CHAPTER 3

WCDMA CAPACITY AND CALL ADMISSION CONTROL SCHEME

3.1 INTRODUCTION

This chapter provides an overview about effects that influence the capacity of the UMTS downlink. General problems of wireless communication due to wave propagation phenomenon as well as CDMA system aspects and special problems in the downlink direction are discussed. The second part of this chapter describes methods to overcome the mentioned difficulties and to improve the system performance in the downlink.

3.2 WAVE PROPAGATION

Wave Propagation over the mobile radio channel has the most significant influence on a mobile communication system's performance. The problem is that it is not possible to exactly describe all effects occurring during transmission over the channel. Therefore, statistical methods are used to characterize the channel behaviour. They do not exactly predict the received power level in a certain area, but gives a probability for a certain channel state. There are three main propagation phenomena, [54] i.e. small-scale fading, large-scale fading and path loss.

3.2.1 Small Scale Fading

Signals transmitted over the radio channel experience a lot of reflections and scattering, which leads to multipath propagation. This means that several replicas of one signal arrive at different times at the receiver. The different arrival times arise due to the different lengths of the propagation paths. Therefore, the multipath components arriving at the receiver have different phase values.
The superposition of the multipath components leads to constructive or destructive interference and hence to fluctuations of the received power level. In general, the signal drops caused by destructive interference, are called small-scale fading as the signal level changes over distances less than a wavelength.

3.2.2 Large Scale Fading

By averaging the received power over some wavelengths the effect of small-scale fading can be removed. The resulting distribution of the field strength shows variations over a larger scale, i.e. some tens of the wavelengths. The main reason for the large-scale variations is shadowing of multipath components caused by obstacles like buildings, trees or mountains.

3.2.3 Path Loss

Path loss effects describe the monotonic signal decrease caused by growing distance between the transmitter and the receiver. This could easily be shown with the free space propagation of an electromagnetic wave, described by Friis’s equation.

$$P_r(d) = P_t \times G_t \times G_r \times (\lambda/4\pi d)^2$$  \hspace{1cm} (3.1)

Equation shows the dependence of the received power $P_r$ on the distance $d$ if the transmitter as well as the receiver is placed in free space. The used symbols, $\lambda$, $P_t$, $G_t$ and $G_r$ denote the wavelength, the transmitted power and the antenna gains of the transmitting and receiving antenna respectively. The last term of Equation is usually denoted as free space loss. Furthermore, Equation is valid, if the far field condition is fulfilled. This means that the distance between the transmitting and receiving antenna has to be at least in the order of the Rayleigh distance $d_R$,

$$d > d_R = (2L^2/\lambda)$$  \hspace{1cm} (3.2)

with the largest antenna dimension $L$.

For realistic scenarios, Equation must be extended, in order to take the propagation over different kinds of obstacles with different electric and dielectric characteristics into account. Smooth surfaces produce reflections, while rough
surfaces cause scattering of the impinging waves. Other effects like diffraction around corners and edges of buildings or refraction within them are taken into account. There exist several empirical or semi-deterministic path loss models, describing different propagation environments, e.g. Okumura-Hata, COST-Walfisch-Ikegami.

The superposition of all the mentioned effects which occur during the propagation of the transmitted signals over the mobile radio channel lead to fluctuations of the received power levels and therefore variation of the Bit Error Rate (BER) of the detected bits.

### 3.3 INTERFERENCE

Interference is the main limiting factor in the performance of CDMA and plays therefore an important role in planning, setting-up and operating CDMA based mobile communication systems. The sources of interference include mobile users in the same cell, in neighbouring cells and other base stations in the surrounding. Unlike thermal noise which can be overcome by increasing the SNR, interference cannot be combated by higher transmission power. The problem is that the increased transmission power causes more interference to other users in the system. In general, interference has more influence on the performance in a CDMA system and hence it is an interference limited system. In the downlink the interference can be divided into: inter cell interference and intra cell interference [1, 19].

#### 3.3.1 Inter-cell interference

Inter-cell interference is the sum of the powers received from all base stations except the serving one. The inter-cell interference at the mobile station j can be calculated according to

\[
I_{\text{inter},j} = \sum_{k=1}^{K} P_k
\]  

(3.3)

where K is the total number of base stations not in connection with the mobile station j. The power received from the k\textsuperscript{th} base station is given by P\textsubscript{k}.
3.3.2 Intra-cell interference

Intra-cell interference is the total power received from the serving base station except the desired signals of the considered user. For the mobile station $j$ the intra-cell interference is given by

$$I_{\text{intra},j} = \alpha \left[ \sum_{i=1}^{N_c} P_i + P_c \right]$$

(3.4)

where $\alpha$ is the orthogonality factor, $N_c$ the number of users within the same cell as mobile station $j$, $P_i$ is the power received at mobile station $j$ but transmitted for the $i^{\text{th}}$ user and $P_c$ is the sum of all common channel powers. The orthogonality factor $\alpha = [0:1]$ depends on the multipath environment. Even if the base station serves only one user, interference due to loss of orthogonality denoted by $\alpha$ is produced.

3.3.3 Code Orthogonality

In the UMTS downlink, OVSF codes are used to separate different physical data or control channels. All OVSF codes for one spreading factor are perfectly orthogonal, as long as they are synchronous.

The problem is that in reality the orthogonality [19, 55] is reduced due to the delay between different multipath components at the mobile station. One mobile receives all signals transmitted from the base station to the users within a cell. The signals are perfectly orthogonal in a flat fading scenario. However, in a multipath environment the mobile receives the superposition of time-shifted versions of the original signals. The codes of these temporally shifted signals are no longer orthogonal which leads to interference. The larger the distance between the base station and the mobile, larger the time shifts between the arriving multipath components and therefore the larger the produced interference. The interference generated due to the mentioned effect, is called intra-cell interference, because only signals of one base station interfere with each other.
But multipath propagation implicates even a strong advantage. If the signals of the different multipath fade independent and if their delay is large enough, their superposition could improve the signal quality dramatically.

### 3.4 UPLINK LOAD FACTOR ESTIMATION

The theoretical spectral efficiency of a WCDMA cell can be calculated from the load equation whose derivation is shown below. $E_b/N_0$ can be defined as energy per user bit divided by the noise spectral density [1]:

$$
(E_b / N_0)_j = \text{Processing gain of user } j \times \frac{\text{Signal of user } j}{\text{Total received power}}
$$

This can be written as

$$
(E_b / N_0)_j = \frac{W}{v_j R_j I_{\text{total}} - P_j}
$$

(3.5)

where

- $E_b/N_0$ bit energy to noise density ratio of $j^{\text{th}}$ user
- $W$ chip rate,
- $P_j$ received signal power from jth user
- $v_j$ activity factor of $j^{\text{th}}$ user
- $R_j$ bit rate of $j^{\text{th}}$ user
- $I_{\text{total}}$ total received wideband power including thermal noise power in the base station.

Solving for $P_j$ gives

$$
P_j = \frac{1}{W(I_{\text{total}})} I_{\text{total}}
$$

(3.6)
To obtain the load factor $L_j$ of one connection

$$L_j = \frac{1}{1 + \left(\frac{E_b}{N_0}\right)_j R_j v_j}$$  \hspace{1cm} (3.7)

where

$L_j$ - load factor for one connection

The total received interference, excluding the thermal noise $P_N$, can be written as the sum of the received powers from all $N$ users in the same cell

$$I_{total} - P_N = \sum_{j=1}^{N} P_j = \sum_{j=1}^{N} L_j I_{total}$$  \hspace{1cm} (3.8)

where

$P_N$ - Noise power

The noise rise is defined as the ratio of the total received wideband power to the noise power

$$\text{Noise rise} = \frac{I_{total}}{P_N}$$  \hspace{1cm} (3.9)

$$\text{Noiserise} = \frac{I_{total}}{P_N} = \frac{1}{1 - \sum_{j=1}^{N} L_j} = \frac{1}{1 - \eta_{UL}}$$ \hspace{1cm} (3.10)

The load factor can be defined $\eta_{UL}$ as

$$\eta_{UL} = \sum_{j=1}^{N} L_j$$ \hspace{1cm} (3.11)

When $\eta_{UL}$ becomes close to 1, the corresponding noise rise approaches infinity and the system has reached its pole capacity. Additionally, in the load factor
the interference from the other cells must be taken into account by the ratio of other cell to own cell interference \( i \)

It is given as

\[
i = \frac{\text{other cell interference}}{\text{own cell interference}}
\]

The uplink load factor can then be written as

\[
\eta_{UL} = (1 + i) \sum_{j=1}^{N} \frac{1}{W} \frac{1}{1 + \frac{(E_b/N_0)_j R_j v_j}{(E_b/N_0)_i R_i v_i}}
\]  
(3.12)

where \( i \) is denoted as the other cell interference to own cell interference ratio

The load equation predicts the amount of noise rise over thermal noise due to interference. The required \( E_b/N_0 \) can be derived from link level simulations, from measurements and from the 3GPP performance requirements. 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 cell interference ratio \( i \) is a function of cell environment or cell isolation and antenna pattern.

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 \( R_j \), it can be noted that

\[
\frac{W}{E_b/N_0 R_v} \gg 1
\]  
(3.13)

and the above uplink load equation can be approximated and simplified to
\[ \eta_{UL} = \frac{E_b / N_o}{W / R} N v (1 + i) \]  

(3.14)

3.5 DOWNLINK LOAD FACTOR ESTIMATION

The downlink load factor \( \eta_{DL} \), can be defined based on a similar principle as for the uplink, although the parameters are slightly different. Compared to the uplink load equation, the most important new parameter is \( \alpha_{av} \), which represents the orthogonality factor in the downlink.

\[ \eta_{DL} = \sum_{j=1}^{N} R_j v_j \left( \frac{E_b / N_o}{W} \right) \left[ (1 - \alpha_{av}) + i \right] \]  

(3.15)

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 propagation environment [1].

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 \( j \). The load factor can be approximated by its average value across the cell, that is

\[ \eta_{DL} = \sum_{j=1}^{N} R_j v_j \left( \frac{E_b / N_o}{W} \right) \left[ (1 - \alpha_{av}) + i \right] \]  

(3.16)

3.6 ERLANG AND NETWORK CAPACITY

Voice network use the Erlang as a standard measure of capacity. The Erlang is a measure of total voice traffic in one hour, usually classified as the busy hour (BH) which is the 60 minute interval during a 24 hour period in which the traffic
load is at a peak. One Erlang is equivalent to one user talking for one hour on one telephone.

There are some variations in the Erlang model. The most common one is the Erlang B, which is used to calculate how many lines are required to meet a given minimum call blocking, usually 2-3% during this BH.

For cellular systems, it is used to estimate capacity per cell at base stations. The Erlang B formula assumes that all calls that are blocked are cleared immediately. This means that if a user attempts to connect and cannot, they will not try again. An extended form of Erlang B factors in that a certain percentage of users who are blocked will immediately try again. This is more applicable to the cellular environment, since if blocked many users will immediately hit the redial button. These Erlang C model is the most complex since it is assumes that a blocked call is placed in a queue until the system can handle it.

Erlang= No. of calls in one hour x average call duration/60

3.7 ADMISSION CONTROL PRINCIPLE

If the air interface loading is allowed to increase excessively, the coverage area of the cell is reduced below the planned values, and the quality of service of the existing connections cannot be guaranteed. Before admitting a new UE, admission control needs to check that the admittance will not sacrifice the planned coverage area or the quality of the existing connections. Admission control accepts or rejects a request to establish a radio access bearer in the radio access network. The admission control algorithm is executed when a bearer is set up or modified.

The admission control functionality is located in RNC where the load information from several cells can be obtained. The admission control algorithm estimates the load increase that the establishment of the bearer would cause in the radio network. This has to be estimated separately for the uplink and downlink directions. The requesting bearer can be admitted only if both uplink and downlink
admission control admit it, otherwise it is rejected because of the excessive interference that it would produce in the network. The limits for admission control are set by the radio network planning.

Several admission control schemes have been suggested, the use of the total power received by the Node B is supported as the primary uplink admission control decision criterion, relative to the noise level. The ratio between the total received wideband power and the noise level is often referred to as the noise rise.

### 3.8 CALL ADMISSION CONTROL SCHEME

The Call admission control is one of the major tasks of radio resource management (RRM), when a new connection is set up, the call admission control will guarantee that there are free radio resources. In addition, CAC determines which base station will have power control and must have sufficient bandwidth to support the new connection without dropping any of the existing ones. If this condition is not met, new connection request will be rejected. This check is done whenever a user enters a new cell, either through a new call or handover call.

#### 3.8.1 Wideband Power-based Admission Control Strategy

In the interference-based admission control strategy the new UE is not admitted by the uplink admission control algorithm if the new resulting total interference level is higher than the threshold value:

$$ I_{\text{total-old}} + \Delta I \leq I_{\text{threshold}} $$

(3.17)

The threshold value $I_{\text{threshold}}$ is the same as the maximum uplink noise rise and can be set by radio network planning. This noise rise must be included in the link budgets as the interference margin. The uplink admission control algorithm estimates the load increase by using either of the two methods, the first method is the derivative method and the second is the integral method.
They can be used in the interference-based admission control strategy. The idea is to estimate the increase \( \Delta I \) of the uplink received wideband interference power \( I_{\text{total}} \) due to a new UE. The admission of the new UE and the power increase estimation are handled by the admission control functionality.

The downlink admission control strategy is the same as in the uplink, i.e. the UE is admitted if the new total downlink transmission power does not exceed the predefined target value:

\[
P_{\text{total-old}} + \Delta P \leq P_{\text{threshold}}
\]

(3.18)

The threshold value \( P_{\text{threshold}} \) is set by radio network planning. Notice that \( \Delta P \) both includes the power of the new UE requesting capacity and the additional power rise of the existing UEs in the system due to the additional interference contributed by the new UE. The load increase \( \Delta P \) in the downlink can be estimated based on a priori knowledge of the required \( E_b/\eta_0 \), the requested bit rate, and the pilot report from the UE. The pilot report implicitly provides information on the path loss towards the new UE as well as the interference level experienced by the UE.

### 3.8.2 Throughput-based Admission Control Strategy

In the throughput-based admission control strategy, the new requesting UE is admitted into the radio access network if

\[
\eta_{UL} + \Delta L \leq \eta_{UL,\text{threshold}}
\]

(3.19)

and the same in downlink:

\[
\eta_{DL} + \Delta L \leq \eta_{DL,\text{threshold}}
\]

(3.20)

where \( \eta_{UL} \) and \( \eta_{DL} \) are the uplink and downlink load factors before the admittance of the new connection and are estimated. Finally, we need to note that different admission control strategies can be used in the uplink and in the downlink.
3.8.3 CAC for WCDMA

The two most commonly used call admission control schemes are Wideband Power Based (WPB) scheme and Throughput Based (TB) scheme. The principle of this scheme is a new user is admitted when the new load factor after the new user’s admission does not exceed the predefined threshold. The uplink and downlink directions are considered and only if the condition is met, the new connection request can be admitted [56-59].

The new load factor for the network uplink or downlink is the sum of the existing uplink or downlink load factor and the increase in load factor $\Delta L$.

$$\eta_{\text{New}} = \eta_{\text{Old}} + \Delta L$$  \hspace{1cm} (3.21)

The computation of the uplink existing load factor and the downlink existing load factor is calculated using equation (3.22) and (3.23) respectively.

The computation of $\eta_{UL}$ is given by

$$\eta_{UL} = (1 + i) \sum_{j=1}^{N} \frac{1}{1 + \frac{W}{(E_b/N_o)_j R_j v_j}}$$  \hspace{1cm} (3.22)

where

- $W$ chip rate
- $v_j$ voice activity factor of $j^{th}$ user
- $R$ bit rate of $j^{th}$ user
- $E_b/N_o$ bit energy to noise density ratio of $j^{th}$ user
- $i$ total interference
- $N$ number user

The computation of $\eta_{DL}$ is given by
\[
\eta_{1\alpha} = \sum_{j=1}^{N} R_j \frac{v_j(E_b/N_0)}{W} [(1 - \alpha_{av}) + i]
\] (3.23)

\[\alpha_{av} \] average orthogonality factor of the cell.

### 3.9 Utility Function Based CAC Scheme

The performance of utility function based CAC algorithms is analyzed in the downlink channel of WCDMA network. The downlink load factor is set to 0.7 to maintain the channel load without affecting the QoS. Within the load factor limit of the channel the load factor for different services are selected according to the service needs and QoS. The new call request is admitted as per flow chart and it is shown in figure 3.1.

The new load factor for the downlink is the sum of the existing downlink load factor \( \eta_{DL} \) and the increase in the load factor \( \Delta L \). The new load factor cannot exceed a predefined threshold:

\[
\eta_{DL} + \Delta L \leq \eta_{DL\text{threshold}}
\] (3.24)

\( \eta_{DL\text{threshold}} \) downlink load factor threshold value

Initially the call is identified as whether it is a voice call or data call and then it is checked for the resource availability as per load factor threshold value for individual service. The sum of new call load and existing connection load is less than the threshold value of individual services then the call is admitted otherwise it is rejected.

\[
\eta_{DL\text{voice}} + \Delta L \leq \eta_{DL\text{voice\text{threshold}}}
\] (3.25)

\[
\eta_{DL\text{data}} + \Delta L \leq \eta_{DL\text{data\text{threshold}}}
\] (3.26)

\( \eta_{DL\text{voice\text{threshold}}} \) downlink load factor voice threshold value.

\( \eta_{DL\text{data\text{threshold}}} \) downlink load factor data threshold value.
One major limitation of the fixed threshold schemes is that the reserved [60] capacity for voice traffic classes may remain unutilized while video priority classes are being blocked. In the proposed scheme the unutilized resources are utilized by blocked users of the fixed threshold scheme. This will improve the capacity of the network as well as reduces the call blocking probability of the network.

Figure 3.1 Flow chart of utility based CAC scheme
3.10 UTILITY FUNCTION ALGORITHM

The step-by-step service utilization function algorithm for capacity calculation for WCDMA network using Utility Based CAC scheme is described below:

Step 1: When user accesses network, its service will be distinguished either into voice or data service.

Step 2: If it is voice service it will go to step 3 else it will go to step 5.

Step 3: The load of new voice user will be calculated with guaranteed QoS.

Step 3: The current voice load will be updated by adding the load of new voice user whenever user access the service.

Step 4: If the updated load is less than its predefined voice threshold value, the user will be accepted.

Step 5: If the current load exceeds its threshold value, the new voice user will be rejected due to non availability of resource.

Step 6: Current data load will be updated by the calculated load of new data user with assured QoS.

If updated load is less than its threshold the user will be accepted to provide service

Else the utility function checks the availability of voice load.

Step 7: The user is accepted if updated voice load, new data load will be added with current voice load, is less than its threshold value.

Step 8: Else data user will be blocked due to insufficient load.
3.11 SUMMARY

In this chapter, the WCDMA network capacity calculation for forward channel and reverse channel is solved from the fundamental. The factors which are associated with load factors calculation are considered in this study. The optimization of capacity calculation problem with more than one objective, the multi-objective problem is converted into single-objective problem using suitable CAC scheme. To improve the capacity of the network with limited recourses a new CAC scheme is proposed in this chapter. The network recourses are effectively utilized based on the proposed utility based CAC scheme.