Bachelor Thesis

INVESTIGATION OF HSDPA SCHEDULERS

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November 2007 - October 2008
Acknowledgements

First, I have to thank Markus Rupp and all the staff of the institute for their warm welcome. During the six months that I was in Vienna I felt as much comfortable as I could imagine.

I would also like to express my deep gratitude to Martin Wrulich for his constant guidance, advice and patience in the development of this bachelor thesis. But I would like to thank especially his support, not only with the work, during all my experience abroad.

I am infinitely thankful to my parents Miguel Ángel and Rosa, who have given me their love and support during all my life. I would also like to express my gratitude to my sister Paula, who tried to talk with me everyday, my brother Oscar and Barbara, who visit me in Vienna, and my grandparents Luis and Milagros, who have always given me their unconditional love.

I want to thank all the friends I met in Vienna (especially Alberto, Cristina and Corinna), who did that this experience was unforgettable. I am grateful to my friends from Spain for his support and interest for me, especially Maxi, Victor, Carlos, Irene, Blanca and Nacho.

Finally, the most special mention is dedicated to Elsa, who shared with me this special experience and has been by my side since the beginning of my career. Her support, care and love have been very important during all these years.
Abstract

In this bachelor thesis, different HSDPA schedulers located in the MAC-hs of the Node-B, shall be investigated. For this purpose, the existing SISO HSDPA simulator, developed for Mobilkom Austria AG has to be extended from a snapshot based simulator to a time-based simulator. In principle, a Jakes fading generator together with the necessary changes in the simulator structure to handle fading traces over time had to be developed. With this functionality, different scheduler metrics and their performance in terms of the sum cell throughput shall be investigated within the HSDPA simulator.
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Abbreviations

16QAM - 16-Quadrature Amplitude Modulation
3G - Third Generation
3GPP - Third Generation Partnership Project
AMC - Adaptive Modulation and Coding
ARP - Allocation and Retention Priority
ARQ - Automatic Repeat Request
AWGN - Additive White Gaussian Noise
BLER - Block Error Rate
BS - Base Station
BTS - Base Transceiver Station
CDMA - Code Division Multiple Access
CmCH-PI - Common Transport Channel Priority Indicator
CPICH - Common Pilot Channel
CQI - Channel Quality Indicator
CSI - Channel State Information
DCCH - Dedicated Control Channel
DTCH - Dedicated Traffic Channel
EsNo - Signal-to-Noise Ratio
FCS - Fast Cell Selection
FCSS - Fast Cell Site Selection
FP - Frame Protocol
GGSN - Gateway GPRS Support Node
GSM - Global System for Mobile Communications
HARQ - Hybrid Automatic Repeat Request
HSDPA - High-Speed Downlink Packet Access
HS-DPCCH - Dedicated High-Speed Physical Control Channel
HS-DSCH - High-Speed Dedicated Shared Channel
HSPA - High-Speed Packet Access
HS-PDSCH - High-Speed Physical Downlink Shared Channel
HS-SSCH - High-Speed Shared Control Channels
HSUPA - High-Speed Uplink Packet Access
IR - Incremental Redundancy
ITU - International Telecommunication Union
Max C/I - Maximum Carrier to Interference
MCS - Modulation and Coding Scheme
MIMO - Multiple Input Multiple Output
MS - Mobile Station
PDP - Power Delay Profile
PDU - Protocol Data Unit
PF - Proportional Fair
QoS - Quality of Service
QPSK - Quadrature Phase-Shift Keying
RLC - Radio Link Control
RNC - Radio Network Control
RR - Round Robin
RRM - Radio Resource Management
SAW - Stop And Wait
SF - Spreading Factor
SGSN - Serving GPRS Support Node
SINR - Signal to Noise and Interference Ratio
SISO - Single Input Single Output
SNR - Signal to Noise Ratio
SPI - Scheduling Priority Indicator
TCP - Transmission Control Protocol
TBS - Transport Block Size
TTI - Transmit Time Interval
UE - User Equipment
UMTS - Universal Mobile Telecommunications System
UTRAN - UMTS Terrestrial Radios Access Network
WCDMA - Wideband Code Division Multiple Access
WSS - Widesense Stationary
Chapter 1

Introduction

1.1 Introduction

Since some years ago data services had an enormous rate of growth and they became the main source of traffic load in 3G mobile cellular networks. To provide these data services in 3G systems, high spectral efficiency solutions are required to increase the capacity of the radio access network and to support for high data rates. For this purpose, 3GPP introduced a new feature in the Release 5 specifications called High-Speed Downlink Packet Access (HSDPA). The three main targets of the HSDPA concept are to increase the peak data rates, improve the quality of service, and enhance the spectral efficiency for downlink packet traffic.

The HSDPA concept appeared as a compendium of diverse features to improve the user and the system performance. The most important features are: an Adaptive Modulation and Coding (AMC) scheme, a fast physical layer Hybrid ARQ mechanism (HARQ), and a reduction of the Transmission Time Interval (TTI) to 2 ms. In addition, the Packet Scheduler functionality is now located in the Node-B, which allows the network to react to instantaneous variations of the users’ channel quality.

Considering the importance of HSDPA, in a collaboration of the institute of Communications and Radio-Frequency Engineering and Mobilkom Austria AG, a SISO HSDPA system-level simulator was developed. The simulator is based on MATLAB and allows for the simulation of a mixed traffic network, i.e. UMTS and HSDPA.

Mobile radio channel simulators are commonly used in the laboratory be-
cause they allow system tests and evaluations which are less expensive and more reproducible than field trials, [1].

1.1.1 Why MATLAB?
MATLAB is a widely used tool in the engineering community. It is an interpreted language for numerical computation and it allows one to perform numerical calculations, and visualize the results without the need for complicated and time consuming programming. MATLAB allows its users to accurately solve problems, produce graphics easily and produce code efficiently. The original concept of a small and handy tool has evolved to become an engineering workhorse. It is now accepted that MATLAB and its numerous toolboxes can replace or enhance the usage of traditional simulation tools for advanced engineering applications.

1.2 Objectives
At the beginning, the main goal of the simulator was to evaluate the throughput performance of HSDPA in a mixed traffic network. Once the first results were achieved, it was possible to think about ways to improve the simulator, to get a more realistic system. One of the most interesting ideas was to investigate one of the main characteristics of HSDPA: the Packet Scheduler functionality, located in the Node-B.

The initial version of the simulator was based on so-called "snapshot" simulations, not allowing for continuous traces over time. Without these, the schedulers investigation was not possible. So we had to separate the work in two different parts:

- Change the functionality of the simulator: the first part of the development was to convert the initial SISO HSDPA simulator into a time-based simulator. Jakes fading generator, a new shadow fading generator and the necessary changes in the simulator structure to handle the simulations over time were implemented in order to get this new functionality working.

- Investigation of HSDPA schedulers: with the time-based simulation up and running, we could start to implement the different scheduler algorithms that we consider the most common and important ones: maximum
C/I scheduler, round robin scheduler and proportional fair scheduler. Furthermore, we investigated these schedulers when they only serve one user (in the classical way) or when they serve more than one user (in the multiuser way: with 2, 3 or 4 served users. Also called "multicode" scheduling). We test their performance in terms of fairness and sum cell throughput. Proposals on packet scheduling in wireless environments have been proposed in [2], [3], [4] or [5].

I. Change the functionality of the simulator:

![Snapshot mode ➔ Time mode]

II. Investigate some HSDPA schedulers:

![Classical or multiuser ➔ Round Robin ➔ Max C/I ➔ Proportional Fair]

Figure 1.1: Basic scheme with the thesis’ objectives

In Figure 1.1 we can see a basic scheme of the objectives that this work wants to achieve. Both parts of the work were implemented aiming for the most efficient way of programming, in order to control as much as possible the potential problems that MATLAB could have with limited memory space and/or with the simulation speed.
1.3 Structure of the Thesis

This subsection provides an outline of this thesis. It has been subdivided in five different chapters:

- **Chapter 1: Introduction.** A short introduction of the work environment, the objectives and the structure of the bachelor thesis is presented.

- **Chapter 2: HSDPA Basics.** This chapter covers the High-Speed Downlink Packet Access (HSDPA) principles and the HSDPA key technologies.

- **Chapter 3: HSDPA Scheduling.** The HSDPA Packet Scheduler functionality, one of the most important HSDPA technologies is explained, which is the main subject of this thesis. It describes the theory of the scheduler algorithms investigated in this work.

- **Chapter 4: HSDPA Simulator.** In this chapter we state everything relevant to our work about the SISO HSDPA simulator: the initial version, the changes implemented to get the time mode functionality and the new time mode performance.

- **Chapter 5: Investigation of HSDPA Schedulers.** This chapter shows the different results and tests done in this work.

- **Chapter 6: Conclusions.** Some conclusions about the new simulator and the HSDPA schedulers investigation are presented.
Chapter 2

HSDPA Basics

2.1 Introduction

HSDPA is the short name for High-Speed Downlink Packet Access, it is the evolution of the third generation (3G) technologies (actually, HSDPA is also called 3.5G), and is considered the previous step before the fourth generation (4G), the future High-Speed Mobile Network. HSDPA and High-Speed Uplink Packet Access (HSUPA) are the components of the family called High-Speed Packet Access (HSPA). HSPA is part of the WCDMA 3G network and is an upgrade of the network infrastructure, [6].

The target of HSDPA is to increase the peak data rates (current HSDPA deployments support downlink speeds of 1.8, 3.6, 7.2 and 14.4 Mbps), improve the quality of service, and enhance the spectral efficiency for downlink asymmetrical and bursty packet data services compared to UMTS. Also, HSDPA was designed to co-exist with R’99 in the same frequency band of 5 MHz. It has to be noted that the downlink speed is the total available speed within one sector, which consequently is distributed between all active users.

HSDPA is able to satisfy the most demanding Multimedia applications such as email attachments, PowerPoint presentations or web pages. HSDPA 3.6 Mbps network can download a typical music file of around 3MB in 8.3 seconds and a 5 MB video clip in 13.9 seconds. Speeds achieved by HSDPA top 14.4 Mbps but most network operators at the moment provide speeds up to 3.6 Mbps, with the rollout of 7.2 Mbps quickly growing. Figure 2.1 shows the current deployment of HSPA networks in the world and the HSDPA data rates supported. In Austria four HSDPA operators are in service, with Mobilkom Austria, Hutchison 3 Austria and ONE Austria serving HSDPA data.
rates of 7.2 Mbps, and only Mobilkom Austria serving HSUPA (with a data rate of 1.4 Mbps). Currently only Telstra (in Australia) is serving HSDPA data rates of 14.4 Mbps.

![Graph showing 220 HSDPA networks in 92 countries](image)

**Figure 2.1:** Current HSDPA networks and HSDPA data rates, [6]

One important thing to note is that compared to UMTS, the spectral efficiency is significantly increased, and this leads to more users being able to use high data rates on a single carrier. The fundamental techniques used in HSDPA to achieve this are Adaptive Modulation and Coding (AMC), extensive multi-code operation and a fast and spectrally efficient retransmission strategy. In addition, a fast scheduler coordinates resource assignment of the HS-DSCH (High-Speed Downlink Shared Channel) among the users on a TTI basis (a short TTI of 2 ms can be used). A deeper analysis of the HSDPA key technologies will be developed in Section 2.5.
2.2 HSDPA Standardization in 3GPP

HSDPA was standardized as part of 3GPP Release 5 with the first specification version in March 2002 and the first commercial HSDPA networks were available at the end of 2005. Many enhancements of HSDPA have been introduced in the following Releases (6, 7 and 8). Figure 2.2 illustrates the main dates and the evolution of the downlink peak data rates in WCDMA and HSDPA.

![Figure 2.2: HSDPA standardization and data rate evolution in WCDMA and HSDPA, [7].](image)

3GPP creates the technical content of the specifications, but it is the organizational partners that actually publish the work. In addition to the organizational partners, there are also so-called market representation partners, such as the UMTS Forum, part of 3GPP. The work in 3GPP is based around work items, though small changes can be introduced directly as ”change requests” against specification. With bigger items a feasibility study is done usually before rushing in to making actual changes to the specifications, [7].

A feasibility study for HSDPA was started in March 2000 in line with 3GPP principles, having at least four supporting companies. The companies supporting the start of work on HSDPA were Motorola and Nokia from the vendor side and BT/Cellnet, T-Mobile and NTT DoCoMo from the oper-
ator side. During the course of work, obviously much larger numbers of companies contributed technically to the progress. This feasibility study was finalized for the TSG RAN plenary for March 2001 and in the HSDPA study item there were issues studied to improve the downlink packet data transmission over Release 99 specifications. Topics such as physical layer retransmissions and BTS-based scheduling were studied as well as adaptive coding and modulation. The study also included some investigations for multi-antenna transmission and reception technology, titled MIMO (Multiple Input Multiple Output), as well as on Fast Cell Selection (FCS), [7].

2.3 HSDPA Concept

In the new transport channel (HS-DSCH), two of the main features of the WCDMA technology have been excluded: closed loop power control and variable spreading factor. On the other hand, some features have been included in the HS-DSCH, like AMC or the shorter TTI. The figure 2.3 shows the fundamental features to be included and excluded in the HS-DSCH of HSDPA.

![Figure 2.3: Fundamental features included and excluded in HS-DSCH of HSDPA.](image-url)
The fast power control used in WCDMA stabilizes the received signal quality, measured by the EsNo (which is some form of signal-to-noise ratio), increasing the transmission power during the fades of the received signal level. This causes peaks in the transmission power and a power rise, reducing the total network capacity. In addition, the operation of power control imposes to keep certain headroom in the total Node-B transmission power, in order to accommodate its variations. The exclusion of power control avoids the power rise and the cell transmission power headroom. However, HSDPA requires other link adaptation mechanisms to adapt the transmitted signal parameters to the continuously varying channel conditions.

With the Adaptive Modulation and Coding (AMC) mechanism, the modulation and the coding rate are adapted to the instantaneous channel quality instead of adjusting the power. Another mechanism used for the link adaptation is the transmission of multiple Walsh codes (which are used to uniquely define individual communication channels, [8]).

Without the power control, the channel quality variations during a TTI are reduced by shortening its time duration to 2 ms (in WCDMA the minimum is 10 ms). A fast Hybrid ARQ technique is included, which rapidly retransmits the missing transport blocks and also combines the soft information from the original transmission with any subsequent retransmission before the decoding process. The network may include additional redundant information that is incrementally transmitted in subsequent retransmissions (i.e. Incremental Redundancy).

To be able to obtain recent channel quality information, the MAC functionality in charge of the HS-DSCH channel is moved from the Radio Network Control (RNC) to the Node-B. Obtaining this recent information permits the link adaptation and the Packet Scheduling entities to track the user’s instantaneous radio conditions. The fast channel quality information allows the Packet Scheduler to serve the users only when their conditions are favourable. This fast Packet Scheduling and the time-shared nature of the HS-DSCH enable a form of multiuser selection diversity with important benefits for the cell throughput. The move of the scheduler to the Node-B is a major architecture modification compared to the Release 99 architecture.
2.4 HSDPA Architecture

HSPA is deployed on top of the WCDMA network either on the same carrier or, for a high-capacity and high bit rate solution, using another carrier. In both cases, HSPA and WCDMA can share all the network elements in the core network and in the radio network including base stations, Radio Network Controller (RNC), Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). WCDMA and HSPA are also sharing the base station sites, antennas and antenna lines. Because of the shared infrastructure between WCDMA and HSPA, the cost of upgrading from WCDMA to HSPA is very low compared with building a new standalone data network, [7]. The figure 2.4 shows the Radio Resource Management (RRM) architecture of HSDPA.

Figure 2.4: HSDPA RRM (Radio Resource Management) architecture in Release 6 from [7].

In HSDPA the HS-DSCH is directly terminated at the Node-B, which is different compared to all the transport channels belonging to the Release 99 architecture, which are terminated at the RNC. The MAC layer controls the resources of this channel (also called MAC-hs), and is located in the Node-B (like we can see in the figure 2.5). This location of the MAC-hs in the Node-B enables to execute the HARQ protocol on the physical layer, which permits faster retransmissions. The new location of the MAC-hs also allows
the acquisition of recent channel quality reports that enable the tracking of
the instantaneous signal quality for low speed mobiles. In Release 99 the
teamer retransmissions and channel quality reports were not possible because
the MAC-hs was located at the RNC.

The functions of the MAC-hs layer are as follows: handle the HARQ func-
tionality of every HSDPA user, distribute the HS-DSCH resources between
all the MAC-d flows according to their priority (i.e. Packet Scheduling), and
select the appropriate transport format for every TTI (i.e. link adaptation).
The radio interface layers above the MAC are not modified from the Release
99 architecture because HSDPA is intended for the transport of logical chan-
nels. The MAC-hs also stores user data to be transmitted across the air
interface, which imposes some constraints on the minimum buffering capabi-
lities of the Node B. The move of the data queues to the Node-B creates the
need of a flow control mechanism (HS-DSCH Frame Protocol) that aims at
keeping the buffers full. The HS-DSCH FP handles the data transport from
the serving RNC to the controlling RNC (if the Iur interface is involved) and
between the controlling RNC and the Node-B, [9].

Finally, it is important to mention that the HS-DSCH does not support
soft handover due to the complexity of synchronizing the transmission from
various cells. The HS-DSCH may optionally provide full or partial coverage
in the cell.
2.5 HSDPA Technologies

This section will give a general overview of the technologies integrated in the HSDPA concept. Each technology by itself provides a significant performance enhancement in the network, but it is their complementary characteristics that convert HSDPA in one important step in the evolution of WCDMA. The following list includes the technical aspects behind the HSDPA concept:

- New HSDPA Physical and Transport Channels.
- Adaptive Modulation and Coding (AMC).
- Link Adaptation.
- Fast Hybrid Automatic Repeat Request (H-ARQ).
- Fair and Fast Scheduling at Node-B.
- Short Transmission Time Interval (TTI).

2.5.1 New HSDPA Physical and Transport Channels

To support HSDPA the following new transport channels have been defined:

- **HS-DSCH or High-Speed Downlink Shared channel**: The High-Speed Downlink Shared Channel is a downlink transport channel shared by one or two UEs. The HS-DSCH is associated with one downlink DPCH, and one or two Shared Control Channels (HS-SCCH). The HS-DSCH is transmitted over the entire cell or over only part of the cell using for example beamforming antennas.

To support HSDPA new Physical Channels have been defined:

- **HS-PDSCH or High Speed Physical Downlink Shared Channel**: This is a downlink channel which is both time and code multiplexed. The channelization codes have a fixed spreading factor, SF = 16. Multi-code transmissions are allowed that translate to UE multiple channelization codes being assigned in the same TTI, depending on the UE capability and channel condition. The same scrambling sequence within one cell is applied to all the
channelization codes that form the single HS-DSCH. If there are multiple UE’s then they may be assigned channelisation codes in the same TTI (multiplexing of multiple UE’s in the code domain). When it is both time and code shared, two to four users can share the code resources with the same TTI, as we can see in the figure 2.6. The signalization on the HS-SCCH restricts Multi-user scheduling to be ≤ 4.

Figure 2.6: HS-DSCH code and time shared.

- HS-DPCCH or dedicated HS-Physical Control Channel: This is an uplink channel that carries the acknowledgements of the packet received on HS-PDSCH and also the CQI (Channel Quality Indication). The HS-DPCCH uses a fixed spreading factor of 256 and has a 2-ms/3-slot structure. The CQI estimation has to be transmitted by the UE every 2 ms frame. This information is very important as it ensures reliability and impacts power capacity. The first slot is used for the HARQ information. The two remaining slots are for CQI use. The power control from non-serving HSDPA cells may reduce the received HS-DPCCH power level in the soft handover region as the terminal has to reduce the uplink transmission power level if any of the cells in the active set sends a power-down command, [7].

With this enhancement, layer 2 (MAC layer) can map logical channels (DCCH and DTCH) onto the transport channel (HS-DSCH). Then, layer 1 in turn maps the transport channel (HS-DSCH) onto one or more physical channels
The physical layer creates HS-SCCH and HS-DPCCH to control and assist HS-DSCH transmission.

2.5.2 Adaptive Modulation and Coding (AMC)

In present WCDMA networks fast power control is used for radio link adaptation. This power control is done per slot in WCDMA. Basically, link adaptation is required because in cellular communication systems the SINR of the received signal at the UE varies over time by as much as 30-40 dB due to fast fading and geographic location in a particular cell. In order to overcome this fading effect and improve the system capacity and peak data rates, the transmitted signal to a particular UE is modified in accordance with the signal variations through a process called link adaptation.

In HSDPA the transmission power is kept constant over the TTI (length of the frame is referred to as Transmit Time Interval) and uses Adaptive Modulation and Coding (AMC) as an alternative method to power control in order to improve the spectral efficiency. HSDPA uses higher order modulation schemes like 16-Quadrature Amplitude Modulation (16QAM) besides QPSK. The modulation to be used is adapted according to the radio channel conditions. QPSK can support 2 bits/symbol where as 16QAM can support 4 bits/symbol, and hence twice the peak rate capability as compared to QPSK, utilizing the channel bandwidth more efficiently. Different code rates used are 1/4, 1/2, 5/8, 3/4. The Node-B receives the Channel Quality indicator (CQI) report and power measurements on the associated channels. Based on these information it determines the transmission data rate. In HSDPA, users close to the Node-B are generally assigned higher modulation with higher code rates (i.e. 16QAM and 3/4 code rate), and both decreases as the distance between UE and Node-B increases. Figure 2.7 shows the end-user data-rate, not considering the overheads (i.e. CRC check, protocol heads).
2.5.3 Link Adaptation

The link adaptation functionality must select the Modulation and Coding Scheme (MCS) and the number of multi-codes to adapt them to the instantaneous EsNo. The selection criterion can be based on various sources:

- **Channel Quality Indicator (CQI):** the UE sends in the uplink a report that provides implicit information about the instantaneous signal quality received by the user. The Channel Quality Indicator (CQI) specifies the Transport Block Size (TBS), number of codes and modulation from a set of reference ones that the UE is capable of supporting with a detection error no higher than 10% in the first transmission for a reference HS-PDSCH power. The RNC commands the UE to report the CQI with a certain periodicity.

- **Power Measurements on the Associated DPCH:** every user to be mapped on to HS-DSCH runs a parallel DPCH for signalling purposes, whose transmission power can be used to gain knowledge about the instantaneous status of the user’s channel quality. This information may be employed for link adaptation as well as Packet Scheduling. With this solution, the Node-B requires a table with the relative EbNo offset between the DPCH and the HS-DSCH for the different MCSs for a given BLER target.

- **Hybrid ARQ Acknowledgements:** the acknowledgement corresponding to the H-ARQ protocol may provide an estimation of the user’s channel quality too, although this information is expected to be less frequent than previous ones because it is only received when the user is served. Hence, it does not provide instantaneous channel quality information. Note that it also lacks the channel quality resolution provided by the two previous metrics.
since a single information bit is reported.

- **Buffer Size:** the amount of data in the MAC-hs buffer could also be applied in combination with previous information to select the transmission parameters.

For an optimum implementation of the link adaptation functionality, probably a combination of all the previous information sources would be need. If only one of them is to be selected, the CQI report possibly appears as the most attractive solution due to its simplicity for the network, its accuracy and its frequent report, [11].

### 2.5.4 Fast Hybrid Automatic Repeat Request (H-ARQ)

In HSDPA a physical layer retransmission functionality is added that improves the HSDPA performance and gives robustness against link adaptation errors. Now that the HARQ functionality is located in the MAC-hs entity of the Node B, the transport block retransmission process is significantly faster than RLC layer retransmissions because the RNC or the Iub are not involved. This benefit is directly reflected on a lower UTRAN transfer delay, which has obvious improvements at end-to-end level (i.e. for TCP).

The retransmission protocol selected in HSDPA is the Stop And Wait (SAW) due to the simplicity of this form of ARQ. In SAW, the transmitter persists on the transmission of the current transport block until it has been successfully received before initiating the transmission of the next one. Since the continuous transmission to a certain UE should be possible, N SAW-ARQ processes may be set for the UE in parallel, so that different processes transmit in separate TTIs. The maximum number of processes for a single UE is 8. The SAW protocol is based on an asynchronous downlink and synchronous uplink.

The Hybrid ARQ technique is totally different from the classical WCDMA retransmissions, because with HARQ the UE decoder combines the soft information of multiple transmissions of a transport block at bit level. Note that with this technique, the mobile terminal must store the soft information of unsuccessfully decoded transmissions, so it requires some memory space. There exist different Hybrid ARQ strategies:

- **Chase Combining:** First proposed in [12]. It involves the retransmission of the same data packet which was received with errors. Once the retransmission is received, the receiver combines the soft values of the original signal
and the retransmitted signal weighted by the SNR prior to decode the data packet.

The advantages are: each transmission and retransmission can be decoded individually (self-decodable), time diversity gain, and maybe path diversity gain. On the other hand, the disadvantage is that the retransmission of the entire packet is a wastage of bandwidth.

- **Incremental Redundancy (IR):** Incremental Redundancy is used to get an increased performance out of the available bandwidth. Here the retransmitted block consists only of the correction data of the original data and carries no actual information (Redundancy). The additional redundancy information is sent incrementally when the first, second, ... retransmissions are received with errors.

The advantage is that IR allows for a better decodability by decreasing the effective coderate after combining the redundancy information. The disadvantage is that the systematic bits are only sent in the first transmission and not in the retransmission which makes the retransmissions non-self decodable. So, if the first transmission is lost due to large fading effects there is no chance of recovering from this situation.

- **Partial Incremental Redundancy:** The partial IR is the combination of chase combining and IR. The disadvantage with IR is removed here by adding the systematic bits along with the incremental redundant bits in the retransmissions. This makes both original and retransmitted signals self-decodable.

### 2.5.5 Fast and Fair Scheduling at Node-B

Typically in WCDMA networks the packet scheduling is done at the RNC, but in HSDPA the packet scheduler is shifted to the Node-B, [10]. This makes the packet scheduling decisions almost instantaneous. In addition to this, the TTI length is shortened to 2 ms. Figure 2.8 shows the scheduling scheme.

A first approach for fair scheduling can be the Round Robin method where every user is served in a sequential manner, so that all the users get the same average allocation time. Another popular fair packet scheduling is proportional fair packet scheduling. A deeper analysis of the different HSDPA schedulers will be presented in Chapter 3.
2.5.6 Short Transmission Time Interval (TTI)

The length of the frame is referred to as Transmission Time Interval (TTI). The HS-DSCH which is added in the HSDPA standard uses a TTI length of 2 ms compared to 10 ms TTI length in Release’99. This is done to reduce the round trip time, increases the granularity in the scheduling process and for a better tracking of the time varying radio channel.
Chapter 3

HSDPA Scheduling

This bachelor thesis analyses the performance of the most common scheduling algorithms with different degrees of fairness among users. This chapter is organised as follows: Section 3.1 presents an introduction to HSDPA Packet Scheduling. In Section 3.2 we describe the different input information available for the scheduler. Finally, Section 3.3 presents the scheduling algorithms investigated in this bachelor thesis.

3.1 Introduction

As we have commented before, the Packet Scheduling functionality plays a key role in HSDPA. The features included in HSDPA and the new location of the scheduler in the Node-B open new possibilities for the design of this functionality for the evolution of WCDMA. The main goal of the Packet Scheduler is to maximize the network throughput while satisfying the Quality of Service (QoS) requirements of the users. In order to improve the cell throughput, the HSDPA scheduling algorithm can take advantage of the instantaneous channel variations and temporarily raise the priority of the favourable users. Since the users’ channel quality varies asynchronously, the time-shared nature of HS-DSCH introduces a form of selection diversity with important benefits for the spectral efficiency, [11].

In UMTS, the bearers do not set any absolute quality guarantees (such can never be given in a wireless transmission) in terms of data rate for interactive and background traffic classes. However the interactive users still expect the message within a certain time, which could not be satisfied if any of
those users were denied access to the network resources. Because of that, the introduction of minimum service guarantees for users is a relevant factor, and it is taken into consideration in the performance evaluation of the different HSDPA schedulers. The service guarantees interact with the notion of fairness and the level of satisfaction among users. Very unfair scheduling mechanisms can lead to the starvation of the least favourable users in highly loaded networks, and as described in [13], the starvation of users could have negative effects on the performance of higher layer protocols, like TCP. These concepts and their effect on the HSDPA performance are thus important for our investigation.

3.2 Parameters

The scheduler has diverse input information available, and we can classify them in four different groups: resource allocation, UE feedback measurements, QoS related parameters and miscellaneous, [11].

3.2.1 Resource allocation

- **HS-PDSCH and HS-SCCH Total Power**: it indicates the maximum power to be used for both HS-PDSCH and HS-SCCH channels. This amount of power is reserved by the RNC to HSDPA. Optionally, the Node-B might also add the unused amount of power (up to the maximum base station transmission power). Note that the HS-SCCH represents an overhead power (i.e. it is designated for signalling purposes), which could be non negligible when signalling users with poor radio propagation conditions.

- **HS-PDSCH codes**: it specifies the number of spreading codes reserved by the RNC to be used for HS-PDSCH transmission.

- **Maximum Number of HS-SCCHs**: it identifies the maximum number of HS-SCCH channels to be used in HSDPA. Note that having more than one HS-SCCH enables the Packet Scheduler to code multiplex multiple users in the same TTI, and thus increases the scheduling flexibility, though it also increases the overhead.
3.2.2 UE Channel Quality Measurements

the UE channel quality measurements aim at gaining knowledge about the user’s supportable data rate on a TTI basis. All the methods employed for link adaptation are equally valid for Packet Scheduling purposes (i.e. CQI reports, power measurements on the associated DPCH, or the Hybrid ARQ acknowledgements).

3.2.3 QoS Parameters

Scheduling Priority Indicator (SPI): this parameter is set by the RNC when the flows are to be established or modified. It is used by the Packet Scheduler to prioritise flows relative to other flows, [14].

Common Transport Channel Priority Indicator (CmCH-PI): this indicator allows differentiating the relative priority of the MAC-d PDUs belonging to the same flow, [15].

Discard Timer: is to be employed by the Node-B Packet Scheduler to limit the maximum Node B queuing delay to be experienced any MAC-d PDU.

Guaranteed Bit Rate: it indicates the guaranteed number of bits per second that the Node-B should deliver over the air interface provided that there is data to deliver, [14].

3.2.4 Miscellaneous

User’s Amount of Data Buffered in the Node-B: This information can be of significant relevance for Packet Scheduling to exploit the multi-user diversity and improve the user’s QoS.

UE Capabilities: They may be limiting factors like the maximum number of HS-PDSCH codes to be supported by the terminal, the minimum period between consecutive UE receptions, or the maximum number of soft channel bits the terminal is capable to store.

HARQ Manager: This entity signals the Packet Scheduler when a cer-
tain Hybrid ARQ retransmission is required.

3.3 Scheduling Algorithms

The operation task of the Packet Scheduler is to select the user to be served in every TTI. Given the users in the cell we can define the desired operation of the Packet Scheduler as to maximize the cell throughput while satisfying the QoS attributes.

The Packet Scheduler distributes the radio resources among the users in the cell. The scheduling algorithms that reach the highest system throughput tend to cause the starvation of the least favourable users (low G Factor users), [16]. This behaviour interacts with the fairness in the allocation of the cell resources, which ultimately determine the degree of satisfaction among the users in the cell. For this reason, in each scheduler evaluation we consider both parameters: fairness and sum cell throughput.

3.3.1 Maximum C/I

Scheduling strategies based on a C/I policy favour users with the best radio channel conditions in the resource allocation process. This scheduling algorithm serves in every TTI the user with largest instantaneous supportable data rate. This serving principle has obvious benefits in terms of cell throughput, although it is at the cost of lacking throughput fairness because users under worse average radio conditions are allocated lower amount of radio resources. Nonetheless, since the fast fading dynamics have a larger range than the average radio propagation conditions, users with poor average radio conditions can still access the channel.

3.3.2 Round Robin

In this scheme, the users are served in a cyclic order. This algorithm allocates equal resources to all users, regardless of their current channel conditions. This method outstands due to its simplicity, and ensures a fair resource distribution among the users in the cell.
3.3.3 Proportional Fair Throughput

The goal of this kind of scheduling is to give all users the same average throughput, regardless of their radio channel quality. Note that this fairness definition aims at the so-called max-min fairness. In [17] it is defined as "A set of user throughputs \{i\}, i=1,...,N is said to be max-min fair if it is feasible (a set of user throughputs is said to be feasible if the sum of all the users throughputs is lower or equal to the link capacity) and the throughput of each user \(\lambda_i\) can not be increased without maintaining feasibility and decreasing \(\lambda_j\) for some other user \(j\) for which \(\lambda_j < \lambda_i\)". This implies that users under more favourable radio conditions get the same throughput as users under less favourable conditions (i.e. users at the cell edge). This kind of scheduling can be seen as a form of inverse C/I scheduling, since users with a low C/I must be allocated larger amount of resources in order to get the same throughput. This scheduling method gives a fair user throughput distribution at the cost of a lower cell throughput [18].

<table>
<thead>
<tr>
<th>Scheduling Method</th>
<th>Serve Order</th>
<th>Radio Resources Fairness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum C/I</td>
<td>Serving according to highest</td>
<td>Unfair Distribution of radio resources</td>
</tr>
<tr>
<td></td>
<td>channel quality instantaneous</td>
<td>in favour of high G factor users</td>
</tr>
<tr>
<td>Round Robin</td>
<td>Round robin in cyclic order</td>
<td>Proportional throughput fairness &amp; same amount</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of average radio resources</td>
</tr>
<tr>
<td>Proportional Fair</td>
<td>Served according to highest relative</td>
<td></td>
</tr>
<tr>
<td></td>
<td>channel quality</td>
<td>Proportional throughput fairness &amp; same amount</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of average radio resources under certain assumptions</td>
</tr>
</tbody>
</table>

Table 3.1: Summary of analysed scheduling methods

It is important to note that the notion of fairness does not give any information of the total amount of resources a user can obtain, but on the relative distribution of resources among the users. This implies that, under the same degree of fairness in the resource distribution (i.e. fair resources, like Round
Robin), the user may obtain different amount of absolute resources as the number of users in the system varies with the average load. However, the end user is only concerned about his absolute performance, and not about his relative performance compared to the rest of the users.
Chapter 4

HSDPA Simulator

This chapter contains all the information about the HSDPA simulator, which was used to develop this work. After the initial simulator has been explained, we will explain some changes that were necessary in order to get the functionality that allows us to include the packet scheduling functions in the simulator. The chapter is organised as follows: Section 4.1 will explain the initial HSDPA simulator created by M.Wrulich et al. [19]. Section 4.2 describes how the new time-based simulator works, explaining all the small and big changes done to achieve the necessary new functionality.

4.1 Initial HSDPA Simulator

As we have commented before, in a collaboration of the institute of Communications and Radio-Frequency Engineering and Mobilkom Austria AG, a SISO HSDPA system-level simulator was developed. The simulator is developed in MATLAB and allows for the simulation of a mixed traffic network, i.e. UMTS and HSDPA.

The first goal of this simulator was to measure the HSDPA performance in a mixed traffic network, because as we explained in the Chapter 2, one of the advantages of HSDPA is that it can be deployed in an existing UMTS network. The operation of HSDPA within an existing WCDMA network is possible sharing the power amplifier and spreading codes.

In order to evaluate the network performance, the initial work investigates the average user throughput in a mixed carrier scenario (Release 4 DCH and
HSDPA) and deduce the optimum Node-B power split under different conditions by means of snapshot based network simulations. These results could be used by network operators for the cell operation planning, [19].

Now the initial SISO HSDPA simulator is going to be explained. As we can see in the figure 4.1 we can divide the process in three different parts: set options, precalculations and simulation loop.

Figure 4.1: Three main parts in the simulator process.

4.1.1 Set Options

The first function called in the simulator is the one which load all the necessary variables in the program, but before this step it is important to know exactly what we want to simulate. Once we have decided what kind of network we are interested in, and what kind of results we want to observe, we assign the according settings.

The settings are divided in four groups: network, channel, user equipment and simulator. With this intuitive division is easy to find and fix the values that we want to use in the simulation. Figure 4.2 shows a graphical scheme with these groups and their subdivisions.

Network Settings

This part includes all the elements belonged to the network:
Figure 4.2: Main elements in a mobile radio communication and their respective groups of variables.

- **R’99**: this group contains the variables of the Release ’99 part, like the bandwidth (5 MHz), the chiprate or the UMTS load in percent (respect the total of the network).

- **Node-B**: in this part the distance between the Node-Bs is fixed, also it is assigned the power distribution of the Node-B and the power level of each Node-B: the maximum power, the CPICH power and the common power.

- **Power distribution**: determines the power distribution among the neighboring Node-Bs, thus specifying the intercell-interference structure.

- **HSDPA**: in this part the number of users of the HSDPA simulation, the spreading factor of HSDPA transmissions (fixed at 16), the number of codes, the absolute HSDPA power and the TTI value (usually 2 ms) are specified.

- **MAC-hs**: has not been used in the initial simulator, but it is the place for the scheduling variables.
- **Network structure:** the number of base stations (7 or 19), the number of sectors for each base station (1 or 3) and the model used for the antenna gain pattern can be chosen here.

- **Other:** here is the place for some variables like the grid density, which determines the number of grid points for user positioning within the cell, or the G factor of the network.

**Channel Settings**

The channel settings are composed by the three fadings that influence the signals in the communications between the base station and the users, and the Power Delay Profile (PDP).

- **Deterministic fading:** once the model (COST231, Berger, fixed, exponent, tr25848 or none) is selected, the necessary variables to apply after the functions are assigned.

- **Shadow fading:** in this initial version of the simulator it is only possible to choose between the lognormal model or the lognormal moving model, loading their variables.

- **Fast fading:** here it is possible to select a simulation model for the Rayleigh fading or choose not to include the fast fading.

- **Power Delay Profile:** the chiprate, the oversampling factor and the model (pedestrian A or B, vehicular A or B) are specified.

**User Equipment Settings**

The groups included here define the general characteristics of the user equipments and some user specific things like the speed or the antenna type.

- **General:** includes the category class and the noise power seen by the receiver.

- **Movement:** it will be used in the improved version developed in this thesis.

- **Receiver:** selection of the receiver type and the number of fingers (in case of a Rake receiver).

- **Traffic:** will be used in further developments of the simulator.
Simulator Settings

The elements define in this part do not belong to the communication scheme, but determine some specific functions of the simulator.

- **Simulation type**: all the options are based on the snapshot scenario, but each type introduces a small variation in the simulation, i.e. ‘exhaustive snapshot’.

- **Link performance model**: the options are: ‘COST290’, where a simple link performance model based on COST 290 is used, or ‘none’, when no BLER (Block Error Rate) model is used (BLER = 0).

- **R’99 datarate model**: a simple data rate model described in [19].

- **Power distribution**: settings for the step-size of the power loop in the simulator.

- **Display/save results**: backup options.

4.1.2 Precalculations

Once all the variables are loaded and we know the kind of simulation we are interested in, it is time to prepare the network before the simulation loop starts. The elements created in this step are: Node-B positions, user positions, PDP for links in serving site, and the path losses for all the users.

Node-B positions

The Node-Bs position generation is implemented as an hexagonal network layout, with the serving Node-B in the centre of the network, and then one or two rings of concentrical Node-Bs around it (one ring if the total of BSs is 7, and two rings if there are 19 BSs) this is the cell layout type 2 according to [20]. One example of the option with 7 Node-Bs is shown in Figure 4.3.

Users positions

The user position generation consists on two steps. First a grid of points inside the cell (the first sector of the serving node) is created, like Figure 4.4. After this process the users position is drawn randomly, with as many users as we have decided in the settings that we want to simulate in the HSDPA traffic simulation.
Power Delay Profile (PDP)

In this part, the PDP for links in serving site, which is the same for all the users, are generated. The PDP is different for each ITU model [21].

Users pathloss

This function generates the pathlosses from all Node-Bs in the simulated network structure to the given users. The radio propagation model used in the simulator considers basically three different parts: deterministic pathloss $d$, shadow fading $s$, and small-scale fading with multiple paths and no correla-
<table>
<thead>
<tr>
<th>Delay tap 1 (ns)</th>
<th>Ped A</th>
<th>Ped B</th>
<th>Veh A</th>
<th>Veh B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coeff. tap 1</td>
<td>0.9923</td>
<td>0.6369</td>
<td>0.6964</td>
<td>0.3226</td>
</tr>
<tr>
<td>Delay tap 2 (ns)</td>
<td>110</td>
<td>200</td>
<td>310</td>
<td>300</td>
</tr>
<tr>
<td>Coeff. tap 2</td>
<td>0.1034</td>
<td>0.5742</td>
<td>0.6207</td>
<td>0.5737</td>
</tr>
<tr>
<td>Delay tap 3 (ns)</td>
<td>190</td>
<td>800</td>
<td>710</td>
<td>8900</td>
</tr>
<tr>
<td>Coeff. tap 3</td>
<td>0.0683</td>
<td>0.3623</td>
<td>0.2471</td>
<td>0.0301</td>
</tr>
<tr>
<td>Delay tap 4 (ns)</td>
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<td>1200</td>
<td>1090</td>
<td>12900</td>
</tr>
<tr>
<td>Coeff. tap 4</td>
<td>-</td>
<td>0.2536</td>
<td>0.2202</td>
<td>0.0574</td>
</tr>
<tr>
<td>Delay tap 5 (ns)</td>
<td>-</td>
<td>2300</td>
<td>1730</td>
<td>17100</td>
</tr>
<tr>
<td>Coeff. tap 5</td>
<td>-</td>
<td>0.2595</td>
<td>0.1238</td>
<td>0.0017</td>
</tr>
<tr>
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<td>-</td>
<td>3700</td>
<td>2510</td>
<td>20000</td>
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<td>Coeff. tap 6</td>
<td>-</td>
<td>0.0407</td>
<td>0.0696</td>
<td>0.0144</td>
</tr>
</tbody>
</table>

Table 4.1: PDPs of the different models.

In time, since this initial simulator is snapshot based with no correlations in between, [19]. So the coefficient channel between the base station and the user equipment can be written as:

\[
h(\tau) = d \cdot s \cdot \sqrt{p_l} \cdot f_l \cdot \delta(\tau - \tau_l)
\]  (4.1)

where \(f_l\) represents \(L\) independent Rayleigh fading processes at fixed time slots, \(\delta\) denotes the Dirac function and \(p_l, \tau_l\) are the relative power and delay of the multipath components.

The deterministic pathloss depends on the distance between the BS and the UE, which is modelled according to the COST231 model [22], and also depends on the antenna gain pattern if a sectorized model is used. The shadow fading is modelled by a lognormal random variable with zero mean and \(\sigma_s = 8\) dB, with no correlation in time.

### 4.1.3 Simulation Loop

Finally the system is prepared to start the simulation of multiple independent snapshots, getting the results after the average of these individual calcula-
tions. The first two parts have the simulator with all the network created and all the values loaded, Figure 4.6 illustrates the BS and the user distribution, using 19 Node-Bs and a 3 sectors model. It is important to note that all the simulations are done in the first sector (with the main radiation in 90°) of the serving Node-B, and is furthermore called the ”target sector”.

Before starting the detailed explanation of the way of modeling the HSDPA and R’99 traffic, it is necessary to talk about the power split between both transmission types, and also to discuss the two different possibilities of allocating the power of HSDPA in the base station downlink power budget.

**Power split**

The total available transmit power in each cell is shared between HSDPA and DCH users. The expression of the total intracell transmission power is:

\[
P_{\text{intra}} = P_{\text{DCH}} + P_{\text{HS-DCH}} + P_{\text{other}}
\]  

(4.2)
where $P_{\text{other}}$ incorporates the power from other needed channels, like the common pilot channel (CPICH) or the common channel. In the simulator, the total power, the R’99 load in percent respect this total power and the different powers included in the $P_{\text{other}}$ are set in the first part, and accordingly the HSDPA power range is determined.

About the possibilities of allocating the power of HSDPA, there are two options of which both are implemented in the simulator:

- The RNC can dynamically allocate HSDPA power by sending Node-B application part (NBAP) messages to the base station, which effectively keeps the HSDPA power at a fixed level, whereas the DCH power varies according to the fast closed loop power control.

- The second option is when no NBAP messages are sent and the base station is allowed to allocate all unused power for HSDPA, which better utilises the power amplifier, [19].

HSDPA System Level Modelling

In principle, a network simulation could be performed by means of an blown-up link-level simulation (incorporating the full physical layer, e.g. channel coding, inter leaving, etc.), but this would result in an unfeasible computational complexity. So, it was necessary to derive a simplified system level description to model the individual links, avoiding the complexity but having still an accurate representation of the HSDPA performance, [19].

The first step is to evaluate the channel quality as observed by the receiver, this part is called link-measurement model, where it was assumed that a standard single antenna Rake receiver is used because it is the most common in the SISO HSDPA terminals. The metric used for this evaluation is the signal-to-noise-and-interference ratio (SINR), it is calculated after Rake-combining and despreading for each user $u$ in the cell, according to

$$SINR_u = \sum_{i=1}^{N_F} \frac{SF \cdot P_{HS-DSCH} \cdot |h_{li}|^2}{P_{\text{intra,residual}} + P_{\text{inter}} + P_{\text{noise}}}$$  \hspace{1cm} (4.3)
where \( SF \) is the spreading factor, \( P_{HS-DSCH} \) is the power used for the HS-DSCH, \( \gamma \) represents the number of assigned spreading codes, \( P_{\text{intra,residual}} \) is the residual intracell interference in the downlink, \( P_{\text{inter}} \) is the transmitted interfering power from the neighbouring base stations, and \( P_{\text{noise}} \) is the noise power as seen at the receiver. The residual intracell interference is given by [23],

\[
P_{\text{intra,residual}} = P_{\text{intra}} \cdot \sum_{l=1}^{L} |h_l|^2,
\]

where \( L \) denotes the total number of taps of the current realisation, denoted by \( h_l \), and \( P_{\text{intra}} \) is the total power transmitted in the serving cell, [19].

In the simulator, the transmission power of the HS-DSCH is divided equally between all used HS-PDSCH. In Equation (4.3) structure of the Rake receiver is implicitly shown, where in the numerator the useful power is added up, which is cancelled out from the interference power in the denominator. This is consecutively done for all the \( N_F \) available fingers. In addition, it was assumed that perfect channel state information (CSI) is available at the receiver so that the receiver weights and the location of the fingers can be chosen perfectly. Considering that, only the squared absolute values of the channel coefficients (for each tap), \( |h_i|^2 \) appear in the equation.

Once the SINR is determined, the simulator calls the function to compute the quantized CQI value for a given SINR, using the expression described in [24]:

\[
CQI = SINR[dB] + 3.5.
\]  

(4.4)

Each CQI value represents a specific combination of the number of codes, modulation type and transport block size; and is used by the link adaptation algorithm at Node-B. The range of values of the CQI index is 0 to 30, where each value indicates the maximum TBS that can be correctly received with 90% probability (as mentioned before).

After the channel quality is evaluated, the second part consists on describing the bit-error/decoding performance, also called link-performance model. An analytical approach based on link-level simulations was selected, as in [24]. In the simulator a link performance modelling for the transport formats of each mobile category class is utilized, given by the range of possible CQI values. The tables for each category, used to determine the Transport Block Size (TBS), the number of codes as a function of the CQI, and specifying
the number of spreading codes, are implemented from [25]. One example of these tables is shown in Table 4.1, valid for the UE categories 1 to 6, which has been used during the HSDPA schedulers investigation.

The Block Error Ratio (BLER) is calculated according to an analytical model, as specified in [24]. The BLER, under AWGN conditions and utilizing a standard Rake receiver together with turbo coding, can analytically be well approximated by Equation (4.5), as in [26]. The BLER is considered directly in the evaluation of the throughput.

\[
BLER = [10^{-\frac{1.596 + 5.26}{\sqrt{4 - \log_{10}(CQI)}}} + 1]^{\frac{1}{2}}
\]

(4.5)

The TBS denotes the maximum amount of data that can be transmitted via the network in one TTI of 2 ms to the UE without exceeding a BLER of 0.1 in average. Accordingly the HSDPA user data rate is calculated as in the Equation (4.6), which is consecutively averaged over fading realizations, and finally averaged over all the individual snapshot simulations to get the
<table>
<thead>
<tr>
<th>CQI value</th>
<th>Transport Block Size</th>
<th>Nr of HS-PDSCH</th>
<th>Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>N/A</td>
<td></td>
<td>QPSK</td>
</tr>
<tr>
<td>1</td>
<td>137</td>
<td>1</td>
<td>QPSK</td>
</tr>
<tr>
<td>2</td>
<td>173</td>
<td>1</td>
<td>QPSK</td>
</tr>
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</tr>
<tr>
<td>30</td>
<td>7168</td>
<td>5</td>
<td>16QAM</td>
</tr>
</tbody>
</table>

Table 4.2: CQI mapping table for UE categories 1 to 6, from [25].

HSDPA data rate.

\[
R\textsubscript{u} = TBS \cdot \frac{1}{2ms} \cdot (1 - BLER). \tag{4.6}
\]
The simulator applies the case that the user always get the full available power, and there is enough data to transmit (full buffer assumption). It is important to note that in the snapshot based simulation approach, no HARQ retransmissions are modelled.

Finally, an overview of the described HSDPA calculations are illustrated in Figure 4.8, where we can observe the SINR evaluation as the first step. After that, the CQI is mapped as function of the SINR, and using both, the Block Error Rate (BLER) and the Transport Block Size (TBS) we are able to estimate the HSDPA data rate.

![Figure 4.7: Overview of the HSDPA calculation](image)

R’99

As we have commented before, the main objective of the initial investigation was the prediction of the achievable HSDPA user data rates in dependence of a given Release 4 DCH load in the cell. So, the Release 4 traffic is modelled only coarse, the simulator just needs to roughly estimate the total DCH cell throughput in order to be able to predict the overall cell throughput, [19].
The R’99 data rate evaluation use a link quality equation for DCH downlink connections proposed by [27], and also assumes the same kind of service for all DCH users in the cell. With these assumptions, an analytical model could be derived to predict the average R’99 cell throughput as function of the power distribution, [19].

4.1.4 Results
In order to have a better idea about the first objectives of the HSDPA simulator, we shortly present one of the main optimizations evaluated by M.Wrulich using the initial version of the simulator, which has been explained in this section. It is an investigation to identify the optimum power setting to maximize the total cell throughput, in the case of the RNC controlling the HS-DSCH power.

With the simulator the evolution of the total cell data rate, the HSDPA user data rate and R’99 cell data rate, in dependence of the power assigned to the HS-DSCH can be analysed. The result of the simulation is shown in Figure (4.9), with a Release 4 load of 20%, and a Node-B distance of 0.5 km, Pedestrian A model, 10 codes used for HS-DSCH and the users utilized equipments of capability class 6. In the figure we can see the maximum total cell data rate when the power assigned to HS-DSCH is 4.605 W, and the maximum HSDPA user data rate in $P_{HS-DSCH} = 6.029$ W. The HSDPA user data rate does not grow unlimited because an increase in power also increases the intercell interference. On the other hand, the R’99 cell data rate drops down since the start, because of the monotounuesly increasing interference seen by these transmissions.

4.2 New HSDPA Simulator: Continuos Time Simulation
In this section the simulator used for the scheduler investigation is described. Firstly, an overview to the new mode and the changes in the code structure will be presented. Then, we will begin the individual and detailed explanation of the main parts changed in the simulator, starting with the multipath and shadow fading, including the simulation model we use and the MATLAB functions implemented (as a small part of code example). After that we will
discuss the users movement, because in a simulation over time, we have a more realistic network simulation with the users moving inside the cell. In addition, we will show the new SNR to CQI mapping used in the new version of the simulator. Subsection 4.2.6 explains the implementation of the three HSDPA schedulers evaluated in this work.

### 4.2.1 Time Mode Simulator

The simulator transformation forced us to make continuous modifications in the code structure. The first thing that we have to comment is that because of the multiple changes, the code was divided into two groups separated by functionality. When the options are set, there are some common parameters and also some specific parameters for each mode, which are loaded in dependence of the selected mode. The time-based simulator has also new variables, like the ones which determine the users movement (i.e. angle) or the ones about the schedulers (i.e. type, number of users scheduled). Also it is relevant to note that in the time mode the concept of number of simulation runs has disappeared in favour of the concept of simulating over time.
In the precalculation part, the Node-Bs and users position generation is basically like in the initial version, and also the creation of the PDPs is like before. However important changes were necessary in the user pathloss generation. Now that the users are moving inside the cell, we cannot pre-calculate the deterministic pathloss because for every slot the user position will be different, and consequently the deterministic pathloss (macrocospic pathloss) suffered by the users will be different for each time slot too.

So, in the precalculations of the time-based simulator, we are only able to generate the non-deterministic pathloss that consists of the multipath and shadow fading. In spite of a big number of uncorrelated values to simulate the multipath and shadow fading (the number depended on the nr. of simulation runs), it was neccessary to find a good model to generate the correlated fading over time of both fadings. For each user as many multipath and shadow traces as sectors exists are generated (i.e. with 19 BSs and 3 sectors model, each user has 57 different traces). In Subsections 4.2.2 and 4.2.3, both are explained in greater detail.

Let us now discuss the main simulation loop. First, it is fundamental to note that now the loop is over time, and the total time simulated is set using the number of time slots (i.e. 30,000 slots = 10,000 TTI = 20 seconds). At the beginning of the loop, the first thing calculated is the the new users position (after one slot has passed) and then it is checked if all the users are still inside the cell (the users movement is widely described in Subsection 4.2.4). After that, we are ready to calculate the deterministic pathloss for each user (based on the distance and angle between the user and the transmitting sectors) and the total pathloss, by evaluating the macro-scale (deterministic) pathloss, the shadow fading and the multipath fading.

After these user dedicated evaluations, the simulator starts to calculate basically the same metrics as in the original simulator. However, some important changes were necessary to let the simulator handle the time-domain.

As we have commented before the loop is over time slots, but transmissions occur every TTI (1 TTI = 3 slots). Thus, we calculate the users SINR in every slot and after three time slots have passed (see Figure 4.11), we begin with the HSDPA dedicated evaluation. The first thing calculated is the average SINR over the last three slots. Once we know this SINR, the next step is to map the CQI as function of the SINR, but with a different equation respect to the initial version (the new functionality is explained in Subsection 4.2.5). It has to be noted that, because of the delay of the feedback information, the simulation works with the CQI obtained some TTIs
before. The delay of the feedback information is set in the options of the simulator.

$$SINR_{TTI} = \left( \sum_{i=1}^{3} SINR_{SLOT_i} \right) / 3$$

In the HSDPA calculation, we simulate the network in each TTI considering the current SINR (averaged over the last 3 slots) and a previous CQI. After the SINR information is known, the scheduling function is introduced in the simulation. Depending on the selected scheduler a different algorithm is used. Using the scheduler algorithms the served users in the current TTI
are chosen. The three different tested schedulers are described with detail in Subsection 4.2.6.

Now that the scheduled users are known, the remaining steps of the HS-DPA throughput evaluation can be executed. For each served user, first the TBS and the necessary number of spreading codes are obtained, following the tables specified by 3GPP. These tables are specified according to the UE category. Second, the BLER is estimated as in the initial version of the simulator (see Equation (4.5)), based on the CQI and the SINR of the user. Using both parameters (TBS and BLER) the amount of data transmitted to each served user is calculated. The BLER is used as a probability to determine if the transmission has been decoded correctly or not. In the positive case, the data transmitted to the user is equal to the TBS, in the opposite case however, the amount of transmitted data equals zero.

So, for each user, we sum up all the transmitted data, and when the simulation has finished, the respective HSDPA user data rates are known. All the results concerning the time-based simulator will be shown in Chapter 5. Let us now go into more detail and discuss the parts of the simulator mentioned above.
4.2.2 Multipath Fading

Let us now provide a complete description of the multipath fading. We will start with a short definition, and explain the mathematical model and the simulation model afterwards. Finally we show the MATLAB implemented function and one example trace.

Definition

Multipath propagation is a phenomenon that affects all wireless systems. Multipath fading is created when radio waves, arrive at a receiving antenna from different paths, of course, the superposition of the incoming waves can be constructive or non-constructive. Multipath fading occurs irrespective of radio signal strength and is particularly common in urban areas where radio waves do not have a line of sight path between the transmitter and the receiver. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings. The figure 4.13 illustrates a simple scheme of the multipath causes.

Figure 4.12: Scheme with the multipath causes

Multipath fading may be minimized by diversity techniques, e.g. space and frequency diversity. In space diversity, two or more receiving antennas are spaced some distance apart. Fading does likely not occur simultaneously at both antennas. Therefore, enough output is almost always available from one of the antennas to provide a useful signal. In frequency diversity, two transmitters and two receivers are used, each pair tuned to a different frequency,
with the same information being transmitted simultaneously over both frequencies. One of the two receivers will almost always produce a useful signal.

Multipath fading can be statistically described by a Rayleigh fading [28]. In digital radio communications multipath can cause errors due to ISI and thus affect the quality of communications. Techniques to combat this are e.g. OFDM, Rake receivers or equalizers.

Simulation Model for Rayleigh Fading Channels

About the last three decades, the well-known mathematical reference model due to Clarke [29] and its simplified simulation model due to Jakes [30] have been widely used for Rayleigh fading channels. But in the multiple uncorrelated fading waveforms generation for frequency-selective fading channels and multiple-input multiple-output (MIMO) channels, the Jakes’ simulator has problems, because it is a deterministic model. Therefore, different modifications of Jakes’ simulator have been reported in the literature (i.e. [31], [32], [33]).

In this work, we present the statistical simulation for Rayleigh fading channels proposed in [1], whereas we implemented this model with a variation introduced by Zemen in [34]. This simulator can be directly used to generate multiple uncorrelated fading waveforms for frequency selective fading channels, MIMO channels, and diversity combining scenarios. The variation introduced by Zemen is for time-variant channels with Jakes’ spectrum especially for low speeds.

In the simulator proposed in [35] random phase shifts are introduced to remove the stationarity problem. But with this improvement other troubles appeared, because higher-order statistics may not match the desired ones, as proven in [36]. In addition, even if the number of sinusoids approaches infinity the results are not matching, [30]. In [1] a new sum-of-sinusoids statistical simulation was proposed, which solves the problem of the high-order statistics, and also achieves good approximations even when the number of sinusoids is as small as eight and the number of random trials is only 50. For us, this model is useful because it can be directly used to generate multiple uncorrelated fading waveforms, which are needed to simulate realistic frequency-selective fading channels, MIMO channels, and diversity-combining scenarios.

Based on the Jakes’ simulator family, but considering the modified model
proposed by Pop and Beaulieu in [35], the improvement of the simulation model explained is based on reintroducing the randomness for all three random variables $C_n$, $\alpha_n$, and $\phi_n$. It considers the following simulation prototype function to introduce the randomness in these variables:

$$
\tilde{g}(t) = E_0 \sum_{n=1}^{N} \tilde{C}_n \exp\{j(w_d t \cos(\tilde{\alpha}_n + \tilde{\phi}_n))\}
$$

(4.7)

where

$$
\tilde{C}_n = \frac{\exp(j\psi_n)}{\sqrt{N}}, \quad n = 1, 2, ..., N
$$

(4.8)

$$
\tilde{\alpha}_n = \frac{2\pi n - \pi + \theta}{N}, \quad n = 1, 2, ..., N
$$

(4.9)

$$
\tilde{\phi}_n = -\tilde{\phi}_N + \frac{\phi}{2} + n, \quad n = 1, 2, ..., N/2
$$

(4.10)

with $N/2$ being an integer, and $\psi_n, \theta$, and $\phi$ being mutually independent random variables uniformly distributed on $[-\pi, \pi]$. The reintroduced randomness in these variables enables to establish a new statistical and widesense stationary (WSS) simulation model for Rayleigh fading channels. By choosing $\psi_{N/2+n} = \psi_n$, gives the possibility to rearrange Equation (4.7) as:

$$
\tilde{g}(t) = \frac{E_0}{\sqrt{N}} \left( \sum_{n=1}^{N/2} e^{j\psi_n} [e^{j(w_d t \cos(\tilde{\alpha}_n + \phi)} + e^{-j(w_d t \cos(\tilde{\alpha}_n + \phi))}] \right).
$$

(4.11)

The first expression in the sum represents waves with radian Doppler frequencies that progress from the range of $[w_d \cos(2\pi/N), w_d]$ to the range of $[-w_d \cos(2\pi/N), -w_d]$, while the radian Doppler frequencies in the second term of the sums shift from the range of $[-w_d \cos(2\pi/N), -w_d]$ to the range of $[w_d \cos(2\pi/N), w_d]$. Therefore, the Doppler frequencies in these terms are overlapping. To represents the fading signals whose Doppler frequencies do not overlap, it is possible to simplify $\tilde{g}(t)$ as:

$$
\hat{g}(t) = \frac{E_0}{\sqrt{N}} \left( \sum_{n=1}^{M} \sqrt{2} e^{j\psi_n} [e^{j(w_n t + \phi)} + e^{-j(w_n t + \phi)}] \right).
$$

(4.12)
where $M = N/4$, and $w_n = w_d \cos(\alpha_n)$. The factor $\sqrt{2}$ is included to make the total power remain unchanged. Based on Equation (4.12), the normalized low-pass fading process of a new statistical sum-of-sinusoids simulation model is defined by:

$$X(t) = X_c(t) + jX_s(t)$$  \hspace{1cm} (4.13)

$$X_c(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^{M} \cos(\psi_n). \cos(w_d t \cos \alpha_n + \phi)$$  \hspace{1cm} (4.14)

$$X_s(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^{M} \sin(\psi_n). \cos(w_d t \cos \alpha_n + \phi)$$  \hspace{1cm} (4.15)

with

$$\alpha_n = \frac{2\pi n - \pi + \phi}{4M}, \quad n = 1, 2, \ldots, M$$  \hspace{1cm} (4.16)

where $\theta$, $\phi$, and $\psi_n$ are statistically independent and uniformly distributed over $[-\pi, \pi]$ for all $n$.

With this model the second-order correlation statistics match the desired ones exactly, even if the number of sinusoids is small; fourth-order statistics asymptotically match the correct ones as the number of sinusoids approaches infinity. And as we have indicated before, with this simulation model it is directly possible to generate multiple uncorrelated fading waveforms.

**Simulation Model**

Finally we implemented in the HSDPA simulator the same simulation model for time-variant channels with Jakes’ Spectrum as proposed in [34]. This model is based on the model from [1] with a correction for low velocities based on [37]. This model ensures a Rayleigh distribution of $h[m]$ for all velocities $v$ and even at $v = 0$ m/s.

The detailed simulation model for $h[m]$ is given by:

$$h[m] = \frac{1}{\sqrt{2}}(h_c[m] + jh_s[m]),$$  \hspace{1cm} (4.17)
\[ h_c[m] = \frac{2}{\sqrt{A}} \sum_{i=1}^{A} \cos(\psi_i) \cdot \cos(2\pi v_D m \cos \alpha_i + \phi_i), \quad (4.18) \]

\[ h_s[m] = \frac{2}{\sqrt{A}} \sum_{i=1}^{A} \sin(\psi_i) \cdot \cos(2\pi v_D m \cos \alpha_i + \phi_i), \quad (4.19) \]

with

\[ \alpha_i = \frac{2\pi i - \pi + \phi}{4A} \quad \text{for} \ i \in \{1, \ldots, A\}, \quad (4.20) \]

where \( \theta, \theta_i, \) and \( \psi_i \) are independent and uniformly distributed over \([-\pi, \pi)\) for all \( i \). For our investigations, we usually fix the number of interfering paths to \( A = 50 \).

**MATLAB code**

```matlab
function [fading_time] = xf_jakes(nr_slots,nr_paths,V,TTI,F)
% function to generate Rayleigh fading with Jakes model
% input: nr_slots ... nr. of realizations
% nr_paths ... nr. of interfering paths
% V ... velocitie of the UE
% TTI ... Transmission Timing Interval
% F ... frequency (in MHz)
% output: fading_time ... vector fading realizations

%% Functionality

% slot time (TTI/3)
t_slot=TTI*1e-3/3;
% Doppler Frequency (V*F/Co)
Vd=(V/3.6)/3e8*F*1e6;
m=1:nr_slots;
k=2*pi*Vd*t_slot;
```

47
\begin{verbatim}
% independent and uniformly over [-pi,pi)
phi=2*pi*rand(nr_paths,1)-pi;
psi=2*pi*rand(nr_paths,1)-pi;
alpha=((2*pi*[1:nr_paths]-pi+phi(1,1))/(4*nr_paths));

hc=zeros(1,nr_slots);
hs=zeros(1,nr_slots);

for i=1:nr_paths
 aux=cos(k*m*cos(alpha(i))+phi(i));
 hc=hc+cos(psi(i))*aux;
 hs=hs+sin(psi(i))*aux;
end

fading_time=sqrt(2/nr_paths)*(hc + j*hs);  
end
\end{verbatim}

The figure below shows an example of the MATLAB function that we created to simulate the Rayleigh fading with the follow settings: nr. slots = 3000, nr. paths = 50, Vel = 3km/h, TTI = 2ms and Freq = 2000MHz.

### 4.2.3 Shadow Fading

**Definition and simulation models**

Shadowing is the reduction in signal strength occurring as a result of the UEs moving in and out of the shadows of large obstacles such as buildings. We present the two different kind of models used in our simulator to generate the shadow fading: an uncorrelated model (used for snapshot simulations) and a correlated model (used for time-based simulations).

**Uncorrelated Model** In this case the shadow fading effect is usually modeled by a log-normal random variable, with the mean $m$ usually given by 0 dB, and the standard deviation $\sigma$ depending on the propagation environment (i.e. 8 dB for urban areas). This random variable is Gauss distributed.
in dB.

When doing the system level simulation, a normal distributed random variable can be generated from time to time to represent the shadow fading for each radio link. The typical way is to generate the random variable independently for different time and for different radio link (i.e. the shadow fading effects for each radio link at each time instance are simulated in uncorrelated manner).

In the snapshot mode, the equation used to generate the shadow fading values is:

$$\text{shadow} = \sqrt{10^{\left(-\text{rand}_{0-1}\right) \times 10^{\sigma/10}}}$$  \hspace{1cm} (4.21)

where \( \text{rand}_{0-1} \) means that a random value between 0 to 1 is generated.

**Auto-correlation model:** Considering that the shadow fading effect of the same radio link is highly correlated for the nearby locations, Gudmundsson proposed a simple and well accepted auto-correlation model [38], which we implemented in the time-based simulator version. Two correlation effects have to be taken into account: site-to-site correlation, generated according to the 3GPP TR25.996 specifications, and also the spatial correlation, gen-
Gudmundson recommends an auto-correlation of

$$R_s(k) = S^2 a^{|k|}$$ (4.22)

$$a = \varepsilon_D^{vT_s/D}$$ (4.23)

for the shadow fading, where $a$ is the correlation coefficient, $\sigma$ is the standard deviation, $\varepsilon_D$ is the correlation between two locations separated by distance $D$, $v$ is the mobile velocity and $T_s$ is the sampling interval.

**MATLAB code**

```matlab
function [shadowfading] = xf_shadowfading_gudmundson(shadow, intersite_constant)

% function to generate spatially (eq. temporally for constant speed) shadow
% fading according to the model proposed by Gudmundson
% ("correlation model for shadow fading in mobile radio systems")
% input:  shadow     ... structure of shadow settings
% output: shadowfading ... trace of correlated shadow fading coefficients
%         (in dB)
```

Figure 4.13: Scheme of the shadow fading
% two correlation effects have to be taken into account
% - site-to-site correlation (generated according to 3GPP TR25.996)
% - spatial correlation (generated according to Gudmundson)

% white Gaussian random process, var=1
tmp_gauss = randn(shadow.nr_samples,1);

% autocorrelation of desired fading
filter_coeff = shadow.corr_coeff(shadow.vkmh/3.6*shadow.t_samp/... shadow.corr_distance);

% gauss with desired autocorrelation
tmp_s = filter(1,[1,-filter_coeff],tmp_gauss);
% normalize
tmp_s = tmp_s*sqrt(1-filter_coeff^2);
% scale by given shadow fading variance
tmp_s = shadow.std*tmp_s;

% correlated shadow fading (linear scale)
shadowfading = exp((sqrt(1-shadow.site2site_corr)*tmp_s + ... sqrt(shadow.site2site_corr)*intersite_constant)/10);

end

The figure below shows an example of the MATLAB function that we created to simulate the shadow fading, following the Gudmundson model. This example generated by defining these values: nr. slots = 3000, correlation coefficient $a = 0.3$, correlation distance $\varepsilon_D = 55$ m, $v = 3$km/h, TTI = 2ms and $\sigma = 8$ dB.

4.2.4 Users Movement

Now that the users are simulated continuously in time, it was necessary to implement the movement of the users within the cell. Accordingly, the macro-scale pathloss and the antenna gain change with the position of the user. Furthermore, the statistics of the shadow fading and the multipath fading depend on the user speed.

To model the users movement we decided to create two new variables as-
signed to the users: angle (randomly between 0-360 degrees) and speed. With these variables and the position of the user, we are able to calculate the user position in the next time slot. Our simulation bases on the assumption that the number of simulated users in the cell stays constant, thus we had to catch the case when a user moved out of the cell. The possible options were the following:

- **Users rebouncing inside the cell.** When the user reaches the limit of the cell, it rebounces to another direction inside the cell. It is easy to see that selecting this option the cell always have the same number of users. An example of this way of implementation, using four users, would be like in Figure 4.14.

- **User out, new user in.** When the user leaves the cell, a new user is generated inside the cell, with the position being drawn from a uniform distribution within the cell. The new user has their own angle of movement and starts their own simulation. Of course with this option we achieve again the same number of users in the cell during the whole simulation.

In this work, we decided in favour of the second option. So each time slot we check if the user has left the cell or not, and in case he did, we generate a new user in the place of the previous one, assigning an initial position and a new angle of movement. An example of the resulting users movement is depicted in Figure 4.15.
The initial users position assignment is like in the first version of the simulator (uniformly and randomly over the first sector of the serving node). But in the time-based simulator, a low number of HSDPA users are set (i.e. 15). In the snapshot based simulator a high number of HSDPA users were used (i.e. 500) trying to cover a big part of the cell in order to avoid the possible bad results of the random users position and get an accurate esti-
mation of the cell throughput.

On the other hand, in the time mode simulations we use only around 15 users, because of two main reasons: now that the users are moving inside the cell, the positions change and we are well protected against the possible negative random effects having a realistic situation where we don’t need to cover the cell with hundreds of users, and secondly, we have to control the potential MATLAB problems with memory and a more complex code.

### 4.2.5 New SNR to CQI Mapping

As we have already said, the Channel Quality Indicator is the indicator for HSDPA downlink channel quality. UE reports CQI and HARQ-ACK feedback information to Node-B through uplink channel HS-DPCCH. The range of CQI values is 0-30, and each step corresponds approximately to a 1 dB step in HS-DSCH SINR. By means of the CQI, the maximum TBS that can be received correctly with at least 90% probability is indicated.

In the new simulation mode we opted for the Equation (4.24), which is also used in many of our consulted papers and articles, like in [26] or [39].

\[
CQI = \begin{cases} 
0 & \text{if } SNR \leq -16, \\
\left\lfloor \frac{SNR}{1.02} + 16.62 \right\rfloor & \text{if } -16 \leq SNR \leq 14, \\
30 & \text{if } 14 \leq SNR 
\end{cases} 
\] 

(4.24)

now this is the formula used to compute the CQI from the measured value of SNR.

### 4.2.6 Schedulers

Here we will describe how to simulate each scheduler (including the parameters it needs and the specific keys of the implementation). Let us begin with the explaining how the HSDPA power and the codes are shared between the served users.

In the snapshot mode, it is supossed that the total HSDPA power and the maximum number of codes are available to each user. This distribution is possible because we evaluate the HSDPA network calculating first the individual user throughput and then the average over all the users. But now, due
to the possibility of multi-code scheduling it is necessary to split the power and the number of codes equally among the users. Then, once the number of served users is selected, the power and codes are divided by this number. Here we can see a simple example:

\[
\begin{align*}
P_{\text{HSDPA}} &= 12 \text{ W} \\
\text{Nr. of codes} &= 15 \\
\text{Nr. of served users} &= 3
\end{align*}
\]

\[P_{\text{user}} = 4 \text{ W with 5 codes per user.}\]

Obviously, if one user is scheduled, it will have all the power and all the codes available. Before we took the decision of an equal distribution among the users, many of the 3GPP related specifications and papers were widely studied, trying to verify that we don’t break the requirements. In future enhancements of the simulator, it would be interesting to investigate other combinations in the power and the nr. of codes distributions, in order to improve the network performance in terms of throughput or QoS.

Figure 4.16: Example with the power and codes split when serving multiple users

**Maximum C/I**

As we explained in Chapter 3, the scheduling strategies based on a C/I policy favours users with the best radio channel conditions in the resource allocation
process. The maximum C/I serves in every TTI the user with largest instantaneous supportable data rate (in the simulator, the CQI is the parameter used to determine the transport block size). This serving principle has obvious benefits in terms of cell throughput, although it is at the cost of lacking throughput fairness.

The implementation of this scheduler was simple, it consists of elaborating the priority table of the users, utilizing the reported CQI values. The table is arranged from the higher to the lower CQI, so the first \( n \) users in this table are the ones selected to be served.

Figure 4.17 shows an example with the user position, the CQI that the users have in this moment, and also the users to be served (after the delay) depending on the number of scheduled users.

![Diagram showing user positions and CQI values](image)

<table>
<thead>
<tr>
<th>USER</th>
<th>CQI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
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<tr>
<td>6</td>
<td>0</td>
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<tr>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

**if nr. of scheduled users is:** 1 2 3 4

**The served users are:** 5 5,9 5,9,4 5,9,4,8

Figure 4.17: Example of the maximum C/I scheduler decisions.

**Round Robin**

In this algorithm the users are served in a cyclic order. The round robin scheduler allocates equal resources to all users, regardless of their current channel conditions. This method outstands due to its simplicity, and ensures a fair resource distribution among the users in the cell.
Before the implementation of this scheduler we thought of two similar possibilities:

- Random user selection: although this is not exactly round robin, the results will be similar, because it allocates resources independently the channel conditions and almost ensures the fair distribution if we simulate a large number of TTIs.

- Cyclic order selection: this is the exact implementation of the round robin scheduler, where created an index value to decide the first user served is created, and then this index is incremented each TTI to maintain the proper order of the users who have to be served in the next TTI.

Considering that both options are easy to implement we finally opted for the second one, in order to avoid random effects.

![ROUND ROBIN diagram](image)

**Figure 4.18:** Round Robin e.g. for 10 active users.

**Fair Throughput**

The goal of this kind of scheduling is to give all users the same throughput, regardless of their radio channel quality. As we have already explained in Chapter 3, this method can be seen as a form of inverse C/I scheduling, since users with a low C/I must be allocated a larger amount of resources in order to get the same throughput. This scheduling method gives a fair user throughput distribution at the cost of a lower cell throughput.
The concept of proportional fairness was introduced in [40] in the setup of a shared resources allocation problem in a generalised network, and this concept can also be adapted to HSDPA based wireless networks. There are many authors who propose fair schedulers, but each one introducing some particular variations to simulate it. We analysed some papers, like [39], [41], [42], [43], [44] and [45]. Finally we decided to implement in our simulator the proportional fair scheduling algorithm proposed in [39].

In [39] is indicated that a set of throughputs $r_i$ is proportionally fair if it is feasible (i.e. $r_i > 0$ and $\sum_{i=1}^{n} r_i < C$) and for any other feasible vector $r^*_i$, the sum of the porportional changes is 0 or negative, i.e.

$$\sum_{i=1}^{n} \frac{r^*_i - r_i}{r_i} \leq 0.$$  \hfill (4.25)

The proportional fair algorithm, as originally proposed in [46], selects user $j$ by:

$$j = \text{arg max}_{1 \leq i \leq n} \frac{r_i(k)}{\overline{r_{ei}(k)}}.$$  \hfill (4.26)

The average throughput is obtained by the following exponential weighted moving average of the instantaneous data rate $r_i$:

$$\overline{r_{ei}(k)} = \begin{cases} (1 - \alpha)\overline{r_{ei}(k)} + \alpha r_i(k) & \text{if } i \text{ served in slot } k, \\ (1 - \alpha)\overline{r_{ei}(k)} & \text{otherwise}, \end{cases}$$  \hfill (4.27)

where $0 < \alpha < 1$ is a weighting factor, whose value may be chosen e.g. as 0.001, [46]. It has to be noted that by $\alpha \to 0$, Equation (4.26) will provide equal air time to all mobile users. In such cases, the denominator in (4.26) is computed by a simple arithmetic mean of the throughput, i.e. in [47]:

$$\sum_{i=1}^{n} \frac{r_i(k)}{n}.$$  \hfill (4.28)

Finally the PF scheduler was created based on the Equations (4.26 & 4.27). Once the priority table (which is elaborated using Equation (4.26)) has been generated, the rest of the calculations can start.
Chapter 5

Investigation of HSDPA Schedulers

In this chapter the results obtained during this work are presented. Sections 5.1 and 5.2 present the different tests of the three investigated scheduler algorithms, in the classical or multiuser way respectively, evaluating their performance in terms of sum cell throughput and fairness. In addition, some network parameters are investigated in different situations.

Depending on the test target of each simulation we include different types of figures. We try to show clearly the scheduler performance and the simulator results.

5.1 Classical (1 user)

Here the scheduler algorithms when only one user is served in a determined TTI are tested. Then, with this configuration, the served user in each slot has available all the HSDPA power and the codes. This way of serving is called classical because it is like in Release ’99, when only one user can be served by DCH.

5.1.1 Test 1

In the first simulation we want to present a general overview of the three scheduler algorithms performance. This test simulates the same network scenario to all the schedulers. We fixed the number of codes in 12, the HS-
DPA power in 8 W and the number of HSDPA users in 10. The simulation time is 18 seconds, that means 9.000 TTIs so we assigned number of slots = 27.000. Figure 5.1 represents the average throughput rate over the time.

![Figure 5.1: Average data rate over time: 1 scheduled users.](image)

It shows the results of the three schedulers, and we can observe after the simulation reaches the second 2, the average throughput is stable. We can see that the maximum C/I is the algorithm which achieves the best throughput, with the Round Robin having the worst results. The Proportional Fair scheduler has an intermediate data rate.

In Figure 5.2 the users position is illustrated, the red cross means the initial users position and the black cross shows the user position after 18 seconds of movement inside the cell. Also we can see the individual data rate obtained by each user in Figure 5.3. Observing both graphics we can analyse the user throughput as function of the position and the scheduler algorithm.
Evaluating both figures, we can check that Proportional Fair scheduling has a
good balance between getting a high user data rate and serving fairly all the
users. The maximum C/I has the best result in terms of sum cell throughput,
but the users with the worst channel conditions finish almost without
transmitted data. Finally, Round Robin is clearly a bad scheduler in terms
of sum cell throughput, and even if the priority is to get a fair service among
the users, the PF would be a better option.

5.2 Multiuser (2-4 users)

In this section the different tests using the "multicode" scheduling are pre-
sented. As in Section 5.1, we try to investigate the schedulers performance
in different situations and also to find the optimum value of some network
parameters.

5.2.1 Test 2

This test simulates the same network scenario to all the schedulers. We fixed
the number of codes in 12, the HSDPA power in 10 W and the number of
HSDPA users in 10. The simulation time is 18 seconds, that means 9.000
TTIs so we assigned number of slots = 27.000. Figure 5.4 shows the average
throughput rate over the time.

![Figure 5.4: Average data rate over time: 2 scheduled users.](image)
It shows the results of the three schedulers, and we can see that the maximum C/I is the algorithm which achieves the best throughput, but not so far away from the Proportional Fair. The RR has again the worst results. We can see that the average data rate is similar comparing it with the classical way, because we increase the HSDPA power. If we would had simulated with the same power, the average data rate would be lower.

5.2.2 Test 3

In this simulation we want to estimate the optimum value of the HSDPA power to maximize the total throughput rate. This test simulates only the Maximum C/I scheduling with 2 scheduled users. We fixed the number of codes in 12, the number of HSDPA users in 10 and the simulation time is 6 seconds (that means 3,000 TTIs). The HSDPA power starts in 1 W and finishes in 18 W. For this test the total power is 30 W. Figure 5.5 illustrates the total data transmitted by each HSDPA power.

![Figure 5.5: Total transmitted data over HSDPA power: 2 scheduled users.](image)

Observing the Figure 5.5 we can determine that 12 W is the optimum HSDPA power when 2 users are served. We could expect this result because
in the Figure 4.8 is shown that the optimum power in the HSDPA traffic with only one served user is 6 W. Now in the multiuser scheduling, with 2 served users, the result is logical. The test 8 shows the same simulation with 4 served users.

### 5.2.3 Test 4

This test simulation is done under a manual user position assignment. We only simulate the maximum C/I scheduler because we try to demonstrate that very unfair scheduling mechanisms can lead to the starvation of the least favourable users. We fixed the number of codes in 12, the HSDPA power in 14 W, the number of users is 10 and the simulation time is 10 seconds. The simulation is done with 3 scheduled users. Figure 5.6 illustrates the users position, with 3 users in a good position and consequently with high probability of good channel conditions, and the rest of the users close to the sector limit.

![Users Position](image)

**Figure 5.6: User position in test 4.**

Figure 5.7 shows the individual data rate of the 10 users. We can see a big difference between the values obtained by the 3 users close to the base
Thanks to this test we have checked that, using the maximum C/I scheduler, the users with the least favourable conditions can be highly ignored in the scheduling and the level of satisfaction among users could be poor.

5.2.4 Test 5

In this test the three schedulers are simulated with 3 scheduled users. We fixed the HSDPA power in 14 W, the number of codes in 12, the number of users in 10 and the simulation time is 8 seconds. We simulate the HSDPA traffic for 6 different Node-B distances, starting in 0.5 Km until 1.5 Km. Figure 5.8 represents the average data rate as function of the Node-B distance.

The throughput rate decrease regularly when the Node-B distance is increased. As we can observe, the better results are obtained when the base stations are close, having not so good results when the distance is bigger than 1 km. On the other hand, we can check again the schedulers performance: Round Robin has very bad results in terms of sum cell throughput, Maximum C/I and Proportional Fair have good results (MAX C/I slightly
better), so considering the PF algorithm uses to be more fair, it should be the selected option by the mobile operator.

5.2.5 Test 6

This test simulates the same network scenario to all the schedulers. We fixed the number of codes in 12, the HSDPA power in 14 W and the number of HSDPA users in 10. The simulation time is 18 seconds, that means 9,000 TTIso we assigned number of slots = 27,000. Figure 5.9 represents the average throughput rate over the time.

It shows the results of the three schedulers, and we can observe that, surprisingly, the highest average data rate occurs using PF algorithm. The possible reason could be a higher BLER in the Maximum C/I, getting a worse rate even thought the served users have the highest CQIs.

5.2.6 Test 7

In this simulation we want to estimate the optimum value of the HSDPA power to maximize the total throughput rate. This test simulates only the Maximum C/I scheduling with 4 scheduled users. We fixed the number of
codes in 12, the number of HSDPA users in 10 and the simulation time is 6 seconds (that means 3,000 TTIs). The HSDPA power starts in 0 W and finishes in 28 W. For this test the total power is 40 W (it is important to note that most power amplifiers that are used today just support 20W, but we change it in order to be able to find correctly the best HSDPA power). Figure 5.10 illustrates the total data transmitted by each HSDPA power.

Observing the Figure 5.10 we can see that 25 W is the optimum HSDPA power when 4 users are served. Again this result is logical compared with the obtained values in the cases when 1 user (6 W) and 2 users (12 W) are served. But we have to note that the total throughput in the interval [22-28 W] is similar, so we cannot determine an absolute optimum value. In this case, it would be better to talk about an optimum HSDPA power interval.
Figure 5.10: Total transmitted data over HSDPA power: 4 scheduled users.
Chapter 6

Conclusions

This work has investigated the Packet Scheduling function in HSDPA, which is a Third Generation (3G) mobile telephony communications protocol and the evolution of UMTS/WCDMA. The goal of 3G systems is to provide users not only with the traditional circuit switched services, but also with new multimedia services with high quality images and video for person-to-person communication, and with access to services and information in private and public networks.

The Packet Scheduling functionality plays a key role in HSDPA. The features included in HSDPA and the new location of the scheduler in the Node-B open new possibilities for the design of this functionality for the evolution of WCDMA.

In this concluding chapter a summary of this bachelor thesis is given as follows: Section 6.1 presents a short summary of the HSDPA simulator, trying to compile and clarify the exposed ideas about the simulator, especially the new functionality implemented to develop this bachelor thesis. In Section 6.2 a summary of the schedulers investigation and the simulator results is presented. Finally, Section 6.3 concludes this bachelor thesis describing some possible uses of the simulator in future enhancements.

6.1 New Simulator Functionality

The MATLAB simulator developed by the Institute of Communications and Radio-Frequency of the Vienna University of Technology has been utilised to
develop this bachelor thesis. It consists in the simulation of a network with
two mixed traffics: R’99 and HSDPA.

The initial purpose of this program was to evaluate the performance of this
mixed network, testing the network with different combinations of the pa-
rameters. Thus, this simulator could be also used to investigate the value of
the parameters which maximize the overall throughput or the throughput of
one specific protocol (R’99 or HSDPA). As we have already explained, the
initial version utilizes a snapshot based simulation. The snapshot mode con-
sists of (once the users and the network layout are created) realizing multiple
simulations of the network, changing the shadow and multipath fading as-
signed to the users uncorrelated and randomly. So, after all the independent
results of each realisation are obtained, the mean over the realisations and
the users was calculated to finally obtain the global results.

Considering the static situation with the users in fixed positions and uncor-
related fadings, it is not possible to simulate scheduling functions, based on
serving at the users considering their radio conditions in previous moments,
among other informations (i.e. in proportional fair, where it is necessary to
know the user average throughput).

As we have commented in Chapter 4, a new functionality was implemented
in a existing HSDPA simulator to add the scheduling part in the simulations.
We worked on the same basis, although some adjusts were done to achieve
that besides snapshot based simulation also the enhanced time-based func-
tionality could exist in the same program. The main modifications to get the
new functionality were done in the pathloss and shadow generation, in a way
that the simulation models utilised give back correlated in time values. Also
we created new functions to simulate the users movement in the cell. And
the most important part was the implementation of the schedulers which
were investigated (Maximum C/I, Proportional Fair and Round Robin).

With the time-based functionality the simulator is more complete and give us
a wide range of possible simulations. As we have seen in Chapter 5, we can
simulate more realistic situations besides the new possibility of investigating
the schedulers.
6.2 Schedulers Investigation

As we have seen in Chapter 5, with the new simulator we can do continuous time simulations and investigate the HSDPA scheduler performance. In tests 1, 2 and 6 the HSDPA throughput over time of the three scheduler algorithms (Max C/I, Proportional Fair and Round Robin) is represented when 1, 2 and 4 users are served respectively.

In terms of sum cell throughput we can conclude that Maximum C/I scheduler has the best data rates and Round Robin the worst rate, and also it is interesting to note that as more users are scheduled in parallel, the closer to the Maximum C/I is the Proportional Fair scheduler one gets. These results also can be confirmed by the test 5. Speaking about the grade of fairness, in test 1 we observed the user data rate and the user position, and as we expected the RR and PF have a pretty fair service among the users. Analyzing the results we would propose the Proportional Fair as the best option, the one who gets a great balance between a fair service and a high data rate.

<table>
<thead>
<tr>
<th>Scheduling Method</th>
<th>HSDPA throughput</th>
<th>Radio Resources Fairness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum C/I</td>
<td>Very High</td>
<td>Unfair Distribution</td>
</tr>
<tr>
<td>Round Robin</td>
<td>High</td>
<td>Fair Distribution</td>
</tr>
<tr>
<td>Proportional Fair</td>
<td>Low</td>
<td>Very Fair Distribution</td>
</tr>
</tbody>
</table>

Table 6.1: Summary of investigated scheduling algorithms

Also we have checked the HSDPA performance as function of different parameters like the Node-B distance and the HSDPA power. We could observe in test 5 how the HSDPA throughput decreases when the Node-B distance increases, and in tests 3 and 7 we found the optimum HSDPA power to maximize the total HSDPA power in the cases of 2 and 4 scheduled users respectively. Finally, we observed in test 4 the possibility of a completely personalized simulation, and we opted to demonstrate that using the maximum C/I scheduler, the users with the least favourable conditions could have extremely bad data rates.
6.3 Future Enhancements

In this bachelor thesis only some possibilities of the new simulator have been explored. During the development of this work was conducted to introduce real data network in the simulation. Accordingly, combining both parts the simulator will be even more realistic. On the other hand, it would be interesting to add to the simulator some HSDPA technologies that still are not incorporated like the H-ARQ.

In addition, I would like to present a short introduction to HSPA Evolved, also known as HSPA+. I would propose that a possible enhancement of the simulator could be to adapt it to evaluate the performance of the new technologies introduced by HSPA+.

HSPA+ is the next step and is more focused on delivering data services enabling speeds of up to 25 Mbps in the downlink and 11 Mbps in the up-link, [6]. It uses MIMO technologies and higher order modulation. It also introduces an optional all-IP architecture for the network where base stations are directly connected to the internet. Several trials are underway and the first commercial launches have been announced for late 2008. On 10 June, 2008 Australia’s Next G was the first network to enable some features of HSPA+, [48].

System level investigations on this topic have already started, [49], [50], [51], [52] and [53], but for sure many more interesting results will follow.
Bibliography


