Principles for Channel Allocation in GSM
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Examensarbete utfört i Reglerteknik
vid Tekniska högskolan i Linköping
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Principer för kanalallokering i GSM

In today’s GSM system there is a complex resource situation when it comes to the scarce TDMA channels in the air interface, the time slots. There are both voice call services that use one or a half time slot and there are packet data users, that may share time slots with other packet data users, and they can use multiple channels at the same time. Allocating time to users is a crucial part in the system and it may affect the performance for the end user substantially.

In the future there may be more types of services than just voice and packet data and that these services may have specific demands on their channels, time slots. That means they would not be able to use just any of the available channels. The way to "give" services channels is what is called channel allocation. In this thesis four different services and three different principles for channel allocation is implemented in a Matlab simulator and simulated. The thesis goal is to determine which principle is best for which mix of services.

The principles that have been investigated are Flexible Algorithm that lets all services use all channels, Fix Dedication Algorithm where all channels are dedicated to a service and only can be used by that one and finally Soft Dedication Algorithm where all channels are dedicated to a service but may be used by other services when it is not needed by the preferred one.

The conclusion is, simplified, that the Soft Dedication Algorithm generates low blocking rates, high bandwidth and that it is a quite robust principle although the borrowing user may be preempted. It may not always be the best one but over all it is the one to prefer.
Abstract

In today's GSM system there is a complex resource situation when it comes to the scarce TDMA channels in the air interface, the time slots. There are both voice call services that use one or a half time slot and there are packet data users, that may share time slots with other packet data users, and they can use multiple channels at the same time. Allocating time to users is a crucial part in the system and it may affect the performance for the end user substantially.

In the future there may be more types of services than just voice and packet data and that these services may have specific demands on their channels, time slots. That means they would not be able to use just any of the available channels. The way to 'give' services channels is what is called channel allocation. In this thesis four different services and three different principles for channel allocation is implemented in a Matlab simulator and simulated. The thesis goal is to determine which principle is best for which mix of services.

The principles that have been investigated are Flexible Algorithm that lets all services use all channels, Fix Dedication Algorithm where all channels are dedicated to a service and only can be used by that one and finally Soft Dedication Algorithm where all channels are dedicated to a service but may be used by other services when it is not needed by the preferred one.

The conclusion is, simplified, that the Soft Dedication Algorithm generates low blocking rates, high bandwidth and that it is a quite robust principle although the borrowing user may be preempted. It may not always be the best one but over all it is the one to prefer.
Sammanfattning

Detta examensarbete är utfört på uppdrag av och i samarbete med Ericsson och rör kanal- och resurshantering i GSM-systemet.

Ett ständigt problem vid trådlös och mobil kommunikation är den begränsade mängd frekvenser som finns tillgängliga i radiogränssnittet och hur pass nära två radioresursers frekvenser kan ligga varandra. I GSM används TDMA (Time Division Multiple Access) för att få plats med många användare på ett smalt frekvensband. TDMA innebär förenklat att tiden delas upp i åtta tidsluckor och att varje användare får tillgång till en av radioresurserna under en sådan tidslucka (kanal). Detta gäller både i upp- och nedlänk.


I detta exjobb har tre nya, enkla och renodlade principer för kanalallokering undersökts för fyra fiktiva tjänster. Det tre principerna är Flexible Algorithm, där alla tjänster tillåts använda alla kanaler, Fix Dedication Algorithm, där alla kanaler är dedicerade till någon tjänst och endast kan användas av just denna tjänst; och slutligen Soft Dedication Algorithm som fungerar liknande den föregående men här kan tjänster "låna" kanaler av andra tjänster så långs som de är lediga. I Soft Dedication Algorithm kan en eventuell "låntagare" bli avbruten om en användare av rätt tjänst inte hittar en ledig kanal.

Utvärdering har skett genom att simulera systemet i en, delvis egengjord, Matlab-simulator.

Resultaten visar, förenklat, att Soft Dedication Algorithm är den bästa vad gäller låg blockering, kanalutnyttjande och även bandbredder. Den är även förhållandevis robust mot variationer i last.
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Jonas Månsson
Linköping, January -08
# Abbreviations

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<th>Definition</th>
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<td>AGCH</td>
<td>Access Grant Channel</td>
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<td>BCCH</td>
<td>Broadcast Control Channel</td>
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<td>BSC</td>
<td>Base Station Controller</td>
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<td>BSS</td>
<td>Base Station Subsystem</td>
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<td>BTS</td>
<td>Base Transceiver Station</td>
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<td>CBCH</td>
<td>Cell Broadcast Channel</td>
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<td>CEPT</td>
<td>Confederation of European Posts and Telecommunications</td>
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<tr>
<td>CN</td>
<td>Core Network</td>
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<tr>
<td>CS</td>
<td>Circuit Switching</td>
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<td>EDGE</td>
<td>Enhanced Data rates for GSM Evolution</td>
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<td>EDGEE</td>
<td>EDGE Evolution</td>
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<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
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<td>FACH</td>
<td>Fast Associated Control Channel</td>
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<td>FCCH</td>
<td>Frequency Correction Channel</td>
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<td>FDA</td>
<td>Fix Dedicated Allocation</td>
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<td>FLX</td>
<td>Flexible allocation</td>
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<td>GGSN</td>
<td>Gateway GPRS Support Node</td>
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<td>GMSC</td>
<td>Gateway Mobile Switching Center</td>
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<td>GMSK</td>
<td>Gaussian Minimum Shift Key</td>
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<td>GPRS</td>
<td>General Packet Radios Service</td>
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<td>GSM</td>
<td>Global System for Mobile communications or Groupe Spéciale Mobile</td>
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<td>HLR</td>
<td>Home Location Register</td>
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<tr>
<td>MS</td>
<td>Mobile Station</td>
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<td>MSC</td>
<td>Mobile Switching Center</td>
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<td>PCH</td>
<td>Paging Channel</td>
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<td>PCU</td>
<td>Packet Control Unit</td>
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<td>PDTCH</td>
<td>Packet Data Traffic Channel</td>
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<td>PDU</td>
<td>Product Development Unit</td>
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<td>PriCAS</td>
<td>Principles for Channel Allocation Simulator</td>
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<td>PS</td>
<td>Packet Switching</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>PSTN</td>
<td>Public Switched Telephone Network</td>
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<td>RACH</td>
<td>Random Access CHannel</td>
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<td>RAN</td>
<td>Radio Access Network</td>
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<td>RBS</td>
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<td>Slow Associated Control CHannel</td>
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<td>SCH</td>
<td>Synchronization CHannel</td>
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<td>TCH</td>
<td>Traffic CHannel</td>
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<td>TDMA</td>
<td>Time Division Multiple Access</td>
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<td>TRC</td>
<td>Transcoder Controller</td>
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<td>TRX</td>
<td>Transceiver</td>
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<td>TS</td>
<td>Time Slot</td>
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<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<td>VLR</td>
<td>Visitor Location Register</td>
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Chapter 1

Introduction

1.1 Background and problem statement

GSM is today the most used system in the world for cellular communication and it keeps growing. In the early days of GSM there were only one or maybe two services available for the subscriber and there was no problem in allocating the available channels. Through the years the number of services have grown and also the needs for each service. This has led to a fairly complex but working algorithm for allocating the physical channels.

Because of the constant development it is impossible to tell if or when a new service will come and what demands on its channels it will have. Maybe its demands will be very different from the services that exist today and a whole new way of allocation is needed. The complexity will also increase and it is possible that there is no option to use an algorithm with an ad hoc solution as it is today. Another problem that is being noticed is the growing number of parameters that needs to be set to make today’s algorithm work in different traffic situations. With more services there will be more parameters if the present algorithm is going to be used. Generally the channels are seen as a costly and limited resource in the systems; the frequencies (spectrum), the hardware in the nodes and the links between them should all be optimized. In this study no care is taken to the link part of the channel resource (it is assumed that existing features are available to handle that).

Ericsson is interested in investigating the possibility of finding a "simple" principle for channel allocation with limited numbers of parameters. This thesis work is a part of the research orientated GSM/EDGE Algorithm Research (GEAR) project in GSM Radio Access Network (RAN) organization and is a close cooperation between Ericsson Research and PDU GSM RAN.
1.2 Thesis scope

This study shall look at the pros and cons of different strategies of channel allocation. The overall cell capacity/utilization as well as individual service availability shall be considered. Also a brief analysis of the cost (in design) and complexity (in configuration etc) shall be done. The following items are to be done:

- Study related work such as technical reports and papers and, if possible, draw conclusions from them, that might be helpful.
- Define some services that shall be supported in simulations, and their requirements.
- Define the different allocation principles/algorithms to evaluate.
- Implement a new or modify an existing simulator.
- Simulate and compare the principles regarding
  - Channel utilization.
  - Service availability and service continuity.
  - Users bandwidth.

See chapter 3.5 for further definitions of which parameters to study.

- Draw conclusions on which allocation principle is best over all and/or for which traffic mix.

1.3 Thesis goal and limitations

The goal of this thesis work is to find some of the pros and cons of different principles for channel allocation for different traffic mixes. The goal is not to find an optimal algorithm but one, or more, not too complex ones, without too many parameters, that is robust to different traffic situations. Also the possibility of using different principles for different traffic mixes will be studied.

Note that the situations and services to be evaluated and simulated do not necessarily have to be a realistic model of the existing GSM network or its traffic situation. It is intended that the results from this thesis work can be applied to other networks and systems with limited resources.

The results shall be possible to use during future BSC implementation. The results can indicate if and when (for which types of services or cells) it will be necessary to abandon the flexible channel allocation that Ericsson (mainly) use today.
1.4 Method

The first part of the work will be devoted to searching for earlier work in different databases like IEEE Xplore.

Before starting the evaluations, the different services and principles are to be defined. Also how the simulations are going to be done is being defined. This will be done in consultation with an Ericsson expert on the channel situation today and possible future services.

The simulations will be made in a MATLAB™simulator. There is an existing simulator, Ducar, for the existing GSM that will be partly used or modified.

1.5 Thesis outline

Chapter 2 gives a brief overview of GSM.

Chapter 3 defines the different services, principles for channel allocation, re-allocation algorithm and some parameters for the simulator.

Chapter 4 explains the functionality of the used simulator, PriCAS.

Chapter 5 presents all made simulations.

Chapter 6 displays the results from simulations.

Chapter 7 points out the conclusions from the study and discusses about future possible work.
Introduction
Chapter 2

Theoretical background

This chapter aims at giving the reader a greater understanding of the relevant technologies and to summarize the earlier studies that have been made in this area. The ones with good understanding of the GSM and its history could skip the parts from 2.1 to 2.4.

2.1 History

In 1982 the first step in creating an European mobile communication standard was taken by the Confederation of European Posts and Telecommunications (CEPT) and the Groupe Spéciale Mobile (GSM) was born. Their objective was to design a European standard for mobile communication to be used all over Europe. In 1989 the responsibility was shifted over to the European Telecommunications Standards Institute (ETSI) and Global System for Mobile communications (GSM) was accepted as an international mobile digital telephony standard.

The first GSM network was launched in 1991.

Since then the number of users have steadily increased and in the spring of 2007 there were 2.4 billion subscribers in the GSM network worldwide, see [1]. Although GSM is a rather old standard it is still very popular and is still growing fast. In many countries the newer 3G technologies such as Universal Mobile Telecommunications System (UMTS) are too expensive and will not be used in many years and even maybe never. Some countries rely on only GSM and have no other telephony network such as a fix Public Switched Telephone Network (PSTN). As the GSM standard is still evolving, the data speeds are increasing, the quality is improving and the hardware is getting more efficient which makes GSM a good complement to 3G systems. The standard allows international roaming and gives the subscribers the possibility to use their phones in almost the whole world. Roaming is defined as the ability for a cellular customer to automatically make and receive voice calls, send and receive data, or access other services, including home data services, when travelling outside the geographical coverage area of the home network, by means
of using a visited network.

Through the years the standard has developed when it comes to speech and data, not only bit rates but also codecs, channel utilization, robustness among other things. The 2.5G technology General Packet Radio Service (GPRS) was the first packet switched (PS) way to transfer data and was followed by Enhanced Data rates for GPRS Evolution (EDGE) and later, EDGE Evolution.

2.2 GSM overview

GSM is a radio based cellular telephony system that uses the frequency bands 900 MHz or 1800 MHz. Cellular means that the operating area can be divided into small areas, so called cells, which is the smallest area the network can identify. There are a few countries that uses the 850 MHz and 1900 MHz bands. Each band is divided into one uplink band and one downlink band with 25 MHz bandwidth each. The uplink and downlink bands are subdivided into 124 frequency channels spaced 200 kHz. These channels are often referred to as carriers or carrier frequencies. The technique to multiply users on each frequency is called Time Division Multiple Access (TDMA) and splits each carrier frequency in 8 time slots (TS), see section 2.4.1. The standard modulation in GSM is Gaussian Minimum Shift Key (GMSK).

There are two different types of traffic. Circuit switched (CS) and packet switched (PS), i.e. GPRS or EDGE. The CS traffic can by divided in two main categories, voice and data, and allocates a whole channel through a connection. The CS data traffic constitutes only a small amount of the total traffic today since there are better PS options.

There is a large number of different interfaces and protocols between the different nodes in the network but these are not handled in this overview, see [3] for details.

2.3 GSM network and nodes

The GSM network consists of two parts, the Base Station Subsystem (BSS) and the Core Network (CN). The BSS is closest to the subscriber and handles all the radio resources. See Figure 2.1 and the following chapter for details.

2.3.1 Base Station Subsystem

Base Transceiver Station

The Base Transceiver Station (BTS) or Radio Base Station (RBS) typically contains a mast, an antenna and a small building containing all the necessary hardware for sending and receiving radio signals to the subscriber’s Mobile Station (MS). The correct notation is that a BTS is a logical unit from the standard and covers
2.3 GSM network and nodes

A cell is defined as the area covered by one Broadcast Control CHannel (BCCH). See chapter [2.4] for a more thorough presentation of the different available channels.

The hardware that handles the radio signaling, both transmitting and receiving is called a transceiver (TRX). Depending on the number of users, that the operator expects to serve, there can be one or more TRXs per cell. Each TRX normally handles one frequency carrier.

**Base Station Controller**

The Base Station Controller (BSC) contains the most of the intelligence in the BSS. It supervises many BTSs/RBSs and controls the radio channels, receives measurements from the MSs and handles handover between cells. A handover is the operation done when the subscriber of an on-going call reaches the cellborder or when the noise/carrier ratio is to big during a call. The call is 'given' to another cell that have better possibility to continue the call.

**Transcoder Controller and Packet Unit Controller**

The Transcoder Controller (TRC) handles the transcoder resources and can be implemented in the RBS or BSC. The transcoder resources converts different coded speech into the correct code to forward to the MSC or the MS.
The Packet Controller Unit handles the GPRS functions in the RBS and is often implemented either in the BTS or BSC.

### 2.3.2 Core Network

The CN is also referred to as the switching subsystem (SS) and handles the communication between the MS and other subscribers like other MSs, the Public Switched Telephone Network (PSTN) and the Internet. It contains many nodes, some of them are listed below, see also figure [2.1](#).

**Mobile Switching Center**

The Mobile Switching Center (MSC) is responsible for setting up calls and switch the calls to the subscribers. There is also a Gateway MSC (GMSC) which is a MSC connecting the GSM network to other networks like PSTN and ISDN network.

**Visitor Location Register**

The Visitor Location Register (VLR) is a database containing temporary information of all the MSs in its serving area. It is often implemented together with an MSC.

**Home Location Register**

The Home Location Register (HLR) is a database containing information about all subscribers of an operator. The subscriber information is current location, available services for the subscriber, settings for packet data and so on.

**GPRS nodes**

There are two main GPRS nodes in the core network which can be shared with other networks like UMTS. The Gateway GPRS Support Node (GGSN) connects the GPRS network to the Internet and other networks. The second GPRS node is the Serving GPRS Support Node (SGSN) which handles the switching of packet data in a geographical area but handles also functions as billing, authentication and other GPRS specific functions.

### 2.4 Channels

In the GSM there are numerous different channels and resources that can be used by a call, signaling or data session depending on where in the network and at which level you look. This section will focus on the channels in the physical radio interface which are important to know about before proceeding to later chapters in this report.
2.4 Channels

2.4.1 TDMA

Each TRX handles one carrier frequency and can be a hopping carrier frequency or a fix carrier frequency. If the carrier frequency is hopping it continuously changes between different radio frequencies. This is done to reduce the interference with other channels and cells.

In order to multiply users per carrier frequency the GSM uses Time Division Multiple Access (TDMA). The TRXs divides the time in 8 Time Slots (TS) of a length of approximately 0.577 ms. Very simplified you can say that one user uses one time slot to make a call in GSM. One period of 8 TSs is called a TDMA Frame and has the length of approximately 4.615 ms. In each cell one of the TRXs, called $c_0$, has to configure one of its TSs to the Broadcast Control Channel (BCCH) and is not allowed to hop, this TS is referred to as TS0. A TS configured to carry the BCCH can not be used for speech or data sessions. Due to frequency hopping the rest of the TSs of the TDMA Frame can be able to use frequency hopping depending on what technique is used. Each TS on a TDMA frame is referred to as a physical channel.

The TSs are called TS0, TS1, . . . , TS7 depending on it is position in the TDMA Frame, see figure 2.2

A TS can be configured to carry one or many logical signaling channels or to carry traffic. When a TS is configured to carry traffic we call it a Traffic CHannel (TCH). While a TCH is not allocated for packet data or other services it can be used to carry speech.

2.4.2 Logical signaling channels

There are many types of information that have to be transmitted between the MS and the BTS. Each type of information is transmitted on one logical channel. Here is a list and a brief description of the signaling channels, for further information see [3] and [2].

Some of the logical channels do not occupy a whole TS in every TDMA frame but is mapped on, for example, TS0 in a larger structure called a multiframe. No further explanation is made here, see [3] for a more thorough explanation.
• **Stand alone Dedicated Control CHannel (SDCCH)**, is a both uplink and downlink channel and is used to setup calls and carry Short Message Service (SMS). The SDCCH allocates 1/8 TS which means that there can be 8 SDCCH on each physical channel but it is not possible to share this channel with traffic. SDCCH can also share channel with the BCCH.

• **Frequency Correction CHannel (FCCH)**, is a downlink only channel and is used to allow the MSs to correct their frequency and to identify the BCCH. This channel is mapped on the multiframe structure.

• **Synchronization CHannel (SCH)**, is used to synchronize the TSs. This channel is mapped on the multiframe structure.

• **Broadcast Control CHannel (BCCH)**, is also a downlink only channel and serves the MSs with general information about the cell. This channel is mapped on the multiframe structure.

• **Paging CHannel (PCH)**, a downlink channel which the MS listen to at certain times to see if it is being paged for new calls. This channel is mapped on the multiframe structure.

• **Random Access CHannel (RACH)**, is an uplink channel used by the MSs to contact the network when it is being paged or when it wants to set up an MS originated call. This channel is mapped on the multiframe structure.

• **Access Grant CHannel (AGCH)**, is used to assign an SDCCH to the MS. This channel is mapped on the multiframe structure.

• **Slow Associated Control CHannel (SACCH)**, uses the same physical channels as the traffic channel (TCH) or SDCCH for sending measurement data, power information and timing instructions.

• **Fast Associated Control CHannel (FACCH)**, is used during handover and uses a small part of the traffic channel (TCH).

• **Cell Broadcast CHannel (CBCH)**, uses the same physical channel as SDCCH and sends Short Message Service Cell Broadcast (SMSCB).

There are about ten logical channels for packet data but these are not mentioned here. For further information see [3].

2.4.3 Logical traffic channels

Except from signaling channels there are also traffic channels carrying the speech and data. There are two types of speech channels, Full Rate (FR) and Half Rate (HR). These are often written TCH/F and TCH/H, the TCH/F allocates one TS and TCH/H allocates a half TS. The logical channel for packet data is Packet Data Traffic CHannel (PDTCH).
2.5 Related work

In Figure 2.3 is an example of how the TCHs might be configured and allocated.

![Diagram of TCH configuration and allocation]

Figure 2.3. An example of how the TCHs might be configured and allocated.

2.4.4 GPRS and EDGE

GPRS, EDGE and the later EDGE Evolution (EDGEE) are techniques in GSM to send and receive PS data. The use of PS data instead of CS data, as in the original standard, is a much more efficient way of using the channels and the air interface due to the traffic’s burstyness.

When GPRS was introduced in the GSM network it came with many new protocols and nodes. EDGE and EDGEE use basically the same infrastructure but new coding schemes and modulation. GPRS uses the GSM modulation GMSK and EDGE uses 8-PSK or GMSK depending on radio situation. To reach even higher data rates, up to 1 MBit/s EDGEE uses modulation techniques called 32QAM and 16QAM and some special coding. For more information see [6].

A TCH that is configured to a PDTCH can carry GPRS, EDGE or EDGEE depending on hardware and software in the network. One subscriber using one of these techniques to send and receive data can use 1 to 8 PDTCHs downlink and uplink (Ericsson limits this to maximum 5 downlink PDTCHs and 4 uplink PDTCHs) uplink. This may vary depending on the MS Multislot Class (MC), traffic situation and many other things.

TCHs are divided into TCH Groups with the same frequency parameters. The frequency parameters vary depending on frequency hopping characteristics. Two or more channels that are being used by one MS must belong to the same TCH Group.

See [3], [2] and [1] for further information about the GSM.

2.5 Related work

Channel and resource allocation is an important field in mobile cellular networks and there is a lot of work done earlier. Many of the papers concerning channel
allocation are focused on other types of channels in other parts of the network than the ones of interest here.

In [4] a way of dynamically allocating channels in the GSM/GPRS network is described. Three different ways of allocating channels are evaluated and compared, Static Channel Allocation (SCA), Dynamic Channel Stealing (DCS) and a combination of the two. The DCS is very similar to the soft dedicated allocation algorithms evaluated in this thesis. Their conclusion is that by allocating unused speech channels with GPRS or other packet data until the channels are needed by a speech call is a cheap way to give resources to data users. It is also shown that by dedicating a few of the channels for packet data and use the DCS technique is even better for the packet data users and with just small negative effects on the speech users. This study is very similar to the one in this thesis except for the number of different types of channels.

In [8] Sheu and Yang evaluates a pre-emptive channel allocation model where on-going real time call (e.g. speech) is allowed to pre-empt on-going non-real time (e.g. e-mail and Internet browsing) while in handover between cells. It is shown that the pre-emptive method reduces blocking probability when handovering real time calls. A mathematical model with 3-D Markov chains is used in the evaluation.

In [7] different ways of allocating a few channels for packet data and some channels to be shared between speech and packet data users are studied. They have made simulations with varying numbers of reserved and shared channels on the non-hopping BCCH carrier. Their results show that dedicating one to two channels for packet data and share four or five channels between speech and data gives the packet data users good data capacity and user throughput without larger degradation of the voice service.

Huang et al. [9] study the impact of a Bandwidth-on-Demand Strategy (BoD). The BoD is a dynamically changing algorithm that changes depending on traffic load and a parameter. In the paper there are two variables that can be affected by the algorithm, the number of channels dedicated for speech and the number of channels dedicated for incoming handover speech calls. The packet data users are allowed to use the other channels. This is an interesting approach but in our case we are just interested in a fix way of allocating the channels, not a dynamic one.

In [5] by Dahmouni et al. three interesting ways of allocating channels are simulated. Their approach is not to evaluate the allocation algorithms as in this thesis but rather to evaluate the used model.
Chapter 3

Definitions

In this chapter all the different services, principles for channel allocation, re-allocation methods and the test cell(s) will be defined.

3.1 Services

The services to be used in the simulations are not existing services in the GSM but at least two of them are very much alike existing ones. The services are defined to be as unlike each other as possible but also to have specific but realistic demands on their channels.

It is assumed that there is a limited amount of hardware (HW) that is able to turn some of the TCHs into fast PS data TCHs. These TCHs are called EDGE-TCHs.

The services are:

- **Service 1, S₁:**
  - It is the only CS service and is very much alike today’s speech traffic.
  - One user uses one and only one TCH and it can not share it with other users.
  - There are no specific requirements on choice of TCH. All TCHs are satisfactory for the service.

- **Service 2, S₂:**
  - It is a PS service and has much in common with the GSM packet data services.
  - It can use both regular TCHs and EDGE-TCHs.
  - In a cell many users may share one or many TCHs but one user can use a maximum of four TCHs at a time.
If a user uses the EDGE-technique all its allocated TCHs must be EDGE-TCHs.  
May share EDGE-TCHs with S₄.

• **Service 3, S₃:**
  
  – It uses one and only one TCH that may not be shared between users.  
  Can be seen as a CS service carrying data even though it might be implemented as a PS service during simulations.
  – Has to be allocated on a TCH located on TS₀.  
  – It has no need for an EDGE-TCH.
  – This service might for example be a broadcasting service. There have be earlier ideas in GSM standardization about a broadcasting service that needed channels on low time slot numbers.

• **Service 4, S₄:**
  
  – It is a PS service with real time requirements.
  – This service allocates two and only two EDGE-TCHs.
  – The EDGE-TCHs must be adjacent and must not be shared with other users of S₄.
  – It may share EDGE-TCH with with S₂ users but the S₄ uses a large part of the bandwidth and the S₂ users will only get what is left.

### 3.2 Principles for allocation

In this study it have been chosen to look at three different principles of channel allocation; Flexible, Fix Dedication and Soft Dedication. The three principles are fairly different and are intended to be extreme cases to make it possible to see differences between them. In Figure 3.1 is an example of how the channels might be allocated. In this cell there are two TRXs and the BCCH and SDCCH use two channels for signaling.

#### 3.2.1 FLeXible allocation (FLX)

The main idea with this principle is that an incoming user is allowed to allocate as many of and which one of the free TCHs as it wants. No pre-emption is allowed. There are some rules for each service to follow before allocating:

• **S₁:**
  
  – Avoid TS₀ and the EDGE-TCHs if possible and prefer low TCH numbers.
  – Choose an EDGE-TCH before a TS₀ TCH.
  – Try to keep as many free adjacent TCHs as possible.
3.2 Principles for allocation

Non-dedicated & non-allocated

Dedicated

Allocated

EDGE capable

\[ S_1 = S_2 = S_3 = S_4 \]

\[ \text{TCHGrp1} \]

\[ \text{TCHGrp2} \]

\[ \text{EDGE capable} \]

\[ \text{Non-dedicated & non-allocated} \]

\[ \text{Dedicated} \]

\[ \text{Allocated} \]

\[ \text{EDGE capable} \]

\[ \text{\( = \) Signaling channel} \]

\[ \text{\( = S_1 \)} \]

\[ \text{\( = S_2 \)} \]

\[ \text{\( = S_3 \)} \]

\[ \text{\( = S_4 \)} \]

Figure 3.1. An example cell with dedicated and non dedicated channels

- \( S_2 \):
  - Prefer EDGE-TCHs and as many as possible adjacent to each other.
  - Avoid TS_0.
  - Avoid splitting free EDGE channels, possible for \( S_4 \), from each other.
  - Prefer high TCH numbers.

- \( S_3 \): Allocate a TS_0 TCH if it is possible.

- \( S_4 \): Allocate two adjacent EDGE-TCHs and try not to separate other TCHs, possible for data use, from each other.

3.2.2 Fix Dedication Allocation (FDA)

In this principle the TCHs are pre-configured to be dedicated to one service. Only the dedicated service is allowed to use the TCH. No pre-emption is allowed. In the example in Figure 3.2 a scenario that might occur is shown. If there is an incoming \( S_1 \) it will be blocked even though there are free TCHs, since all the free channels are dedicated to \( S_2 \) and \( S_4 \). On the other hand it is guaranteed that an incoming \( S_4 \) will be able to establish a connection.

3.2.3 Soft Dedication Allocation (SDA)

As in Fix Dedication Allocation (FDA) the TCHs are pre-configured to be dedicated to one service. The difference here is that all services are allowed to use
TCHs dedicated for other services as long as they are free and there are no incoming services of the type that the TCH is dedicated to. All services are allowed to pre-empt other types of services if they are allocated on its own dedicated TCH. If the channels in Figure 3.2 are allocated with the SDA, an incoming $S_1$ will be able to establish connection on one of the free TCHs. But if there is an incoming $S_2$ the $S_1$ risks to be pre-empted if it cant find another channel to borrow.

### 3.3 Re-allocation

Re-allocation is the procedure when users are moved from the previously allocated channels to new ones during an ongoing call or session. Re-allocating channels for the users is allowed in order to make the algorithms more efficient. There is one re-allocation algorithm (RAA) for each principle of allocation. The frequency of when to re-allocate may either vary or be fix and can also be event based.

#### 3.3.1 Re-allocation in FLX

The FLX RAA tries to make $T_{S_0}$ free if it is not allocated to a $S_3$ and to move non- $S_2$ or $S_4$ from the EDGE-TCHs. It also tries to make $S_2$ more effective by allocating the $S_2$ users on more channels and more EDGE-TCHs if possible. Reserving new channels are only made if the mean value of the rate of users per channel are above the parameter $TBF\text{limit}$. If the rate is under $TBF\text{limit}$ one channel is unreserved. Some hysteresis is used here to avoid oscillating behavior, see 3.4.

This RAA also tries to move users to attain large areas of free, consecutive TCHs. Re-allocation also tries to create large, consecutive areas of $S_2$-allocated TCHs.

#### 3.3.2 Re-allocation in FDA

In FDA only intern re-allocation in the dedicated areas is possible. Try to spread the $S_2$ users to maximize their bandwidth. Try to make the amount of two free, adjacent, $S_4$-possible TCHs (EDGE) as large as possible.
3.4 Parameters

3.3.3 Re-allocation in SDA

The RAA in SDA is alike the FLX RAA but it also tries to move services to the channels dedicated to that service.

3.4 Parameters

The idea with the approach with all the three principles is, among others, to minimize the number of parameters the operator needs to set in each cell. But there is still a few parameters that has to be set, either automatically or manually.

- **TBFlimit:** This parameter is used by the system to know when to reserve or un-reserve new or old channels for the $S_2$ users. If the mean value of users per channel is 10% above respectively below this value the system tries to reserve or un-reserve one new channel for the $S_2$ users. Note that this parameter is not used by the Fix Dedication Algorithm, FDA, because all $S_2$ dedicated channels are also reserved for $S_2$ in this principle.

- **Dedication matrix:** This parameter is actually a matrix containing information of all the channels’ dedication. Every row in the matrix corresponds to a TCH group and the columns correspond to TSs. Each item in the matrix can have an integer value between 0 and 4. 0 means that the channel is blocked and 1-4 describe which service the channel is dedicated to ($S_1$-$S_4$).

- **Re-allocation interval:** A parameter limiting the system to re-allocate at most that often.

- **Control channel parameters:** Defines which channels to be used as control channel, consists of multiple parameters.

These parameters are the only ones needed for the operator to set, the rest is taken care of by the principles for channel allocation.

Note: There are of course other parameters to be set but not regarding channel allocation.

3.5 Simulation - evaluation

When simulating a system like the one in this thesis work, loads of data is produced and there are many ways to evaluate the subscribers’ happiness and the utilization of the cell. It is decided to measure and compare the following parameters/data:

**All services:** Blocking factor, ratio of pre-emptions and ratio of re-allocations.

$S_2$: Throughput, e.g., average bandwidth, normalized or in kbit/s.

**The system:** Rate of channel utilization and the amount of time each individual channel is allocated.
Chapter 4

PriCAS - the simulator

In this chapter some of the functions of PriCAS (Principles for Channel Allocation Simulator) is briefly described. A large portion of the work done during this thesis has been devoted to implementing the simulator of the system and allocation principles. As mentioned earlier the Ericsson simulator, DuCar, have been used as a framework but most of the code have been changed or removed and replaced with new. Many functions in DuCar were supererogatory or not general enough. The new simulator is known under the name PriCAS.

4.1 Presumptions and limitations

It is very important to observe that PriCAS only simulates a small part of the network and do not take other resource limitations in account. All other nodes and interfaces are supposed to be static and working without any flux due to traffic load or the behavior of the users or the network. No respect is taken to the air interface, the different distances and radio situation real users may have. The user’s possibility to use a certain service is the same for all users and do not change over time.

The subscribers are supposed to arrive (start a call) as generated by a Poisson distribution with the probability function $p_X$.

$$p_X(\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$

This is a normal way to model users in a cellular network and in queue theory and is shown to be a good approximation of the real behavior of the subscribers. It is also used in related work mentioned earlier. The subscribers behavior is not affected by the situation in the cell, the data rates, the rate of blocking, quality of speech or any other external factor. Which service the subscribers use is generated by a known distribution defined by parameters before each simulation starts. See Figure 4.1 for an example of a service distribution Cumulative Distribution Function(CDF). All subscribers are supposed to have the same MS class and coding schemes.
The data traffic in the simulations is not considered to be in any particular protocol layer but is supposed to be a single file transfer per call (session). The variation of the file size is also defined by a distribution and the distribution is defined by parameters before the simulation and is set to be a distribution with three different file sizes, see section 5.1.1. In each time interval each user’s bandwidth for the moment is calculated and the bandwidth is multiplied with the length of the time interval and that amount of data is removed from the remaining data of the user.

Only one cell is simulated and its size may vary. Size in this case is defined as the number of TRXs the cell has and is also tied to the number of users the cell may handle. The capability, dedication of channels and number of different channels are parameters to be set before starting the simulations.

### 4.2 Fundamental functionality

PriCAS is a simulator using Monte Carlo methods that uses random numbers to calculate the system’s behavior. Most parts except for the traffic generator of the simulator is deterministic and follow the simple laws defined earlier. The rate of arriving users and the services they use is generated by random numbers (i.e. pseudo random). The simulator consists of about 40 MATLAB™m-files with functions and scripts. PriCAS is built to be modular and it should be easy to, for example, implement another principle for channel allocation or additional services.

The simulator has one big main loop in which functions are called from, see Figure 4.2 for schematic view of the loop. Depending on which principle that is simulated for the moment, different functions are called. First in every loop new subscribers
are generated (may be 0 or more) and then the system tries to allocate channels for them using one of the specific channel allocation algorithms. If no channels are found the users are blocked, i.e. kicked out and not able to complete their calls or sessions. When channels are allocated the users are ready to send data or make their call. This is done in a number of functions depending on users and principle. The time to terminate the call for the non S\textsubscript{2} users is also determined when generated.

Data rates are determined by dividing the maximum rate of the channel with the number of S\textsubscript{2} users on the channel. The exception is if there is a S\textsubscript{1} user allocated on a EDGE channel, then that user will get 90\% of the possible data rate of the channel. The maximum data rates and the factor between EDGE and non-EDGE is specified before starting simulations. In the simulations in this study the EDGE and GPRS channels have the rates 10kbit/s respective 45kbit/s. In each loop data is removed from the users by the amount of the calculated data rate multiplied by the period of the loop.

In each loop the non-S\textsubscript{2} users are checked if they are finished or not, if so they are removed. The S\textsubscript{2} users are removed when all their data is sent.

In the end of the loop some logging of variables and the system is made. If the user of the simulator decides to activate the animation and diagnose functions in the simulator, plots are continuously displayed and the simulator is diagnosed. The diagnose function monitors all variables and identifies errors. For example, the diagnose function verifies that the number of users in each channel correspond correctly to the channels used by the users and cross check all variables. The last thing that happens in the loop is that the re-allocation algorithms are applied. It is possible to re-allocate with other intervals than the loop period.

To ensure that the variations between the principles are not just random and statistical noise, simulations should be longer than at least 600 seconds. In simulations that long, the same result is generated most of the times when identical setup simulations is run. Simulations in this work is run for 1800 seconds which should be long enough. The simulations done in this study have been performed multiple times with the same results even though not all simulations are displayed in this report.

4.3 Outputs

A simulation generates a very large amount of data and it is important to store and present this information in a correct and comprehensible way. In PriCAS all important data about the simulation and also data generated during simulation is, after the simulation, stored in a structure in a .mat-file. This structure contains the par-structure, with all simulation parameters, and the r-structure, with all stored data about the traffic situation and statistics.
Figure 4.2. A schematic flow chart of the code in PriCAS. The blocks are described in detail in Section 4.2.
4.3 Outputs

Calculated results are presented in a "pretty-print" output on screen after every simulation. The same print is also stored in a txt-file, see Figure 4.3. There is a possible option to simulate the same traffic situation for the three channel allocation principles as a batch. In that case the two stored files contain information from all three simulations. The displayed information differs depending on what allocation principle that is simulated.

Plots are also displayed when a simulation is finished. Plots are automatically stored as other data but may be regenerated from the stored structure in the .mat-file. The displayed plots are:

- A CDF of the $S_2$ mean data rates.
- Channel utilization for each channel, service and principle.
- Total channel utilization.
- Blocking rate for each principle and service.
- Number of $S_2$ users in the cell through the simulation of each principle.
- Number of pre-empted users of each service in the different principles.
- Rate of re-allocation (number of re-allocations per finished users) per service and principle.

See Figure 6.1, 6.2 and 6.3 for plot examples.
PriCAS finished without errors

The system simulated:
Principle of channel allocation: FLEXIBLE ALLOCATION
Number of TRXs: 5
Load (par.sp.trafficload): 80
Relative load (S1 S2 S3 S4): 2.00 2.50 0.40 0.15

The Dedication matrix:
0 0 0 0 0 1 1 1
3 1 1 1 4 4 4 4
3 1 1 1 2 2 2 2
3 1 1 1 2 2 2 2

Simulated time: 1800s
Total number of users trying to connect: 4237 (S1: 1698, S2: 2080, S3: 343, S4: 116)
Total channel utilization: 82.1%

Blocked users
Total number of blocked users: 284
Number of blocked S1 users: 160
Number of blocked S3 users: 53
Number of blocked S4 users: 71
Total rate of block: 7%
Rate of blocked users per service: S1: 9.42% S2: 0.00% S3: 15.45% S4: 61.21%

S2, data packet users
Mean data speed: 53.8kbit/s
10% quantile: 29.8kbit/s
50% quantile (median): 48.8kbit/s
90% quantile: 83.9kbit/s

Reallocation
Total number of reallocated users (and per service): 1522 (S1: 329, S2: 1193, S3: 0, S4: 0)
Rate of reallocated S1 users (reallocations per finished users): 16450.00%
Rate of reallocated S2 users (reallocations per finished users): 98650.00%
Rate of reallocated S3 users (reallocations per finished users): 0.00%
Rate of reallocated S4 users (reallocations per finished users): 0.00%
Total rate of reallocation (reallocations per finished users): 19025.00%
Total rate of reallocation (reallocations per finished users): 19025.00%

Figure 4.3. Output from a single simulation with PriCAS
Chapter 5

Simulations

This chapter describes the setup of the simulations and how the simulations are performed and thought of.

5.1 General setup

The simulated system is set up the same way in all simulations with small variations in traffic scenario and load, i.e. number of arriving users. The goal with the simulations is that they should be close to a possible scenario in a real cell. For example, cells with huge load and more than 90% block rate are not studied because it is not a likely situation. But the simulation will look at situations not perfect for the cell nor the cell configuration. The situation in a not optimized cell configuration is a very likely.

Many different simulations have the same dedication of channels but the traffic load vary and thereby simulates different scenarios.

The idea is to start looking at the cell during simulations when the operator have configured it in a close to perfect way. This might be a likely situation for some time in the cell but the load and relative load between services will vary and that situation is as important to study. Those simulations will identify the principles' robustness.

5.1.1 The cell

The simulated cell is of "normal size", that means it is not a very small cell but not a very large one either compared to possible scenarios in reality. It has EDGE capability on a few of its channels, see Figure 5.2 and 5.3 for cell configuration and dedication of channels. Note that dedication is not used in the flexible principle for channel allocation.
The cell has:

- 5 TRXs.
- 5 channels blocked by BCCH and SDCCHs located on the lowest TS numbers on TRX1.
- 4 TRXs with EDGE capability on 4 of their TSs.
- Bit rates of 45kbit/s for EDGE and 10kb/s for GPRS.
- Reallocations are made with the same frequency as the simulator loop (50Hz) if there are any reallocations to be performed.
- The packet sizes of the S2 users come in three sizes: 10kbit, 100kbit and 1000kbit with an expectation-value of 605 kbit. The size of each user’s packet is generated from a distribution with a CDF as shown in Figure 5.1.

![Figure 5.1. A CDF of packet sizes of the S2 users.](image)

5.2 Simulation 1 - Optimal dedication and load

The first traffic situation to be simulated is the one where the dedication of the channels are ‘optimal’ or at least good. To find this optimum multiple simulations have been made and traffic load has been trimmed. Of course this is not a true
5.3 Simulation 2 - Non-optimal dedication with many S₁ users

The second traffic scenario to simulate is not as optimized as the earlier. Here the number of dedicated channels for each service do not correspond to the relative load between the services. There are many more S₁ users and a very small amount of S₃ and S₄ users. This is a highly possible situation to upcome either for short
periods of time, peak hour traffic, or in longer periods of time due to user’s different behavior. In reality, even though the operator is meticulous when configuring the cell, the load will vary during hours, days and weeks. Also the difference of interest for a new service will vary during time. This simulation aims at demonstrate the robustness of the different principles. The dedication of channels is the same as in Simulation 1, i.e. Figure 5.2.

Four simulations with different load are made and referred to as sim 21, sim 22, sim 23, sim 24. Sim 21 has a very high load, sim 22 high load, sim 23 medium load and sim 24 light load.

This specific simulation is set up as:

- Load (par.sp.trafficload), vary: 95, 70, 35, 20 (sim 21, sim 22, sim 23, sim 24)
- Relative load (par.sp.relload): [4.00 2.50 0.10 0.08] ([S₁ S₂ S₃ S₄])
- Simulation time: 1800s

5.4 Simulation 3 - Non-optimal dedication with many S₃ and S₄ users

The third traffic situation to simulate is, like Simulation 2, not optimally dedicated to the traffic mix but here the relative load is opposite to the earlier ones. Another dedication matrix is used in this case than earlier, see Figure 5.3. There are both less S₃ and less S₄ dedicated channels and higher relative load of these. These simulations differ from the earlier ones in that way that both the relative load and the overall load vary in these simulations.

Figure 5.3. The matrix describing dedication and configuration of Simulation 3
5.4 Simulation 3 - Non-optimal dedication with many $S_3$ and $S_1$ users

Four simulations with different load and relative load are made and referred to as sim 31, sim 32, sim 33, sim 34. Sim 31 has a very high load, sim 32 high load, sim 33 medium load and sim 34 light load. In this case it is harder to tell which one of the four traffic mixes are loading the cell most.

This specific simulation is set up as:

- Load ($\text{par.sp.trafficload}$), vary: 30, 15, 50, 10 (sim 31, sim 32, sim 33, sim 34)

- Relative load ($\text{par.sp.reload}$):
  - sim 31: [4.00 1.00 1.00 1.00] ($S_1$ $S_2$ $S_3$ $S_4$)
  - sim 32: [1.00 1.00 1.00 1.00] ($S_1$ $S_2$ $S_3$ $S_4$)
  - sim 33: [0.50 1.00 2.00 2.00] ($S_1$ $S_2$ $S_3$ $S_1$)
  - sim 34: [0.50 1.00 2.00 2.00] ($S_1$ $S_2$ $S_3$ $S_4$)

- Simulation time: 1800s
Chapter 6

Results

Here the results from the simulations will be presented and displayed. As mentioned earlier each simulation generates 6 pages of information and plots and of course it is too much to display all from all simulations here. Some examples are shown (i.e from sim 12 and 32) and some new summarizing plots are displayed. Sim 12 and sim 32 are choosen because they represent two fairly different traffic scenarios and they have a quite interesting, e.g. high, over all traffic load.

It is not possible to write everything about all plots and outputs hence only significant differences are pointed out in the following sections. In Figure 6.7, 6.8 and 6.9 one can find summarizing plots.

6.1 Results - Simulation 1

In this simulation the dedication matrix was made to fit the traffic mix which resulted in a good overall channel utilization. See Figure 6.1, 6.2 and 6.3 for outputs from sim 11. Observations made from plots and printouts are presented below:

• Blocking:
  – When the load is light, none of the principles cause blocking for any service.
  – When load is medium-heavy the services with high demands (i.e. S\textsubscript{3} and S\textsubscript{4}) experience some blocking mainly with FLX and FDA.
  – When load is heavy all principles generate high rate of blocking but the FLX is unmistakable giving S\textsubscript{4} more block and FDA S\textsubscript{1} more.
  – SDA handles heavy load best and even S\textsubscript{3} and S\textsubscript{4} experience just small rates of block.

• Data speeds, throughput, for FLX and SDA is very alike undepending on load. FDA distinguishes with higher data speeds due to a different strategy when reserving channels but approaches FLX and SDA when load is heavy.
• Total channel utilization is quite the same for the different principles. See Figure 6.7.

• Pre-emptions: SDA pre-empt some users already when medium loaded and pre-empt more than 5% of $S_1$ users when heavy loaded.

• Re-allocation: FLX re-allocates multiple times more often than the other principles. FDA never needs to re-allocate. SDA only uses the re-allocation when heavy or medium loaded.

![CDF S2 user data speeds for the three principles](image)

Figure 6.1. Output plot from PriCAS, sim 11, showing a CDF of the data speeds for each principle when using optimal dedication and high load.
6.2 Results - Simulation 2

Here the traffic mix do not correspond to the dedication matrix, there are much more $S_1$ users and fewer $S_2$ and $S_4$ than what it should be if using optimal dedication. Observations from plots, Figure 6.7, 6.8 and 6.9 among others, and printouts give:

- Blocking:
  - When using FLX and load is heavy and very heavy the services with high demands, $S_3$ and $S_4$, experience high blocking ratio, as high as 30% ($S_3$) and 90% ($S_4$) while it is close to zero for SDA and FDA.
  - In general FDA has a blocking ratio higher than FLX and SDA. See Figure 6.8.

- Throughput, data speed, is as in Simulation 1 higher for FDA due to the other strategy for reserving $S_2$ channels. FLX and SDA have close to the same mean data speeds during lower load but SDA is best when the cell is heavy loaded. See Figure 6.9.
The total channel utilization is unmistakably lower with FDA than the other two that are quite alike, at least for (very) heavy loads. See Figure 6.7.

Pre-emptions occur in SDA during heavy and very heavy load for $S_1$ users for up to about 4-6% of non-blocked users. This of course happens when $S_1$ users use a channel dedicated for other services and being pre-empted by 'correct' service.

There is no reallocation when using FDA. FLX reallocate much more often than SDA.

**Figure 6.3.** Output plot from PriCAS, sim 11, displaying (a) Total channel utilization (b) Rate of blocking per service and principle (c) Number of $S_2$ users in cell during time (d) Number of pre-empted users per service and principle (e) Rate of reallocation per service and principle.
6.3 Results - Simulation 3

The scenario in this simulation is opposite to the one in Simulation 2, except for the fact that the dedication is also here made non-optimal. Here there are too many $S_1$ dedicated channels and a very heavy load of $S_3$ and $S_4$ users, see Figure 6.3, 6.5, 6.6 and 6.9 for outputs from sim 32. Observations made from plots and printouts are presented below:

- **Blocking:**
  - The over all blocking is indubitably larger in FDA.
  - Blocking for $S_4$ users is very high when using FDA even when the cell is lightly loaded as seen in Figure 6.8.
  - The difference for $S_3$ users is not as big as for $S_4$ but still the FDA generates largest rate of blocking.

- When it comes to channel utilization the FLX and SDA is best and the FLX is slightly better than SDA. See Figure 6.6 and 6.7.

- Throughput, data speed, is best for FDA for the same reasons as in the earlier simulations.

- The throughput for FLX is higher or the same as for SDA for all traffic loads, see Figure 6.8.

- $S_2$ users reallocate very often when using FLX but not at all when using FDA and SDA and almost undepending on the cell load. See Figure 6.6.

- $S_4$ users reallocate one or a couple of times when using SDA but not at all when using FLX or FDA. This is undepending on cell load. See Figure 6.6 for an example.

- $S_1$ users need to reallocate very often when the cell is heavy loaded and using FLX.

  - Generally, reallocation is multiple times more common when using FLX.

6.4 Summarizing results

A brief summation gives these over all results (see Figure 6.7, 6.8 and 6.9):

- **Throughput:**
  - FDA generates the highest data speeds because of its strategy of keeping all $S_2$ dedicated channels reserved for $S_2$ users all the time.
  - It is not possible to determine any big differences between FLX and SDA data speeds.

- **Blocking:**
– FDA generates high blocking rates. When non-optimally dedicated cell the FDA generates multiple times more blocking than the other principles.

– SDA is better than FLX when dedication is optimal but there are no obvious differences in other cases.

– SDA keeps blocking factor even between services while the services with high demands experience very high block when heavy loaded cell and FLX.

– SDA generates 0 block and FLX gives 1-9% block when the cell is optimal dedicated.

• Pre-emption:

  – SDA is the only principle that generates pre-emption.

  – When cell is heavy loaded and not optimally dedicated, a pre-emption rate of under or close to 10% is observed.

• Channel utilization:

  – FDA has the poorest channel utilization and SDA and FLX is distinguishably better.

  – There is no clear signs of that either SDA or FLX utilize the channels better than the other.

• Reallocation:

  – FLX generates many times more reallocations, in some ten or even hundred times, more than the others, though depending on reallocation period.

  – SDA reallocates about one or a few times per user.

It is likely that the rate (frequency) of reallocations in the real system not is possible to dispose as high as here and that may change the behavior of the principle. FLX is the one most depending on the reallocation and will probably lose most when reducing the rate. FDA that almost not uses reallocation at all will probably not be affected that much.
**Figure 6.4.** Output plot from PriCAS, sim 32, showing a CDF of the data speeds for each principle.
**Figure 6.5.** Output plot from PriCAS, sim 32, showing the channel utilization over all and per service for each channel.
6.4 Summarizing results

Figure 6.6. Output plot from PriCAS, sim 32, displaying (a) Total channel utilization (b) Rate of blocking per service and principle (c) Number of $S_2$ users in cell during time (d) Number of pre-empted users per service and principle (e) Rate of reallocation per service and principle.
Figure 6.7. Summarizing plot over the total channel utilization for all 11 simulations.
Figure 6.8. Summarizing plot of the total blocking ratio from all simulations for all principle.
Figure 6.9. Summarizing plot of the mean data rates of the $S_2$ users.
Chapter 7

Conclusions and discussion

In this chapter the conclusions from the study will be pointed out and discussed. At first some of the results that could have been figured out before simulations are presented and after that some results that are more unexpected are focused on.

7.1 Expected and verified

The results show that the FDA principle is not a good option when selecting a channel allocation algorithm. This is because it is very hard to dedicate the channels in a way so that all channels are used as much as possible and blocking is kept as low as possible. Compared to FLX, FDA is though better for the services with high demands on their channels because it always has some channels for each service. FDA gives much higher data speeds than the others due to that all $S_2$ dedicated channels also are reserved for $S_2$ and ready to be used without making new reservations as needed in the other principles. In reality the difference in data speed between FDA and the other two would probably be smaller due to the different strategies for allocation channels for $S_2$ users that have be used here. In this study the FDA uses a strategy for reserving the first $S_2$ channel that is much better for $S_2$ than the one in FLX and SDA. The strategies in FLX and SDA is probably possible to make better without causing higher blocking rates, preemptions etc. for the other services.

When load is low the differences between the principles are small and in some cases the FDA actually has slightly higher channel utilization.

Data rates in FLX and SDA is very close to each other and are closely bound to the \texttt{TBFlimit} parameter. It is possible that SDA could be made better than FLX by reserving more channels for $S_2$ when the load of other services than $S_2$ and $S_4$ is low (i.e. when no other services are willing to borrow channels).

Most of the time when using non-optimal dedication, SDA performs better than FLX when it comes to blocking. This is specially noticed by the services with high
7.2 Non predictable results

The results from the simulations are not that surprising, many conclusions could have been made without simulations but there are some that are not that obvious.

SDA does not preempt that often. Before the simulations are done it is easy to expect that there would be a very high rate of preemptions when load is high and dedication non-optimal but that is not the case. Highest observed value of preemption rate is 6% in sim 32. This is presumable partly due to the fact that a good re-allocation algorithm is run very often. Without it or if it is run more seldom the preemption rates would probably be higher.

The blocking rates of FLX and SDA are very close to each other which is not that easy to predict. The fact that they are better than FDA is easier to forecast. Worth mentioning is the strength of SDA when dedication is optimal where the blocking ratio is very low.

FDA does not need to reallocate at all or very seldom compared to the other principles. FLX, as implemented in the simulator, reallocates multiple times per user in the cell. This may be reduced in a real implementation but with possible negative effects on blocking ratio and channel utilization. The cost of reallocation is maybe the biggest disadvantage for FLX and SDA.

7.3 Which principle is the best?

There are many parameters and variables to look at and it is not easy to decide which of the principles is the best. At first one has to know if it is even possible to use a principle like FLX where it is important that users can be moved between channels easily. Also the costs for, for example, blocking, reallocation and preemption are important factors when choosing allocation algorithm.

A great benefit of all three principles is the small amount of parameters needed to set. The number of parameters is smallest in FLX.

If the operator of the system know precisely or close to precisely the load and relative load in the system, it is not a bad choice to use the FDA. No preemptions will appear, reallocation is needed very seldom and it is easier to optimize the use of e.g. $S_2$-like services. It is highly possible that reallocation is both affecting the user in a negative way and that it is a cost for the operator of the system. On the other hand, if the scenario changes in the cell the block ratio will rise dramatically.

If the operator on the other hand have no idea of the relative load or if it of-
ten changes then maybe the FLX is a better option. It is very flexible to different loads and utilizes the channels very well. On the downside it cannot guarantee that services with high demands on their channels are possible to use. This is a problem when introducing a new service when an operator wants to assure that they, to some extent, will be able to use a service. There will be many reallocations and this may be expensive. It is also very important that even though all services are allowed to use any channels the allocation algorithm has to choose channels in a way that it does not affect other users in a bad way (e.g. $S_1$ keeping $TS_0$ free as long as possible).

A more likely situation is where the operator has some idea of the relative load but it varies during, for example, hours, days and weeks. This is where the strength of SDA comes in handy. SDA ensures high demand services a minimum number of channels while it at the same time allows other users to use all unused channels. Most likely the biggest disadvantage with this principle is the fact that users may be preempted, an operation not always appreciated or not even allowed. The SDA keeps the blocking ratio low and is more or less fair to different services. The scenario with varying relative load over time is very likely when introducing a new service in a network.

To make the two dedicating principles well functioning the dedication of the channels is critical and require good statistics of the load in the cell.

When deciding which principle to use the operator or developer of the system wants to maximize his/her happiness in some way. To do this they need to know how much a preemption, a blocking or low data rates affect the system and the subscribers. In the existing GSM the cost for blocking is high and for preemptions even higher while low data rates for a short time is no problem. In other systems the costs may be different.

Worth mentioning is the fact that the FLX probably is much more time consuming to implement due to all the rules needed and reallocation algorithms to make it perform well. The principle that is easiest to implement is most likely FDA.

7.4 Recommendations to Ericsson

In the Ericsson GSM implementation there is no part of the system that has full control or insight of what is going on in all parts of the system and this makes that GSM system more unflexible than the simulated system. It is possibly not an option to implement neither of the three principles exactly as defined here but this study hopefully gives a hint in which direction to go. There are also other scarce resources not taken into account here.

It is quite obvious that the existing principle for channel allocation will not be
very good when the number of services and demands on their channels increase. If one of the principles in this study is the one to use stand to be seen.

The SDA is presumably the way to go. The largest disadvantage of it is the fact that users may be preempted. It is possible to imagine an algorithm of channel allocation very alike the SDA but with some restriction when it comes to preemptions. As in the existing system it is likely that, for example, the system does not have the same possibilities as the simulated system. This may be that one or more of the channels are not allowed to be preempted by one or more other services. Here it is important to be careful and observe that in this study only SDA with full preemption is considered and other cases have to be studied further if so.

The best way to dedicate channels in SDA, when introducing new services, is probably to dedicate more channels for the new services than what is being used in the beginning. In this way the other services will be able to borrow channels from the new one as long as there are not that many users using it. To be able to make good dedications it is important to have accurate statistics from cells to see when it is time to re-dedicate.

A completely different strategy is to use FDA and re-dedicate very often or have an over time changing dedication. This may be by a pre-configured pattern or by an auto-tuning dedication i.e. a feedback control loop. This may also be used in SDA.

Good statistics is a must to be able to dedicate channels in a correct way.

The complexity of the principles will also be of interest and here are some assumptions about that; FDA is probably the easiest one to implement while it require more settings of parameters for the operator. The most complex one to implement in a good way is likely FLX due to all rules. FLX on the other hand do not need any parameter settings. SDA is somewhere in between the other two.

A more complex but also robust method is probably to use an algorithm that is a mix of the three principles. Then you get the advantages of more than one principle but also, at least, twice the complexity of implementation.

7.5 Future work

This thesis has pointed out what is probably the right direction to go when it comes to future channel allocation in GSM but there are also weaknesses in the study. Before switching to a new channel allocation algorithm future studies should be made. Below are some suggestions on further studies to be made and other ideas of channel allocation that have been found during the study.

When it is established which the new services are and their precise demands on their channels, more simulations should be done. Simulation with a system more
real and with more variation of the cell structure is recommended. Other strategies for the packet data users in FLX and SDA principles should be interesting to look at. It should not be that hard to modify PriCAS to simulate new services and principles, most of the functions are probably going to be unchanged.

A possible future channel allocation algorithm that would be interesting to analyze is a principle that is a mix of the ones evaluated here. For example a principle where a part of the channels are fix dedicated to services as in FDA, to guarantee each service some access, and the rest of the channels are flexible as in FLX is interesting. To study the SDA where one or some of the services are not allowed to be preempted is also a interesting scenario.

Longer and more varying simulations are not made here but different ‘static’ ones. To study longer lasting simulations with varied relative and overall load to imitate the real world is important to further look at robustness of the principles.
Bibliography


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