Hence, by connecting to two BSs simultaneously, fading dips can be neutralized.

The same applies to multipath fading. Also in this case, soft handover gives an additional diversity that neutralizes fading dips.

The total gain due to soft handover is estimated to be 2-3 dB [1].

It should be noted that the definition of soft handover gain varies quite much.

2.2 Uplink capacity

2.2.1 Introduction

Up until this stage, nothing has been mentioned about capacity of WCDMA. We have just reserved some space in the link budget, the so-called noise rise. This was introduced in order to account for the interference from other users. It is quite obvious that the more users the higher noise rise, thus the smaller the cell. This effect is often referred to as cell breathing. In the following sections a relationship between the noise rise and the number of users in the network will be derived. For more information please refer for instance to [1].

2.2.2 Single cell, single service

As an introduction, the case of a *single cell* and a *single service* (e.g. speech) is studied. In the coming sections this equation will be extended to cover also multiple services and multiple cells.

Assume a single cell with N users using the same service. The total interference at the BS can be expressed as the sum of thermal noise and the received power from each one of the N users.

$$P_{\mathrm{int},tot} = P_{noise} + \sum_{i=1}^{N} P_{RX,i}$$

Now, consider the impact of inner loop power control. The purpose of the power control is to make sure that each user reaches his *SIR* target. Thus:

$$\frac{P_{RX,i}}{P_{\mathrm{int},tot} - P_{RX,i}} = SIR_i$$

Since in this case a single service system is considered all users will have the same *SIR*, thus:

$$\frac{P_{RX}}{P_{\mathrm{int},tot} - P_{RX}} = SIR \Rightarrow P_{RX} = \frac{SIR}{1+SIR} \cdot P_{\mathrm{int},tot} \qquad \text{Eq. 1}$$

$$P_{\text{int},tot} = P_{noise} + NP_{RX} \qquad \text{Eq. 2}$$

Eliminating P_{RX}:

$$P_{\text{int},tot} = \frac{P_{noise}}{\left[1 - \frac{N \cdot SIR}{1+SIR}\right]}$$

Remembering the definition of noise rise finally gives:

$$Noiserise = \frac{P_{\text{int},tot}}{P_{noise}} = \frac{1}{1 - \frac{N \cdot SIR}{1+SIR}}$$

or in dB:

$$Noiserise = 10\log\left[\frac{1}{1 - \frac{N \cdot SIR}{1+SIR}}\right]$$

which is the desired relationship.

It is customary to introduce the concept of *Load* to obtain the following useful equations. Please note that the theoretical maximum possible load (corresponding to infinite noise rise) equals 100%. The number of users corresponding to 100% *Load* is usually referred to as the pole capacity of the cell. The equations are the fundamental basis for the analysis of the relationship between uplink capacity and coverage in WCDMA.

$$Load = \frac{N \cdot SIR}{1+SIR} \qquad \text{Eq. 3}$$

$$Noiserise = 10\log\left[\frac{1}{1-Load}\right] \qquad \text{Eq. 4}$$

2.2.3 Some remarks

Cell breathing

Before extending Eq. 3 and Eq. 4 to include multiple services and also interference from other cells some interesting remarks can be made. First of all, an expression for how the coverage is reduced when the capacity is increased has been derived. The relationship (Eq. 4) is plotted in Figure 1.

As the load is low so is the noise rise. As the load increases, however, so does the noise rise. Recalling the link budget in Table 1, a higher noise rise leads to a reduced coverage.

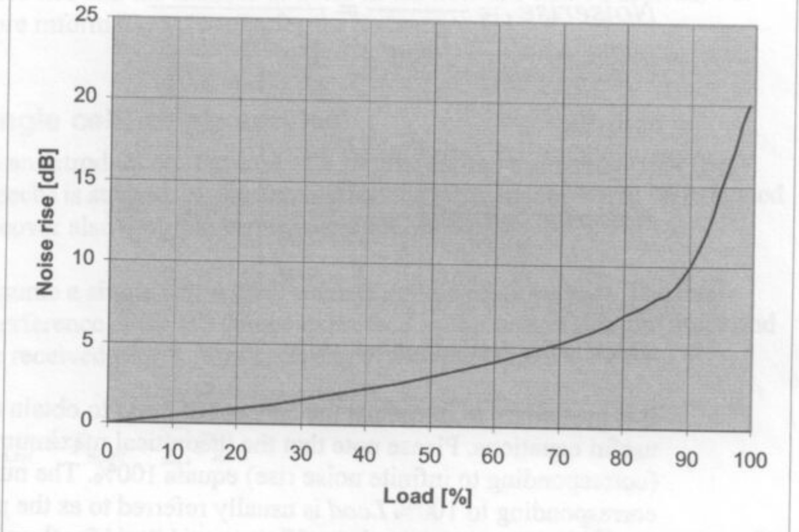

Figure 1. *Relationship between load and noise rise.*

Instability

Another interesting aspect that the figure reveals is that the noise rise increases very rapidly for high loads. For instance, the noise rise increases as much as 3 dB (from 7 to 10 dB) when the load is increased from 80% to 90%. In a real system these extreme fluctuations can not be handled since the system would become unstable. The maximum load limit in WCDMA depends on how effective the admission algorithms will work. Typical load figures used in for instance simulations are in between 50%-75%.

Capacity proportional to SIR
Looking at Eq. 3 another interesting feature of WCDMA is revealed: *the capacity is proportional to the required SIR*. Thus, any feature that will reduce *SIR* will not only improve coverage but also improve capacity. This explains why it is so important with an effective power control in WCDMA.

Pole capacity
A common term in WCDMA is the pole capacity, which is identical to the number of users corresponding to 100% *Load*. Note that at this load level the noise rise is infinite implying that the coverage is reduced to zero. Hence, a real network could never be loaded to the pole capacity.

2.2.4 Single cell, multiple services

The derivation of Eq. 3 and Eq. 4 was for the special case where all users in the cell used the same service for instance speech 12.2 kbps. However, WCDMA shall support a wide range of services and the question is how this will affect the noise rise.

By examining the equations in section 2.2.2 one can see that they easily can be extended so that they cover also case of multiple services:

In a situation of multiple services where each service is denoted by *s* equations Eq. 1 and Eq. 2 extend to:

$$\frac{P_{RX,s}}{P_{\mathrm{int},tot} - P_{RX,s}} = SIR_s \Rightarrow P_{RX,s} = \frac{SIR_s}{1+SIR_s} \cdot P_{\mathrm{int},tot}$$

$$P_{\mathrm{int},tot} = P_{noise} + \sum_s N_s P_{RX,s} \qquad \text{Eq. 5}$$

By repeating the steps in section 2.2.2 the following result is obtained:

$$Load = \sum_s Load_s = \sum_s \frac{N_s \cdot SIR_s}{1+SIR_s} \qquad \text{Eq. 6}$$

$$Noiserise = 10\log\left[\frac{1}{1-Load}\right] \qquad \text{Eq. 7}$$

The equations might look rather complex, but they are very easy to use.

2.2.5 Multiple cells, multiple services

Up until this stage only a single cell has been considered and interference from surrounding cells has been neglected. Obviously this is too optimistic. WCDMA will be planned with a 1 re-use meaning that the same carrier will be used in the entire network. Under such circumstance interference from other cells will be high and coverage as well as capacity will be reduced compared to the optimistic single cell case.

Usually, the interference from other cells is modelled with the parameter *f*, defined as the ratio between the interference from other cells and the interference generated in the own cell, i.e.:

$$f = \frac{P_{\text{int},other}}{P_{\text{int},own}}$$

When going from a single cell system to a system with multiple cells Eq. 5 is modified as:

$$P_{\text{int},tot} = P_{noise} + P_{\text{int},own} + P_{\text{int},other} = P_{noise} + (1+f)\cdot\sum_{s} N_s P_{RX,s}$$

By repeating the steps in section 2.2.2, it is easy to see that:

$$Load = (1+f)\cdot\sum_{s} Load_s = (1+f)\cdot\sum_{s}\frac{N_s \cdot SIR_s}{1+SIR_s} \qquad \text{Eq. 8}$$

$$Noiserise = 10\log\left[\frac{1}{1-Load}\right] \qquad \text{Eq. 9}$$

A typical value of *f* in a system consisting of three-sector sites is 0.65; however, it must be emphasised that *f* can change very much depending on the environment. To reduce the interference coming from other cells is an important task in the art of WCDMA cell planning. More about this in section 4.

Power rise

At this stage it is illustrative to discuss the phenomenon of power rise. Power rise is something that occurs when the inner loop power control in WCDMA tries to compensate for the multipath fading. The concept of power rise can be explained by means of the following example.

Look at a BS and a UE with a median path loss (predicted by the radio network planning tool) of 130 dB. Assume that the required SIR is –20 dB and that the BS noise power is –101 dBm. In a fading environment, the inner loop power control will try to keep the received power at the BS at a constant level of –101-20=-121 dBm. To accomplish this the median value of the UE power can be calculated as –121 +130 = 9 dBm. However due to the statistics of the multipath fading (Rayleigh) the *average value* will be higher. This difference between the median and the average value is called the power rise and is dependent on the channel model. For instance, the power rise in the ITU Pedestrian A channel model and speed 3 km/h is about 2 dB [1]. Thus the average power of the UE in the scenario would be 11 instead of 9 dBm.

It is customary to use two different types of SIR values (or Eb/Io), one which relates to the receiving side (in the example above $SIR_{RX} = -20$ dB) and one which relates to the transmitting side that includes the effects of power rise (in this case $SIR_{TX} = -20+2 = -18$ dB).

Considering the uplink it is easy to believe that the SIR_{TX} is irrelevant since the capacity is limited not by how much the UE transmits but rather by how much power the BS receives from every user. This reasoning would be correct in a system with only one cell, however the *adjacent cells* are not unaffected by the increase in UE power due to the power rise! In these cells the power rise will be experienced as increased interference or equivalently as an increased *f*.

In other words the *f* value is actually dependent not only by propagation aspects such as attenuation, antenna pattern etc but also on the channel model. For fast UEs the power control can not compensate for the multipath fading and thus there is no power rise. On the other hand the required Eb/Io of the receiving side is increased compared to a slowly moving UE.

2.2.6 Voice activity

Some services, like for instance speech, can benefit from the fact that the voice activity is less than 100%. The effect on the air interface of a reduced voice activity is simply that the average transmit power can be lowered.

The effect can be captured by introducing an activity factor in the load equation.

$$Load = (1+f)\cdot\sum_s Load_s = (1+f)\cdot\sum_s \frac{N_s \cdot SIR_s \cdot AF_s}{1+SIR_s \cdot AF_s} \qquad \text{Eq. 10}$$

For speech with a voice activity factor of 50%, *AF* will be approximately 67%. The reason that the activity factor is not identical to the voice activity factor is that control channel information must be transmitted continuously.

It should be emphasised that the usage of $AF = 67\%$ in Eq. 10 corresponds to the optimistic situation where at every instant the number of users being silent equals the number of users that are speaking. This corresponds to a situation of perfect averaging and is only correct for very large populations of subscribers.

Nevertheless, it is very interesting to see the large impact that the reduced interference has on the capacity in WCDMA. If only speech users had been considered, the number of users that could be admitted would be raised by 50%! This huge effect can not be expected in GSM. The reason is the poor averaging in GSM where each user experiences interference only from a few users.

3 DOWNLINK CAPACITY AND COVERAGE ESTIMATION

3.1 Introduction

Up till now, only the uplink has been considered. What about the downlink? Are there any big differences? Yes there are. The three most important differences are that:

1. All connections share one common power resource.

2. Each receiver experiences a unique interference situation.

3. The channels on the downlink are partly orthogonal.

As will be seen these three differences will have a large impact on the dimensioning process and unfortunately make the dimensioning process more complex.

3.2 Developping an equation for capacity and coverage

The starting point when developing a DL equation is the fact that all users share one power amplifier. This can mathematically be expressed as:

$$P_{TX,tot} = P_{CCCH} + \sum_{i=1}^{N} P_{TX,i} \qquad \text{Eq. 11}$$

The equation shows that the link budget is restricted of the size of the power amplifier, $P_{TX,tot}$. The more power each subscriber consumes $P_{TX,i}$ the fewer is the number of subscribers that the cell can support. Obviously, this is very different from GSM where each subscriber has its dedicated power resource. Some of the power is also required to transmit common control channels, like for instance the pilot channel and paging channels. The power allocated to common control channels is denoted by P_{CCCH}. Typically, the power amplifier limit is in between 10 and 20 W, and the power required for common control channels is in the order of 20% of the power total power, see for instance [2].