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# MASTER THESIS

**PROJECT TITLE : Auto-tuning of RRM Parameters in UMTS Networks. Feasibility Study**

**MASTER: Master of Science in Telecommunication Engineering & Management (MASTEAM)**

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## Resumen

El presente PFC está incluido en el marco de redes UMTS, concretamente en el desarrollo de nuevas estrategias de Gestión de Recursos Radio (RRM) capaces de maximizar la capacidad y el funcionamiento de la red. Se ha desarrollado una potente herramienta de simulación capaz de analizar el comportamiento de la red UMTS. Ésta se centra en el estudio de los principales algoritmos que gestionan la asignación de recursos radio: Control de Potencia (CP), Control de Admisión (AC) y Soft/Softer Handover (SHO).

El problema observado en las estrategias clásicas de SHO es la rigidez del mecanismo que no se adapta a las variaciones en el modelo de tráfico. Las mejoras en los procedimientos de SHO desarrolladas se basan en una sintonización automática y dinámica (ATS) de los parámetros de SHO. Se describe una arquitectura funcional basada en tres bloques que permiten adaptar los parámetros en función del service mix superando así los problemas de capacidad. Se han realizado varias pruebas sobre diferentes situaciones de tráfico para demostrar la viabilidad del sistema. Los resultados obtenidos muestran un incremento considerable de la capacidad de la red. En este sentido, el ATS se considera una estrategia efectiva previa a la necesidad de aplicar un control de congestión.

Respecto al mecanismo de AC es importante remarcar que tres nuevos algoritmos han sido implementados: AC dinámico, AC basado en la partición completa de recursos (CP-AC) y AC basado en la compartición completa de recursos (CS-AC). El AC dinámico se ha propuesto para proporcionar flexibilidad al actual algoritmo. Esta estrategia se basa en una filosofía ATS en la que se determina un umbral dinámico de AC que se fija a un umbral óptimo a tiempo real de acuerdo con el actual service mix. Por otro lado, CS-AC y CP-AC son estrategias basadas en algoritmos estáticos donde se aplican umbrales fijados o márgenes de carga para observar sus ventajas e inconvenientes dependiendo de la distribución de los usuarios: uniforme o más próxima a los límites de la celda.

Este PFC ha dado como fruto una publicación científica en el contexto de los proyectos europeos COST 2100 "Pervasive Mobile & Ambient Wireless Communications". El título de la publicación es "Automatic Tuning of Soft Handover Parameters in UMTS Networks". El trabajo fue presentado oralmente en la reunión número 3, celebrada en Duisburg (Alemania) entre el 10 y el 12 de Septiembre de 2007.



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## Overview

The present PFC is located inside the framework of the UMTS networks, and more specifically in the development of new Radio Resource Management (RRM) algorithms capable to maximize the capacity and the performance of the network. In this sense a powerful simulation tool capable to analyze in depth the behavior of the UMTS network under different simulation scenarios has been developed. It has been focused in the study of the main algorithms that manage the allocation of radio resources in UMTS networks: Power Control (PC), Admission Control (AC) and Soft/Softer Handover (SHO).

The problem observed in classical SHO strategies is the rigidity of the mechanism, which cannot adapt to variations in the traffic patterns. The improvements on SHO procedures are based on dynamic automated tuning of SHO parameters. A three blocks based functional architecture is described to adapt parameters to service mix dynamics and overcome capacity problems. Several tests have been done over different traffic situations in order to demonstrate the feasibility of the Auto-Tuning System (ATS). The results obtained show a considerable increment in the network capacity. In this sense ATS is considered as an effective pre-congestion-control strategy.

Referring now to AC strategies, it is necessary to underline that three new AC algorithms have been implemented: Dynamic AC, Complete Partitioning AC (CP-AC) and Complete Sharing AC (CS-AC) strategies have been developed with the same goal, enhance the capacity of the network. Dynamic AC was proposed to provide flexibility to the current AC algorithm. This strategy is based on the ATS philosophy where a dynamic AC threshold is fixed to the optimum threshold in real time according to the current service mix. On the other hand, CS-AC and CP-AC are complex strategies based on static algorithms where fixed thresholds or load margins were applied in order to note their advantages and drawbacks depending on the users distribution, uniform or mostly close to the cell edge.

As a result of this project a scientific publication inside the context of COST european projects has been carried out. In special, is about the COST 2100 "Pervasive Mobile & Ambient Wireless Communications" and the title of the publication is "Automatic Tuning of Soft Handover Parameters in UMTS Networks". The paper was presented in the meeting number 3, held in Duisburg (Germany) between 10th and 12th of September 2007.



Y por fin un pequeño espacio para poder agradecer el apoyo y la confianza a todas aquellas personas que me han acompañado durante el desarrollo de este proyecto.

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# INTRODUCTION

3G cellular systems were born with the main aim of providing a great number of services. In particular, a diverse range of multimedia services for mobile users with different quality of services (QoS) is being achieved with the deployment of UMTS networks (Universal Mobile Telecommunications System). In particular, one of the reasons that allows this and also one of the main differences with respect to 2G systems, is the use of Wideband Code Division Multiple Access (WCDMA) as a radio access technology.

WCDMA utilizes the direct sequence Code Division Multiple Access method to achieve higher data rates compared to the implementation of frequency and time division multiplexing (FDMA and TDMA) used by GSM networks. It differs from FDMA/TDMA radio access technology in the fact that the available spectrum is not divided into multiple narrow carriers, so a frequency allocation procedure is not needed. WCDMA only divides the available spectrum in several radio channels per network service provider (three in the Spanish case), each one of 5 MHz wide. Frequency division duplexing is usually implemented in order to distinguish between uplink (hereafter UL) and downlink (hereafter DL) (a TDD option is also considered by the 3GPP), but not in order to distinguish among users. It means that all users can use all the available spectrum at the same time, since no TDMA is applied either. Therefore, the available bandwidth is greater and higher speed data rates services can be offered.

Due to the complexity of the access technique, network simulators are needed in order to plan a network correctly. Moreover, coverage and capacity are now concepts intimately linked, because the use of WCDMA all the users present in the system are considered as interference by another user. The receiver is able to detect the desired signal since it knows the code used, while other users remain as a residual interference. In this way the relationship between coverage and capacity is established by the number of users presents in the scenario. The more the number of users, the higher the interference level and less coverage radio.

The simulation tool developed during this project allows to study in depth the UMTS network behavior under different traffic situations. A friendly interface has been implemented in order to allow the user configure easily the main simulation parameters. Thus, the simulation tool allows to the user:

- Define the dimensions and the resolution of the scenario where the UMTS network will be deployed.
- Define propagation losses.
- Define the number of users that will be launched to the system.
- Define the type of services associated to the users launched to the system.
- Define Nodes-B and User Equipment (UE) features.
- Define Radio Resource Management (RRM) parameters.

Special attention has been focused on RRM, specially in Soft/Softer Handover (SHO) and Admission Control (AC). In this project not only current strategies have been simulated, but improvements in the current algorithms have been carried out in order to enhance the performance of the network.

An important study of SHO strategies has been done in order to overcome the shortcomings associated with current management. Due to the great number of services offered by 3G cellular systems, UL and DL become much more dynamic. Changes in services do not affect in the same way to both links and the use of a specific service can represent much more radio resources consumption in a specific link. In this way the unbalanced situation between UL and DL is an evidence.

What it is interesting is that the study discloses that UL and DL are affected in a different way by SHO parameters values [2]. Consequently a specific treatment for each one of the links can be done in order to favor the limiting link and enhance the network performance. The solution proposed is the creation of an automated tuning of SHO parameters in real time which allows to adapt the different parameters to the current service mix situation. As explained later, this provides a higher network capacity and extra guaranties to achieve the demanded QoS of all the users. In order to understand correctly the necessity to adapt in real time SHO parameters it is necessary to point out the limitations associated to current SHO management. Nowadays, UMTS network providers configure SHO parameters with fixed values according to the most common network situation that is predicted. However, since the network does not remain static, and its contour conditions change, these fixed values can cause the impairment of the system performance and the maximum profit is not achieved.

On the other hand, within the framework of achieving an enhancement of the UMTS AC algorithms, different strategies have been implemented and compared as well. A deep study of the AC has been done in order to understand the limitations associated with usual managements. In this project, the traffic is classified into two priority classes, lowest or highest priority traffic class. Consequently, the available resources are divided into two main groups, the resources reserved for the first traffic class and the resources reserved for the second one. Nevertheless any other possible classification according to the network service provider necessities could be applied. Four new algorithms have been studied and finally two have been selected, proposed and simulated in order to overcome the shortcomings associated to the fix set of values that manage the AC procedure. The advantages and disadvantages associated to each one of them have been identified according to their appliance over different scenarios.

Taking the previous paragraphs into account, the structure of the document is as follows. Section 1 is focused on disclosing the scenario creation. It includes aspects such as, Nodes-B deployment and configuration, propagation models to find propagation losses, scenario dimensions, etc. During section 2, the RRM in UMTS network is analyzed in depth. Special attention is applied to Power Control algorithm (PC), SHO procedure and AC. The RRM methods implemented in the UMTS network simulator are also described. The simulator interface that has been created is explained and showed along section 3, it is indeed a complete guide to follow the simulator operation. Finally sections 4 and 5 are dedicated to develop the two proposal solutions previously introduced, Automated tuning of SHO parameters and Dynamic AC algorithms respectively.

# CHAPTER 1. DEVELOPMENT OF A UMTS SIMULATOR

## 1.1. Introduction

The system simulator presented in this project is based on the *Montecarlo* model. It allows obtaining solutions to mathematical or physical problems by mean of repeated random tests. Therefore, statistics will be obtained from snapshots of the system in different instants of the simulation time. It is important to emphasize the fact that it is a system level simulator and therefore its purpose is to show the global behavior of the network.

The objective of simulations is to make feasible the analysis of the UMTS network behavior under different possible configurations, for example with different node-B deployments, configurations or different users behaviors (in terms of services usage, movement, etc). Also it allows to observe the improvements that different RRM algorithms offer to the network.

The present chapter is organized as follows: in section 1.2. the necessity of simulation is justified in detail for 3G systems. Section 1.3. is devoted to analyze the theoretical concepts taken into account to develop the simulator code. Finally, section 1.4. explains what are the mobility considerations that have been considered in order to turn the simulator from a static *Montecarlo* based into a dynamic one.

## 1.2. Necessity of simulation in UMTS networks

WCDMA is the radio access technology that supports all the multimedia services offered by UMTS cellular networks. WCDMA supports data rates up to 384 kbits/second efficiently with wide area coverage, and can go up to 2 Mbits/second for more local coverage. It will thus complement the wide coverage and international roaming of GSM to give the capacity needed for multimedia services.

As explained before, one of the main features that differs WCDMA from the traditional FDMA/TDMA technical access is the frequencies allocation process. The frequency planning and the reutilization frequency concept used in 2G cellular networks disappears in UMTS networks, since all the bandwidth that conform the available spectrum can be used by all the cells and by all the users. Regarding this new concept, a hard interdependence appears between coverage and capacity.

The coverage and the capacity studies in 2G cellular networks deployment are independent processes. The propagation loss is the main parameter that will establish the coverage level. On the other hand, the capacity supported by the system is only dependent on the number of carriers associated with each one of the base stations (BS) deployed in the area under study.

In UMTS networks the procedure is carried out in a different way. The resources are not associated with a cell, but all the cells can take profit of all the available resources. In this terms, the users transmit in the same frequency bands and can be only split up by the orthogonal codes defined during the transmission process. All the users see the others as an interference, so UMTS is a system limited by interference. Moreover, and consequently, the coverage is strongly connected with the network capacity. The more the number of users is connected to a cell, the more is the reduction in its coverage area. This effect is known as "cell breathing" and it is typical of WCDMA wireless networks. In order to achieve the desired QoS in all the services offered by a network, the user will have to reach a certain signal to interference ratio (dynamically adjusted by the so called outer loop PC). The more the users connected to a cell, the more is the interference level and as a consequence, the higher the required transmitted powers needed to reach the target quality thresholds. In certain cases, the required power to compensate the interference level will exceed the maximum power that can be transmitted by a mobile phone. Therefore, the user under this circumstance remains without service from this cell and, if possible, it should be handed over to another cell.

But the "cell breathing" effect not only appears in the UL, it also can be appreciated in the DL direction. The coverage in UMTS networks is determined by the received quality of the Common Pilot Channel (*CPICH*), which is also used to enable channel estimation. The *CPICH* uses a pre defined bit sequence, which allows the user equipment (UE) to equalize the channel in order to achieve a phase reference with the synchronization channel and also allows initial estimations for the first PC adjustments. Moreover, it also participates in the criteria to decide to which cell a UE is connected to. As the pilot channel can only transmit a fixed power level (decided by the operator during the planning process) and the propagation losses strongly depend on the distance, the radius in which the received quality of this channel is enough can be reduced by an increase in interference, and so the outer cell users could become out of coverage.

The level of interference present in the system or in the same way the number of users in the system is managed by techniques as AC or PC, which are considered RRM, and will be explained in more detail in next sections. Other RRM strategies are SHO, congestion control algorithms, codes assignment and management, etc.

Given this interdependence between capacity and coverage and the presence of complicated RRM algorithms, sophisticated network simulators are used by operators to guarantee a correct cellular planning. Indeed one of the main purposes of this project is to develop a realistic simulator that gathers all the features associated with a UMTS network. Many considerations must be taken into account in order to create a realistic environment, some of them are unpredictable in behavior and are mentioned below:

- The global visibility over the coverage area is reduced by environmental characteristics that can reduce the performance of a cell.
- The users are not uniformly distributed in the coverage area.
- The interference level depends on the distance.
- Overload situations

- The cells do not present the same performance under the same load situations.

The network simulator will allow to:

- Define coverage maps under different traffic situations
- Study the different RRM algorithms performance
- Determine the performance of the network under different traffic situations
- Overcome the shortcomings associated with the rigidity of the current RRM algorithms
- Evaluate the proposed solutions to increase the network capacity
- ...

In summary, the creation of a simulation tool will permit to develop an in depth analysis and more correct planning of a 3G cellular network.

### 1.3. Scenario creation

In this section, the architecture and topology of the network will be explained. In a network deployment the dimensions of the cells are one of the parameters that determine the scenario. Table 1.1 shows the classification of the cells on the basis of the coverage radio and the corresponding application.

Cell	Coverage radio	Application
Macrocells	1,5 - 20 km	Roads and rural environments
Minicells	0,7 - 1,5 km	Urban areas
Microcells	0,3 - 0,7 km	Cities with high traffic density
Picocells	30 - 200 m	Specific places, like: Shopping centers, airports, office...

Table 1.1: Type of cells

According to the coverage area achieved by the transmitter antennas, the scenario can be classified in three types of environments: macro, micro and picocellular

Our UMTS simulator is oriented to work in macrocell/microcell environments. In particular, the geometric radius is the parameter that allows to configure the type of scenario according to the needs of the user. It is necessary to emphasize that the simulator has been developed prioritizing the flexibility. For this reasons, many are the parameters that can be configured by the user so different investigations could be carried out without the need of changing the font code.

All the parameters that define the features of the selected scenario for our specific studies are developed and explained along next sections.

### 1.3.1. Nodes-B configuration

The scenario to be evaluated is a 3GPP based, urban and macrocellular one, with an area of  $5 \times 5 \text{ km}^2$  and 42 cells in a regular layout. As it was explained above, the macrocellular or microcellular scenario is totally adjustable via the geometric radius. A macrocellular scenario is characterized by extensive cells and higher transmission powers, while the microcellular one is characterized by small cells and lower transmission powers. More specific configurations as the classical Manhattan microcellular one could be implemented with minor changes in the fonts, but are not currently supported by the simulator. The geometric radius is fixed at 500 m for all the simulations and analysis developed during this project.

Table 1.2 shows the corresponding distance between all the Nodes-B to decide their specific position in the simulation scenario.

	Odd Node-B	Even Node-B
1st Node-B coordinate	$R \cdot 0.5$	$R \cdot 2$
Vertical spacing	$R \cdot \sqrt{3}$	$2 \cdot R \cdot \sqrt{3}$
Horizontal spacing	$R \cdot 3$	$R \cdot 3$

Table 1.2: Node-B coordinates

The distances fixed for the scenario under study will determine the number of Node-B that allow to cover all the area (in our particular case  $5 \times 5 \text{ km}^2$  imply 14 sites) . The following picture depicts the situation of the Node-B in the scenario under study.

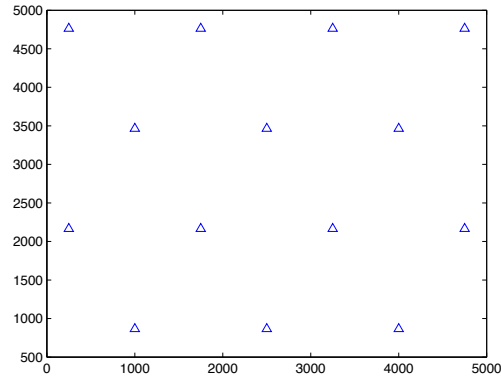


Figure 1.1: Nodes-B position

Each Node-B is composed by three base BS, which implies  $12 \times 3 = 42$  cells. To achieve this trisectorial configuration, commercial antenna models have been used whose particular features are explained in the section 1.3.3.

The simulator allows the option to change all the configuration parameters in order to solve the necessities of the user. In this way, the user will be able to configure the following parameters corresponding to the initial stage of the scenario creation.

- Vertical dimension of the scenario



- Horizontal dimension of the scenario
- Geometric radius
- Resolution

### 1.3.2. Propagation losses

The propagation environment can be characterized by three different components which reflect the effect of different phenomena over the signal:

- Path loss, it is in fact the average propagation loss which may be due to many effects, such as free-space loss, refraction, diffraction, reflection, absorption, etc. The path loss is also influenced by the clutter, the distance between the transmitter and the receiver, and the height and location of antennas. It is depicted by a propagation model that accounts some or all of these effects.
- Slow fading, mainly caused by events such as shadowing, where a large obstruction obscures the main signal path between the transmitter and the receiver. The amplitude change caused by shadowing is often modeled using a log-normal distribution with a standard deviation which depends on the environment.
- Fast fading, due to multi-path propagation. It is usually modeled using a Rayleigh distribution, but other distributions model better certain specific situations for example a Rician distribution is more suitable when one of the paths, typically a line of sight signal, is much stronger than the others.

By means of the program interface, it can be decided which kind of attenuation will be present at the scenario:

- Propagation model (alone)
- Three types of shadowing modelling: completely random, correlated in one dimension and correlated in two dimensions.

The easier way to model the shadowing effect is by directly adding a log-normal random variable to propagation losses. In this way, shadowing is considered as an individual effect for each user and every pixel of the scenario is independent of the rest. The advantage of this option is its low computational cost but it does not account for the spatial correlation that exists in reality it is just a first approach. The agents that cause shadowing of the signal (obstacles, land orographic, in short shade areas) do not appear and disappear suddenly. For example a user is walking and comes into an obstacle gradually during a few seconds and then leaves it. To take into account this effect it is necessary to introduce a model with space correlation. This can be done considering only one direction, or even more realistically considering both x and y directions.

The basic idea of every option and how they are implemented will be described with more detail in the section below.

### 1.3.2.1. Propagation model

Many propagation models exist for every kind of environment, and allow estimating the value of the average losses introduced by the transmission channel.

The propagation model that has been used is the one proposed by 3GPP for simulations in macrocellular environments. It is known as Cost231-Hata (1.1), a classic model for urban and suburban areas that consider frequencies until 2 GHz. It is an extension of the traditional Hata model to work at higher frequencies.

$$L = 40(1 - 4 \cdot 10^{-3} D_{hb}) \log_{10}(R) - 18 \log_{10}(D_{hb}) + 21 \log_{10}(f) + 80 \text{ dB} \quad (1.1)$$

- $R$ : Distance between Node-B and UE, in kilometers.
- $f$ : Carrier frequency (2000 MHz).
- $D_{hb}$ : Node-B antenna height (25 meters).

Considering the carrier frequency and the Node-B tower height, the equation looks as follows:

$$L = 36 \log_{10}(R) - 124.16 \text{ dB} \quad (1.2)$$

Notes:

1.  $L$  cannot be lower than propagation losses in free space. If it is the case, the value of attenuation corresponds to free space losses model:

$$\text{free space} = 20 \log_{10}\left(4\pi \cdot \frac{R}{\lambda}\right) \text{ where } \lambda = 0.15 \quad (1.3)$$

2. This model is valid only for non line of sight (NLOS) cases and it is quite pessimistic because it describes the worst case of propagation that is possible.

In order to determine the attenuation values present at the scenario, a matrix is generated whose number of pixels is fixed by the length and resolution chosen by the user. Every pixel contains the attenuation value provided by the Hata-Model, applying the equation in (1.2). Since it is necessary one matrix of propagation losses for each Node-B present at the scenario, the result is a hypermatrix of depth equal to total number of Nodes-B (figure 1.2). The sum of all matrixes generates the attenuation present at the real scenario.

The inputs used for all simulations are shown in table 1.3.

Figure 1.3 shows the effect of one Node-B present at the scenario when only the propagation model is applied. It reflects that losses grow up as the users move further away from the BS until maximal values of 150 dB.

The best server configuration is a useful representation illustrated in figure 1.4, it is obtained from the hypermatrix losses by choosing the lowest value of every pixel of all matrixes. It is the minimum value of losses in the scenario. In this case the maximal value of losses is reduced in respect to the previous image 1.3. It is important to note that, now, the radiation effect of the selected antennas is considered. Further details on antennas features will be given in section 1.3.3.

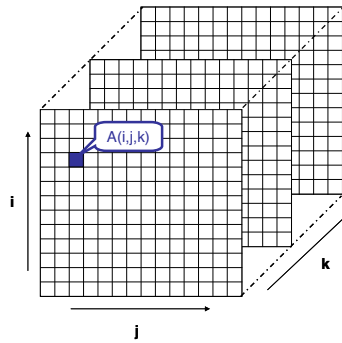


Figure 1.2: Three dimension hypermatrix

Parameter	Value
Scenario Length in x	5000 km
Scenario Length in y	5000 km
Geometric radius	500 m
Resolution	15 m
Work frequency	2000 MHz
Maximum antenna gain	18 dB
Nodes-B level	25 m

Table 1.3: Propagation model input parameters

### 1.3.2.2. Slow fading or shadowing

Any kind of obstacles between UE and Nodes-B are responsible of the shadowing effect that generates slight variations in propagation losses. As previously stated, the power slow variations are modeled by means of a log-normal distribution (normal or Gaussian if it is expressed in dBW, dBm). It means that, once the received power by the UE is estimated with the propagation model, the real received value will vary with a certain probability according to this log-normal distribution, without losing temporal and spatial correlation of the received power levels.

The three kind of models implemented to represent the shadowing effects are explained

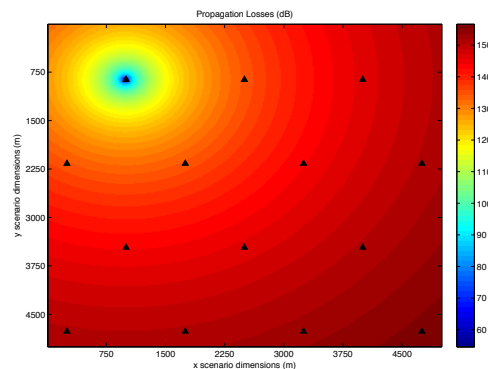


Figure 1.3: Propagation model losses

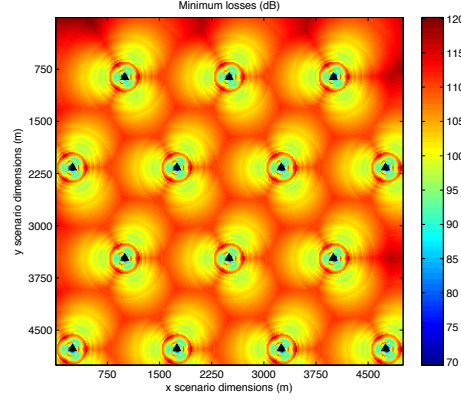


Figure 1.4: Best server configuration

in the following section. Note that the one that is correlated in both x and y dimensions is the most realistic but also the one that requires a higher computational cost.

### Random shadowing

This is the simplest case in which just a log-normal distributed random variable is added to the losses provided by the propagation model. So, the final losses present at the scenario are computed as equation (1.4) where all the values are expressed in logarithmic units:

$$L = L + G(0, \sigma) \quad (1.4)$$

- $L$  = Propagation losses.
- $G(0, \sigma)$  = Gaussian variable with mean 0 and standard deviation,  $\sigma$ .

Standard deviation usually varies, depending on the kind of environment, between 4 and 12 dB. Scenarios with more shadowing areas have higher standard deviation, for example urban environments. For all simulations the standard deviation is fixed at 8 dB.

In the same way that happened with propagation model losses, in the case of random shadowing a hypermatrix of depth equal to the number of Nodes-B is generated. It is filled with the values of the normal distribution, which is the one that simulate the shadowing produced because of shadow areas. A normal distribution and not lognormal distribution is used, due to the fact that attenuation values are expressed in dB. Every element of the matrix will present different attenuation levels with no correlation that simulates the effect of buildings and any kind of obstacles that generate shadow areas in real environments.

Next, the simulation of the attenuation produced because of the propagation model added to the random shadowing effect. The scenario is simulated with the inputs shown in table 1.3.

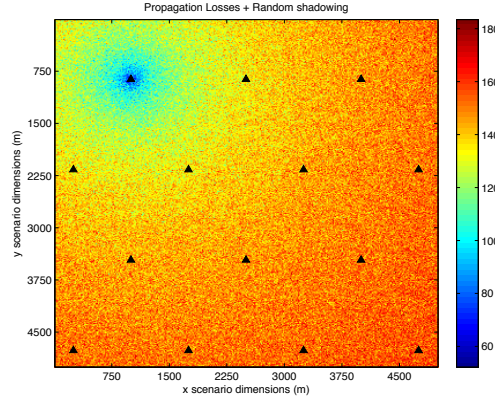


Figure 1.5: Propagation losses added to the random shadowing effect for one cell

The simulation result is present in figure 1.5, and shows that the random shadowing is not the more realistic one. An active user can quickly move from an area of maximum attenuation level to another one in which scarcely losses are present. As previously explained, this effect does not correspond with the reality. Next sections present better approaches considering spatial correlation among pixels.

### One-dimension correlated shadowing

In this second approach to model shadowing a certain spatial correlation is introduced, it means that sudden unrealistic variations do not take place. The main difference with random shadowing resides in the fact that equation 1.4 is only used once and to calculate the first element of the losses matrix. For the rest of the elements an autocorrelation function described by equation 1.5 is used. All the matrix elements, except the first one, are correlated according to the normalized correlation function 1.5:

$$R(\Delta x) = e^{\frac{\Delta x}{d_c} \ln(2)} \quad (1.5)$$

The correlation distance  $d_c$  is a parameter that defines the distance where the attenuation values remain more or less equal. This value is usually comprised between  $18m < d_c < 20m$ .

When users mobility is assumed in this type of shadowing, the correlation time is intimately bounded to the correlation distance  $d_c$ . It varies according to the kind of environment under study and defines the distance in which the surroundings in terms of obstacles presence, remain invariable.

Taking into account the autocorrelation term, the variation of the lognormal fading term can be calculated. Supposing that S1 is the lognormal component of the propagation losses in the position P1, and S2 is the lognormal component of the propagation losses in the position P2, the distance between P1 and P2 is what will be known as  $(\Delta x)$ , it means that, is the distance that the user covers in two consecutive steps.

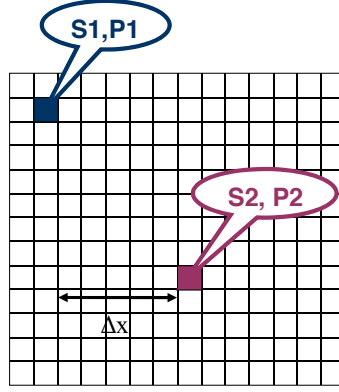


Figure 1.6: Autocorrelation

$S_2$  is calculated with a normal distribution with mean  $R(\Delta x)S_1$  and a standard deviation  $\sqrt{1 - R^2(\Delta x)} \cdot \sigma$ , where  $\sigma$  is the standard deviation of the lognormal component corresponding to the environment under study.

As a result, a matrix with dimensions  $B \times H$  is obtained. It represents the coverage area of an scenario with length  $b$  and width  $h$ . In this way each element of the matrix corresponds to one region of length  $\beta = b/B$  and width  $\eta = h/H$ , this is the vertical and horizontal resolution. The first element of the matrix  $M_{0,0}$  is generated randomly and the rest of the elements are generated following a lognormal distribution with mean:

$$\frac{1}{2} \cdot (R(\eta) \cdot M_{r-1,c} + R(\beta) \cdot M_{r,c-1}) \quad (1.6)$$

and standard deviation:

$$\frac{1}{2} \sigma (\sqrt{1 - R^2(\eta)} + \sqrt{1 - R^2(\beta)}) \quad (1.7)$$

Similarly, correlation is introduced among different sites. This means that the perceived shadowing from one site will be somewhat similar to that of another nearby (even the same obstacle can generate the same shadow areas for two different sites). So, the final lognormal component is found by the following expression:

$$G = \sqrt{\rho} \cdot G_1 + \sqrt{1 - \rho} \cdot G_i \quad (1.8)$$

- $\rho$ : Typical correlation coefficient of 0.5.
- $G_i$ : Gaussian variable with mean 0 and standard deviation  $\sigma$  for the base station  $i$ .

As occurred with the random shadowing, in order to simulate the correlated shadowing, an hypermatrix of width equal to the number of Nodes-B present in the scenario is generated. Nevertheless, in this case the first element of each matrix will be generated by a variable

with normal distribution with mean 0 and typical deviation of 8 dB. The rest of the elements of each matrix that characterize each one of the BSs will be calculated by the autocorrelation equation described in 1.5. In this way all the elements of the matrix are forced to have a certain dependence, they are correlated.

Now some results are depicted in order to appreciate the effects of a correlated shadowing. The inputs used are shown in table 1.4.

Parameter	Value
Scenario Length in x	500 km
Scenario Length in y	500 km
Geometric radius	50 m
Resolution	1 m
Work frequency	2000 MHz
Maximum antenna gain	18 dB
Nodes-B level	25 m
Correlation distance	18 m
Correlation coefficient between sites	0.5

Table 1.4: Correlated shadowing input parameters

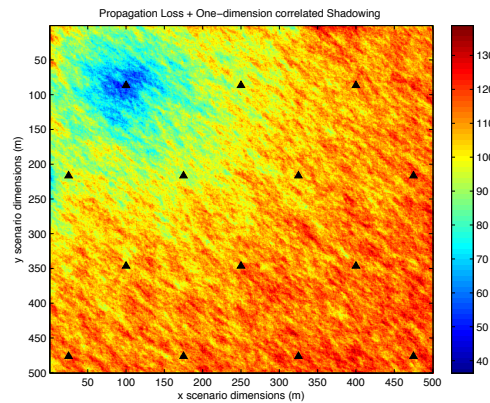


Figure 1.7: Propagation losses plus correlated shadowing

It is important to consider that for same scenario dimensions, an increase of the resolution (smaller resolution value) have an influence in the attenuation. The higher the resolution is, the higher is the number of pixels. The result traduces in the fact that the correlation distance provide a constant value during more number of pixels. In the same way, if the resolution is worst, less number of pixels are present in the scenario, it means that attenuation variations among pixels are not so smooth (although, indeed "inside the pixel" the attenuation level remains constant).

In figure 1.7 a simulation with a good resolution of 1 meter is shown. The correlation distance is 18 meters. As a consequence the effect of the correlation can be seen. Attenuation values do not change in each pixel suddenly, but gradually. This figure takes into account the attenuation values produced by the propagation model added to the correlation shadowing effect.

### Two-dimensions correlated shadowing

The two-direction shadowing [1] is based on the correlated shadowing in one dimension. In spite of this, it presents certain differences regarding to the concept and implementation. When correlating only in one direction, each pixel takes its value according to the element immediately before in the vertical and horizontal axes.

In the case of the two-dimensional correlated shadowing, two coordinates are identified for each location,  $x$  and  $y$  and all the elements in the matrix are considered at the moment of applying the equation described in 1.9. In this way, between an element located in the coordinates  $(x_1, y_1)$  and another one in  $(x_2, y_2)$ , the distance that divide them is  $\Delta r = \sqrt{\Delta x^2 + \Delta y^2}$ . Being  $\Delta x$  and  $\Delta y$  the horizontal and vertical space out respectively. The autocorrelation equation is now the following:

$$R(\Delta x) = e^{-\frac{\sqrt{\Delta x^2 + \Delta y^2}}{d_c} \ln(2)} \quad (1.9)$$

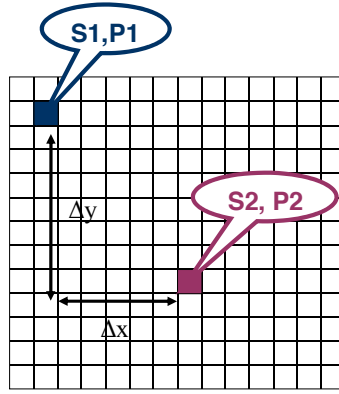


Figure 1.8: Autocorrelation in two dimensions

According to the elements of the matrix, the sites must be also correlated pursuant to expression 1.8.

In order to simplify the calculation of correlating each element with all the elements of the matrix, in this approach the attenuation matrix is filtered in such a way that it provides the same effect as if the elements were correlated with the rest. In short, once the correlated shadowing in one direction is generated, this matrix will pass through a filter that smooths transitions, providing the same effect as if all the distances between pixels were calculated.

Figure 1.9 shows the result of a simulation taking into account this third strategy. Inputs are shown in table 1.4.

Shadowing correlated in two dimensions is the most realistic approach to consider the slow fading effects and that is why it is the option selected and implemented in all simulations. In figure 1.10 the best server configuration for the same input parameters can be seen.



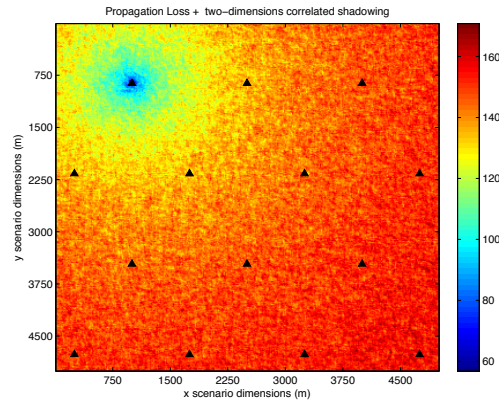


Figure 1.9: Shadowing correlated in two dimensions added to the propagation model losses

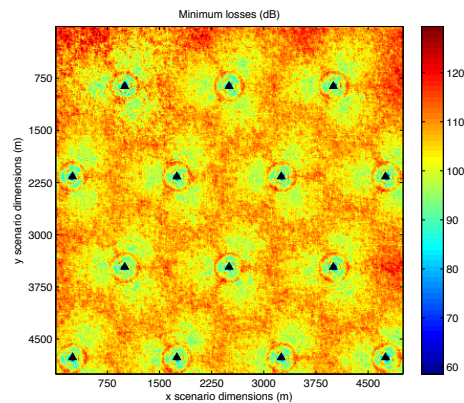


Figure 1.10: Best server configuration for shadowing correlated in two dimensions

### 1.3.2.3. Fast fading

Fast fading is produced because of the sum contribution of different propagation paths that exist in a wireless communication system.

The system simulation tool does not implement the fast fading effect directly because it works in average terms of power. Nevertheless this effect will be considered through  $E_b/N_0$  target demanded by services. For example, users at different rates and with the same service will not require the same  $E_b/N_0$  to achieve the same BER, because channel conditions are different in terms of multipath.

### 1.3.3. Antenna characterization

In this section, a few details about the main features of an antenna will be described. It is not an object of the present project to study in depth the operation of the BTS antennas [7], so only a few lines will be dedicated to explain the influence of the antenna election in the UMTS network performance. The antennas used during this project are commercial

models typically used in real UMTS networks.

They have been chosen according to its design frequency and radiation patterns, which is normally represented in polar coordinates and provides the gain values (or losses with respect to the maximum gain) for two particular cuts (horizontal and vertical) of the 3D real diagram.

The azimuth angle determines the exact point in the horizontal plane where the antenna is fixed. The elevation angle determines the slope of the antenna with respect to the vertical plane. The figure 1.11 shows this graphically and in more detail.

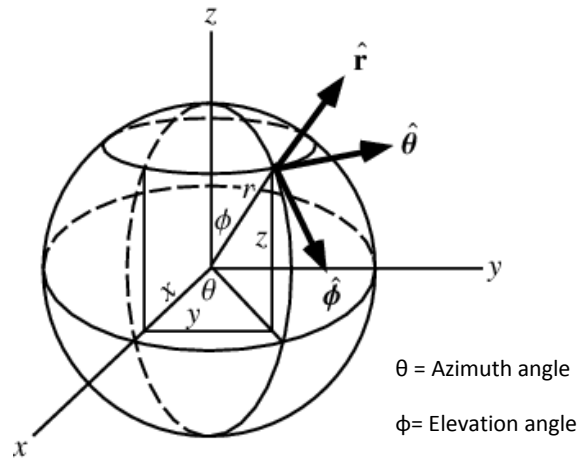


Figure 1.11: Azimuth and Elevation angles

The simulator allows to choose the antenna with the desired radiation pattern. The radiation pattern of all the possible antennas will be showed in the section explaining the user interface details.

In our simulations, it is assumed that one Node-B is formed by three cells. It means that there are three trisectorial antennas separated by 120. In this way, an optimum beam width value of 60-65 is chosen. The azimuth angles selected are 60, 180 and 300. As explained before, the elevation angle determines the tilt of the antenna that maximizes coverage, this angle can be also changed by the user.

The simulator developed during this project is designed to work with .msi files. This type of files are formatted according to a standard containing all the information explained above and are typically used by commercial planning software packages.

## 1.4. Dynamic scenario: Mobility model

In this section the mobility model implemented in order to simulate the motion of the users is explained in detail.

The users are uniformly scattered in the first sample and their direction is randomly chosen at initialization. Periodically, the position of each mobile is updated according to next equations:

$$x = x_o + speed \cdot update_{interval} \cdot (\cos\alpha_o + \alpha) \quad (1.10)$$

$$y = y_o + speed \cdot update_{interval} \cdot (\sin\alpha_o + \alpha) \quad (1.11)$$

The inputs of the model are:

- Speed of the users, which is fixed to  $v = 3km/h = 0.83m/s$ . In a first stage a pedestrian velocity is adopted.
- Time step or update interval, which is fixed to 100 ms

The direction of the users is determined by its angle of advance, which is randomly modified. In particular, in order to approximate to real situations, the users change their direction once a distance of 20 meters is covered. The direction is changed with a probability of 0.2 acquiring a random angle between -45 to 45. This angle new is added to the previous direction.

The model is graphically shown in figure 1.12.

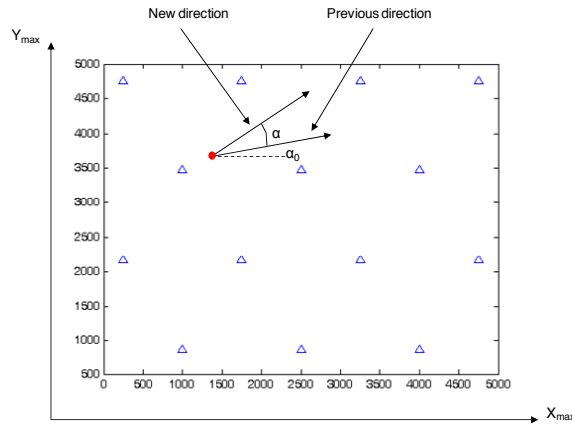


Figure 1.12: Mobility model

Inputs values can be changed to simulate other possible and real situations. In these terms, changing the velocity, a vehicular model could be simulated. At the same time, the mobility model implemented during this project presents the flexibility that not all the users must present the same velocity. This fact, allows considering many kinds of possible scenarios.

Moreover, to improve simulation performance a "wrap-around" technique is used 1.13. Thus, when a mobile is located at the edge of the scenario, it continues its movement from one side of the area to the opposite one, so the scenario is wrapped around itself. Using this technique it is possible to maintain constant the number of simulated users without concentrating them in the borders of the scenario. As figure 1.13 depicts, a wrap-around technique considers that points on opposite borders are adjacent. Finally, figure 1.14 shows the whole mobility scheme.

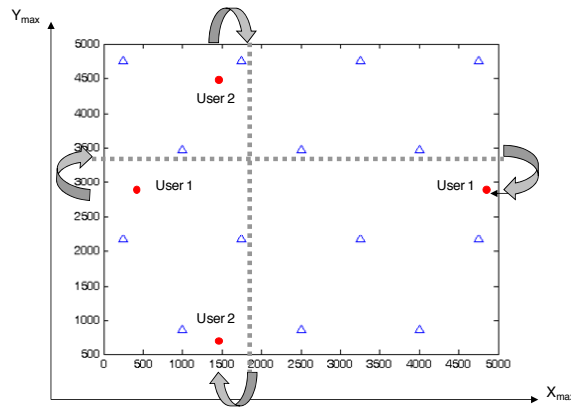


Figure 1.13: Wrap around

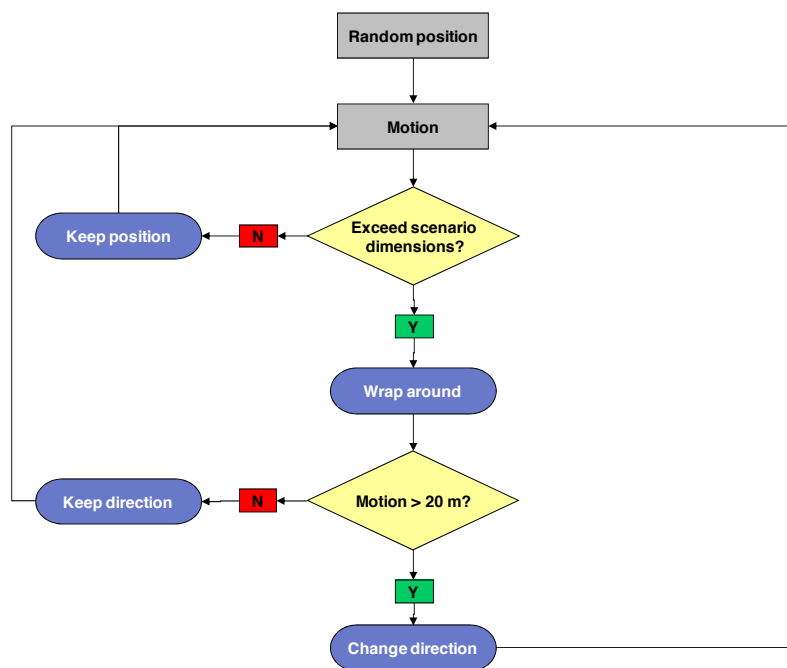


Figure 1.14: Mobility scheme

Figure 1.15 represents a simulation case that shows the mobility model of some pedestrian users ( $v = 3km/h$ ) during an observation time of 10 minutes.

Due to the great dimensions of the scenario the mobility is not clearly appreciated in the figure 1.15. For this reason two more pictures are extracted from the simulation results. Each one shows the mobility associated to a specific UE. In this figure, the changes in the direction when the covered distance is higher to 20 m can be appreciated.

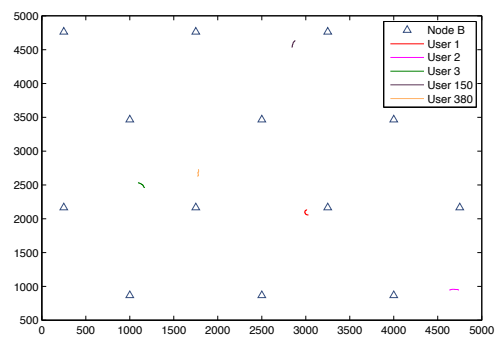


Figure 1.15: Mobility associated to users with ID 1 2 3 150 380

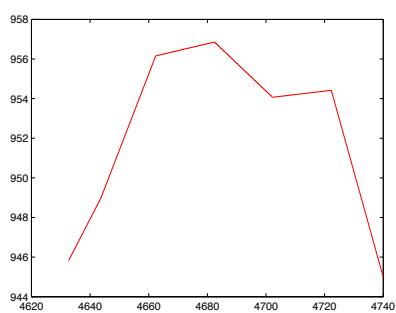


Figure 1.16: Mobility associated to user with ID 1

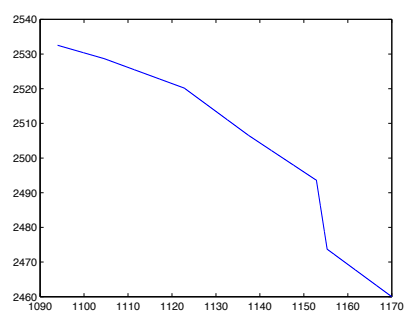


Figure 1.17: Mobility associated to user with ID 2



## CHAPTER 2. RADIO RESOURCE MANAGEMENT (RRM)

### 2.1. Introduction

WCDMA is one of the main technologies for the implementation of third-generation (3G) cellular systems. It is based on the radio access technique proposed by ETSI Alpha group and the specifications were finalized 1999. With this access technique it is possible to achieve major data rates that with those used in GSM cellular systems, FDMA/TDMA. In order to understand correctly the relevance of RRM it is necessary to know some notes about the operation of WCDMA.

In WCDMA [4] different users can simultaneously transmit at different data rates and data rates can even vary in time. The users share all the available spectrum, the available bandwidth is greater than in previous older systems and, in consequence, the data rates that can be reached are higher. To distinguish the signal arriving from different users, a set of orthogonal and non-orthogonal codes are used. The treatment of these code sequences is different in each one of the links. In UL, the BS differentiates the signal from a user of those transmitted by other users by a non-orthogonal code. Although the signals arriving from the rest of users remain spread, this lack of orthogonality implies that they are seen as a residual interference by the receiver. The orthogonal codes are used to differentiate between the own users transmissions. On the other hand, in the DL, the orthogonal codes are used to differentiate between the users served by the same cell. However because of multipath there is always a certain loss of orthogonality, which generates the so called intracell interference. Besides, non-orthogonal codes are used to differentiate users from other cells and therefore intercell interference is also present.

From this, it is observed that 3G cellular systems are systems limited by interference. For this reason a correct management of the radio resources available is needed in order to maximize both, coverage and capacity.

As explained before, the WCDMA technology does not present a constant capacity value, like occurs with the 2G cellular systems. In these ones the maximum network capacity is known before the deployment of the same. It is known, for instance, that a carrier in a concrete GSM BS can serve a maximum of 8 users. In 3G cellular systems, the capacity is straightly connected with the level of interference present in the radio interface. This interference level can be reduced and managed to some extent with RRM.

RRM [5] comprise a set of algorithms and strategies that allow to maximize the capacity of a 3G cellular system, guarantying the fulfilment of the QoS parameters required by users.

The RRM strategies can be classified in two main groups:

- Connection strategies
- Network strategies

The PC and the SHO mechanisms are included inside the connection strategies, while the AC is considered a network strategy. These are the algorithms studied in this section. However, other existing strategies that are not analyzed in this project exist, for example: the codes management, packet scheduling, congestion control, etc.

In this section a deep study of PC, SHO and AC algorithms is done. In a first stage, the procedure to determine the Active Set (AS) of the UE is disclosed. During the second part, the AC will be explained in depth. Finally the section continues with the explanation of PC, in particular, the focus of this section is on the different mechanisms that can be used to simulate the real algorithm and in the final election that was done. The section concludes with an algorithm that has been developed to determine the maximum capacity of a UMTS network.

## 2.2. Soft Handover and Active Set configuration

The concept of AS has been introduced by the third generation systems to implement a *Soft/Softer* Handover strategy. It is defined as the set of BSs at which UE is connected simultaneously. In particular, its main function consist in keeping the users connected to different BSs during the Handover process.

Note that, when the UE is in SHO, it will respond to different PC commands. It is simultaneously connected to all BSs but the UL transmission power will be the one related to the base that demands less power. On the other hand, in the DL, all the stations in the AS will transmit a certain amount of power and the UE will coherently combine them to obtain the required level of  $E_b/N_0$ .

Along next subsections further details are given on how a given UE configures and modifies this set of BSs:

### 2.2.1. Pilot channel (*CPICH*) measurements and cell selection

The performance of UMTS SHO algorithm is closely related to the adjustment of different thresholds and hysteresis margins that participate in the algorithm. While the user equipment (UE) is in connected mode, it continuously monitors the primary control pilot channel (*CPICH*) of the cells and reports to the network whenever certain conditions on this measure are accomplished. One of the most important parameters is the Addition Window, also called macrodiversity window, which defines the maximum relative difference in terms of  $CPICH E_c/I_0$  of those cells that are to be included in the AS with respect to the best received one. The number of BS that can be included is not indefinite and must be also fixed by the operator. Given this, the notation that has been used to define the AS of a user is:

$$\text{Active Set: AS}(m, n) \quad (2.1)$$



- $m$  = maximum number of BSs that can be included in the AS.
- $n$  = macrodiversity window size.

The exact quality measure that is carried out by one UE to add or eliminate BSs from its AS is the relation between the chip energy measured in the own pilot signal and the spectral density of the total received power in the antenna connector. In this way, the  $CPICH E_c/I_0$  of the user  $k$  with respect to a certain BS  $m$  is calculated as follows:

$$CPICH E_c/I_0(m, k) = \frac{P_{tx, pilot}(m)/L_p(m, k)}{\sum_{j=1}^M \frac{P_{tx}(j)}{L_p(j, k)} + N_T(k)} \quad (2.2)$$

- $P_{tx, pilot}$ : Pilot signal power transmitted by the Node-B.
- $L_p(m, k)$ : Attenuation between BS  $m$  and UE  $k$ .
- $N_T(k)$ : Thermal noise power measured at UE  $k$ .
- $P_{tx}(j)$ : Total transmitted power by the BS  $j$  (pilot + control + traffic channels).
- $M$ : Number of BSs present in the scenario.

The first cell selection in UMTS is carried out once two conditions are met. First, the minimum coverage threshold, the UE must receive at least one  $CPICH$  signal with an  $E_c/I_0$  level higher than -18 dB. Second, the UE has to pass the AC of that cell. Only if the AC allows the incorporation of the user, he could transmit to the mentioned BS. Once the first BS meets both conditions, and therefore, is part of the AS, the second best received BS is evaluated. It must again accomplish both the coverage and AC conditions. Also the difference in terms of  $E_c/I_0$  with respect to the best station must be below the macrodiversity window. Third, fourth, etc BSs are evaluated similarly and always considering which is the maximum number of stations inside the AS.

In a suitable approximation to the reality, the pilot signal is not considered constant in the framework of the simulation tool, since it can vary according to different criteria, for instance based on the number of users launched to the system. Its variability depends on the interference level present in the system. The more are the number of users in the system, the more are the interference levels achieved. An increment in the interference level produce a reduction in the SIR measured in the pilot channel, which can be translated into a reduction of the coverage area. On the other hand, the  $CPICH$  power can be changed to equalize the traffic among cells. For example, if a BS reduces its  $CPICH$  level, that would induce that part of the UEs that were served by this BS initiate a handover to other neighboring cells. Whereas an increase of the pilot channel power will cause that some UEs are handed over from these cells.

For all the simulations carried out during this project, the  $CPICH$  value considered is equal to 30 dBm. The pilot channel power represents a percentage of the total transmitted power by the cell. The total transmitted power is composed by the own pilot channel power, control channels and traffic channels.

### 2.2.2. Users Active Set implementation

Because the system is interference limited, the simulation tool will take into account that every time a new user come into the system, the  $CPICH E_c/I_0$  measurements will suffer a variation, and in this way the AS of the users can be modified according to the concepts previously introduced by [3]. Therefore, the first step is to generate an array with all  $CPICH E_c/I_0$  values for each user in the system.

The first BS that is going to be part of the AS has to fulfil the coverage condition ( $CPICH E_c/I_0 > -18dB$ ) and has to be the best listened in terms of  $CPICH E_c/I_0$ . If no BS satisfies the first condition, the user will be tagged without coverage. As stated, other BSs (up to the configured maximum number) will be included in the AS if they also accomplish the macrodiversity window condition. If all the cells that configure the AS belong to the same node-B, the user will be considered to execute a *softer* handover. Otherwise, one just talks of a *soft* handover user.

An exact calculation of the  $E_c/I_0$  value implies to know all BS transmitted powers in the scenario. However, it was not necessary to have this exact information. Since the  $I_0$  accounts for all the power measured at the antenna connector, it is the same for all the measurements done by the UE, irrespective of the BS. So, the AS can be correctly found without approximations, without having to find the real values of  $E_c/I_0$ . The simulation tool only needs the pilot transmitted power and the losses between the UE and the BS. However, do note that one approximation is made to decide if a BS meets the coverage condition, in this case, the real  $E_c/I_0$  value is needed. So for the calculus of  $I_0$  it has been considered that all the cells transmit the pilot power.

Figure 2.1 shows the number of cells that would be added to the AS of a UE according to his position in the scenario.

A user situated in a white area would add one cell in his AS. In the same way, a user situated in a green area could add two cells to his AS. Finally, a user situated in a brown area would add three cells to his AS, which is the maximum defined for this specific case (macrodiversity window fixed to 3 dB).

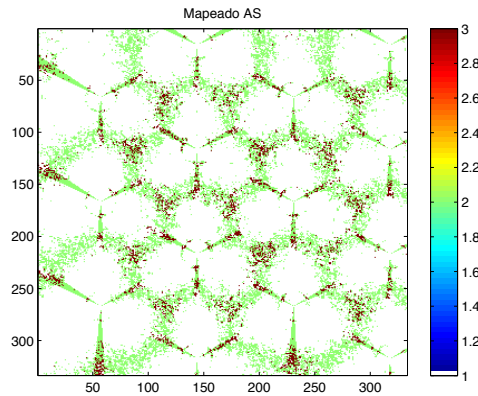


Figure 2.1: Active Set mapping

## 2.3. Admission Control

AC is the mechanism in charge of deciding whether a connection request can be accepted or not. The decision to admit a user depends on the interference level that would be added in case of accepting the request in order to guarantee QoS requirements of the existing connections. Admission control principles make use of the estimated load factor as well as the estimation of the load increment:

$$\eta + \Delta\eta \leq \eta_{max} \quad (2.3)$$

- $\eta$  is the estimated cell load factor
- $\Delta\eta$  is the load increment estimation
- $\eta_{max}$  is the admission threshold

When the admission control algorithm estimates the load increase of a new connection in both UL and DL links, the user can be admitted only if both links admit it, otherwise it is rejected because of the excessive interference that it would produce in the network.

The AC implemented is used as an indicator of the UL load factor and unless contrary instructions all users present the same priority. Eventually, some priorities could be defined (chapter 5) in order to guarantee QoS requirements and resources utilization for a certain group of users.

Because of the necessity to use the load factor when deciding if a user is admitted or rejected, the AC functionality must be located in RNC where the load information from cells can be obtained. Two basic RRM strategies exist to carry out the AC, based on measurements and the statistical model.

### 2.3.1. Based on measurements

The load factor in a certain cell can be estimated from power measurements made at the node-B and applying the following equation:

$$\eta_{UL} = \frac{P_R + \chi}{P_R + \chi + P_N} \quad (2.4)$$

- $P_R$  being the total own-cell received power at the BS
- $\chi$  the intracellular interference level
- $P_N$  the background noise

In practice, the load factor fluctuates sharply and that is why this measurement is averaged during a certain amount of time.

The inaccuracy of this method comes from errors in the physical measurement, quantization errors, and so on.

### 2.3.2. Statistical model

In this second case, the load factor is modeled by the statistical characterization of every connection in the BS (transmission rate, mean required  $E_b/N_0$  and activity factor) and also by characterizing the impact of intercellular interference through the f-factor parameter. This parameter represents the relationship between the intracell and the intercell interference. Once, these parameters are estimated, the load factor can be evaluated as (2.5). Note that both (2.4) and (2.5) are equivalent expressions and one can be obtained from the other, however, what it is different is the way of obtaining the different parameters to calculate them. Whereas the first case uses direct measurements, the second one makes a statistical characterization and uses average values.

$$\eta_{UL} = (1 + f) \sum_{i=0}^k v_i \cdot \frac{1}{\frac{SF_i}{\left(\frac{E_b}{N_0}\right)_i} + 1} \quad (2.5)$$

- $(E_b/N_0)_i = E_b/N_0$  of the *user<sub>i</sub>*
- $v_i$  = Activity factor
- $SF_i$  = Spreading factor
- $f$  = The intercell to intracell interference factor

This model does not need to feed the equation with real time measurements, but inaccuracies in the estimations can imply that it does not correspond with the actual conditions, particularly in environments in which they vary quickly along time.

### 2.3.3. Admission control implementation

The AC that has been selected and implemented in the simulator is the measure based strategy. Possible measurements or quantization errors are not considered.

To implement the AC with the simulation tool, the main input needed is an array with all the AS of all users. The output is the load factor associated to each cell of the scenario. Once the AC is applied to all BSs conforming the AS of a specific user is passed, the user will be labeled as *non admitted* if none of the cells in his AS have passed the AC. If, on the contrary, the user surpass the AC of at least one BS, the user will be admitted in the system. Finally, whenever one new user is admitted into the system its transmission power is calculated so that the load factors can be updated.

## 2.4. Power Control

The main mission of PC is to maintain the minimum interference level in the radio interface. To achieve it, it must ensure the minimum transmitted power that guarantees the QoS fixed by the network service provider to each user.

In this section, the operation of the PC algorithm will be explained in depth, in particular the two types that are used in UMTS: open and closed loops based PC. At the same time, various strategic methods to simulate this algorithm will be studied in order to decide the more suitable for the simulator over development.

- Open Loop PC

This is the mechanism used by the user to estimate the initial power that has to transmit to start a transmission to the network, to start a transmission in the random access channel (RACH). Before any RACH access, the UE transmits a set of short preambles. This is done continuously until it receives and *Acquisition Indicator* from the Node-B, which signifies that the network has correctly detected one of them. In this process, the power of the first preamble is computed from the DL measurement (through the *CPICH*) and after each attempt, the UE updates its transmission power increasing the value in a power step  $P_{i+1} = P_i + \Delta P$ . Since UL transmission power is estimated from the DL received one, one talks of open loop.

Thanks to this there is no near-far effect, otherwise the user would have to transmit with the maximum available power to ensure the correct reception by the BS. In this situation and due to the propagation losses, not all the signals arrive with the same level to the BS. The signal arriving from near users overlap the signal arriving from far users, who are in a worse propagation losses condition.

The open loop PC is only used when a UE is accessing to the network, as an estimation measure. This type of PC can not be used in other situation because of its imprecision, due to the differences existing between the multi-path propagation behavior in both up- and DL.

- Closed Loop PC

The main aim of the closed loop PC is to maintain the Signal to Interference Ratio (SIR) required by the service in use. The Radio Network Controller (RNC) stores the QoS parameters fixed by the network service provider, while the BS request to the RNC, for the SIR target associated with the service used by the UE. Note, that the RNC can update the required SIR if the block error rate (BLER) increases. This is also considered part of the PC and it is called the outer PC.

The SIR received by a cell from the UE is measured with a frequency of 1500 Hz. These measures are compared with the SIR target fixed by the RNC. If the received power exceeds the target, the BS sends an order to the UE for decrease the transmitted power

level. If on the contrary, the received power is not enough, the UE is ordered to increase the transmitted power, in order to arrive to the BS with the desired QoS. In the DL the process is the same but now the command to update the transmission power are sent by each UE. This closed loop based process is called the inner loop PC of UMTS.

### 2.4.1. Simulating uplink power control

In order to develop a PC algorithm nearest to the PC applied in real UMTS networks, different strategies have been studied and developed in next subsections. These strategies allow to implement a simulated PC management without the necessity to directly simulate the 1500 corrections per second, which can result inefficient in terms of memory and processing capacity. In order to facilitate the understanding of the proposed solutions, some notation and parameters that take part in the development of the PC algorithm is explained next.

The SIR associated to the user  $k$ ,  $\gamma(k)$  is defined as the quotient between the power received from  $k$ ,  $P_R(s(k), k)$  in the serving cell  $s(k)$  and the received power from the rest of the users in the system (there is a total of  $K$  users) plus the thermal noise associated with the BS,  $n(s(k))$ .

$$\gamma(k) = \frac{P_R(s(k), k)}{\sum_{j=1}^K P_R(s(k), j) - P_R(s(k), k) + n(s(k))} \quad (2.6)$$

By intuition, the expression detailed above could be simplified using the SSIR (Signal to Signal to Interference Ratio,  $\gamma'$ ) instead the SIR by means next conversion.

$$\gamma'(k) = \frac{\gamma(k)}{1 + \gamma(k)} = \frac{P_R(s(k), k)}{\sum_{j=1}^K P_R(s(k), j) + n(s(k))} = \frac{P_T(k)/L_P(s(k), k)}{N_T(s(k))} \quad (2.7)$$

- $P_T(k)$ : Transmitted power by user  $k$ .
- $L_P(s(k), k)$ : Propagation loss between  $k$  and  $s(k)$ .
- $N_T(s(k))$ : Total received power at  $s(k)$ , including noise.

In consequence if the SSIR is known, the calculation of the required transmitted power by the UE is simplified, since there is only necessary to know the total received power in the cell. From this, the power that must be transmitted by the UE in order to achieve the target SIR can be calculated as follows.

$$P_T(k) = \gamma'(k) \cdot N_T(s(k)) \cdot L_P(s(k), k) \quad (2.8)$$

In subsections below the different strategies to carry out the power allocation, are disclosed. In spite of only the two methods have been chosen for the simulated PC develop-

ment, the three that have been evaluated are explained. The advantages and disadvantages of each one are analyzed and justify the election made.

#### 2.4.1.1. Microscopic analysis

The microscopic analysis is the method which consists in solving the lineal equation derived from equation (2.8), which can be written as:

$$P(k) = \gamma'(k) \cdot L_P(s(k), k) \cdot \left( \sum_{j=1}^K \frac{P_T(j)}{L_P(s(k), j)} + n(s(k)) \right) \quad (2.9)$$

And leads to the next lineal equation system:

$$A \cdot P_T = N \quad (2.10)$$

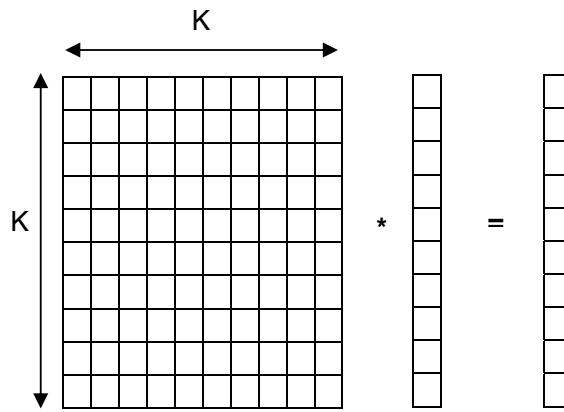


Figure 2.2: Microscopic analysis matrix

- $P_T$  = Array with the UE power values
- $N$  = Array with the thermal noise associated to all the cells in the system
- $A$  = Matrix of dimensions  $(K \times K)$ . The value associated with each one of the matrix elements is calculated as:

$$\begin{aligned} A(i, j) &= L(s(i), i) / \gamma(i) \quad \text{if } i = j \\ A(i, j) &= -L(s(i), j) \quad \text{if } i \neq j \end{aligned} \quad (2.11)$$

This method presents one important drawback, which is the high number of equations to be solved, equal to the number of users in the system. For this reason, the microscopic analysis has been ruled out.

#### 2.4.1.2. Macroscopic analysis

The macroscopic analysis is one of the methods chosen for being implemented in the simulated PC development. The lineal equation system suggested in this method is similar to that proposed in the microscopic analysis. The underlined difference is the matrix dimensions, which now equals the number of cells in the scenario. To achieve this, one variable change must be introduced in the previous proposed system and according to (2.12).

$$N_T(m) = \sum_{j=1}^K \frac{P_T(j)}{L_P(m, j)} + n(m) = \sum_{j=1}^K \frac{L_P(s(j), j)}{L_P(m, j)} \cdot \gamma'(j) \cdot N_T(s(j)) + n(m) \quad (2.12)$$

Given this, the lineal equation system is turned into this new one:

$$B \cdot N_T = N \quad (2.13)$$

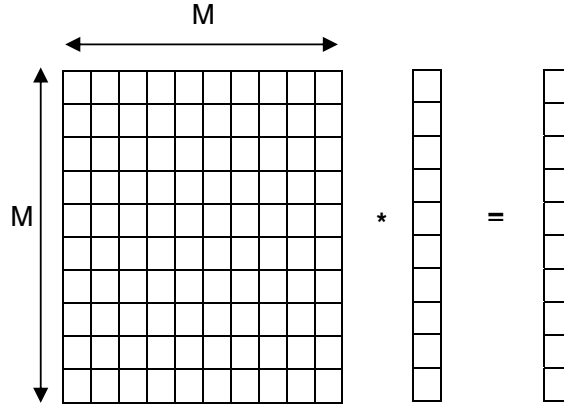


Figure 2.3: Macroscopic analysis matrix

- $N_T$  = Array whit the total received power values
- $N$  = Array whit the thermal noise associated to all the cells in the system
- $M$  = Number of BSs deployed
- $B$  = matrix ( $M \times M$ )

Each one of the matrix elements is calculated as:

$$B(m, n) = \delta_{m,n} - \sum_{k=1}^K \frac{L_P(n, k)}{L_P(m, k)} \cdot \gamma'(k) \quad (2.14)$$

This expression defines the relation between the attenuation suffered by the user under study and all the cells included in his AS, and the propagation losses associated to other cells of the system. If the expression above is developed, the simplification obtained allows easily calculating the total received power as:



$$N_T = N \cdot \text{inv}(B) \quad (2.15)$$

Finally, the next step lies in calculating the required transmitted power by the user:

$$P_T(k) = \gamma'(k) \cdot N_T(s(k)) \cdot L_P(s(k), k) \quad (2.16)$$

Last step differs from the methods analyzed above. A recalculation of the real interference present in the system is needed, since the number of users that scour the network are less than those analyzed.

In order to consider SHO, the equation system must be solved twice. Initially, all UEs that in a handover situation are split in as many "virtual" UEs as bases in their AS. Next, the equations are solved and the transmission power of the different virtual connections are compared. Since the UE will transmit to the BS that requires less power from them, the virtual connection with a lower power is maintained, the others being eliminated. So, this first evaluation aims at deciding to which BS transmit the UEs in handover. Now, the system can be evaluated normally, without virtual connections and assigning handover UEs to the chosen cell, subsequently this second step is called as PC fine adjustment.

The drawback of this algorithm is that under overload circumstances it can give impossible negative powers as a result, or powers over the maximum allowed levels.

#### 2.4.1.3. Iterative analysis

This method is not very efficient in the resources consumption, since the computational load required is elevated. However, it solves the problems of the macroscopic case. It is based in an iterative calculus that allows to find the power levels of the system. The steps are listed below:

1. All the users transmit with the minimum power level required.
2. The total power received in the cells is calculated.
3. The transmitted power that allow the required SSIR and according with the interference level approximated in the previous step is calculated. Note that in the first iteration, the only present interference is the thermal noise at each BS.
4. If the required transmitted power is higher than the allowed one, the power is updated and limited to this maximum. Therefore the terminal will be in *degraded mode* and all the powers will have to be updated accordingly.
5. The process will be continued following the same steps until the convergence of the algorithm. The convergence occurs when the difference between the received power in the cells in a specific frame and the same level of power in the following frame differs in 0.03 dB for each one of the cells under analysis. The expression for

a specific cell is defined in lineal units in 2.17, it is necessary that all the cells fulfil this requirement.

$$\frac{N(s(k))_i}{N(s(k))_{i+1}} = 1.07 \quad (2.17)$$

#### 2.4.1.4. Implemented method

In this subsection the PC algorithm that has been developed for the UMTS simulator is described. In fact, it combines two of the techniques explained above. The macroscopic and the iterative. With the first one, non overloaded situations are solved very quickly. However, whenever the algorithm does not reach a valid solution (negative powers because of high load levels) the solution is provided by the iterative one. The complete and detailed procedure is depicted in the scheme shown in figure 2.4.

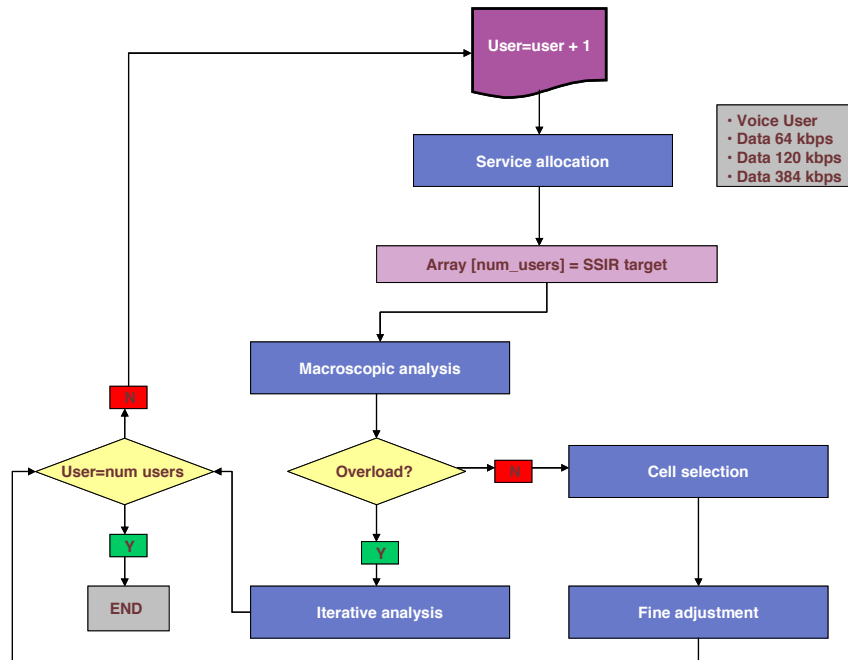


Figure 2.4: CP scheme

A set of inputs are provided in order to establish the lineal equation system. All the users have assigned an  $E_b/N_0$  according to its service and mobility conditions. From this, the SSIR can be calculated through equation 2.18. The processing gain  $G_p$  is also known from the service rate. All these parameters can be changed via the user interface of the simulator.

$$SSIR_{target} = \frac{E_b/N_0}{W/R_b} = \frac{E_b/N_0}{G_p} \quad (2.18)$$

- $E_b/N_0$  = Signal to noise ratio
- $W$  = Chip rate 3,84 Mchips/s

- $R_b$  = Specific service rate

The velocity of the algorithm in the convergence process will increase if the condition changes to lower values but at the expense of less accurate values. Although the iterative analysis need more resources consumption and can reduce considerably the velocity of the simulation, its use is only limited to the situations where the macroscopic analysis does not get a correct solution.

### 2.4.2. Simulating downlink power control

Before explaining the details on how to implement the UMTS DL power control in a simulator, some effects are described so that they are realistically considered in the font code.

In the DL the PC control will decide the power that each BS devotes to each one of its UEs. Moreover, it is necessary to point out that in the DL, all the cells that are included in the AS of one user must serve him. The UE coherently combines the signals arriving from all BSs via a Rake receiver. Therefore, it is only necessary a power portion from these cells. This fact minimizes considerably the dedicated resources to a specific user, particularly when it is in the cell edge. Besides, when one of the links is in a shadow area or in a fast fading, it is very likely that the other ones are not in the same situation providing a clear benefit to the user. The combination of these effects is usually called the macrodiversity gain.

The combination method that is used is the Maximum Ratio Combining (MRC), which is the best option in situations where the signals arriving from each one of the possible propagation paths are different in terms of amplitude, delay and phase. The receiver corrects the phase rotation caused by a fading channel and then combines the received signals of different paths proportionally to the strength of each path. The Rake receiver is composed by several "sub-receivers" called fingers, each one tuned to the particular delay of the individual multipath components. Each component is decoded independently, but combined at a later stage in order to make the most use of the received power.

The cells are power limited, so a correct management of the resources available is necessary in order to avoid overloaded situations. The correct management of the power level available in the Nodes-B is obviously carried out by the PC algorithm. Only the required power that guarantees the SSIR target is transmitted. This ensures minimum resources consumption and maximizing the network capacity.

The SHO parameters in this case produce an opposite effect. While in UL, an increase of these parameters values results interesting in order to reduce the interference level of the system, in the DL too high values would cause a reduction in the DL capacity because of increased transmission powers due to many links. Eventually a very far away BS could be forced to transmit a certain amount of power to a user. Imagine a macrodiversity window of 6 dB, it means that the difference between the cells best listened can be of 6 dB, so very distant cells can be included and in consequence they are forced to serve far away users. A cell under this situation wastes its resources in far users, contributes to increase interference and therefore to reduce the global capacity of the system.

Thus, an important trade-off in the SHO process is observed. This commitment will be

studied in depth in following chapters, in order to maximize the capacity and the performance of an UMTS network.

#### 2.4.2.1. Implemented method

One of the main differences between UL and DL is that, in the second case, the users are differentiated by orthogonal codes (OVSF family codes). However, this orthogonality is not perfectly maintained when reaching the receivers because of multipath so a certain interference appears. Note that among cells this family of orthogonal codes is reused. This implies that intra and inter-cell interference will have a different treatment. Given this initial comment, along subsequent paragraphs is described the process to obtain the DL transmission powers.

The first step implies the creation of a matrix that will help to implement the MRC behavior of users.

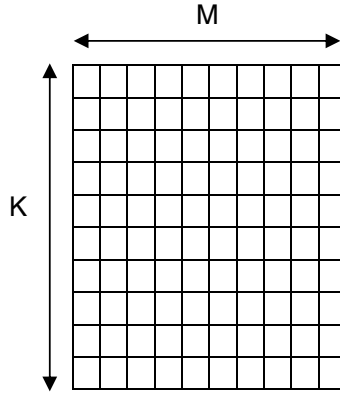


Figure 2.5: Allocation Matrix

The dimensions of this allocation matrix are the number of cells ( $M$ ) and the number of users ( $K$ ). And each element is calculated as:

- $\varepsilon(m, k) = 0$  If the cell is not included in the AS of the UE
- $\varepsilon(m, k) = 1$  If the cell is included in the AS of the UE

This allocation matrix allows calculate the number of connections associated to each user, and in consequence the portion of SIR target that must be granted by this connections. In this way, the following condition must be fulfilled:

$$\sum_{m=1}^M \varepsilon(m, k) = 1 \quad (2.19)$$

And it is straight forward that the total SIR can be calculated as:

$$\sum_{m=1}^M \varepsilon(m, k) \cdot \gamma(k) = \sum_{m=1}^M \gamma(m, k) = \gamma(k) \quad (2.20)$$

In a first study the equality criteria has been chosen. It means that all the cells that form the AS of an UE contribute to reach the SIR target in the same way. Another possibility would be to that those cells in a better condition of proximity provide a higher contribution than other in worse propagation conditions. A contribution selection mechanism could also be developed. For instance, if it is detected that a cell which an initial contribution fixed to the 40%, is closely to an overload situation, the contribution of this cell could be reduced to reduce its overload and increasing the contribution of the less loaded cell in the AS.

The orthogonality factor will model the loss of orthogonality in the intracell power. Thus, a novel matrix is created with the orthogonal factors  $\rho(m, k)$  associated to each user  $k$  with respect to each cell  $m$ . The criteria that has been followed is:

- If the cell is added in the AS of the user under study, an orthogonality factor lower than the unity is considered.
- If the cell do not form part of the AS of the user under study, an orthogonality factor equal to zero is considered. It means that no reduction is applied to the interference level because there is a complete lack of orthogonality.

The values from the previous equations will help to find the received SIR, which is defined as the fraction between the received power that the cell devotes to that users and the whole interference: intra and intercell interference plus thermal noise. The mathematic expression is defined in the equation below:

$$\gamma(m, k) = \frac{P_T(m, k)/L_P(m, k)}{\sum_{n=1}^M \rho(n, k) \cdot P_{T, tot}(n)/L_P(n, k) - \rho(m, k) \cdot P_T(m, k)/L_P(m, k) + n(k)} \quad (2.21)$$

Where  $P_{T, tot}(m)$  is the total transmitted power level of one cell. It is calculated as the addition of the individual transmitted powers required by the users connected to the cell being evaluated plus the power devoted to control channels  $c(m)$ . According to the nodes-B specifications this maximum value is fixed to 43 dBm.

$$P_{T, tot}(m) = \sum_{k=1}^K P_T(m, k) + c(m) \leq P_{T, max} \quad (2.22)$$

Similarly as was done in the UL, equation 2.21 can be further simplified as follows:

$$\gamma'(m, k) = \frac{\gamma(m, k)}{1 + \rho(m, k) \cdot \gamma(m, k)} = \frac{P_T(m, k)/L_P(m, k)}{\sum_{n=1}^M P_{T, tot}(n) \cdot \rho(n, k)/L_P(n, k) + n(k)} = \frac{P_T(m, k)/L_P(m, k)}{N_T(k)} \quad (2.23)$$

From the equation above, the total transmitted power by the cell under study to the user under consideration can be found:

$$P_T(m, k) = \gamma'(m, k) \cdot N_T(k) \cdot L_P(m, k) \quad (2.24)$$

And finally, with the combination of the previous equations, a lineal equation system can be obtained.

$$P_{T,tot}(m) = c(m) + \sum_{k=1}^K \gamma'(m, k) \cdot L_P(m, k) \cdot \left[ \sum_{n=1}^M \frac{P_{T,tot}(n) \cdot \rho(n, k)}{L_P(n, k)} + n(k) \right] \quad (2.25)$$

Or in the same way:

$$P_{T,tot}(m) = c(m) + \sum_{k=1}^K \gamma'(m, k) \cdot n(k) \cdot L_P(m, k) + \sum_{n=1}^M P_{T,tot}(n) \cdot \sum_{k=1}^K \frac{\gamma'(m, k)}{L_P(n, k)} \cdot L_P(m, k) \cdot \rho(n, k) \quad (2.26)$$

Therefore, the macroscopic algorithm for the DL PC will be given by:

$$H \cdot P_{T,tot} = V \quad (2.27)$$

Where H is calculated as follows:

$$H(m, n) = \delta_{m,n} - \sum_{k=1}^K \frac{L_P(m, k) \cdot \rho(n, k)}{L_P(n, k)} \cdot \gamma'(m, k) \quad (2.28)$$

and V is obtained from:

$$V(m) = c(m) + \sum_{k=1}^K \gamma'(m, k) \cdot n(k) \cdot L_P(m, k) \quad (2.29)$$

The output obtained to apply this lineal equation system is the transmitted power by a cell to each one of the users served by it.

Similarly to the UL, if the macroscopic approach is not able to find one solution, the algorithm jumps to an iterative resolution.

### 2.4.3. Maximum capacity algorithm

As explained during this section *CPICH* Power variations and AS parameters have an influence over the system capacity. Maximum capacity is defined as the situation in which at least one cell of the scenario reach a number of degraded users higher or equal to 5%.

This part of the simulation tool is very important in order to determine the number of users that must be launched to the system in order to avoid overload situations. The number

of users launched to the system depends on the purpose of the simulation but always is interesting to find a balanced situation between the UL and the DL.

In figure 2.6 the block diagram of the maximum capacity algorithm is represented. One restriction is that AC can not be executed, in consequence all the users launched to the system are admitted. Only the CP as a RRM is needed for the resolution of the maximum capacity algorithm.

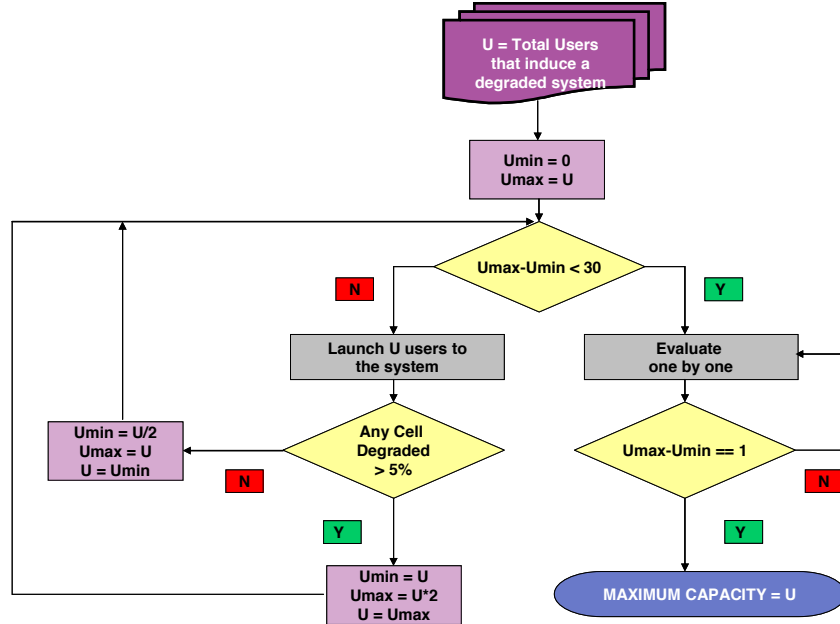


Figure 2.6: Maximum capacity scheme

The steps carried out to determine the maximum capacity in a concrete AS and *CPICH* configuration, are the following:

- Admit all the users into the system.
- Launch a number of users ( $U$ ) large enough to cause a degraded system (at least one cell with 5% users not reaching  $E_b/N_0$  target).
- Minimum capacity ( $U_{min}$ ) will be 0 at the initial state, and maximum capacity ( $U_{max}$ ) will be the total number of users that were launched.
- Until  $U_{max} - U_{min}$  is equal to 30 users, the process is:
  - PC resolution with  $U$  users.
  - If a cell reaches 5% users in degraded mode then next  $U$  that must be evaluated is divided by 2 and  $U_{max}$  is equal to the previous value of  $U$ .  $U_{min}$  is maintained at the same value.
  - If any cell of the system reaches the maximum percentage of degraded users that it is allowed, then next  $U$  that must be evaluated is multiplied by 2.  $U_{min}$  is equal to the previous value of  $U$  and  $U_{max}$  is maintained at the same value.

- When the difference between  $U_{max}$  and  $U_{min}$  is equal to 30 users, then the process continue evaluating users one by one. The calculation of maximum capacity carry on until arriving to a situation in which increasing one user suppose a degraded system and remain at  $U$  users is a good state. This is the maximum capacity.

Logically, depending on the location of the last user that is evaluated and that causes the difference between a good system and one working in degraded mode (5% of degraded users), more or less users could be added to the system. Nevertheless, in some snapshots this situation will be present by excess and in others by fault, so an average of enough snapshots is necessary in order to cancel exaggerate variations.

According to the algorithm, maximum capacity can be calculated in both links, UL and DL. In the UL the maximum number of users that can be assumed by the system is the one that guarantee minus than 5% of users degraded in each one of the cells. This value is independent of the DL, it is possible to be in a situation where all users in the UL are well served and in the DL they are not. The degraded mode in the UL is defined with the transmitted power by users to the BS. Maximum value of transmitted power is 21 dBm.

Regarding to the DL, the concept is the same as in the UL, but now the condition of maximum 5% of degraded users is imposed to the DL, without depending on the UL state. Now the degraded mode is defined with the transmitted power by the BS to the users. There are two possibilities, the first one is that the BS transmits more than the maximum power that can be delivered to one connection fixed at 30 dBm. The second one is that the cell reaches its maximum available power for all connections fixed at 43 dBm.

Once the maximum capacity of the system is detected, estimations of the network behaviour can be done simply knowing the number of users launched to the system.

One example obtained in our simulation with 100% of the users having a conversational service is shown next. Subsequent chapters will make an extensive use of this algorithm to find maximum capacity conditions under other circumstances.

Initially, in figure 2.7 the results of maximum capacity for the UL are shown. The maximum number of users for different AS configuration and as a function of the central pilot power can be seen. The pilot power is the same in all cells except in the central cell where different situations have been evaluated: 0 dB +/- 3 dB and +/- 6 dB with respect to the other cells. According to the curves, the maximum capacity is practically the same with all the relative *CPICH* configuration except in the case of +6 dB, so for this range of variation, no particular degradations or gains in capacity are obtained. Recall the uniformities of our scenario.

In simulations where AS parameters are higher, users are able to listen more BSs, and therefore a capacity increase is observed. This is due to the fact that the users can select the best BS in order to transmit the minimum required power in the UL. For example, in the case of a relative *CPICH* in central cell of 0 dB and AS configurations (1,0) vs (3,6), the difference of maximum capacity is approximately an 7.27% higher in the case of AS=(3,6).

Next, in figure 2.8 the results of the probability to have a certain number of BSs in the AS for different AS configurations are depicted. Three cases have been considered, the probability to have one, two or three BSs in the AS. As the size and macrodiversity values



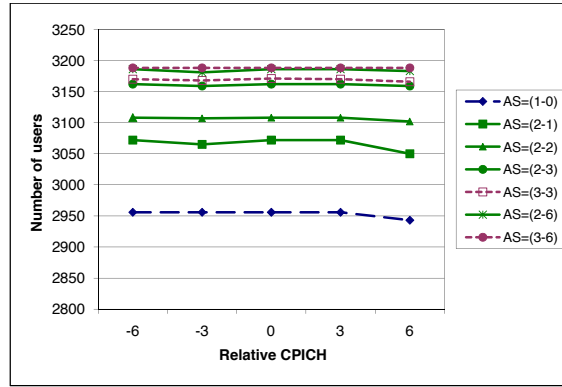


Figure 2.7: Maximum capacity curves in the UL for different AS configurations and as a function of the central pilot power

are higher, then the probability to have only one BS in the AS is decreased because users can listen more Nodes-B.

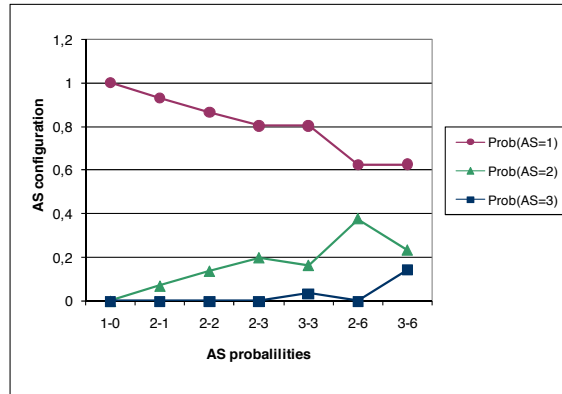


Figure 2.8: Probability to have a certain number of BSs in the AS as a function of different AS configurations

The maximum capacity results for the DL are shown in figure 2.9. The condition to reach the maximum capacity in the DL is different to the one imposed in the UL, a significant difference in both links results can be seen in the figure 2.9. In the DL maximum values of capacity are also very similar for all relative *CPICH* configuration except -6 dB of relative *CPICH*. So the consideration taken is that maximum capacity is achieved when relative central *CPICH* power is equal to 0 dB.

The main difference between the capacity curves of the UL and the DL is that in the second case the best situation is an AS configuration of (1,0). As AS parameters are smaller, the system performance is better. This is due to the fact that when parameters are higher, users can listen more BSs and then put them into the AS. The result is that the BS can be forced to transmit to users located farther away. So despite the provided power is distributed among all the cells in the AS, the global effect is worse.

Another thing that can be observed in both links is that the maximum capacity is more sensitive to a macrodiversity variation than a different size configuration. There are almost the same results for an AS=(2,3) and AS=(3,3), so increasing the number of BSs that can

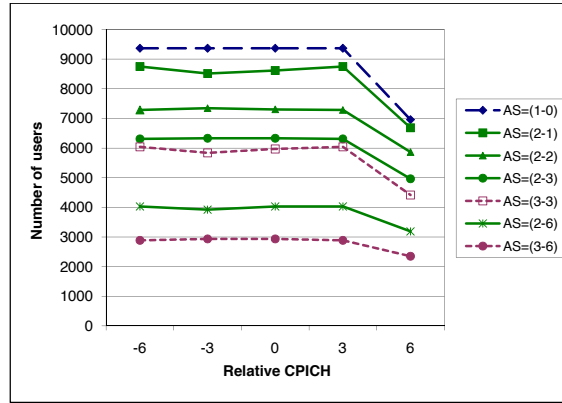


Figure 2.9: Maximum capacity curves in the DL for different AS configurations and as a function of the central pilot power

be included to the AS do not affect to the capacity. Nevertheless, when macrodiversity value is increased then the BSs have to serve users located increasingly further away and the propagation losses are higher, so they require more power from the Nodes-B.

Finally, after looking the results in both links, there are opposite effects in the UL and the DL capacity. Figure 2.10 shows the difference between the maximum number of users that the DL can support and the maximum capacity of the UL.

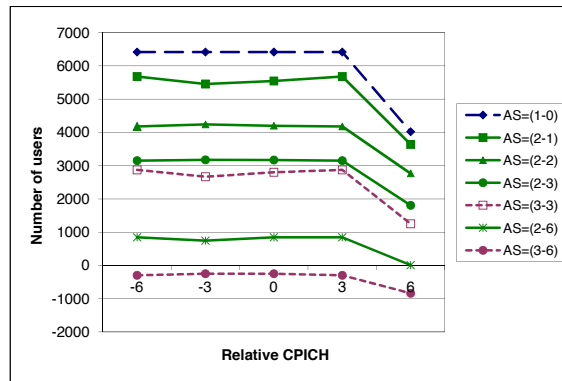


Figure 2.10: Difference in number of users between the UL and the DL maximum capacity values

The optimum configuration in order to have a balancing situation between UL and DL is the one situated closer to the 0 value. Those configurations that are in the positive area correspond to case where the limiting link is the UL. The negative values belong to cases where the limiting link is the DL. In short, according to the figure 2.10, the optimum AS configuration to balance the UL and DL effects, is the AS=(2,6) or AS=(3,6).

## CHAPTER 3. SIMULATOR USER INTERFACE

### 3.1. Introduction

The main objective of the present chapter is to explain the simulation tool used to carry out all the simulations. The program interface is only the tool to execute the code font. The creation of the interface has been carried out in order to facilitate the usage of the simulation tool and it was not one of the primary objectives of the project. Next sections include a detailed description of the main screens as well as their functionalities.

### 3.2. User interface

The screen in figure 3.1 is the first one that appears and represents the program presentation interface. It allows to accede to the different steps that compose the simulation: scenario creation, propagation losses and finally UL and DL simulation.



Figure 3.1: Access to user interface

To continue the simulation process the "enter" button must be pressed. Afterwards, the user will be able to select among two options: A static scenario (that is, based on the *Montecarlo* model) or a dynamic scenario with a specific mobility model.

### 3.3. Introduction to a static or dynamic scenario

The flexibility of the simulation tool is found in the variety of tests that can be made over a specific scenario defined by the user. The possibility to choose an static or dynamic scenario is presented in this screen.

The static simulations are featured by the fact that different snapshots with different traffic characteristics can be launched in each frame without none kind of correlation. This function allow to take "photos" of the system at different time intervals. Within the static

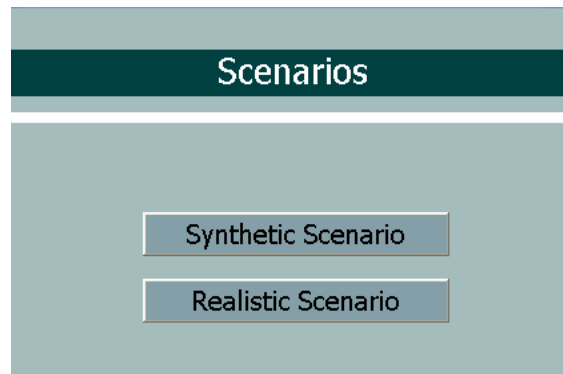


Figure 3.2: Type of scenario selection

simulations, it can also be found the development of the maximum capacity algorithm. This value is calculated and averaged for several snapshots.

On the contrary, the dynamic simulations are those where each frame is correlated with the previous one. Users are launched randomly only once, at the beginning of the simulation time, but in subsequent frames the users move around the network according to a mobility model. This kind of scenario is useful when time evolution is important in the algorithms to study or the statistics to be found. It allows to determine the behaviour of the network very realistically, but at the cost of much more computational cost if several snapshots (several observation times) are going to be simulated.

The interfaces that will be explained next can be applied to the static configuration as well as to the dynamic one.

### 3.4. Scenario creation interface

The first step to carry out the simulation process is the scenario creation. Figure 3.3 shows the appearance of the corresponding screen. A set of inputs can be configured by the user in order to determine the dimensions of the scenario as well as the suitable Nodes-B position according model described in section 1.3.1..

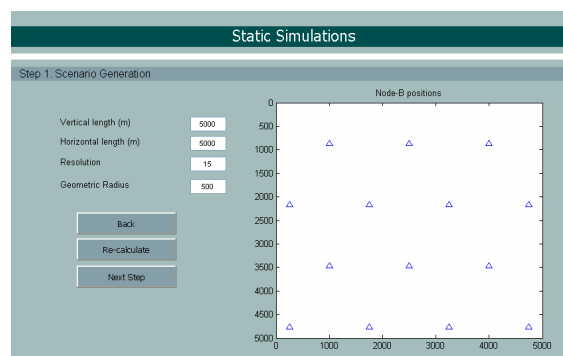


Figure 3.3: Scenario creation interface

Therefore, this interface establishes the first step that must be carried out. The input parameters that can be modified are:

- Vertical and horizontal scenario dimensions, specified in meters.
- Scenario resolution in meters.
- Geometrical radius of the cells in meters.

When all parameters are fulfilled, the program interface generates as output a figure gathering all the inputs where the final Nodes-B positioning can be appreciated. Once the Nodes-B position is determined, and taking into account the azimuth angles for each antenna, the cells location are known. The next step is to determine the propagation losses of the system according to the propagation conditions selected by the user. The possible options are shown in the following section.

### 3.5. Propagation model

The simulation tool allows to select the attenuation type that will be present in the scenario, the screen is shown in figure 3.4.

Figure 3.4: Propagation model

Four possibilities are available for the user to choose. The first one only considers the average loss given by the propagation model, as figure 3.5 shows. Selecting this option, the configuration parameters associated to shadowing are automatically disabled. Propagation model parameters (work frequency in MHz and node-B height) and antenna selection must be also specified, these two options are always enabled since they do not depend on whether the user considers shadowing or not:

Once all the parameters are introduced, propagation losses are calculated when the button "calculate and save to sim.mat" is pressed. Another option is to press the "import data from sim.mat" button, which loads the results stored in the file "sim.mat". So, scenarios from

previous simulations can be easily recovered. Once, the calculus are finished or the file has been completely loaded, the best server configuration is plotted.

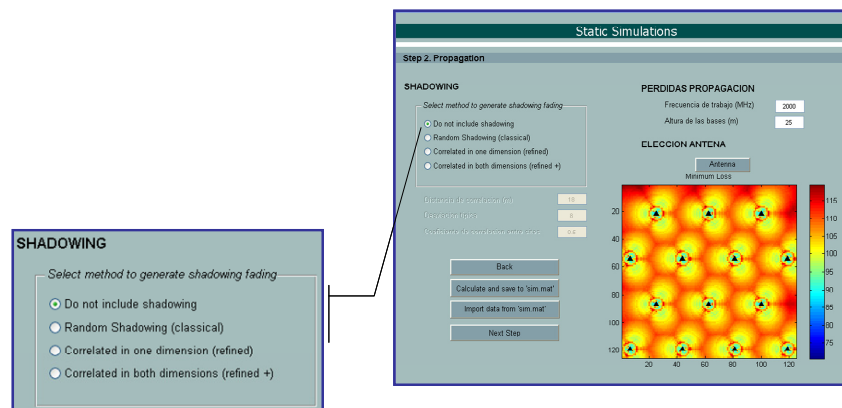


Figure 3.5: Propagation model without considering none shadowing type option

### 3.5.1. Antenna selection

In order to select the commercial antenna model one specific button named "antenna" has been created. If it is pressed the screen represented in figure 3.6 appears.

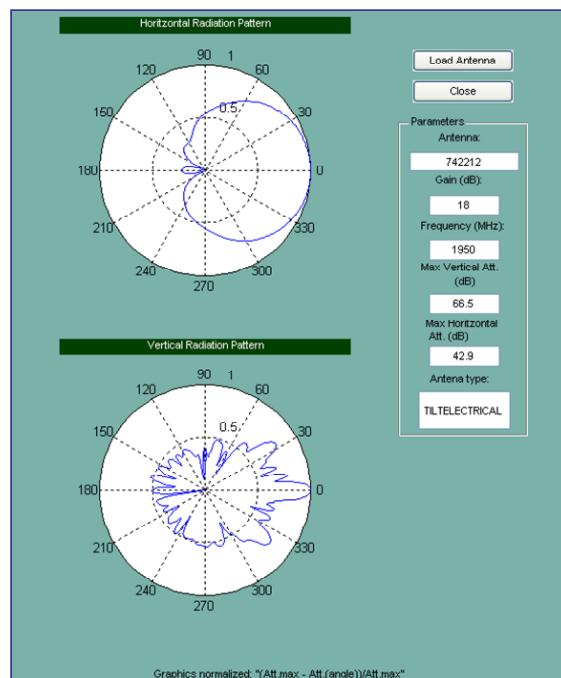


Figure 3.6: Antenna selection screen

This screen allows selecting an antenna from the available models that are stored in a specific directory. Of course, it is possible to navigate through other directories to find other .msi files. This is the extension of the files that contain the required information in a standardized format (figure 3.7). Once the antenna model is loaded, the screen shows its most important parameters:

- Name of the antenna model (established by the vendor)
- Gain (dB)
- Frequency (MHz)
- Maximum vertical and horizontal attenuation with respect to the direction of maximum gain (dB)
- Antenna type. Describes a particular feature of the antenna as for example the support of electrical downtilting. This information is written by the vendor in the file.

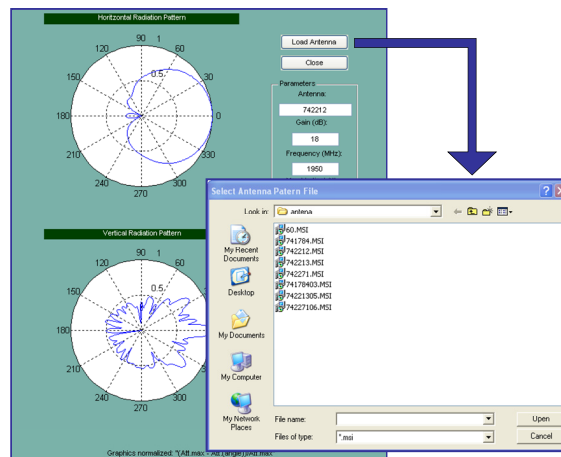


Figure 3.7: Antennas' directory

### 3.6. Shadowing simulation

The user can select to simulate the shadowing effect in the scenario. The three options that were described along section 1.3.2.2. can be chosen. It must be recalled their different accuracies and computational times.

If spatial correlation is considered (both one in one dimension and in two dimensions are available), three new options located below are enabled: correlation distance in meters, standard deviation and correlation coefficient between sites.

### 3.7. UL and DL simulation interface

Once the characterization of the scenario is carried out, only a final step is required completely feature the UTRAN network. The last screen, showed in figure 3.9, allows to start the UL and DL simulation. The parameters that can be edited in this screen are the following:

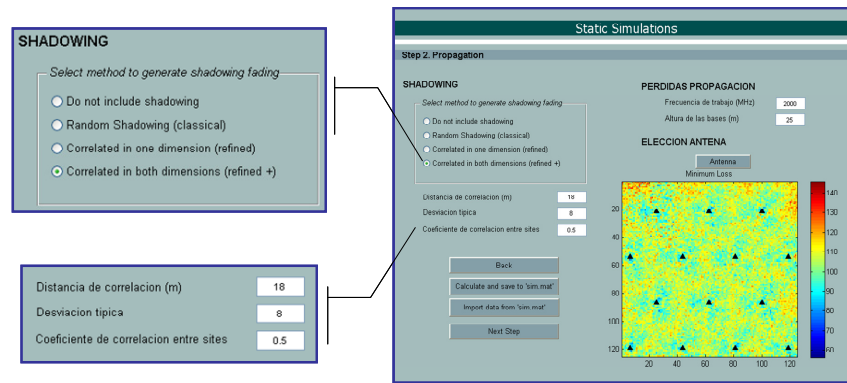


Figure 3.8: Considering shadowing in the simulations

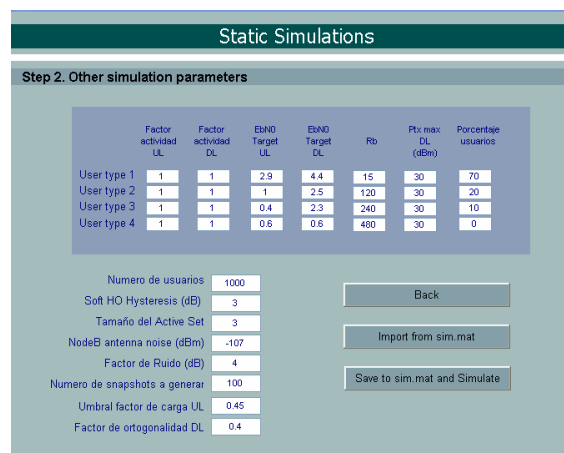


Figure 3.9: UL and DL simulation screen

- Number of users that would be launched to the system.
- Macrodiversity margin in dB.
- Active Set size.
- Antenna noise in dBm.
- Noise factor in dB
- Number of snapshots that will be simulated.

Four type of services have been defined in order to enlarge the simulation possibilities. The user interface can select the number of UEs launched to the system as well as the services associated to each one of them. Values by defect have been predefined as a first proposal and can be changed. These values can be also easily stored in a file and recovered afterwards by means of the import button. Finally, the simulation is initiated when the "Save to sim.mat and Simulated". The results obtained are stored within a file in a specific format for allowing his subsequent analysis.



# CHAPTER 4. AUTOMATED UP- AND DOWNLINK CAPACITY BALANCING

## 4.1. Introduction

The RRM is one of the main parts that must be studied in the development of a UMTS network. A correct management of the radio resources yields a growth of network capacity, so a special attention is required.

As justified and explained in previous chapters, UMTS implements a WCDMA as radio access technique. It is due to the intrinsic characteristic of WCDMA that a numerous new applications and services are supported. This great number of services produces constant fluctuations in the traffic volume. Moreover, the behaviour of these services will be often different in up- and DL, particularly in asymmetric data services. Moreover, the QoS required by the different services differs in up- and DL. It means that one specific service can consume more resources in DL than in UL. This situation may imply degradation in only one of the links for certain sectors or cells in the system. The capacity of the system, of course, will be always constrained by the most limiting link and, as a result, the scenario might be up- or DL limited. One of the main objectives of this project and the purpose of this chapter is to analyse the possibility to avoid this situation by means of the dynamic adjustment of certain RRM parameters.

The design of a radio access network is a complex process. In the first stage, there is a coverage, capacity and QoS study. Once the scenario has been defined, it is necessary to implement correct RRM strategies that guarantee the optimum utilization of the radio interface. Nowadays, the target parameters that control RRM have a static configuration. They are fixed when planning the network, and at most, are manually readjusted during network exploitation. Due to this static configuration, the system can not adapt to the continuous traffic changes and consequently there is a non optimal consumption of the available resources.

To solve this problem, this chapter focuses on the design of a control algorithm that allows the automated tuning of some important RRM parameters, more specifically the parameters that control the SHO procedure, in order to enhance the performance of the network in different situations.

The chapter is divided into three main parts. First part tries to explain the problem existing in the static management of the radio resources, used in current networks. At the same time, a solution to solve this problem is disclosed. Second part focuses on the functional architecture of the proposed algorithm. Third part presents the main features of the scenario that has been studied. Finally an exhaustive study and description of the three main blocks that form the Auto-Tuning System (hereafter ATS) will be done.

## 4.2. Problem statement and solution principle

Nowadays, UMTS operators fix uniformly their network parameters during the planning process and make readjustments considering long-term effects. This configuration does not guarantee the maximum network capacity, due to the variable conditions of the network. It implies that the current static configuration of the RRM strategies do not take full advantage of the radio resources capacity. In order to maximize the capacity of the network, dynamic optimization of these parameters is being proposed in the specialized literature.

The deployment of a third generation network is usually carried out as follows. In a first place, a coverage-capacity study is required, in order to estimate how many Nodes-B are necessary to cover all the area under study. This is done by means of link budgets. Secondly, if no previous 2G network exist, by means of more or less complex algorithms the Nodes-B position is decided. Operators having a 2G network will try to reutilize their existing network to the maximum. The final Nodes-B number and position is iteratively readjusted by means of simulations carried out by sophisticated planning and optimization tools. Finally, once the Nodes-B deployment has been done, suitable QoS parameters are fixed by the network provider. This is also done according to a set of simulations and live tests (drive testing).

In a second place, once the coverage, capacity and QoS study has been done, it is necessary to fix the parameters that manage the available radio resources. At this point, it is important not to forget that with the access technique used in UMTS networks, WCDMA, all users share the available spectrum. In consequence, a user sees the rest as interference, featuring the UMTS network as a system limited by interference. A good election of RRM parameters can cause an increment in the capacity of the network. Otherwise a strict configuration can reduce the capacity wasting the available radio resources. Thus, a suited election of the RRM parameters is needed to enhance the performance of the network.

Nevertheless, there is an important inconvenient that prevents this configuration to take the maximum profit from the radio resources. As previously explained, the network characteristics change dynamically along time, so fixed values at RRM are not optimized for each one of the possible network situations. At the same time, both links UL and DL do not show the same behavior in the same circumstances, so an individual study for each one is required. The SHO process is one of the main algorithms that form part of the RRM and it has the particularity of not being identical in up- and DL. So it is feasible that particular adjustments to each link can be done and that is why the SHO constraints are the first set of parameters to be included in the ATS proposal.

The impairment of both links is caused by the fact that the SHO process in up- and DL is different. While in UL a diversity selection is used, in DL a maximum combination rate (MRC) is carried out (MRC is also used in the UL when both cells belong to the same node-B, in this case one talks about *softer* handover). It means that in DL, the users receive signals from all BSs present in their AS and constructively combine them via the Rake receiver. The performance of UMTS SHO algorithm is closely related to adjustment of two of the most important parameters, the AS size and the macrodiversity window (see 2.2. for

further details on them. The influence of these parameters on the network performance will be explained in detail later in this chapter. However, first of all the proposed functional architecture for our ATS will be used. It is based in the one that was introduced in [2].

### 4.3. Functional architecture

The ATS system is composed by three main blocks, as it is depicted in figure 4.1:

- Learning Stage
- Monitoring Stage
- Control Stage

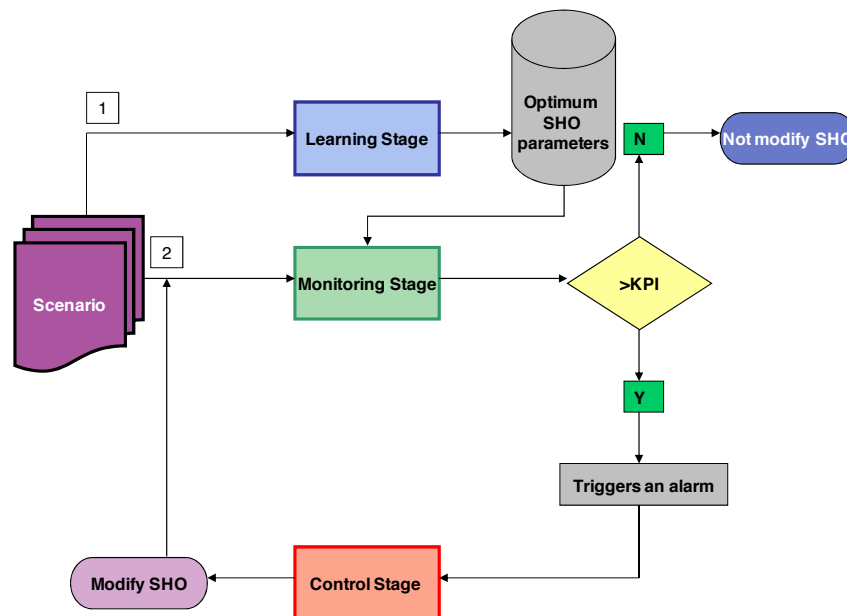


Figure 4.1: Global architecture ATS

During the learning stage a deepest study of the network performance is carried out. Measurements from the networks are done in this first stage and trends are found when the system works under different traffic situations. Although this data and statistics are obtained from an operative network, simulations can be also done as initial training when real measurements are not still available. Moreover, within the framework of the simulation environment, numerous changes can be made in order to create different traffic situations and obtain a fully characterization of the network. In our case, the maximum capacity algorithm explained in 2.4.3. is adopted to evaluate the network behaviour under a set of defined traffic situations. The output of this algorithm is the maximum capacity value in terms of simultaneous transmitting users.

The second stage that forms the ATS is the monitoring stage. In this phase, several parameters concerned to all the cells that constitute the UMTS network are monitored and

turned into suitable Key Performance Indicators (KPI) whose value is constantly evaluated. An essential input in this stage, is the reference QoS values because KPIs values will be compared with them. As an example, one of the main parameters that is monitored during this stage in the proposed ATS is the percentage of users that do not achieve their  $E_b/N_0$  target. If the measurements of this parameter exceed the reference value during a certain period of time, an alarm is triggered to the control stage.

The main milestone of the control stage is to ensure the correct performance of the network. If the control stage receives an alarm, a reconfiguration order (in this case, of the SHO parameters), is sent to the cell to change the corresponding parameters and try to maintain a correct performance of the cell and delay the possible execution of congestion control algorithms.

## 4.4. ATS:Learning Stage

The aim of this phase is to accumulate statistical information about the network performance to feed subsequent stages. Initially, this section includes different case studies to evaluate the behavior of the SHO parameters for Up- and DL and for different service mixes. Secondly, one specific and more realistic scenario is chosen to carry out later simulations with the complete ATS.

### 4.4.1. Learning from the Network and Scenario Definition

During this section a study of the network has been done to understand the network behaviour under different situations, in particular under different service mixes. Due to the presence of a great number of services, traffic in UMTS networks is in constant variation. These fluctuations do not affect in the same way to both links, so a complete study of the changes in Up- and DL because of different service mix configurations is required.

In our simulations, users can select among a great number of services. Each one presents their own characteristics as for example bit rate, QoS or maximum DL transmitted power (table 4.1). A service mix can be easily configured by changing the number of users that use one of the services defined in table below.

Service	$E_b/N_0$ target UL	$E_b/N_0$ target DL	$R_b$	Max. DL Tx Power
Voice	2.9 dB	4.4 dB	15 kbps	30 dBm
Data 1	1 dB	2.5 dB	64 kbps	30 dBm
Data 2	0.4 dB	2.3 dB	128 kbps	30 dBm
Data 3	0.6 dB	0.6 dB	384 kbps	30 dBm

Table 4.1: Services features

Next figures depicts some capacity curves obtained for three study cases with different service mix configurations. Different SHO parameters values are simulated in order to appreciate their opposite impact in UL and DL. The first example corresponds to the simplest

possible service mix, that is 100% of conversational UEs. The second and third cases also introduce data services. It will be observed that, whereas the first case is a clear UL limited situation, the second and third examples are DL limited. Nevertheless, the interest is focused on obtaining a balance configuration of both links, where they present the same maximum capacity value. Since different AS configurations are simulated, several crossing points are obtained as well. The best selection, obviously, is the one located at a higher abscissa, which implies more capacity.

The first example of capacity evolution is presented in figure 4.2. The plot shows the evolution of the capacity curve for different values of addition window when users in the system are 100% voice UEs. The AS size value is fixed in 2 in blue and violet curve and in 3 for green and pink curve. The curve depicts that higher values of macrowindow produce a capacity increment for UL direction while DL experiment a detriment in the maximum capacity.

Increasing the AS, in size as in addition window, involves that UEs can listen more cells, so they have more possibilities to be connected to a very unloaded one. Thus, the UE can select the cell which asks for less power reducing in this way its transmitted power. However, this effect has a negative influence in the DL direction because all the new extra cells are forced to transmit to the UE. Far away cells will transmit more power and generate more interference. Thus, although individual links consume less power, the global effect is worse and the final number of users correctly served is reduced.

Figure 4.2 also shows how the effect of macrowindow variations is sharper in the DL than in the UL, for example if macrowindow increases from 3dB to 6dB a great reduction in the maximum capacity value is obtained. In the UL variations are smoother because the scenario has the sites homogeneously distributed and opening the window does not provide new interesting nodes-B demanding less power.

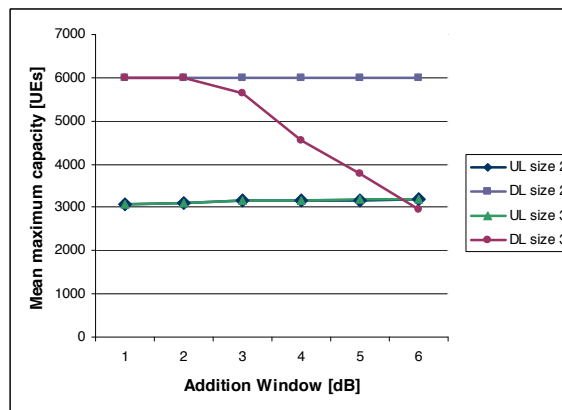


Figure 4.2: Maximum Capacity for different configurations of SHO parameters (100% voice UEs)

In the particular case presented in figure 4.2, an UL limited scenario is observed, since the crossing point of the curve take place at a high value of addition window. All UEs are 100% conversational service users, due to the usage of a symmetric service maximum capacity goes up. There is only one crossing point for the case of AS size 3 and addwin 5.5dB, hereafter denoted as configuration (3,5.5). Note that it must be a second crossing point

for the other case of size 2 but the capacity supported by the system under this situation is very high, and the degradation that should be observed when the addwin is increased is not produced. For this reason, a crossing point between uplink and downlink for this specific service mix in the case that the AS size is fixed to 2 never occurs.

Regarding the other two examples, Figures 4.3 and 4.4 show the corresponding capacity curves. Unlike the previous case, crossing points of the curves are produced at the left zone, for very small macrodiversity windows which means they are clear DL limited scenarios. In particular, Figure 4.3 shows the maximum capacity curve obtained when the service mix consists of 80% voice and 20% data type 2 UEs. Both, AS size 2 and 3 have the crossing point in an AS configuration (2,2.7). The second DL limiting scenario is presented in figure 4.4. It is composed by 35% voice, 25% data type 1 and 40% data type 2 UEs. Mean maximum capacity is near to 500 users, but crossing point is in AS configuration (2,2) even more towards the left side.

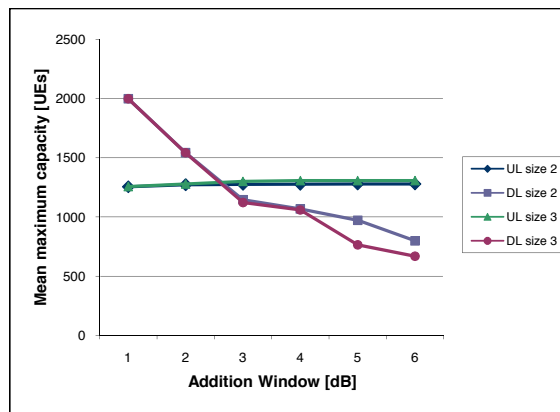


Figure 4.3: Maximum Capacity for different configurations of SHO parameters (80% voice, 20% Data type 2 UEs)

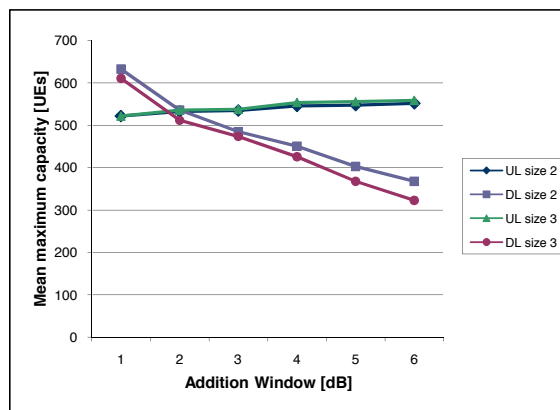


Figure 4.4: Maximum Capacity for different configurations of SHO parameters (35% voice UEs, 25% Data type 1, 40% Data type 2 UEs)

#### 4.4.2. Selected scenario

The third previous preliminary study cases were just examples on how the service mix can affect the capacity of the system and the limiting direction. Also the impact of SHO parameters on this capacity was shown. However, for the project purposes, a more complex scenario has been designed. In particular, it is defined a dynamic situation in which the UEs start with a certain service mix and evolve and change it through the time until reaching a complete different situation. This could happen for example when along a day, users utilize certain services during working hours and change them at night, or when working days have finished and the weekend starts, etc. Finally, it is necessary to recall that in a real operating network the process of learning stage is made with real data obtained from the network, so what is present in this section will be used as an "initial training" previous to the real statistical information.

Figure 4.5 shows the capacity curves corresponding to the first service mix. Note that it is another UL limited scenario. In this occasion the mean value of maximum capacity is reduced considerably because of the service mix used, it consists of 90% voice users and 10% data users of type 1 (64 kbps). As a few percentage of data services are introduced to the system, maximal values of capacity are reduced from 3000 to 1750 users (crossing points in figure 4.2 versus crossing points in figure 4.5).

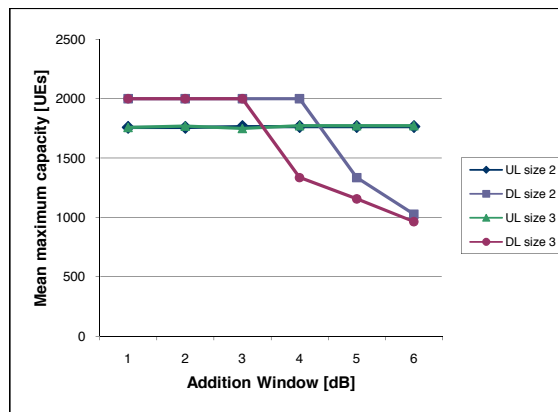


Figure 4.5: Maximum Capacity for different configurations of SHO parameters (90% voice, 10% Data type 1 UEs)

The UEs will evolve from this first service mix to a second one by substituting their services, so one can talk about a dynamic service mix that passes through many intermediate states. The final scenario state is presented on figure 4.6, where other data services are introduced in the service usage configuration, 30% voice, 25% data type 1, 35% data type 2 and 10% data type 3 UEs. It can be observed, that this second configuration is DL limited. The maximum capacity value decreases with respect to the maximum capacity value achieved in figure 4.3, concretely it decrease from 1250 users in previous case to 400 users in the current case. Now the crossing point is located in an macrowindow of 2.5 dB independently of the size, so an appropriate AS configuration for this scenario would be (2,2.5).

Comparing all service mix configurations, and taking a look to the UL and DL representative scenarios, the best AS configuration is AS (2,6); whereas for the DL limited scenario

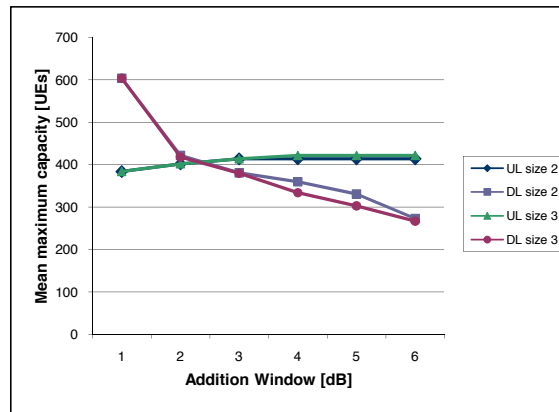


Figure 4.6: Maximum Capacity for different configurations of SHO parameters (30% voice UEs, 25% Data type 1, 35% Data type 2, 10% Data type 3 UEs)

a suitable configuration is AS (2,2.5).

A network service provider can detect automatically and in real time which link is the limiting one, since the service mix in use is well known. Adapting the SHO parameters to each one of the possible network situations in real time via the ATS, will increase the capacity of the network enhancing, in this way, its performance.

Finally, Figure 4.7 describes as a summary the Learning Stage algorithm that has been used.

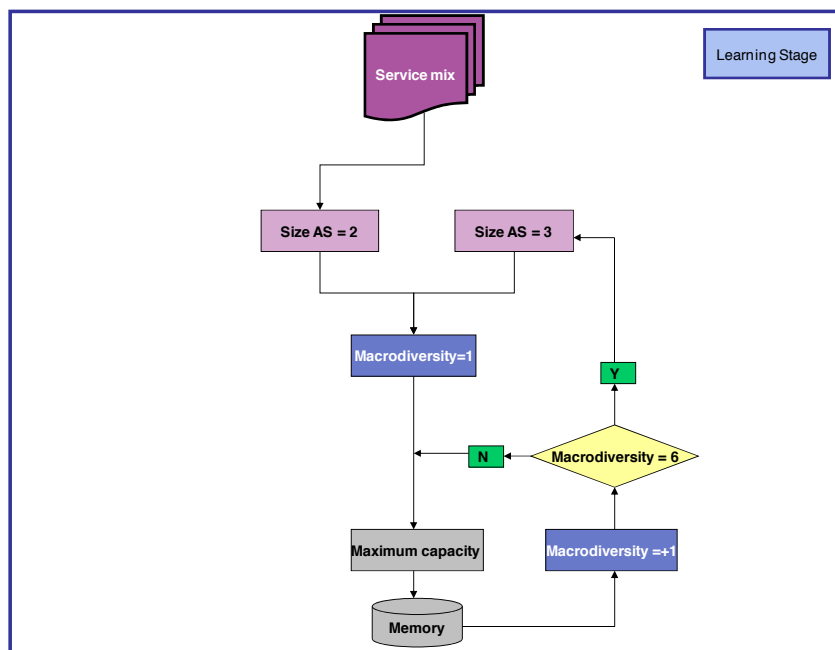


Figure 4.7: Learning stage architecture



## 4.5. ATS: Monitoring Stage

As previously indicated, the Monitoring stage is responsible of obtaining measurements from the UTRAN and converting them into clear KPIs which will be compared with the QoS thresholds that ensure the desired network performance.

In order to define appropriate KPIs it is necessary to do some tests without implementing none auto-tuning algorithm. Results are obtained and, from the analysis, the final KPIs are proposed.

The starting scenario situation is the first service mix that was defined, and SHO parameters are fixed according, that means (2,6). According to the learning stage with this SHO configuration all the users present in the system reach the required  $E_b/N_0$ . As simulation time advances, voice users commute to data services until at the end of simulation time the scenario is featured by the second defined service usage situation, as figure 4.9 shows. This scenario becomes DL limited and degradation appears gradually because AS configuration is not the best one for data users.

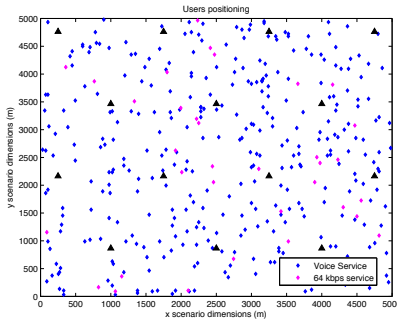


Figure 4.8: Starting services usage

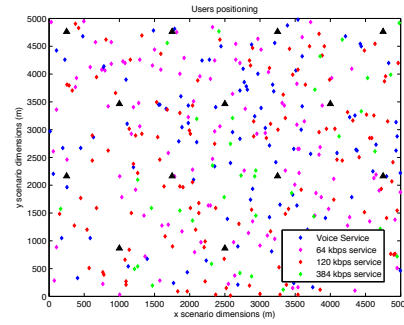


Figure 4.9: Final services usage

The results obtained from the initial test are presented in the section below, together with the auto-tuning simulation results without monitoring parameters implementation.

### 4.5.1. Blind Auto-tuning, without Monitoring

Along with the initial test (without ATS), another simulation has been done to evaluate how the system performance changes when all AS are reconfigured in the middle of the observation period. Figure 4.10 shows the evolution of the % of UEs reaching the required DL  $E_b/N_0$  in the central cell. The pink curve corresponds to the case in which no ATS is running. For this case, it can be seen that the central cell can serve all the UEs correctly at the beginning, but there is a point where the network is not able to support all users in the scenario (because of the new data services which are far more demanding in the DL) and a high degradation appears at the end of the simulation time. If the SHO parameters are not reconfigured, most of users will be in degraded mode and the network reaches an unstable situation. The blue curve shows that changing the SHO configuration in the middle of the simulation implies that the percentage of users correctly served increases.

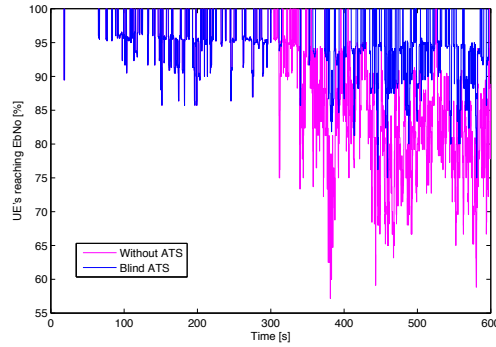


Figure 4.10: % of UEs reaching  $E_b/N_0$  target

Figure 4.11 represents the evolution the DL transmitted power by the central cell. BSs are able to provide a maximum of 43 dBm. If no AS reconfiguration is taken into account, it can be seen that the total transmitted power at the end of the simulation time is close to 41 dBm. On the other hand, if the blind ATS is executed, the BS never reaches 37 dBm (figure 4.12).

Fluctuations that can be visualized in the graphs are due to the movement of the users and the corresponding changes in power, which implies changes in the interference patterns and therefore new readjustments in transmitted powers, and so on.

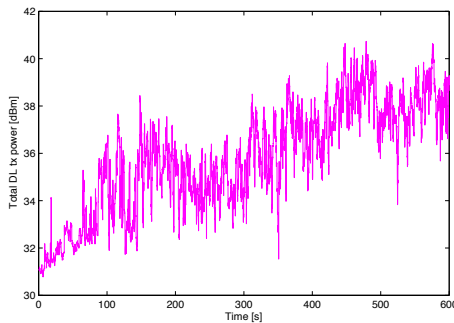


Figure 4.11: DL transmitted power without ATS

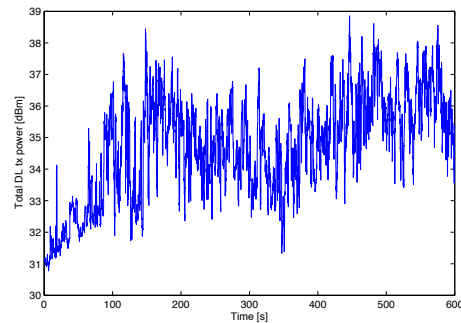


Figure 4.12: DL transmitted power with blind ATS

The evolution of degraded users is presented in figure 4.13, they appear even if the cell does not reach its maximum available power. This is because several users require more power than the 30 dBm that can be devoted to a single connection. The pink curve again represents the case in which no auto-tuning algorithm is applied. The number of total degraded users in the system grows up due to the service mix progress towards a scenario dominated by data services. The blue curve considers blind ATS and it can be seen how the total users that are not well served are reduced drastically from 17% to around 5%.

In figure 4.14 the evolution of the total degraded users for the central cell is presented. The same fact that in the global system occurs, data services produce an increment that exceed the limited dedicated power of 30 dBm for a single connection. In consequence many users do not reach  $E_b/N_0$  target and are degraded.

Blind ATS shows that modifying SHO parameters and adapt them to the service mix can solve unstable situations and delay congestion control algorithms. However, a blind execution would not be the best approach, unless the operator had a perfect knowledge of the time in which the services usage is going to change. In some cases this information can be available because traffic patterns are reiterative in time, however there will always be unpredictable situations and that is why it would be better to define KPIs that inform about the network state and its evolution. This problem is tackled along next subsection.

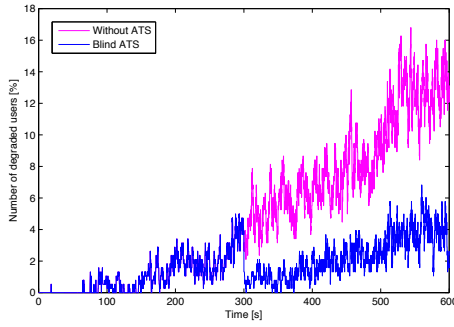


Figure 4.13: % Total degraded users

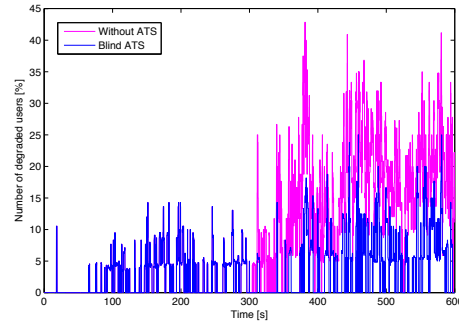


Figure 4.14: % degraded UEs. Central cell

#### 4.5.2. Key performance indicator definition

It could be expected that the total power transmitted by every cell is a good candidate for a KPI. The % of consumed power is usually used as a measurement of the DL load. However, as results showed the situation of degradation that should trigger the ATS does not appear as a consequence of exceeding the total DL transmitted power of 43 dBm. The users cannot reach the required  $E_b/N_0$  due to the fact that the required power per single connection exceeds the 30dBm limit. In this way, it seems that a suitable KPI election is the power devoted to a single connection. Of course, this implies higher computation time, because all single connections have to be monitored from each cell. In particular, two KPIs are defined in order to implement the monitoring stage for all the system with a cell-by-cell control:

- KPI-A: The first key performance indicator defines the percentage of mobiles that require more power than a certain threshold. This threshold is related to the maximum power that can be devoted to a single connection. To find the more appropriate value for this threshold, several values are simulated. This target values used during the control stage are 70%, 80%, 90% and 100%. Note that this last value corresponds to the case in which the UE reaches it maximum power and starts to work in degraded mode.
- KPI-B: The second key performance indicator is a counter of the number of continuous monitoring frames in which KPI-A is accomplished for 5% of users. When a cell perceives 5 consecutive snapshots that reach more than 5% UEs transmitting at a higher power than the selected threshold, the control block is triggered.

In short, when KPI-A is up to 5% of mobiles and this happens 5 successive times in a particular cell, a reconfiguration of AS is sent to all users connected to the cell. This is graphically described by figure 4.15.

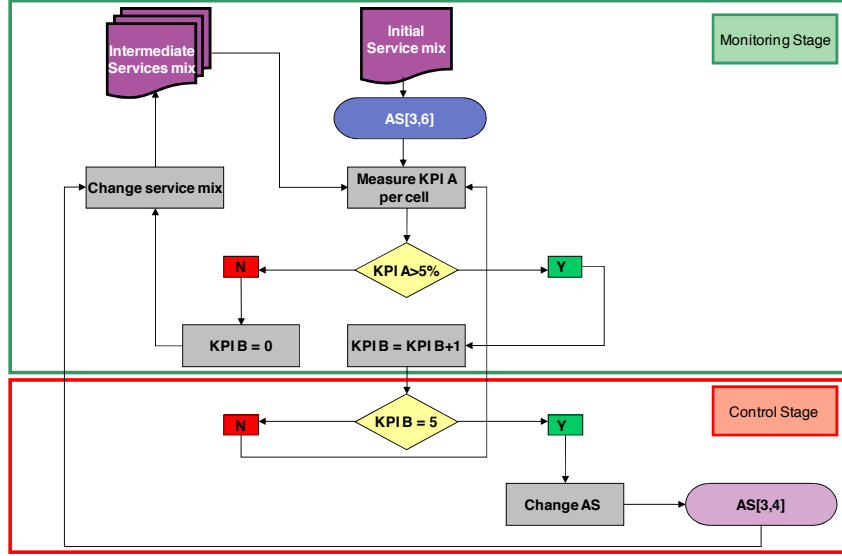


Figure 4.15: Monitoring and control stage architecture

## 4.6. ATS:Control Stage

The control Stage is the last step of the ATS algorithm. It takes place after the Monitoring stage explained above. Whenever an alarm is triggered to the control stage, it interacts with UTRAN so that the SHO parameters are changed to the optimum values that were found by the Learning & Memory block.

Taking into account that the scenario starts in an UL limited situation, SHO parameters suitable for this first approximation are adopted initially. The optimum value for these parameters starts to change when the number of data users increase. These changes in real time are carried out by the control stage.

In our particular study case, the system becomes DL limited, and consequently there will be a reduction in the AS configuration. This implies a reduction in the the resources consumption, thus the cells are not forced to serve to users far away, which need a great deal of power to achieve the  $E_b/N_0$  target desired.

It is necessary to notice that only the users connected to a cell that triggers an alarm change their AS configuration. The users that can be added to this BS in next frames maintain their original configuration. Therefore a cell with frequent handovers, perhaps will have to optimize the AS configuration of the users more often if the service mix is maintained.

The study developed in this chapter is always done under an UL limited situation that becomes, during the time, in a DL limited situations. However for the opposite process,

it means start in a DL limited situation and become to an UL limited situation, the same concept would be applied.

#### 4.6.1. Effects in the transmission power and $E_b/N_0$

This section will study in a first stage, the evolution in the DL resources consumption with the deployment of the ATS over the scenario. At the same time, the percentage of users reaching  $E_b/N_0$  is monitored. It will be shown that the ATS system allows to enhance the network performance, fulfilling the requirements in terms of QoS.

The scenario has been tested under different targets, which are shown in the table below.

Case	Monitoring thresholds [mW]	Monitoring thresholds [dBm]
70%	700	28,45
80%	800	29,03
90%	900	29,54
100%	1000	30

Table 4.2: Monitoring thresholds

As it is observed, the parameter that takes relevance in this analysis is the maximum transmitted power per connection.

There are two situations that avoid reaching the  $E_b/N_0$  target required by the user connection. First situation is the situation where one of the cells that are included in the AS of the user has reached the maximum DL transmitted power, which is fixed at the standard value of 43 dBm. In this situation the BS can not serve the user, since no resources are available. The user remains degraded, because the  $E_b/N_0$  that guarantee the QoS fixed by the service provider is not reached. The second case is the situation where the resources request made by the user exceed the allowed DL transmitted power per connection. As shown in the previous sections, in the particular study case of the project, the second one is the cause of degradation.

Next figure, shows the evolution of the total DL transmitted power by one of the central cells (cell 13), which is one of the cells under study. Several curves are shown, each one corresponding to every one of the monitoring thresholds.

As the figure shows, the total DL transmission power increases along the time because the scenario becomes more hostile. The number of data users increase and more interference is generated. These UEs demand more resources from the network, particularly in the DL. In this situation, the central cell with identification number 13, has to increase the transmission power of each connection to achieve the  $E_b/N_0$  required.

There is a clear change between the transmission power in the scenario without ATS 4.11, and the transmitted power obtained in a scenario with ATS. As it is observed in the figure 4.16, for the maximum allowed threshold the total DL transmitted power by the cell remain below 38 dBm, unlike the 40 dBm achieved when no auto-tuning is applied to the system,

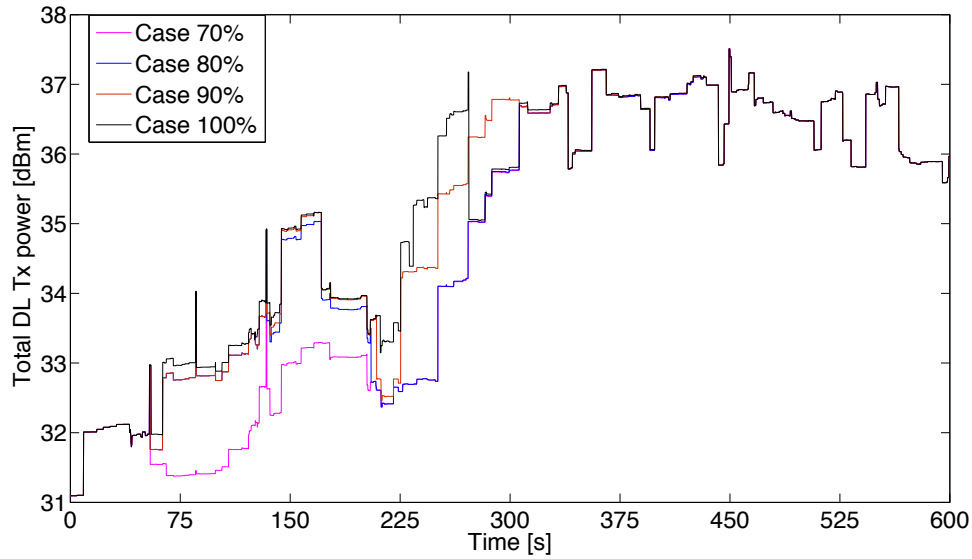


Figure 4.16: DL Transmission Power when ATS is running and for different monitoring thresholds

as it is depicted in figure 4.11. So, interferences are reduced and a gain in the number of degraded users is expected.

It is necessary to notice that the more restrictive is the threshold, the more is the reduction in the total DL transmitted power. Thresholds 70% and 80% even give an extra 1 dB margin over the other two cases. However, by the end of the observation time, there are so many data users, that all the algorithms give the same solution, they have reconfigured the same cells at the end, though not at the same time nor with the same number of reconfigurations.

Figure 4.17 shows the percentage users reaching their  $E_b/N_0$  target. Differences are not significant among the simulated cases.

#### 4.6.2. Key performance indicator evolution

The evolution in the key performance indicators experimented under the different considered targets is studied in this section.

As it has been explained above, two are the main Key Performance indicators. On one side KPI A is the responsible of measuring the percentage of users that can not reach the required  $E_b/N_0$  for the service in use. The figure 4.18 depicts the evolution of the percentage of UEs reaching their  $E_b/N_0$  target during the simulation time.

In order to evaluate in depth how changes in SHO parameters affect to KPI results, two simulation cases have been tested. In the first case only changes in macrowindow have been considered, in this sense the AS size remains in 3. However in the second case both SHO parameters, the AS size and the macrowindow have been modified. In this second case benefit over the network performance are observed, since not only the macrowindow

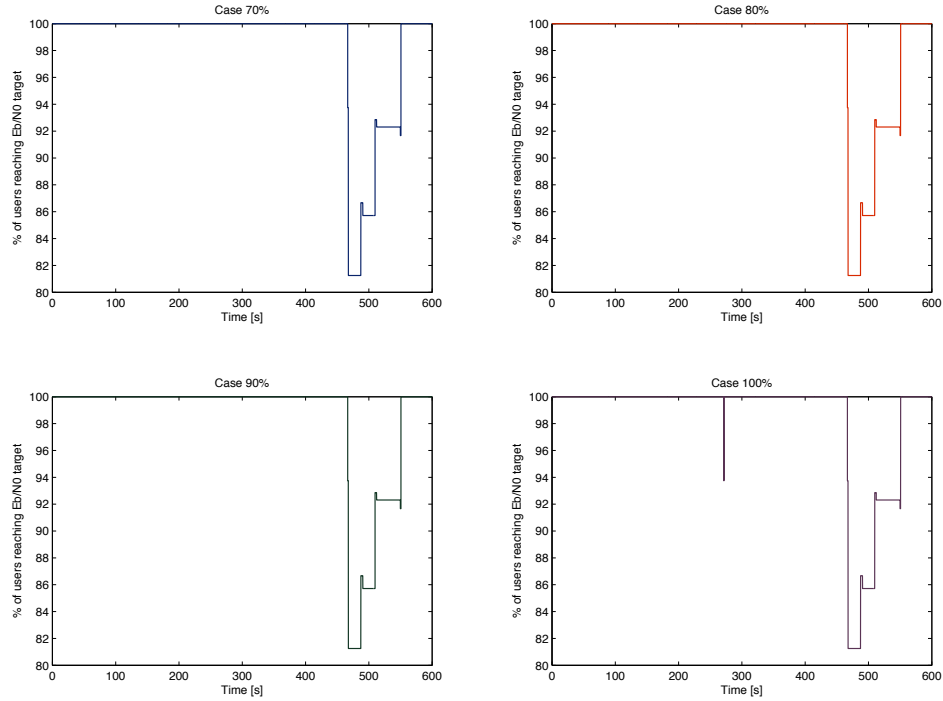


Figure 4.17: % of users reaching  $E_b/N_0$

is favourable for the DL but also the AS size.

The optimum SHO parameters chosen for the UL limited situation and for the first simulation case are:

- AS size = 3 cells
- Addition window = 6 dB

And, when an alarm from the monitoring block is triggered, they are turned into:

- AS size = 3 cells
- Addition window = 2.4 dB

SHO parameters configuration will represent the e

The number of users launched to the simulated system is 380. This value has been chosen according to the simulation results extracted from the learning stage, and more specifically from figure 4.5. This is a suitable value, since it is over the maximum capacity value shown in figure 4.5.

As figure 4.18 depicts, the cell with identification number 13 remains in a congested situation, since the reconfiguration orders do not achieve to reduce the traffic of the cell.

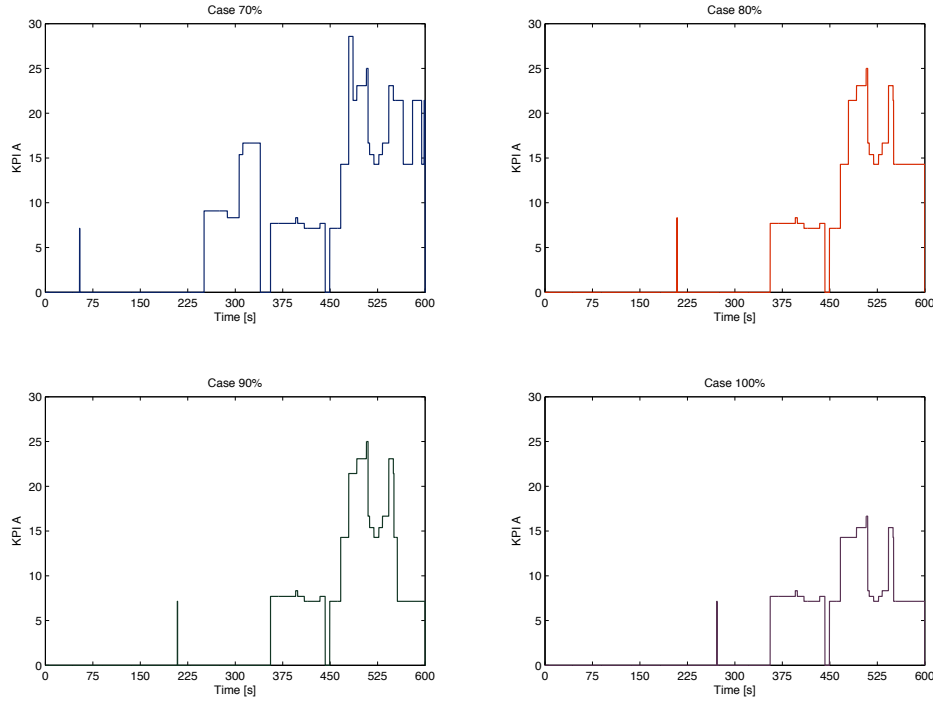


Figure 4.18: KPI A cell 13 AS size 3

The base station is forced to serve a great number of users that request more down-link transmitted power that the allowed by the monitoring threshold. In consequence the percentage of users that exceed the transmitted power per connection threshold is high. Therefore, although the ATS is applied in this situation, a suitable delay for avoiding the control congestion appearance is not obtained. It is necessary to notice that with a permissive threshold of 100% the number of users that reach the target is reduced with respect to the situation where a more restrictive threshold, as 70% is applied.

Figure 4.19 shows the behavior of the KPI A for one of the central cells with less traffic load (cell 17). In this figure, a considerable reduction of the users that reach the target is observed. The reduction in the traffic is observed in the fact that for the same threshold (70%) the number of users that exceed the threshold is higher for the central cell labeled with the number 13, which is more congested. The users exceeding is around the 30% while for the cell less congested the users exceeding is around the 20%.

Nevertheless, if the order of reconfiguration sent by the control stage to the cell that triggers the alarm becomes more restrictive, it means more favorable for a DL limited situation, the percentage of users that exceed the threshold fixed for the total DL transmitted power per connection, remain below the 7 %.

Now, for the second simulation case the SHO parameters for an UL limited situation are:

- AS size = 2 cells
- Addition window = 6 dB



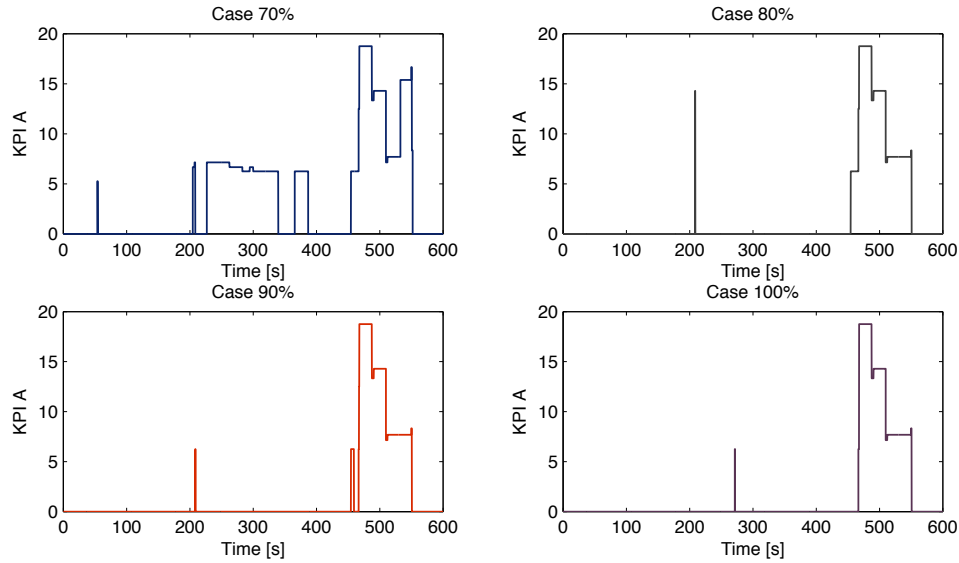


Figure 4.19: KPI A cell 17 AS size 3

In the same way, the SHO parameters for a DL limited situation are:

- AS size = 2 cells
- Addition window = 2.4 dB

It means, that a great reduction is appreciated with regard to the situation explained above, where the changes in the SHO parameters only took into account the addition window. In this case, not only the addition window is reduced. The numbers of cells that can be included in the AS are reduced too. In these terms the total DL transmitted power per connection is less, and in consequence the users that can be in a degraded situation.

As a conclusion, the scenario with these SHO parameter values remains under control during all the period. Only in the middle of the simulation, where the scenario begins to start more hostile for the DL direction, a slight number of users that exceeds the threshold are observed. When this threshold becomes more permissive, all the users present in the network achieve the  $E_b/N_0$  target without the necessity of extra resources from the cells included in their AS. The figure 4.20 shows that in this situation, the KPI A is 0 % during all the time, so the control stage do not have to sent any reconfiguration order, as it is depicted in 4.20.

In addition, the percentage of users reaching the threshold is extremely reduced in the figure 4.20 for two reasons. Firstly, it is necessary to notice that the cell under study is the less congested cell. Secondly the number of users launched to the system are below the maximum capacity value obtained from figure 4.5.

In order to force a degraded situation in the DL direction, a great number of users (500) is launched to the system. This value is over the maximum capacity value obtained from the learning stage curves for an AS size 2 configuration. Figure 4.21, shows the KPI A

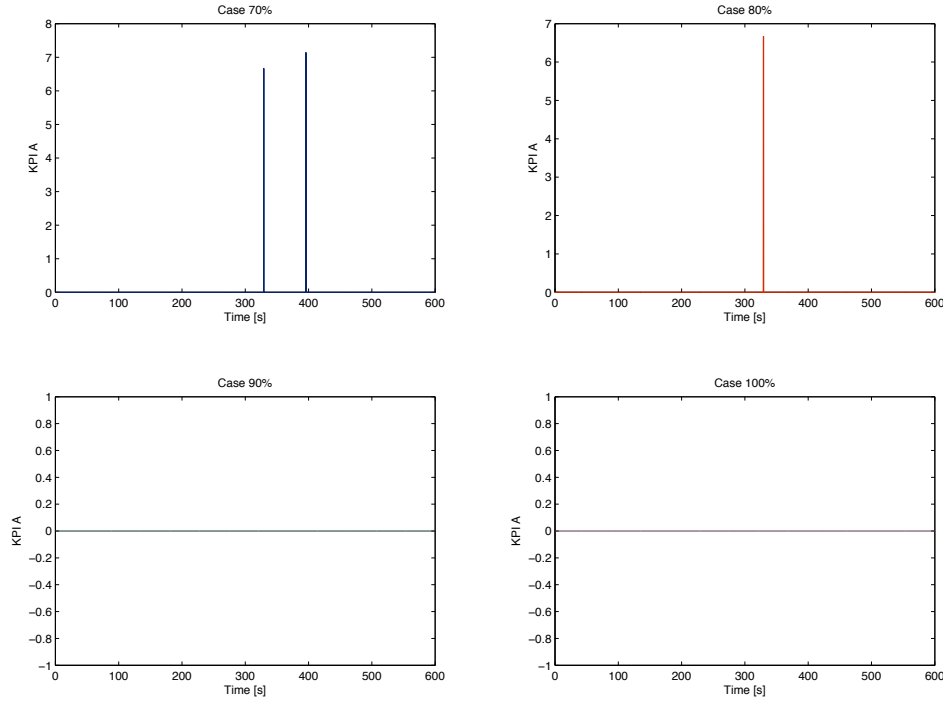


Figure 4.20: KPI A cell 17 AS size 2

obtained from the cell more congested (cell 13) when a number of 500 users is launched to the system and the SHO parameters remain under the values defined above.

If a comparison is established between figure 4.18 and figure 4.21 a reduction in the number of users that exceed the power threshold is observed, due to the fact that now, the SHO parameters chosen are appropriated for take full advantage of the DL direction.

As it is observed in all the figures showed above, the more restrictive is the threshold the more is the number of users that reach the target. This fact causes an increase in the KPI B, which can be seen as the counter that detects this degraded situation and triggers the alarm to the control stage when the counter arrive to the maximum value established by the service network provider.

The evolution of the KPI B is depicted in the figure 4.22. As it occurs with the KPI A, the more restrictive is the threshold the more is the number of reconfigurations launched to the system, as it is shown in figure 4.22, which corresponds to the more congested cell (cell 13) studied previously in the analysis of the KPI A evolution.

If the cell under study is a cell with controlled traffic fluctuations (cell 17) as shown in figure 4.23, a less number of reconfigurations order are necessary. In this case, the ATS achieve the desired delay in the control congestion appearance during a long period of time.

In the same way as KPI A behavior, if the election of the SHO parameters is more favorable for a DL limited situation (AS size 2), the number of reconfigurations orders is reduced, as it is depicted in figure 4.24.

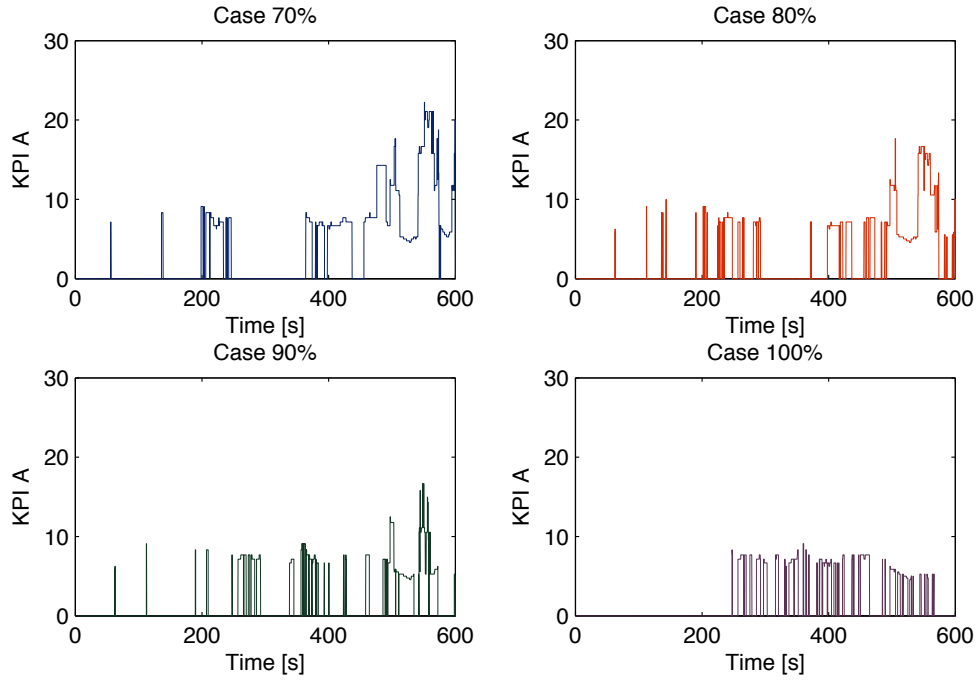


Figure 4.21: KPI A cell 13 AS size 2

For the same scenario conditions, the results associated to cell 13 with AS size 2 and for a 500 users scouring the network are depicted in figure 4.25.

Figure 4.26 shows the number of cells that need a SHO parameters reconfiguration along the simulation time. As it is expected, in view of the KPI evolution observed in the above figures, the number of cells that need a reconfiguration of the SHO parameters, in order to improve the DL resources consumption, increase when the threshold becomes more restrictive.

In the same way, that occurs with A and B key performance indicators, the more favorable is the threshold the more are the cells that must reconfigure the SHO parameters, in order to adapt them to the more favorable conditions for the DL direction.

With an AS size more restrictive (size 2), the number of cells that need to do reconfigurations is less than when the AS size is more permissive. It is due to the fact that during the initial simulation time the situation in the DL direction is controlled, since a great number of cells make reconfigurations and maintain the reconfigured SHO parameters for the rest of the simulation time.

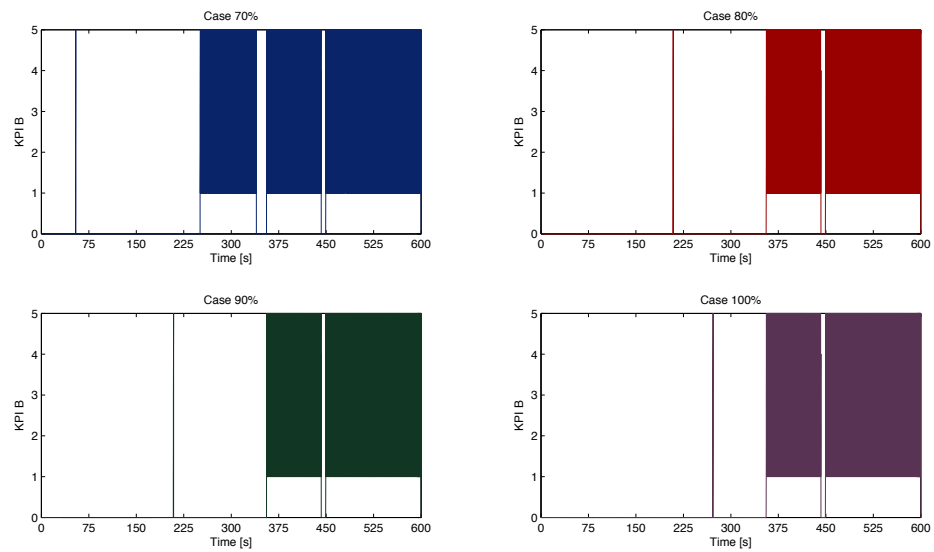


Figure 4.22: KPI B cell 13 size 3

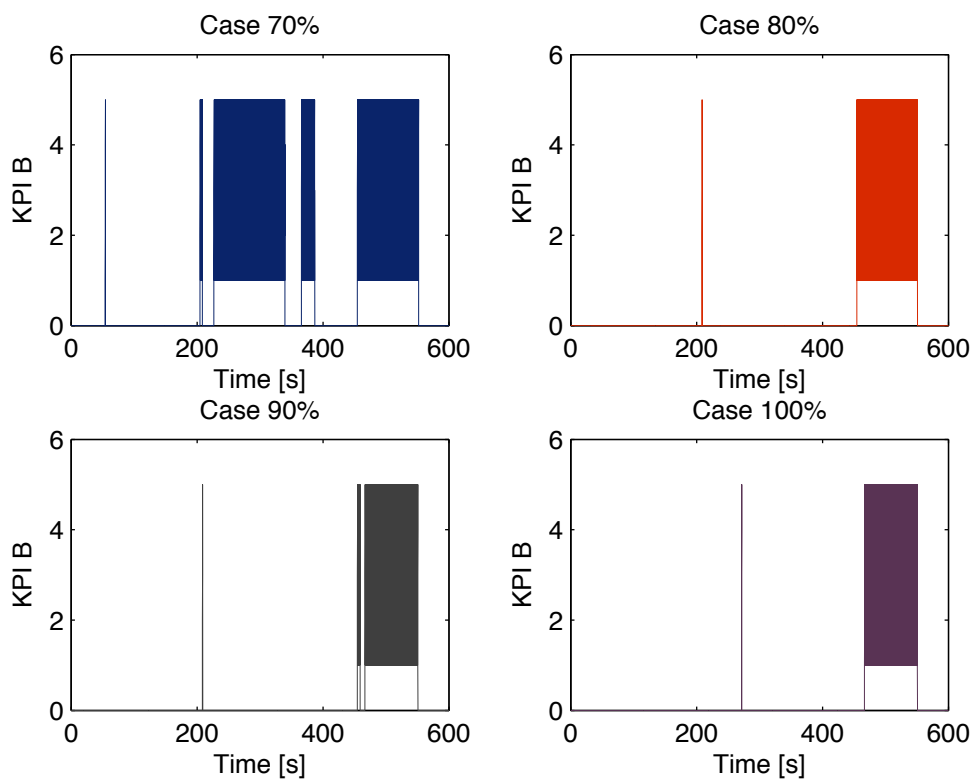


Figure 4.23: KPI B cell 17 size 3

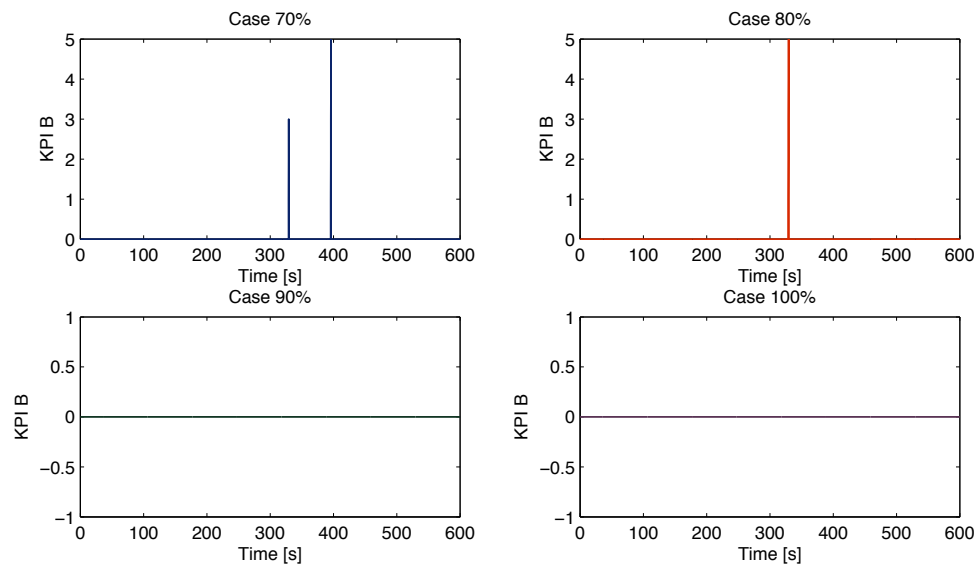


Figure 4.24: KPI B cell 17 size 2

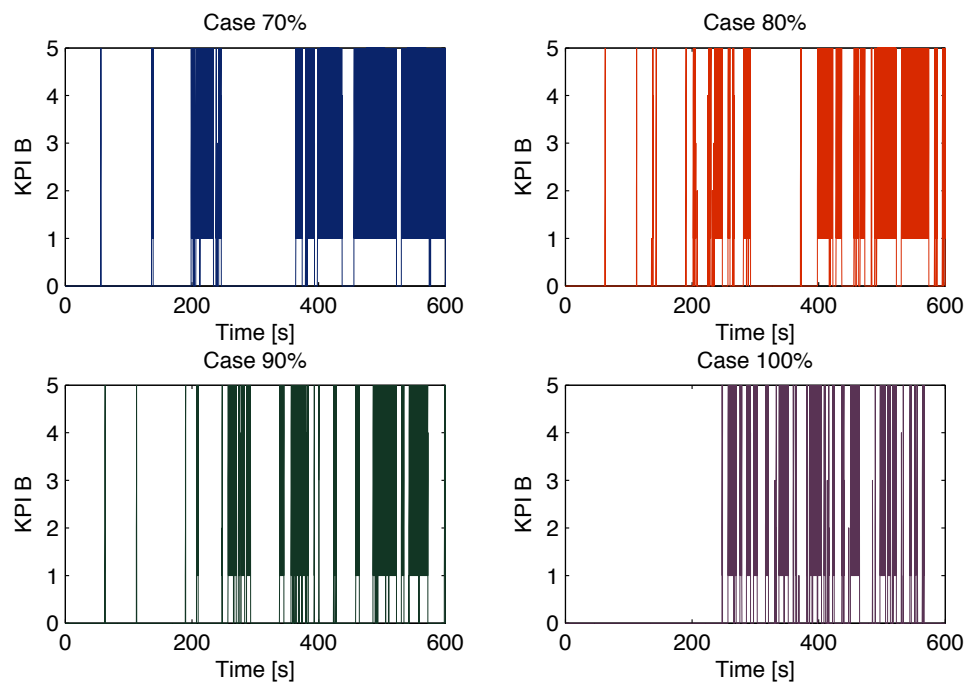


Figure 4.25: KPI B cell 13 size 2

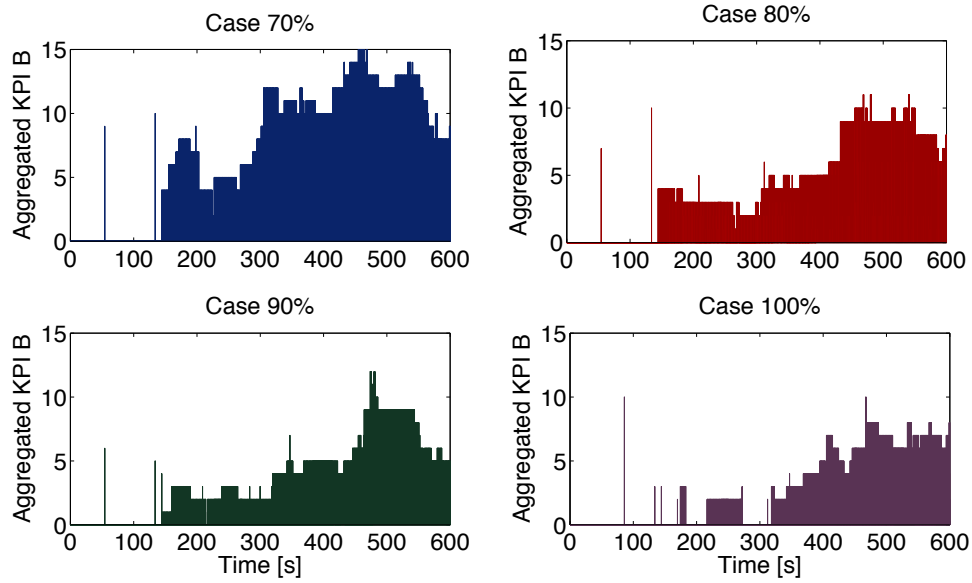


Figure 4.26: KPI B aggregated cells AS size 3

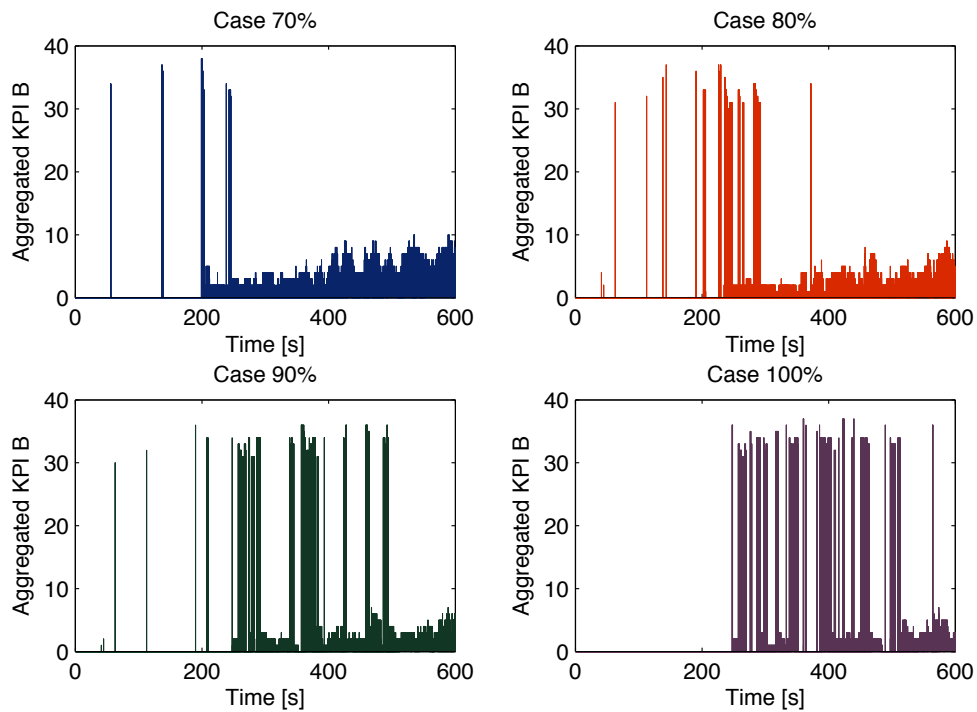


Figure 4.27: KPI B aggregated cell AS size 2

### 4.6.3. Capacity gain

In this section the capacity gain obtained by the ATS system is quantified.

Different service mixes have been evaluated during the learning stage, and their traffic characteristics are shown in table 4.1. Table 4.3 shows the different service mixes that has been studied.

Service Mix	Voice	Data at 64 kbps	Data at 128 kbps	Data at 384 kbps
1	100%	0%	0%	0%
2	90%	10%	0%	0%
3	90%	0%	10%	0%
4	80%	0%	20%	0%
5	80%	20%	0%	0%
6	70%	20%	10%	0%
7	75%	0%	25%	0%
8	30%	20%	20%	30%
9	30%	25%	35%	10%
10	30%	45%	15%	10%

Table 4.3: Services Mix evaluated

From the previous sections, one of the conclusions that was drawn is that for the DL direction not too much cells in the AS is favourable, while for the UL direction is preferable choosing among a great quantity of cells, in order to find the one that requires less power from the UE. With ATS, the network is able to detect which is the limiting link and adapt the parameters accordingly. Table 4.4 shows the capacity gain observed in the network with the ATS use. The capacity gain has been evaluated for different services mix.

Service Mix	Capacity without ATS	Capacity with ATS	Gain Capacity
1	2950	4547	35.12%
2	1928	2465	21.78%
3	964	1535	37.20%
4	1261	1720	26.69%
5	1156	2000	42.20%
6	569	883	35.56
7	559	824	32.16%
8	230	303	24.09%
9	273	375	27.20%
10	303	435	30.34%

Table 4.4: Capacity gain obtained with ATS

As a conclusion, the dynamic automatic tuning of RRM parameters developed during this project allow to detect which is the limiting link and force a reconfiguration order of the SHO parameters in order to favor it. A three blocks based auto-tuning architecture has been described to adapt parameters to service mix dynamics and overcome capacity problems. These blocks have been described and tested, showing an effective adaptation to changes

in traffic patterns, significant capacity gains are obtained when ATS is running. When DL starts to jeopardize capacity in a cell, a reduction in its resources consumption is executed. This allows a margin in the available power and so, the approach is able to stabilize the network and delay congestion control mechanisms. Four different monitoring cases have been tested showing the feasibility of the approach. The most conservative case reacts faster but generates more reconfigurations. The less conservative also guaranteed network performance.

Therefore, the ATS system achieves a considerable increment in the capacity of the network maintaining the QoS required by all the users present in the system. With the correct usage of the ATS, a network service provider is able to increase the capacity of his network in values comprised between 21 and 45% as shown in table 4.4, which depicts the ATS gains.



## CHAPTER 5. ADMISSION CONTROL ALGORITHMS

As it was explained in the "Radio Resource Management" chapter, two are the mechanism entrusted to carry out the correct management of the available radio resources. The previous chapter was focalized on the auto-tuning of the SHO parameters. Different solutions have been proposed in order to overcome the shortcomings present in current UMTS management. Although with the solution proposed, an enhancement in the performance of the network is achieved, it is necessary continue studying the improvements that can be implemented in the current management of 3G cellular networks. For this reason, this chapter focus its attention on other key management function, called as AC. The procedure is similar to the methods used during the auto-tuning of the SHO parameters, for this reasons the chapter is organized in a similar way.

In a first stage an study about the limitations associated with the current AC management present in real UMTS networks will be carried out. Secondly, three algorithms that allow improving the management and in consequence the network capacity will be proposed. Finally a comparison between the different algorithms will be done.

### 5.1. Introduction

Due to the great number of services offered by the 3G networks and especially by the UMTS network, a correct management of the radio resources available is necessary.

The resource allocation presents high importance in the deployment of a 3G network, since a correct use of them ensure the QoS required by each one of the services offered by the service provider. It is translated into a fulfillment of the customers necessities guarantying his faithfulness.

The mechanism studied and developed in this chapter, as well as in previous chapter, is focused to enhance the capacity of the network. In the previous one, the improvement of the network performance was obtained via the auto-tuning of the main SHO parameters. Nevertheless, in this chapter the improvement on the network performance is achieved through the AC algorithm.

The current AC used by the service network providers has been explained in depth in section 2.3. Normally, in current UMTS networks the AC presents fixed thresholds that somewhat represent the cell load and allow to decide if a service request can be attended or not. These thresholds have been fixed in base to the more frequent networks situations, specially in terms of traffic. This strictness make difficult to exploit efficiently the flexibility in the resource management offered by the WCDMA technique, since the AC is not able to adapt the targets to all the traffic situations that can take place in the system.

This chapter attempts to adapt efficiently the number of active calls in each cell, according to the interference levels and power availability in all the possible traffic situations. To obtain it, a differentiation between services has been done. Not all the services have the

same QoS parameters, so a priority statement in the AC must be applied.

In the following sections the different proposed algorithms will be explained in more detail. All the algorithms proposed will be studied in depth in order to find the advantages and disadvantages associated with each one of them. Once the evaluation has been done, a selection is carried out and only the more suitable algorithms for the scenario under study will be implemented. The implemented algorithms are developed during section 5.6. Finally the results obtained by applying the algorithms selected are discussed in section 5.7.

## 5.2. Dynamic Admission Control

In this section a dynamic algorithm that improves the current AC is proposed.

In a UMTS system, the network is continuously monitored by the operator. So the service provider is able to detect the common traffic patterns and optimize the AC threshold accordingly. Indeed the main aim of the algorithm proposed in this section is to provide flexibility to this current AC algorithm. The solution proposed is based on a dynamic AC threshold. Instead of deciding this threshold by means of an extracted average of the more common service mix situations, the dynamic AC threshold is able to fix the optimum threshold in real time according to the current services usage. A suitable admission threshold is therefore, the parameter that directly impacts over system performance indicators, such as coverage, capacity, QoS, etc. So a special attention is required.

In an operating network, it is necessary to monitor constantly three main parameters in order to evaluate its performance and to detect possible problems in specific cells:

- **Dropping Probability:** Is the probability associated to users that passed the AC but are not well-served during the connection, usually because of high interferences or poor RF conditions. It means, that the QoS required by the UE is not achieved since there is not enough available resources (basically power) to mitigate the problems.
- **Blocking Probability:** Is the probability associated to the user that can not pass the AC. The users can not be served by the system, since there are not available resources in the system (power in the DL, interference margin in the UL, codes, etc).
- **Grade of Service (GoS):** It is a function that combines both blocking and dropping probabilities. It is usually considered the measure to optimize in the cell. It is usually calculated as shown in equation 5.1.

$$GoS = P_{blocking} + 10 \cdot P_{dropping} \quad (5.1)$$

It is necessary to notice that dropping probability take relevance over the blocking probability during the GoS calculus. It is due to the fact that dropping probability is assumed to have a larger impact onto the GoS, since dropping an existing user is assumed to be more detrimental than blocking a new user, under the QoS point of view.

A deep analysis of the network performance under different traffic situations has been done, for a set of different AC. Next figures show the analysis of the system, and the optimum threshold that minimizes the GoS for each service mix situations. The number of users launched to the system is 1000 users.

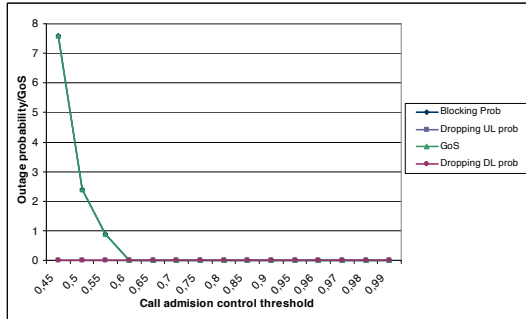


Figure 5.1: 90% voice users and 10% 64 kbps data users

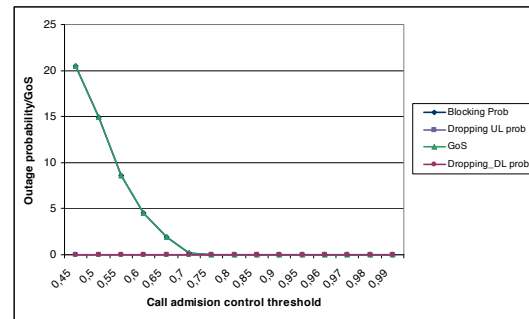


Figure 5.2: 80% voice users and 20% 64 kbps data users

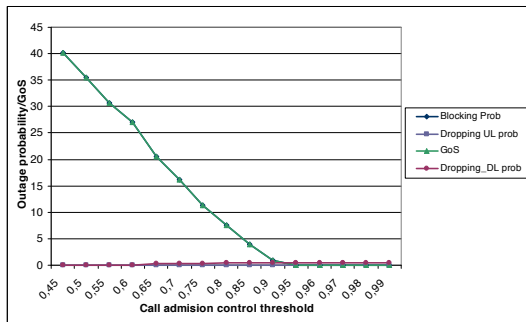


Figure 5.3: 70% voice users and 20% 64 kbps data users

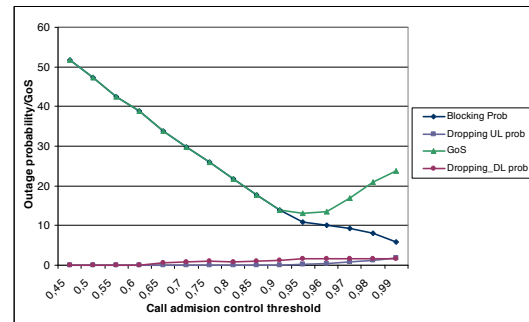


Figure 5.4: 60% voice users and 20% 64 kbps data users

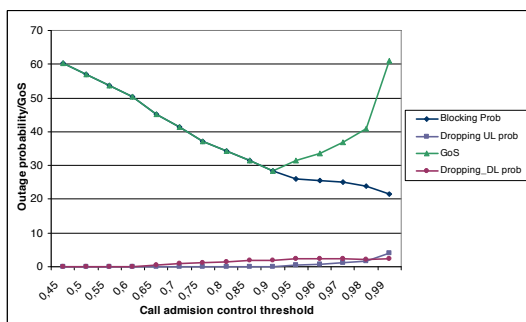


Figure 5.5: 50% voice users and 20% 64 kbps data users

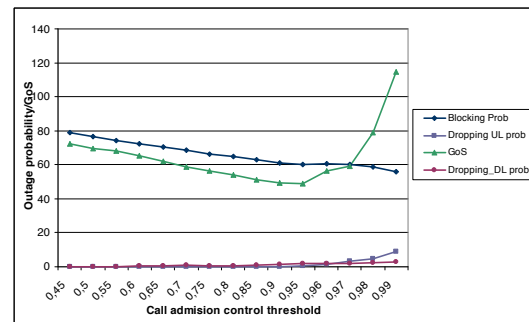


Figure 5.6: 50% voice users and 20% 64 kbps data users

For a low AC threshold the number of blocking users increase while the number of dropping users remain in zero level. Insofar the AC becomes more permissive, a major quantity of users are admitted to the system and therefore the blocking probability decreases. Nevertheless, the dropping probability increase since the number of admitted users increase and therefore the interference level present in the system. In this way, the transmitted power required increase in order to compensate the interference level. Hence, the number

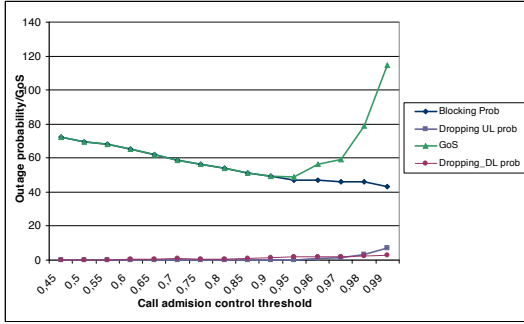


Figure 5.7: 30% voice users 20% 64 kbps data 20% 128 kbps data 30% 384 kbps data

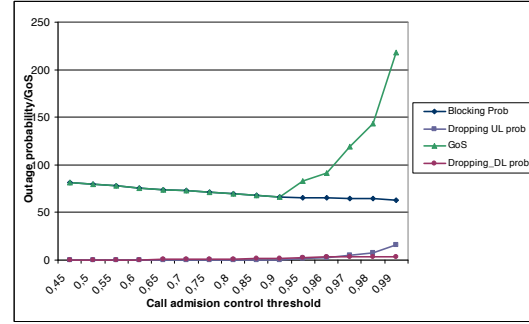


Figure 5.8: 10% voice users 25% 64 kbps data 30% 128 kbps data 35% 384 kbps data

of dropping users increase since the total transmitted power allowed is limited. This effect is appreciated in all the figures depicted.

In a situation where a soft service mix is applied over the scenario 5.2., a degraded situation is not observed, so the dropping probability is zero for all the possible thresholds. It means that the GoS fits in with the blocking probability. In this way, the optimum threshold is the one that ensures that all the users will be admitted according to the AC threshold. Under this traffic situation, an optimum AC threshold is situated between 0.6 and 0.7 values.

It is important to underline that scenarios with more data traffic present an optimum threshold near to 0.9 value. As explained before, when the AC threshold increases, the blocking probability decreases until arriving to 0% as it occurs in soft scenarios. However, in scenarios with a high number of data users the blocking probability never arrives to 0%, since the load factor is always kept above the threshold. It is due to the fact that the number of users launched to the system is over the maximum capacity estimated for the service mix under study, as it is shown in section 4.4. The interference level increases considerably due to the overload situation and consequently the load factor which remains over 0.99. For this reason the number of blocking users reduces in each iteration but is impossible to achieve a 0% blocking probability. In the same way, for this type of service mix a degraded situation appears quickly and therefore the dropping probability appears before. The optimum threshold minimizes the GoS and consequently the dropping and blocking probability of the scenario.

As a conclusion, the AC developed during this section ensures the highest capacity and the best performance of the network on many common situations.

### 5.3. System model

The system that is considered is a UMTS network that supports heterogeneous traffic. It can be assumed 4 type of priority classes that are represented in figure 5.9 in order of priority. They are classified in a first place according to real-time services (RT) and non-real-time services (NRT). And the second criterion of classification is referred to handoff

calls and new calls. Because of the necessity to simplify the code programming, only the second criterion has been considered independent of the RT or NRT nature.

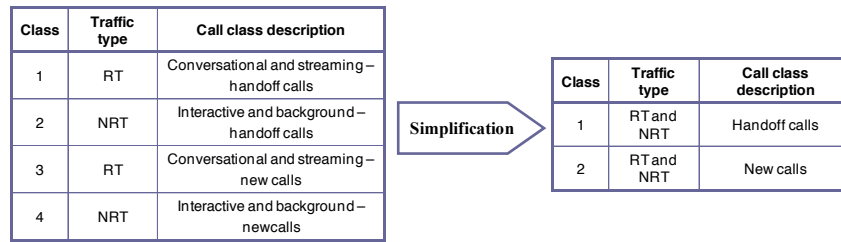


Figure 5.9: Types of services and priority classes' simplification

Firstly, new calls are from those users that come into the system for the first time. These users have not been registered before in the network and they do a cell selection in order to fill the first place of their AS, the next positions of the AS correspond to handoff requests. Secondly, handoff calls appear in two cases, the first one is when new users add more BSs in their AS after the cell selection; and the second one is when users that are not new (they have been admitted before) add more BSs to their AS.

This criterion can be seen reflected in figure 5.10. If the AS is of size 3, three "different" users must be considered and each one has to overcome the AC. A new user appears in the scenario and does the cell selection, as a result cell 22 is added to the AS first position. Then, after the cell selection a new BS is added to the AS, it is considered as handover BS. After a time the user moves through the scenario and listen the cell 25, it is also a handoff BS.

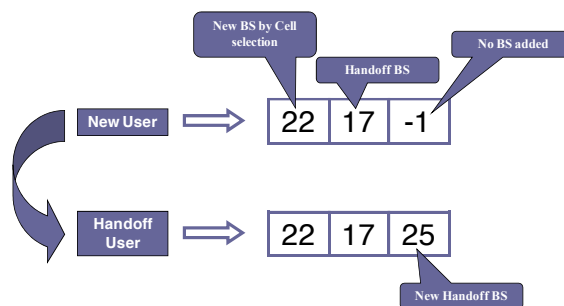


Figure 5.10: Type of users' definition

As it was explained in section 2.3.3. of chapter 2, until now the type of AC that has been implemented is the measured based. Independently of the type of AC, the load factor,  $\eta$ , takes great significance because it defines all the cell loads in terms of resource utilization.

According to the load factor, now the interest is to find other QoS-aware AC algorithm techniques by using the concept of queuing and thresholds for the different traffic classes. Each one of the two classes have assigned a queue, in the case of new users this queue has a finite capacity. When a user tries to enter into the system, if the cell load factor is very high and does not have enough resources to admit it, then this user will be switched on a waiting mode. This mode has duration of maximum 15 continuous frames, after this time if the user can not connect to the system by none of its AS BSs he will be automatically not admitted into the system. In the case of handoff users, this queue will be endless because

is the case of admitted users that add new BSs. In each frame, the handoff BSs are added to the AS against as they will be trying to enter into the scenario until *CPICH* signal is good enough.

Finally, the concept of thresholds is implemented in such a way that for each traffic class a load margin (LM) 1 and 2 is defined, and  $\eta_{max}$  is the maximum load that can be present in the system. Regarding to the way on how the LMs are set, there are established 4 different AC algorithms explained in detail on next sections.

## 5.4. Admission Control algorithms

In this section two important strategies for radio resource allocation in cellular wireless networks known as complete partitioning (CP) and complete sharing (CS) will be studied in depth. They are based in the ones that were introduced in [6].

Following the basic AC explained in 2.3., the criteria adopted to admit or reject a service demand is the load factor of the cell under study, which is defined as a ratio between the interferant noise and the total noise received in a specific cell.

The load factor of the cell increases when users demand increases. In order to achieve the required QoS parameters for all the services in use inside a specific cell, it is necessary to fix a threshold. The main aim of the AC threshold is to avoid blocking situations or degraded connections, which can not accomplish the required QoS parameters.

Network services provider manage the AC in the same way as the SHO parameters configuration. It means that on a first stage an study of the network is done and the most common situations are detected. The AC and the SHO parameters are optimized for this frequent situations. During next stage a continuous monitoring of the network is carried out and if the common situation changes, the network service provider manually reconfigure all the parameters that affect to the RRM.

This technique does not guarantees the maximum performance of the network, since no optimization on the available radio resources is applied. In this way, a fixed AC threshold does not provide the flexibility required by a UMTS network, because of the fact that all the users are treated in the same way. It means that no distinction is applied between services.

Therefore, the main purpose of this section is to demonstrate the superior of the two strategies proposed against the basic AC explained in 2.3..

The section is divided into the following way. Firstly the AC algorithms based on the CS scheme, HP-AC and QP-AC will be explained in depth. Secondly the attention will be focused on the CP scheme, which includes the CP-AC and finally the hybrid solution DP-AC is explained.

### 5.4.1. Hybrid Priority Admission Control

The main purpose of this section is to explain in detail the Hybrid Priority AC (HP-AC). This AC procedure is classified inside the CS-AC algorithms.

The HP-AC proposed in this section can distinguish between different types of users applying them different AC thresholds, and therefore reserving specific radio resources for each traffic class. In this way, different resources utilization thresholds are assigned to each traffic class based on each traffic priority. The higher priority class is allowed to use the resources dedicated to the lowest priority class.

The figure 5.11 shows the scheme of a possible configuration to distinguish between users in a SHO situation and users with a new call. In this situation it is logical to reserve more radio resources for a user in a SHO process. Dropping an active call is assumed to have a larger impact onto the Grade of Service (GoS), since dropping an existing user is assumed to be more detrimental than blocking a new user.

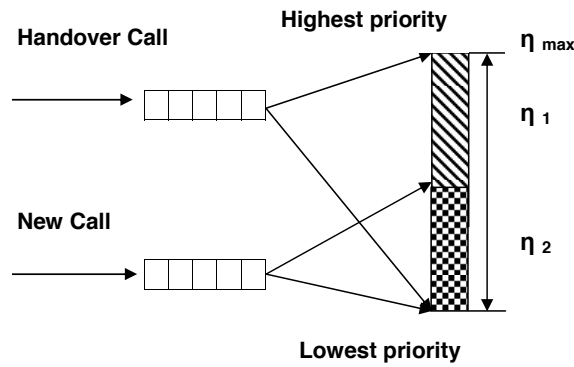


Figure 5.11: HP-AC scheme

Regarding to the HP-AC scheme, a highest resource utilization is achieved, but the QoS requirements of a certain class of traffic can not be guaranteed. The highest priority traffic class can use all the available resources, while the lowest priority traffic class only can use the resources reserved for this kind of traffic class.

Applying these concepts to the figure 5.11, the conclusion extracted is that all the radio resources should be available for users in a SHO situation while users with a new call only could use the resources reserved for this traffic class.

The main problem of this scheme is that the resources allocated for lower priority traffic class are not protected. It means that they are exposed to be consumed by the highest priority traffic class, leaving without available resources the lowest priority traffic class.

The implemented HP-AC will be described in depth in 5.6.1.

### 5.4.2. Queuing Priority Admission Control

The main purpose of this section is to study the performance of the Queuing Priority AC (QP-AC) which in the same way as AC scheme explained above, is one of the methods



proposed to manage radio resources with the purpose to optimize the overall network performance.

This is a method based on the CS-AC. For this reason, the main aim of this algorithm is to share the available resources between the different traffic classes defined. In the same way as the HP-AC scheme, a queuing priority method is established. It means that not all the defined traffic classes are treated in the same way. The different traffic classes are divided into two main groups:

- Highest priority traffic class
- Lowest priority traffic class

The classification defined above has been carried out as follows. Users in a SHO situation has been gathered in the highest priority traffic class, while users with a new call has been assigned to the lowest priority traffic class. This configuration is shown in the figure 5.12.

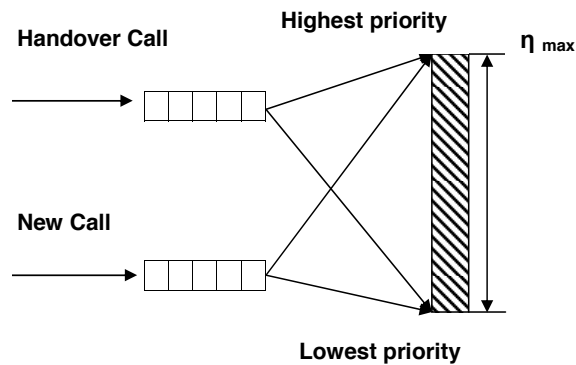


Figure 5.12: QP-AC scheme

Although this is the classification under study, other many configurations can be selected. A possible criteria would be divide the traffic into the four QoS classes defined for UMTS network: Conversational, Streaming, Interactive and Background. The service with more QoS requirements would be associated with the highest priority class.

The main advantage of this method is that each call class has its own queue and all classes share the available resources assuring the highest resources utilization. Otherwise, this method is not able to guarantee the required QoS by each service, since no resources are dedicated. On the one hand, the QP-AC based in sharing the available resources, ensures that highest priority traffic class as always will be able to use the available resources. On the other hand, if there is an increase on the traffic class with a highest priority, the lowest priority traffic class run the risk of remain without service until the highest priority class release some resources.

#### 5.4.3. Complete Partitioning Admission Control

As it was mentioned before, there are two principal strategies to tackle the process of radio resource allocation in cellular wireless networks. In the first place there are the CS



strategies that have been explained in detail previously. In the second hand there are the CP strategies. In this section only one CP based AC is described.

The basis of the CP strategy is that all the available resources are partitioned in such a way that each call class has associated a fixed part of these resources. Calls from a specific class will be admitted in the only case that free resources from its corresponding class partition are available, otherwise they will come into a waiting mode or probably will be blocked.

Next, figure 5.13 shows the resource partitioning that is carried out by the CP-AC algorithms. It can be seen the CP that is explained above.

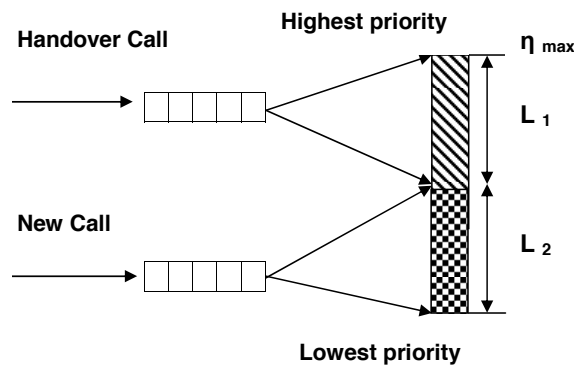


Figure 5.13: CP-AC scheme

The main improvement in respect with the CS-based algorithms is that with a partition of the resources, CP-AC algorithms can guarantee the QoS requirements of each traffic class. Every call class has its own resources and if a low priority call need to access into the network, could enter whenever free resources are available in its partition. In this way, the AC of a lowest priority class is independent of the other call classes (that have higher priority) necessities.

Nevertheless, this AC strategy has an important drawback. The scenario that shows up the main disadvantage of the CP-AC is the one that have under-loaded traffic classes in contrast with others that are over-loaded. In this way, the free resources are under-utilized because there are heavily loaded traffic classes that need more resources than the rest. This fact is not present in the CS-based algorithms, so the next proposal is an hybrid algorithm that implement the best aspects of each AC type.

#### 5.4.4. Dynamic Prioritized Admission Control

In order to solve all the shortcomings of CS-AC and CP-AC strategies, the dynamic prioritized UL AC (DP-AC) is presented. In figure 5.14 the DP-AC scheme is illustrated.

According to the CS-AC algorithms, the problem was that in HP-AC could be present an unutilization of the loading limits of the higher classes that can not be used by the lower traffic classes. As well, the QP-AC together with the HP-AC present the disadvantage that when higher priority classes are overloaded in contrast with the low priority class, calls

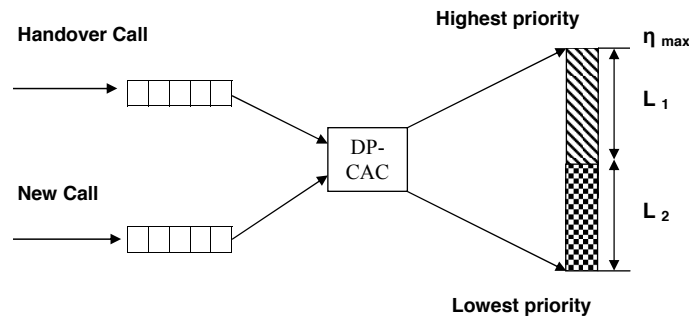


Figure 5.14: DP-AC scheme

belonging to the higher class overwhelm the ones coming from lower class. The result is that individual QoS requirements for each call class are not achieved because there is not a protection for under-loaded classes from resource starvation.

Regarding to the CP based algorithms, the QoS requirements are guaranteed, but it is achieved by an inefficient utilization of the available system resources. It is due to the fact that higher priority classes can not use free resources from the under-loaded lower traffic classes.

The dynamic prioritization AC takes the two problems, of the above strategies, into account. In this scheme there is a resource partitioning as it occurs in the CP-AC, and also there is a control of the current system load in order to admit dynamically the queued calls. In this way, higher priority classes are served as long as the QoS requirements of the lower classes are not affected. The total resources are available for all arriving calls, if lower traffic classes are overloaded they could use resources until free resources are available, so an efficient resource utilization is achieved.

When a call is attempting to come into the system, at congestion condition the dynamic priority is used to differentiate between the queued calls priorities. The resource allocation of traffic classes is dynamically adjusted in order to ensure QoS requirements and according to the traffic load variations. In short, the main objectives of this new AC scheme are:

- Insure best system utilization while satisfying the QoS requirements:
  - At low and moderate traffic load, it ensures the best system utilization while QoS is satisfied (as best as CS)
  - At high load, it ensures the fairness of resource usage amongst different class (as good as CP).
- Provide a scalable and easy way to implement RRM procedure.
- Eliminate the requirement for traffic estimation and communication with neighboring cells.
- Supports preferential treatment to higher priority calls by serving its queue first.

## 5.5. Traffic Model

The traffic model that is implemented in the study of this chapter is very simple. For each user of the system, a variable that defines the connection time is created. It is generated by a random gaussian distribution of average 150 seconds and standard deviation of 70 seconds. It can be seen in figure 5.15 the connection time for each user (x axis), the example considers 1000 users.

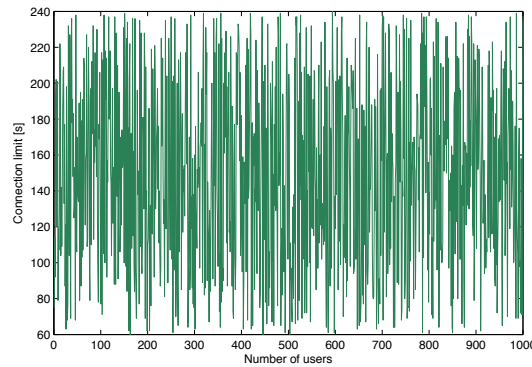


Figure 5.15: 1000 users time connection

The complete traffic model is represented in figure 5.16 and works as follows:

- A concrete number of users is launched into the system.
- At the moment of locating each one of the users, a variable that defines the time connection is generated.
- As time of simulation advance, the users time connection increases.
- When the time connection of a user gets to its end, this users is eliminated and another one is generated to enter into the system. This way, the number of users remain constant in the simulation time and so the results can be more easily analysed.

## 5.6. Implemented methods

In this section the implementation of the two selected methods described above have been carried out. The AC algorithms algorithms selected are:

- HP-AC algorithm
- CP-AC algorithm

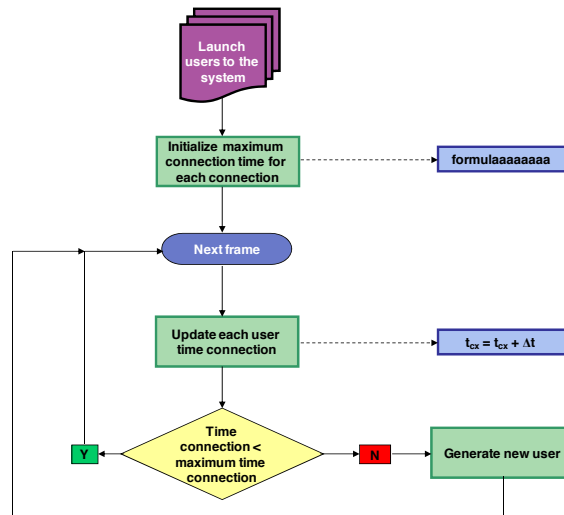


Figure 5.16: Traffic model

Both are considered the most interesting methods to be developed during this project. Each one of the selected algorithms come from each one of the main two AC-algorithms that gather all the possible AC procedures.

- CS based ACs (Complete Sharing ACs)
- CP based ACs (Complete Partitioning ACs)

The comparison can be established not only among the selected algorithms, but also between the AC algorithms based in a CS of the available resources and the AC algorithms based on the CP of the available resources.

### 5.6.1. Hybrid Priority Admission Control implemented method

In this section the implemented method to develop the HP-AC is accurately detailed.

The procedures during the first stage are the same for all the simulations carried out during this project. The users are launched to the system and a specific service with the corresponding QoS parameters is associated to each of them.

Due to the simulator dynamism there is a distinction between the initial frame where the users are located randomly, and the subsequent frames where the users are in motion according to the mobility model previously described in figure 1.12.

During the initial simulation frame all the users are considered new users. It is necessary to point out that this time interval differs from the others by the simple reason that during this initial stage does not exist none input about the behavior of the network. For this reason, it is necessary to apply the AC individually. It means that UEs are evaluated one by one.

AS determination is carried out according to the  $CPICH E_c/I_0$  level received by the UEs. Regarding to the fact that the AS determination method is not instantaneous, appears a period of time between the first cell added to the AS and the other cells that could be added. This effect is known as the cell selection procedure.

The first cell added is considered as the new cell, and subsequently added cells are considered as SHO cells. This concept is directly connected to the main idea of the algorithm proposed, where two different AC thresholds are established.

The handover AC threshold is softer than the new AC threshold. It allows to guarantee more efficiently the service required by the UE. If the first cell added to the AS can not attend the service demand, the softer threshold will make that other possible connections ensure it.

This is the advantage associated to the HP-AC, where resources utilization thresholds are assigned to each traffic class while allowing the higher priority traffic class to share the resources of the lower traffic class in addition to allowing each call class to be queued.

In figure 5.17 the flux scheme that gathers the necessary steps to carry out the AC during the first time interval is shown.

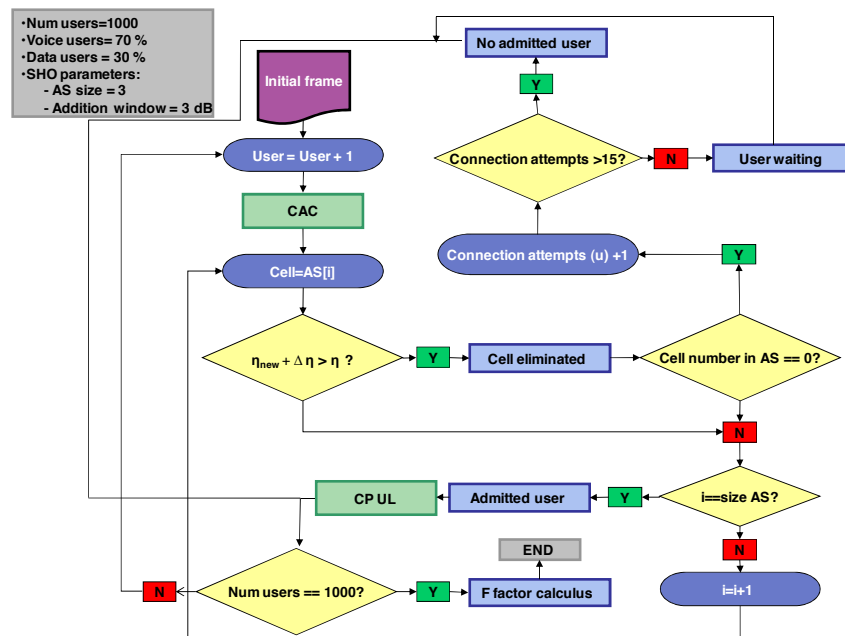


Figure 5.17: HP-AC first frame

For new users the first cell added to the AS by the cell selection procedure has associated a AC threshold more strict than the other ones. While the SHO cells have associated a more permissive threshold. The soft threshold of the SHO cells ensures the service of the user in case that it was rejected by the new cells.

As it was shown, if a user is rejected by all the cells added to his AS, the user is located to a queue until a resources release. When a user exceed the allowed permanence time in queue, the users is rejected permanently by the system.

In order to overcome the problems derived from eliminating users from the system, the traffic model explained in 5.5. is used. With the use of this traffic model the system ensures the same number of users asking for a service during all the simulation period.

Once all the users launched to the system have been evaluated, the F factor per cell is calculated in order to have an input about the network state. This fact, simplifies very efficiently the AC for the next frames. The F factor is calculated as the quotient of the intercell and intracell powers:

$$F_{factor} = \frac{P_{inter}}{P_{intra}} \quad (5.2)$$

Once an accurate analysis of the first frame is accomplished, the following frames will be treated in the same way. It is necessary to consider that users in next frames do not remain in the same position, since a mobility model is applied. Depending on the distance covered, UEs in motion could produce a change in the conditions of the scenario. For this reason users are divided into three types from a simulation viewpoint:

- **New User:** An UE is labeled as a new user when the configuration of the AS between adjacent frames changes completely. This happens, for example, when a UE finishes its connection and it is removed from the system and repositioned as a new user in another geographical point.
- **Handover User:** An UE is labeled as a handover user when a cell or a group of cells do not match from those ones added in the previous frame. A requirement is needed to regard an UE as a handover user. It is necessary that at least one cell added in actual frame match with other cells added in the previous frame. If all the bases added in the AS of the user during the frame under study differs from the cells added in the AS of the same user in a previous frame, this user is considered as a new user.
- **Normal User:** An UE is labeled as a normal user when no changes are appreciated between ASs of adjacent frames.

The distinction above explained and applied between users, is necessary in order to reduce the complexity of the AC procedure. Figure 5.18 shows the procedure of the flux scheme that has been carried out for implementing the HP-AC during all the frames, excluding first frame.

From second frame until the end of the simulation time, all the users will be classified in the three types explained previously.

The UEs classified as handover users will pass the AC firstly, because they are classified inside the highest priority traffic class and the resources associated to the lowest priority traffic class will be able to be used by the highest priority traffic class.

The handover users only must pass the AC of the new cells added to their AS. The user must not pass the AC of the cells that gave him service in previous frames, since it is assumed that the user already passed the AC of these cells in previous frames.

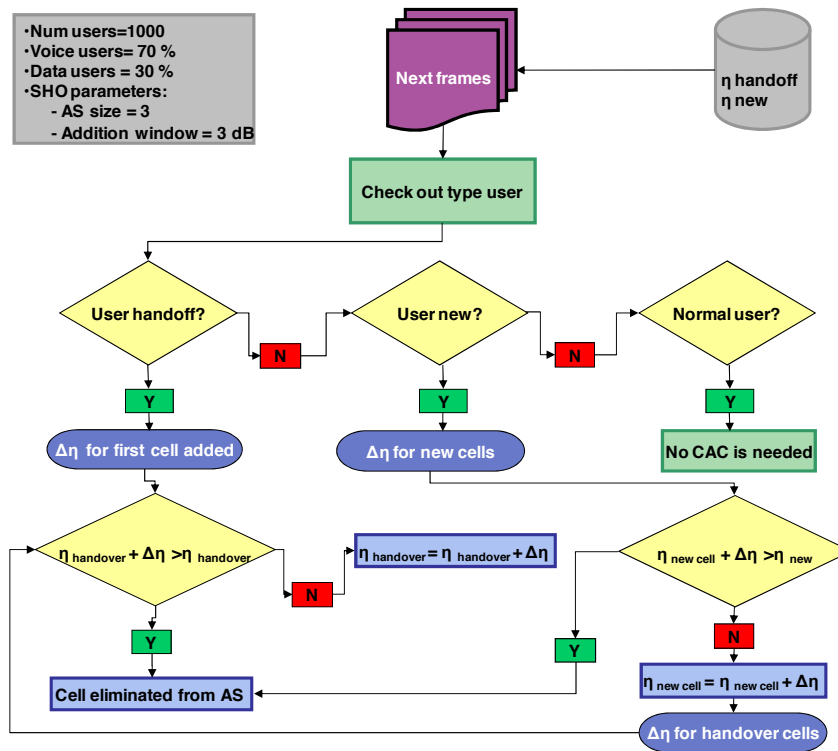


Figure 5.18: HP-AC next frames

In the same way, the AC must not be applied to normal users since no changes are appreciated in their AS.

The evaluation of the new users will be carried out as it was described during the analysis of the first frame, where all the users were considered as new users.

As it will be explained during 5.7. the main advantage of this algorithm is that users in a handover situation will not be penalized, since all the available resources are reserved for this highest priority traffic class. However if it is not the main traffic class in the scenario under study, this algorithm would not be the suitable election. In a situation where the majority of the traffic in the scenario belong to the lowest priority traffic class, the HP-AC waste the available resources, since only a bit quantity of them is reserved for the lowest priority traffic class, and it is not allowed to use the resources reserved for the highest priority traffic class.

In order to overcome the shortcomings explained above, a certain dynamism in the HP-AC is proposed. The idea is to control the traffic that appears in the Network.

The figure 5.19 depicts a dynamism in the threshold associated to the lowest priority class. With this dynamism scheme the network service provider will be able to adapt the resources reserved to the lowest priority traffic class in base to the quantity of traffic with this characteristics that is present in the network.

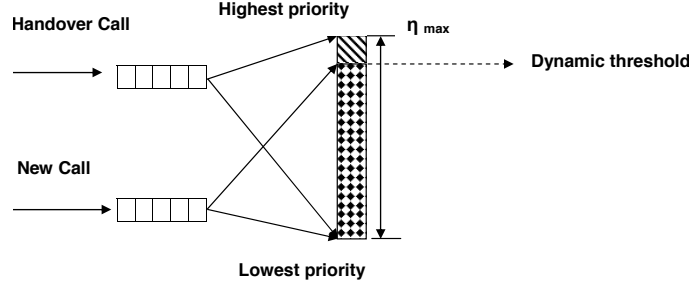


Figure 5.19: Dynamic threshold HP AC

### 5.6.2. Complete Partitioning Admission Control implemented method

Finally in this section the implemented method for the CP-AC is explained in detail.

The simulation process is very similar to the HP-AC scheme; the first step is to launch users to the system with its corresponding service and QoS parameters. After that, they will be frame by frame in constant movement according to the mobility model.

The initial frame, where users are located randomly, is similar to the one explained in the previous section. During this frame UEs are evaluated one by one because all of them are considered as new users, the system does not have any information about previous time.

Users fill the AS by the *CPICH* signal level that they receive. As it is explained before, firstly there is a cell selection to include the best BS that is listened, this is the new cell. The consecutive cells added to the AS are handoff cells, because conceptually they are added just a short time after than the first one.

At this point appears the first difference with HP-AC. Because of the differentiation between new cells and handoff cells, two AC thresholds are applied. According to the CP-AC procedure, the cell load is divided into two partitions that are not overlapped,  $L_1$  for new users and  $L_2$  for handoff users. These partitions must fulfil the condition in equation 5.3.

$$L_1 + L_2 = \eta_{max} \quad (5.3)$$

These two partitions can be configured regarding to the traffic characteristics. Depending on the total number of handoff or new users, and the predefined QoS requirements, each service class will have a higher division of the cell load. In figure 5.20 the block diagram of the first frame procedure is shown.

All the users do the cell selection and these new BSs have to overcome the AC condition. New users will be admitted if and only if the current new cell load plus the increase load that generates is less than the load margin  $L_1$  imposed. After verifying the new cell AC, handoff BSs have to accomplish their corresponding condition in order to be admitted. Handoff cells are admitted if and only if the current handoff cell load plus the increase load is less than the load margin  $L_2$  imposed.

User by user, if he is admitted to the system, the PC is carried out in order to update the current handoff and new cell loads. Otherwise, if the user is not admitted by any of the



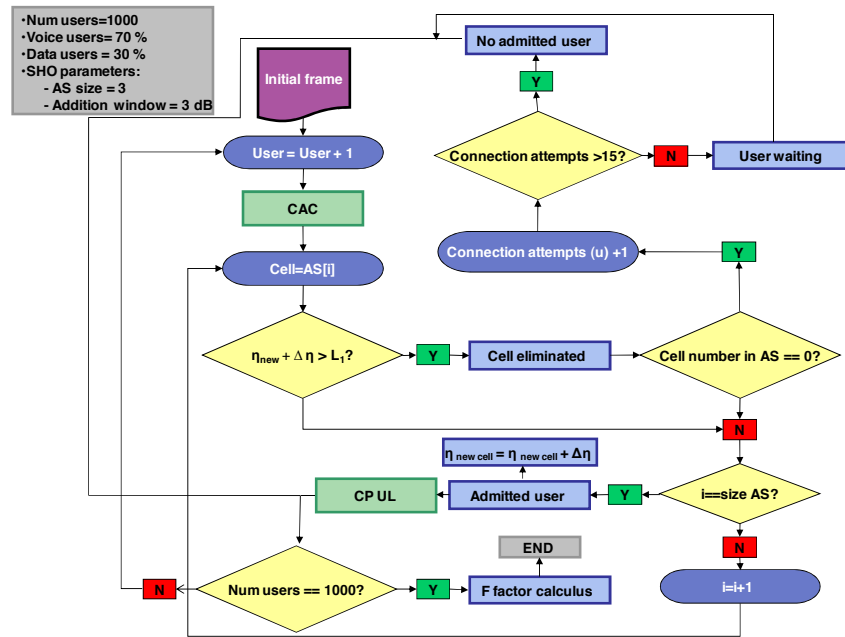


Figure 5.20: CP-AC first frame

cells in his AS, the user come into a waiting mode so it will be queued until he is admitted. If the maximum allowable time of 15 consecutive frames in the waiting mode is exceeded, these users will be permanently rejected by the system.

At the same time that PC is applied, the F factor is calculated in order to update the two different current loads, the one for new cells and the one for handover cells. It is another difference in respect with the HP-AC, where only was calculated once all the users were evaluated. Now it is necessary to update this value each time a user is admitted because of the need to have two separated monitored loads.

From here on, the next frames have the same treatment. The block diagram is presented in figure 5.21. Users are constantly in movement according to the mobility model, so their coverage conditions can be modified. Because of this, each time there is users movement, it is necessary to distinguish between the three kinds of users that may be present in the scenario: new users, the handoff or handover users and finally the normal users. As it is explained before, this distinction allows simplifying the procedure and therefore the time of simulation is considerably reduced as it is only necessary to calculate the PC at the end of the frame.

Handoff users, those that add new BSs to its AS, are the ones with higher priority, so they are the ones that are served as free resources are available in its corresponding partition. Only the new handoff cells added have to pass the AC and they will never come into a waiting mode because they were admitted in a previous frame.

When all handoff users are evaluated then is new users' time. They have to overcome the AC procedure as in the first frame and in this case they can enter into the waiting queue.

Finally normal users do not need to overcome any AC until they do not present any modification in its AS.

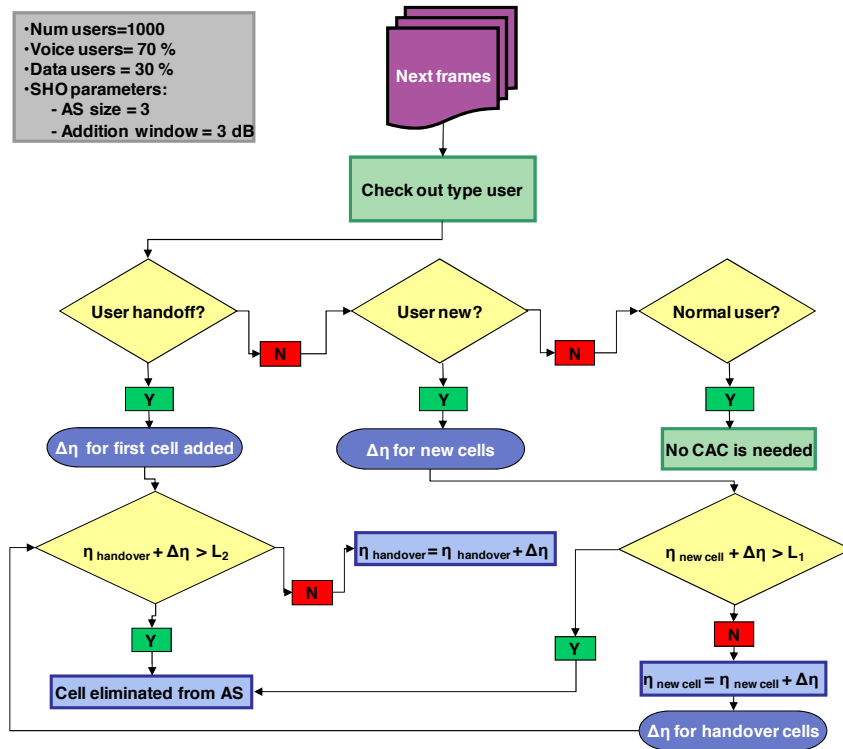


Figure 5.21: CP-AC next frames

In short, this implementation method of AC has its advantages and disadvantages as it was explained in section 5.4.3. CP-AC can guarantee the QoS requirements for each call class, but may under-utilize the free resources depending on the traffic conditions. In the simulation results different load margins and different scenario conditions are applied in order to visualize these effects.

## 5.7. Simulation results

The main purpose of this section is to analyze the results obtained from the application of the two AC algorithms proposed over two different types of scenarios. The comparison between algorithms is done in order to detect the situations where a CS-AC diagram is more suitable than a CP-AC diagram.

The scenarios defined are:

- SHO Scenario
- Uniform Scenario

A uniform scenario is featured by the fact that the users are randomly scattered around the network and therefore the majority of the users are placed inside the coverage area of a specific cell. According to the Nodes-B location explained in detail in 1.3.1., only a 20% of SHO areas are defined. It means that in an 80% of the cases, users are located in an

area covered by a single cell, so no SHO procedure is possible since the users can not receive correct signal levels from other cells. Only the mobility model applied over the user will contemplate this situations. Nevertheless, regarding to the simulation time, the users velocity and the scenario dimensions, changes to SHO situations are not very frequent.

Otherwise, a SHO scenario is a scenario featured by the fact that most users present in the system are placed in SHO areas. It means that they can receive suitable  $E_c/I_0$  levels from at least two cells. To achieve this type of scenario a new mobility model has been implemented. In the initial frame users are forced to be place in SHO areas and in subsequent frames users remain in SHO areas due to the mobility model implemented. It is necessary to say that along the time the scenario will become in a uniform scenario, since when a call is finished a new user is launched to the system, but a SHO position is not guaranteed in this situation. Picture 5.22 depicts the position of the users assuring a scenario 80% handover.

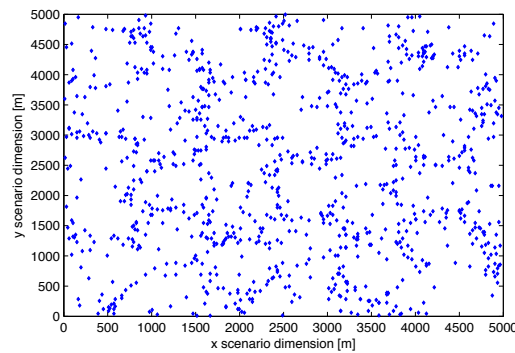


Figure 5.22: 80% of the users located in a SHO area

Regarding the organization of next sections. Firstly, simulation parameters that are common for all AC schemes are shown. Secondly, a comparison between the HP-AC and the CP-AC in a uniform scenario will be explained. And finally, a comparison between HP-AC and CP-AC in a scenario dominated by handover UEs is carried out.

### 5.7.1. Simulation parameters

In order to do a comparison between HP-AC and CP-AC algorithms with users launched uniformly, the main parameters of the scenario that have been selected are shown in table 5.1. The characteristics of the services are shown in table 4.1 of chapter 4. Regarding the traffic situation it is necessary to point out that the service mix selected is 70% voice users, 20% data type 1 and 10% data type 2. It is considered as the most frequent service mix in current UMTS networks.

The maximum capacity of the network in this situation is depicted in figure 5.23. It is shown in order to illustrate the situation of the network under this traffic condition.

Finally other simulation parameters for the network are presented in table 5.2.

The results that are going to be compared are in the first place the conditional blocking

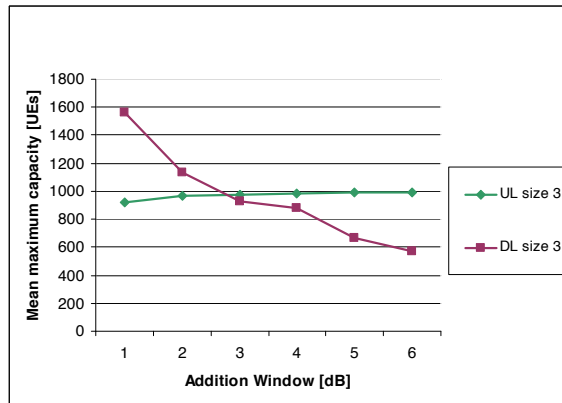


Figure 5.23: Maximum Capacity for different configurations of SHO parameters (70% voice UEs, 20% Data type 1, 10% Data type 2 UEs)

Parameter	Value
Scenario Length in x	5000 Kilometers
Scenario Length in y	5000 Kilometers
Geometric radius	500 meters
Resolution	15 meters
Work frequency	2000 MHz
Maximum antenna gain	18 dB
Nodes-B level	25 meters

Table 5.1: Scenario parameters

probability depending on the type of user. In the second place global blocking probabilities of the system will be presented. And finally load factor curves and dropping probabilities are also shown.

To understand the results that are shown in this section, is important to distinguish between the meaning of new or HO users and the meaning of new or HO cell, because the meaning is not the same at code programming level.

- New user: is the one that attempts to enter in the system for the first time.
- HO user: is the one that is already connected to the system but adds another BS to the AS.
- New cell: is the first one that is added to the users AS by a cell selection process. It is located in the first position of the AS.
- HO cell: is the one that is added to the user AS after the first new cell obtained by the process of cell selection.
- HO areas: are those areas of the scenario where coverage levels from 2 or more cells are overlapped.

Parameter	Value
Max cell load	0.9
Class 1 load limit	0.9
Class 2 load limit	0.6
Class 1 load margin $L1$	0.3
Class 2 load margin $L2$	0.6
Call duration	rand(60-240)
Number of users	1000
Queue size	15

Table 5.2: Simulation parameters

As it can be seen, all these classifications form a particular nomenclature of the simulation code. For this reason and in order to understand better the results obtained in following sections, it is necessary to take into account each one of the classifications explained above.

### 5.7.2. HP-AC and CP-AC in a uniform scenario

The operation analysis of each one of the methods under study will be carried out during this section. The algorithms will be applied over a uniform scenario, which are formed by an 80% of users located in areas where a SHO process is not contemplated.

#### 5.7.2.1. Central cell conditional blocking probability

The conditional blocking probability is defined at cell level and responds to the expression in equation 5.4. The conditional HO blocking probability is defined as the relation between the blocked users, conditioned to the fact that they are HO users, with respect to the total HO users. The same concept is applied to the new users as it is shown in equation 5.5.

$$\text{HO cells conditional blocking probability (\%)} = \frac{\# \text{ HO cells blocked}}{\# \text{ Total HO cells}} \cdot 100 \quad (5.4)$$

$$\text{New cells conditional blocking probability (\%)} = \frac{\# \text{ New cells blocked}}{\# \text{ Total new cells}} \cdot 100 \quad (5.5)$$

The results of the conditional blocking probability for the central cell is present in figures 5.24 and 5.25, corresponding to HP-AC and CP-AC respectively.

Left area from representations shows the number of new and HO BSs that are going to pass the AC. And the right area represents the conditional blocking probabilities depending on the type of cell.

Generally, in the scenario a cell can have under its coverage area an average of  $1000/42 = 23$  users/cell. At the first range of the simulation period there are 25 users attempting to

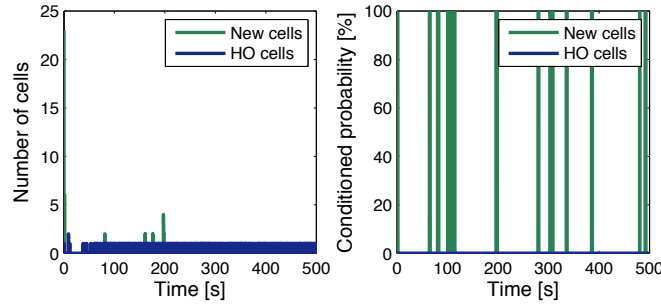


Figure 5.24: HP-AC: number of cells from each call class and conditional blocking probabilities depending on the type of user

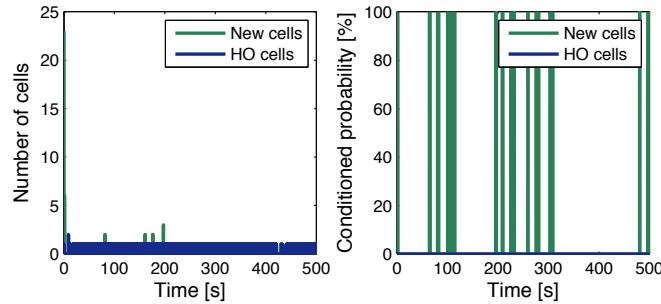


Figure 5.25: CP-AC: number of cells from each call class and conditional blocking probabilities depending on the type of user

connect with central cell. The consequence is that after the AC of the first frame, the conditional blocking probability of being new cell increases.

During the next frames, the number of users who add a HO cell in their AS is very low because approximately an 80% of the scenario is constituted by no HO areas. In the same way, the quantity of users that are completely new is also small. This effect is produced by the fact that in general a new user does not appear until his call is finished. All these conditions produce a reduction in the number of new or HO users during the rest of the simulation period.

Because of the uniform behavior of the scenario, not an excessive number users are present in the system. The result is that the HO cell conditional blocking probability is zero in both AC schemes. There are not many HO users, and in the case that one appears, as he has more priority than new users in both diagrams, the system will serve him if free resources are available.

The blocking probability conditional to new cell type switches from 0 to 100% because of the following reason. A user will have a new cell if he was waiting in a queue or a user that modifies completely his AS (this second case only occurs when a new call is generated when another previous connection is finished). Regarding 42 users in the waiting queue during a frame (normally this number is lower) and thinking that each one of the 42 cells have one of these users, is logical assume that the presence of a waiting user in each cell is due to the fact that all the resources are occupied, so if free resources were available, these would be given to the HO users.

In the case of HP-AC, the blocking probability conditional to new bases is higher than in CP-AC. It means that, there are more hops from 0 to 100% than in the CP model. It is because the performance of the AC algorithm. In CP-AC resources are completely partitioned for each call class; therefore new cells have their own resources ensured. Nevertheless, new cells that need more resources than their own partition (in simulation results is 0.6) are also blocked. Whereas in HP based scheme, HO cells can use the new cells resources and because of this, the blocking probability of new cells is slightly higher. The system is so charged that big differences can not be appreciated in the blocking percentages.

#### 5.7.2.2. Central cell load factor

In figures 5.26 and 5.27, load factor for central cell in both AC schemes are shown. The fast variations are due to interferences in the system and the slow variations are due to the users mobility. The maximum load factor is more or less the same in the two cases, but in CP-AC there are stretches where the load factor is higher because there are more users blocked in HP-AC and therefore, load factor in CP-AC is higher.

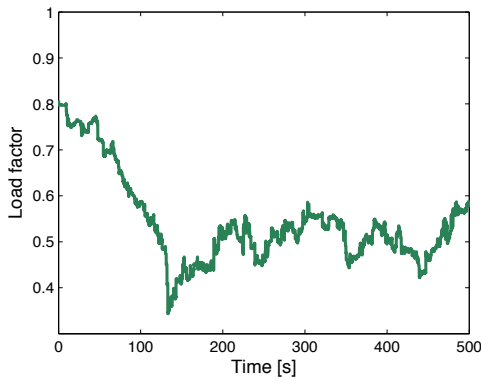


Figure 5.26: HP-AC: Load factor for central cell

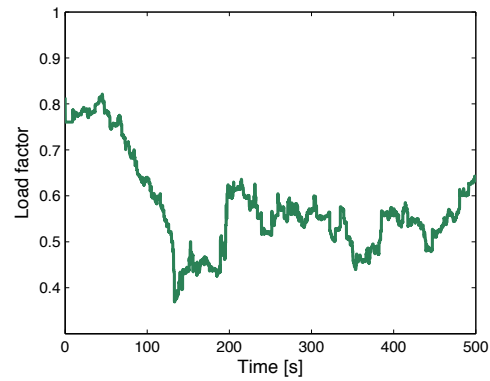


Figure 5.27: CP-AC: Load factor for central cell

#### 5.7.2.3. Global system blocking probabilities

Previously, the conditional blocking probabilities were obtained in such a way that the global blocking probability is equal to the conditional blocking probability multiplied by the probability of being new or HO users. The expression of the global blocking probability is shown in equations 5.6 and 5.7.

$$\text{HO cells blocking probability (\%)} = \frac{\# \text{ HO cells blocked}}{\# \text{ Total HO cells}} \cdot \text{HO cell probability} \cdot 100 \quad (5.6)$$

$$\text{New cells blocking probability (\%)} = \frac{\# \text{ New cells blocked}}{\# \text{ Total new cells}} \cdot \text{New cell probability} \cdot 100 \quad (5.7)$$

The results of the global blocking probabilities are shown in figures 5.28 and 5.29 that represents:

- System blocking probability = # not admitted users / # users
- Waiting probability = # waiting users / # users
- HO blocking probability = # HO blocked users / # users
- New blocking probability = # New blocked users / # users

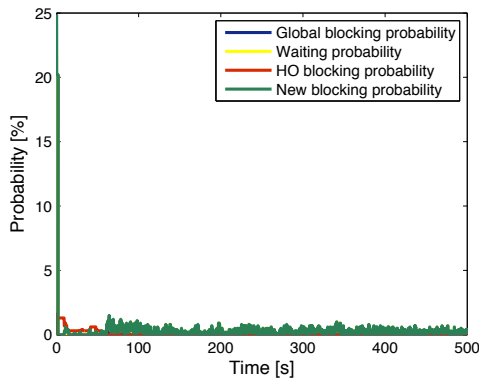


Figure 5.28: HP-AC: Global blocking probabilities, waiting probability, HO users blocking probability and new users blocking probability

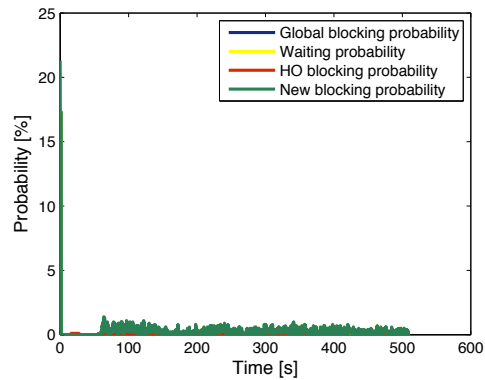


Figure 5.29: CP-AC: Global blocking probabilities, waiting probability, HO users blocking probability and new users blocking probability

New users, who agree with the ones in waiting mode, pass the AC with the new traffic class threshold for the first cell in the AS; and with HO threshold for the remaining cells. Whereas HO users, pass the AC only for the new HO cells added to their AS with the HO threshold. Therefore, when counting HO blocked users, if a user add 2 HO cells that block him, the number of HO users blocked increase in 2 (although he is an unique user). Because of this, the blocking probability of HO users in the figure could be higher than in the new blocking curve, because the numerator could be higher. This can not be appreciated here because the scenario has a uniform behavior and there are not much HO users.

In the previous figures the global results for all the simulation period are not very clear, so explanations will be done representing separated sections of the total simulation period.

Firstly, in figures 5.30 and 5.31, the early 20 frames are shown. They represent a time step of 100 ms (2 seconds altogether). From 0 to 1.7 seconds it could be seen that there are not users not admitted and nevertheless there are waiting users, this is because new users that are trying to connect with the system are blocked for all cells in their AS (generally they have only one cell in the AS because the scenario is uniform) and enter into a waiting mode. It is for that reason that the waiting probability curve and the new blocking probability curve are similar, because new users blocked pass to the waiting queue. In respect with the AC scheme, it can be seen how the HP-AC block more because it does not ensure QoS requirements, whereas in CP-AC new users have their own partition of resources. The HO blocking probability is zero because the scenario is uniform.



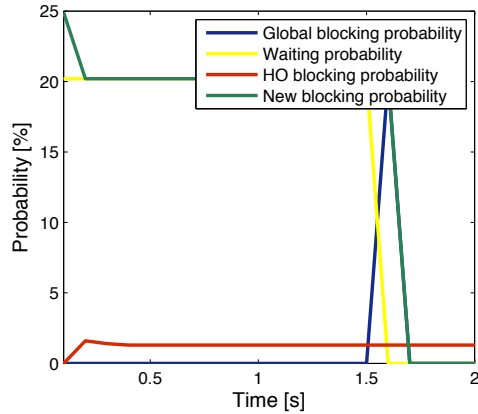


Figure 5.30: HP-AC: Global blocking probabilities from section 0 to 2 seconds

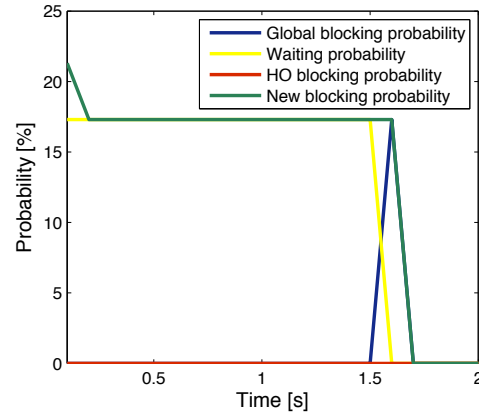


Figure 5.31: CP-AC: Global blocking probabilities from section 0 to 2 seconds

When new users already take 15 consecutive frames in the waiting queue trying to enter into the system, they pass automatically to be not admitted users. For that reason, around the instant 1.7s it can be seen how the curve of waiting mode switch with the curve of global not admission probability.

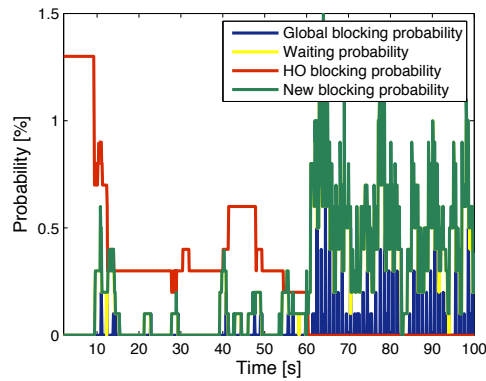


Figure 5.32: HP-AC: Global blocking probabilities from section 2 to 100 seconds

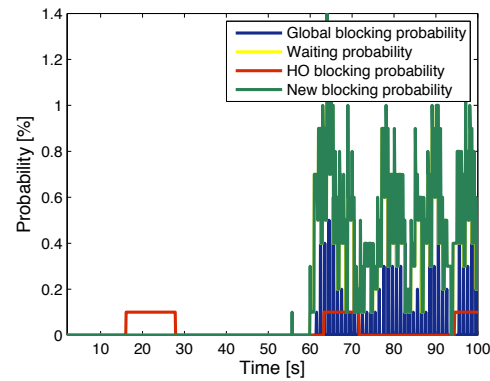


Figure 5.33: CP-AC: Global blocking probabilities from section 2 to 100 seconds

Until users time connection does not finish, other new users do not appear in the system. It is because the traffic model, explained in section 5.5. of the present chapter. A user has an average time connection of 150 seconds, but it can vary from a minimum value of 60 seconds to a maximum of 240 seconds. Figures 5.32 and 5.33 represents a section of the simulation period from 2 to 100 seconds, where is shown how the behavior of the scenario remains without changes until 60 seconds, because new users begin to appear. This is the reason why variations of new users blocking probability are appreciated in both schemes, because the system is at that moment completely loaded.

Finally, the following graphs represent the rest of the simulation period, but to understand clearly the results there is a separation between the waiting probability and the no-admission curves on the one hand, and by the other one it is shown the new and HO users blocking probabilities.

In figures 5.34 and 5.35 the waiting probability and the not admitted probabilities are repre-

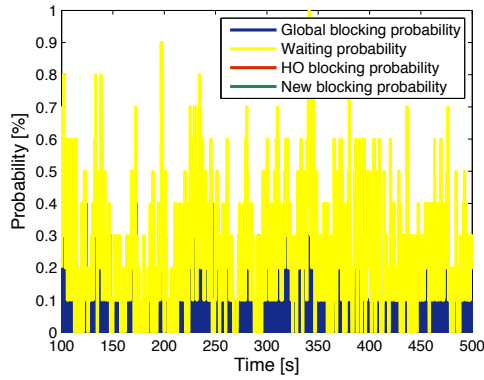


Figure 5.34: HP-AC: HO and new blocking probabilities from section 100 to 500 seconds

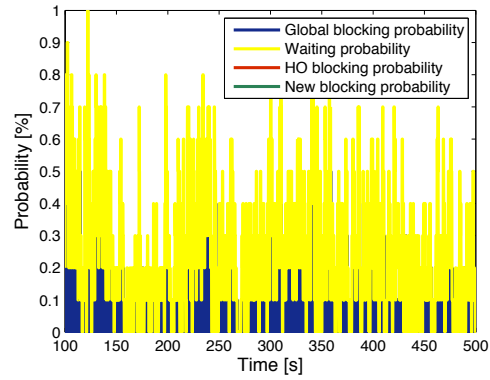


Figure 5.35: CP-AC: HO and new blocking probabilities from section 100 to 500 seconds

sented. It can be seen how waiting users appear until the maximum allowable attempts to enter in the system are exceeded, that is the moment where they pass to be not admitted users.

According to the uniform scenario, for HP-AC it can be seen how the system blocking probability is higher than in CP-AC. The performance of HP-AC shows how the fact of sharing resources for HO users but not for new users causes a higher blocking probability because most of users in the uniform scenario are new. Individual blocking probability associated to new users is higher than global blocking probability, since blocking a new user does not mean that this user is completely blocked by the system because he can be served by another BS included in his AS.

The blocking probability for waiting users is higher in the HP-AC scheme during the early frames because of the fact that new users do not have their own resources reservation, and therefore free resources are used by the HO users.

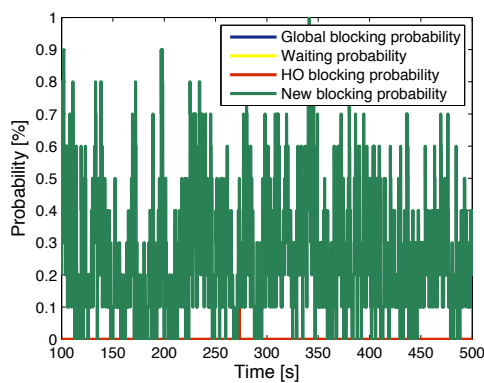


Figure 5.36: HP-AC: HO and new blocking probabilities from section 100 to 500 seconds

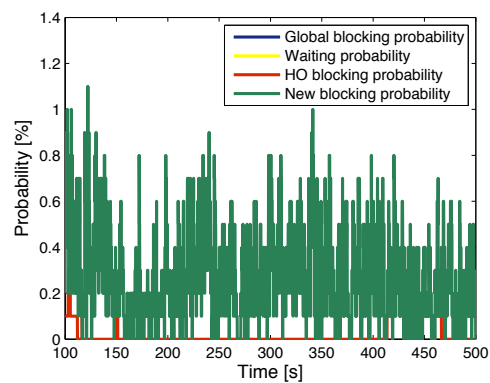


Figure 5.37: CP-AC: HO and new blocking probabilities from section 100 to 500 seconds

In respect with the new users blocking probability is higher than the HO blocking probability as it can be seen in figures 5.36 and 5.37. As it was explained in some occasions, a scenario with uniform behavior practically do not include HO users. At this time of sim-

ulation the system is very loaded and if there is a liberation of resources, they are given automatically to HO users and the new ones become blocked.

The total number of new and HO users during the simulation period is equal independent of the AC scheme. While blocking probability of HO users is very low in both schemes, the blocking probability of new users present significant differences. In HP-AC scheme HO users use resources from new users, while CP-AC has independent partitions for both types of users, as a consequence blocking probability for new users is higher in HP-AC.

#### 5.7.2.4. Dropping probability

Finally, the dropping probability is shown in figures 5.38 and 5.39. The simulations have been carried out for a scenario 70% voice and 30% data users, and the number of users launched to the system correspond to the one obtained from maximum capacity curves. Because of this, the dropping probabilities do not exceed the 5% of degraded users that was defined in the maximum capacity concept. Also, it can be seen that in CP-AC the percentage of degraded users is higher according to the load factor curves previously commented in figures 5.26 and 5.27.

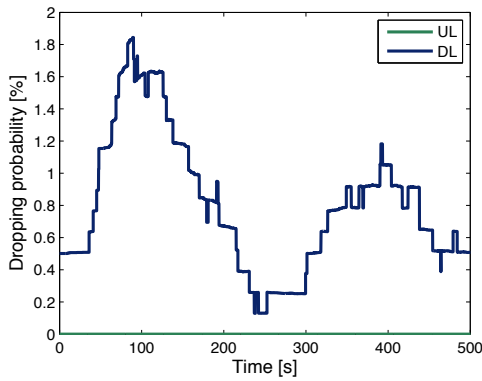


Figure 5.38: HP-AC: dropping probability

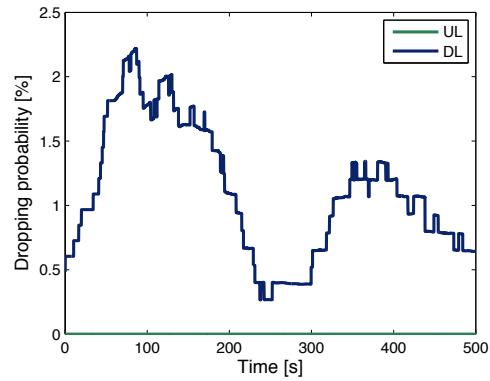


Figure 5.39: CP-AC: dropping probability

### 5.7.3. HP-AC and CP-AC in a handover scenario

During this section the different simulation results obtained from applying a HP-AC or applying a CP-AC in a SHO scenario will be analyzed in depth.

#### 5.7.3.1. Central cell conditional blocking probability

As it was explained in 5.7.2.1., the conditional blocking probability is defined at cell level. The main concept is defined in equations 5.6 and 5.7. Figures 5.40 and 5.41 show the central cell conditional blocking probability.

Left area of the plot represents the number of users that have the central cell as a HO cell or as a new cell. Blue line represents the number of users classified as new users that

have the central cell as a new cell. Otherwise green line shows the number of handover users that have the central cell as a handover cell.

During the initial period of simulation time, an increment in the conditional blocking probability is observed. It is due to the fact that handover users that consider this central cell as a HO cell is also increased.

During the rest of simulation time the conditional blocking probability corresponding to handover users remain in 0 for both AC algorithms. For the HP-AC a user in a Handover situation is always well served, since handover users are classified as a highest priority traffic class and can use the resources reserved for the lowest priority traffic class. Nevertheless, CP-AC do not ensure this blocking probability for all the simulation time. In the middle of the simulation time a handover blocking probability is observed.

Regarding to the conditional blocking probability of new users, it is necessary to point out a better behavior in CP-AC since handover users can not use the resources reserved for new users. In the HP-AC the conditional blocking probability associated to new users increases because when a new user is evaluated, the cell is already overloaded and can not admit him. Therefore, a new user is always considered as a waiting user since he remains in queue until the release of some resources. In the case of some resources release, these would be reserved for the highest priority traffic class.

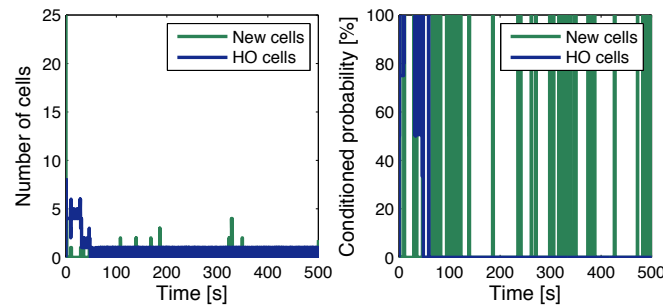


Figure 5.40: HP-AC: number of cells from each call class and conditional blocking probabilities depending on the type of user

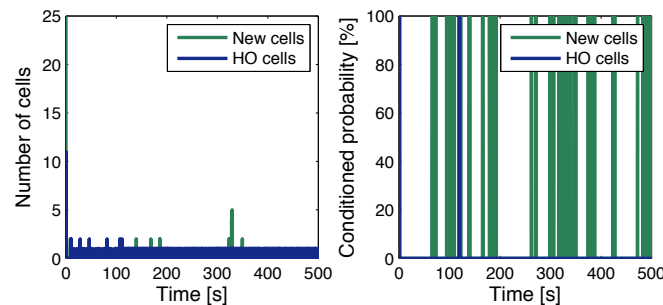


Figure 5.41: CP-AC: number of cells from each call class and conditional blocking probabilities depending on the type of user

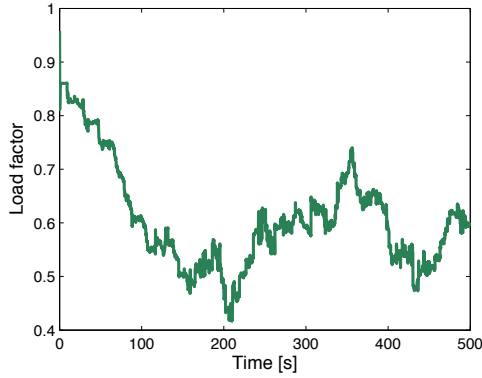


Figure 5.42: HP-AC: Load factor for central cell

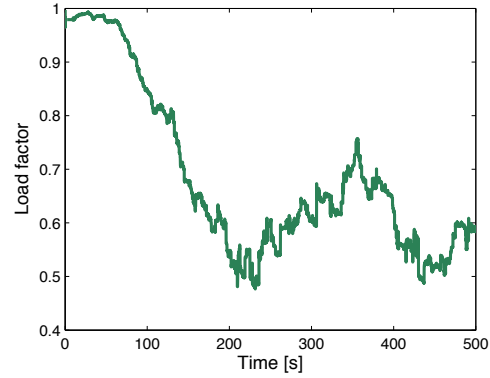


Figure 5.43: CP-AC: Load factor for central cell

### 5.7.3.2. Central cell load factor

In figures 5.42 and 5.43, load factor for central cell in both AC schemes are shown. The fast variations are due to interferences in the system and the slow variations are due to users mobility. The pictures show that load factor is higher for the CP-AC algorithm, since with the application of HP-AC a great number of new users are being blocked. In consequence the load of the system decrease in HP-AC.

### 5.7.3.3. Global system blocking probabilities

As it was explained, this plot depicts the probabilities associated to each one of the situations that can be considered in the scenario under study. Therefore and in the same way, the analysis made in the uniform scenario section above, four are the probabilities that have been analyzed.

Graphs 5.44 and 5.45 depict the values of each one of the probabilities obtained during all the simulation time. As it is difficult to analyze the difference between the two proposed AC diagrams considering all the simulation time, different simulation time intervals have been analyzed separately.

In figure 5.46 the time interval shown correspond to 10 frames. Regarding to the time step between frames of about 100 ms, the total time interval considered is just a second. Due to the mobility model implemented and considering the pedestrian velocity of the users, the distance covered during this simulation time is approximately 0.8 meters. Although it represents a short distance, it is necessary to point out that slow variations in the users position can produce a pixel change and therefore a significant change in the cell condition and so even in the network situation.

Regarding to the handover scenario where an 80% of the users are located in SHO areas, it is logical to think that during the simulation time and due to the mobility model a great deal of users will leave the HO area turning in this way into no HO users, since an approximation to the new cell is observed.

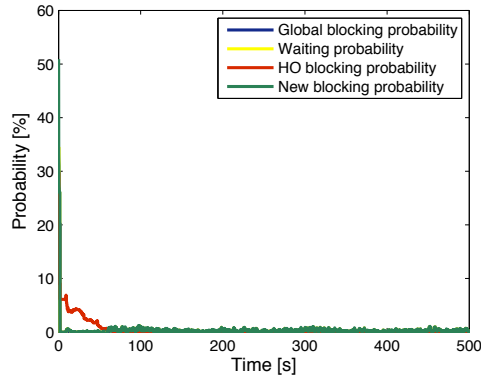


Figure 5.44: HP-AC: Global blocking probabilities, waiting probability, HO users blocking probability and new users blocking probability

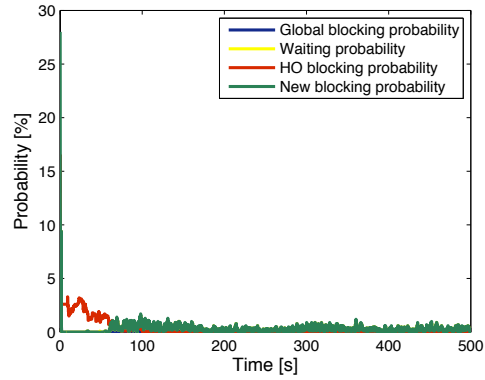


Figure 5.45: CP-AC: Global blocking probabilities, waiting probability, HO users blocking probability and new users blocking probability

Therefore, the users who must pass the AC threshold will be users in queue that were rejected in previous frames. For this reason, during the 10 first frames do not appear any global blocking user, since all the users that have been rejected by all the cells included in their ASs are located in queue. Consequently the probability of waiting users increases.

In following frames users classified as waiting ones have to pass the AC again as new users. In the same way, users that have covered a sufficient distance for changing the propagation conditions must also be evaluated.

Regarding to the CP-AC (results observed in figure 5.47), the blocking probability associated to new users is higher than the blocking probability associated to handover users. According to the AC threshold allocated to new users (0.6 load margin), it would be more logical an increment in the HO blocking probability, but this is not observed. The possible explanation is found in the mobility of users where some in a SHO situation can move to non SHO area. Therefore, a user in this situation that has to pass again the AC only consider a cell in his AS, so if this cell reject the connection the blocking probability associated to new users increase, but not the blocking probability associated to handover users since no HO cells have been evaluated.

For the HP-AC algorithm, the blocking probability associated to new users is higher than the blocking probability associated to handover users, since handover users are classified as a highest priority traffic class and can have at one's disposal the resources reserved for the lowest priority traffic class.

When the simulation time exceeds the maximum allowed time in queue the global blocking probability increases, since users in queue are not admitted by the system. Only when the maximum connection time is achieved a new user will be launched to the system. For this reason the global blocking probability associated to new users remains in 0.

In CP-AC results, the effect of the AC thresholds is well observed in figures 5.48 and 5.49, since the handover blocking probability is higher than the new blocking probability.

Next pictures corresponding to 5.51 and 5.52 only shows the new blocking probability

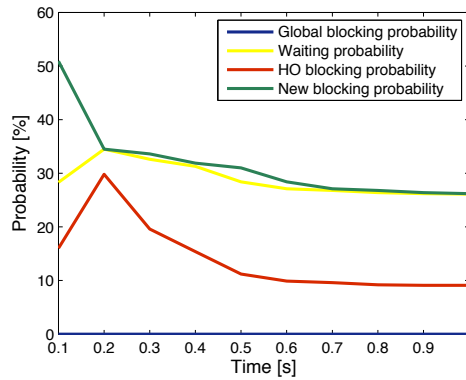


Figure 5.46: HP-AC: Global blocking probabilities from section 0 to 1 seconds

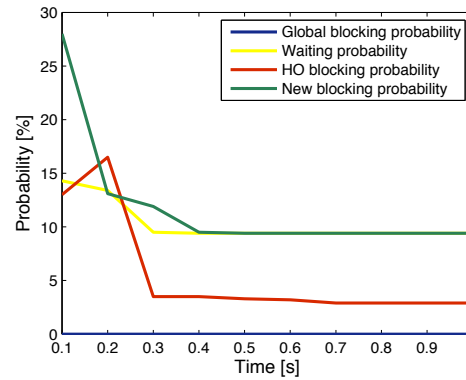


Figure 5.47: CP-AC: Global blocking probabilities from section 0 to 1 seconds

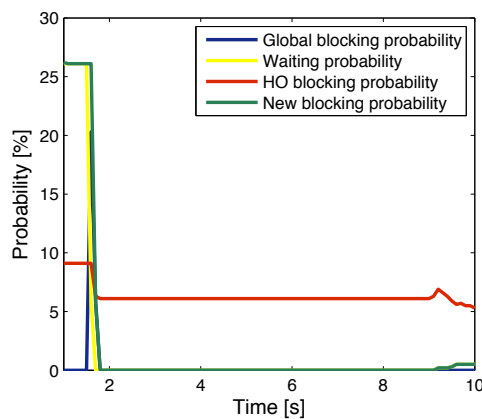


Figure 5.48: HP-AC: Global blocking probabilities from section 1 to 10 seconds

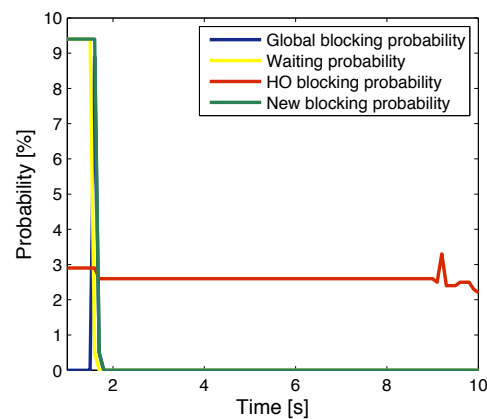


Figure 5.49: CP-AC: Global blocking probabilities from section 1 to 10 seconds

values and the handover blocking probability values for the rest of simulation time. The new blocking probability increases concerning to the handover blocking probability. This effect is due to the fact that when a new user is launched to the system his position in a SHO area is not guaranteed. Therefore a non HO position is more frequent since the scenario is formed by a 80% of no HO areas. Picture 5.50 depicts this effect. Different colors gather the new users that are launched in three specific frames.

When the situation gets a stable point, the handover blocking probability is always kept below the new blocking probability. In the HP-AC case, this is due to the priority established between classes while in CP-AC it is due to the thresholds assigned to each class.

It is important to point out that from approximately 60 seconds the handover blocking probability is higher for CP-AC than for HP-AC. It is due to the fact that for HP-AC handover users are classified as a high priority traffic class, so all the available resources can be used by them.

In figures 5.53 and 5.54 the waiting and global probability is shown. Basically these curves show the performance of the queue. During the simulation time users in queue appear and when the maximum allowed time in queue is exceeded these users are converted in

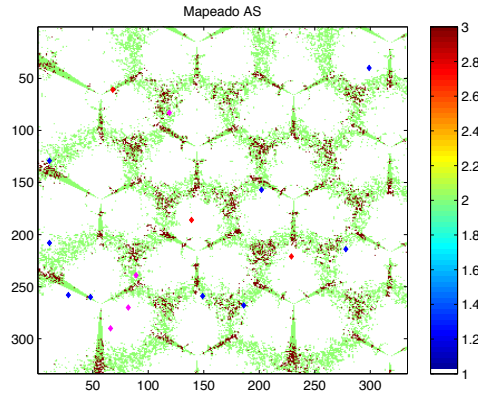


Figure 5.50: New users position

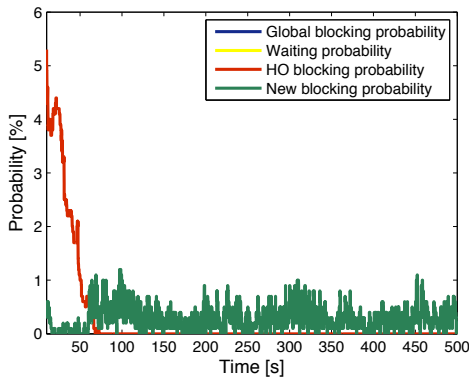


Figure 5.51: HP-AC: HO and new blocking probabilities from section 10 to 500 seconds

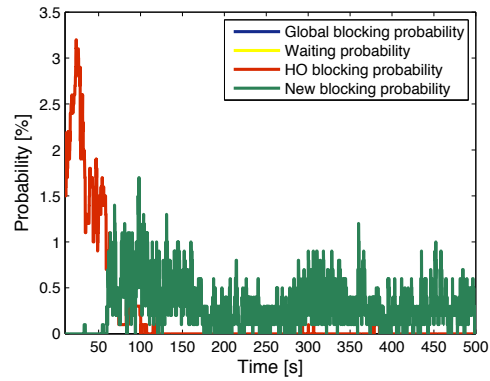


Figure 5.52: CP-AC: HO and new blocking probabilities from section 10 to 500 seconds

not admitted users.

Regarding to the algorithm under study a better performance of the HP-AC is observed for a SHO scenario, since the global blocking probability is lower than the global blocking probability obtained of applying the CP-AC algorithm.

#### 5.7.3.4. Dropping probability

Pictures 5.55 and 5.56 show the probability of dropping a new user. In both algorithms the probability of dropping a user in the DL direction is higher than the probability of dropping a user in the UL direction. From picture 5.23 and regarding the main parameters that features the scenario, is obvious that the number of users launched to the system overloads the maximum capacity calculated for the DL direction under this traffic situation. This implies an increment in the number of dropping users.

As a conclusion, new AC algorithms have been implemented in order to enhance the capacity of the network. The improvement of the network is achieved by resource allocation that ensure QoS requirements to each one of the call classes.



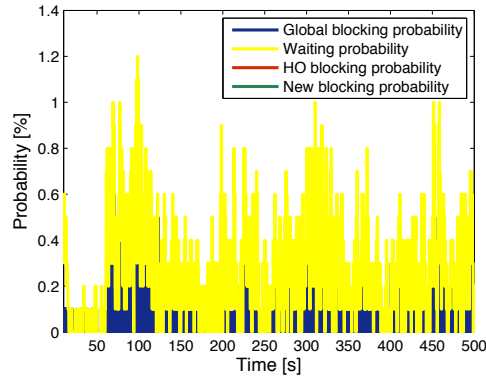


Figure 5.53: HP-AC: HO and new blocking probabilities from section 10 to 500 seconds

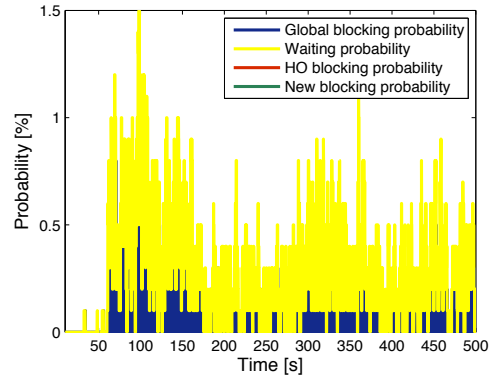


Figure 5.54: CP-AC: HO and new blocking probabilities from section 10 to 500 seconds

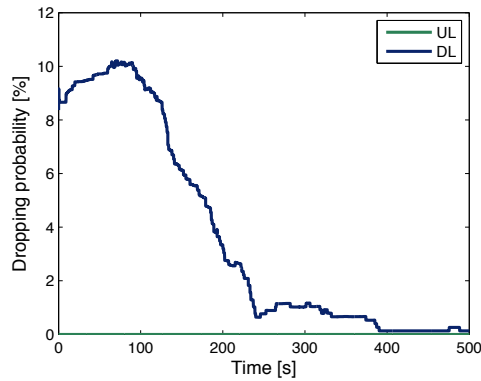


Figure 5.55: HP-AC: dropping probability

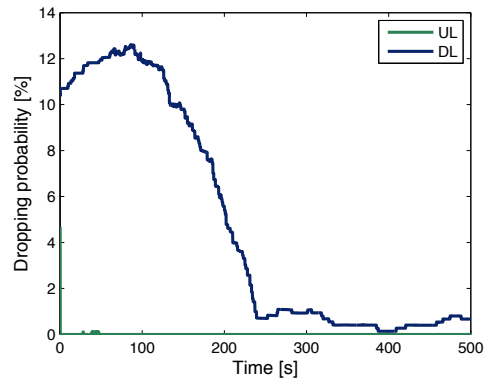


Figure 5.56: CP-AC: dropping probability

Dynamic AC is based on the ATS philosophy and applies an optimization of the load factor thresholds. The other two algorithms evaluated, CP and CS, are based on static algorithms with fixed thresholds or load margins depending on the scenario behavior.

From results of the implemented HP and CP algorithms, the CP-AC is better for scenarios with a uniform behavior. The users belonging to each call class is very variable and therefore patterns cannot be easily predicted.

Regarding to the handover scenario, the HP-AC is more suitable because it ensures a better use of the resources than in CP-AC where inefficient utilization of the resources could occur.

An algorithm based on a DP-AC could be a good solution in order to overcome the shortcomings of the previous algorithms.



## CONCLUSIONS

The starting point of the final career project is the simulation tool created in the previous TFC. This simulation tool is named SIMNA UMTS and was about a static simulator, based on the Montecarlo model, that did not have temporary evolution. Statistics were obtained from different snapshots of the system by repeated random tests. The initial objective of the simulation tool was to develop a graphical interface, friendly and simple, thought to student purposes.

In the present PFC, additional functionalities have been added to the first version of the SIMNA UMTS. The main purpose is to create a program code that allows to analyze significant results obtained from different simulation scenarios.

During the development of this project a deep study of the PC and the AC has been carried out. They represent two of the main algorithms that manage the allocation of radio resources in current 3G cellular networks and more specifically in UMTS networks. The UMTS network simulator implement these two important algorithms and all the stages that take part in a real UMTS network deployment are considered.

The scenario evaluated is a 3GPP based, urban and macrocell with an area of 5x5 km and 42 cells in a regular layout. To simulate propagation losses a COST231-Hata propagation model considering a 2 GHz carrier and radiation patterns from commercial antennas have been used. In addition, the effect of the shadows produced by buildings, mountains or other similar obstacles usually found in real scenarios has been simulated considering correlation over the two dimensions of space X and Y and also introducing correlation among the shadowing losses perceived from different sites. Consequently, the propagation losses have been careful and realistically modeled. Although these are the particular features of the environment used for the simulations in this project, the implemented graphic user interface allows to select among several models with different degrees of refinement and computational times.

The fast fading effects produced by multipath propagation existing in wireless communication systems are taken into account through the values of  $E_b/N_0$  targets demanded by users. Not all of them require the same  $E_b/N_0$  to achieve the same bit error rate (BER), because channel conditions are different.

The traffic that could be present in the network is controlled by the simulation tool. It allows to determine the number of users that will be launched to the system and the service associated to each UE. In order to provide dynamism to the network two different mobility models have been developed.

The traffic demand is asymmetric and depends on the service associated to each user. According to the service, the resources consumption is different in up- and DL. Four typical services have been considered.

Three RRM strategies have considered SHO, PC and AC. In future updates of the simulator congestion control and DL codes management could be introduced with some minor changes. In a first stage the algorithms have been implemented and tested in order to evaluate their impact on the network performance. During a second stage, an automate-

tuning of the SHO parameters is proposed in order to enhance the performance of the network. In the same way, two new AC strategies have been implemented with the same goal.

Related to the PC, maximum capacity algorithms for UL and DL have been developed and implemented. This algorithm allows to obtain detailed information about the network performance and its behavior in front of different situations, also is useful to determine the appropriate number of users that must be launched to the system to carry out a specific study.

It has been seen how AS parameters have an influence over the system capacity. The maximum capacity in the UL increases as AS size and macrodiversity parameters are higher. Otherwise in the DL, the more BSs are able to include in the AS, system capacity diminishes. In short, it is interesting to find a balanced situation between the UL and the DL. It has been found that this closely depends on the services usage that can lead the system to up- or DL limited situations. Consequently the optimum balanced point is different depending on the service mix.

The problem observed in classical SHO strategies is the rigidity of the mechanism, which cannot adapt to variations in the traffic patterns. Thus the utilization of the radio interface is not maximized.

Given this, a generic ATS has been proposed and implemented for the SHO case in order to achieve the optimal utilization of resources depending on the scenario behavior. The functional architecture of this ATS has been described in depth. It is composed of three main blocks: learning & memory, monitoring and control stage. The first stage consists in gathering measurement from the network to find statistics and trends. This has been approximated by means of static simulations. The maximum capacity for different service mix configurations has been found as long as the optimum AS configurations. The monitoring stage aims at detecting when the SHO should be changed. Initially, two initial tests were done, without applying ATS and applying a blind ATS. The appropriate KPIs were derived from the results. These KPIs are monitored and whenever certain thresholds are not met an alarm was triggered to the control block so that SHO parameters were appropriately modified. In particular, once the limiting link is detected ATS force a reconfiguration of the SHO parameters in order to favor it.

Several scenarios were evaluated and a final study case was chosen for being realistic. The service mix evolved along time from an UL limited situation to a DL one. The developed ATS was applied to dynamically adjust SHO parameters and increase the network performance so that congestion control algorithms can be delayed. In this sense ATS was shown to be an effective pre-congestion-control strategy. Therefore, the results obtained shows a considerable increment in the network capacitance applying this dynamic automated-tuning of SHO parameters.

Finally, a second study on AC has been also done with the developed simulator. New AC algorithms have been implemented in order to enhance the capacity of the network. The improvement of the network performance is achieved by resource allocation that ensure QoS requirements to each one of the call classes.

Dynamic AC was proposed to provide flexibility to the current AC algorithm. This strategy

is based in a dynamic AC threshold that fix the optimum threshold in real time according to the current service mix. This solution ensures the highest capacity and best performance of the network if the evolution of service mix during the day is known.

The base of the previous algorithm is indeed the ATS philosophy. It needs a previous learning from the network in order to apply the optimization of the threshold. On the other hand, other two more complex strategies were implemented, known as CP and CS. These strategies are based on static algorithms where fixed thresholds or load margins were applied in order to note their advantages and drawbacks depending on the scenario behavior: uniform or handover.

From our results, several conclusions have been drawn. CP-AC scheme is more suitable for scenarios where UEs are uniformly distributed. The number of users belonging to each call class is very variable and therefore patterns cannot be easily predicted.

According to the mobility behavior (pedestrian, vehicular,) a user can change rapidly from being a *new* user to be a *HO* or *normal* user if the mobility cause that its position remains in the same place during all the simulation period. In this way, it is better to assign separated resources for each call class regarding to each call class appearance probabilities. In the uniform scenario studied, an 80% is composed by non HO areas. Because of that, it is logical to reserve more resources to new users with only one BS in their AS. If there are not resources allocated for new users in the uniform scenario, it could not be ensured the new incoming calls, because users with a connection in course that add HO cells in their AS could use the free resources. Therefore the QoS requirements for each call class are not achieved.

Regarding to the scenario in which most of users were in a handover situation, the HP-AC scheme is better than CP-AC, because keep the global blocking probability lower. It is better not to reserve resources to new users because HO ones have major priority and in HP-AC they can use free resources from new users, assuring this way a better use of the resources than in CP-AC where inefficient utilization of the resources could occur.

Finally and in reference to the environmental impact, it is necessary to underline that the simulation tool developed in this project, has been designed to contribute to a correct UMTS network planning, minimizing the number of Nodes-B required to ensure coverage to a specific area. This improvement allows a significant reduction in the energetic consume (KWh/BTS) and in the radioelectric emission. Furthermore, the visual impact is reduced and in consequence the urban landscape can be improved.



## FUTURE WORKS

Regarding the possible future works, the authors of this final career project mainly suggest a set of options to enlarge the simulations capabilities to continue improving the new RRM techniques disclosed.

1. The scenario creation of the project is done in a way that all BSs are located uniformly, and at the same height. To do simulations in a realistic scenario would be an interesting option, taking into account real information about real BSs locations, ground heights and clutter data. This considerations would modify the propagation losses of the system reaching a more realistic behavior.
2. Following the previous proposal, if a realistic scenario is carried out, also real data for traffic generation could be gathered according to the real behavior of the cities.
3. Another alternative located in the same line could be to improve the traffic model implemented. For example for conversational users it could be applied a Poisson distribution for the arrival call rate. In the same way, a exponential distribution for the service time could be implemented as it is explained in [6]. Other more complex models could be programmed for data services.
4. Regarding SHO auto-tuning more study cases could be simulated. For example, it could be analysed the optimum parameters to be applied when demonstrations or sportive events are celebrated. This situations clearly imply important variations on the usual traffic patterns.
5. Also it could be a good idea to do the necessary in order to maintain the handover behavior in the algorithms carried out during the AC schemes simulations. In this way, results of HP-AC and CP-AC could be compared for longer simulation times.
6. Finally, QP-AC and DP-AC algorithms could be also programmed in order to complete all the AC schemes comparison. DP-AC would be a good solution to do an automated tuning of resources allocation.





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