

Mobile Communications

Data Services and General Packet Radio System

3. Data Services and General Packet Radio System

3.1 Data services: new requirements and features

3.2 GPRS services

 **3.3 Radio transmission and Radio Resource Management**

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3 Data services and General Packet Radio System

3.3 Radio transmission and Radio Resource Management

the base-band physical layer
layer 2
control of the radio resources

extensions: e3.3 Timing advance and Power control

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This paragraph analyses the functional issues arising at the physical layer. It highlights in particular the GPRS peculiar aspects, arising for the packet transmission of data and characterising the GPRS with respect to the GSM.

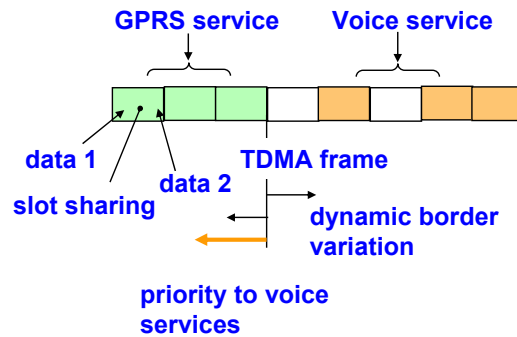
An extension addresses with a greater detail two key aspects tied to the packet connection:

- the *timing advance* mechanism
- the power control algorithm.

The physical layer

sharing resources and functions with GSM

- Radio resource sharing with GSM voice and data services
- Dynamic & static allocation of the physical channels
- One or more slots to a single GPRS user
- One or more GPRS users on a single slot
- Radio-frequency part unchanged



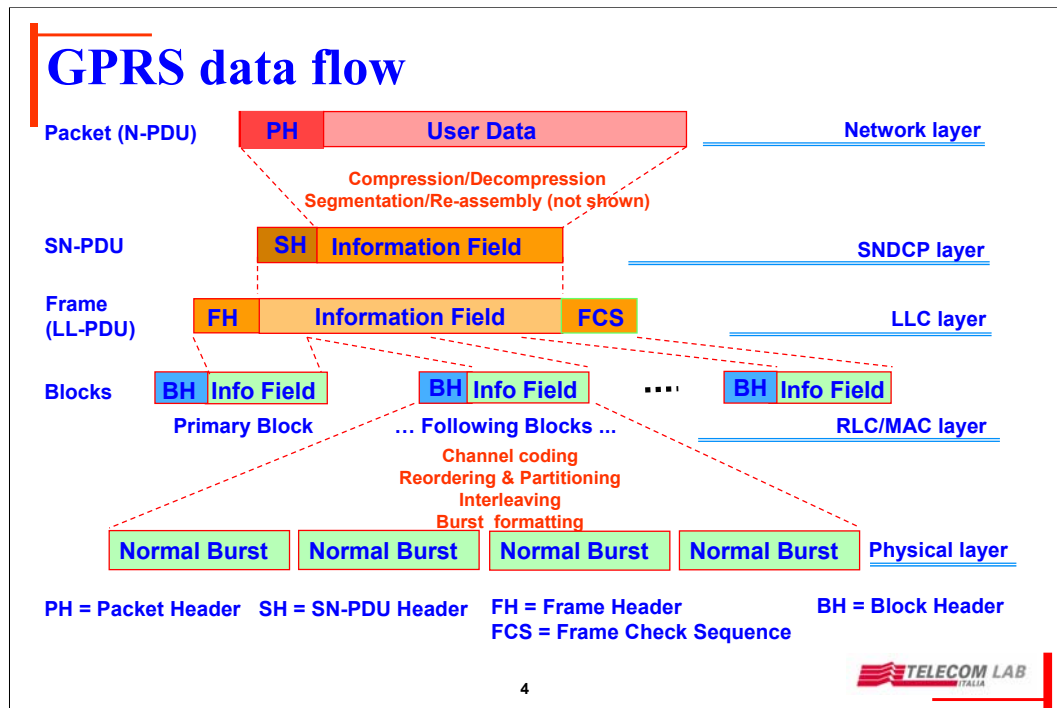
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As stated in the previous paragraphs, the GPRS is grafted in the GSM infrastructure and the two systems fully share the radio resources, the bandwidth and the physical radio solutions like the modulation.

It represents a *superimposed* system where the resource sharing issue has been solved in an advanced way, by adopting flexibility and efficiency criteria.

First, the base band physical layer will be considered, then, the Layer 2 information blocks and protocols will be described (*Radio Link Control, Medium Access Control – RLC – MAC*).



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The starting point is the *Normal Burst*, already introduced for the GSM physical layer. 4 GSM *Normal Bursts* form a radio block with its own *header*. Each radio block takes then 18.5 ms to be transmitted. Exactly as for the GSM, the slot belonging to the 13th TDMA frame is not transmitted to transport control information. The average transmission time of a radio block is then equivalent to $18.5 \times 13 / 12 = 20\text{ms}$ (4 TDMA *time* slots taking place over 4 consecutive TDMA frames).

The radio blocks undergo the following processes before being transmitted: coding, interleaving, and re-ordering.

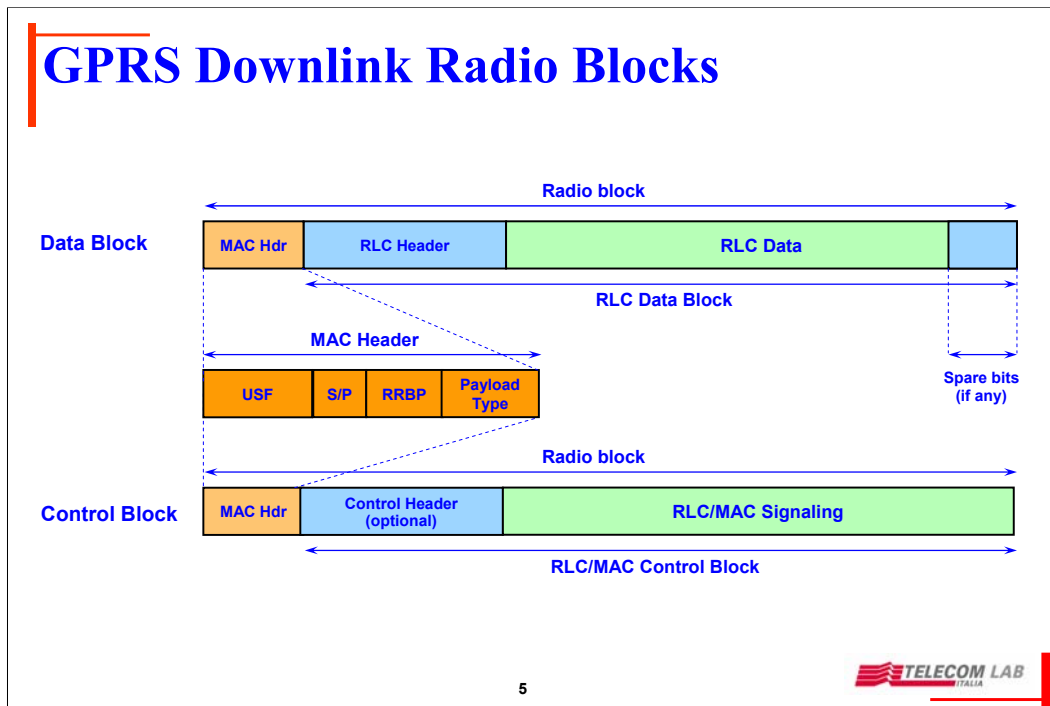
The radio blocks are filling-up a *Link Layer (LL)* frame whose *information field* can contain up to 1520 bytes.

The *Sub-network dependent Protocol Data Unit* are inserted in the *Link Layer* frames.

One or more *Protocol Data Units* of the *Sub network dependent Protocol Data Unit* form the network layer packet.

This apparent complexity come from coding, protection and re-transmission requirements.

GPRS Downlink Radio Blocks



The radio blocks adopt different configurations in function of the transmission direction (*up* or *down link*). Moreover, their configuration depends on the role they are assigned to: data or control transport.

The radio block is subject to retransmission for error protection. The retransmission does not take place for a single radio block but for a group of radio blocks: those contained in the retransmission window, concerning 64 radio blocks (both in the *up* and in the *down link*). The retransmission involves the more than one GPRS users: those who can share the same time slot. The MAC layer contains the *header* of the upper layer frames (RLC). As for the MAC *header*, it contains some data range driving the retransmission mode.

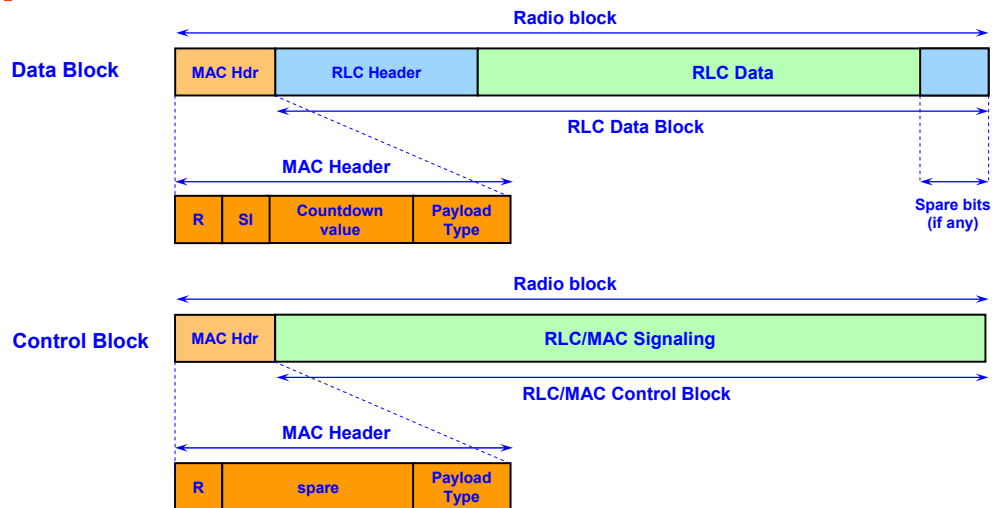
The *Up Link State Flag* (USF) transmitted on the *down link*, is composed of 3 bits. It specifies the MS which is allowed to transmit on the *up link* along the 4 subsequent *time slots* (1 block) and, set to 0, the presence of a *Packet Random Access Channel* (PRACH) always on the *up link*. Hence, the maximum user multiplexing level on the up link over the same *time slot* is 7. Often on the *up link*, some signalling messages associated to the traffic received on the *down link* are to be transmitted: another USF value has then to be reserved. This reduces to 6 the maximum multiplexing degree on the *up link*.

The *supplementary/polling* (S/P) range contains 1 bit; it states the presence (or the absence) of the subsequent range.

The *Relative Reserved Block Period* (RRBP) is composed of 2 bits specifying the radio block period when the MS must transmit a control packet which may be for instance a *Packet Control Acknowledgement* (PACK) transmitted over a *Packet Associated Control Channel* (PACCH). The MS that has to transmit is the one identified by the *Temporary Flow Identity* (TFI) specified in the RLC *header*.

The *Payload Type* (2 bits) specifies the kind of information transported by the radio block (Data or Control) and, whenever the block is a control block, it specifies if the subsequent range (RLC *header*) è present or not present.

GPRS Uplink Radio Blocks



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On the up link the following ranges are present:

The *Retry* (R) (1 bit) designates if the MS has sent the *Packet Channel Request* at least one time within the *Temporary Block Flow* (TBF). The TBF defines a physical connection utilised for one or more LL-PDU over one or more PDCH in a point-to-point mode between the MS and the Network.

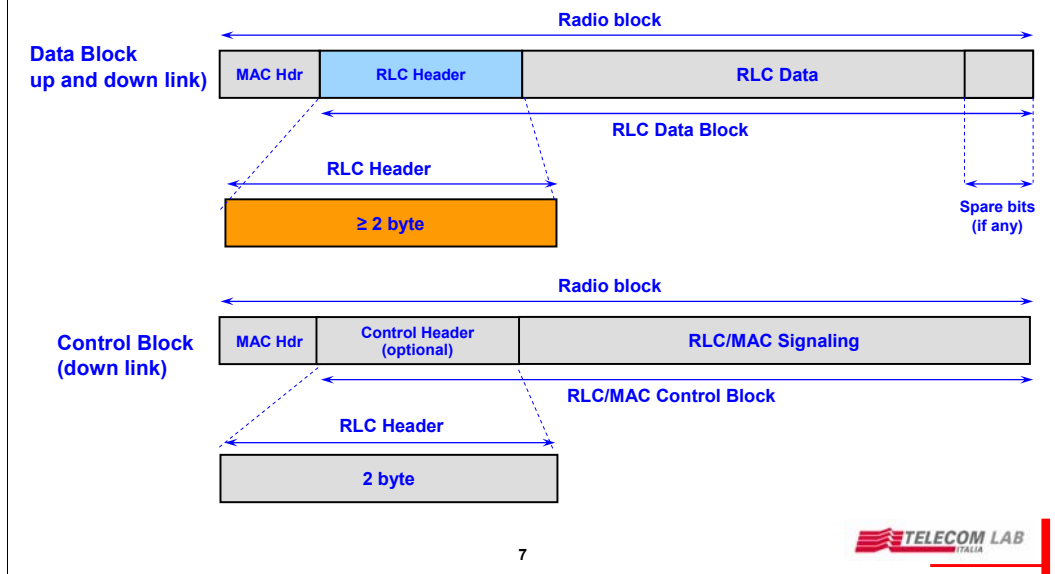
The *Stall Indicator* (SI) is composed by 1 bit. It establishes if the counter of the transmission window at the RLC level can be increased or not.

The *Countdown Value* bears 4 bits specifying how many RLC data blocks are still to be transmitted within the current *Temporary Block Flow*. The

Spare range (5 bit) are not utilised by teh network.

The *Payload Type* (2 bits) specifies as for the *down link*, the kind of information carried by the radio block (Data or Control) and, whenever the block is a control block, it specifies if the subsequent range (RLC *header*) è present or not present.

RLC header and data - data block



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The header of the **RLC frame of the data block** contains the following information.

Final Block Indicator (FBI) (1 bit) on the DL, denoting the last RLC data block of the current Temporary Block Flow.

Temporary Logical Link Identifier Indicator (TI) (1 bit) on the UL, denoting if the range TLLI is present or not.

Temporary Flow Identity (TFI) (5 bits) on the UL and the DL, denotes to which Temporary Block Flow the RLC data block belongs to (it is the current number of the TBF).

Power Reduction (PR) (2 bits) on the DL, drives the up link power control mechanism (two control modes).

Extension (E) (1 bit) on the UL and DL, extends the RLC header to further information content.

Block Sequence Number (BSN) (7 bits) on the UL and DL, sequential number of the RLC data block within the current Temporary Block Flow.

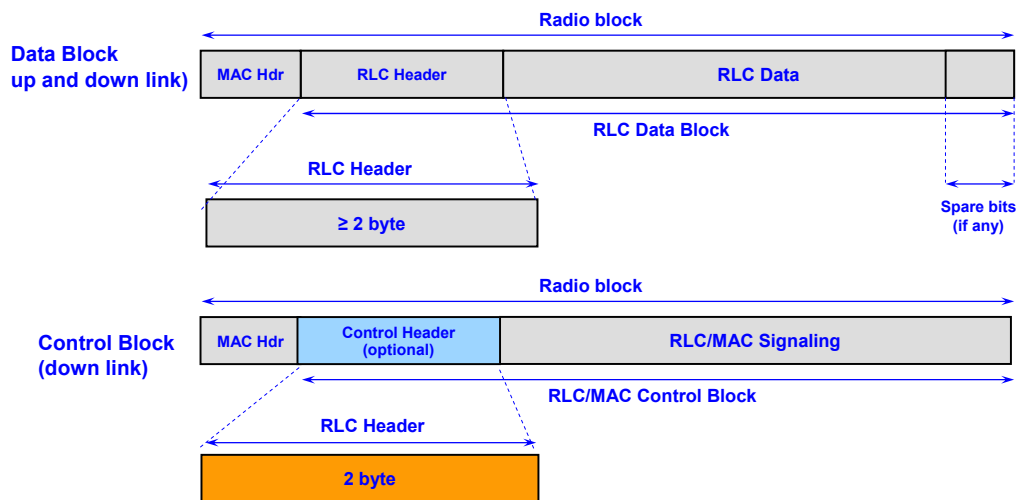
More (M) (1 bit) on the UL and DL, indicates if the RLC data block contains bytes of the LL-PDU following the present one.

Length Indicator (LI) (6 bits) on the UL and DL, both on the uplink and on the downlink, it delimits an LL-PDU within the RLC Data Block.

Temporary Logical Link Identity (TLLI) (32 bits) on the UL, specifies the identity assigned to the link (it is either based on the TMSI or randomly chosen; it may be defined by the MS or by the SGSN).

Spare (2 bits) on the UL, ignored by the network.

RLC header and signaling - control block



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The header of the **RLC frame of the control block** contains, if present on the down link, the following information, occupying two octets:

Address Control (AC) (1 bit) denotes the presence of the ranger D and TFI (see below).

Final Segment (FS) (1bit) denotes the presence in the RLC/MAC Control Block of the final segment of an RLC/MAC Control message.

Radio Transaction Identifier (RTI) (5 bits) denotes the sequential number (within the message) of the segment of an RLC/MAC Control message included in the RLC/MAC Control Block.

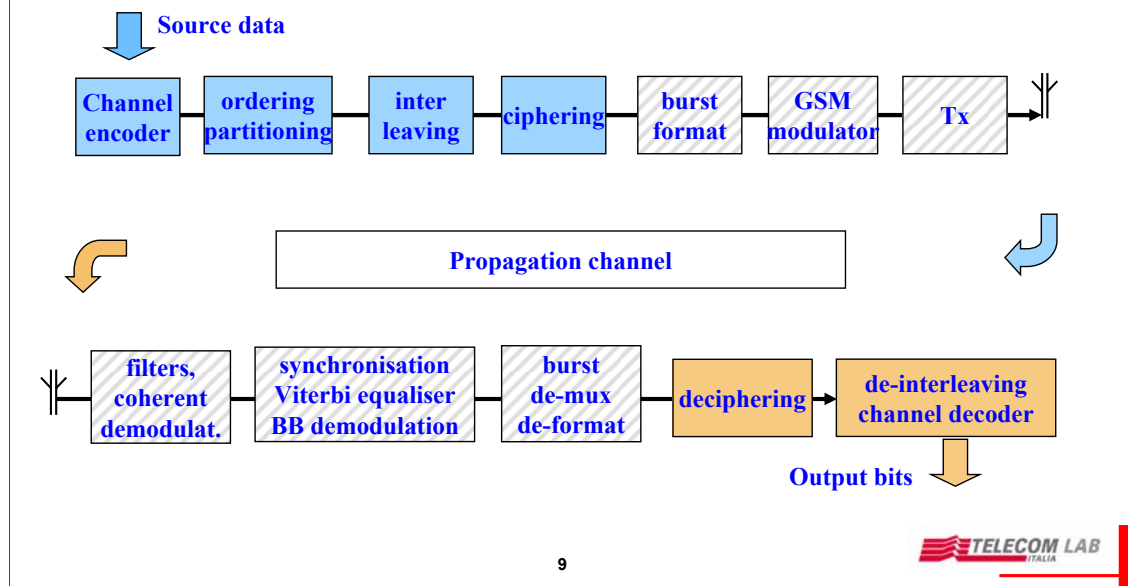
Reduced Block Sequence Number (RBSN) (1 bit) assumes the values 0 or 1 if the RLC/MAC Control Block is bearing the first segment of the transported RLC/MAC Control message or, conversely, anyone of the subsequent segments.

Direction (D) (1 bit) identifies the direction (UL, DL) of the Temporary Block Flow whose sequence number is identified by the TFI.

Temporary Flow Identity (TFI) (5 bits) specifies the sequence number of the TBF to which the RLC/MAC Control message belongs to.

Power Reduction (PR) (2 bits) drives the down link power control mechanism of the RLC/MAC Control Block (two control modes: Mode A e Mode B).

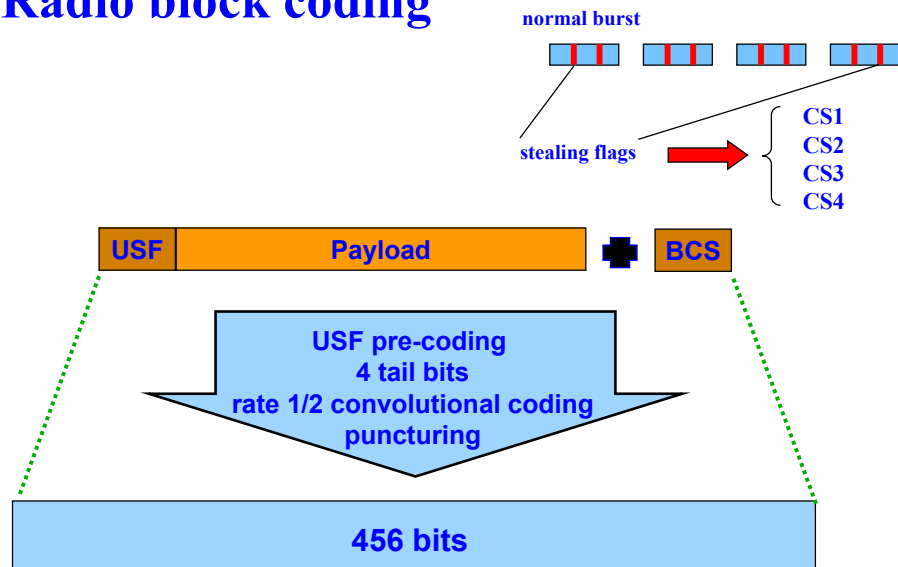
Tx/Rx chain *peculiarities compared to GSM*



The figure is taken from the GSM chapters. It represents the functional steps of the physical chain where the GPRS fully reproduces the GSM features. The dashed parts do not undergo any modification in either case.

Moreover, in the GPRS, ciphering is performed at the LLC level.

Radio block coding



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This general scheme holds for the 4 types of coding defined for the GPRS. The *Coding Schemes* (CS1, CS2, CS3, CS4) are defined with decreasing protection from the first to the fourth. All include the error detection (which is eventually followed by the RLC retransmission).

CS1, CS2, CS3 adopt a convolutional encoding. CS4 just protects the USF range. USF is protected in all the cases and without puncturing.

The 4 schemes are foreseen for data transmission. Signalling only adopts CS1.

Remind that *Normal Bursts* of the GSM (those used for the data transmission in the GPRS) bear a 2 bit range for the *stealing flag*. Now, the set of *stealing flags* transmitted in the 4 consecutive *slots* forming the radio block, defines the *coding scheme* to be used.

In any scheme a *Block Check Sequence* (BCS) is used to detect errors as well as a $\frac{1}{2}$ convolutional encoding (except for CS4).

Any scheme generates 456 bits to be transmitted in 20 ms: the bit rate already seen for the GSM *Traffic Channel Full Rate*.

CS1 is the same used to encode the SACCH, with a range of 40 bits: the protection degree is around 10-12.

Coding parameters

Scheme	Code rate	Payload (bits)	BCS (bits)	Pre-coded USF (bits)	Tail bits	Coded bits	Punctured bits	Data rate (kbps)
CS-1	1/2	181	40	3	4	456	0	9.05
CS-2	~ 2/3	268	16	6	4	588	132	13.4
CS-3	~ 3/4	312	16	6	4	676	220	15.6
CS-4	1	428	16	12	-	456	-	21.4

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The (net) bits to be transmitted in the *Packet Data Channel* (PDCH) are respectively, for the 4 CSs: 181 - 268 - 312 - 428.

The USF bits are to be added. The encoding sequence is adding:

- Block Check Sequence (40 bits for CS1, 16 bits for CS-2/3/4)
- pre-coding of USF for CS2, CS3 e CS4
- 4 *tail bits* (apart for CS4)
- convolutional encoding *rate* 1/2 (apart for CS4)
- punctured encoding (for CS2 and CS3)
- 456 bits in the output.

For the *Packet Random Access Channel* (PRACH) the encoding is that specified for the GSM RACH (if the *packet access burst* is used). If instead the *extended packet access burst* is used, a specific code has to be applied.

The table summarises the parameters used for the 4 CSs.

Data rates

Scheme	Maximum net payload (bytes)	Maximum net RLC/MAC data rate (kbit/s)	Nominal data rate (kbit/s)	Application data rate (kbit/s)
CS-1	20	8	9.05	7.7
CS-2	30	12	13.4	11.5
CS-3	36	14.4	15.6	13.8
CS-4	50	20	21.4	19.2

Coding scheme	Application data rate (kbit/s) @ IP packet size (bytes)		
	576	1200	1500
CS-1	7.3	7.7	7.7
CS-2	11	11.5	11.6
CS-3	13.2	13.8	13.9
CS-4	18.3	19.2	19.4

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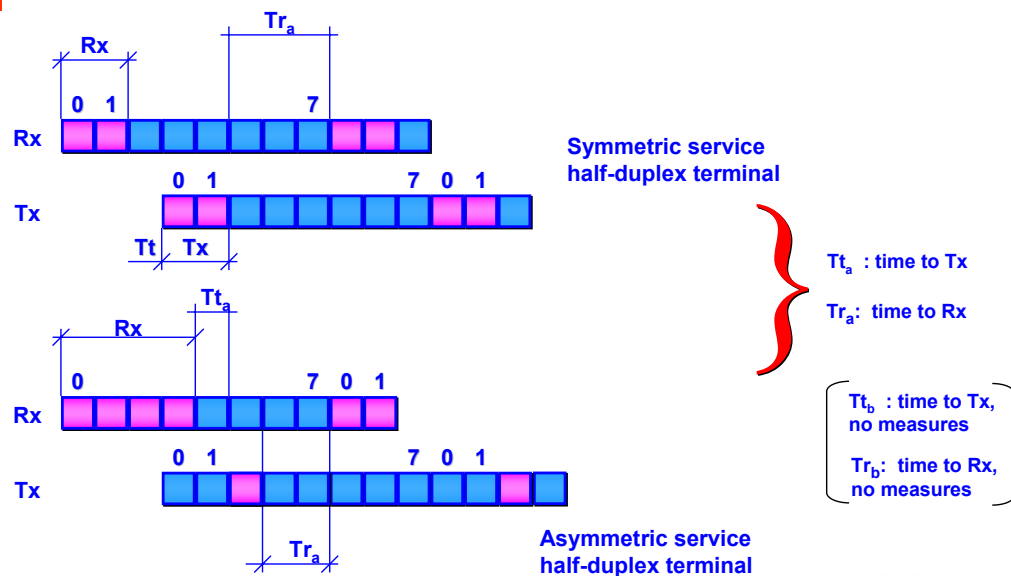


The two tables report respectively:

- the effective data rate per each CS, obtained by depurating the stream from headers and control data previously introduced
- the effective data rate resulting at the application level for the IP packets of some typical dimensions (576, 1200, 1500 bytes); here, all the overhead to be introduced between the application level and the RLC/MAC level, namely *headers* and control bits belonging to the *Sub-network dependent convergence protocol* and *Logical Link Control*.

All the cases refer to a single *time slot* assigned to a single user. The data have to be multiplied by a factor *n* (from 1 to 8) if more than one slot is assigned to the user.

Time Slot Utilisation - simplex Terminal



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The GPRS specification proposes several configurations, corresponding to an equivalent number of the terminal configurations. In relation to the number of slots that can be used, terminal configurations are specified by the following parameters:

- maximum number of slots in the TDMA frame used in up and down link
- total number of slots of the TDMA frame where MS can transmit
- T_{ta} minimum number of *time slots* between the last *slot* used in Tx or Rx and the first *slot* where MS transmits (if MS is performing measures in the surrounding cells)
- T_{ra} minimum number of *time slots* between the last slot used in Tx or Rx and the first *slot* where MS receives (if MS is performing measures in the surrounding cells)
- T_{tb} T_{rb} as for T_{ta} T_{ra} (if MS is not performing measures in the surrounding cells).

Similar definitions hold for *full-duplex* terminals and in function of the presence of *frequency hopping*.

The connection flexibility depends on the used terminal. The figure reports two examples referred to the *half-duplex* terminal.

GPRS: physical layer performance (II)

GSM @ 900 MHz

Propagat. Charact.: static TU50 no FH TU50 ideal FH RA250 no FH HT100 no FH

PDCH BLER ≤ 10%
USF BLER ≤ 1%
PRACH BLER ≤ 15%

PDTCH/CS1	(dBm)	-104	-104	-104	-104	-103
PDTCH/CS4	(dBm)	-101	-90	-90	---	---
USF/CS1	(dBm)	-104	-101	-103	-103	-101
PRACH/11 bit	(dBm)	-104	-104	-104	-103	-103

← sensitivity levels

Propagat. Charact.: TU3 no FH TU3 ideal FH TU50 no FH TU50 ideal FH RA250 no FH

← propagation

PDTCH/CS1	(dB)	13	9	10	9	9
PDTCH/CS4	(dB)	21	23	24	24	---
USF/CS1	(dB)	19	10	12	10	10
PRACH/11 bit	(dB)	8	8	8	8	10

← C/I levels

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The Standard defines the levels of C/I co-channel (or the receiver sensitivity) for which the *block erasure rate* (BLER) of the figure must be obtained.

PDCH is the physical channel bearing all the logical channels with any coding scheme: for each of them the required C/Ia (or sensibility) levels are changing.

USF undergoes two different coding schemes: one for CS1, the second common to CS2, CS3, CS4. USF is an header range, hence it bears data completely different compare dto those carried by PDCH.

PRACH is the access channel: the same remark holds as for the USF.

The sensitivity requirements are different from those fixed for the GSM. This is due to the different service requirements (low delay and relatively low BER for voice, very low BER and even variable delays for data).

The two tables represent respectively the sensitivity and the C/I values for which the required BLER performance is obtained. Reference propagation conditions and the reference mobile speeds are: stationary with AWGN; urban traffic at 50 km/h, with and without *frequency hopping*; rural area at 250 km/h).

Reordering and interleaving

Interleaving depth 8:

- minimising the BER (after decoding)
- increasing the probability of block re-transmission or erasure

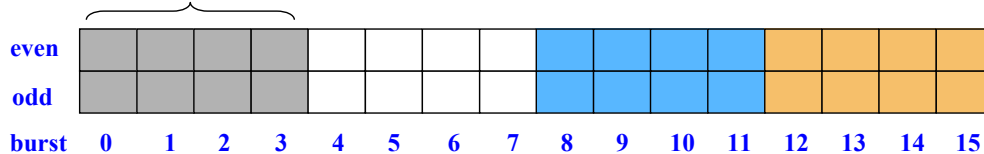


Interleaving depth 4:

- increasing the BER
- decreasing the probability of block re-transmission or erasure



456 bit (8x57bit)
4 bursts for transmission
rectangular interleaving



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The re-ordering of the bits generated by the channel encoder, coincides with that described for the TCH/FS of the GSM.

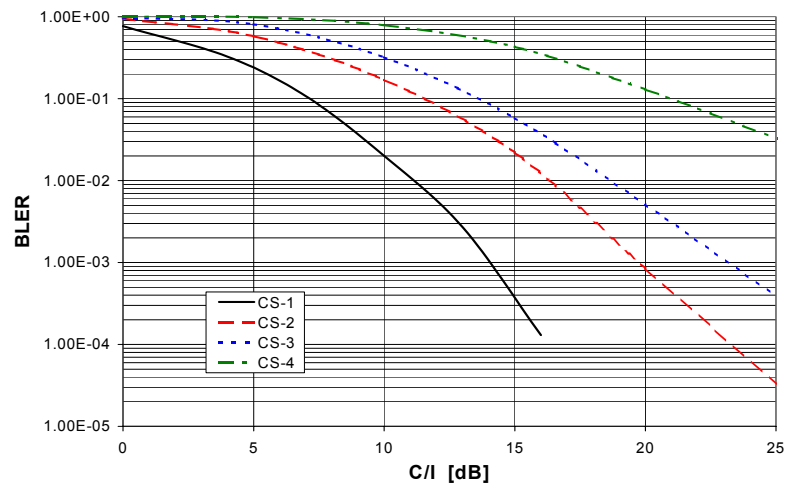
The interleaving coincides with that defined for the signaling flows described in section 1.2 of the GSM (see the above figure).

The interleaving takes place over 4 consecutive bursts. Again (as for the voice) 8 sub-blocks are defined (57 bits each) but, instead of allocating them over 8 consecutive bursts, they are allocated over 4 bursts only: the first 4 sub-blocks assigned to the even side of the blocks, the second 4 sub-blocks assigned to the odd part.

An interleaving depth of 4 has been chosen to reduce the block erasure rate, which is tied to the retransmission mechanism, applied at the RLC level, to the data block (4 consecutive bursts).

The depth 4 increases the number of wrong bits per block but, conversely reduces the exposure to retransmission and to the potential need of block rate erasure.

GPRS: physical layer performance



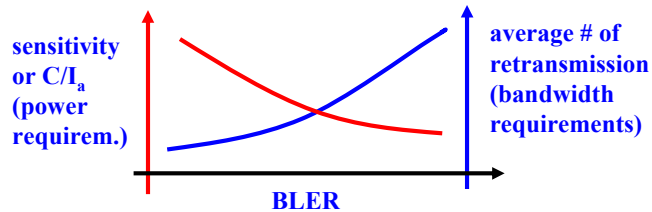
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The figure represents the block erasure rate in function of the C/I in an urban environment, at 50 km/h, when an ideal frequency hopping is guaranteed.

Receiving radio performance

PDCH BLER $\leq 10\%$
 USF BLER $\leq 1\%$
 PRACH BLER $\leq 15\%$



Coding scheme	BLER @ GSM 900 - TU3 ideal FH	
	9 dB	13 dB
CS-1	10%	1%
CS-2	30%	10%
CS-3	50%	20%
CS-4	90%	70%

Coding scheme	BLER @ GSM 900 - TU3 no FH	
	9 dB	13 dB
CS-4	60%	40%

CS-4 BLER = 10% @	
GSM 900 - TU3 no FH, $C/I = 21$ dB	
GSM 900 - TU50, $C/I = 24$ dB	
DCS 1800 - TU50, $C/I = 27$ dB	

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Note that the BLER values define for the PDCH represent a compromise: high values of BLER require low C/I figures (power gain) but imply a great number of retransmissions (bandwidth loss). Conversely, low values of BLER allow to reduce the number of needed retransmissions (bandwidth gain) but require the high C/I values are reached (power loss).

The figure reports also the BLER values obtained in correspondence to C/I of 9 and 13 dB for the 4 coding schemes. In CS4, to obtain a BLER of 10% in urban propagation characteristics at 50 km/h, one must have C/I values of 24 and 27 dB for GSM@ 900 and 1800 MHz respectively.

The above consideration suggests to look at the throughput reached by the 4 coding schemes in the various environmental conditions. In fact, the throughput involves the redundancy adopted for each scheme. In function of the radio context conditions, it is possible to choose the CS ensuring the optimal throughput. For instance, in good conditions, CS4 supplies a throughput much higher than CS1 (in these conditions the latter *wastes* resources in an excess of redundancy).

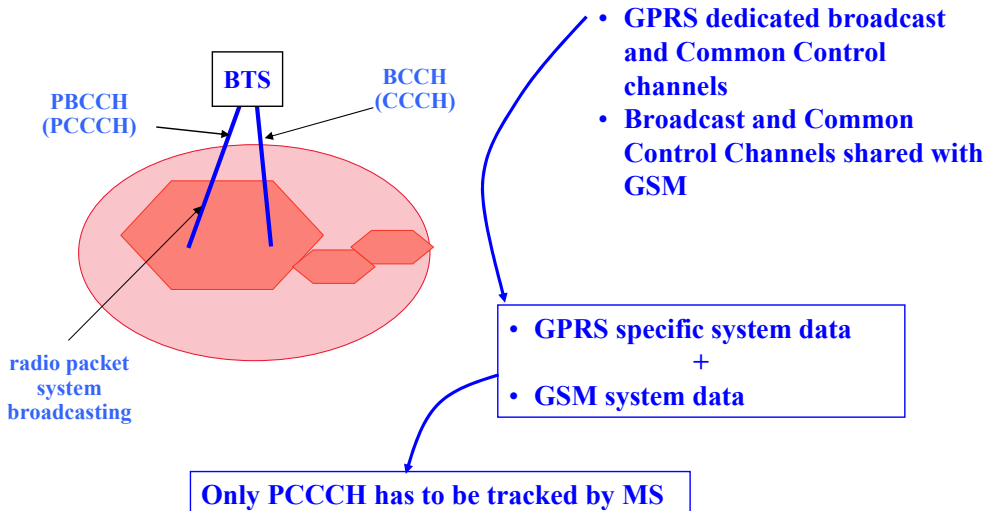
Expected throughput per user

MS 4+1											
CS-1			CS-2			CS-3			CS-4		
Number of users			Number of users			Number of users			Number of users		
8	3	1	8	3	1	8	3	1	8	3	1
GSM 900 - TU3 ideal FH, C/I = 9 dB - Expected application throughput/user (kbps)											
3.5	9.2	27.7	4.0	10.7	32.2	3.5	9.2	27.6	1.0	2.6	7.7
GSM 900 - TU3 ideal FH, C/I = 13 dB - Expected application throughput/user (kbps)											
3.8	10.2	30.5	5.2	13.8	41.4	5.5	14.7	44.2	2.9	7.7	23.0
GSM 900 - TU3 no FH, C/I = 9 dB ; CS -4 →									3.8	10.2	30.7
GSM 900 - TU3 no FH, C/I = 13 dB ; CS -4 →									5.8	15.4	46.1
TU3 no FH, C/I = 21 dB or TU50, C/I = 24 ÷ 27 dB; CS-4 →									8.6	23.0	69.1

The table confirms what said earlier. The configuration is here 4 slots in DL, 1 in UL allocated for the GPRS service.

The GPRS can adapt the coding scheme to the radio context conditions: this is done thanks to the link adaptation technique, which is able to adapt the CS dynamically along the single call.

GPRS channels - general



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GPRS can either have Broadcast and Common control Channels in common with the GSM or specifically defined for the GPRS data traffic.

In the second case, we have the *Packet Broadcast Communication Channel* (PBCCH) and the *Packet Common Control Channel* (PCCCH). Whenever the MS is receiving the PBCCH, it receives also some data essential for the GSM side. In this way the MS does not need to monitor also the GSM channels.

When the cell uses a common control channel for the GPRS, the physical channel bearing it is named *master* channel. The other traffic transport channels and the associated signalling channels are allocated (in a permanent or a dynamic way) over *slave* physical channels.

The number of PDCHs assigned to the GPRS within a cell can be varied. The decision can be taken on the basis of a statistical traffic evaluation (it is the a network management decision) or, conversely, on the basis of the traffic channels not utilised for GSM services (*real time* mode). In the latter case, the system is performing a fast release procedure whenever a voice call has to be allocated on the temporary-borrowed *GPRS channels*.

The fast release can either be performed on the basis of the residual assignment times of the traffic channels or on a specific command sent to all the GPRS mobile terminals which are allocated on that specific PDCH when the voice pre-emption arrives.

Packet Data Logical Channels (I)

- **Packet Common Control Channel (PCCCH):**
 - PRACH: random access (uplink)
 - PPCH: paging (downlink)
 - PAGCH: access grant (downlink)
 - PNCH: PTM-M notification (downlink)
- **Packet Broadcast Control Channel (PBCCH) (downlink)**
- **Packet Traffic Channels:**
 - PDTCH: data traffic (up and down link)
- **Packet Dedicated Control Channels:**
 - PACCH: associated control (up and down link)
 - PTCCH/U: timing advance estimation (uplink)
 - PTCCH/D: timing advance information (downlink)

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The logical channels defined for the GPRS do not require many explanations, being their role quite similar to that explained for the equivalent GSM channels.

The *Packet Common Control Channel* (PCCCH) is used for the common control channels:

- *Packet Random Access Channel* (PRACH) used for the access. The MS can transmit the access burst over any of the 4 bursts composing the PRACH. The access burst is also used to manage the *Timing Advance* (TA) mechanism.
- The *Packet Paging Channel* (PPCH) used by the paging messages (towards all the users belonging to a given *paging group*). For class A and B MSs (able to monitor packet and circuit control channels at the same time) the *paging* may also be sent over the circuit segment. If MS is in the active phase (data are transmitted) the *paging* is sent over the associated channel PACCH.
- The *Packet Access Grant Channel* (PAGCH): used to assign radio resources in the session set-up phase.
- The *Packet Notification Channel* (PNCH) is used to send a notification of the kind *Point-to-Multipoint/Multicast* to a group of MSs.

The *Packet Broadcast Control Channel* (PBCCH) is the system channel used to spread the system information all over the cell (if not defined, BCCH is used for the purpose).

The *Packet Data Traffic Channel* (PDTCH) is the data packet transport channel; more than one PDTCH can be associated to the same packet transfer session.

Packet Data Logical Channels (II)

- The radio blocks are transmitted over 4 bursts belonging to 4 consecutive TDMA frames
- Transmission on a Packet Data Channel (PDCH):
 - transmission on PRACH and PTCCH/U is performed by sending an access burst
 - transmission on all the other packet data logical channels is performed by sending radio blocks constituted by four consecutive normal bursts
 - a Packet Control Acknowledgement can be sent via 4 access bursts, if required by the network

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The transport of the system information is also assigned to the associated control channel: the *Packet Associated Control Channel* (PACCH). It is in fact needed that the data packet transmission are preceded by the knowledge of the system info, that are by turn utilized to accelerate the *Cell Re-selection* procedure.

The *Packet Dedicated Control Channel* carries:

- the *Packet Associated Control Channel* (PACCH). It is activated whenever the following info are to be send on both the up and down link (this channel is not allocated in a fixed way as for the GSM):
 - resource assignment for the traffic channel and for the same associated channel
 - resource request and related acknowledgements
 - *power control* messages.
- the *Packet Timing advance Control Channel, uplink* (PTCCH/U). It carries on the *up link* the *access bursts* allowing the network to evaluate the needed *timing advance* to be requested to an MS in *packet mode*
- the *Packet Timing advance Control Channel, downlink* (PTCCH/D) carries the time transmission correction messages (they may refer to more than a single terminal).

Packet Data Logical Channels (III)

- PBCCH is mapped on one physical channel
- PCCCH is mapped on one or several physical channels, following a 52-multiframe
 - PRACH is determined by Uplink State Flag (USF) set FREE and broadcast on the downlink or by a fixed allocation
- A given PDTCH is mapped on one physical channel
 - An MS can use up to 8 PDTCHs on the same carrier
- A given PACCH is mapped on one physical channel and is allocated dynamically on a block basis
- PTCCH/U is mapped on one of the PDCHs where PDTCHs are allocated to the MS; PTCCH/D is associated to several PTCCH/Us sharing the same PDCH

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The presence of the PRACH over the *up link* is indicated over the down link through a specific configuration of the *Up-link State Flag*. The latter assigns the subsequent block for transmission over the up link to one of the mobiles (max 7) sharing the same PDCH. When the content of the *Up-link State Flag* is set to 0, the subsequent radio block is assigned to the PRACH. This is accessed (with contention) by those MSs which want to start a packet transmission.

The access over the PRACH takes place through the transmission of a *packet access burst*, launched over one of the 4 *time slot* of the radio block. The *access burst* is coded over 8 or 11 bits. The time slot is chosen randomly to reduce the collision probability (hence the need of retransmission).

Also the *Packet Associated Control Channel* (PACCH) is allocated in a dynamic way (no fixed pace). The is a bidirectional channel and it is transmitted over the up and down link independently from the use of the PDTCH (to which PACCH is associated) in both directions. The MS must hence verify over the PDCH *down link* if the network is sending PDTCH-associated messages even if the latter is just allocated on the *up link*.

The PACCH may be used on the *up link* whenever needed. The network can require the transmission of radio blocks over the up link. In this case, the MAC range named *supplementary/polling* (S/P) is used. S/P defines the presence of the subsequent range: the *Relative Reserved Block Period* (RRBP - 2 bits) specifies the radio block period where a given MS must transmit over the PACCH channel (the MS is specified by the *Temporary Flow Identity* (TFI) reported in the RLC header).

Multiframe Structure

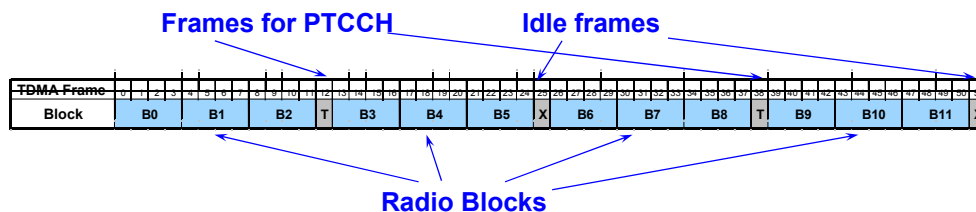
52 TDMA frames divided in:

- 12 radio blocks B0-B11 (of 4 consecutive frames)
- 2 frames used for PTCCH (T)
- 2 idle frames (X)

BCCH

MS

PDCH on which
PBCCH and
PCCCH are
mapped



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The following logical channels are defined over the same *Packet Data Channel* (PDCH): PBCCH, PCCCH, PDTCH, PACCH e PTCCH.

The sharing of many logical channels over the same physical channel is assigned to a multiframe mechanism. GPRS adopts a 52-frame multiframe. The first two channels are multiplexed over the PDCH just in case the GPRS is not using the equivalent GSM channels (BCCH e CCCH).

The sequence followed by the mobile station to read PBCCH and PCCCH is: read over the BCCH the allocation of the PDCH where PBCCH and PCCCH are defined; move to this PDCH channel and reading of the control (and possibly the data channel).

12 radio blocks are contained in the multiframe. Two frames are used for the *Packet Timing Advance Control Channel*.

The logical channels are defined over the 12 radio blocks according to a fixed sequence:

B0, B6, B3, B9, B1, B7, B4, B10, B2, B8, B5, B11

- once identified the PDCH, the MS can read the PBCCH over B0 and eventually also over B6, B3, B9 on the *down link*
- the PBCCH specifies other (eventual) PDCHs where other PCCCH logical channels can be found; over these PDCHs, the first radio blocks are assigned to PAGCH, PNCH e PDTCH, PACCH; the remaining blocks, consistently with the above sequence, are assigned to PPCH and, still to PAGCH, PNCH e PDTCH, PACCH
- on the *up link*, over the PDCHs where a PCCCH is defined, all radio blocks are used for PRACH, PDTCH and PACCH
- the PDCHs not bearing the PCCCH are fully devoted to PDTCH and PACCH.

A single multiframe - advantages

26 frame voice, data



51 frame signaling



GSM multi-frames:

- 26 TDMA frames for voice/data
- 51 TDMA frames for BCCH, CCCH, SDCCH

Key elements

for a choice:

- statistical behaviour of data services
- need for higher degree of flexibility

52 frame for signaling and traffic



GPRS multi-frame:

- 52 TDMA frames for data and signaling

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Summarising, the allocation of the logical channels to the physical ones is much more flexible for the GPRS than in the GSM configuration.

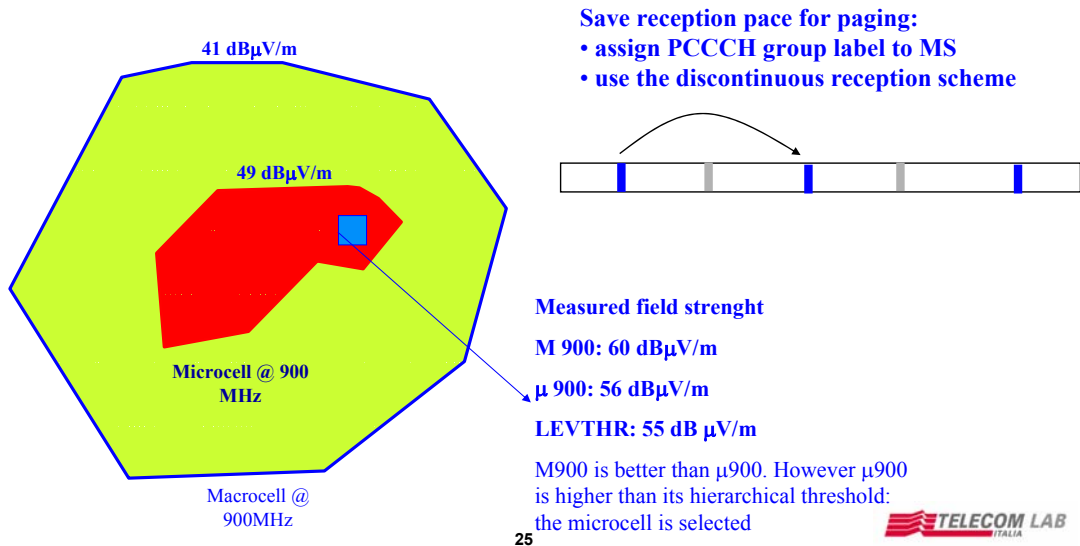
The GSM adopts two multiframe schemes, the former (26 frames) is devoted to voice services; the latter (51 frames) to the signalling channels. In the GSM, each physical channel bearing signalling channels is fully devoted to them. (BCCH, CCCH, SDCCH). No multiframe sharing is adopted.

In the GPRS, the adoption of a single multiframe scheme and the dynamic assignment of the logical to the physical channels ensure a greater flexibility: the PDCH hosting the PBCCH and/or the PCCCH, traffic channels can be hosted (PDTCH+PACCH) in function of the radio block availability.

Due to the frequency sharing, GSM and GPRS signalling slots can be hosted on the same carrier. In this case, 3 different multiframe scheme are operating at the same time over a single TDMA frame.

Basic radio functions

cell re-selection (coverage hierarchy) and discontinuous reception



The cell re-selection mechanism assigns the mobile to the cell bearing the highest BCCH power. As usual, the data needed to receive the BCCHs of the contiguous cells are transmitted in the BCCH *list*.

In the *idle mode* status, the MS can easily read the BCCHs. In fact it can use almost the entire frame to read (it must also read the *paging* channels). Conversely, when it is in the *transfer mode* status, the BCCH-reading time decreases with the increase of the slots used for transmission and reception of the user data.

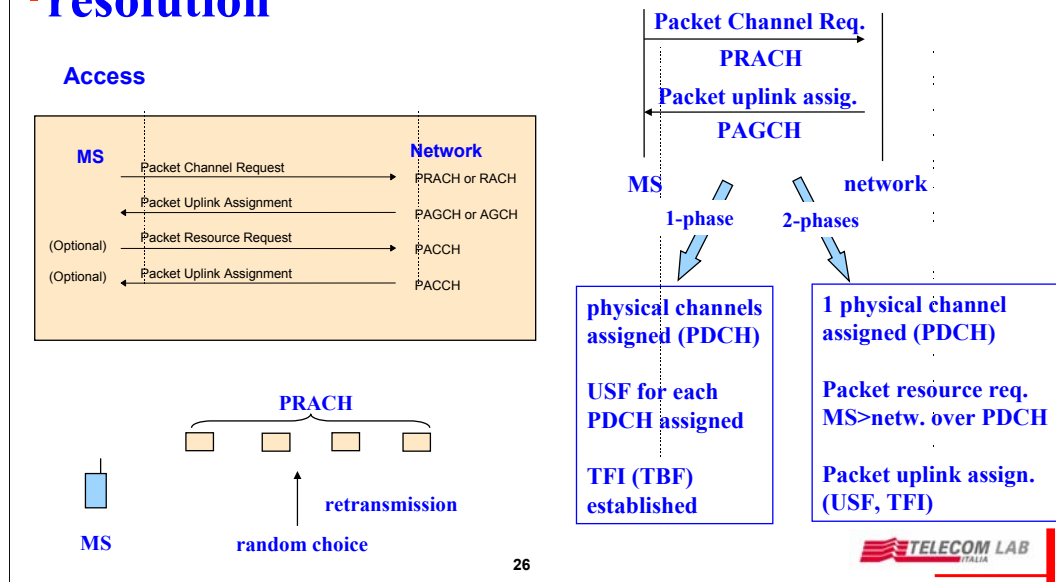
The cell re-selection takes place according to the criteria based on:

- the received field intensity
- pre-defined thresholds in case of hierarchical coverage (figure)
- the *cell* priority.

The re-selection control is usually assigned to MS. The network is supplying the threshold and priority values driving the cell choice. However, the network can fully or partially assume the re-selection control through a specific message sent over the PCCCH or the PACCH. In this case, the MS must send to the network the measurements performed over the BCCHs.

Two mechanisms exist to reduce the monitoring pace of the paging channel during the attach mode. This reduction takes place by assigning a group label to the MSs.

Uplink Transmission and contention resolution



The RLC level functions are:

- transfer of the LLC PDU between the LLC level and the MAC functions
- segmentation and assembly of the LLC PDU into the RLC blocks
- segmentation and assembly of the control messages RLC/MAC in the relative blocks
- selective re-transmission of the RLC data blocks.

The MAC layer functions are:

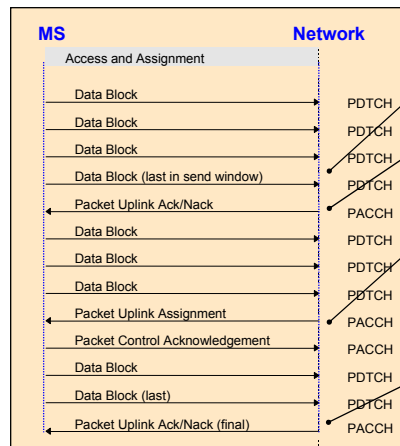
- procedure tied to the PBCCH e PCCCH channels
- assignment of the *Temporary Block Flows* the user data and signalling data transfer
- management of the resource sharing.

The access for channel acquisition is performed in a *Slotted Aloha* mode. It may run through either one or two phases.

In the single-phase approach the *Packet Channel Request* is followed by a *Packet up link Assignment*. The latter assigns the resources and, in addition, sends the MS the *timing advance* and the info needed for the *power control* mechanism. The network can also assign more than one PDCH, if previously specified by the MS. For each assigned PDCH, the network manages the mechanism, scheduling the up-link transmissions. It manages also the *Temporary Block Flow* used for the point-to-point exchanges.

Contention resolution and resource allocation

Uplink data transfer



Resource allocation

Possible limitations (network side) on the number of transmitted blocks

Selective retransmission required through Packet uplink Ack/Nack

Resource re-assignment along the packet transfer:

- packet uplink assign. (over PACCH and bearing the RRBP for answer)
- packet control acknowledgment via PACCH reserved through RRBP

Resource release started by MS through count/down procedure.
Packet uplink final ACK (netw.) and Packet control ack (MS) are sent

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In the case of two-phase assignment, the *Packet up link Assignment* assigns (TA and PC) a single block, enabling the MS to transmit a *Packet Resource Request*, which describes completely the needed resources. The subsequent *Packet up link Assignment* assigns the needed resources. The network can force the use of the two-phase procedure by allocating a single radio block in the *Packet up link Assignment*: the mobile is forced to specify the needed resources through a *Packet Resource Request*.

Anyway, when the answer to the *Packet Channel Request* does not arrive (collision) the original request is re-transmitted after a random time interval (the related retransmission parameters like the max number of retransmissions are sent in the PBCH). The network can transmit a *Queuing Notification* in case there are no available resources, by avoiding in such a way, useless retransmissions. After a given number of (useless) retransmissions, MS indicates a *failure* to the upper layers.

The contention resolution mechanisms (when several users are multiplexed onto the same PDCH) is based on the assignment of a *Temporary Logical Link Identifier* to the MS. This is used on the up link in the *Packet Resource Request* and over the down link in the *Packet up link Assignment*.

By means of the latter, the network communicates with the MS in a unique way, avoiding misunderstandings about the identification (the mobile identifies itself exactly through that TLLI) Possible multiple accesses are then avoided.

Therefore, the resource control mechanisms guarantee a great system flexibility and, at the same time, the high sharing degree ensures a great efficiency.

Uplink transfer channel allocation

Dynamic Allocation:

- the MS transmits its radio blocks on the assigned time slots with the assigned USF

Fixed Allocation:

- fixed uplink resource allocation to the MS based on a bitmap indicating the assigned blocks per time slot
- No need to monitor the downlink for the USF

Extended Dynamic Allocation:

- monitoring of the USF without transmitting and receiving simultaneously

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Radio resources are allocated through three different mechanisms.

The dynamics allocation forces the MS to read continuously the USF over all the PDCH that have been assigned. (the USF is transmitted over all the blocks on the *down link*). The *full-duplex* terminals are the most suited for this type of allocation. With *half-duplex* terminals, the time slot constraints are to be taken into account.

In the fixed allocation the use of resources is defined since the beginning through the *Packet up link Assignment* sent by the network after the access phase. MS has not to read the USF continuously. If the resources are not sufficient, MS can require additional resources by sending a *Packet Resource Request* over the PACCH, which is followed by a *Packet uplink Assignment* (from the network) and a *Packet Control ACK* (as confirmation from the MS).

The *Extended Dynamic Allocation* applies to the case of multislot assignment. Here the MS must read in sequence over the *down link* slots (those assigned in *up link*) until it does not reveal the USF value that has been assigned to it at the beginning of the session: MS is then authorized to transmit over all the remaining *time slot* assigned (over each of them it transmits for an entire radio block). In this way the up link capacity is regulated in function of the number of slots that are *open* to transmission. In the dynamic allocation mechanism was instead applied slot by slot.

[illegible]

USF range bears 3 bits: $8-1=7$ are the users that can be multiplexed over the same slot. The USF schedules the up link transmission block per block. In alternative, the authorisation can concern 4 consecutive radio blocks instead of 1 only. The choice between the two alternatives is made by the network through a parameter sent in the *Packet up link Assignment* (or in the *Packet time slot Reconfigure*): the parameter is the USF *granularity* (1 bit).

Pag. 29

Fixed Allocation

Frame	Block		Slot #0	Slot #1	Slot #2	Slot #3	Slot #4	Slot #5	Slot #6	Slot #7
1000	B0	uplink	PRACH	open	open	open	open	open	open	open
		downlink								
1004	B1	uplink	open	open	open	open	open	open	open	open
		downlink								
1008	B2	uplink	open	open	open	open	open	open	open	open
		downlink	Fixed Assignment							
1013	B3	uplink	PRACH	open	open	open	open	open	open	open
		downlink								
1017	B4	uplink	"00"	"00"	"00"	"00"	"00"	"00"	"00"	Request
		downlink								
1021	B5	uplink	"00"	"00"	"00"	"00"	"00"	"00"	"00"	"00"
		downlink								
1026	B6	uplink	PRACH	"00"	"00"	"00"	"00"	"00"		
		downlink								Fixed Assignment
1030	B7	uplink	"00"	"00"	"00"	"00"	"00"	"00"		
		downlink								Packet Ack/Nack
1034	B8	uplink	"00"	"00"	"00"	"00"	"00"	"00"	"00"	"00"
		downlink								
1039	B9	uplink	PRACH	"00"	"00"	"00"	"00"	"00"	"00"	"00"
		downlink								
1043	B10	uplink	"00"	"00"	"00"	"00"	"00"	"00"		
		downlink								Packet Ack/Nack
1047	B11	uplink	"00"	"00"	"00"	"00"	"00"	"00"	"00"	"00"
		downlink								
1052	B0	uplink	PRACH	open	open	open	open	open	open	open
		downlink								
1056	B1	uplink	"01"	"01"	"01"	"01"	"01"	Request		
		downlink								Packet Ack/Nack
1060	B2	uplink	"01"	"01"	"01"	"01"	"01"	"01"	"01"	"01"
		downlink								

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The fixed allocation is here requested by MS through an access to the PRACH (slot 0) (random access). The network assigns the slots to the mobile with the identifier 00, by specifying those that can be used in the subsequent blocks (*Packet up link Assignment* in the same TS 0).

In the block B4 the user requires further resources (*Resource Request*) in TS 7. The network assigns the requested resources in B6, TS 7 and in the new assignment MS is identified with 01. The new assignment will take place starting from the subsequent multiframe.

Periodically the network sends in TS 7 some *Packet Ack/Nack* which control the selective retransmission of the wrong blocks.

In conjunction with these messages, the network plans a non-transmission of the (half duplex) MS to give it time enough to switch to Rx on the *down link*.

Extended Dynamic Allocation

up link transmission

downlink	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
uplink	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4

down link transmission

downlink	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
uplink	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4

downlink	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
uplink	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4

downlink	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
uplink	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4

downlink	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
uplink	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4

block i

block i+1

block i+2

block i+3

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The *Extended Dynamic Allocation* mode offers the possibility to avoid that MS has to read continuously the USF.

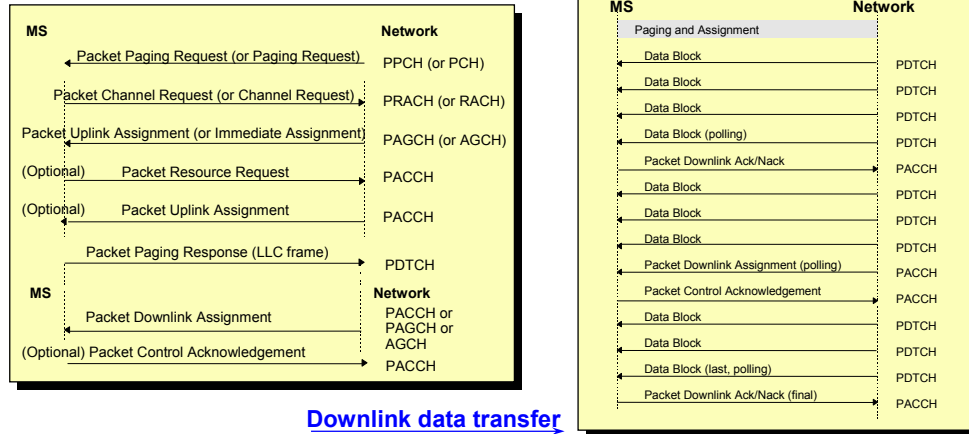
In the example, for transmission over the up link MS is assigned 4 slots (for *possible* transmission). MS detects the USF value only over TS 2 (*down link*) and it is then authorised to transmit in slots 2, 3 and 4. USF is then red twice: over TS 1 (where USF is not detected) and over TS 2 where it detects the USF.

For the *down link* transmission, 6 TS are assigned in the second example. The MS receives over all the assigned TSs (PDCH) for two consecutive blocks. TS 3 is used (during the block period 3) on the *down link* to request the MS to transmit on the *up link* a *Packet down link Ack/Nack*. For this purpose, it uses the *Supplementary/Polling* (S/P) mechanism, that *opens* the *Relative Reserved Block Period* (RRBP) range. The latter specifies the block period over which the *up link* transmission must take place (period 3 in the example). In the subsequent block period the network transmits up to the TS 3 in *down link* and then interrupts the transmission to give room to the MS to transmit (over the PACCH) the requested ack).

In the example this request is regularly sent to the MS.

Downlink Transmission

Paging



Downlink data transfer

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The *Paging* on the *down link* is sent in the *Packet Paging Channel* (PACH) over the entire *routing area* (equivalent to the *location area* seen for the GSM). The *Packet Paging Request* bears the MS identity IMSI (or TIMSI).

The paging procedure of the figure is self explanatory. In the *Paging Response*, MS sends (among other info) its TLLI identifier which becomes the identifier to be used along the procedure. The optional segment reflects the case of a two-phase access earlier described.

In the *Packet down link Assignment* the network specifies also the *Temporary Flow Identity* (TFI) pointing at the actual *Temporary Block Flow*. As seen, the TFI enables the addressing of several radio blocks over the same PDCH. The *Packet down link Assignment* also bears the *Timing Advance* and the *Power Control* commands.

The *Packet down link Ack/Nack* requires the selective re-transmission of the wrong radio blocks. Again, a new assignment of the down link resources may be requested by the network (*Packet down link Assignment*). The release procedure is started by the network. To have the needed guarantees about its outcome, the network require MS to send a *Packet down link Ack/Nack* which confirms the reception of all the radio blocks until that phase. Once received, the network de-activates all the PDCHs and the TFIs assigned to MS.

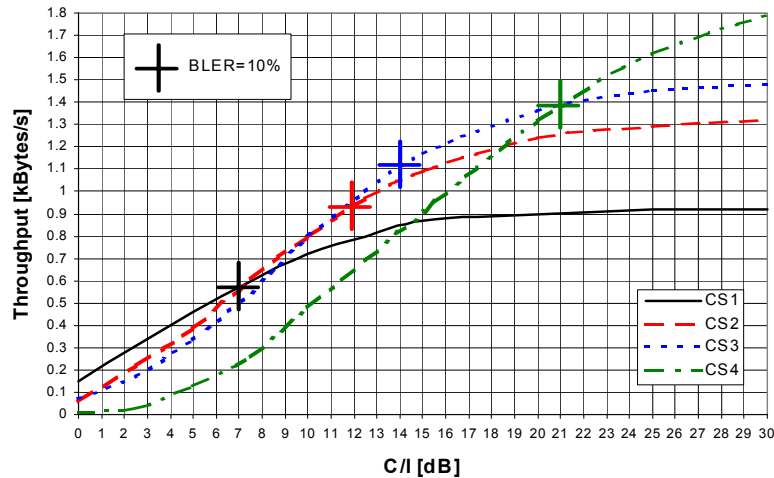
A *Fast Release* procedure is also defined.

Along the down link data transfer, MS must read continuously the associated channel to be able to read the *Packet Downlink Assignment* or the *Packet Timeslot Reconfigure* messages.

In the *Packet down link Ack/Nack*, MS can require the assignment of *up link* resources (simultaneous transmission).

GPRS: RLC/MAC performance

Throughput (saturation) vs. C/I (TU50 ideal FH)



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The figures show the RLC/MAC layer performances in terms of *throughput*.

The coding scheme CS1 ensures the highest *throughputs* for low values of C/I (*Traffic Urban*, 50 km/h and *Frequency Hopping* ideal is considered).

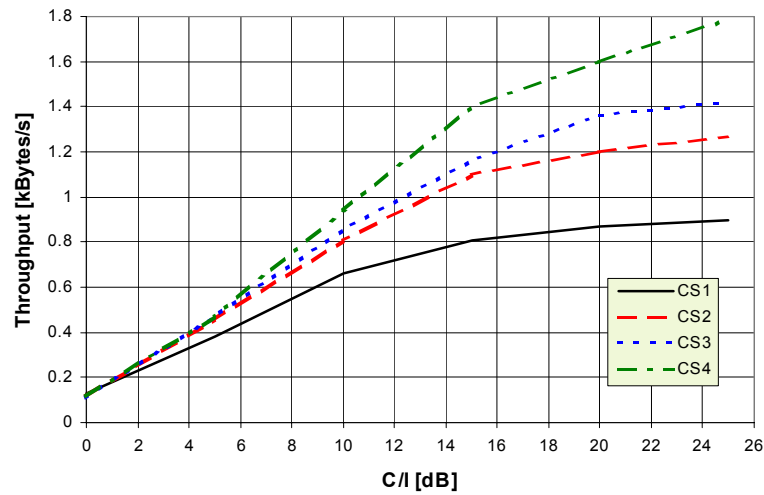
CS2 and CS3 show similar performance.

CS4 may be applied only for high values of C/I. It has good performances (with respect to the other schemes) for high values of C/I in condition TU 3, no FH.

Through *Adaptive Coding Scheme* mechanisms it is possible to optimise the system performance in function of the context conditions.

GPRS: RLC/MAC performance

Throughput (saturation) vs. C/I (TU3 no FH)



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Selective ARQ

- Modulo-128 numbering of the RLC Data Blocks within one TBF
- **Sending window of 64 blocks**, then waiting for acknowledgement (ACK/NACK)
- Each **temporary ACK/NACK** acknowledges a given number of blocks, thus moving the beginning of the sending window. Erroneous blocks are indicated through a bitmap. In an ACK/NACK there is no change in the current channel assignment
- The network can allocate additional/de-allocate resources to the MS (Packet Uplink / Downlink Assignment, Packet Timeslot Reconfigure messages)
- A **final ACK/NACK** is sent to acknowledge all the blocks within a TBF