

Mobile Communications

The course structure

1. Basic elements

 **2. GSM and voice services**

3. Data services and General Packet Radio System

4. Universal Mobile Telecommunication System

5. Network engineering

Mobile Communications

GSM and voice service

2. GSM and voice services



2.1 The physical layer

2.2 Network architecture; functions and protocols

2.3 Services and Service enablers

The chapter describes the basic functions of the GSM, starting from the physical layer up to the service layer, passing through the network architecture. The description remains at the conceptual level, hence non essential details are avoided.

2. GSM and voice services

2.1 The physical layer

frequencies and access

TDMA and the GSM; physical and logical channels

coding

modulation techniques

extensions:

e2.1

frames, super-frames, hyper-frames

e2.2

modulation technique

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The subjects are listed in the figure. This section has two extensions.

The description of the physical layer will touch some functional aspects which will be useful also for the subsequent parts of the course.

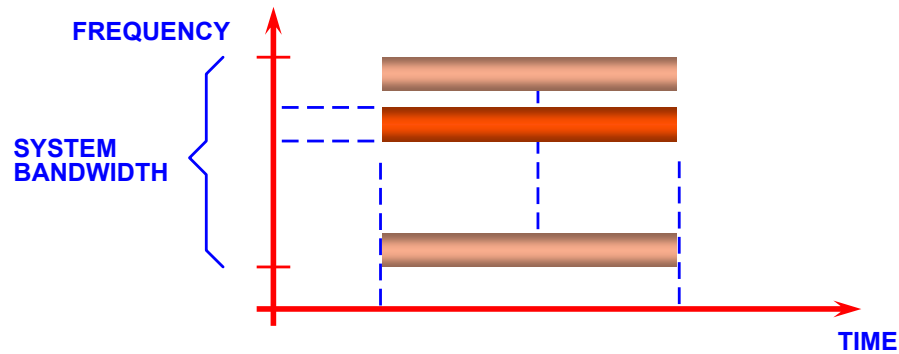
First, the access technique is considered together with the relationship arising between access and frequency assignment.

Then, the logical channels are introduced as well as their mapping onto the physical channels. In this respect, the frame and super frame concepts are described (extension e2.1 may help).

The modulation technique used in the GSM is described in the extension e2.2, but it will be just mentioned since it is much deeply described in another course of the Master Programme.

SCPC / FDMA

single channel per carrier/frequency division multiple access



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The figure shows the most popular access scheme. In the Frequency Division Multiple Access (FDMA) mode, the single connection is assigned a specific frequency (radio channel or carrier) for all the needed time (e.g. for the entire duration of the communication itself). For this reason, FDMA is also named Single Channel Per Carrier (SCPC) access mode.

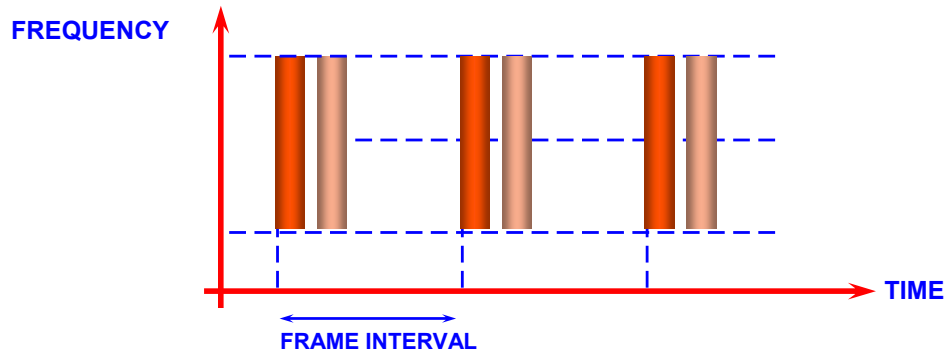
FDMA is typically used by analogue systems like the Total Access Communication System (TACS) and the *Nordic Mobile Telecommunication System* (NMT) or the AMPS (USA). It is a mature technology and requires narrow band modulation techniques. Selective receivers are used.

FDMA requires highly stable carriers. In fact, an FDMA system is working with a low ratio between the channel spacing (the distance between contiguous radio channels) and the working frequency (the bandwidth assigned to any single channel).

Also for the FDMA systems (as for the GSM and the UMTS), all the mobiles roaming in a given cell in the *stand-by* status, are tuned to a common channel, the *broadcast* channel. The latter supplies all the necessary data to access the system.

TDMA

Time Division Multiple Access



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The Time Division Multiple Access scheme (TDMA) adopts a time structure (frame) defined over each radio channel (carrier). A given number of time slots are defined within each frame. The scheme is suited for a digital system, where the voice source is sampled and coded.

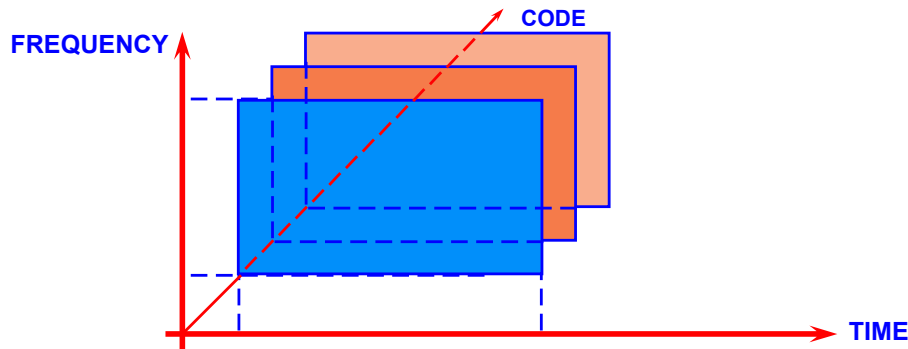
Each connection is here assigned a frequency and a time slot along the frame and this association is maintained as long as needed. The information is transmitted at a bit rate that is higher than the single source bit rate. In fact, the information has to be transmitted in bursts (time slots) spaced one frame time from each other. This implies that the radio channel (carrier) is wider in bandwidth with respect to the FDMA case.

The bandwidth expansion is also due to the introduction of preambles and guard times, that are respectively used for the identification of the exact time slot location and to avoid slot overlapping in variable propagation delay conditions.

TDMA has lower constraints on carrier stability with respect to the SCPC/FDMA case. Traffic and control channels are to be time multiplexed. On the mobile terminal side, transmission and reception take just one slot along the frame. This implies that the mobile terminal has some time available to perform measurements which are (as it will be explained) the driving elements of the handover mechanism.

DS-CDMA

Direct Sequence - Code Division Multiple Access



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In the Code Division Multiple Access (CDMA) schemes, all connections are transmitted on the same (wide) radio channel. Each connection is identified by a code which is associated to the connection itself (at least for a given time period).

In January 1998 ETSI took an important decision about the radio access technique to be used for UMTS and the choice was centred around this kind of access scheme:

- for the asymmetric portion of the spectrum available for UMTS, a hybrid solution based on a wide band CDMA time divided scheme
- for the symmetric portion of the spectrum, a wide band CDMA scheme.

The former solution is thought mainly for in-door applications, the latter for public/outdoor/high mobility services.

CDMA belongs to the family of spread spectrum techniques, where the original signal is *spread* over the entire available spectrum during the transmission time.

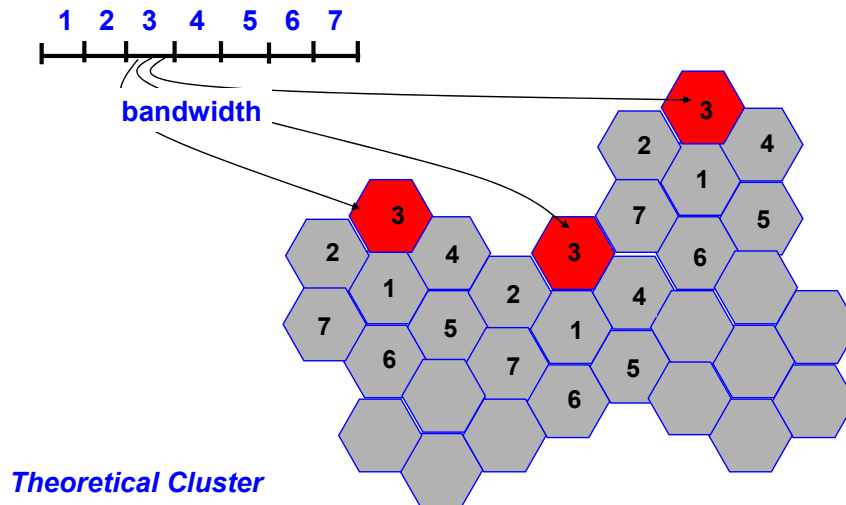
The subsequent part of the Seminar is giving a lot of attention to CDMA, since a significant portion of the innovative features expected for UMTS derive from this technological choice.

The basic CDMA characteristics are:

- high transmission rate (large bandwidth)
- complex receiver to recover the original information
- strict requirements on power control
- easy access (no synchronisation required)
- no frequency planning required.

Space Division Multiple Access

....other words for frequency re-use



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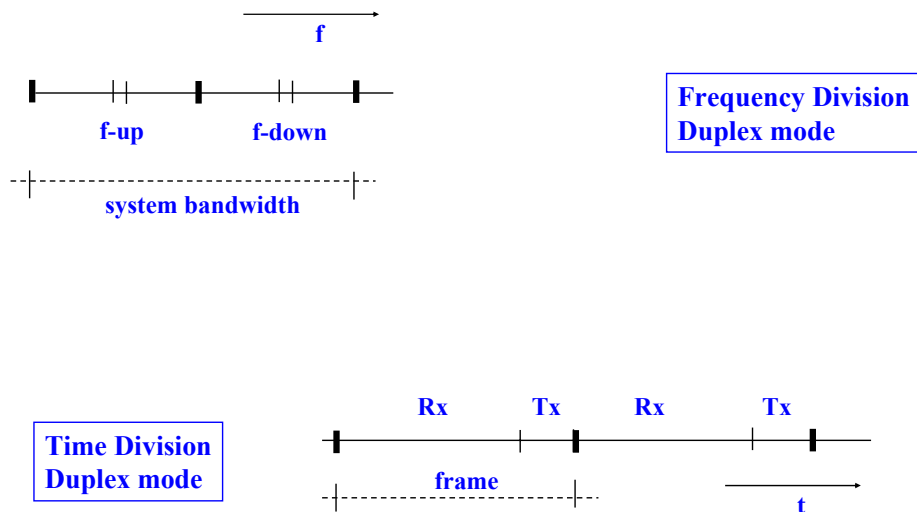
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The concept of Space Division Multiple Access applies to the frequency re-use scheme already seen.

The space division may be applied to different cellular schemes:

- low-power micro cells (-5 dBm o 3 W) used in high traffic conditions
- umbrella cells showing a great extension often used as overflow resources in conjunction with a microcellular layer or to supply signalling channels in big areas to a multiplicity of underlying cells
- sector cells, defined through directional antennas (60° to 120°) allowing for a minimisation of the site costs.

Duplex operation



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In order to guarantee the full duplex operation (useful for both voice and data traffic) two mechanisms can be adopted:

- Frequency-division duplex. Each bidirectional channel (up and down connection) is realised by using a couple of frequencies suitably spaced in the spectrum. The receiving side must be able to distinguish among them. The Rx/Tx splitting can be done within a single antenna (duplexer)
- Time division multiplexing. Both transmission directions rely on a single frequency. Tx and Rx phases are framed in regular way along a transmission frame. The transmission and receiving phases are distinct in time and suitably synchronised in order to avoid overlapping.

The GSM adopts a Frequency-division duplex scheme.

GSM: the available bandwidth

		Uplink (MHz)	Downlink (MHz)	Duplex spacing (MHz)	Bandwidth (MHz)
GSM 900	P-GSM 900	890 ÷ 915	935 ÷ 960	DL=UL+45	25
	E-GSM 900	880 ÷ 915	925 ÷ 960	DL=UL+45	35
	R-GSM 900	876 ÷ 915	921 ÷ 960	DL=UL+45	39
DCS 1800		1710 ÷ 1785	1805 ÷ 1880	DL=UL+95	75
PCS 1900		1850 ÷ 1910	1930 ÷ 1990	DL=UL+80	60
GSM 400	GSM 450	450,4 ÷ 457,6	460,4 ÷ 467,6	DL=UL+10	7,2
	GSM 480	478,8 ÷ 486	488,8 ÷ 496	DL=UL+10	7,2
GSM 700	GSM 750	747 ÷ 762	777 ÷ 792	DL=UL+30	15
GSM 850		824 ÷ 849	869 ÷ 894	DL=UL+45	25

The GSM available frequencies are depicted in the figure. Within the 25 MHz initially made available for each transmission sense (*up-down-link*) the bandwidth has been split into 125 channels each of 200 kHz width.

Channel 0 is not used (it separates the GSM system from systems using contiguous bands).

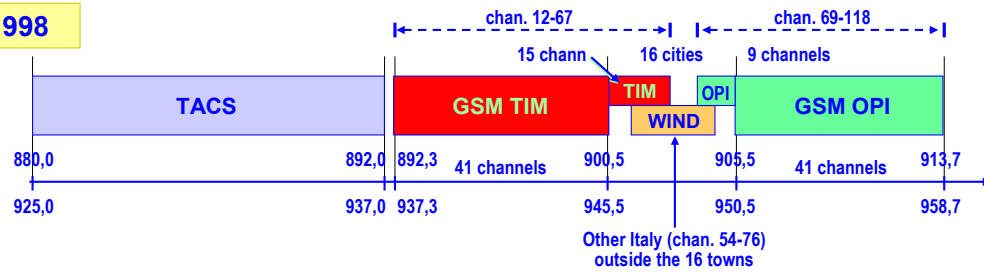
Each channel is described through a simple number $n=1, 2, 3, \dots, 124$, which allows to identify the *absolute frequency* the channel is using:

$$F_{\text{uplink}} = 890 \text{ MHz} + (0.2 \text{ MHz}) \cdot n$$

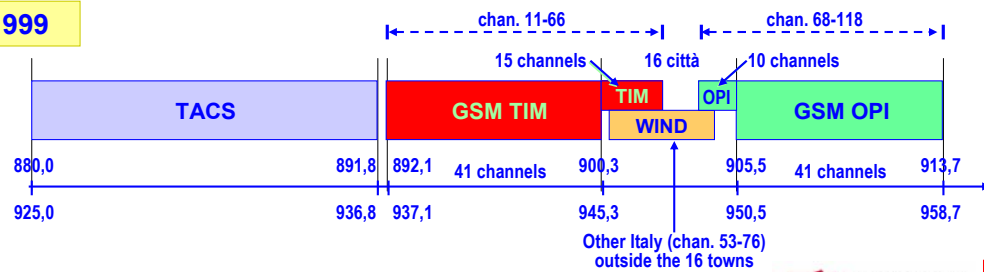
Successively assigned band extensions follow the same mechanism.

GSM frequencies @ 900 MHz in Italy

01.11.1998



01.03.1999



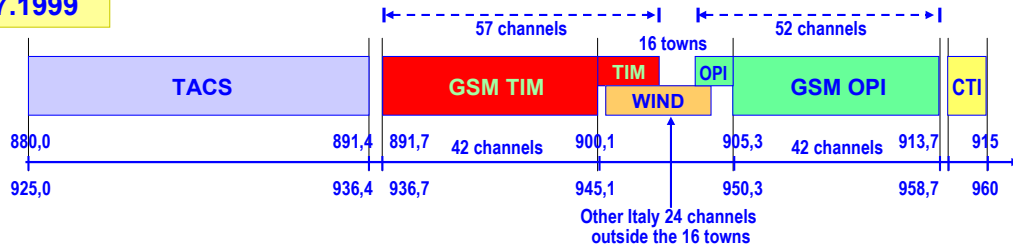
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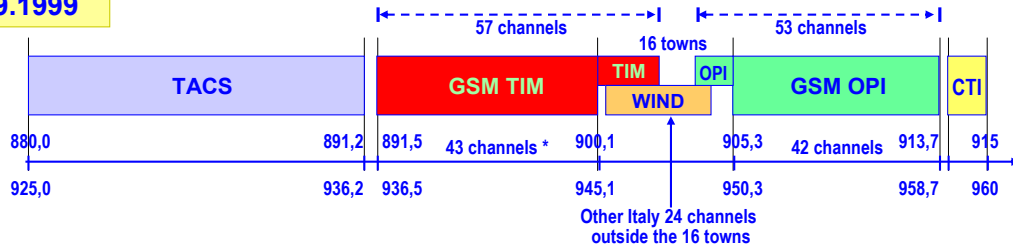
Typical splitting of resources.
The Italian case.

900 MHz frequencies - evolution

01.07.1999

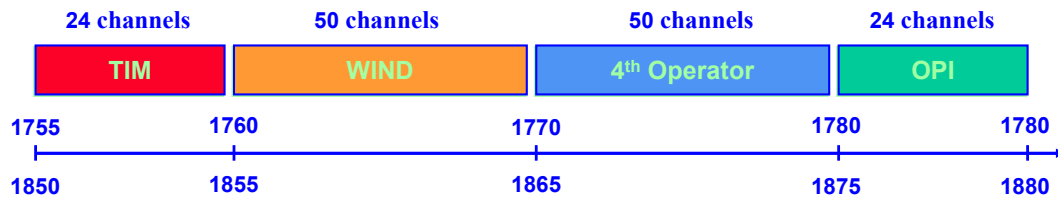


15.09.1999



Typical splitting of resources.
The Italian case.

Frequencies @ 1800 MHz



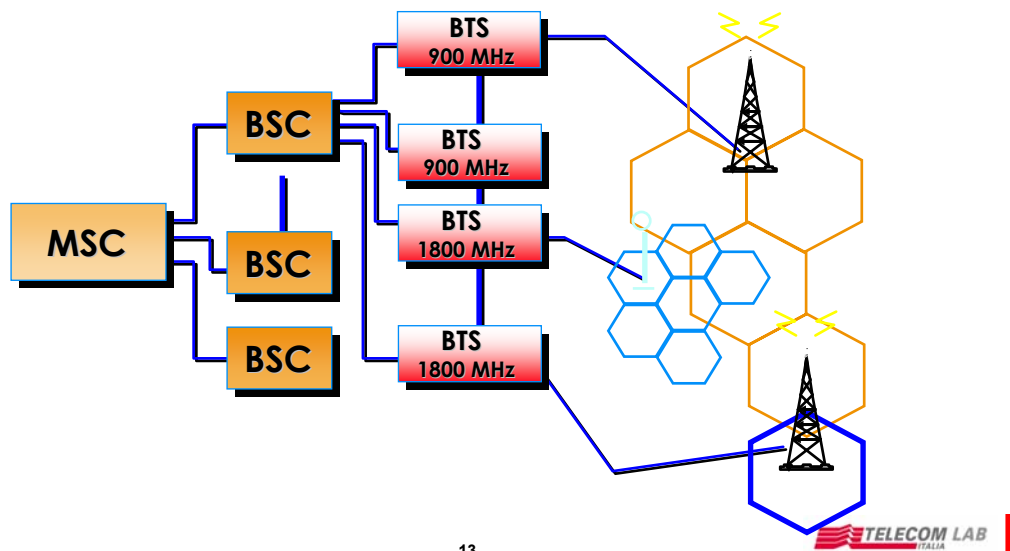
from 01.01.99 in 8 towns: RM, MI, NA, TO, BO, PA, FI, GE

from 01.07.99 over the whole national territory

Typical splitting of resources.

The Italian case.

GSM 1800: the compatibility value



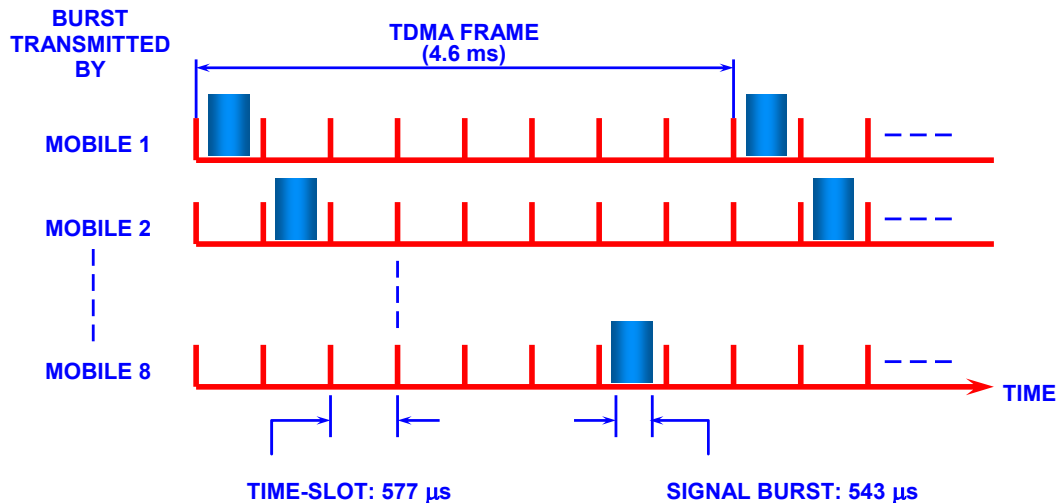
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GSM is enlarging the application possibilities also thanks to the significant enlargement of the assigned bandwidth in the range of 1800 MHz (GSM 1800). On the architectural side, GSM 1800 is completely based on the GSM system. The band available around 1.8 GHz, is 75 MHz.

The GSM 900 and the GSM 1800 infrastructures can be integrated to each other: the latter can be planned to cover high density zones (micro cells) being completely based (controlled) by the GSM infrastructure (BSC). As depicted in the figure, the integration can be realised at different hierarchical levels, and offers a variety of possible configurations, depending on the traffic needs and the level of saturation of the previous infrastructure.

This implies an efficient utilisation of the GSM infrastructure and can solve several bandwidth problems, allowing for a flexible and context-dependent exploitation of the system characteristics.

GSM functions - TDMA access technique



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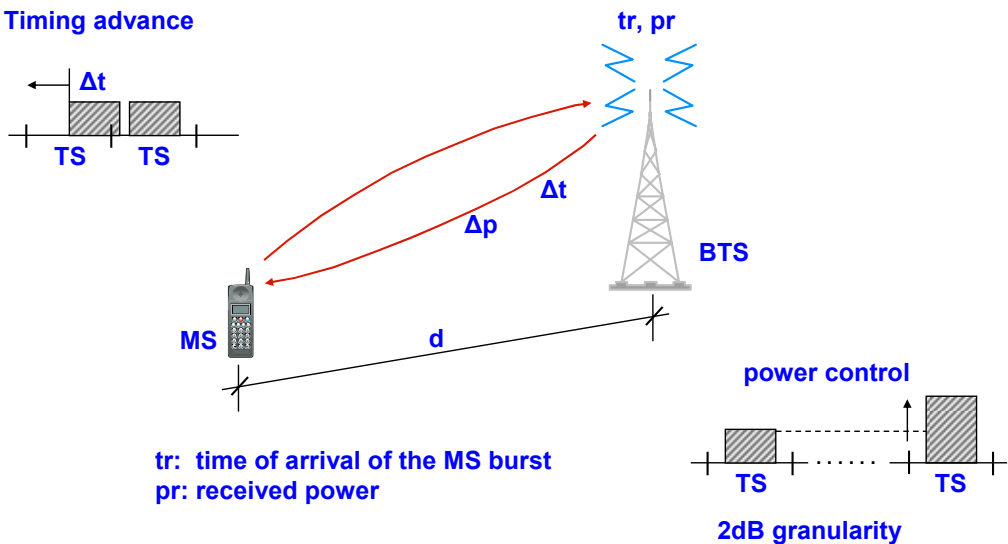
The GSM has adopted the TDMA solution for the access scheme, hence each connection is assigned a frequency and a slot along the TDMA frame. As said, in this case the bandwidth is shared among the cells according to a pre-defined scheme: the adopted frequency plan.

Within each cell, a second level of sharing takes place between mobile terminals roaming in that cell.

The figure shows how eight mobile terminals can share the same carrier by making use of the eight frame time slots. It will be clarified that some of the available slots among those available in a cell are devoted to realise some logical channels carrying signalling information (both system and connection related information).

Time and power control

Timing advance



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The mobile experiences different distances with respect to the base station (in different instants). As a consequence, the system must be able to regulate two important transmission parameters:

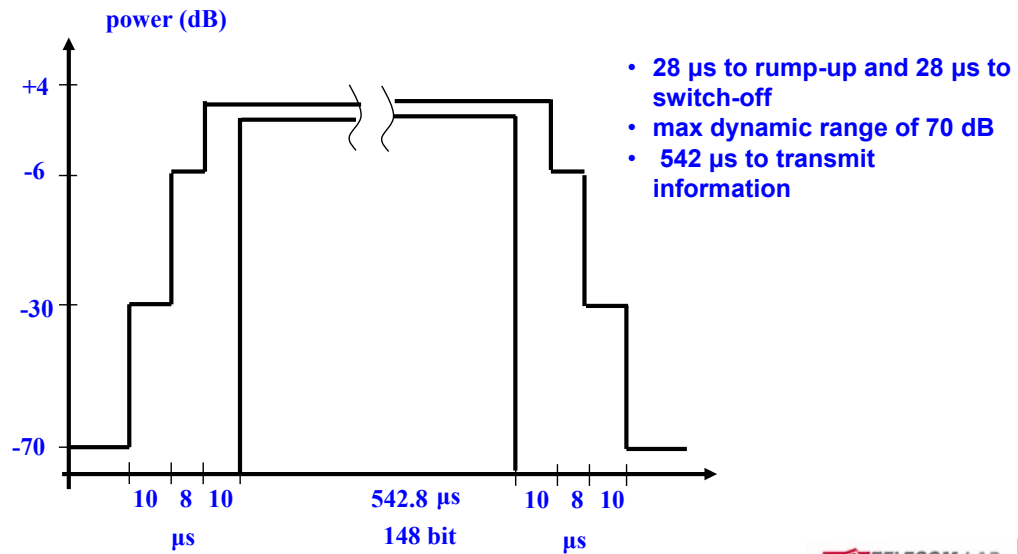
- the transmission time
- the emitted power.

The former is regulated through timing advance mechanisms. The base station (BS) performs continuously measurements on the time of arrival of the mobile-emitted bursts. The BS compares the time of arrival of the relevant burst with its *slot times*. BS sends commands to the mobile in order to correct its transmission time by recovering the needed time alignment. The BS uses an associated channel to communicate with the terminal.

A similar mechanism is used for the power regulation (the needed power also depend on the distance between the mobile and the BS).

The GSM allows also to adopt a regulation of the power emitted by BS with a Time Slot granularity (in correspondence with each connection in progress).

Time and power control (II)

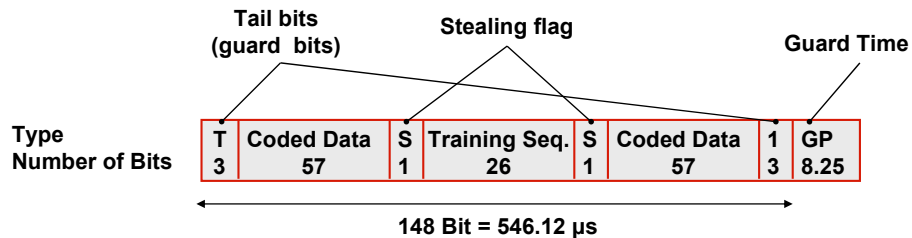


The emission within a timeslot time forces the terminal to obey very stringent time and power dynamics constraints.

The power ramp is 28 μs with a dynamic that can be up to 70 dB. Along the 543 μs of the time window, the terminal transmits a burst composed of 148 bits that can adopt different configurations.

Burst structure

normal burst



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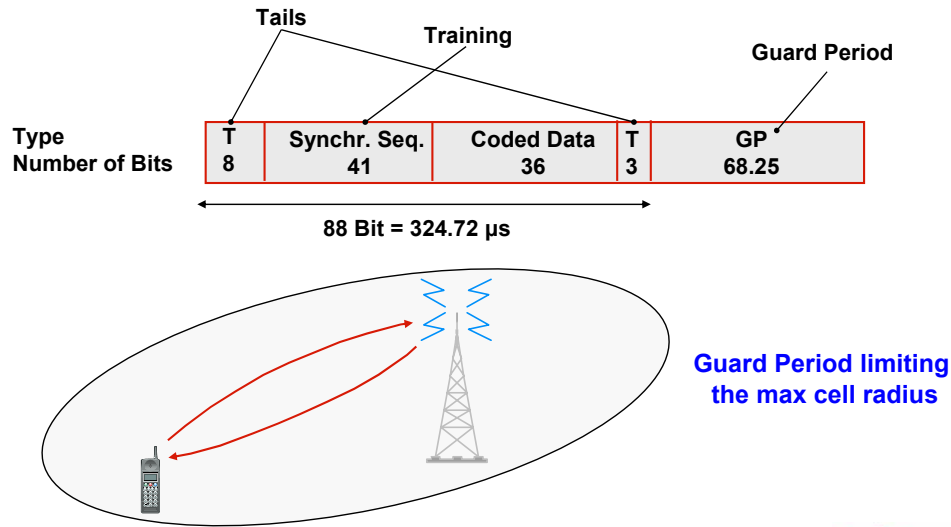
Three possible burst arrangements are adopted for the burst transmitted in a given time slot.

The normal burst bears both user and signalling data.

- 3 bits are inserted at the beginning and the end of the burst (tail bits); all are set to 0; they cover the uncertainty phases during the up and down ramps
- 57+57 are the real information content (coded data)
- 26 bits are the training sequence. They are configured according to a sequence that is known by the mobile and the station; the sequence is used by the receiver to compensate the effect of the multipath (equaliser). The training sequence is tied to the Base Station Information Code (BSIC) (see the role of the synchronisation burst)
- 30 μs are assigned to the guard time (they correspond to 8.25 bits); in this period no bit is transmitted
- 2 bits (stealing flag) are used to specify the kind of data transported by the normal burst (they are used by the decoder).

Burst structure (II)

random access burst



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The random access burst carries the former message the mobile is sending to the network to request the activation of a connection. The initial phase is particularly delicate for at least two reasons;

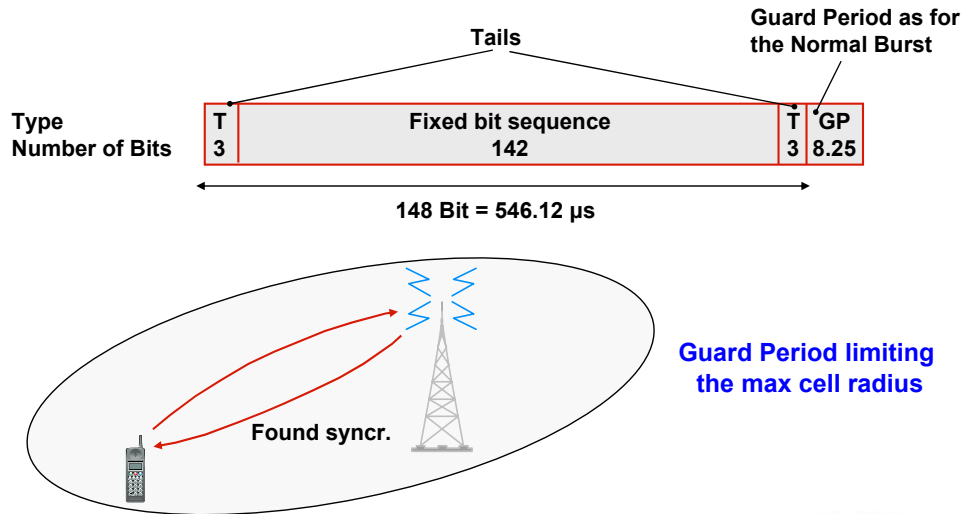
- the access message can be launched by many terminals at the same time
- the mobile does not know its distance with respect to the station hence, even if slot synchronous it ignores the correction induced by the timing advance mechanism.

The first circumstance can be resolved through retransmission mechanisms. In addition, to avoid transmissions outside the slot window, the random access burst uses wide guard times (see figure).

The synchronisation sequence has the same meaning as the *training sequence* had for the *Normal Burst* (also in this case, it is defined by the *base station information burst* - BSIC). The only difference is that it must be longer due to the fact that the receiver in this phase is not yet aligned with the data stream.

Burst structure (III)

frequency correction and synchronisation burst



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The frequency-correction burst allows the synchronisation of the terminal. The synchronisation burst is transmitted in a specific slot, in a precise position of the multi frame. It transports a sequence of zeroes (un-modulated waveform). The mobile receiver, recognises the sinusoidal waveform, hence the slot where it is transmitted.

The data flow to be read from that instant on, must be decoded by using the appropriate key. This is one of the 8 training sequences that are allowed in the system. The synchronisation burst is always followed in the multi frame scheme by the Synchronisation burst (not represented here) which carries the Base Station Information Code (BSIC) which contains by turn the Base Station Colour Code and the National Colour Code (the latter is the national colour code).

The Synchronisation Burst contains also the frame number, necessary to synchronise the mobile with the multi frame pace. The synchronisation burst has a configuration similar to that of the normal burst.

See extension e2.3, where the *frequency correction* and the *synchronisation bursts* are described in a greater detail.

GSM traffic channels

TCH/FS: Traffic Channel Full rate Speech

- Speech transmission at a net bit rate of 13 Kbit/s (up and down link)

TCH/HS: Traffic Channel Half rate Speech

- Speech transmission at half bit rate (up and down link)

TCH/F: Traffic Channel for Data transmission

- Data transmission at 9.6/4.8/2.4 Kbit/s (with different coding schemes)

TCH/H: Traffic Channel for Data transmission

- Data transmission at halved speed (with different coding schemes)

In the GSM, several traffic channels are defined. They carry both voice and data streams.

Half rate channels use voice encoders working at a lower bit rate (1/2) with respect to the full rate case.

Similar conditions hold for the data channels.

GSM signalling channels

BCCH: Broadcast Control Channel

- point-to-multipoint unidirectional control channel
broadcasting system information to MS

CCCH: Common Control Channel

- up-link: RACH (Random Access CHannel)
- down-link: PCH (Paging Channel)
AGCH (Access Grant CHannel)

DCCH: Dedicated Control Channel

- point-to-point bidirectional control channel
- SACCH (Slow Associated Control CHannel)
- FACCH (Fast Associated Control CHannel)
- SDCCH (Stand Alone Dedicated Control CHannel)

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In order to drive the various functions needed to manage connections and mobility, one (or more) slots of the TDMA frame are devoted to carry logical channels for signalling and control purposes.

The *Broadcast Communication Channel* (BCCH) carries in a broadcast mode all the system information needed to the mobile terminals roaming in that cell.

The *Common Control Channel* (CCCH) carries a series of channels which are time-multiplexed:

- on the up link it carries the random access channel, accessed with contention by all the mobiles roaming in the cell;
- on the down link, two logical channels are time multiplexed on CCCH, namely:
 - the paging channel, addressing the mobile which is requested by an incoming call
 - the access grant, carrying the acknowledgements to the mobile access.

The *Dedicated Control Channel* (DCCH) carries in both up and down links, control channels that are either signalling-dedicated or associated control channels; the former are carrying the call signalling in the phases when the traffic channel has not yet been activated for that call; the latter are active in conjunction with any channel activated (either signalling or traffic channel) and are basically devoted to transport measurement and handover-related information.

- *Stand Alone Control Channel* (SDCCH) carries the signalling procedure outside the activation of a traffic channel
- *Slow Associated Control Channel* (SACCH) and *Fast Associated Control Channel* (FACCH) carry the control information associated to traffic (TCH) and signalling channels (SDCCH).

..some other broadcast channels

FCCH: the Frequency Correction Channel

- Gives the mobile station the reference frequency of the system

SCH: the Synchronisation Channel

- Gives the mobile station the training sequence for demodulate the down-link information

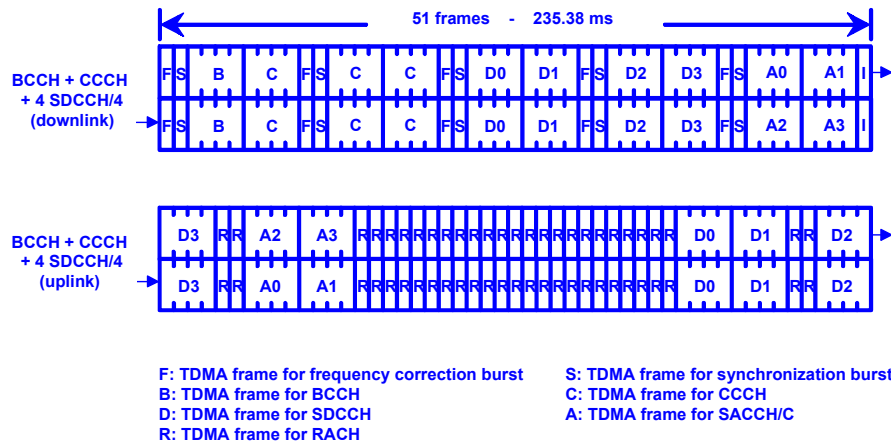
The Frequency correction and the synchronisation channels (FCCH and SCH) are also defined over the multi frame configuration.

Their will be described in extension e2.3.

[illegible]

Pag. 23

GSM - logical and physical channels



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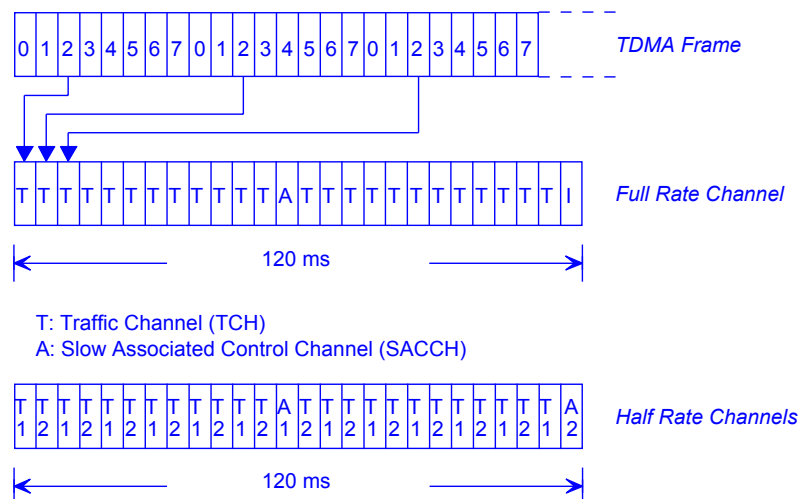
In this configuration, a single physical slot is supporting all the control and signalling channels. This case is suited for a lower dimensioning of the signalling resources. In fact, here the reference cell can rely on 4 SDCCH only.

The choice between either configuration depends of course on the number of radio channels associated to the cell, namely on the traffic insisting on the related coverage area.

The solution requires a multi frame arrangement based on 2X51 frames. The multi frame organisation is known to all MSs as system information transmitted on the BCCH).

The figure is self-explanatory.

GSM - associated channels



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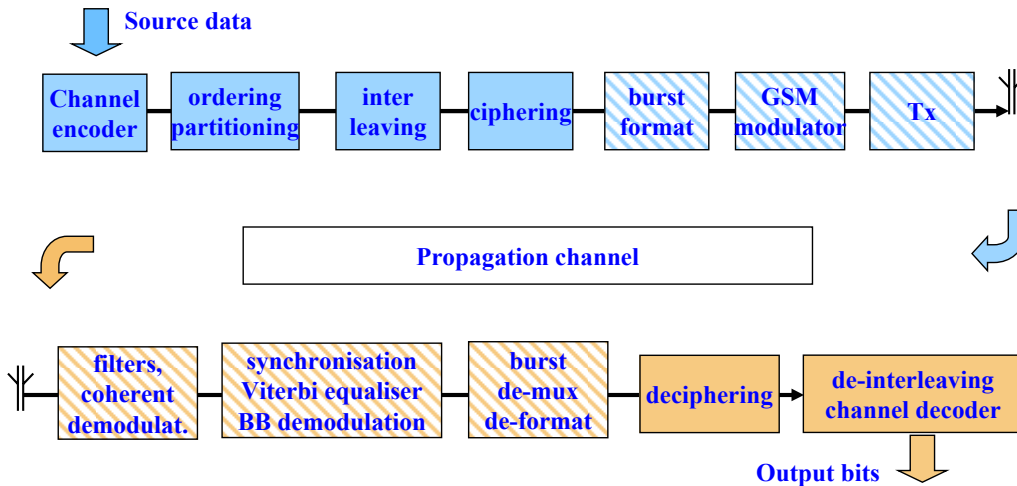


The SACCH is associated to the traffic channel as soon as the latter is set-up. This association is done by dropping the content of one slot every 26 slots (120 ms) of the TCH. This choice makes available a low bit rate channel (as SACCH is) without using other resources on the radio interface.

In case half rate coding is used, each TCH is multiplexing two different communications. The above multi frame arrangement allows to identify a double SACCH per each period of 120 ms: one per each communication.

GSM radio transmission and reception chain

a conceptual scheme



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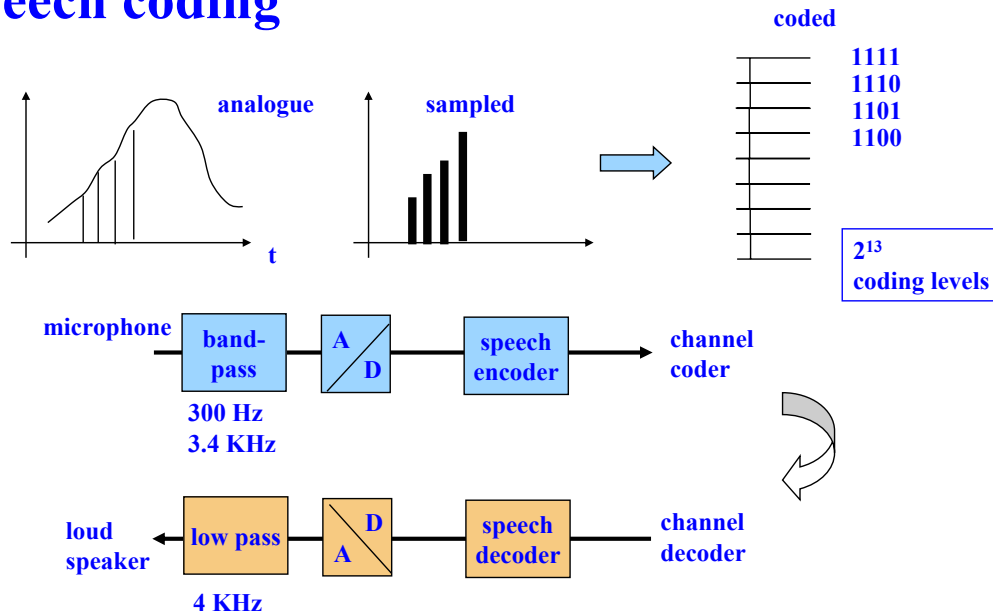
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The physical layer chain is realised through many steps.

The GSM Standard specifies the transmission segment only. The receiving segment is left to the proprietary solutions proposed by the Manufacturers.

The dashed blocks are the same for GSM and GPRS. The other blocks are different for the two systems.

Speech coding



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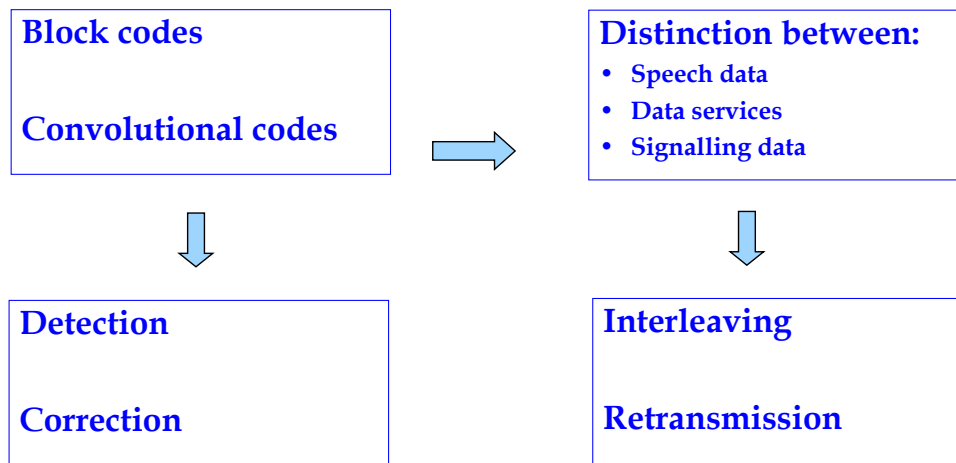
The analogue signal is first of all filtered to reduce the frequency components above 4kHz. It is then sampled at a frequency of 8kHz (every 125 μ s) with a code based on 13 bits (2^{13} levels). This would imply a transmission requirement of:

$$8000 \times 13 \text{ bit/s} = 104 \text{ kbit/s}$$

The voice encoder reduces these requirements to 13 kbit/s through numerical filtering and other complex mechanisms (e.g. bit sequentialisation, choice of the most representative bits based on the sequence energy).

These operations are done over blocks of 160 samples of the voice signal, collected in 20ms (voice frame). The encoder output is a block of 260 bits every 20 ms, corresponding to a bit rate of 13 kbit/s.

Channel coding *and other protection mechanisms*



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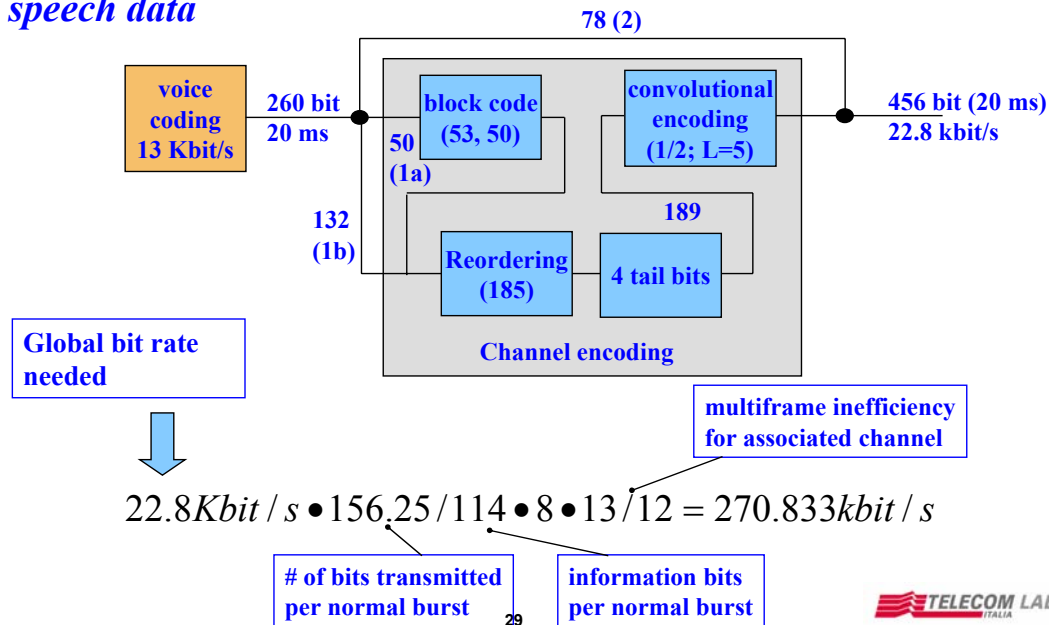
The source encoder produces a voice frame of 260 bit every 20 ms. This is delivered to the channel encoder.

Bits are ordered according to their importance (subjective importance). The 260 bits are ordered according to a decreasing order and are classified in 6 classes of importance

The subsequent channel coding operates on the bits in a differentiated way:

- the first coding class contains 182 bits belonging to the first 5 importance classes (excluding the last 9 bits of class 5) and uses the convolution encoding as a FEC technique
- the second coding class includes 78 bits (9 bits from class 5 and all the bits of the last class of importance; These are not undergoing any coding on the channel).

Channel coding *speech data*



The figure shows how bits of the voice service are coded in two phases. First a block coding is applied to detect errors (not to correct them) The block code is applied to the 50 most important bits deriving from the voice coding. 3 bits are added to the original 50 bits.

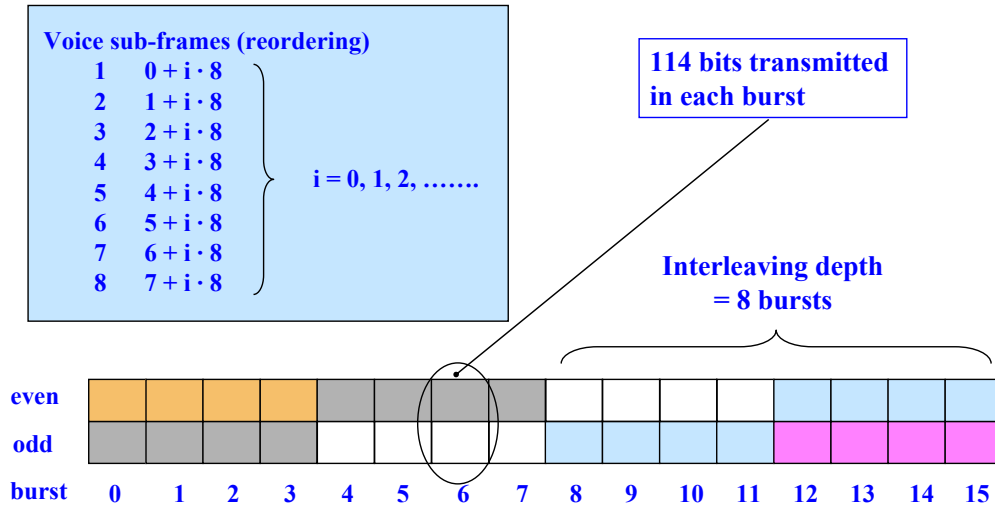
Then, a convolution coding is applied with a coding rate $\frac{1}{2}$ and 5 stages (constraint length). The convolution encoding is applied to the 53 bits generated by the block encoder and the 132 bits of class 1b. 4 bits are added to the 53+132 bits to create a known starting state for the Viterbi decoder.

So, 378 bits are obtained, to which the less important 78 bits are added (no encoding is applied to the latter). The channel bit rate is then 456bits/20 ms =22.8 kbit/s. This is a fixed data for the GSM demodulator.

On the receiving side, if the block code reveals an error within the first 50 bits, the entire voice frame is discarded and the decoder must perform an interpolation between the previous and the subsequent frame. Being the parity bits subject to the channel errors, the probability of accepting a wrong frame is high.

For this reason, this mechanism is modified for the GPRS.

Reordering and Interleaving speech data



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The 456 bits resulting from the channel encoder, correspond to the content of 4 normal bursts (each carrying 114 bits). Their transmission in 4 consecutive bursts would expose them to the risk of being corrupted by error bursts which are typical of the radio channel. The voice frame of 456 bits is the subdivided i8 sub-frames according to the scheme of figure (each sub-frame contains 57 bits: $\frac{1}{2}$ of the capacity of a normal burst).

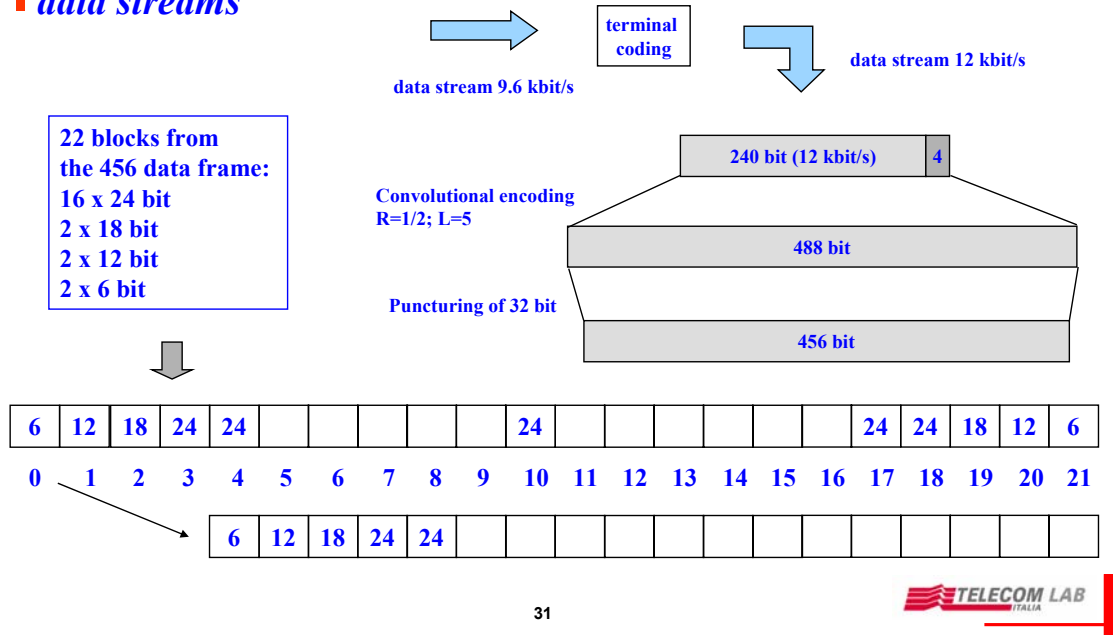
Remember that the voice blocks are formed at the pace of 1 each 4 bursts. The first 4 sub-frames are located in the even position of 4 consecutive normal bursts; the second ones in the odd positions of the subsequent 4 normal bursts. Once the first 4 sub-frames are allocated, the subsequent voice frame is already available from the same process. The first four sub-frames of the new frame are hence allocated in the even positions of the subsequent 4 normal bursts. Which have included in the odd positions, the second 4 frames of the preceding voice frame.

The scheme is repeated as reported in the figure.

The FACCH channel is created by *picking up* when necessary (handover) one or more bursts. The two flags foreseen in the normal burst reveal exactly the presence in the 57 even (or odd) bits of the burst (or in both) of the FACCH channel.

Channel coding and interleaving

data streams



The bits of the data channels have to be protected with particular attention: losing even a single bit, may destroy an entire block of information. Hence, for data specific mechanisms are used.

Each bit rate (each class of transport) has a specific coding and interleaving scheme.

The block coding is in any case performed by the terminal. For instance, for the 9.6 kbit/s the original flow is extended by the terminal coding up to 12 kbit/s. The data flow is collected in frames of 240 bits, split into 4 burst of 60 bits each.

4 bit (set to 0) are added to the 240 bits in order to allow the Viterbi decoder to initiate its work from a known state. Then a convolution code is applied with rate $\frac{1}{2}$ and 5 stages (as for the voice). This leads to 488 coded bits (32 are exceeding with respect to the canonical 456 of the radio block, which are compatible with the transmission speed of 22.8 kbit/s). 32 bits are then eliminated (puncturing) before entering the interleaving phase.

The interleaving is more accurate than for voice streams (grater protection constraints and reduced delay constraints). The 456 bits of the data block a subdivided in 22 blocks as in figure. They are the assigned to the bursts according to an interleaving scheme based on a 22 depth mechanism. The structure is repeated each 4 bursts. In this way, each single burst is carrying data belonging to 5 or 6 consecutive data blocks.

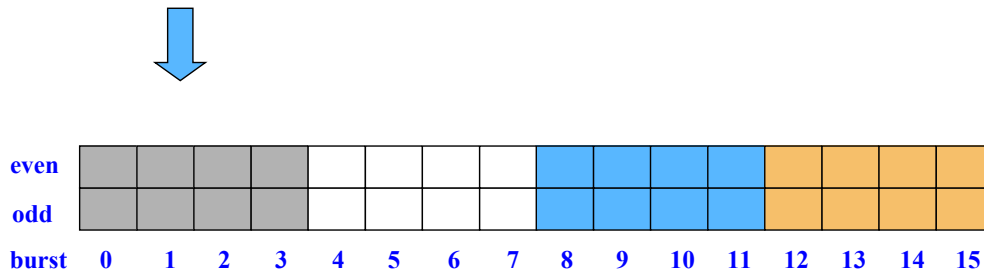
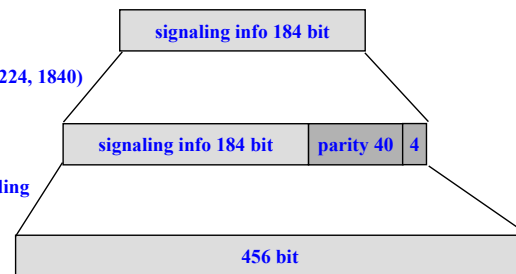
The transmission of a FCCH may interrupt the data stream. The FCCH channel adopts an interleaving depth of 8, as for the voice traffic.

Channel coding *signaling streams*

Spreading of the signaling
block over 4 consecutive
bursts

Convolutional encoding
 $R=1/2$; $L=5$

Block code (224, 1840)



32

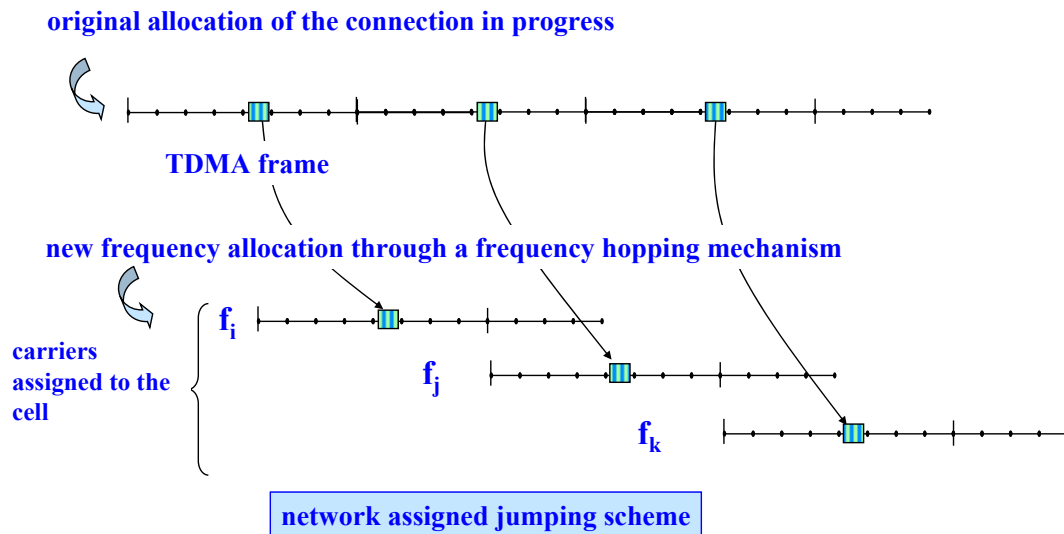
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The channel encoding for the signalling channels is also particularly delicate. The signalling block are all formed by 184 bits. First a block coding is applied, working for both detection and correction (within given limits). The resulting flow is applied a convolutional encoding having the same characteristics of the one used for voice service.

The interleaving is developed over 4 consecutive bursts. Still (as for the voice) 8 sub-blocks are defined, each of 57 bits, but, instead of allocating them over 8 consecutive bursts, these are allocated over 4 consecutive bursts only: the first 4 sub-blocks are assigned at the even places, the second at the odd places of the same bursts.

The above allocation, clarifies why in the logical channel definition, according to the multi frame concept (51 frames) all the signalling channels require 4 consequent frames to be transmitted. Just in the case of the SACCH, being this defined on a single slot every 26 frames (the voice multi frame), 4 multi frames are needed to have the entire signalling block.

Base band frequency hopping



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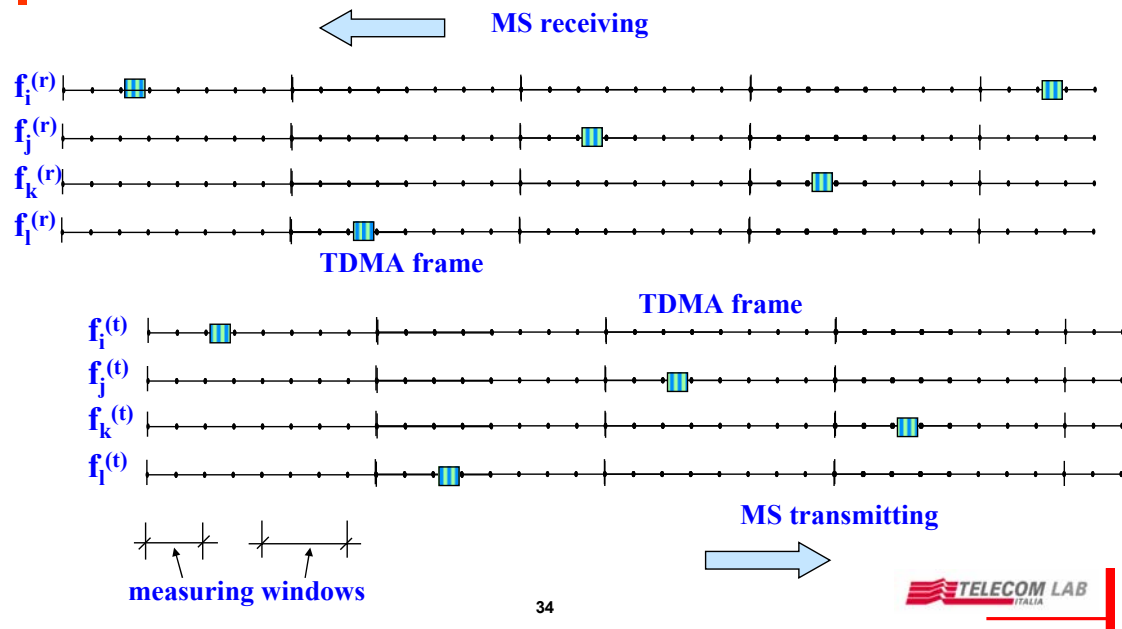
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The frequency hopping procedure protects the system against the frequency selective fading. This fading has a dynamic effect over all the frequencies in time. Hence, in addition to the optimal choices that have been done in constructing the frequency plan, the carriers assigned to the cells undergo a variation of the radio characteristics in function of the various random elements affecting their behaviour.

To combat these effects, the GSM adopts the slow frequency hopping technique: the information content related to the same connection is assigned dynamically to the different carriers allocated in to the cell. The pace of carrier change is the TDMA frame time. The channel can take significant advantages from the frequency hopping mechanism: if applied, the $(C/I)_{\min}$ can pass from 11 to 9 dB.

The mobile terminal is predisposed to support frequency hopping. The reference BTS can decide to adopt one of the available frequency hopping schemes. To start the process, it sends the MS the frequency hopping number that identifies the hopping sequence to be done on the Rx and Tx parts.

Base band frequency hopping (I)



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Slot 0 carries channels FCCH, SCH and BCCH, cannot take part to the pool of carriers involved in the frequency hopping. This slot is in fact measured by all the mobile terminals, including those roaming in neighbouring cells)

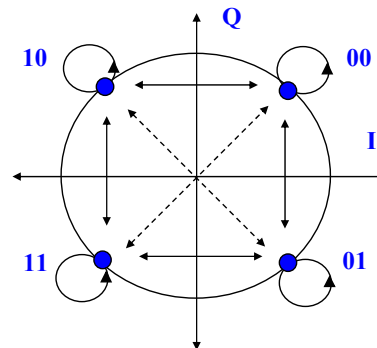
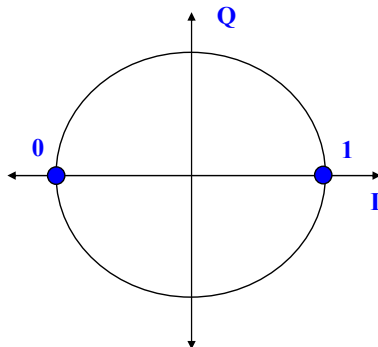
The frequency hopping can be realised at the base band level (described here) and at radio frequency.

The figure represents a sequence of *jumps* between 4 carriers, performed by a connection in progress over slot #3. The mobile receiver, which has to move in frequency to receive the BCCH of the neighbour stations, can rely in 4 TS to do this job in the figure example.

The shift of 3 TS between the receiving and the transmitting parts makes possible these operations.

Modulation techniques

Binary Phase Shift Keying



Quadrature Phase Shift Keying

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Modulation takes place by varying the characteristics of the wavelength in function of the numerical signals that are to be transmitted. The modified characteristics may be:

- the carrier amplitude (*Amplitude Modulation; Amplitude Shift Keying*)
- the frequency (*Frequency Modulation; Frequency Shift Keying*)
- the phase (*Phase Modulation; Phase Shift Keying*).

Phase modulation over two levels is an example. Each symbol represents a single bit (M is the number of bits that are transmitted during a symbol period).

$$M = 2^1$$

The *Quadrature Phase Shift Keying* (QPSK) modulation is based on 4 modulation levels. Each symbol is here representing a couple of bits.

$$M = 2^2$$

The modifications arising between subsequent symbols may result in significant changes in amplitude (the greater the phase shifting, the lower the amplitude during the passage). This requires a great linearity of the amplifiers.

To limit this effect, it may be convenient avoiding the passage between states that have opposite phase. (dashed line for QPSK case).

Some extensions for the modulation adopted in the GSM case are reported in extension e2.2.