DIPLOMARBEIT

Optimum Default Base Station Parameter Settings for UMTS Networks

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unter der Leitung von

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Zusammenfassung

Die große Anzahl an Benutzern und die hohen Lizenzgebühren für Frequenzbänder im Mobilfunk machen es notwendig, die Frequenzen so gut wie möglich auszunützen. Das WCDMA-System in UMTS bietet im Vergleich zu Systemen aus der zweiten Generation schon eine sehr gute Lösung für hohe spektrale Effizienz, zum Beispiel durch Wegfall der Schutzbänder zwischen den einzelnen Trägern oder durch variable Datenraten. Durch den Frequenz-Wiederhol-Faktor von 1 und die daraus resultierende Inter-Zell- und Intra-Zell-Interferenz kann man eine hohe spektrale Effizienz jedoch nur erreichen, wenn die Parameter des UMTS-Netzes optimal eingestellt sind. Nur durch ständige Optimierung der Netzparameter kann eine gewisse Qualität, hohe Kapazität und somit der größtmögliche Gewinn für den Netzbetreiber garantiert werden.

In zellulären CDMA-Netzen gibt es unzählige einstellbare Parameter, die voneinander abhängig sind und deren Wirkung auf das Netz höchst nichtlinear ist. Als Folge dieser Komplexität spielen Simulationen von zellulären Systemen eine wichtige Rolle im Netzaufbau und in der Netzoptimierung. Außerdem werden automatisierte Optimierungs-Algorithmen benötigt um die Optimierungs-Prozesse effizient durchführen zu können. Diese Optimierungs-Algorithmen erfordern viele Bewertungen von verschiedenen Parameter-Einstellungen, benötigen dabei viele Simulationen des UMTS-Netzes und sind dadurch sehr zeitaufwändig.

In der vorliegenden Arbeit wurden Strategien für die automatisierte Einstellung von Antennen-Azimut, Antennen-Neigungswinkel und CPICH-Leistung entwickelt, mit dem Ziel, unabhängig von der Verteilung der Mobilstationen im Szenario die optimale Grundeinstellung der drei Schlüsselparameter zu erreichen. Im Gegensatz zu den zeitaufwändigen adaptiven schrittweisen Optimierungs-Algorithmen, die viele Simulationen erfordern, finden diese Strategien die optimalen Parameterwerte in nur einem Schritt, in einem so genannten "ad hoc" Vorgang. Anstatt der nahezu "blinden", versuchsweisen Suche nach

besseren Einstellungen in den schrittweisen Algorithmen, soll in diesen "ad hoc" Strategien aufgrund des Wissens über zelluläre CDMA-Systeme direkt von der Netzstruktur auf die optimale Grundeinstellung der Parameter geschlossen werden.

Diese Grundeinstellung der Parameter durch die Strategien aus der vorliegenden Arbeit ist auch als Starteinstellung für darauf folgende adaptive schrittweise Optimierungs-Algorithmen gedacht. Diese erreichen dadurch ihr Ziel möglicherweise in einer kürzeren Zeit und erzielen dabei eventuell sogar ein besseres Ergebnis.

Die MATLAB-Programme für die Automatisierung der Strategien verwenden einen statischen UMTS Frequency Division Duplex (FDD) Netzsimulator um zur optimalen Grundeinstellung der Schlüsselparameter zu gelangen. Hierfür sind nur drei Simulationen notwendig. Die Bewertung der Strategien wird mit dem selben Netzsimulator mittels eines virtuellen Szenarios der Stadt Wien vorgenommen. Die Ergebnisse zeigen, dass die Strategien in der Lage sind, eine sehr gute Grundeinstellung der Parameter zu finden. In der vorliegenden Arbeit werden die Ergebnisse dieser optimalen Grundeinstellung auch mit Ergebnissen von schrittweisen Optimierungs-Algorithmen verglichen. Dabei wird gezeigt, dass fast die gleiche Kapazität erzielt werden kann, und der Vorteil der "ad hoc" Strategie darin liegt, dass ein Bruchteil an Rechenleistung und Zeit benötigt wird.

Abstract

The large number of users and the high license fees for frequency bands in mobile radio communications are forcing the operators to exploit the existing resources as much as possible. The WCDMA system in UMTS is the right approach to better frequency usage, but due to the frequency reuse factor of 1 and the resulting inter-cell and intra-cell interference, high spectrum efficiency in WCDMA can be reached only if the network is running with optimum parameter adjustments. Only constant optimisation of the network parameters can guarantee a certain QoS, a high capacity, and therefore the highest profits for the operators.

In CDMA cellular networks there are numerous configurable parameters which are interdependent, and their influence on the network is highly non-linear. Hence, finding optimum network configuration is a very complicated and difficult task. As a result, simulations of cellular systems play an important role in the initial design, deployment and optimisation. Automated optimisation algorithms are needed to perform the optimisation process efficiently. However, these optimisation algorithms need many evaluations of the network with different parameter settings, and therefore are very time-consuming.

In this work, a strategy for automatic adjustment of antenna azimuth, antenna downtilt and CPICH power level is developed in order to reach an optimum default parameter setting of these three key parameters, independent of the user distribution in the scenario. The strategy is in contrast to time-consuming adaptive step by step optimisation algorithms and adjusts the parameters in an 'ad hoc' manner only by analysing the structure of the UMTS network. The idea is to use knowledge about cellular CDMA networks for reaching an optimum default setting of the key parameters in one or only few steps, instead of 'almost blind' trials of different parameter settings as in step by step optimisation algorithms.

This optimum default parameter setting is intended to be used as the initial setting for a further adaptive step by step optimisation. Thus the following optimisation algorithms could be accelerated and maybe even reach better results.

The MATLAB routines of the strategy are using a UMTS Frequency Division Duplex (FDD) static radio network simulator. To obtain the optimum default parameter setting, only up to three simulations are necessary. The performance of the strategy is evaluated by using the same network simulator on a virtual scenario of Vienna city. The results show that the strategy is able to reach a good default parameter setting compared to the improvements of adaptive step by step optimisation algorithms, and furthermore less computational effort is needed.

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Contents

List of Figures

List of Tables

Abbreviations

3G	3rd Generation
3GPP	3rd Generation Partnership Project
ACIR	Adjacent Channel Interference Ratio
AICH	Acquisition Indicator CHannel
BS	Base Station
CPCH	Common Packet CHannel
CPICH	Common Pilot CHannel
DL	Downlink
DL-DPCCH	Downlink Dedicated Physical Control CHannel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GoS	Grade of Service
GSM	Global System for Mobile Communication
IS-136	North American TDMA
IS-95	North American Version of the CDMA Standard
ISIR	Inter System Interference Ratio
KPI	Key Performance Indicator
MRC	Maximum Ratio Combining
MS	Mobile Station
OVSF	Orthogonal Variable Spreading Factor
P-CCPCH	Primary Common Control Physical CHannel
P-CPICH	Primary Common Pilot CHannel
PCH	Paging CHannel
PDC	(Pacific) Personal Digital Cellular

PICH	Paging Indicator CHannel
PN	Pseudo Noise
PSD	Power Spectral Density
QoS	Quality of Service
RAN	Radio Access Network
RSCP	Received Signal Code Power
RSSI	Received Signal Strength Indicator
S-CCPCH	Secondary Common Control Physical CHannel
S-CPICH	Secondary Common Pilot CHannel
SCH	Synchronisation CHannel
SHO	Soft Hand Over
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TPC	Transmission Power Control
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UTRA(N)	Universal Terrestrial Radio Access (Network)
WCDMA	Wideband Code Division Multiple Access
XML	Extensible Markup Language

List of Symbols

α_k	Orthogonality factor of cell k
β_k	Scaling factor (relative maximum link powers) for different base stations in the active set
C	Power level of the carrier
E_c/I_0	Ratio of the received energy per PN chip to the total received power spectral density at the UE antenna connector
E_b/I_0	Ratio of the bit energy to the total received power spectral density at the UE antenna connector
E_b/N_0	Ratio of the bit energy to the noise power spectral density
G_p	Processing gain of the link
I	Power level of the Interference
I_k	Total wideband power received at the mobile station from base station k
I_{oth}	Inter-cell interference
I_{own}	Intra-cell interference
I_{tot}	Total wideband interference power received at the mobile station
i	Other to own cell received power ratio
K_N	Number of MS connected to base station N
L_p	Propagation path loss between base station and mobile station
L_{p_k}	Link loss from base station k to the mobile station
N_0	Background noise
ν	Service activity

P_{common}	Average transmit power of the common channel
P_{CPICH}	CPICH power of the best server
P_n	Required transmit power for the connected user n
$P_{T,max}$	Maximum base station transmit power capability
P_{TX}	Maximum transmit power on one channelisation code on a given carrier
$P_{TX,MS}$	Needed transmit power in the MS
η	Cell load
$\eta_{UL\_threshold}$	Planned maximum permissible level of uplink cell load
R	Bit rate
ρ	E_b/I_0 requirement
W	WCDMA chip rate

Chapter 1

Introduction

1.1 Introduction to Radio Network Optimisation for UMTS

The first generation of mobile communication was an analog cellular system. In the second generation, the wireless communication systems became digital and are called GSM (global system of mobile communication), cdmaOne (IS-95), US-TDMA (IS-136) or PDC (pacific digital cellular, 2nd generation cellular system in Japan). These systems have enabled wireless voice communication in most countries all over the world, and customers are also provided with other services such as text messaging and access to data networks.

Due to the increasing demand for multimedia communication a new system was designed. The third generation (3G) mobile communication system, in Europe known as the Universal Mobile Telecommunications System (UMTS), is able to deliver high-value broadband information and commercial as well as entertainment services to mobile users. Enabling anytime, anywhere connectivity to the internet is just one of the opportunities for UMTS networks. UMTS will bring more than just mobility to the internet. The major market opportunity will build on new possibilities for mobile users like multi-media-messaging, location-based services, personalized information, and entertainment. Nobody knows the killer application up to now, but all agree in one point: packet data will increasingly dominate the traffic flows.

Due to the fact that GSM is a TDMA (Time Division Multiple Access) / FDMA (Frequency Division Multiple Access) system, we are not able to reach high spectral efficiency because of the necessary guard bands between different carriers in FDMA. There is also the problem of blocking one channel in up- and downlink actually using one direction.

The need for higher spectral efficiency, bit rates up to 2Mbit/s, variable data rates, multiplexing of services with different QoS requirements on a single connection and the support of asymmetric uplink and downlink traffic led the standardization forums to WCDMA (Wideband Code Division Multiple Access) technology as the most widely adopted third generation air interface. Its specification has been created in 3GPP (the 3rd Generation Partnership Project) where WCDMA is called UTRA (Universal Terrestrial Radio Access). In WCDMA the frequency reuse factor is 1, that means that neighbouring cells are transmitting in the same frequency band and therefore causing mutual interference. This point together with the variable datarates, different available services with different QoS and the asymmetric up- and downlink traffic causes the main problems in optimising UMTS networks.

Throughout this thesis I am focussing on the FDD(Frequency Division Duplex) mode of WCDMA.

1.1.1 Why Radio Network Optimisation in UMTS ?

The frequency spectrum is limited and therefore we must try to get the highest throughput in the frequency band available to each UMTS network operator. The WCDMA system with its flexibility in data rates and different services and its missing guard bands between the different carriers (there is only one carrier) is the right approach to better frequency usage, but because of the frequency reuse factor of 1 and the resulting intercell and intracell interference we can reach high spectrum efficiency in WCDMA only when the network is running with optimum parameter adjustments.

For the network operators in most countries the launch of UMTS is connected with both enormous expenditures for the licences for the UMTS frequency bands as well as heavy investments in UMTS infrastructure. This huge amount of money has to be earned by the operators before getting revenues out of their networks. Only constant optimisation of the network parameters can guarantee a certain QoS, the highest possible throughput, the highest capacity and therefore the highest profits for the operators.

1.1.2 Technical Challanges in UMTS Network Optimisation

Now, where are the problems especially in optimising UMTS networks compared to GSM networks? The GSM system is based on FDMA/TDMA, which means that each user is allocated one time-frequency slot. Due to the fact that each operator only has a limited spectrum, the frequencies have to be re-used within a certain distance. This causes co-channel interference and so frequency planning to minimize the interference from cells using the same frequencies, is an important task in GSM system opimisation. But GSM is not interference limited in the CDMA sense. So the system coverage can be well seperated from the capacity aspect and to get higher capacity in a cell, it is enough to assign more frequencies to this cell.

As already mentioned above, the UMTS system is based on a Wideband Code Division Multiple Access (WCDMA) technique. CDMA systems are interference limited in nature. The direct consequence of this is that capacity and service-coverage estimation cannot be seperated anymore, and because of a frequency reuse factor of one in UMTS the interference of the whole system has to be modeled simultaneously. To understand this we have a look at Equation (1.1),

$$\frac{E_b}{N_0} = \frac{W}{R} \cdot \frac{C}{I} = G_p \cdot \frac{C}{I} \tag{1.1}$$

where E_b/N_0 is the bit energy to noise power spectral density ratio. The processing gain of the link is given by $G_p = W/R$, where W is the chip rate and R is the bit rate of the user. The carrier power is represented by C, and I is the interference. To reach the QoS targets of this link, it has to be recieved with a certain E_b/N_0. The processing gain of the link is fixed because of the data rate of the user. So, if we want to have a higher capacity in one cell, we have to transmit more power for the additive links. This raises the interference for the other links at the same time, and the system coverage shrinks.

Another problem in UMTS network optimisation is the main advantage of the UMTS system: the mixed services with variable data rates. When looking at Equation (1.1) again we can see that at a higher bit rate we have to use higher transmit power to reach the same E_b/N_0. As a consequence of that, the interference for the other users rises. Therefore the capacity, which can be calculated for a given system, will heavily depend on the service profile of the individual users as well. To guarantee high data rates for all users, we would need more base stations to reach the desired system coverage, or, since finding new base station sites can be quite difficult, a good optimisation strategy for the existing network.

1.2 UMTS Network Optimisation Algorithms

The CDMA cellular networks are very complex. There are numerous configurable parameters which are interdependent and their influence on the network is highly non-linear. Hence, finding optimum network configuration is a very complicated and difficult task. As a result, computer simulations of cellular systems play an important role in the initial design, deployment and optimisation, and automated optimisation algorithms are needed

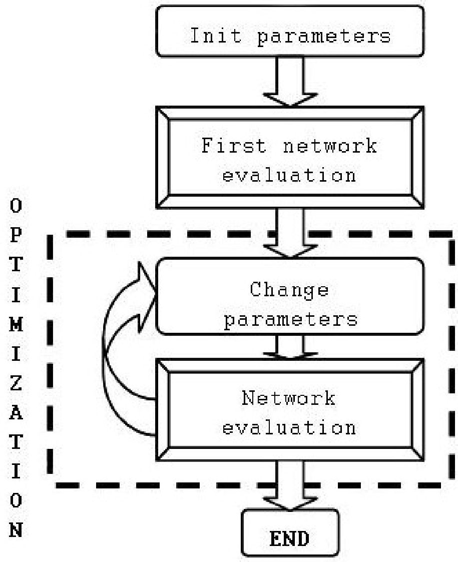

Figure 1.1: Structure of optimisation process

to perform the optimisation process efficiently. There is some published research [1, 4, 5, 6] regarding various methods and algorithms for the individual control of base station parameters such as CPICH (Common Pilot CHannel) power and antenna downtilt settings, which are the two most common optimisation parameters that have significant influence on network capacity.

In [4] different algorithms are researched and evaluated on two different network scenarios and planning tools. The optimisation of the base station parameters (CPICH power level, antenna downtilt) starts with a first evaluation of the network. After analysing the results of the first evaluation the iterative optimisation process is launched. Each optimisation loop includes two steps. In the first step the parameters are changed according to a certain optimisation technique (e.g. Rule Based Algorithm, Simulated Annealing). After changing the parameters, the network is evaluated in the second step. Then the next iteration of the optimisation loop is started and the parameters are changed again. The optimisation is running until a specific terminating condition is fulfilled. In Figure 1.1 the flow chart of the optimisation process is shown.

The evaluation of the network is done by looking at the Key Performance Indicators (KPI) [1] of the RAN (Radio Access Network) in the output of the network simulator. Typical KPIs are: the average load, the throughput or the soft handover overhead for example. Beside these KPIs there are important output parameters, like the number of served users in the target area or the Grade of Service (GoS) which is defined as:

$$GoS = \frac{served}{existing} \tag{1.2}$$

Served is the total number of served users in a defined target area and *existing* is the total number of users in this area. The GoS denotes the probability that a specific service is available. The operators of UMTS networks usually try to guarantee a minimum GoS of about 90 percent.

As a summary we can say that the task of UMTS network optimisation algorithms is to adjust the network parameters according to some rules to get the highest number of served users in the target area with the side constraint of a certain GoS. The rules in the optimisation process are based on the KPIs of the system.

1.3 Motivation for this Thesis

I will come to the motivation for this thesis now.

- As we have seen in 1.1.2, it is necessary in WCDMA systems to simulate the whole network at once because of the interference limitation and the frequency-reuse factor of one. But due to the complexities of the UMTS networks, the simulation of an entire real cellular system, such as in the case of a major city wide deployment, is very time consuming and requires an inordinate amount of computing power. The optimisation algorithms need many simulation runs of the network and therefore will be very time consuming as well.
  So the question is: Is there a possibility to find default parameter settings in a so called 'educated guess' to get close to the optimum or at least achieve high system capacity? In this case 'educated guess' means having a look at the network and adjusting the parameters of the system in one step in an 'ad hoc' manner by using knowledge about UMTS cellular networks. This idea is in contrast to the step by step adjustment of the optimisation algorithms in [4] or [6]. However, optimisation algorithms using the result of this 'ad hoc' adjustment as initial parameter setting, are probably able to reach their result in a shorter time.

- The optimisation algorithms mentioned in 1.2 use the KPIs from the output of the network simulator as a basis for the rules to adjust the key optimisation parameters in each step. These algorithms never look at the network itself. They don't take into account e.g. the distance and height of the BSs or the height structure of the area and hence, these algorithms are almost 'blindly' searching for better results. Therefore a good question in this point is: Is there a possibility of finding good parameter adjustments by looking at the structure of the UMTS network only without taking into account the output of the simulator or the user distribution?

- In [6] the final capacity of the UMTS network after running an optimisation algorithm was researched in dependency of the starting parameter settings of the system before the optimisation. The result was that the initial adjustment of e.g. the downtilt of the antennas has a great influence on the gain of the optimisation process. Hence, probably with a good initial default parameter setting, taking into account the structure of the network, the optimisation algorithms are able to reach even a better result in capacity or system coverage.

1.4 Objectives of this Thesis

The scope of research in this thesis can be devided as follows:

1. Analyse and identify the capacity limitation factors in the UMTS Radio Network.
2. Identify the key optimisation parameters and investigate their influence on network capacity.
3. Find an 'ad hoc' strategy for adjusting the key optimisation parameters antenna azimuth, antenna downtilt and CPICH power which is independed of the instantaneous user distribution.
4. Build a MATLAB routine to adjust the key optimisation parameters automatically, using the simulator software CAPESSO from SYMENA, Software & Consulting GmbH, Austria.
5. Analyse the results of this automated 'ad hoc' adjustment routine by using the simulator software CAPESSO.

The main objective of this thesis is to find a good default parameter setting for the key optimisation parameters antenna azimuth, antenna downtilt and CPICH power level. This adjustment of the three key parameters should be reached in an 'ad hoc' manner by analysing the structure of the UMTS network. The parameter setting is good, if the system is able to serve a passable high number of users in a target area, compared to the capacity results of the optimisation algorithms in [4] or [6].

The following are the objectives of this default parameter setting:

- To reach an improvement in capacity of the system in a short time compared to the optimisation algorithms in [4].
- To accelerate the following optimisation process: The following optimisation algorithms should be able to reach their final result in a shorter time by using this default parameter setting as initial values.
- To reach an even better result with optimisation algorithms by using this default parameter setting as an initial parameter adjustment.

1.5 Outline

This thesis has the following structure: In Chapter 2, UMTS radio network capacity limiting factors are discussed and possible solutions are given. Chapter 3 presents the key optimisation parameters I am focussing on in this thesis and their influence on the capacity of the network is explained in detail. Chapter 4 is a description of the simulation environment. The main characteristics of the used simulator are specified as well as the simulation scenario, the user distribution in this scenario and the used antenna pattern. Chapter 5 describes the different ideas for the optimisation strategies for the individual key optimisation parameters. In Chapter 6 the developed MATLAB routines for automatic adjustment are explained in detail and Chapter 7 presents some results achieved with these automatic adjustment routines. Finally, Chapter 8 summarises and concludes the thesis and gives a brief outlook on possible future work.

Chapter 2

Coverage and Capacity limiting Factors

2.1 Introduction

In WCDMA systems coverage and capacity enhancement methods cannot be separated anymore like in GSM. Some of the methods improve coverage at the cost of capacity, while others improve capacity and decrease coverage. Therefore, understanding and identifying the limiting factors is important in being able to develop an optimisation strategy for increasing the network capacity and improving the system coverage effectively at the same time.

UMTS Radio network coverage and capacity can be either uplink or downlink limited depending upon the site configuration, terminal performance and traffic profile [1].

When a cell's capacity limitation is reached, additional users cannot be served and are therefore put to outage. Outaged users are within the coverage area of a cell, but unable to access to the network services due to other reasons.

This chapter provides the basis for understanding the reasons for limited service coverage and capacity in the uplink and downlink, and some solutions for enhancement are presented.

2.2 Uplink and Downlink Coverage-limited Scenarios

The majority of existing literature makes the assumption that service coverage is uplink limited [1]. In general this is true, though it is fairly easy to identify scenarios where service coverage is downlink limited, for example when the data rate is asymmetric (more traffic in downlink) and the base station has a limited transmit power capability.

The simplest method for studying service coverage performance is using a link budget (see e.g. [1]). A link budget is also useful to identify which parameters need to be improved to enhance service coverage performance. WCDMA link budgets follow the same basic principles as those for GSM. The main differences are the inclusion of processing gain, E_b/I_0 requirement, soft handover gain, target uplink cell loading and a headroom to accommodate the power control [1]. The service coverage is uplink or downlink limited as indicated by the lower allowed propagation loss figure in the link budget.

Obviously the highest data rate service defines the cell range in terms of the allowed propagation loss. Hence, planning the network for 384kbit/s service coverage will be sufficient to ensure acceptable coverage performance for lower data rate sevices.

The main techniques for improving service coverage are active antennas, mast head amplifiers, higher-order receive diversity, increased sectorisation and repeaters. Improving any of the parameters in the link budget will lead to an improvement in service coverage performance. However, improving service coverage leads to a greater average base station transmit power requirement per downlink connection. If the system capacity is uplink limited, then this is of no consequence. But if the system capacity is downlink limited, then improving service coverage will lead to a loss in system capacity. A different approach would be to improve the E_b/I_0 performance. Then it is possible to simultaneously enhance both service coverage and system capacity.

2.3 Uplink Capacity-limited Scenarios

The available uplink power and the uplink cell load form the limiting factors for uplink capacity-limited systems. The first case is a limiting factor when the mobile does not have enough transmit power to achieve the required bit energy to interference plus noise density ratio (E_b/I_0) to access the network services. In the second case the maximum planned uplink cell load level is reached and therefore no new users can be accepted in the system. Traffic in an uplink capacity-limited scenario is generally relatively symmetric.

2.3.1 Insufficient Uplink Power

At the BS receiver a certain E_b/I_0 requirement must be fulfilled for a MS to get access to the services of the UMTS system.

The transmit power needed for the MS (Mobile Station) $P_{TX,MS}$ is calculated using Equation (2.1) and compared to the allowed maximum.

$$P_{TX,MS} = \frac{N_0 \cdot L_p}{\nu \cdot (1-\eta) \cdot (1 + \frac{W}{R \cdot \rho \cdot \nu})} \tag{2.1}$$

Where N_0 is the background noise, L_p is the propagation loss between MS and BS, R, ν and ρ are the bit rate, service activity and UL E_b/N_0 requirement of the chosen service respectively, W is the WCDMA chip rate and η is the UL loading.

The required transmit power of a mobile station is direct proportional to the path loss as we can see from Equation (2.1). Consequently this power level could be reduced by decreasing the path loss e.g. by adjusting the antenna downtilt or the antenna azimuth.

2.3.2 Uplink Cell Load Limitation

Capacity limitation due to uplink cell load is likely to occur in environments where the capacity requirements are relatively low and the network has been planned with a low uplink cell load to maximise cell range and thus reduce the requirements for the sites. The greater the cell loading, the greater the required number of sites, as well as the higher potential capacity per site. The uplink load equation is defined in [1] as Equation (2.2).

$$\eta_{UL} = \sum_{k=1}^{K_N} \frac{1}{1 + \frac{W}{\rho_k \cdot R_k}} \cdot (1 + i) \tag{2.2}$$

Where $K_N$is the number of mobiles connected to base station N. R and ρ are the bit rate and E_b/N_0 requirement of the chosen service respectively. W is the WCDMA chip rate and i is the other to own cell received power ratio.

Each user who establishes a connection and has the same E_b/N_0 requirement and activity factor, increases the cell load by the same amount. Doubling the maximum cell load results in double the cell capacity for an uplink capacity-limited system. The impact upon cell range is dependent upon the absolute levels of the cell load. The relationship between the cell load and the maximum allowed propagation loss is exponential [1]. Equation (2.3) describes the relationship between the cell load and the resulting increase in receiver interference floor.

$$L = 10 \cdot log_{10}(1 - \eta) \tag{2.3}$$

As the cell load approaches 100%, the receiver interference floor increases without limit. This condition never occures in practice because the mobile terminals have a finite transmit power capability.

When the maximum uplink load of a cell is reached, $\eta_{UL} \geq \eta_{UL\_threshold}$ (where $\eta_{UL\_threshold}$ is the planned maximum permissible level of uplink cell load), any additional users will be set to outage even though the users would have enough transmit power to access the network services.

Increasing system capacity for an uplink-limited scenario requires the uplink load equation to be enhanced.

2.4 Downlink Capacity limited Scenarios

In the UMTS system there are several scenarios with the limiting factor in the downlink, such as: the base station transmit power limit, OVSF code utilisation reaches its limitation, or the requested code power is higher than the available level.

Downlink capacity-limited scenarios are likely to occur in suburban or urban environments where the network has been planned to a relatively high uplink cell loading [1]. The traffic associated with a downlink capacity-limited scenario is generally asymmetric, with a greater amount of traffic on the downlink.

2.4.1 Cell Power Limitation

Downlink capacity-limited scenarios due to maximum cell power are likely to occur where the network has been configured with low base station transmit power capabiliy, which may have been done in some circumstances to reduce the requirement for power amplifier modules.

The total transmit power from the serving base station is defined as:

$$P_T = \sum_n P_n + P_{common} \tag{2.4}$$

P_n is the required transmit power for the connected user n, and P_{common} is the average transmit power of the common channel.

When the base station reaches its maximum transmit power level - $P_T = P_{T,max}$ (where $P_{T,max}$ is the maximum base station transmit power capability), it can not allocate extra power to an additional user even though the cell is not higly loaded. In this case, additional users can not be added without modifying the base station configuration.

The transmit power assigned to a WCDMA cell must be shared amongst all active users belonging to that cell, including those connected by soft handover. Hence, a lower average transmit power requirement results in a higher cell capacity. Furthermore it is possible to increase the number of served users by reducing the soft handover (SHO) links. This is because SHO links only occur at the cell border, which experience maximum path loss and require higher base station transmit power.

The capacity offered by each transmit power configuration is a function of the traffic profile as well as the maximum allowed propagation loss defining the cell range. The greater the propagation loss, the greater the average transmit power requirement and the lower the cell capacity or, in other words, the smaller the cell size, the lower the average transmit power requirement per user and the higher the cell capacity.

A part of the total transmit power of a base station is assigned to the common pilot channel and other common control channels, as we can see in Equation (2.4). Consequently, by reducing the common pilot channel power allocation, more power will be available to support the traffic capacity.

2.4.2 Orthogonal Variable Spreading Factor (OVSF) Code Limitation

The WCDMA system divides spreading and scrambling (randomisation) into two steps. The user signal is first spread by the channelisation code, called orthogonal variable spreading factor (OVSF) code, and then scrambled by the scrambling code. In the downlink, scrambling codes are used for the separation of the individual cells. The separation of the individual downlink connections for different users within one cell is done by the channelisation codes. Channelisation codes become the limiting factor under relatively high throughput scenarios [1]. This is likely to occur in either microcell or indoor scenarios where the cell range is limited and code orthogonality is high.

One possible solution to avoid OVSF code limitation is to reduce soft handover (SHO) links. Hence, the number of available OVSF codes for serving links increases. This is because soft handover connections require independent channels from several base stations at the same time and therefore are reducing the available OVSF codes.

Another possibility when the channelisation codes become the limiting factor would be to use a second scrambling code to indroduce a second channelisation code tree. The two code trees will not be orthogonal to one another and so this will cause higher intra-cell interference.

Further information regarding the scrambling and channelisation codes can be found in [2].

2.4.3 Code Power Limitation

In a WCDMA system, each link needs a certain transmit power in the BS to reach the E_b/N_0 requirement for a sufficient connection to the mobile station. This needed transmit power [1] is given in Equation (2.5).

$$P_{TX} \geq \frac{\rho \cdot \frac{R}{W}}{\sum_k \frac{\beta_k}{L_{p_k} \cdot (I_{tot} - \alpha_k \cdot I_k + N_{MS})}} \tag{2.5}$$

Where N_{MS} is the background noise level at the mobile station, I_{tot} is the total wideband interference power received at the mobile station, I_k is the total wideband power received at the mobile station from base station k, L_{p_k} is the link loss from base station k to the mobile station, α_k is the orthogonality factor of cell k and β_k is the scaling factor (relative maximum link powers) for different base stations in the active set.

This base station transmit power P_{TX} is defined as the maximum transmitted power on one channelisation code on a given carrier and is limited per single traffic link. If the transmit power requested by a mobile is higher than the permitted level, the mobile will not be admitted.

2.5 Summary

Coverage is generally uplink limited, although a low base station transmit power capability combined with asymmetric data services may lead to a downlink coverage-limited scenario. Capacity may be either uplink or downlink limited depending upon the planned level of uplink loading, the base station transmit power capability, the traffic loading of the network and the performance of the base station and mobile terminals.

Due to the many possible limitations of the performance of a WCDMA system, understanding the mechanisms limiting service coverage and system capacity forms an essential part of being able to develop effective optimisation strategies for the UMTS radio network.

There are various available techniques to increase the network capacity. According to [1], the simplest and most effective way to increase the system capacity is to add one or more carriers. When all the available carriers have been used, then other methods such as additional scrambling codes, mast head amplifiers and active antennas, remote RF head amplifiers, higher-order uplink receive diversity, downlink transmit diversity, beamforming, sectorisation, repeaters and microcells could be applied. All these techniques are described in [1].

In this thesis I am focussing on possible ways of increasing the network capacity without additional infrastructure investment or costs in general. These include for example minimising the intra and inter cell interference or optimising the common pilot channel power allocation.

Chapter 3

Key Optimisation Parameters

3.1 Introduction

In UMTS networks there are numerous configurable parameters which influence and determine the capacity of the system, for example:

- Antenna downtilt, -azimuth, -height
- Antenna pattern
- Primary Common Pilot Channel (P-CPICH) power level
- Secondary Common Pilot Channel (S-CPICH) power level
- Primary Common Control Physical Channel (P-CCPCH) power level
- Secondary Common Control Physical Channel (S-CCPCH) power level
- Synchronisation Channel (SCH) power level
- Soft Handover Parameters

This chapter presents a description of the three key optimisation parameters I am focussing on in this thesis, which are: antenna azimuth, antenna downtilt and P-CPICH power level. Furthermore I will explain the influence of these key optimisation parameters on the network, especially on system capacity and coverage.

3.2 Antenna Azimuth

This work focusses on BSs with 3 sectors and a spacing of 120° between the three antennas. When adjusting the antenna azimuth, all three antennas are turned in the same direction at the same time, so the spacing between them will be kept at 120° as shown in Figure 3.1, where the arrows are the directions of the main beams of the antennas.

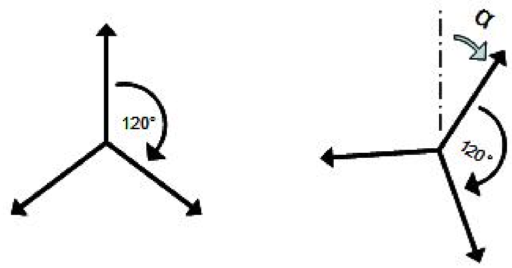

Figure 3.1: Adjustment of BS azimuth

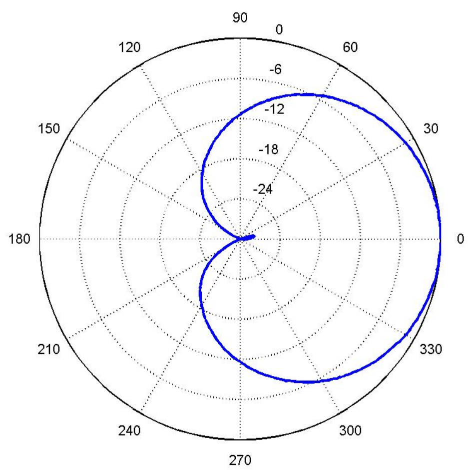

Figure 3.2: Horizontal pattern of BS antenna (in dB)

As shown in Figure 3.2, in the horizontal pattern of the used antenna there is a difference in antenna gain of about 6dB between the main direction of the antenna (0°)

compared to an angle of ±60° (at this angle the adjacent sectors of this base station begin, and there the mobile stations will initiate a handover to the neighbouring cell). Due to that difference of 6dB, the direction of the main beam of the antenna is quite significant and thus it is important to adjust the azimuth of the antennas in order to reach the highest antenna gain for the users in the cell and the lowest gain or highest attenuation for the mobile stations located in neighbouring cells.

3.3 Antenna Downtilt

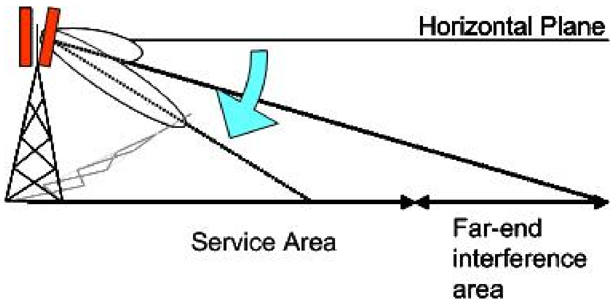

Figure 3.3: Adjustment of BS downtilt

As you can see in Figure 3.3, the antenna downtilt is defined as the negative elevation angle of the main beam of the antenna relative to the horizontal plane. The service area in Figure 3.3 is the own cell and the far-end interference area is the area of the adjacent cells.

The antenna downtilt can be implemented in a mechanical way as well as by electronical tilting. These two tilting mechanisms have a different effect, as shown by [7]: When using mechanical tilting, the antenna pattern itself stays constant and is only tilted, while with electical tilting the antenna pattern changes when adjusting the tilt. Due to the complexity of analysing the system with changing the antenna pattern for every tilt value, in this work only mechanical tilting is applied, with a fixed predefined electronical tilt of 3° included in the vertical antenna pattern as shown in Figure 3.4.

Antenna downtilt is often used in mobile wireless systems. Particularly in UMTS networks, where the traffic in all cells is simultaneously supported using the same carrier frequency, it is used to reduce the other-to-own-cell interference ratio i, which is defined as [1]:

$$i = \frac{I_{oth}}{I_{own}} \tag{3.1}$$

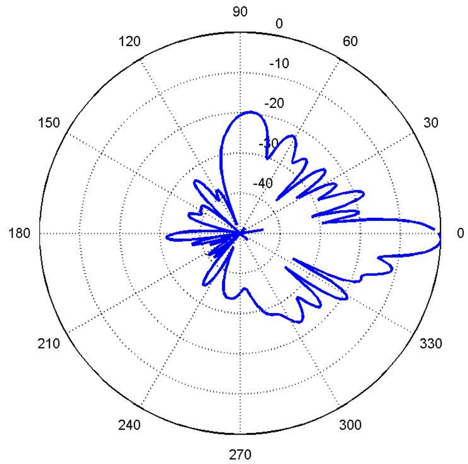

Figure 3.4: Vertical pattern of BS antenna (in dB)

where I_{oth} ist the inter-cell interference and I_{own} is the intra-cell interference.

By increasing the antenna downtilt in a cellular system, the inter-to-intra-cell interference ratio i is decreased. This is because the antenna main beam delivers less power towards the other cells, and therefore most of the radiated power is going to the area that is intended to be served by this particular base station. Due to the fact that the interference in the system is decreasing, the capacity increases and more users can be served in the network.

There is always an optimum value for the tilting, which depends on the environment, site and user locations and the antenna radiation pattern. If the tilting angle is too high, the service area could become too small. Furthermore, if the downtilting reaches a certain value, the interference in the neighbouring cells increases again due to the side lobes of the vertical antenna pattern.

3.4 CPICH Power Level

In a UMTS system there are two types of common pilot channels, the Primary and Secondary CPICH. They are transmitted at a fixed rate (15kbit/s, spreading factor 256) and carry a predefined symbol sequence. The Primary Common Pilot Channel (P-CPICH) is characterised by a fixed channelisation code and is always scrambled using a primary scrambling code [1, 2]. There is one P-CPICH per cell, and it is broadcast over the entire cell. The P-CPICH is the phase reference for the SCH, P-CCPCH, AICH, PICH, DL-DPCCH, CPCH and S-CCPCH, and it is also used to aid the channel estimation at the mobile station for the dedicated channel. The Secondary Common Pilot Channel (S-CPICH) is characterised by an arbitrary channelisation code with a spreading factor of 256 and is scrambled by either a primary or a secondary scrambling code. In a cell there may be no, one, or several S-CPICHs. Each S-CPICH may be transmitted over the entire cell or over only a part of the cell. The typical area of Secondary CPICH usage is operations with narrow antenna beams intended for service provision at specific 'hot spots' [1].

In this work I am only researching the P-CPICH, and therefore I will only use CPICH for P-CPICH further in this thesis.

The CPICH is also very important for the handover, cell selection and reselection. After turning on the power of the mobile station, the mobile measures and reports the received level of chip energy to interference plus noise density ratio (E_c/I_0) on the CPICH to the base station for the cell selection procedures. E_c is the average energy per pseudo noise (PN) chip, and I_o denotes the total received power density, including signal and interference, as measured at the mobile station antenna connector [1]. This E_c/I_0 ratio is given by Equation (3.2),

$$\frac{E_c}{I_o} = \frac{RSCP_{CPICH}}{RSSI} \tag{3.2}$$

where the Received Signal Code Power ($RSCP_{CPICH}$) is the received power of the CPICH measured at the mobile station. It can be used to estimate the path loss, since the transmission power of the CPICH is either known or can be read from the system information. The Received Signal Strength Indicator ($RSSI$) is the wideband received power within the relevant channel bandwidth in the downlink.

The cell with the highest received CPICH level at the mobile station is selected as the serving cell. As a consequence, by adjusting the CPICH power level, the cell load can be balanced between different cells, thus improving the overall network capacity. Reducing the CPICH power of one cell causes part of the terminals to hand over to adjacent cells, while increasing it invites more terminals to hand over to the own cell, as well as to make

[1]There exist quantities that are a ratio of energy per chip to PSD. This is the common practice of relating energy magnitudes in communication systems. It can be seen that if both energy magnitudes in the ratio are divided by time, the ratio is converted from an energy ratio to a power ratio, which is more useful from a measurement point of view. It follows that an energy per chip of X dBm/3.84 MHz can be expressed as a mean power per chip of X dBm. Similarly, a signal PSD of Y dBm/3.84 MHz can be expressed as a signal power of Y dBm.

their initial access to the network in that cell.

In radio network planning, the CPICH transmit power of the BSs should be set as low as possible, while ensuring that the serving cells and neighbour cells can be measured and synchronised to and the CPICH can be sufficiently used as a phase reference for all other downlink physical channels. Too high values of CPICH power will cause the cells to overlap and therefore create interference to the neighbouring cells, called 'pilot pollution', which will decrease the network capacity. Furthermore the CPICH power is part of the total transmit power of the BS, which is generally limited. Thus, less CPICH power would provide more power for the traffic channels, and therefore increase the capacity. On the other hand, the mobile stations are only able to receive the CPICH down to a certain threshold level of E_c/I_0, which determines the coverage area. Due to that fact, setting the CPICH power too low will cause uncovered areas between the cells. In an uncovered area, CPICH power is too weak for the mobile to decode the signal, and call setup is impossible. According to the specifications of the Third Generation Partnership Project (3GPP), the mobile must be able to decode the pilot from a signal with E_c/I_0 of -20dB [3].

To make Equation (3.2) better understandable, the E_c/I_0 ratio can also be described with Equation (3.3).

$$CPICH_{E_c/I_0} = \frac{\frac{P_{CPICH}}{L_p}}{\sum_{i=1}^{numBSs} \frac{P_{TX,i}}{L_{pi}} + I_{ACI} + N_0} \tag{3.3}$$

Where P_{CPICH} is the CPICH power of the best server, L_p is the link loss to the best server, $P_{TX,i}$ is the total transmit power of BS i, L_{pi} is the link loss to BS i, I_{ACI} is adjacent channel interference, N_0 is the thermal noise of the MS and $numBSs$ is the number of base stations in the network.

As conclusion, the level of the CPICH power is very important to reach high capacity in the system. Therefore the CPICH power level is a key optimisation parameter and is included in the strategy for the optimum default parameter setting presented in this thesis.

3.5 Summary

As we have seen in this chapter, the correct adjustment of the base station parameters CPICH power, antenna tilt and antenna azimuth is very important to achieve high capacity in the UMTS network. Using these parameters, it is possible to increase the capacity of the network through:

- Reduction of inter-cell interference and pilot pollution.
- Optimisation of base station transmit power resources.
- Load sharing and balancing within cells.
- Optimisation of SHO areas.

The most important advantage is that by optimising network capacity through adjustment of the three key parameters CPICH, tilt and azimuth, no expenditure in network infrastructure is necessary.

Chapter 4

Simulation Environment

4.1 Introduction

In this chapter I will describe the main parameters of the simulator I used to derive the optimum default parameter setting and to analyse the results of this strategy. I will also present the simulation scenario with the corresponding characteristics required to reproduce the achieved results.

4.2 Simulator Interface

As we will see in Chapter 5 and 6, MATLAB procedures are programmed for automatic adjustment of the key parameters according to the strategies. These MATLAB programs are using the simulator for reaching the optimum default parameter setting. As interface between the MATLAB procedures and the simulator engine, XML [1] files are used as shown in Figure 4.1.

[1] Extensible Markup Language. The next-generation of HTML, is now viewed as the standard way information will be exchanged in environments that do not share common platforms. (*www.xml.org*)

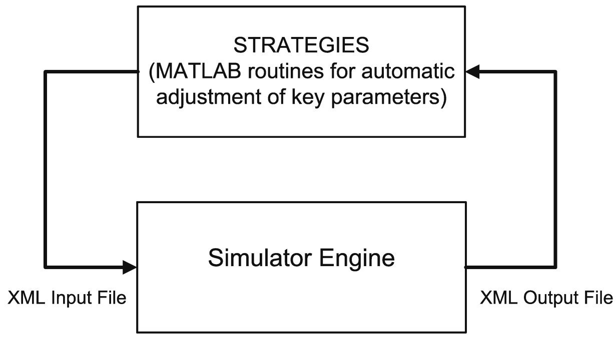

Figure 4.1: Interface between simulator and MATLAB code

4.3 Main Simulator Parameters

For this work I am using the static UMTS FDD network simulator $CAPESSO^{TM}$ which was kindly provided by *SYMENA, Software & Consulting GmbH, Austria*.

Coverage, capacity and quality of service related issues can be analysed with this tool. Input to the simulator is the network configuration and the user distribution. Uplink and downlink are jointly analysed and the simulation results comprise coverage and capacity information, traffic statistics, outage reasons for the unserved users, and SHO statistics.

During the simulations the following system parameters were used for calculations (summarised in Tables 4.1, 4.2, 4.3, 4.4 and 4.5 at the end of this chapter):
The UMTS system had one carrier and one OVSF (Orthogonal Variable Spreading Factor) code tree. The maximum power of all cells in the system was set to 43dBm, the maximum code power to 40dBm and the minimum to 15dBm. The P-CPICH power level (CPICH) was varied between the different simulations and in the reference scenario it was set to 33dBm (10% of maximum cell power). Additionally there are parameters for SCH and PCH power, which are both 5dBm. But these two parameters are only included in the calculations as additional interference in the system, but otherwise they are not important in the simulation. The active set window was 3dB and the active set size was set to two. The receiver of the base station utilised three rake fingers and used a maximum ratio combining efficiency for uplink softer handover operations of 100%. The transmitter loss was 0dB and the base station noise figure 5dB. Furthermore there is the possibility to set the downlink and uplink transmission power control (TPC) headroom, which where 1dB and 2dB respectively.

In the system a conventional antenna type was used, with a height of 30m in all cells. The BSs had three sectors using antenna type 739707 from Kathrein with an antenna gain of 16dBi (www.kathrein.de, KATHREIN-Werke KG, D-83004 Rosenheim, Germany). The horizontal and vertical antenna pattern is shown in Figure 3.2 and 3.4. The vertical antenna pattern presents an electronical tilt of 3°. The additive mechanical tilt was varied during the simulations and was set to 0° in the reference scenario.

As parameters of the channel, the following parameters can be specified in the simulator:
The background noise floor was set to -107dBm, and as path loss model the model of Okumura-Hata was used. The large scale fading has zero mean and a standard deviation of 2dB. The maximum delay of the channel was 2μs and the total number of multipath components of the channel was set to 5.

The inter-symbol interference of the channel destroys the orthogonality of the codes. This is described by the downlink orthogonality factor, which is 0 if the codes are perfectly orthogonal, and 1 if the codes are totally non-orthogonal. The downlink orthogonality factor was chosen to be 0.4.

The standard deviation of the gaussian distribution of the azimuth angles of the channel taps (sigma azimuth of taps) was set to 5°. The adjacent cell interference ratio (ACIR) was 5% and the inter system interference ratio 5% as well. These two parameters only describe an increase of the existing interference level in the system due to other carriers or other systems like GSM.

4.4 CPICH Coverage Verification Modes

As already mentioned in Chapter 3.4, for the optimisation of a UMTS system the CPICH power level is very important. The level should be optimised very accurately to use the power recources of the BS efficiently, to reduce the interference level, and nevertheless provide the required CPICH coverage in the system.

Due to the importance of the CPICH coverage and to achieve the possible minimum of CPICH power level, it is mandatory to know how the simulator defines CPICH coverage when deriving CPICH optimisation strategies.

The simulator $CAPESSO^{TM}$ from SYMENA provides two modes for CPICH coverage verification as explained in the following.

4.4.1 CPICH Coverage Verification Mode 'ATOLL'

In the CPICH coverage verification mode 'ATOLL', the CPICH coverage is defined by using the received power of the CPICH measured at the mobile station compared to a certain threshold for the lower limit, the receiver sensitivity. Expressed in Equation (4.1) it is:

$$RSCP_{CPICH} \geq S \tag{4.1}$$

where $RSCP_{CPICH}$ is the received signal code power of CPICH and S is the receiver sensitivity with a default value of -120dBm.

It is crucial to mention that the CPICH coverage verification mode 'ATOLL' does not take any interference into account for calculation of coverage. In this mode the CPICH coverage of a single cell would be the same with or without the presence of the total system.

4.4.2 CPICH Coverage Verification Mode 'ODYSSEY'

The CPICH coverage verification mode 'ODYSSEY' includes the interference level of the system in the calculation of CPICH coverage. In this mode, a pixel in the simulated scenario is covered by the CPICH if the Signal to Noise Ratio (SNR) of the received CPICH at the mobile station exceeds a certain threshold. A pixel is an area with 100m times 100m in the scenario and in the center of that square the received CPICH power level is calculated. In this work the threshold for the CPICH is called $CPICH\_E_c/I_0\_thres$ according to 3GPP Specification [3] and was set to -11.91dB or -17.91dB. Also the SNR is called $CPICH\_E_c/I_0$ although there is an important difference, which will be explained later. In Equation (4.2) the calculation of mode 'ODYSSEY' is presented,

$$CPICH_{E_c/I_0} = \frac{RSCP_{CPICH}}{RSSI - RSCP_{CPICH}} \geq CPICH\_E_c/I_0\_thres \tag{4.2}$$

where the Received Signal Code Power ($RSCP_{CPICH}$) is the received power of the CPICH as measured by the mobile station and the Received Signal Strength Indicator ($RSSI$) is the wideband received power within the relevant channel bandwidth in the downlink.

The mentioned difference is that in 3GPP specifications the $CPICH_{E_c/I_0}$ is the ratio of the received energy per PN chip for the CPICH to the *total received power spectral density* at the UE antenna connector as you can see in Equation (3.2) or (3.3), whereas in the Simulator $CAPESSO^{TM}$ the $CPICH_{E_c/I_0}$ is the real SNR.

4.5 Simulation Scenario

For the simulations a virtual scenario of a UMTS system in the city of Vienna with 25 three-sector macro cells was used, as shown in Figure 4.2. The base stations or more precisely the antennas of the base stations are represented by the thick arrows, and the mobile stations are displayed as black dots.

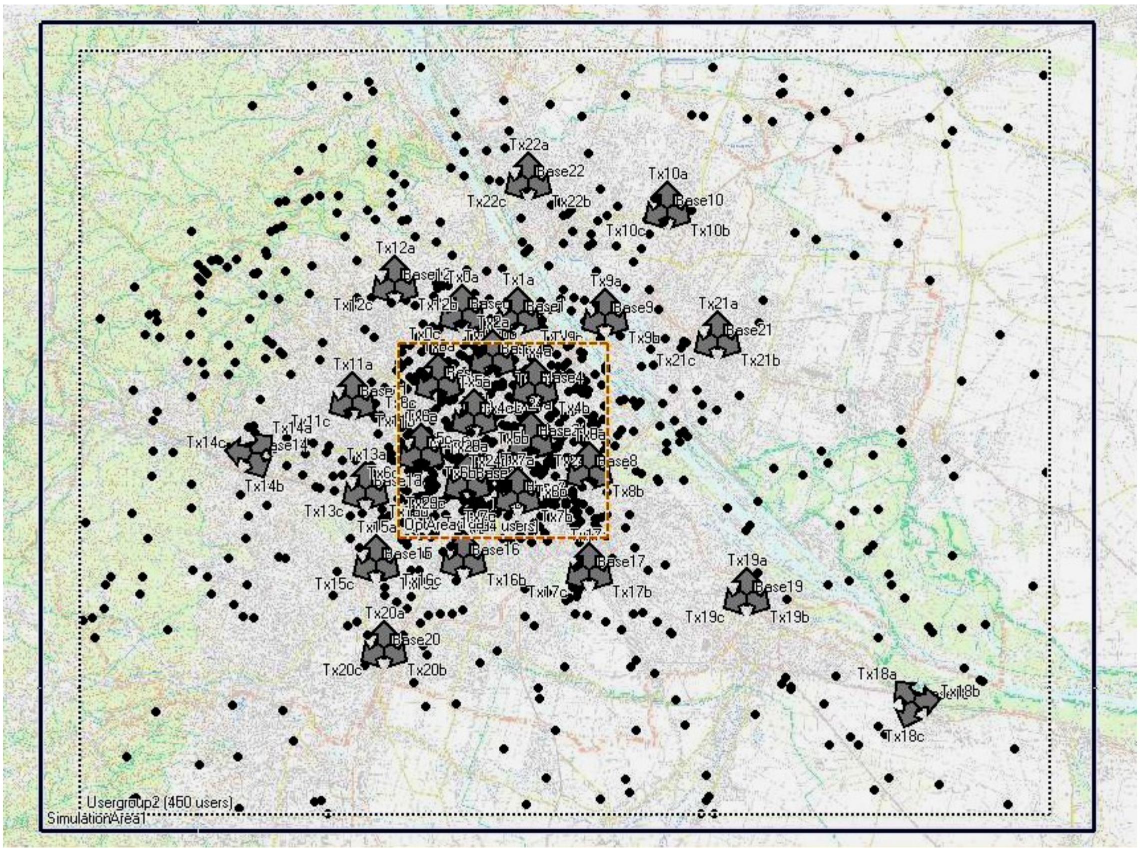

Figure 4.2: Screenshot of the reference scenario in simulator $Capesso^{TM}$

In this simulation scenario there are two defined areas, shown in Figure 4.2 as the solid blue and the dashed orange box. These two boxes define the area that is included in the simulation and the area in which the capacity of the system should be optimised (target area), respectively.

In the total simulation area the users are distributed equally in each cell according to the best server plot. The best server plot shows the regions of the dominance areas of the different cells due to the highest received CPICH power level. That means, all the pixels in the best server plot of the scenario with the highest received CPICH power level from one cell (the serving cell) are dedicated to that cell and describe the best server area of that certain cell. The same number of mobile stations is distributed in each of these areas. This kind of distribution will be called 'Best Server Equal Distribution' in this work. It is also possible to switch the distribution of the mobile stations, for example in the target area, to 'Equal Distribution'. Then the users are equally distributed in the usergroup, as the name says.

In the simulator all the mobile stations are assigned to four different usergroups. It is possible to use 'Best Server Equal Distribution', 'Equal Distribution' or other distributions in each usergroup, as well as a certain service. In the simulator the four usergroups are called *usergroup1*, *usergroup2*, *optarea1* and *optarea2*, with the first two usergroups building the service mix in the total scenario and the last two usergroups building the service mix in the target area. In the scenario a service mix with 40% of 12,2kbit/s speech users and 60% of 64kbit/s data users was applied with an activity factor of 50% when using speech service and 100% when using a data communication link.

For varying the positions of the mobile stations in the scenario, the initialisation value of the random generator can be changed by the parameter 'rand_init'.

In the simulator also some parameters of the mobile stations can be defined or varied. The maximum transmission power of the MSs was set to 21dBm. The MSs had an antenna gain of 0dB, and the body loss as well as the receiver noise figure were also set to 0dB. The threshold down to which the received CPICH power level was considered was -126dBm, and the receiver sensitivity of the mobile station was -120dBm. However, as described in section 4.4, this receiver sensitivity is changed due to the fact that the CPICH coverage is defined with that value.

4.6 Summary

For a better overview, the main parameters mentioned in this chapter are presented in the following tables.

Number of carriers	1
Number of OVSF code trees	1
Maximum base station transmit power	43dBm
Maximum code power	40dBm
Minimum code power	15dBm
CPICH power	33dBm (varied)
SCH power	5dBm (only for additional interference)
PCH power	5dBm (only for additional interference)
Active set window	3dB
Active set size	2
Transmitter loss	0dB
Base station noise figure	5dB
Number of RAKE fingers	3
MRC efficiency	1
DL TPC headroom	1dB
UL TPC headroom	2dB

Table 4.1: System parameters in simulator $CAPESSO^{TM}$

Antenna type	Conventional
Antenna height	30m
Antenna sector	65°
Antenna gain	16dBi
Antenna pattern	Kathrein 739707 (Figure 3.2 and 3.4)
Antenna downtilt	0° mechanical (varied) + 3° predefined electrical

Table 4.2: Base station antenna parameters in simulator $CAPESSO^{TM}$

Background noise floor	-107dBm
Path loss model	Okumura - Hata
Maximum delay of channel	2μs
Number of channel taps	5
σ azimuth of taps	5°
Downlink orthogonality factor	0.4
σ of log normal large scale fading	2dB
μ of log normal large scale fading	0
ACIR	5%
ISIR	5%

Table 4.3: Channel parameters in simulator $CAPESSO^{TM}$

Maximum mobile station transmit power	21dBm
Mobile station antenna gain	0dB
Body loss	0dB
Receiver noise figure	0dB
Receiver sensitivity	-120dBm (varied)
Receiver CPICH threshold	-126dBm

Table 4.4: Mobile station parameters in simulator $CAPESSO^{TM}$

User distribution	Best Server Equal / Equal
Service mix	40% 12.2kbit/s speech, 60% 64kbit/s data
Activity factor	50% speech, 100% data

Table 4.5: User parameters in simulator $CAPESSO^{TM}$

Chapter 5

Optimisation Strategies

5.1 Introduction

In this chapter 'ad hoc' strategies for adjustment of the three key optimisation parameters antenna azimuth, antenna downtilt and CPICH power level are developed based on the knowledge presented in chapters 2 and 3. 'Ad hoc' in this context means to reach the result only by considering the structure of the UMTS network, for example the position of the BSs to each other, the height of the antennas, the height profile of the terrain, or the maximum transmit power of the BSs. The objective of these strategies is to use as few steps as possible in contrast to step by step optimisation strategies, therefore needing as few simulations in the simulator $CAPESSO^{TM}$ as possible.

The three key optimisation parameters are highly interdependent. For example with decreasing the CPICH level, the coverage area of a cell shrinks, but decreasing the antenna downtilt afterwards makes the cell bigger again. Therefore a combined adjustment strategy in this 'ad hoc' way is very difficult. Due to that, apart from Section 5.5, strategies for individual adjustment of each of the three key optimisation parameters have been developed and then combined for the optimum default setting. Section 5.5 presents a strategy for adjustment of antenna downtilt and CPICH power level at once, which is only valid for the CPICH Coverage Verification Mode 'ATOLL', this means without considering interference in the coverage calculation.

In the following sections strategies are developed from a theoretical point of view, either due to analyses done in the simulator, due to results from the adjustment in step by step optimisation algorithms, or by using background knowledge about UMTS systems. After that, Chapter 6 describes how the strategies use the simulator and how the optimum default setting of the key parameters is found automatically.

5.2 Azimuth Optimisation

As explained in section 3.2, there is a difference in antenna gain in the horizontal pattern of the used antenna of about 6dB between the main lobe and at 60°, which is the cell border to the next sector. Due to this difference it is quite important to adjust the azimuth in a correct way for achieving the best coverage of the system. This way less power is needed for covering the whole area, and therefore also less interference is generated.

There only exists sparse literature (e.g. [8]) for adjusting the BS azimuth in UMTS systems. The problem is furthermore, that in these publications only the optimum adjustment of BS azimuth in a regular hexagonal grid is presented. There is no information of the performance of azimuth adjustment in a real 'irregular' UMTS system.

Thus, I will start from the information for the best antenna directions in a regular hexagonal grid. Then I will do a performance analysis of rotated base stations with the simulator in the virtual but irregular scenario of the city of Vienna. With this analysis, the strategy of best antenna directions in regular grids is expanded to irregular BS positions.

5.2.1 Optimum Azimuth in a regular Grid

According to [8], an improper direction of sector antennas in a regular hexagonal layout can cause a capacity degradation exceeding even 20% and requires an increase of base station transmit power in the range from 3 to 6dB. In [8] also the best and the worst case of antenna directions for a CDMA system in a regular hexagonal grid is shown, as can be seen in Figure 5.1.

The effect of these directions in a regular hexagonal grid can be seen in Figure 5.3 and 5.2 (kindly provided by T. Baumgartner) where the pathgain is presented in the area of 5000 times 5000 meters with 19 3-sector base stations. If the transmitted CPICH power level is added to the pathgain in the diagram, the received CPICH power level at each point of the area can be obtained.

What is shown in Figure 5.3 and 5.2 is that in the worst case of BS azimuth there are zones in the system with bad coverage. These critical zones would need more transmit power to be covered and therefore would cause more interference in the system. In the best case, there are no such holes of bad coverage, and the total area is covered more regularly.

This opimimum direction of the BS antennas to each other will be called *'ideally spatially interleaved'* in the further work. I will call the process to reach this ideal spatial interleaving of the cells in this work *'interleaving'*.

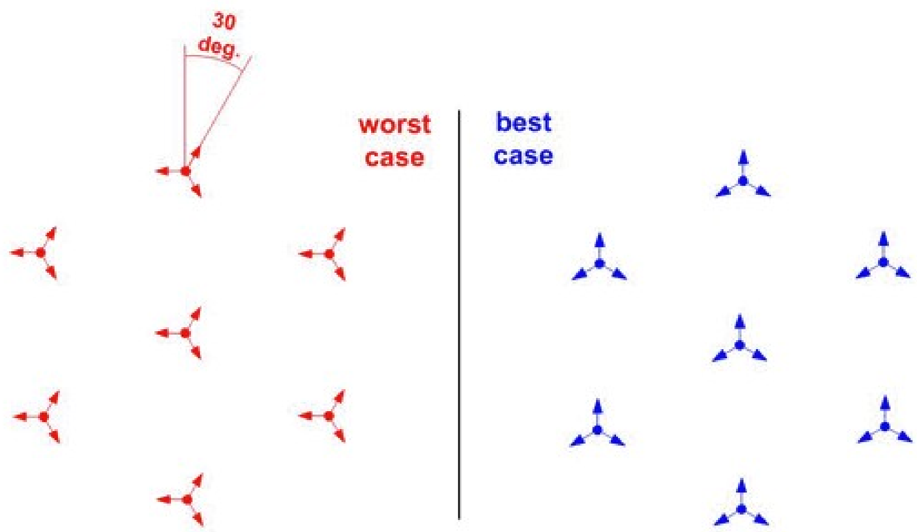

Figure 5.1: Best and worst case of antenna directions in a regular hexagonal grid

5.2.2 Performance Analysis of rotated Base Stations

In this analysis the virtual scenario of the city of Vienna with 25 3-sector BSs was used and simulated with CPICH coverage verification mode 'ATOLL' of simulator $CAPESSO^{TM}$. The base stations azimuth was varied between 0° (the north, as can be seen in Figure 4.2) and 120° turned to the right side, in steps of 1°.

At this point it should be mentioned that there must be a period of 120° in the results of rotating the base stations. In the simulator $CAPESSO^{TM}$ however this is not the case. The sectors of a base station have different fading characteristics, and when turning a base station, the fading characteristics are turned the same angle in the simulator, but should remain unchanged in reality. Thus, there are slightly different results for 60° and 180° for example. Despite this difference I only turned the BSs from 0° to 120° in this analysis.

During the simulations for this analysis the downtilts of all cells were adjusted to 3° (there also was an additive electronical tilt of 3°), and the CPICH power levels were set to 30dBm. The users in the target area were equally distributed, and in the rest of the scenario the best-server distribution was used. The positions of the mobile stations were derived randomly with a random initialization value of 1 in *usergroup1* (speech users in total scenario), 4 in *usergroup2* (data users in total scenario), 7 in *optarea1* (speech users in target area) and 10 in *optarea2* (data users in target area). To achieve the results,

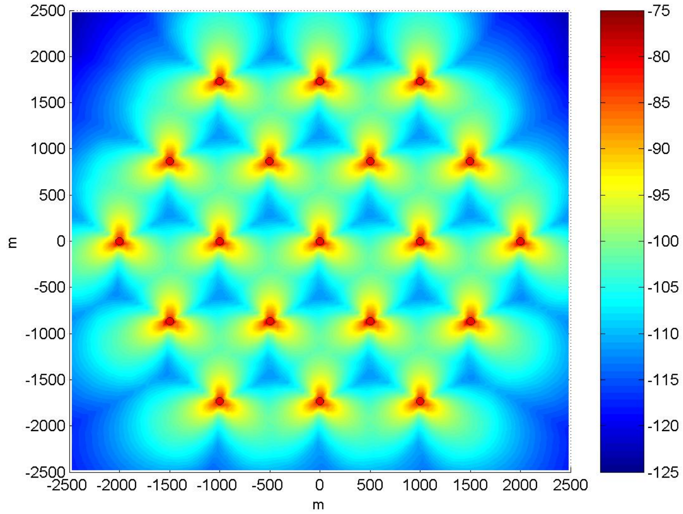

Figure 5.2: Worst case of BS azimuth in a regular grid, pathgain in dB (source: T. Baumgartner)

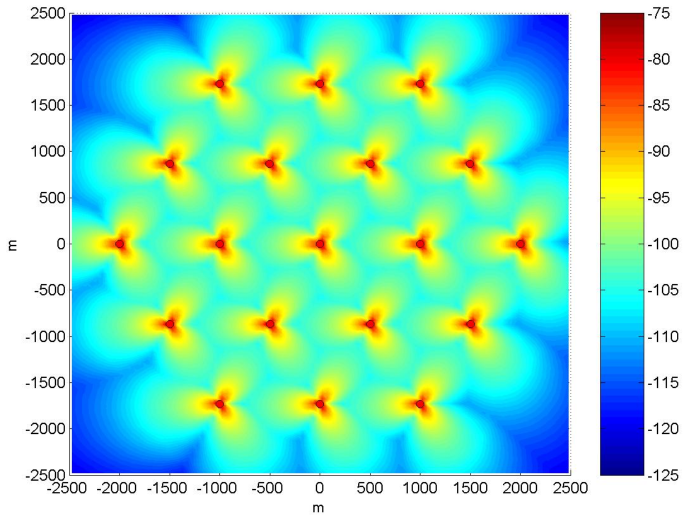

Figure 5.3: Best case of BS azimuth in a regular grid, pathgain in dB (source: T. Baumgartner)

the mean value of 10 different user distribution snapshots was calculated. These different snapshots were achieved by adding a value of 4 to the random initialization value in each of the four previously mentioned usergroups. This was done in order to make the analysis independent of the instantaneous positions of the mobile stations in the UMTS network.

To summarise, in this analysis all the cells of the reference scenario (Figure 4.2) are turned to the right side from 0°(north) to 120° in steps of 1°. In each step 10 simulations are done with different user distribution snapshots. Out of these simulations the mean of the sum of the cumulative transmit powers of the cells in the target area is calculated in watts. Furthermore, the mean of the sum of the noise rise in the target area in linear values, as well as the mean number of served users in the target area and in the total scenario are obtained from the simulations.

Out of the results of these 25 turned base stations (Tx0 to Tx24), I will present the most significant results in the following, which are the turning of BS Tx05, Tx13, Tx03 Tx08 and Tx21.

When wathing the results of this analysis, we should first have a look at the diagram of the mean sum of cumulative transmit powers of all cells in the target area in Figure 5.4. In this diagram we can see that the curve has a clear tendency: a maximum of the sum of power levels at about 90° and a distinct minimum at about 10°. As the optimum azimuth adjustment is reached, when having least transmit powers in the target area, the ideal direction of BS Tx05 would be at an angle of 10°.

At the same time we should consider the other diagrams of Figure 5.4 to verify that the result is not falsified by different numbers of served mobile stations in the target area or in the total scenario. Due to fewer served users in the target area for example, the mean sum of the transmit powers of the cells in the target area would decrease as well, but that would be a worse adjustment of azimuth and not an optimum. What we can see in Figure 5.4 is, that as well as having a minimum of the sum of cumulative power levels in the target area, there are also more users served in the target area and in total scenario compared to the azimuth adjustment of 90°.

If the best and worst case (10° and 90°) of adjusting the azimuth of BS Tx05 is presented in a screenshot of the simulator (Figure 5.5), we can see that in the latter case the directions of the antennas of BS Tx05 point to the surrounding base stations. It is easy to come to the conclusion, that in the optimum case (10°) BS Tx05 is *interleaved* in the sense of optimum azimuth in a regular grid.

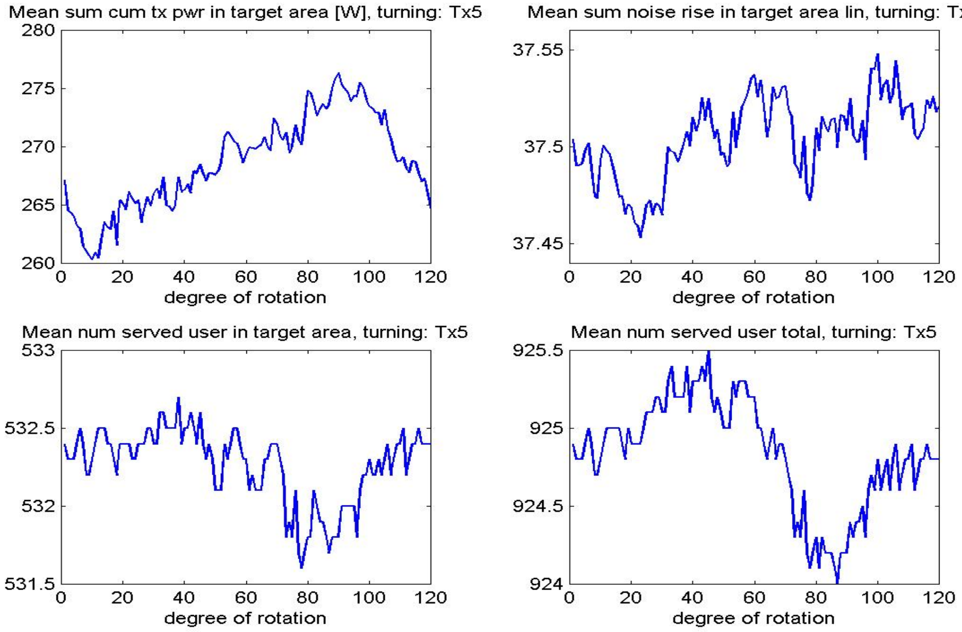

Figure 5.4: Result of turning BS Tx05

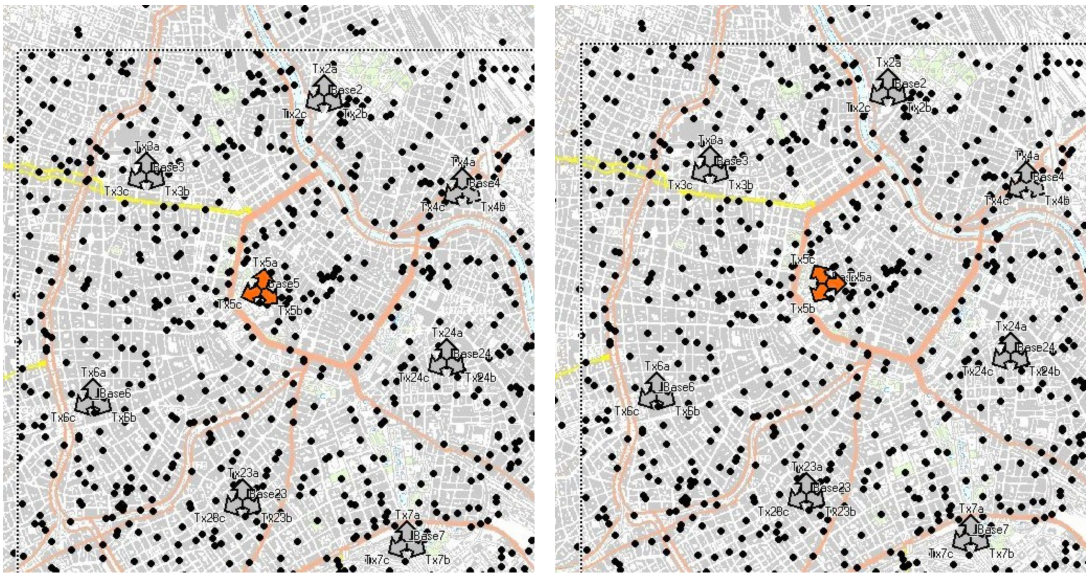

Figure 5.5: Simulator screenshot of BS Tx05 at 10°(best case) and 90°(worst case)

In Figure 5.6 it can be seen that there is also a clear trend in the diagram of the mean sum of transmit powers in the target area when rotating BS Tx13 from 0° to 120° in steps of 1°. As an optimum adjustment of the azimuth, 0° would be the best solution due to the minimum in the power level at that angle. Furthermore, the mean number of served users and the mean sum of noise rise in the target area show the same ideal direction and the worst case at about 60°.

Again visualising these directions of the antennas of BS Tx13 in screenshots of the simulator in Figure 5.7 shows, that the base stations are again *interleaved* in the sense of optimum azimuth in a regular grid, but the antenna of BS Tx13 also has its main lobe pointing to a so called 'critical point', which is marked red in Figure 5.7. A 'critical point' is a point in the target area with a big distance to all the surrounding base stations compared to all other points in the target area. Therefore the system has problems in covering that point and serving mobile stations located there. In the next figure we will see that these 'critical points' are very important in adjusting the direction of antennas in cellular systems.

The optimum antenna direction of the base station Tx03 is around 60° due to the minimum of the mean sum of transmit powers of the cells in the target area, but also because of the highest mean values of served users as presented in Figure 5.8. As well as in adjusting BS Tx13, the main lobe of the antenna of BS Tx03 is turned towards such a 'critical point' shown in red in Figure 5.9. The important fact in this case is, that the cells are not interleaved, which can easily be observed in the screenshot of the simulator. The direction of the main lobes of the antennas of BS Tx03 are adjusted against the main lobes of the neighbouring cells in the optimum case. That is just the contrast to interleaving.

Thus the conclusion is, that adjusting the main lobes to the critical spots is more important and with higher weight as interleaving the cells.

A totally different effect when turning a base station in celluar networks is shown in Figure 5.10, where the diagrams show that the optimum angle of BS Tx08 is about 25°. We can conclude from the screenshot of the simulator in Figure 5.11 that the reason for this optimum is because of the direction of the antennas in reference to the borderline of the target area. In this position of the base station, all three cells of BS Tx08 have their main lobes somewhere inside the target area and therefore cause the minimum required transmit powers and the highest capacity. In the opposite of this optimum direction, the worst case is when one antenna points completely out of the target area, and thus cannot help to increase the capacity in the area which should be optimised.

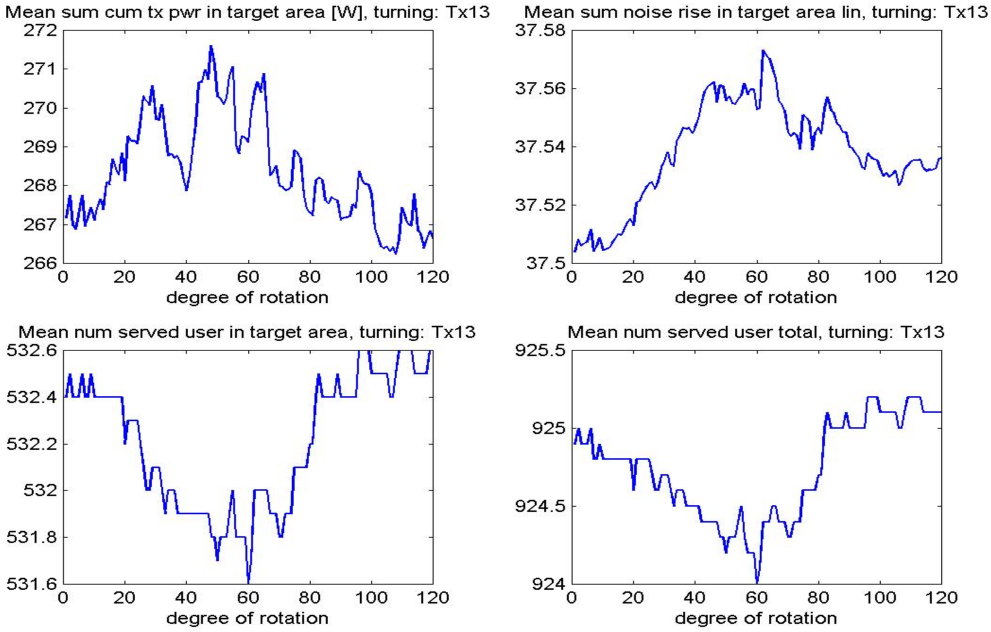

Figure 5.6: Result of turning BS Tx13

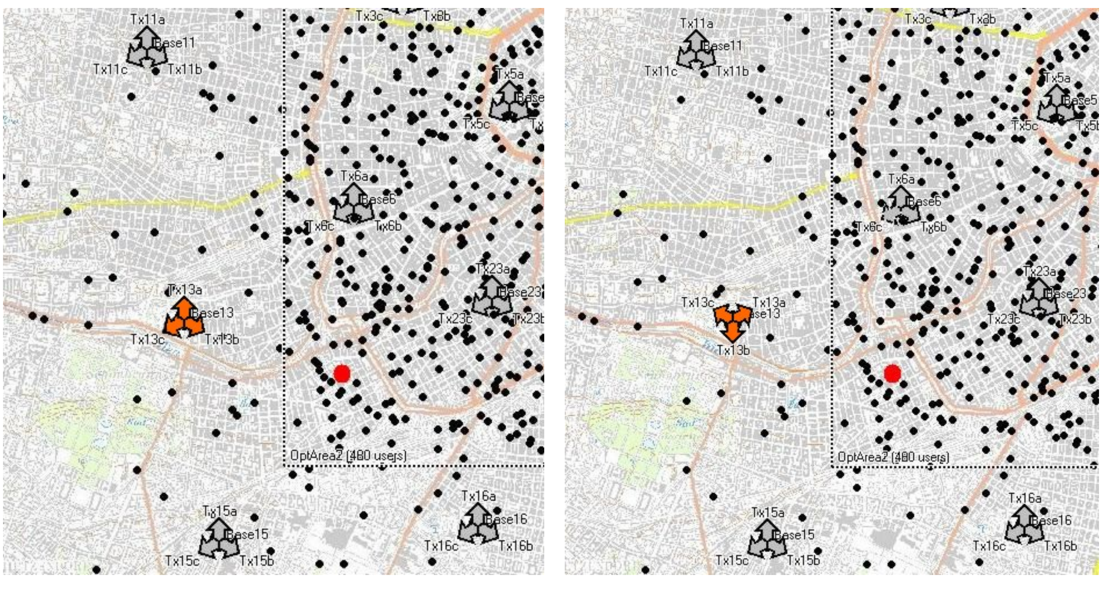

Figure 5.7: Simulator screenshot of BS Tx13 at 0°(best case) and 60°(worst case)

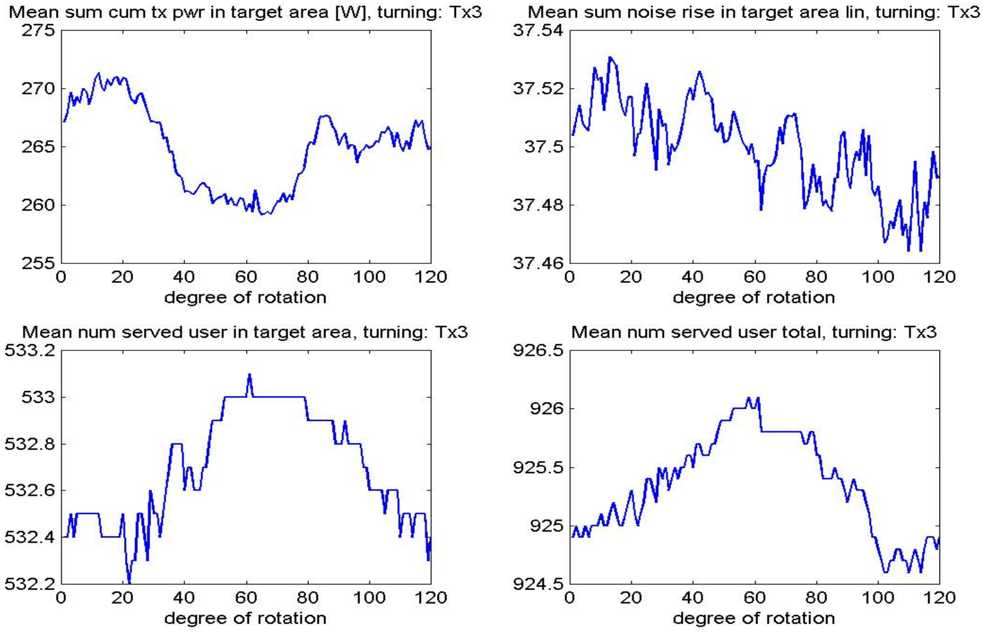

Figure 5.8: Result of turning BS Tx03

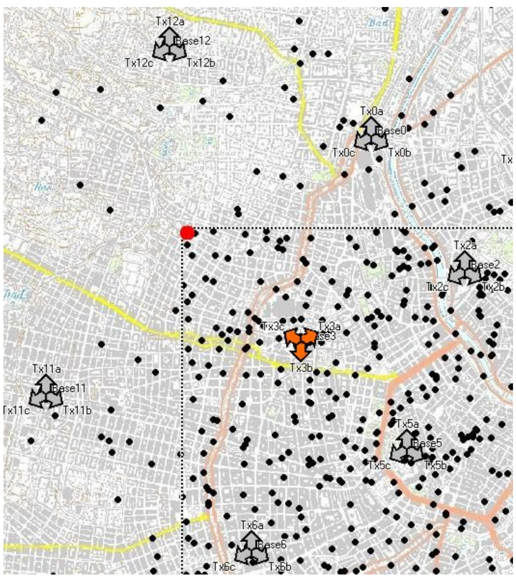

Figure 5.9: Simulator screenshot of BS Tx03 at 60°

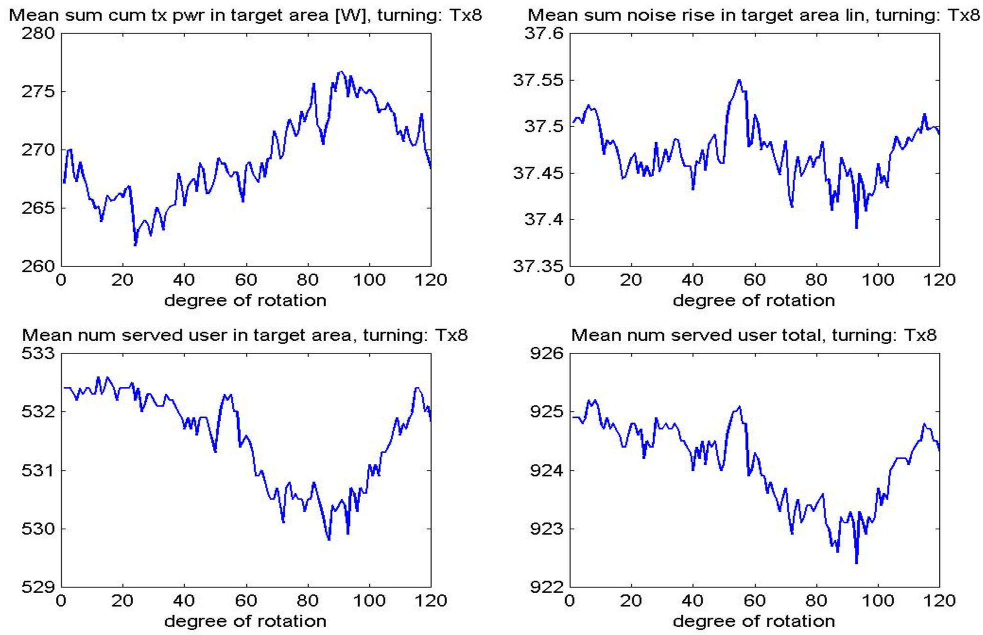

Figure 5.10: Result of turning BS Tx08

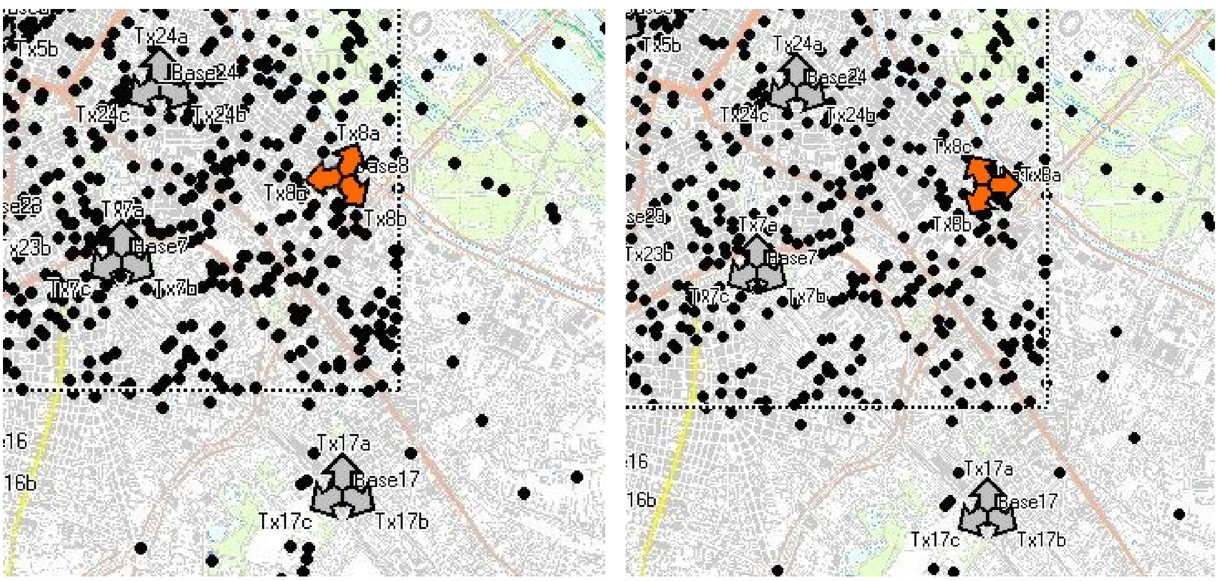

Figure 5.11: Simulator screenshot of BS Tx08 at 25°(best case) and 90°(worst case)

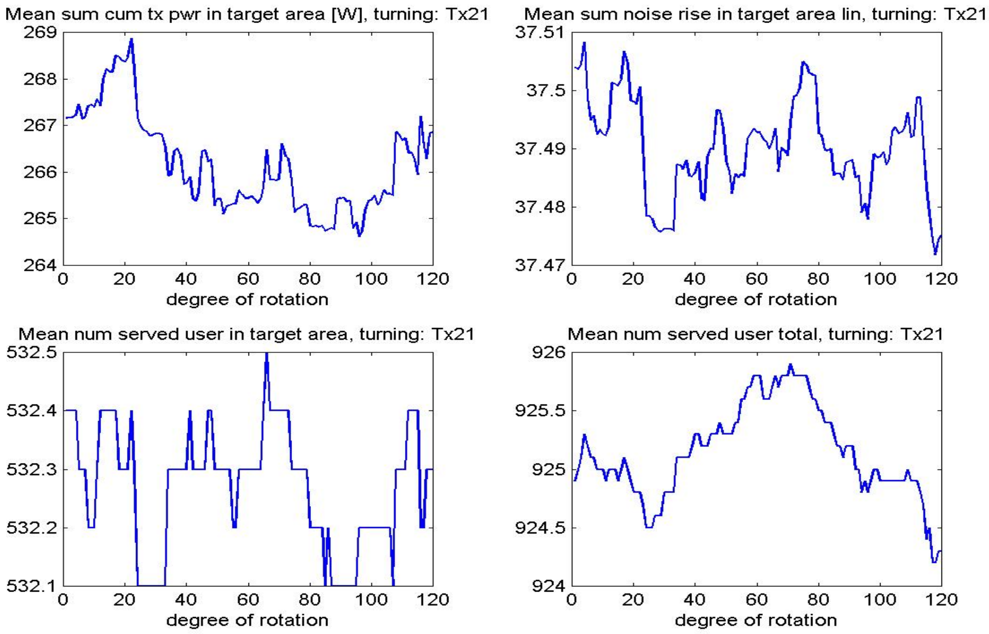

Figure 5.12: Result of turning BS Tx21

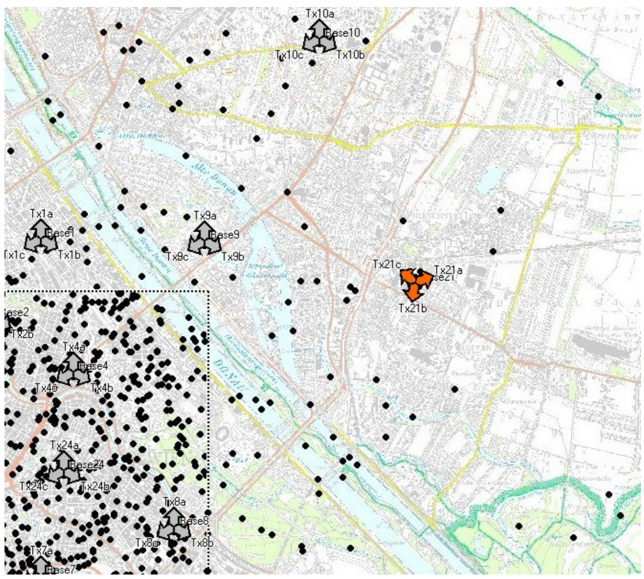

Figure 5.13: Simulator screenshot of BS Tx21 at 70°

Consequently, the antenna direction compared to the border of the target area is quite important and can cause a great gain in capacity.

The same conclusion is valid for base stations located outside the target area but with contribution of coverage in the target area. The fine adjustment of the azimuth of these cells can increase the capacity quite a lot.

However, I decided not to include the adjustment of azimuth in reference to the borderline of the target area in my default parameter setting, because this adjustment due to such a strict border is not realistic and therefore would falsify the result.

Another effect of the BS direction in reference to the target area is, that base stations located outside the target area with no contribution of coverage in the area should be turned in a way that no main lobe points directly to the target area. Obviously, this adjustment reduces the interference level in the target area and therefore increases the capacity, but the effect is only marginal as presented in Figure 5.12 and 5.13.

One additional aspect would be to research the dependency of the optimum azimuth adjustment to the altitude profile of the terrain around the base station. This would be a point for future work in searching for the ideal antenna direction and I think it would cause a further increase in capacity.

5.2.3 Azimuth Strategy and Results

The main conclusions of the performance analysis of rotated base stations in a non-regular virtual UMTS scenario are:

1. Adjust the main lobes of the BS antennas to the 'critical points'.
2. 'Interleave' the cells in the scenario.
3. BSs located in the target area at the borderline: adjust in a way that as many main lobes as possible are pointing inside the target area.
4. BSs located outside the target area with contribution to the coverage in the target area: fine adjustment to serve as many mobile stations as possible from the target area, to help the cells in the target area.
5. BSs located outside the target area with no contribution to the coverage in the target area: adjust in a way that no main lobe points directly to the target area.

In the strategy for finding the best adjustment of base station azimuth in an 'ad hoc' manner I take the first two points out of the list above. As already mentioned, the other rules for adjustment are too far from reality or the result is only marginal. Thus my strategy is to find and define the 'critical points' in the target area, to adjust the main lobes of the base stations located around these 'critical points' towards these points, and to interleave the cells.

In order to see some results of this strategy, I adjusted the azimuth of all the base stations in the reference scenario (Figure 4.2) manually (cell by cell) according to the rules mentioned above. The downtilt of all antennas was set to 3° (+3° electronical tilt) and the CPICH power level was at 30dBm in all cells. I used three 'critical spots' with the coordinates: critical spot1: (750700, 338050), critical spot2: (749864, 343146) and critical spot3: (756550, 341737). The achieved numbers of served users in the target area are mean values over 40 different user distribution snapshots at a grade of service of 95% and calculated with the simulator mode 'ATOLL'.

These results of my strategy are compared to the number of served users in the target area of a scenario with randomly adjusted azimuths of the base stations. In Figure 5.14 you can see that the maximum number of served users in the target area is about 655 and the minimum is 600. The values of these 100 different random azimuth adjustments are mean values over 40 different user distribution snapshots at a GoS of 95% and in simulator mode 'ATOLL' again.

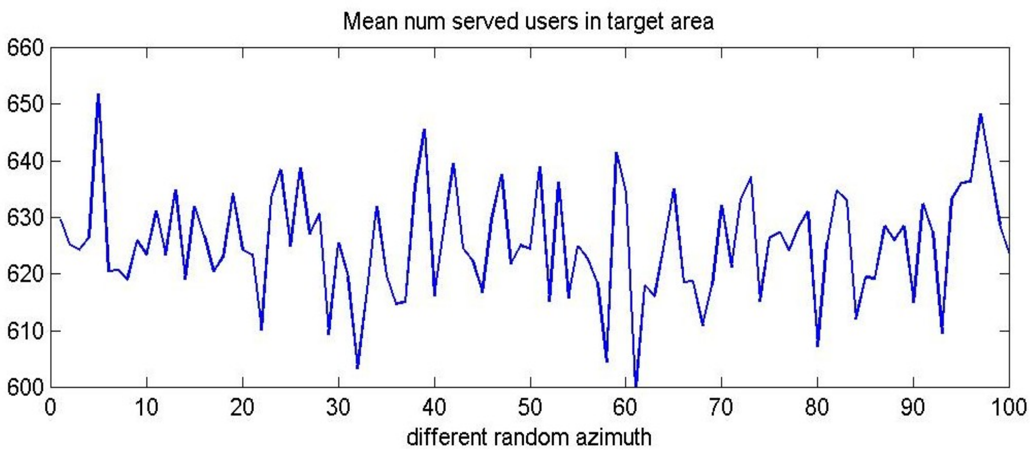

Figure 5.14: Mean results in capacity of 100 different random azimuth adjustments

These are the results of the azimuth strategy:

- When using all the five rules mentioned above (critical spots, interleaving, adjustment according target area) the number of served users in the target area is *656*. This is a gain of *+9.5%* compared to the worst case of the random azimuth adjustment.
- With interleaving the cells in the scenario only, the result is *636* served users, a gain of *6%*.
- Adjusting to critical spots and interleaving all the other cells provides *650* served users in the target area, and a gain of *8.5%* compared to the worst case of random azimuth.
- The direction of antennas presented in the reference scenario (Figure 4.2) yields a result of *624*.

It is important to mention that due to the strict borderlines of the target area, the capacity in the target area is highly dependent on the position of the cell coverage areas in reference to that border!

The results presented above were achived by adjusting the azimuth of the base stations by hand in the simulation environment. The automatic adjustment routine for the azimuth is described in section 6.2 and the results of that automatic adjustment are presented later in this work.

5.3 Optimisation of Antenna Downtilt

In this work only the mechanical tilt of the BS antennas is adjusted, as explained in section 3.3, with a fixed electronical downtilt of 3° included in the antenna pattern. As we have seen in section 3.3, it is crucial to adjust the downtilt of the antennas of the base stations to reduce the interference level in the system on the one hand [1], to maintain coverage and to do load balancing between the cells on the other hand [9]. We have seen that the maximum downtilt is reached when the interference level increases due to the side lobe of the antenna pattern or when the required coverage is lost.

Obviously the optimum value of antenna tilt depends on the cell size, the altitude profile of the cell area, the height of the BS antenna, the CPICH power level and on the used antenna pattern.

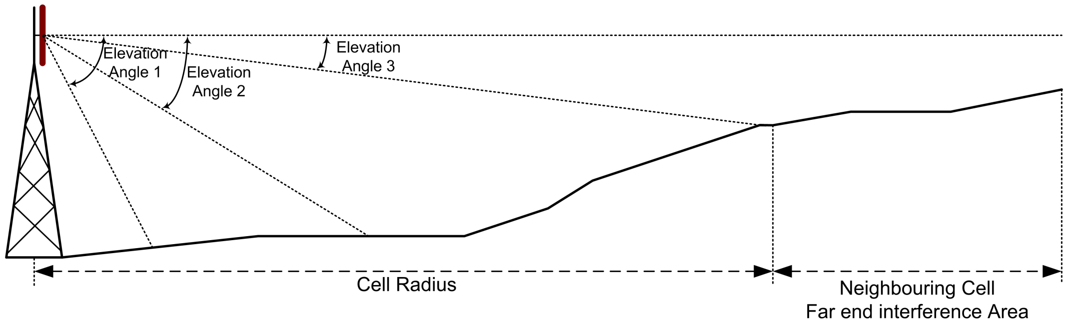

Figure 5.15: Elevation angle of the cell area

The optimum adjustment of the antenna downtilt would be to achieve maximum antenna gain for the mobile stations in the own cell and at the same time having maximum loss in the far end interference area, that means in the neighbouring cells. The minimum interference in the neighbouring cell would occur if the antenna points straight up into the sky, or vertically down to the ground. The own users would see the maximum gain, if the main lobe of the antenna would point straight to them. These two optimum directions are quite different, therefore the problem is how to achieve the ideal adjustment of the antenna for the whole system. A trade off has to be found between the requirements of the own users and the advantages for the neighbouring cells.

It is easy to maximize the sum of antenna gains for all the points or users in the coverage area. But which points or users of the neighbouring cells should we take for maximising the loss? How much of them do we take and how much weight do we add to them in order that their influence does not become too big in comparison to the points in the own cell?

In my optimisation strategy I am adjusting the antenna downtilt according to the mean elevation angle of the points or users in the coverage area of the cell in reference to the base station antenna, as shown in Figure 5.15. I am not setting the antenna downtilt directly equal to the mean elevation, but due to certain rules obtained from results of the step by step optimisation algorithms in [4]. You can see these rules for simulator mode 'ATOLL' in Table 5.1 and in Figure 5.16 as a linearised function over the mean elevation angle. For simulator mode 'ODYSSEY' these rules are shown in Table 5.2 and in Figure 5.17.

mean elevation angle	antenna downtilt
$\phi \leq$ -1.5	-4
$-1.5 < \phi \leq -1$	-3
$-1 < \phi \leq -0.5$	-2
$-0.5 < \phi \leq 0$	-1
$0 < \phi \leq 0.5$	0
$0.5 < \phi \leq 1$	1
$1 < \phi \leq 1.5$	2
$1.5 < \phi \leq 2$	3
$2 < \phi \leq 2.5$	4
$2.5 < \phi \leq 3$	5
$3 < \phi \leq 4$	6
$4 < \phi \leq 5$	7
$5 < \phi \leq 6$	8
$6 < \phi \leq 7$	9

Table 5.1: Rules for adjusting the antenna downtilt according to the mean elevation angle in simulator mode 'ATOLL'

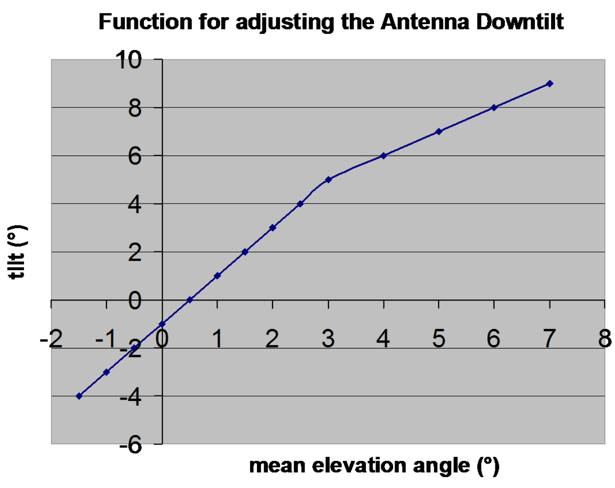

Figure 5.16: Function for adjustment of the antenna downtilt according to the mean elevation angle in simulator mode 'ATOLL'

mean elevation angle	antenna downtilt
$\phi \leq$ -1.5	-6
$-1.5 < \phi \leq -1$	-5
$-1 < \phi \leq -0.5$	-4
$-0.5 < \phi \leq 0$	-3
$0 < \phi \leq 0.5$	-2
$0.5 < \phi \leq 1$	-1
$1 < \phi \leq 1.5$	0
$1.5 < \phi \leq 2$	1
$2 < \phi \leq 2.5$	2
$2.5 < \phi \leq 3$	3
$3 < \phi \leq 4$	4
$4 < \phi \leq 5$	5
$5 < \phi \leq 6$	6
$6 < \phi \leq 7$	7

Table 5.2: Rules for adjusting the antenna downtilt according to the mean elevation angle in simulator mode 'ODYSSEY'

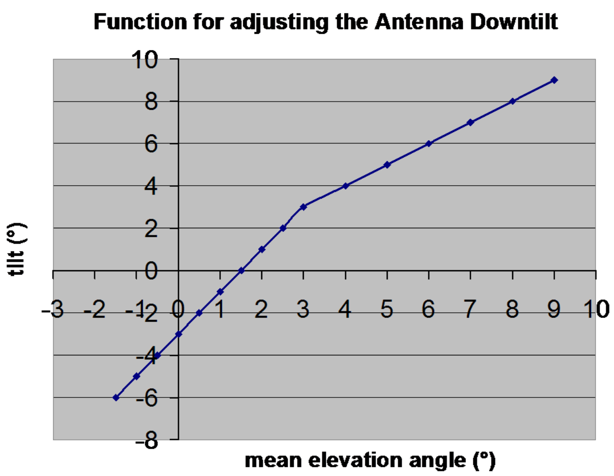

Figure 5.17: Function for adjustment of the antenna downtilt according to the mean elevation angle in simulator mode 'ODYSSEY'

These rules of course are different when using other types of antennas and only are valid for the antenna pattern of the used antenna 739707 from Kathrein.

The difference in the rules for simulation mode 'ATOLL' and mode 'ODYSSEY' might be due to the incorporation of interference into the calculation of CPICH coverage in mode 'ODYSSEY' and is about $-2°$ in downtilt. That means, that in mode 'ODYSSEY' the antennas are not as much downtilted as in mode 'ATOLL'. Therefore, the main beams of the antennas are pointing more towards the adjacent cells and are producing more interference for the neighbouring cells. This could signify that the intra-cell interference is worse than the inter-cell interference in a UMTS system.

The great advantage of adjusting the tilt according to certain rules based on the mean elevation is that the tilt adapts to the cell radius and to the cell height structure at the same time.

The mean elevation angle of the cell serving area itself could be used as an upper bound for the adjustment in step by step optimisation algorithms.

The MATLAB routine for automatic adjustment is presented in Chapter 6 and results will be explained in Chapter 7.

5.4 Optimisation of CPICH Power Level

In Chapter 3.4 has been shown that the optimum CPICH power level is the lowest CPICH value that can be received correctly by the mobile stations in the serving area. With this minimum power level, too much overlapping in the CPICH coverage areas is avoided and therefore the minimum pilot pollution and the minimum interference is created in the system. Furthermore, due to the transmit power limitation of the base stations, it is also an advantage to have the minimum CPICH level, in order to provide more power recources to the traffic channels and therefore achieve a higher capacity.

The same result can be seen in Figure 5.18, where the cumulative transmit power of the cell Tx07a in the virtual scenario of the city center of Vienna is presented over the CPICH power level. This curve is a result of simulations in the simulator $CAPESSO^{TM}$ in CPICH coverage verification mode 'ATOLL'. During the whole simulation the CPICH power levels of all the cells in the scenario have been decreased. To achieve a valid result, the cell had 19 mobile stations served in all the measurement points. What we can see is that by decreasing the CPICH power level of the cells, the cumulative transmit power of the cells decreases as well, not only due to the amount of reduced CPICH power but also because of a certain down swinging effect due to a reduced interference level in the system.

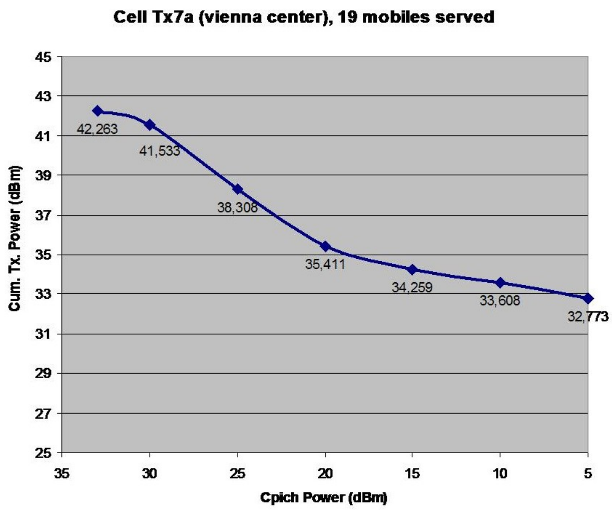

Figure 5.18: Transmit power of cell Tx07a in the center of Vienna

Thus, the main task in optimising the CPICH power level is to avoid a too high degree of cell overlapping while still having a certain minimum CPICH power for providing the required CPICH coverage in the defined area. Therefore the overall problem is to find that minimum CPICH level for maintaining CPICH coverage. Due to the significance of the correct calculation of CPICH coverage and because of the quite different coverage verification in simulator mode ‘ATOLL’ and ‘ODYSSEY’, it is important to find two different CPICH optimisation strategies for the two CPICH coverage verification modes in the simulator $CAPESSO^{TM}$.

Simulator Mode ‘ATOLL’:

In simulator mode ‘ATOLL’, the CPICH coverage is defined by the MS receiver sensitivity, but without consideration of any interference. Therefore the required coverage can be maintained down to a non realistic CPICH power level of less than 0dBm at a receiver sensitivity of -120dBm, as set in the simulator. To have a more realistic lower bound of CPICH power level, a minimum of 15dBm was set for the CPICH in the optimisation strategy for simulator version 'ATOLL'.

Starting from that minimum CPICH power level of 15dBm, it is quite easy to adjust the CPICH power levels in all cells for the required CPICH coverage in the defined area, since no interference is included in the coverage verification. What we have to do is look at all the points in the defined area which are not covered and adjust the CPICH power level of the cell with the smallest path loss to that point. The amount of CPICH power which has to be changed in the BS is the difference of the received CPICH power level at the mobile station to the threshold, in our case the -120dBm receiver sensitivity. In this way we try to cover a predefined part of the system area. One UMTS network operator for example could aim for a coverage of 98% in urban and 80% in rural areas.

In the output file of the simulator no direct information about the received CPICH power levels at every pixel of the scenario is available, so I am using a overcrowded scenario with about 100 users per cell. This is no problem in the simulation mode 'ATOLL', as for CPICH coverage verification the interference is not considered. These 100 mobile stations per cell, which are measuring the received CPICH level, are almost covering the whole cell area and therefore provide a good statistics for the CPICH levels in the cell.

Simulator Mode 'ODYSSEY':

In simulator mode 'ODYSSEY' the CPICH coverage is defined by a certain $CPICH_{E_c/I_0}$ threshold, for example -18dB or -12dB as used later in this work. In that mode the simulator considers the interference level in the system for the CPICH coverage verification. Due to the fact that when changing the CPICH power levels, the interference is changing as well, it is very difficult or impossible to adjust the minimum required CPICH power level in one step.

So, to find a solution, we have to ask the two questions: "Why do we need the CPICH coverage?" and "When do we need the CPICH coverage?". The answer to the first question is that we need the coverage of the CPICH to have a phase reference, for channel estimation or for cell selection. Thus, we need CPICH coverage in order that the mobile stations can be served. But also if there is no possibility of serving one mobile station due to other outage reasons, it would be good for psychological effects if the user sees the logo of the network operator on the display of his mobile. This leads us to the answer of the second question, because to maintain this psychological advantage of the operators name on the display, we want to have CPICH coverage also in the worst case. The worst case for coverage is the case with the highest possible interference level in the system which happens when all the base stations are transmitting with the maximum power. At the same time this is the ideal case for capacity, because the system will accept users until the power limit is reached if there is no other capacity limitation factor reached before.

Therefore we can conclude that the CPICH coverage should always be adjusted according to the worst case which is the highest possible interference level in the system. This way the user can always see the logo of the network operator, thinks that he has access to the system, and therefore is content. But what should be optimised in that case are the maximum transmit power levels of the base stations. It is the ideal case, if all the cells are transmitting with maximum power. But it is not ideal, if all the base stations have the same maximum transmit power level. Then the cells which are small, due to the transmitted CPICH power level, are creating more intercell interference level for the adjacent cells because of the high cumulated transmit power. Therefore it could be a good idea to adapt the transmit powers of the cells in a way, that the interference levels do not exceed a certain threshold at the cell border. With that optimisation smaller cells for example have a lower total power limit than big cells and so the total system can have the optimum worst (=ideal) case.

In the strategy for CPICH optimisation in simulator mode 'ODYSSEY' the worst case is determined by creating the highest possible interference level in the system with the maximum transmit powers of the cells and then adjusting the CPICHs of the cells in order to achieve the required coverage probability in the defined area. The maximum transmit powers of the BSs are achieved by setting the PCH value in the simulator to the maximum (40dBm) and the SCH value in a way that the total transmit power of the cell (43dBm) is reached. As already mentioned, the PCH and SCH values don't have any real function in the simulation - they are just additive interference for the system.

Like in the simulation mode 'ATOLL' an overcrowded scenario is used again for adjusting the CPICH power levels. When setting the cumulative transmit powers of the cells to the maximum by increasing the SCH and the PCH, there won't be any mobile served however. Therefore I am looking at the for example 100 mobiles in each cell and adjust the CPICH of the cell with the smallest pathloss to that certain mobile station in order to reach the received E_c/I_0 requirement. That also can be done in one step, because the interference level stays the same although the CPICH level changes.

The process for the automatic adjustment of the CPICH power by using a MATLAB routine with the simulator $CAPESSO^{TM}$ will be described in Chapter 6 and the results in Chapter 7.

5.5 Combined Optimisation of Antenna Downtilt and CPICH Power Level

Due to the fact that in simulator mode 'ATOLL' the interference level in the system is not considered in the CPICH coverage calculation, it is possible to predict a cell radius according to CPICH power level and antenna downtilt. Of course, the cell radius with fixed CPICH power level and antenna tilt depends on the antenna height, antenna pattern and the surrounding. But in a given scenario we are able to achive curves like Figure 5.19, where we can see the CPICH power level and the antenna downtilt on the horizontal axes.

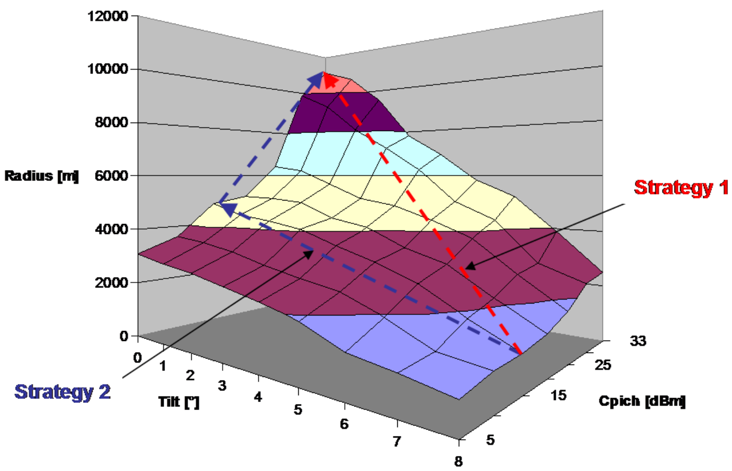

Figure 5.19: Combined strategy for CPICH and tilt adjustment in mode 'ATOLL'

On the vertical axis the achieved radius of the cell is presented. These values were taken from simulations of a single isolated cell in the center of the virtual scenario of Vienna by using the best server plot. The best server plot usually shows the area of the best serving cells, which means the area in the scenario in which one and the same cell provides the highest received CPICH power level for the MSs. But in case of a single cell and simulation mode 'ATOLL' it shows the maximum cell radius, i.e. the area where the received CPICH power level is greater than the receiver sensitivity of -120dBm, as used in the simulations. So, the radius used in Figure 5.19 is the distance from the BS up to which the coverage is guaranteed without significant holes.

When having the diagram for the cell radius versus CPICH and downtilt, the combined optimisation process is as follows. First, the required cell radius can be measured in the best server plot of the scenario with the same CPICH and antenna tilt in all cells. From this radius the suitable CPICH power level and antenna downtilt can be adjusted according to the diagram using two different strategies. In *Strategy 1* the CPICH power level and the antenna tilt are adjusted at the same time in a continuous way from a minimum CPICH power level of 15dBm and a maximum tilt of 8° up to maximum CPICH power level and minimum tilt, as indicated by the red arrow in Figure 5.19. So, starting from a required radius of the cell I take the projection point on the red arrow and take the projection again on the CPICH and the downtilt axes. These values of CPICH power and downtilt have to be adjusted in the cell in order to reach the radius. In *Strategy 2* at first the tilt is varied at a constant minimum CPICH level of 15dBm and after that the CPICH power level is increased in order to reach a higher cell radius than by varying the antenna tilt. That idea is shown in blue arrows in Figure 5.19. The procedure in order to reach a required cell radius is the same as in strategy one, that means using the projections on the axes over the arrows.

With this diagram we are able to adjust the required cell radius for minimum cell overlapping by tuning the CPICH power level and the antenna downtilt only for comparable environment. This means, that the adjustment of CPICH and downtilt according to Figure 5.19 is only possible for urban plain areas with the same characteristics like in the simulation for this diagram. For other environments like suburban, rural, different altitude profile of the terrain or other heights of the buildings, Figure 5.19 is not valid anymore and corresponding curves have to be created from certain simulations due to different propagation properties.

As we can see in Figure 5.19, the curves along the arrows of the strategies can simply be linearized without making a big error. Thus we have the great advantage that for different scenarios (urban, rural, ...) we just have to do the simulations of starting and ending point of the arrows in order to adapt the strategies to a different propagation loss for example. When fitting the antenna downtilt to the height structure of the surrounding, the diagrams from a plain area can be used for tilted areas as well.

We can conclude that in case of simulator mode 'ATOLL', i.e. in absence of interference, this combined strategy would be an excellent way to avoid too high cell overlapping, to minimize the interference and to provide CPICH coverage as required. But due to the fact that absence of interference is a rather unrealistic assumption, this combined optimisation strategy was not developed any further and therefore there are no results available to compare the gain of the strategy in Chapter 7.

Chapter 6

Automatic Adjustment Routines for Key Parameters

6.1 Introduction

In order to reach the optimum default parameter setting for the UMTS network automatically, I have developed MATLAB programs for automatic adjustment of the three key optimisation parameters antenna azimuth, antenna downtilt and CPICH power level. These programs use the simulator $CAPESSO^{TM}$ for calculations by accessing the input and output XML files of the simulator as interface.

In this Chapter the optimisation strategies of Chapter 5 are developed further for automatic adjustment of the key parameters, and the MATLAB routines for the automatic optimisation process are described.

6.2 Automatic Adjustment of Base Station Azimuth

As developed in Chapter 5.2.3, the adjustment of the optimum base station azimuth consists of two main parts. The first one is to turn the main lobes of the antennas to the 'critical spots' and the second is to 'interleave' the base stations in the defined area.

To adjust the antennas of the base stations to 'critical spots', these points have to be known first. As already defined in section 5.2.2, a 'critical spot' is a point in the target area with a higher minimum distance to all the base stations than all other points; or in other words: a 'critical point' is a point in the target area with a big distance to all the surrounding base stations (compared to all other not critical points in the target area). Therefore it is difficult to cover that point and to serve mobile stations located there. Due to that definition, it is quite easy to find e.g. the three most critical spots in the target area through a geometrical calculation. In my program though, these spots are defined manually by looking at the graphical user interface of the simulator. After that we have to define how many nearest base stations should be turned to these points. This is also done manually.

Figure 6.1 shows the flowchart of the MATLAB routine for automatic azimuth adjustment by turning the base stations to the critical spots: After defining the number of critical spots, their coordinates and the number of base stations to be turned to these critical spots, the program starts with the calculation of the distances from all critical spots to all base stations. These distances are sorted with the nearest first, and for every critical spot the previously defined number of nearest base stations are selected and adjusted, so that one of the main lobes of the three antennas points directly to that critical spot. The routine selects the rotating angle in a way, that the base stations have to be turned between $0°$ and $120°$ to the right from north ($0°$).

After the calculation of the azimuth values of all the base stations which should be adjusted, a vector (`bs_changed`) with the base station names is built for the following interleaving routine, and the new azimuth angles are written to the XML input file of the simulator.

In the MATLAB program for automatic azimuth adjustment by interleaving, there has to be at least one cell defined to be fixed at the beginning of the routine. According to that cell(s), all the other cells are interleaved. As shown in Figure 6.2, the base stations with fixed azimuth can either be defined manually, or the vector `bs_changed`, containing the base stations already adjusted to the critical spots from the MATLAB routine for adjusting the azimuth to critical spots, can be used.

After that, the program for interleaving the base stations begins with calculating the distances from all base stations which should be interleaved to the base stations which are already changed and fixed. These distances are sorted and the closest base station is taken. This BS will be interleaved to the already changed base stations and is called `bs_tointerleave`. Then the distances are calculated from that `bs_tointerleave` to all the base stations which are already adjusted, and the closest 5 base stations are taken for calculation of the angle for interleaving the `bs_tointerleave`. These base stations are called `bs_forinterleaving`. However, base stations are only taken as `bs_forinterleaving`,

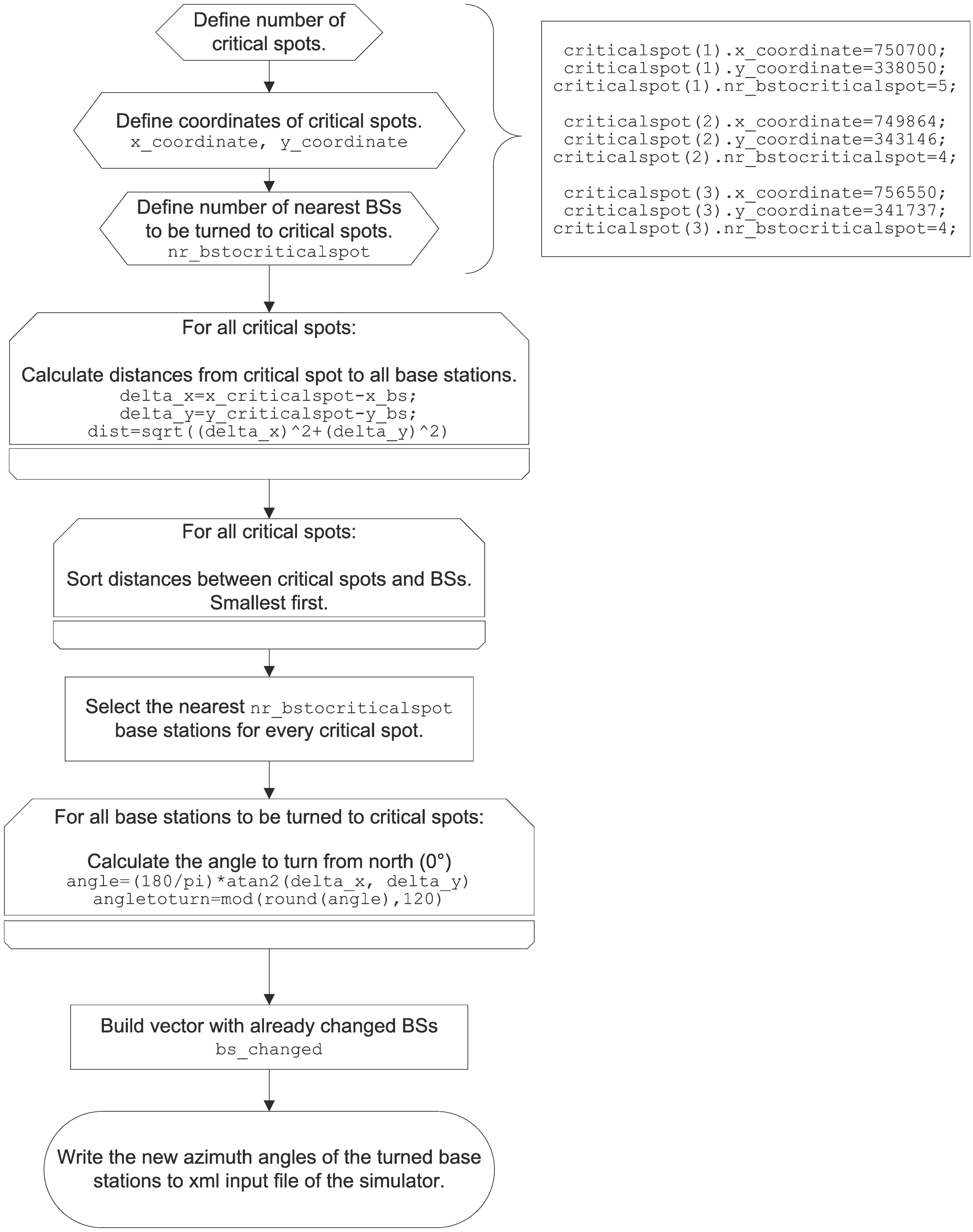

Figure 6.1: Automatic azimuth adjustment routine for turning BSs to critical spots

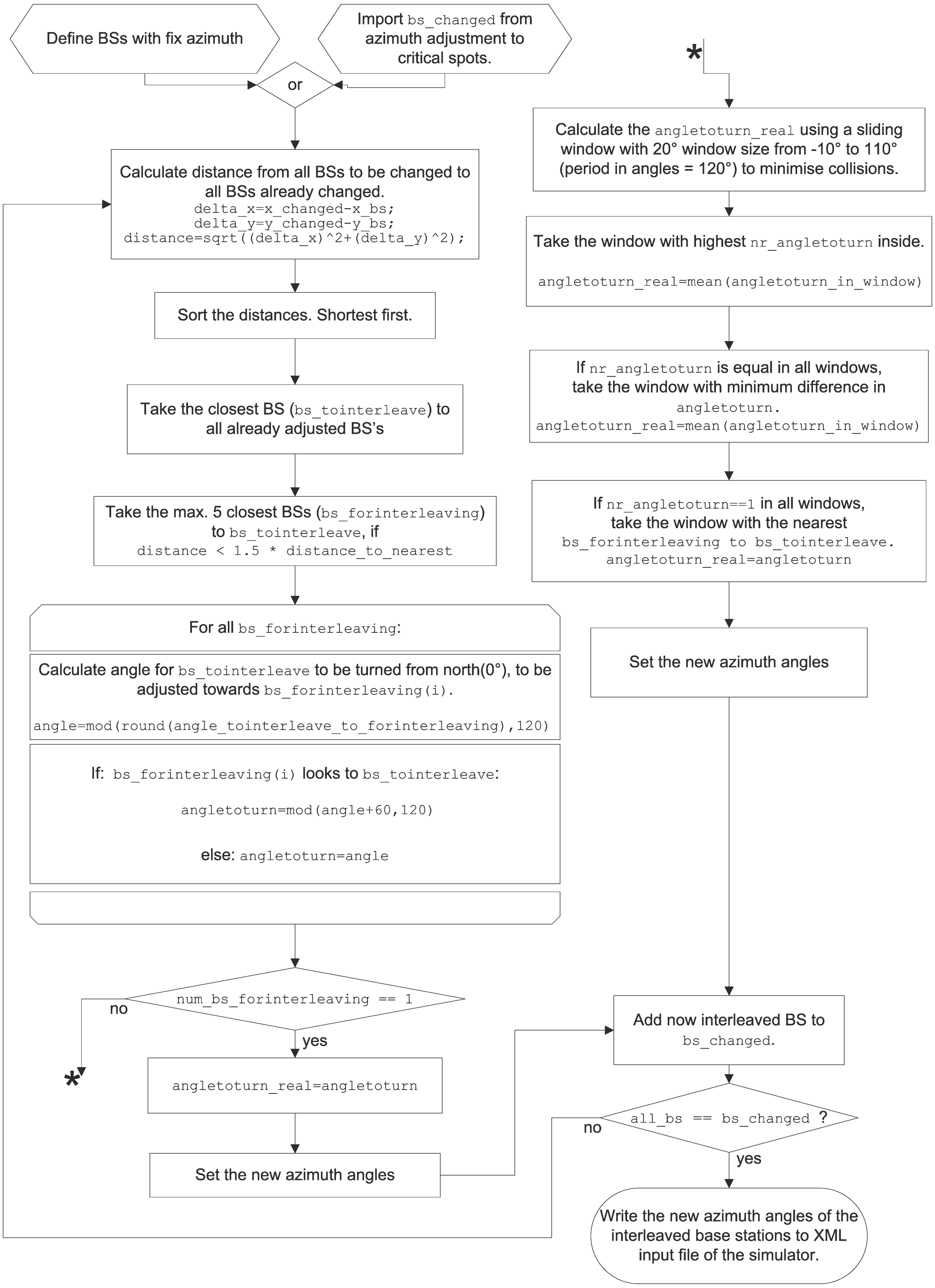

Figure 6.2: Automatic azimuth adjustment routine for interleaving BSs

if they have a distance to `bs_tointerleave` smaller than 1.5 times the distance of the closest base station. Consequently, the number of `bs_forinterleaving` can be smaller than 5. The reason for this limit is to avoid that one base station behind another one is used for interleaving if there doesn't exist a circle of 5 nearest and already changed base stations around the `bs_tointerleave`. That can also be seen in Figure 6.3 where only 3 already changed base stations are within the circle of 1.5 times the minimum distance *dmin*. So, the other two base stations of the nearest of the already changed base stations to the `bs_tointerleave` are outside the circle and therefore can not be used as `bs_forinterleaving`. This is very useful, because these two base stations are not in the direct surrounding of the `bs_tointerleave` and thus would cause an error in the interleaving strategy.

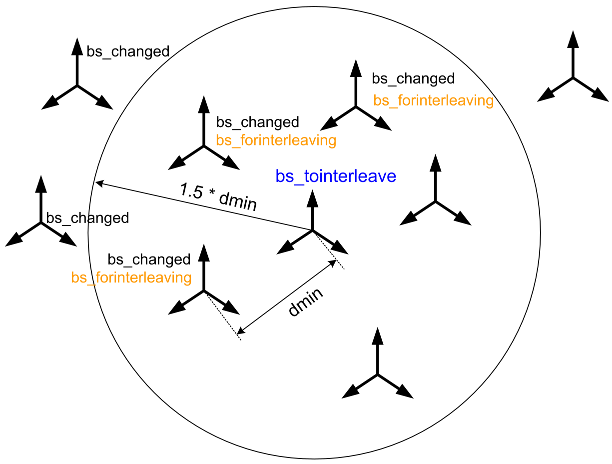

Figure 6.3: Selection of the BSs for interleaving

Then the MATLAB routine calculates the rotation angles the `bs_tointerleave` has to be turned from 0° (north) in order to be interleaved with each `bs_forinterleaving(i)`. These angles (angle_tointerleave_to_forinterleaving) are calculated in a way, that the main lobe of one of the three antennas of `bs_tointerleave` points directly to the `bs_forinterleaving`. If the `bs_forinterleaving(i)` looks directly to `bs_tointerleave` however, the angle is calculated so that no main beam of an antenna of `bs_tointerleave` points directly to `bs_forinterleaving(i)`. This is done by adding 60° modulo 120 to the angle calculated previously. The `bs_forinterleaving(i)` is defined as directly looking to `bs_tointerleave`, if `bs_tointerleave` is in an angle of ±30° around a main lobe of one antenna of `bs_forinterleaving(i)`, as can be seen in Figure 6.4.

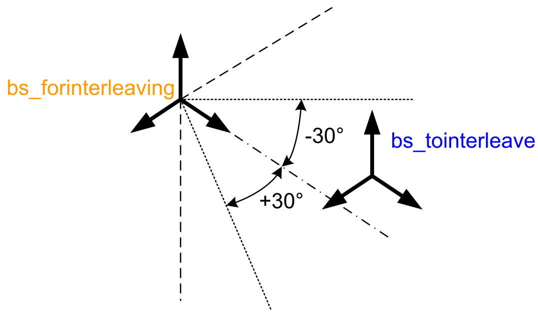

Figure 6.4: Check if bs_forinterleaving looks to bs_tointerleave

Now we have up to 5 possible angles for turning the base station which should be interleaved (`bs_tointerleave`). The problem is how to calculate the real angle for turning `bs_tointerleave`, avoiding as many conflicts of different ideal interleaving directions as possible. If there is only one base station as reference, it is quite easy. Then we only have one single value for the turning angle and thus can take that angle as the real adjusting angle for `bs_tointerleave`. If there are more than one reference base stations (`bs_forinterleaving`) however, the real angle for adjusting the `bs_tointerleave` is calculated by using a sliding window over all the angle values for the different `bs_forinterleaving`. The sliding window size was selected to be 20°, so that the maximum deviation, resulting from calculating the mean angle, does not exceed 10°. Due to the period of the angles of 120°, the center of the sliding window runs from $-10°$ to 110° to close the calculation of the period, as shown in Figure 6.5. Of course, the angles between 100° and 120° have to be copied to the equivalent locations between $-20°$ and 0° first.

To calculate the real rotation angle for the base station which should be interleaved, we take the window which contains the most angles. Then the real angle is the mean of the angles in the window. If the number of angles is equal in all windows, we take the window with the minimum difference between the angles contained in it and calculate the mean angle. If there is only one angle in every window, the angle of the nearest base station is taken as the value for turning the `bs_tointerleave`.

After calculation of the angle for the base station, the base station name is added to the vector which contains the base stations with already adjusted azimuth or fixed azimuth.

That procedure is repeated until all the base stations have a changed or fixed azimuth, and then the new azimuth values are written to the XML input file of the simulator.

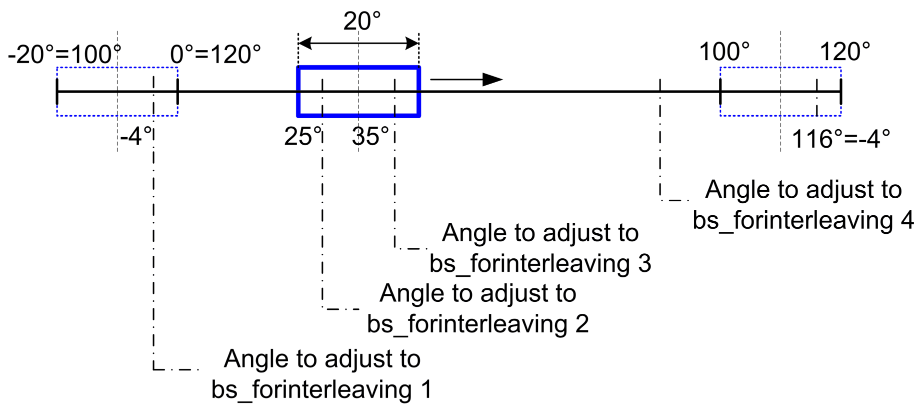

Figure 6.5: Example for calculation of the angle to turn with a sliding window

We see that it is not trivial to adjust and interleave the base station azimuth automatically, since there are lots of conflicts between different possible interleaving directions when adjusting to surrounding base stations in a non-regular grid.

The results of this strategy for automatic adjustment of base stations azimuth have been calculated with simulator $CAPESSO^{TM}$ and are presented in Chapter 7.

6.3 Automatic Adjustment of Antenna Downtilt

The flowchart of the automatic tilt adjustment MATLAB routine can be seen in Figure 6.6 and shows the function of the MATLAB program for simulator mode 'ODYSSEY'. The differences in the routine for using simulator mode 'ATOLL' will be mentioned in the following description.

The first step in the program for automatic adjustment of the antenna downtilt in UMTS networks is to define the initial value of downtilt (`start_tilt`). This is important due to the fact that the calculation of the mean elevation angle of the mobile stations in the cells is not independent of the `start_tilt`. What is the reason for that dependency? The problem is that with e.g. 0° downtilt, the cell broadcasts the CPICH straight horizontally from the base station, and therefore the coverage area is quite large. So it is possible that areas far away from a certain cell (for example on a hill) receive the highest level of CPICH power from that cell, and therefore are in the coverage area of a cell which is far away. Only a few mobile stations on that mentioned hill would lead to a totally different result in the calculation of the mean elevation angle for that cell. The optimum would be to set the initial tilt value according to the altitude profile of the surroundings

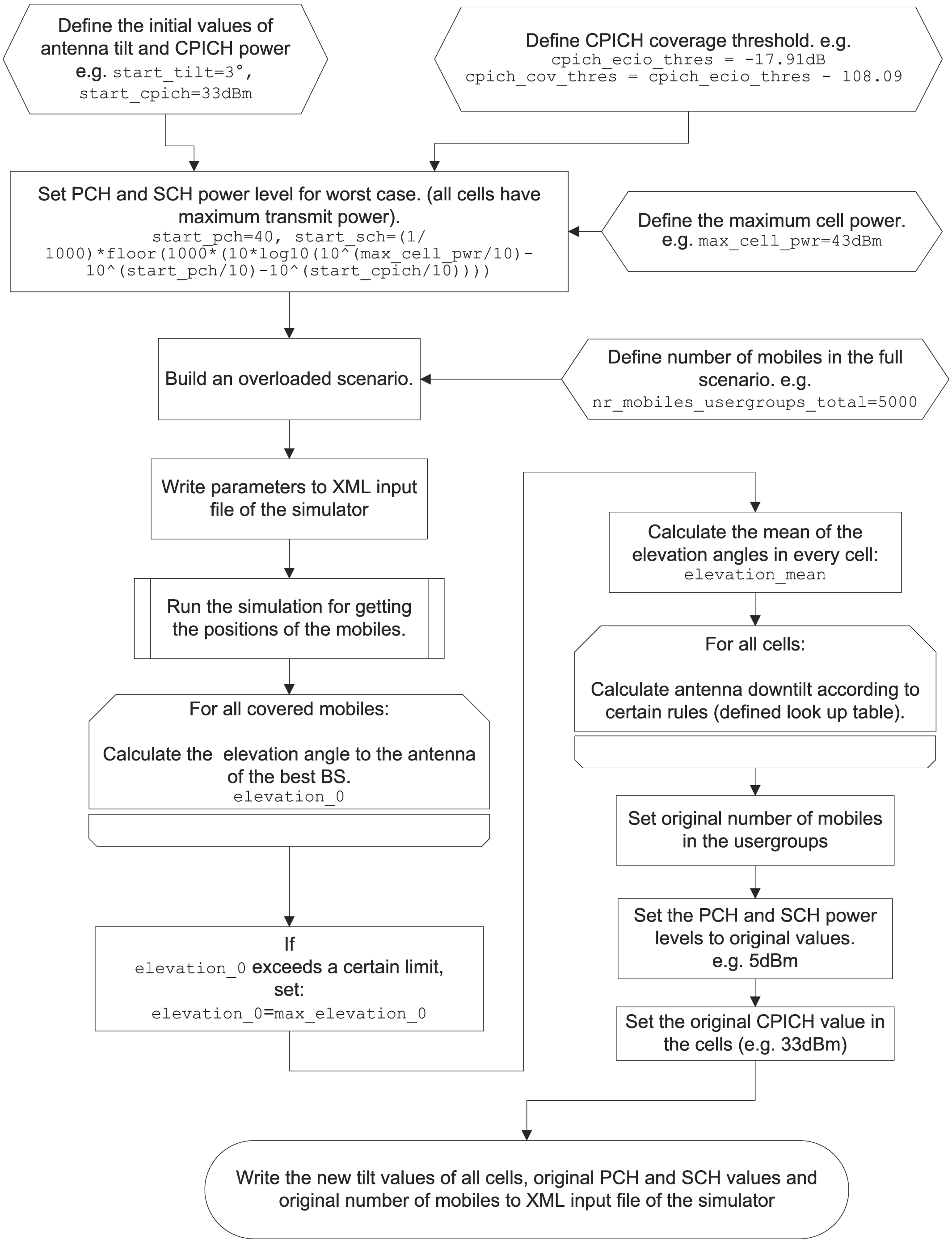

Figure 6.6: Automatic tilt adjustment routine for simulator mode 'ODYSSEY'

and in a way so that only the required area is covered. In this work the `start_tilt` was set to 3° (+ 3° electronical tilt) in all cells, which has been determined to be sufficient for avoiding coverage of remote areas. The same problems arise when setting the initial value of CPICH power. The CPICH power level must have a value so that the required coverage is reached while avoiding coverage of (too many) remote areas.

The next definitions in the routine in case of simulator mode 'ODYSSEY' are the CPICH coverage threshold and the maximum cell power. These values are for example -17.91dB or -11.91dB and 43dBm, respectively. When using simulator mode 'ATOLL', these definitions are not necessary, since in this mode the coverage is defined by the receiver sensitivity (-120dBm) and does not change during the simulations.

Ideally, for the calculation of the mean elevation angle, all points (or pixels) of the area covered by a cell should be taken into account. Due to easier availability in the simulator, in this work the positions of the mobile stations are used instead of all the pixels of the scenario. Together with an overcrowded scenario the positions of the covered mobile stations provide sufficient statistics for the whole terrain. In simulator mode 'ATOLL' there is no difference in coverage between normal scenario or overcrowded scenario because the coverage is defined without interference. In simulator mode 'ODYSSEY' the interference is taken into account in calculation of CPICH coverage. Therefore, the next step in the MATLAB routine for automatic tilt adjustment in mode 'ODYSSEY' is to set the worst case for CPICH coverage. The worst case is when all the cells are transmitting with maximum power and therefore produce the highest interference level in the system. That maximum transmit power level in the cells is reached by setting the SCH and PCH power level, where the start value of PCH is set to 40dBm and the start value of SCH is set to $P_{SCH} = P_{max} - P_{PCH} - P_{CPICH}$ rounded down at the third decimal behind the comma. So no mobile station is served, we have a fixed interference level and the coverage of the different cells can be detected.

After that, the already mentioned overloaded scenario is built with the predefined number of mobiles, the parameters are written to the XML input file of the simulator and the simulation is started to get the positions of the mobiles.

In order to obtain the mean elevation angle of the mobile stations in the cell, first we have to calculate the elevation angle(`elevation_0`) of all mobiles to the antenna of the BS with the highest received CPICH power level in the mobile. Single mobiles, which are covered in the cell but are situated e.g. just below the antenna or in a remote area of coverage, have very big or small elevation angles and therefore would falsify the result of the mean elevation. Thus, if `elevation_0` exceeds a certain level (`max_elevation_0`=10°), it is limited to 10° in order to prevent the influence of one very high or very low `elevation_0` on the result of the mean elevation angle of the cell.

With the mean elevation angle (`elevation_mean`), calculated by the arithmetic mean of all the `elevation_0` in the same cell, the adequate value for the antenna downtilt can be found with the rules from Tables 5.1 and 5.2.

At the end of the routine, the number of mobiles as well as the PCH and SCH power levels and the CPICH power levels are set back to the original values and are written to the XML input file of the simulator together with the new antenna downtilt values of all cells. You can see the numerical results of the simulations with Simulator $CAPESSO^{TM}$ in Chapter 7.

6.4 Automatic Adjustment of CPICH Power Level

The main function of the automatic CPICH adjustment routine is to find the minimum CPICH power level which is necessary to achieve the required CPICH coverage in the system in the worst case (highest interference level = all cells are transmitting with maximum power). For finding the minimum CPICH power level the procedure starts from a level a little bit lower than the expected required power level. Then the CPICH is increased until the required CPICH coverage is reached. Therefore, we have to define the initial value of CPICH power, e.g. `start_cpich=26dBm`, as well as the required coverage probability in the total scenario and in the target area. Furthermore, the CPICH coverage threshold, the maximum cell power for setting the worst case and the number of mobiles in the overcrowded scenario have to be defined.

It is important to mention that the procedure for automatic CPICH adjustment consists of two main parts, as shown in Figure 6.7 and 6.8.

The first part (Figure 6.7) is the adjustment of the CPICH power levels in order to achieve the required CPICH coverage in the total scenario, and the second part (Figure 6.8) is the adjustment of the CPICH power levels for achieving the generally higher required CPICH coverage in the target area.

So, after all the previously mentioned definitions, the routine continues with setting the PCH and SCH power level for the worst case in the scenario. This is not necessary in simulator mode ‘ATOLL’, as the coverage is calculated without interference. Also the definitions of CPICH coverage threshold and maximum cell power are useless in case of mode ‘ATOLL’.

In the next step, the overloaded scenario is created in order to have sufficient statistics for the surrounding area by using the mobile stations as measurement points for the received $CPICH_{E_c/I_0}$ ratio. The parameters are written to the XML input file of the

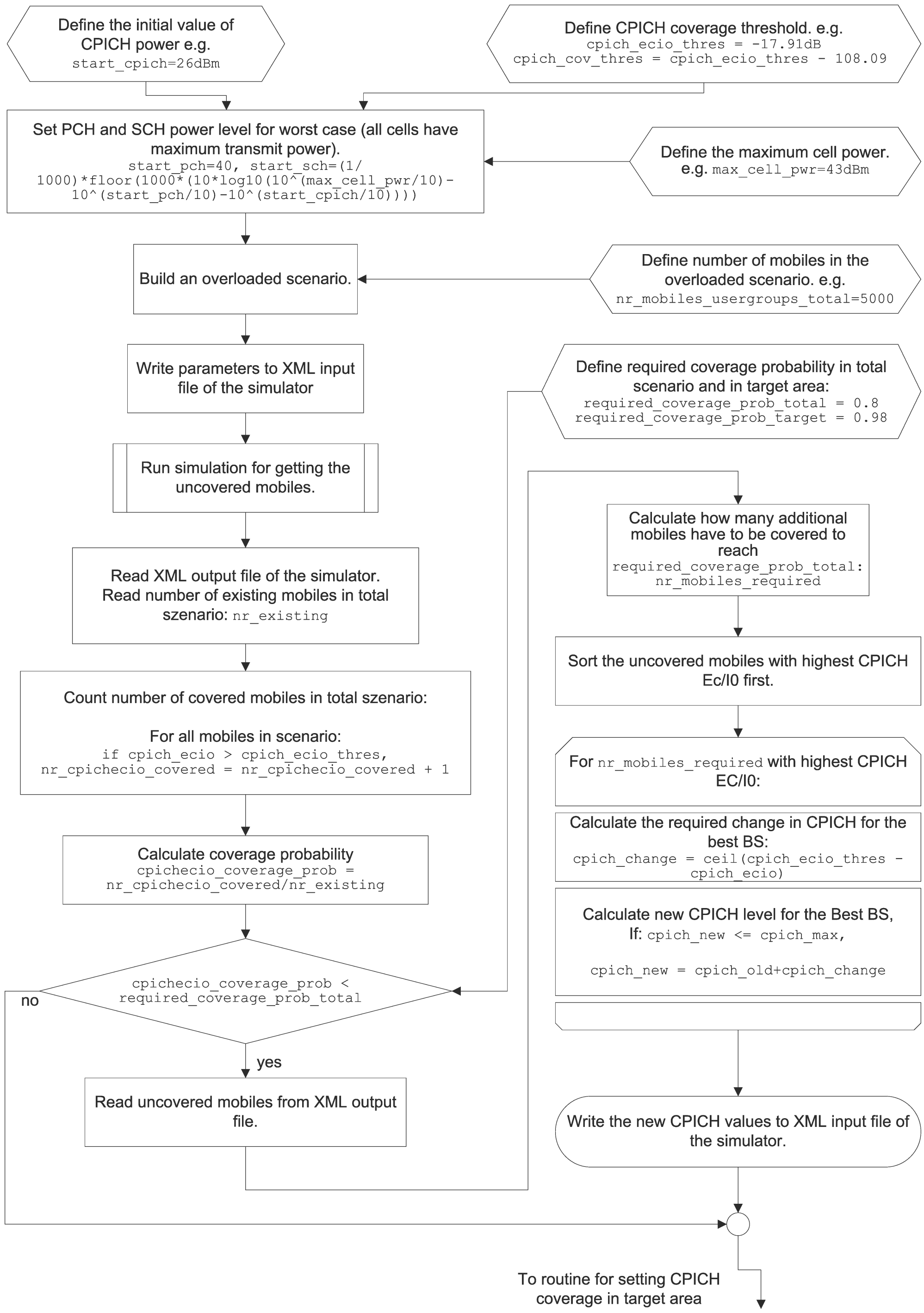

Figure 6.7: Automatic CPICH adjustment routine for simulator mode 'ODYSSEY', function: set CPICH coverage in total scenario.

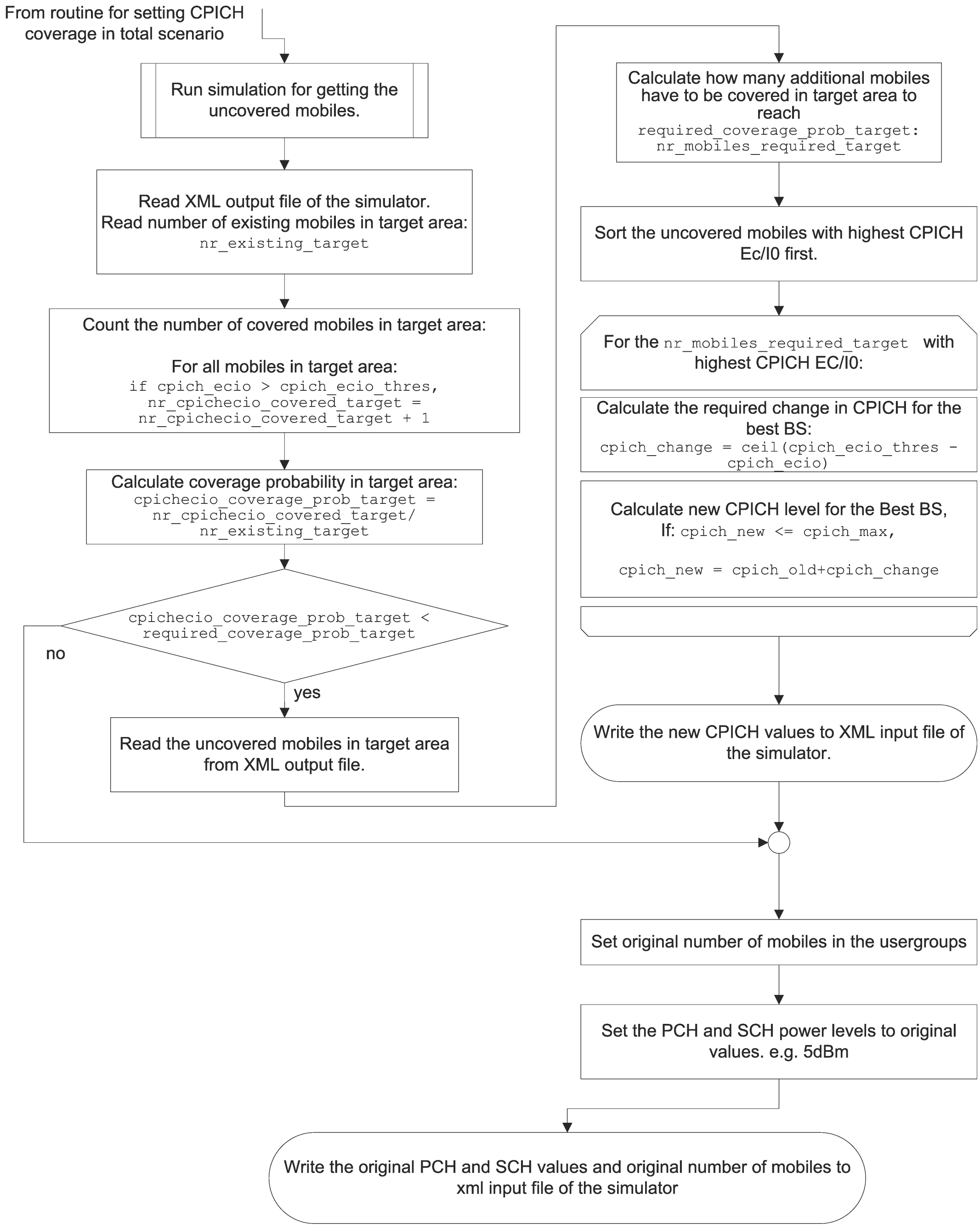

Figure 6.8: Automatic CPICH adjustment routine for simulator mode ‘ODYSSEY’, function: set CPICH coverage in target area.

simulator and one simulation is started. From the XML output file of the simulation the procedure reads the number of existing mobiles (`nr_existing`) and the number of covered mobiles (`nr_covered`) in the total scenario. In simulator mode 'ODYSSEY' a mobile is covered, if the received $CPICH_{E_c/I_0}$ ratio exceeds the CPICH coverage threshold. The coverage probability in the total scenario is calculated with (`nr_existing`) and (`nr_cpichecio_covered`). In the simulator mode 'ATOLL' a mobile is covered, if the received CPICH power level exceeds the threshold of -120dBm. In this case the coverage probability can be taken directly from the XML output file of the simulator and therefore need not be calculated separately.

If the calculated coverage probability in the total scenario fullfills the requirements, the procedure continues directly with the routine for adjusting the CPICH coverage in the target area (Figure 6.8). If the coverage probability in the system is less than the previously defined required coverage probability, the program proceeds on the flowchart in Figure 6.7 with calculating how many additional mobiles have to be covered (`nr_mobiles_required`) to reach the required coverage probability. The uncovered mobiles are sorted with the highest $CPICH_{E_c/I_0}$ ratio first, and the (`nr_mobiles_required`) with the highest $CPICH_{E_c/I_0}$ are taken to calculate the required change in CPICH power level (`cpich_change`) for the best server of this mobile. The `cpich_change` value is the difference between the $CPICH_{E_c/I_0}$ threshold and the received $CPICH_{E_c/I_0}$ ratio of the best server and is calculated as: $cpich\_new = min(cpich\_old + cpich\_change, limit)$, where $limit$ is a predefined maximum level.

The first part of the automatic CPICH adjustment routine ends with writing the new CPICH values to the XML input file of the simulator, and the second part starts by running the simulator again with the new CPICH power levels in the cells. This part consists of the same functions as the first part, with the difference, that here only the mobiles in the target area are considered, and the required coverage probability in the target area is tried to be reached.

After fullfilling the coverage probability requirements, the original number of mobiles in the usergroups and the original levels of PCH and SCH power levels are written back to the XML input file of the simulator.

In the automatic CPICH adjustment routine the CPICH power levels are increased starting from an initial value, until the required CPICH coverage probability is reached in the system. An enhancement of the procedure would be to make the CPICH adjustment independent of the CPICH start values. This way, the program would also be able to decrease the CPICH values if they are too high, and thus work in both directions.

Another suggestion for improving the CPICH adjustment is to adapt the maximum transmit power levels of the cells either in one step or in a step by step method. This way the worst case would be more realistic, and the capacity would reach a higher level.

6.5 Combination of the Automatic Adjustment Routines

The automatic adjustment routines for the three key parameters are individual MATLAB programs. Since the final goal is the optimum adjustment of all the three parameters in the "optimum default parameter setting", we have to find a suitable combination of the different automatic adjustment routines. Especially the order of using these programs is important.

Obviously, the procedure for the antenna azimuth has to be the first, due to the fact that adjusting the antenna downtilt is only possible for an already fixed altitude profile of the surrounding terrain, which would change when rotating the base stations. After adjusting the antenna azimuth, the antenna downtilt is optimised according to the height and cell structure. Finally, the last step is to achieve the required CPICH coverage probability by using minimum CPICH power levels in the cells.

Chapter 7

Numerical Results of Automatic Optimisation Routines

7.1 Introduction

This Chapter contains the numerical results of the automatic parameter adjustment strategies for antenna azimuth, antenna downtilt and CPICH power level. The different strategies are introduced from a theoretical point of view in Chapter 5, and derived for automatic adjustment of the parameters as well as explained in flowcharts in Chapter 6. The delivered parameter settings from the strategies were used in the XML input file of the simulator $CAPESSO^{TM}$ from SYMENA to get numerical results showing the effort of the routines in optimisation of the UMTS system. Furthermore, these results are compared with the results of certain step by step optimisation algorithms.

7.2 General Remarks on the Results

For obtaining the results of the automatic optimisation routines with the simulator $CAPESSO^{TM}$, both CPICH coverage verification mode 'ATOLL' and mode 'ODYSSEY' have been used. In both simulator modes, simulations have been done with a 'best server equal distribution' of the mobile stations in the total scenario and alternately with 'best server equally distributed' and 'equally distributed' mobile stations in the target area. The characteristics of these user distributions as well as the used reference scenario are described in Section 4.5.

The two main results in the following sections are the number of served users in the target area (*nr_served_target*) (the capacity in the target area) and the mean number of served users in the target area over 40 different user distribution snapshots (*mean_cap_target*). It is important to look at the mean capacity over different user distribution snapshots to avoid the heavy influence of the actual positions of the mobile stations in the scenario on the result. In case of a single snapshot for *nr_served_target*, the positions of the mobile stations were determined randomly with a random initialisation value of 1 in *usergroup1* (speech users in total scenario), 2 in *usergroup2* (data users in total scenario), 3 in *optarea1* (speech users in target area) and 4 in *optarea2* (data users in target area). For the mean capacity in the target area, the positions of the mobile stations in the first snapshot were determined randomly with a random initialisation value of 1 in usergroup1 (speech users in total scenario), 4 in usergroup2 (data users in total scenario), 7 in optarea1 (speech users in target area) and 10 in optarea2 (data users in target area). The 40 different user distribution snapshots were then built by adding a value of 4 to the random initialisation values in each of the four previously mentioned usergroups in each snapshot.

The reference scenario is characterised by antenna downtilts of 0° (+3° electronical tilt in the antenna pattern) for all the antennas, and CPICH power levels of 33dBm in all the cells in the scenario. In the Tables 7.1 to 7.10, four columns of results are presented. The first column shows the results of the reference scenario. The other three colums titled adj_azimuth, adj_tilt and adj_cpich contain the results after running the strategy for the adjustment of the antenna azimuth, after the additional strategy for the antenna downtilt and after the CPICH adjustment strategy, respectively.

In the adjustment routine for the antenna azimuth, three 'critical spots' inside the target area were used with the coordinates: *critical spot1* (750700, 338050), *critical spot2* (749864, 343146) and *critical spot3* (756550, 341737). The sliding window width was set to 20° and the maximum distance to the other base stations compared to the nearest was set to 1.5 for the interleaving procedure. In the strategy for adjustment of the antenna downtilt, the initial tilt value was set to 3° (+3° electronical tilt) in all cells, while the initial CPICH value (*start_cpich*) was varied for the diverse simulations. The reason for this initial tilt value and for the different initial CPICH values has been explained in Section 6.3. An initial CPICH power level (*start_cpich*) is also necessary for the CPICH adjustment strategy, as explained in Section 6.4. The actually used initial CPICH level for the special simulation is given in the additional notes in Tables 7.1 to 7.10.

In the simulations, the required coverage probability for the worst case in the total scenario was set to 50% and in the target area to 75%, or 80% in the total scenario and 98% in the target area, as again indicated in the additional notes in the various tables. For the overcrowded scenario in the automatic tilt adjustment routine and the automatic CPICH adjustment routine, 5000 mobile stations were used. The maximum cell power for all simulations was set to 43dBm in all cells.

The simulation results presented in the following are all determined at a GoS of 95% in the target area. In order to reach this constraint, a special mode of the simulator was set during the evaluation stage. In this mode, users are added in the target area until a GoS of 95% is reached. Users are added both to *optarea1* (speech users in target area) and to *optarea2* (data users in target area), in order to maintain the predefined service mix. In our case, after writing the parameters of the strategies to the XML input file of the simulator, one simulation is started in that special mode to achieve the results for evaluation of the success of the strategy. For the calculation of the mean capacity over 40 different user distribution snapshots, the special mode of the simulator is used as well. More precisely, in each of these 40 different results, the side constraint of 95% GoS was tried to be fulfilled. It is important to remember that the simulation runs in that special mode are not a part of the strategies, and only necessary in order to see the results of the default parameter setting.

In simulator mode 'ODYSSEY' the coverage probability is indicated as $cpich_{E_c/I_0}\_cov\_prob\_total$ or $cpich_{E_c/I_0}\_cov\_prob\_target$, while in simulator mode 'ATOLL' simply as *cov_prob_total* or *cov_prob_target*. The difference is that in mode 'ATOLL' the coverage probability can be read directly from the output file of the simulator and is calculated without interference, and in mode 'ODYSSEY' the coverage probability is calculated in the automatic adjustment routines and counts all the mobiles with a received $CPICH_{E_c/I_0}$ ratio greater than the threshold.

In Figures 7.1 to 7.8, the mean numbers of served users in the target area from the Tables 7.1 to 7.10 are presented in bar charts. The bar charts for mode 'ATOLL' (Figure 7.1 and 7.2) show the mean capacity in the target area in the reference scenario (initial parameter setting) in blue, as well as after the automatic adjustment of BS azimuth (green bar), antenna downtilt (yellow bar) and CPICH power level (red bar). The bar charts for mode 'ODYSSEY' (Figure 7.4, 7.6, 7.7, 7.8) present an additional bar for the variation of the required coverage probability for worst case in the target area. Thus, in mode 'ODYSSEY' there are two different bars for the mean number of served users in target area after the CPICH adjustment routine, one for required coverage probability in the total scenario of 0.8 and 0.98 in the target area, and another for the required coverage probability in the total scenario of 0.5 and 0.75 in the target area. It is important to remember that these required coverage probabilities are only for worst case. The effective coverage probabilities in normal interference situation are presented in the Tables 7.1 to 7.10 and are between 0.91 and 1, both in total scenario and in the target area.

7.3 Results for Simulation Mode 'ATOLL'

7.3.1 'Best Server Equally' distributed Mobile Stations in Target Area

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	508	540	691	821
mean_cap_target	512	557	703	**829**
cov_prob_total	1	0.9963	0.9904	0.9193
cov_prob_target	1	1	1	1
additional notes	*start_cpich* in adj_tilt: 15dBm, *start_cpich* in adj_cpich: 15dBm, final CPICH values = 15dBm in all cells, required coverage probability: 0.8 total and 0.98 in target area, best server equal dist.			

Table 7.1: Results of total strategy in mode 'ATOLL', best-server-equal distribution

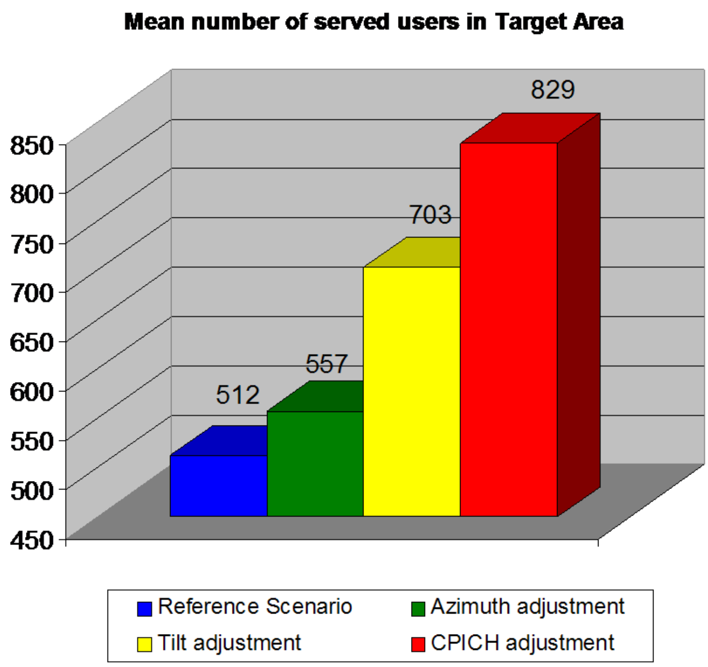

Figure 7.1: Results in mode 'ATOLL', best-server-equal distribution in target area

7.3.2 'Equally' distributed Mobile Stations in Target Area

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	501	514	645	728
mean_cap_target	516	542	663	**774**
cov_prob_total	1	0.9962	0.99	0.9132
cov_prob_target	1	1	1	1
additional notes	*start_cpich* in adj_tilt: 15dBm, *start_cpich* in adj_cpich: 15dBm, final CPICH values = 15dBm in all cells, required coverage probability: 0.8 total and 0.98 in target area, equal dist.			

Table 7.2: Results of total strategy in mode 'ATOLL', equal distribution

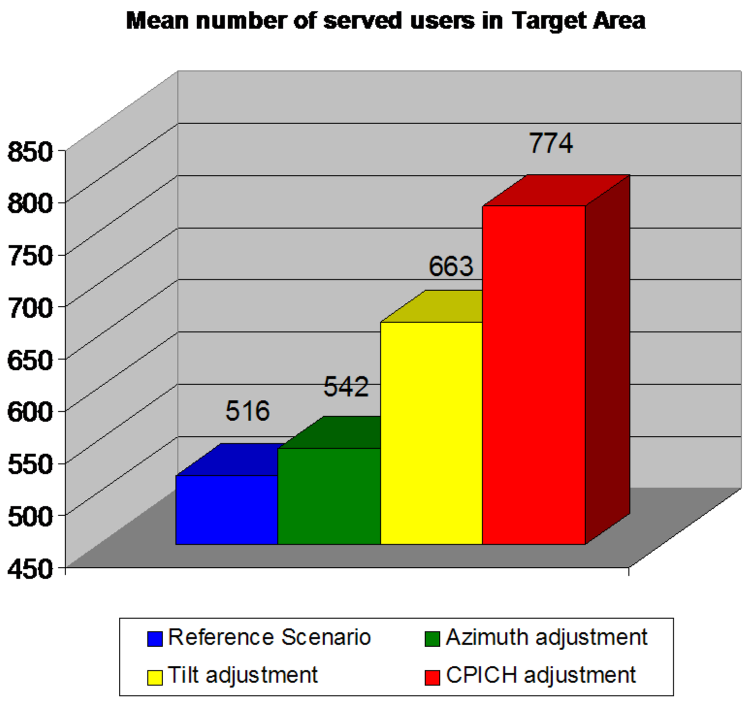

Figure 7.2: Results in mode 'ATOLL', equal distribution in target area

7.4 Analysis of the Results and Conclusion - Simulation Mode 'ATOLL'

As Figure 7.1 shows, by using the default parameter setting obtained from the strategies, the mean capacity in the target area can be increased from 512 mean served users in the target area in the reference scenario (blue bar) up to 829 mean served users (red bar) in simulator mode 'ATOLL'. This denotes a gain of 62% in mean capacity compared to the reference scenario. It is important to mention that after the CPICH adjustment routine the CPICH power level in all cells is 15dBm, equal to the minimum CPICH power level defined in Section 5.4. It is also shown in Table 7.1 and 7.2 that the reached coverage probability after the CPICH strategy in the total scenario (*cov_prob_total*) is more than 91% and in the target area (*cov_prob_target*) is 100%, even though the required coverage probability was set to 0.8 and 0.98 in the total scenario and in the target area, respectively. Consequently, the minimum CPICH power level should be defined as 10dBm or even 5dBm. The problem is that these values are even more unrealistic than the 15dBm of minimum CPICH power level used in the simulations. However, if using a default parameter setting with a CPICH power level of 33dBm in all cells, thus utilising the routines without the CPICH procedure, there is also an increase in mean capacity in the target area from 512 to 703 mean served users in the target area (yellow bar in Figure 7.1), which is an improvement of 37% compared to the reference scenario.

Table 7.2 and Figure 7.2 show the results of the optimum default parameter setting in simulation mode 'ATOLL' with 'equally' distributed mobile stations in the target area. What we can see is that for this kind of distribution it is harder to optimise the capacity in the target area. The results are worse than for 'best server equal' distribution, both after the total optimum parameter setting and also after the individual strategies for the antenna azimuth and the antenna downtilt.

When comparing the results of this default parameter setting with the achieved capacity by using certain optimisation algorithms, we can see that almost the same improvement is reached. As Figure 7.3 shows, the number of served users in the target area is 821 for this default parameter setting, and 814 or 836 for a rule based algorithm and a simulated annealing algorithm, respectively. These numbers are from one user distribution snapshot in the target area and with 'best server equal' distribution, but without adjustment of the antenna azimuth. For further information of the optimisation algorithms, their results and the used parameters, see [4]. It is important to mention that the computational effort for the default parameter setting is much smaller than for these optimisation algorithms, since the default parameter setting only needs three simulations in $CAPESSO^{TM}$, while the algorithms need 62 or 75 simulation runs to reach the mentioned results.

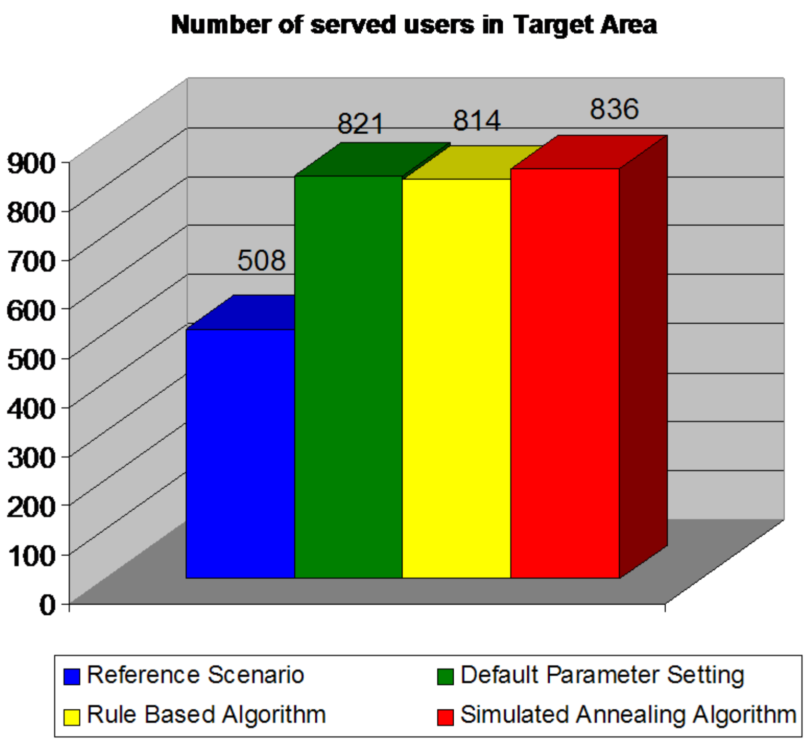

Figure 7.3: Results of the default parameter setting compared to optimisation algorithms, best-server-equal distribution in target area

7.5 Results for Simulation Mode 'ODYSSEY'

7.5.1 'Best Server Equally' distributed Mobile Stations in Target Area

$CPICH_{E_c/I_0}$ **Threshold = -18dB**

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	637	665	696	756
mean_cap_target	655	681	721	**773**
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9966	1	1	0.978
$cpich_{E_c/I_0}$*_cov_prob_target*	1	1	1	0.9824
additional notes	*start_cpich* in adj_tilt: 33dBm, *start_cpich* in adj_cpich: 27dBm, final CPICH values: $\simeq$ 27-29dBm, required coverage probability in worst case: 0.5 total and 0.75 in target area, best server equal dist., $cpich_{E_c/I_0} threshold = -18dB$			

Table 7.3: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -18dB, best-server-equal distribution and required coverage probability in worst case of 0.5/0.75

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	637	665	696	725
mean_cap_target	655	681	721	**753**
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9966	1	1	0.9996
$cpich_{E_c/I_0}$*_cov_prob_target*	1	1	1	1
additional notes	*start_cpich* in adj_tilt: 33dBm, *start_cpich* in adj_cpich: 27dBm, final CPICH values: $\simeq$ 29-32dBm, required coverage probability in worst case: 0.8 total and 0.98 in target area, best server equal dist., $cpich_{E_c/I_0} threshold = -18dB$			

Table 7.4: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -18dB, best-server-equal distribution and required coverage probability in worst case of 0.8/0.98

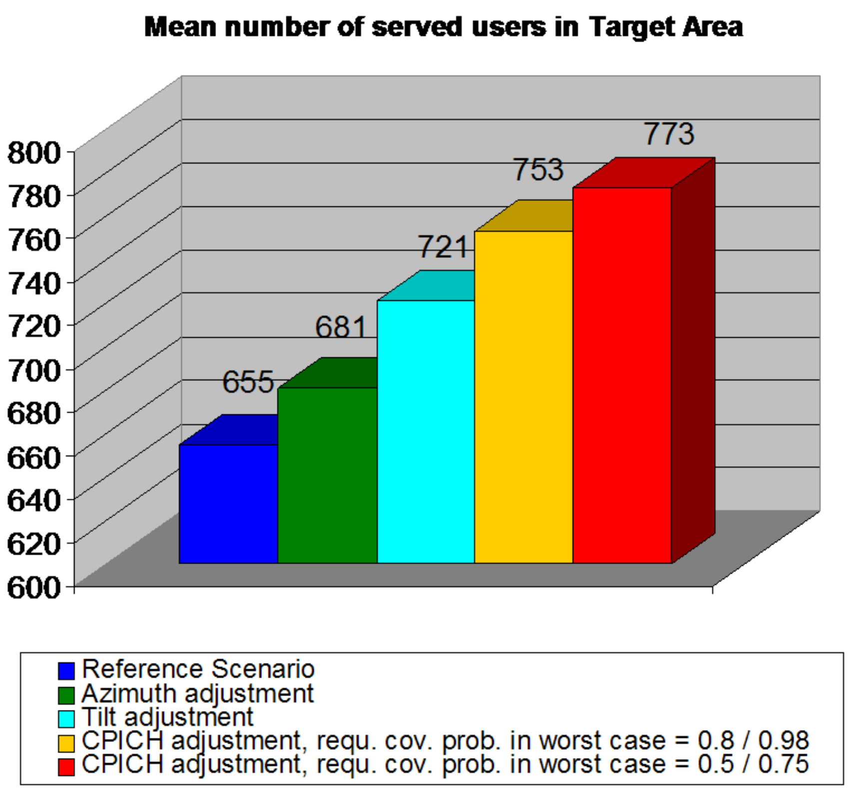

Figure 7.4: Results in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -18dB, best-server-equal distribution in target area

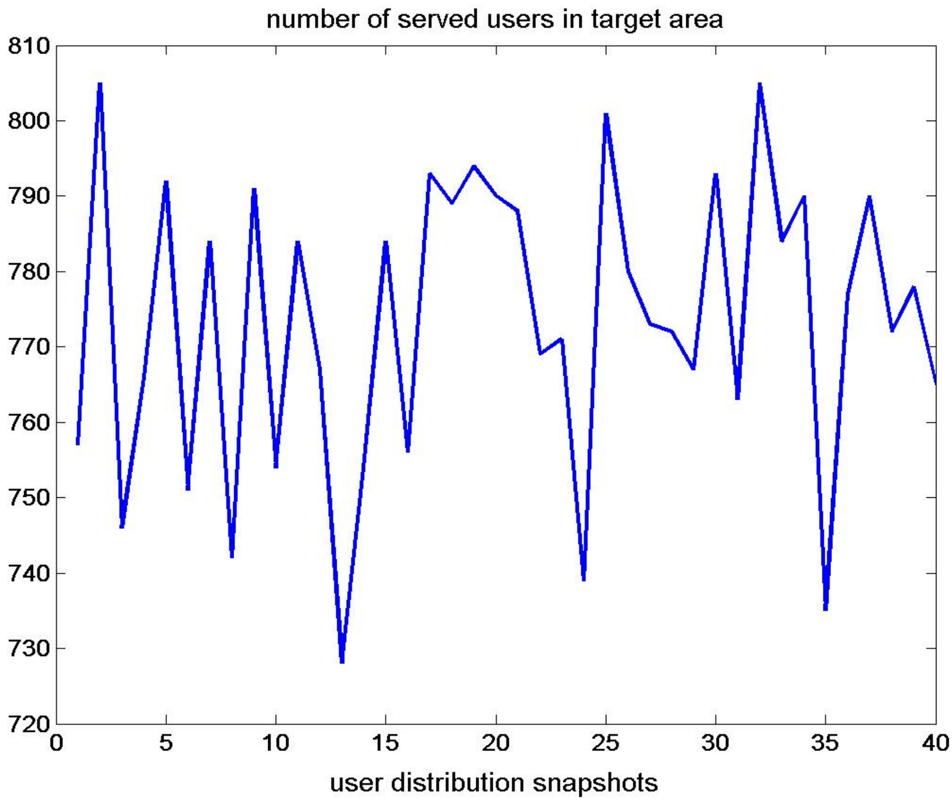

Figure 7.5: Number of served users in target area of 40 different user distribution snapshots for calculation of mean capacity of adj_cpich in Table 7.3

$CPICH_{E_c/I_0}$ Threshold = -12dB

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	480	569	624	614
mean_cap_target	520	595	**630**	612
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9339	0.9288	0.9433	0.9598
$cpich_{E_c/I_0}$*_cov_prob_target*	0.9545	0.9533	0.9635	0.9860
additional notes	*start_cpich* in adj_tilt: 36dBm, *start_cpich* in adj_cpich: 32dBm, final CPICH values: ≃ 32-35dBm, required coverage probability in worst case: 0.5 total and 0.75 in target area, best server equal dist., $cpich_{E_c/I_0} threshold = -12dB$			

Table 7.5: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -12dB, best-server-equal distribution and required coverage probability in worst case of 0.5/0.75

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	480	569	624	522
mean_cap_target	520	595	**630**	553
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9339	0.9288	0.9433	0.9823
$cpich_{E_c/I_0}$*_cov_prob_target*	0.9545	0.9533	0.9635	1
additional notes	*start_cpich* in adj_tilt: 36dBm, *start_cpich* in adj_cpich: 32dBm, final CPICH values: ≃ 35-37dBm, required coverage probability in worst case: 0.8 total and 0.98 in target area, best server equal dist., $cpich_{E_c/I_0} threshold = -12dB$			

Table 7.6: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -12dB, best-server-equal distribution and required coverage probability in worst case of 0.8/0.98

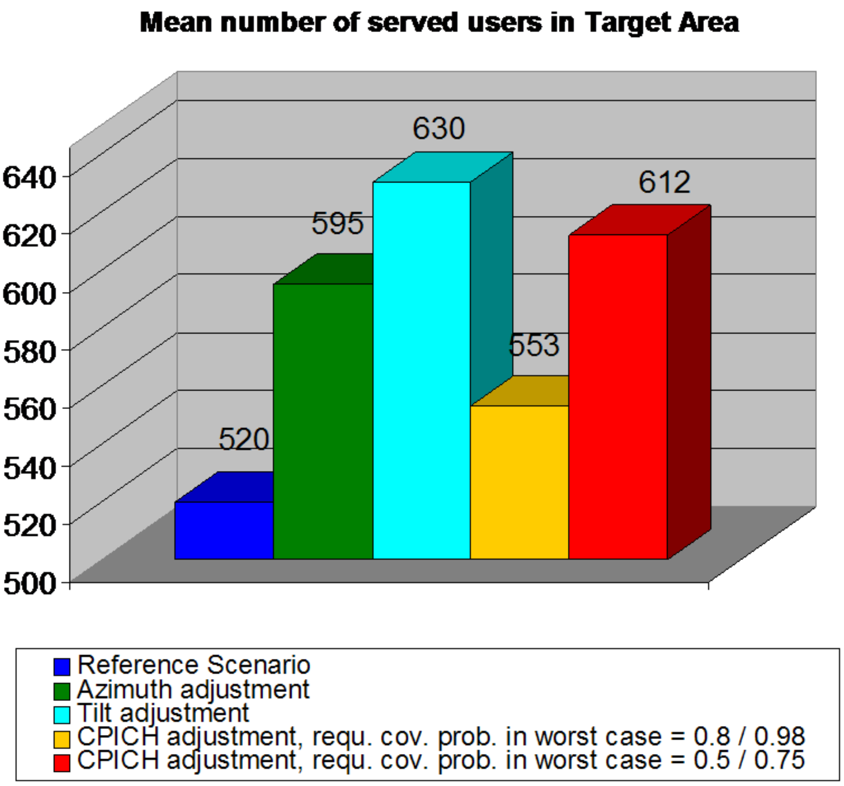

Figure 7.6: Results in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -12dB, best-server-equal distribution in target area

7.5.2 'Equally' distributed Mobile Stations in Target Area

$CPICH_{E_c/I_0}$ **Threshold = -18dB**

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	620	591	616	674
mean_cap_target	626	634	654	**708**
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9991	1	1	0.9797
$cpich_{E_c/I_0}$*_cov_prob_target*	1	1	1	0.9803
additional notes	*start_cpich* in adj_tilt: 33dBm, *start_cpich* in adj_cpich: 27dBm, final CPICH values: $\simeq$ 27-29dBm, required coverage probability in worst case: 0.5 total and 0.75 in target area, equal dist., $cpich_{E_c/I_0} threshold = -18dB$			

Table 7.7: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -18dB, equal distribution and required coverage probability in worst case of 0.5/0.75

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	620	591	616	644
mean_cap_target	626	634	654	**676**
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9991	1	1	0.9992
$cpich_{E_c/I_0}$*_cov_prob_target*	1	1	1	1
additional notes	*start_cpich* in adj_tilt: 33dBm, *start_cpich* in adj_cpich: 27dBm, final CPICH values: $\simeq$ 29-31dBm, required coverage probability in worst case: 0.8 total and 0.98 in target area, equal dist., $cpich_{E_c/I_0} threshold = -18dB$			

Table 7.8: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -18dB, equal distribution and required coverage probability in worst case of 0.8/0.98

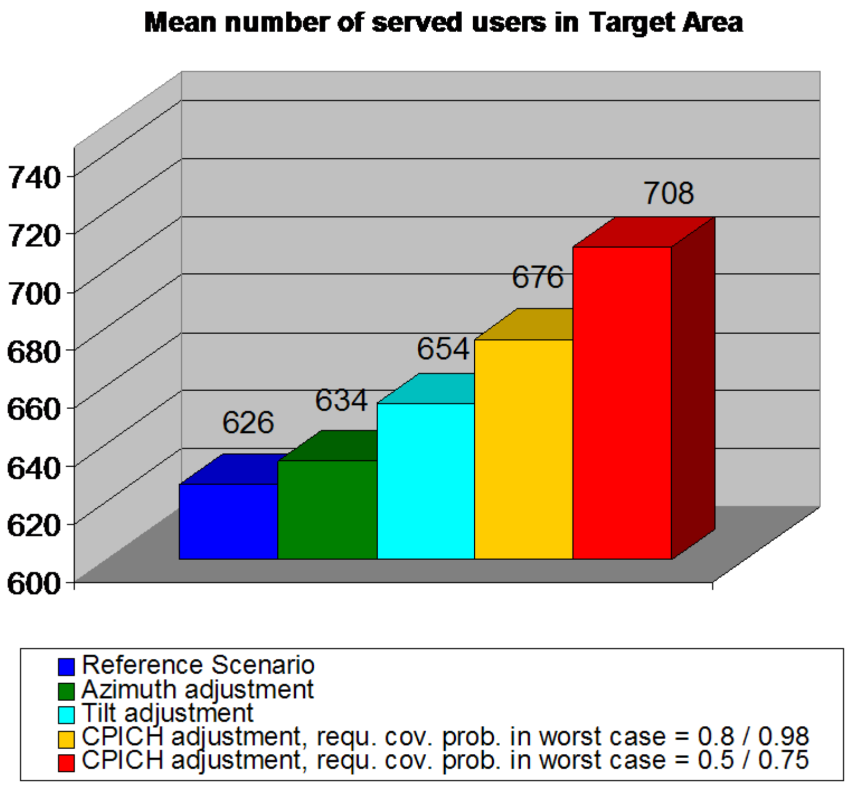

Figure 7.7: Results in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -18dB, equal distribution in target area

$CPICH_{E_c/I_0}$ **Threshold = -12dB**

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	508	495	549	524
mean_cap_target	547	556	572	**572**
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9321	0.9407	0.9456	0.9619
$cpich_{E_c/I_0}$*_cov_prob_target*	0.9533	0.9558	0.9585	0.9837
additional notes	*start_cpich* in adj_tilt: 36dBm, *start_cpich* in adj_cpich: 32dBm, final CPICH values: ≃ 33-35dBm, required coverage probability in worst case: 0.5 total and 0.75 in target area, equal dist., $cpich_{E_c/I_0} threshold = -12dB$			

Table 7.9: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -12dB, equal distribution and required coverage probability in worst case of 0.5/0.75

	Reference Scenario	adj_azimuth	adj_tilt	adj_cpich
nr_served_target	508	495	549	478
mean_cap_target	547	556	**572**	508
$cpich_{E_c/I_0}$*_cov_prob_total*	0.9321	0.9407	0.9456	0.9815
$cpich_{E_c/I_0}$*_cov_prob_target*	0.9533	0.9558	0.9585	1
additional notes	*start_cpich* in adj_tilt: 36dBm, *start_cpich* in adj_cpich: 32dBm, final CPICH values: ≃ 35-37dBm, required coverage probability in worst case: 0.8 total and 0.98 in target area, equal dist., $cpich_{E_c/I_0} threshold = -12dB$			

Table 7.10: Results of total strategy in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -12dB, equal distribution and required coverage probability in worst case of 0.8/0.98

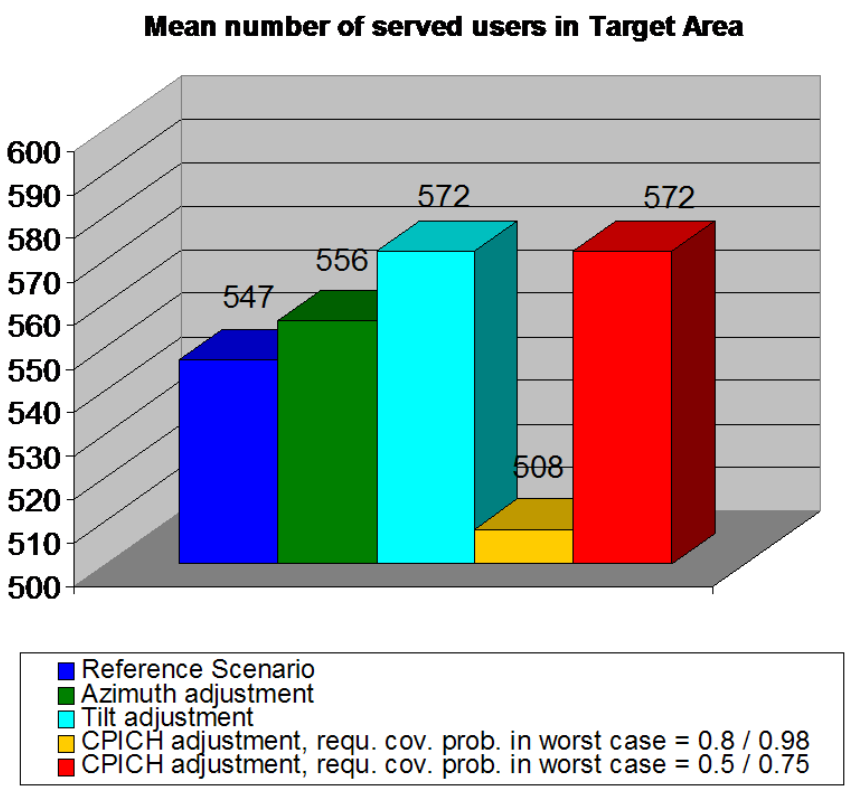

Figure 7.8: Results in mode 'ODYSSEY' with $CPICH_{E_c/I_0}$ threshold -12dB, equal distribution in target area

7.6 Analysis of the Results and Conclusion - Simulation Mode 'ODYSSEY'

The improvement of capacity in the target area, which can be reached by using the default parameter setting in simulation mode 'ODYSSEY', is 18% compared to the reference scenario. That is an increase in mean number of served users in the target area from 655 to 773, as shown in Figure 7.4. If using the more severe requirements in coverage probability for the worst case (as explained in Section 5.4), that means a coverage probability of 0.8 in the total scenario and a probability of 0.98 in the target area, the final result goes down a little to 753 served users in the target area. We can see in the Tables 7.3 and 7.4 that in both cases of the different required coverage probabilities for worst case, the coverage probabilities for normal parameter setting ($cpich_{E_c/I_0}\_cov\_prob\_total$, $cpich_{E_c/I_0}\_cov\_prob\_target$) are between 97% and 100%. Another interesting result, presented in the additional notes of Table 7.3 and Table 7.4 is, that the final CPICH values after all the individual strategies are only varying by 2 or 3dB. These marginal differences in the CPICH power levels of all the cells lead to the conclusion, that it would be almost as good setting the same CPICH power levels in all the cells.

Comparing the results of the optimum default parameter setting of mode 'ODYSSEY' and mode 'ATOLL', we can see that the possible improvement by optimisation is smaller in the more realistic simulator mode 'ODYSSEY' due to the CPICH coverage verification including interference calculations.

Figure 7.5 shows the results of the 40 different user distribution snapshots for calculation of the mean capacity in case of mode 'ODYSSEY' with 'best server equally' distributed users in the target area and a $CPICH_{E_c/I_0}$ threshold of -18dB. We can see that the number of served users in the target area is varying between 730 and 805, depending on the instantaneous positions of the mobile stations in the scenario. Due to these huge differences in the results of the different snapshots, we can conclude that it is very important to look at the mean capacity of a sufficiently high number of user distribution snapshots.

The default parameter setting of this work even reaches an improvement in capacity compared to the reference scenario, if the $CPICH_{E_c/I_0}$ threshold is changed from -18dB, (-20dB is recommended in the 3G specifications [3]) to a more severe ratio of -12dB. These results are shown in Figure 7.6. We can see, that there is an increase in mean capacity of about 15% (to 595 served users) after adjusting the BS azimuth and of 21% (to 630 served users) after the tilt routine. After the procedure for automatic adjustment of CPICH power levels, however, Figure 7.6 shows a decrease in capacity. This is due to the fact that for reaching the coverage requirements in worst case with this quite severe $CPICH_{E_c/I_0}$ threshold of -12dB, the CPICH power levels have to be increased from the initial value of 33dBm in the reference scenario. The final CPICH power levels after CPICH adjustment are between 32dBm and 35dBm with a required coverage probability of 0.5 in total scenario and 0.75 in target area, and between 35dBm and 37dBm for required coverage probability of 0.8 and 0.98, in total scenario and target area, respectively.

Figure 7.7 and 7.8 show that it is more difficult to optimise the scenario with 'equally' distributed users in the target area. In that case only a gain of 13% in case of $CPICH_{E_c/I_0}$ threshold of -18dB and 5% with a threshold of -12dB is possible. When using the CPICH adjustment for worst case, it is also possible that the resulting capacity is worse than in the reference scenario as shown in Figure 7.8. Especially in case of using the severe required coverage probability of 0.8 in total scenario and 0.98 in target area, with a $CPICH_{E_c/I_0}$ threshold of -12dB, the result goes down to 508 served users in the target area. It is significant to note that in this case there is obviously more weight on reaching the coverage in worst case than on improving the capacity.

Chapter 8

Summary, Conclusions and Outlook

8.1 Summary and Conclusions

In this work, a strategy for automatic adjustment of antenna azimuth, antenna downtilt and CPICH power level has been developed in order to reach an optimum default parameter setting of these three key parameters. The strategy is in contrast to time-consuming adaptive step by step optimisation algorithms and adjusts the parameters in an 'ad hoc' manner only by analysing the structure of the UMTS network, but independent of the user distribution in the scenario. 'Ad hoc' in this context means, not to try different parameter settings in many steps and always take the setting with highest capacity as in step by step optimisation algorithms. The idea is to use the knowledge about CDMA cellular systems and the structure of the network to reach the optimum default setting of the key parameters in almost one step. Actually, only up to three steps have been necessary in the strategies of this work.

Due to the many possible limitations of the performance of a WCDMA system, understanding and identifying the limiting factors is fundamental in being able to develop an optimisation strategy for increasing the network capacity and improving the system coverage effectively at the same time.

It has been shown that correct adjustment of the base station parameters antenna azimuth, antenna downtilt and CPICH power is very important to achieve high capacity in the UMTS network. Through fine tuning of these parameters, it is possible to increase the capacity of the network by reducing the inter-cell and intra-cell interference, by reducing the pilot pollution and by optimising the base station transmit power resources.

The three key optimisation parameters are highly interdependent. Consequently, a combined 'ad hoc' adjustment strategy is very difficult. Therefore, different strategies for individual adjustment of each of the three parameters have been developed and then combined for the optimum default setting.

In order to reach the optimum default parameter setting for the UMTS network automatically, MATLAB programs for automatic adjustment of the three key optimisation parameters antenna azimuth, antenna downtilt and CPICH power level have been developed. These programs use a static UMTS Frequency Division Duplex (FDD) radio network simulator for calculations by accessing the input and output XML files of the simulator as interface. The performance of the strategy is evaluated by using the same static UMTS FDD radio network simulator on a virtual scenario of Vienna city. The main results used for evaluation are the number of served users in the target area as well as the mean value obtained from several snapshots with varying user distribution.

It has been shown that it is important to use the mean capacity in the target area as indicator for the performance of the UMTS network to avoid the strong dependency of the result on the instantaneous positions of the mobile stations in the scenario.

The performance of the strategy has been analysed and investigated for different user distributions in the target area, for the two different CPICH coverage verification modes of the simulator, and for different thresholds. The success of the strategy has been shown in each of the mentioned cases. Improvements in mean capacity in the target area compared to the reference scenario of 62% in simulator mode 'ATOLL' and 18% in simulator mode 'ODYSSEY' have been reached. Furthermore, the results show that the strategy is able to reach a good optimum default parameter setting also compared to the results of adaptive step by step optimisation algorithms which require much more computation power and time.

8.2 Outlook on possible future work

Although the results of the strategy for this default parameter setting show good success, more work can be done to further improve the setting of the parameters of a UMTS system. In the following I want to give some suggestions.

The validity of the results of the strategies should be checked on other scenarios beside the used virtual scenario of Vienna city, and if possible, real scenarios should be used for evaluation of the strategies.

As one of the objectives of this default parameter setting is to accelerate subsequent optimisation algorithms which are using this optimum default setting as initial adjustment, it should be analysed how much time or computational effort can be saved. It is also important to investigate if the following optimisation algorithms are able to achieve better results in this case.

Up to now, the strategies for this default parameter setting did not consider the user distribution in the scenario. In fact, this setting was designed to be independent of the instantaneous position of the mobile stations in the network and to be as general as possible in reference to the user distribution. However, incorporation of the user distribution into the strategy could still provide additional benefits, for example to try to perform load balancing between neighbouring cells and to try to do this in an 'ad hoc' manner like the adjustment of the other parameters.

An alternative approach for adjusting the BS azimuth would be to assign 'charges' to the main beams of the antennas and the opposite charges to critical spots. As identical charges reject each other, the antennas tend to interleave; and as opposite charges attract each other, the main beams of the antennas will turn to the critical spots, as intended. The advantage of this approach would be a more balanced way of avoiding conflicts in interleaving the cells.

In the strategy for automatic adjustment of the antenna downtilt, the slope of the terrain and the cell size are considered in one step. As this could lead to incorrect adjustment of the downtilt, it could be an advantage to adapt the downtilt to the slope of the cell area first. Then the terrain is equal to a flat plane and now the antenna downtilt could be adjusted to the cell size easily.

Due to the fact that the CPICH coverage in UMTS systems should be adjusted in reference to the highest interference level (worst case), it is important to have the optimum worst case. The worst case denotes the case when all the cells of the scenario are transmitting with maximum transmit power level. In this work all cells have the same maximum transmit power level of 43dBm, but small cells should have a lower maximum transmit power level than big cells in order to avoid too much inter-cell interference in worst case. The optimum maximum transmit power of the cells could be set a certain margin above the actual cumulative transmit power levels of the cells in a normal situation and could probably be determined in an 'ad hoc' way.

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