

# GSM

## Global System For Mobile Communication

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# GSM

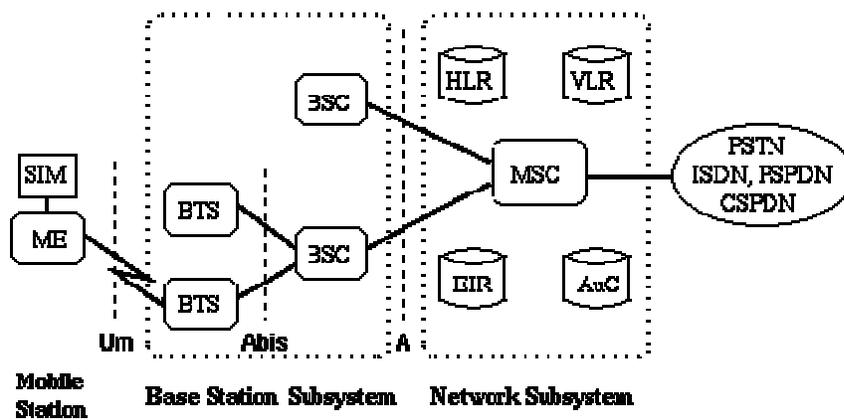
Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard that would formulate specifications for a pan-European mobile cellular radio system operating at 900 MHz. It is estimated that many countries outside of Europe will join the GSM Partnership.

GSM was devised as a cellular system specific to the 900 MHz band, called "The Primary Band". The primary band includes two sub bands of 20 MHz each, 890 to 910 MHz and 930 MHz to 960 MHz. GSM-PLMN has allocated 124 duplex carrier frequencies over the following bands of operation.

Uplink frequency band: 890 to 910 MHz (MS transmits, BTS receives).  
 Downlink frequency band: 930 to 960 MHz (BTS transmits, MS receives).  
 Carrier spacing :- 200 KHz.

## Architecture of the GSM network

A GSM network is composed of several functional entities, whose functions and interfaces are specified. Figure 1 shows the layout of a generic GSM network. The GSM network can be divided into three broad parts. The Mobile Station is carried by the subscriber. The Base Station Subsystem controls the radio link with the Mobile Station. The Network Subsystem, the main part of which is the Mobile services Switching Center (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The MSC also handles the mobility management operations. The Mobile Station and the Base Station Subsystem communicate across the Um interface, also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile services Switching Center across the A interface.



SIM Subscriber identity Module	BSC Base Station Controller	MSC Mobile services Switching Center
ME Mobile Equipment	HLR Home Location Register	EIR Equipment Identity Register
BTS Base Transceiver Station	VLR Visitor Location Register	AuC Authentication Center

Figure 1. General architecture of a GSM network

## Mobile Station

The mobile station (MS) consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another GSM terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services.

The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility. The SIM card may be protected against unauthorized use by a password or personal identity number.

## Base Station Subsystem

The Base Station Subsystem is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). These communicate across the standardized Abis interface, allowing (as in the rest of the system) operation between components made by different suppliers.

The Base Transceiver Station houses the radio transceivers that define a cell and handles the radio-link protocols with the Mobile Station. In a large urban area, there will potentially be a large number of BTSs deployed, thus the requirements for a BTS are ruggedness, reliability, portability, and minimum cost.

The Base Station Controller manages the radio resources for one or more BTSs. It handles radio-channel setup, frequency hopping, and handovers. The BSC is the connection between the mobile station and the Mobile service Switching Center (MSC).

## Network Subsystem

The central component of the Network Subsystem is the Mobile services Switching Center (MSC). It acts like a normal switching node of the PSTN or ISDN, and additionally provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a roaming subscriber. The MSC provides the connection to the fixed networks (such as the PSTN or ISDN). Signaling between functional entities in the Network Subsystem uses Signaling System Number  $\nu$  (SS $\nu$ ), used for trunk signaling in ISDN and widely used in current public networks.

The Home Location Register (HLR) and Visitor Location Register (VLR), together with the MSC, provide the call-routing and roaming capabilities of GSM. The HLR contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the mobile. The location of the mobile is typically in the form of the signalling address of the VLR associated with the mobile station. There is logically one HLR per GSM network, although it may be implemented as a distributed database.

The Visitor Location Register (VLR) contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR. The geographical area controlled by the MSC corresponds to that controlled by the VLR. Note that the MSC contains no information about particular mobile stations --- this information is stored in the location registers.

The other two registers are used for authentication and security purposes. The Equipment Identity Register (EIR) is a database that contains a list of all valid mobile equipment on the network, where each mobile station is identified by its International Mobile Equipment Identity (IMEI). An IMEI is marked as invalid if it has been reported stolen or is not type approved. The Authentication Center (AuC) is a protected database that stores a copy of the secret key stored in each subscriber's SIM card, which is used for authentication and encryption over the radio channel.

## CHANNEL STRUCTURE

Depending on the kind of information transmitted (user data and control signaling), we refer to different logical channels which are mapped under physical channels (slots). Digital speech is sent on a logical channel named TCH, which during the transmission can be allocated to a certain physical channel. In a GSM system no RF channel and no slot is dedicated to a priori to the exclusive use of anything (any RF channel can be used for number of different uses).

Logical channels are divided into two categories :

- i) Traffic Channels (TCHs)
- ii) Control Channels .

### 1. Traffic Channels (TCHs)

A traffic channel (TCH) is used to carry speech and data traffic. Traffic channels are defined using a 4-frame multiframe, or group of 4 TDMA frames. The length of a 4-frame multiframe is 4.615 ms, which is how the length of a burst period is defined (4.615 ms divided by 4 frames divided by 4 burst periods per frame). Out of the 4 frames, 3 are used for traffic, 1 is used for the Slow Associated Control Channel (SACCH) and 1 is currently unused . TCHs for the uplink and downlink are separated in time by 4 burst periods, so that the mobile station does not have to transmit and receive simultaneously, thus simplifying the electronics

TCHs carry either encoded speech or user data in both up and down directions in a point to point communication.

There are two types of TCHs that are differentiated by their traffic rates.

They are:

- i. Full Rate TCH
- ii. Half Rate TCH

#### **Full Rate TCH**(Also represented as Bm)

It carries information at a gross rate of 12.2 Kbps.

# Half Rate TCH

It carries information with half of full rate channels.

## 2. Control Channel

Basic structure of Control channel

1	2	3	4	.	.	.	.	.	.	10	11	.	.	.	.	.	.	.	21	.	.	.	.	26
F	S	x	X	X	X	X	X	X	X	F	S	X	X	X	X	X	X	X	F	S	X	X	X	X

Fig\:

Actually in the above diagram S will be at slot 1 of next frame ,F is frequency correction channel which occurs every 10<sup>th</sup> burst. The next frame to S contains service operators information.

Logical Control Channel(LCC) s are of three types  
They are of the following types:

- • Broadcast Control Channel(BCCH)
- • Common Control Channel(CCCH)
- • Dedicated Control Channel(DCCH)

### 2.1 Broadcast Control Channel(BCCH)

The BCCH is a point-to-multipoint unidirectional control channel from the fixed subsystem to MS that is intended to broadcast a variety of information to MSs, including information necessary for the MS to register in the system. BCCH has 26 bursts. BCCH is dedicated to slot 1 and repeats after every 26 bursts.

Broadcast Control Channel(BCCH) continually broadcasts, on the downlink, information including base station identity, frequency allocations, and frequency-hopping sequences. This provides general information per BTS basis(cell specific information) including information necessary for the MS to register at the system. After initially accessing the mobile, the BS calculates the requires MS power level and sets a set of power commands on these channels. Other information sent over these channels includes country code network code, local code, PLMN code, RF channels used with in the cell where the mobile is located, surrounding cells, hopping sequence number, mobile RF channel number for allocation, cell selection parameters, and RACH description. One of the important messages on a BCCH channel is CCCH\_CONF, which indicates the organization of the CCCHs. This channel is used to down link point-to-multipoint communication and is

unidirectional; there is no corresponding uplink. The signal strength is continuously measured by all mobiles which may seek a hand over from its present cell and thus it is always transmitted on designated RF channel using time slot 0 (zero). This channel is never kept idle-either the relevant messages are sent or a dummy burst is sent.

The **BCCH** includes :

-- **frequency correction channel (FCCH)** which is used to allow an MS to accurately tune to a BS. The **FCCH** carries information for the frequency correction of MS downlink. It is required for the correct operation of radio system. This is also a point-to multipoint communication. This allows an MS to accurately tune to a BS.

-- **synchronization channel(SCH)**, which is used to provide TDMA frame oriented synchronization data to a MS. When a mobile receives both **FCCH** and **SCH** signals, the synchronization is said to be complete. **SCH** repeats for every 8 frames. **SCH** carries information for the frame synchronization (TDMA frame number of the MS and the identification of BTS ). This is also required for the correct operation of the mobile.

The Synchronization Channel contains 8 encoded parameters :

- • BTS identification code (BSIC)
- • Reduced TDMA frame number(RFN).

## 2.2 Common Control Channel(CCCH)

A **CCCH** is a point-to-multipoint (bi-directional control channel) channel that is primarily intended to carry signaling information necessary for access management functions (e.g., allocation of dedicated control channels).

The **CCCH** includes :

-- **paging channel(PCH)**, which is used to search(page) the MS in the downlink direction ,

-- **random access channel (RACH)** which is used by MS to request of an **SDCCH** either as a page response from MS or call origination/ registration from the MS. This is uplink channel and operates in point-point mode(MS to BTS). This uses slotted ALOHA protocol. This causes a possibility of contention. If the mobiles request through this channel is not answered within a specified time the MS assumes that a collision has occurred and repeats the request. Mobile must allow a random delay before re-initiating the request to avoid repeated collision.

-- **access grant channel(AGCH)** which is a downlink channel used to assign a MS to a specific **SDCCH** or a **TCH**. **AGCH** operates in point-to-point mode. A combined paging and access grant channel is designated as **PAGCH**.

## 2.3 Dedicated Control Channel (DCCH)

A **DCCH** is a point to point, directional control channel.

Two types of **DCCHs** used are :

**Standalone DCCH (SDCCH)** is used for system signaling during idle periods and call setup before allocating a TCH , for example MS registration, authentication and location updates through this channel. When a TCH is assigned to MS this channel is released. Its data rate is one-eighth of the full rate speech channel which is achieved by transmitting data over the channel once every eighth frame. The channel is used for uplink and downlink and is meant for point-to-point usage.

**Associated Control Channel(ACCH)** is a **DCCH** whose allocation is linked to the allocation of a CCH. A **FACCH** or burst stealing is a **DCCH** obtained by pre-emptive dynamic multiplexing on a TCH.

**SACCH** is data channel carrying information such as measurement reports from the mobile of received signal strength for a serving cell as well as the adjacent cells. This is necessary channel for the assisted over hand over function.

**SACCH** is also used for power regulation of MS and time alignment and is meant for uplink and

down link. It is used for point-to-point communication. **SACCH** can be linked to TCH or an **SDCCH**. A **FACCH** is also associated to TCH .**FACCH** works in a stealing mode. This means that if suddenly during a speech transmission it is necessary to exchange signaling information with the system at a rate much higher than the **SACCH** can handle, then

10 ms speech (data) bursts are stolen for signaling purposes. This is the case at the case at the hand over. The interruption of the speech will not be heard by the user since it lasts only for 10 ms and cannot sensed by human ears.

## STRUCTURE OF TDMA SLOT WITH A FRAME

There are five different kinds of bursts in the GSM system.

They are

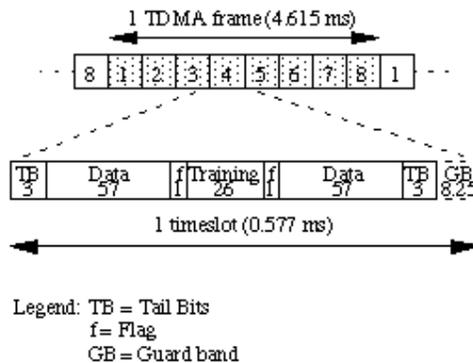
- • Normal Burst
- • Synchronization Burst
- • Frequency Correction Burst
- • Access Burst
- • Dummy Burst

## Normal Burst

This burst is used to carry information on the TCH and on control channels. The lowest bit number is transmitted first. The encrypted bits are 148 bits of data or (speech + 1 bit stealing flag) indicating whether the burst was stolen for FACCH signaling or not. The reason why the training sequence is placed in the middle is that the channel is constantly changing. By having it there, the chances are better that the channel is not too different when it affects the training sequence compared to when the information bits were affected. If the training sequence is put at the beginning of the burst, the channel model that is created might not be valid for the bits at the end of a burst there are 4 training sequences shown at the diagram. The 148 bits equalization patterns are determined at the time of the call setup.

Tail Bits (TB) always equal (1, 1, 1), which has bit location from 1 to 3 and 146 to 148. The

Guard Period are the empty spaced bits and are used to synchronize the burst with exact accuracy and makes sure that different time slots does not overlap during transmission.



**Figure 5:** GSM TDMA structure and Normal Burst. Number of bits per field below the field legend.

fig 5

## Synchronization Burst

This burst is used for the time synchronization of the mobile. It contains 148 bit synchronization sequence. The encrypted 148 bits carry information of the TDMA frame number along with the BSIC. It is broadcast together with the correction burst. The TDMA frame is broadcast over SCH, in order to protect the user information against eavesdropping, which is accomplished by ciphering the information before transmitting. The algorithm that calculates the ciphering key uses a TDMA frame number as one of the parameters and therefore, every frame must have a frame number. By knowing the TDMA frame number, the mobile will know what kind of logical channel is being transmitted on the control channel TS0. BSIC is also used by the mobile to check the identity of the BTS when making signal strength measurements (to prevent measurements on co-channel cells).

### **Frequency Correction Burst**

This burst is used for frequency synchronization of the mobile. It is equivalent to an un-modulated channel with a specific frequency offset. The repetition of these bursts are called FCCH.

### **Access Burst**

This burst is used for random access and longer GP to protect for burst transmission from a mobile that does not know the timing advance when it must access the system. This allows for a distance of  $r_0$  km from base to mobile. In case the mobile is far away from the BTS, the initial burst will arrive late since there is no timing advance on the first burst. The delay must be shorter to prevent it from overlapping a burst in the adjacent time-slot following this.

### **Dummy Burst**

It is sent from BTS on some occasions as discussed previously which carries no information and has the format same as the normal burst.

## **TIME ORGANISING OF SIGNALING CHANNELS**

### **FULL RATE CODING**

In this coding each slot will be assigned to a particular user through out the session so frame can be used by  $\wedge$  users. If one user is allotted a particular slot, through out his session he must be using this same slot for each frame. After the speech data is transmitted in  $\vepsilon$  frames (Say, if the slot  $\vee$  is chosen, after sending in  $\vee^{\text{st}}$  slot of such  $\vepsilon$  frames), in the  $\vee^{\text{th}}$  frame measurement information is transmitted. The  $\vee^{\text{th}}$  burst is blank. This  $\vee^{\text{th}}$  frame is kept idle which may be used for future use. This pattern repeats for every  $\vee$  frames.

### **HLAF RATE CODING**

In this coding each slot will be assigned to  $\vee$  particular users alternatively. If one user is allotted a particular slot, through out his session he must be using this same slot for each alternative frame. Here in the  $\vee^{\text{th}}$  slot signaling information of mobile A is sent while the signaling information for the mobile B is sent on the  $\vee^{\text{th}}$  slot.

The signaling information has to be transmitted at  $\vee \text{ Kbps}$  ( $\vee / \vepsilon$ ).

### **Timing Advance Example**

Base station instructs the mobile station about the slot synchronization. First the base station sends the signal to mobile A, it will be receive after some propagation delay in the down link. After this on the uplink channel (after  $\vee$  slot duration), the base station will be expecting signal after next  $\vee$  slots. When ever the signal is received by the base station, it will calculate the delay and send the respective advance (timing advance), time by which it has to advance.

## Measurement

Once the base station receives a signal, after  $\tau$  slots this has to transmit. To make any measurement of signal strength, we need to switch to some other frequency. Base station has  $\tau$  slots time only to transmit, after this, the base station has to transmit. To make measurement these slots are not enough, so  $\tau$ th frame (which is empty) is used to make measurements.

The signal strength depends upon distance, padding etc. The control channel will have highest signal strength. Suppose  $\nu$ th channel is our control channel, if the mobile has moved to other base station, some other channel, say  $\nu$ th channel is found to have the highest signal strength (for measurement) than the  $\nu$ th channel, this indicates that the mobile has moved to different base station.

## Propagation Delay

The delay is signaled using  $\tau$  bit number ( $\tau = \tau$  steps) which are counted from 0 to  $\tau$ . Actually  $\tau$  steps only are used. The reason is that the time at which it send will be neglected. Each step advances by 1 bit duration ( $\tau$  micro secs). The adjustment corresponds to the round trip time.  $\tau$  steps allows compensation over a maximum propagation time of  $\tau$  bit periods ( $\tau * \tau = \tau$  => Maximum distance of  $\tau$  km).

## Access granting and Mobile registration

TDMA frame structure is present in uplink direction and are not pre-assigned. Any mobile can access any slot. If more than one mobile tries to access the same slot that causes collision, the collisions are detected using random algorithm (For example slotted aloha). In this mechanism the mobile waits for a random amount of time.

One might have a doubt of how much time the mobile station has to wait to send a packet.

Keep the arrival rate,  $\lambda < 0.5$  packets/slot (as per slotted aloha). Then the system will be stable i.e the packets will be transmitted even after some random amount of time.

In order to register mobile itself sends a request packet to the base station on uplink channel. After receipt of this signal, the base station send successful receipt of request on access grant channel. This communication also contains the channel number on which the mobile station has to communicate for further signaling information, then the mobile station has to switch to that particular channel and slot to start communication. Now the signaling communication takes place in dedicated channel (say  $\nu$ th channel -  $\tau$  slot). Now the communication is point-to point and not broadcast. All others mobiles still listens on  $\nu$ th channel as broadcast channel.

Now this dedicated channel functions as a duplex channel.

## FULL RATE SPEECH CODING

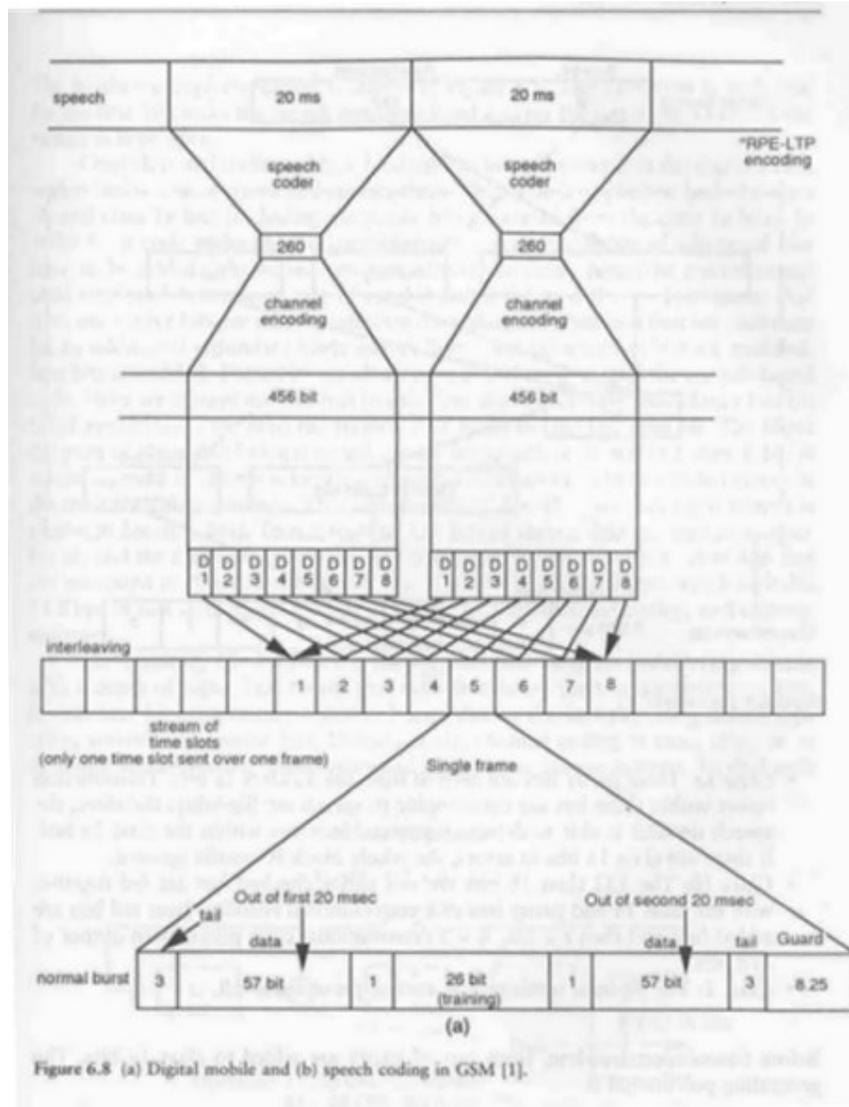


fig 3:

To understand how the basic information is compiled in to a frame, consider the speech coding mechanism shown in the figure. Basic speech is sensed by a coder for 20 ms segments and produces 260 bits at the output. Thus the output data rate of speech coder is 13 kbps (260 bits/20 ms). Every 20 ms channel releases 456 bits. The residual data consisting of 182 bits and 74 bits of side information when passed through the half-convolution encoder provides 456 bits of coded data. The speech blocks are grouped into 3 classes of sensitivity to errors depending on their importance of intelligibility of the speech.

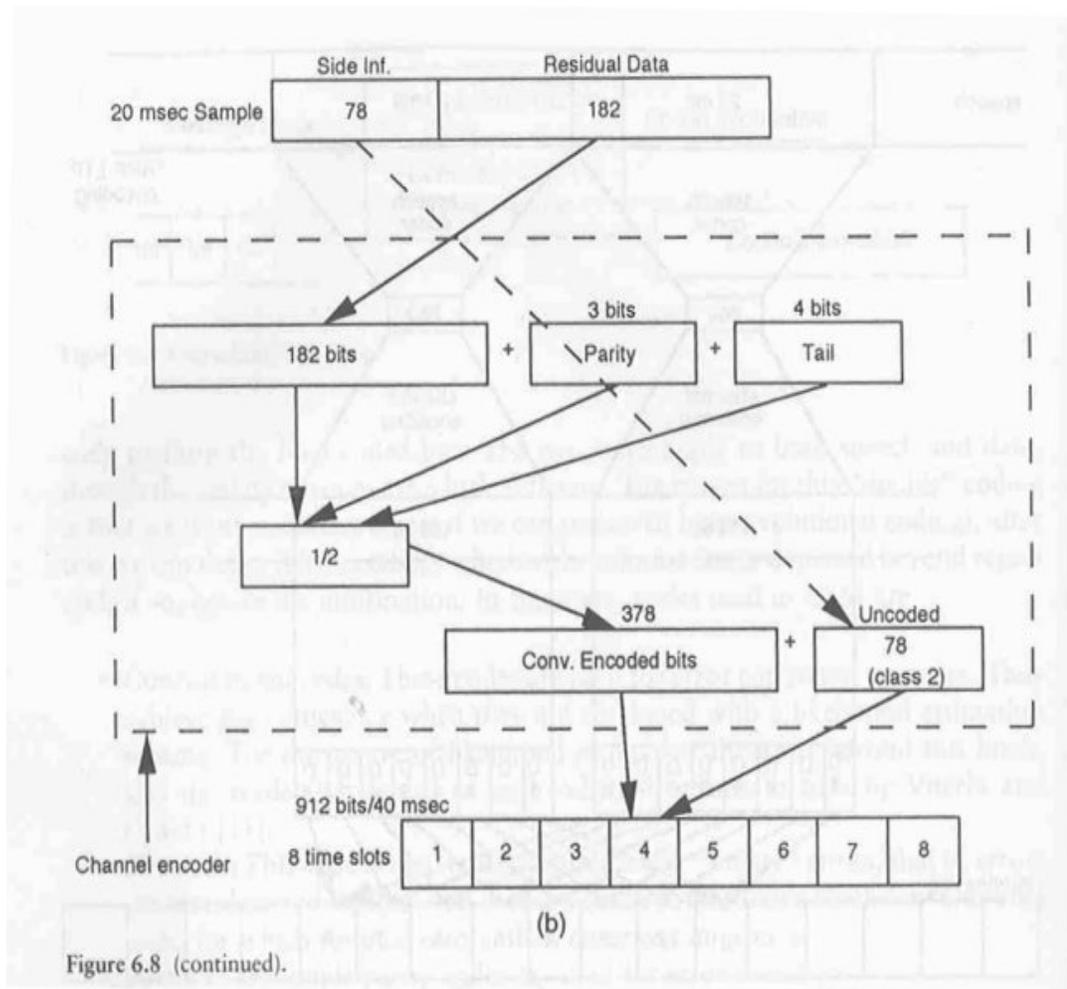


fig 4

**Class a:** 3 parity bits are derived from 182 class a bits. Transmission errors with in these bits are catastrophic to speech intelligibility, therefore the speech decoder is able to detect uncorrectable errors within the class a bits. If there are class a bits in errors the whole block is usually ignored.

**Class b:** The 182 class b bits are not parity checked but are fed together with the class a and parity bits to convolution encoder. 4 trail bits are added first and then  $r=1/2$ ,  $K=2$  convolution code provides an output of 378 bits.

**Class c:** The 78 least sensitive bits are not protected at all.

The probability of errors generated in air-channel is more than 0.1. So, interleaving is used to convert burst errors into random errors, at the receiver it de-interleaves them. There is a trade-off between number of burst errors and the throughput.

## AIR INTERFACE

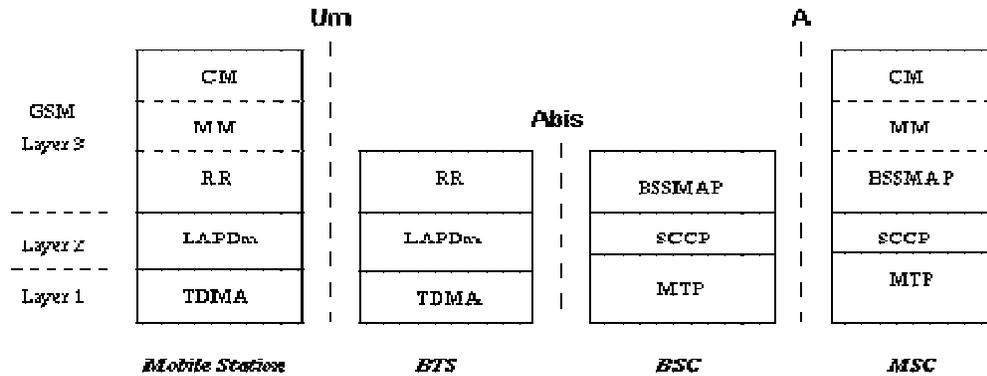


fig 1  
Signaling protocol structure in GSM

The standard interfaces in GSM are :

**Air or Um interface** which is between the mobile and the BTS

**A-bis interface** which is between the BTS and BSC

**A interface** which is between the BSC and the network subsystem MSC.

The physical layer of the Air Interface uses the TDMA frame structure defined by the GSM, while the data link layer is based on the LAPDm protocol derived from LAPD. Above the LAPDm level is the application which is divided into three sub layers.

The 3 sub layers are:

RR sub-layer, for the protocol between the MS and the BS subsystem, controls the radio connection.

MM sub layer between the MS and network subsystem manages subscriber mobility in the network, in particular due to location procedure that let the mobile locate itself each time it changes from one area of coverage to another

The sub layer CC, SMS and SS handle procedures needed to set up services such as an incoming or outgoing calls, SMS or SS.

Here in this chapter we limit our selves to the physical layer in the Air interface which involves TDMA.

### **TDMA ---- (Physical layer)**

Several mobile stations may try to access the base station at the same time which in turn may cause collisions. To avoid the collisions mobile stations use TDMA.

Mobile stations sends data to Base-station (multiple access) on the up-link. The Base station broadcasts the data. The uplink frequency (900 MHz) is used into 120 frequency channels with each channel being allocated 300 KHz. One channel will be allocated to one user. So we can allocate this total uplink frequency to 120 users. This phenomenon is termed as Frequency Division Multiplexing (FDM). Each channel is further divided to time division slots which is termed as Time Division Multiplexing (TDM).

Each channel is divided into frames and each frame will have  $N$  slots. For example, if a mobile station is allocated to channel  $N$ , then it continues to use the slot- $N$  on all frames. Here each channel can be used by  $N$  users. So the maximum number of users using a Base station is limited to  $N \times (N \times N)$ . But practically speaking only  $N$  channels are used leaving the remaining channel for the broad cast channel (BCCH). There is a total of  $N$  bursts during a frame cycle, which is defined as the information format during  $N$  time slot on the TDMA channel; that is, with regular time intervals (every eight time slot on TDMA Channel, the user transmits or receives his information), we send a burst of information (either speech or data). Thus, a burst is considered as period of RF Channel that is modulated by a data stream. A burst therefore represents the physical content of time slot. The typical value of the burst field is  $10/26$  ms. In the uplink channel, each frame actually is displaced by  $N$  slots compared to the down link frame. Thus a mobile station can use same slot or both sending and receiving. At a time only sending or only receiving a packet will be allowed.

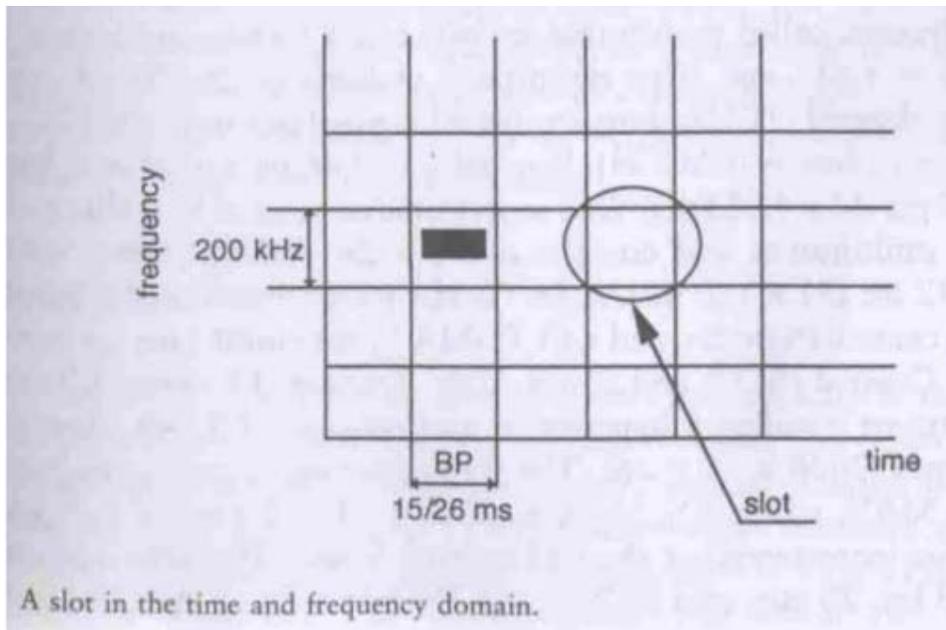


Fig 2:

The modulation spectrum (Frequency bands of channel slots) is some what wider than  $200$  KHz, resulting in a some level of interference on adjacent frequency slots. The normal practice is not use the frequency slots at he border except when a special agreement has been reached with the users of adjacent band. As a consequence the number of frequency slots that can be used in  $20$  MHz can be limited to  $122$ . The start of an uplink TDMA frame is delayed with respect t a downlink by a fixed period of  $N$  slots. Staggering TDMA frames allows the same time slot number(TN) to be used in both down and uplinks while avoiding the requirement for mobile to transmit and receive simultaneously. The TN with a frame is numbered from  $0$  to  $N$ , and each TN can be referenced by a unique TN.

Higher order frames, called multi frames, consists of 26 frames and have a duration of 120 ms ( $26 * 4.61$  ms). This multi frame consists of 26 TDMA frames and carries a traffic channel (TCH), slow associated control channel (SACCH), and a fast associated control channel (FACCH). One super frame consists of 81 traffic multi frames or 26 control multi frames and consists of  $81 * 26$  TDMA frames with a total duration of  $81 * 120$  ms. A 26 TDMA frame multi-frame supports traffic and associated control channels, and a special TDMA frame multi-frame supports Broadcast common control (BCC) and stand alone dedicated control channels. The highest order frame is Hyper frame and consists of 2048 super frames (2,710, 468 frames). The frame number is cyclic and has a range from 0 to 2,710,467. Time duration of hyper frame is 2,710,468 \* 4.610 ms. This long period is required to support encryption with high security.

### How a call is made ?

Suppose if a call has come for mobile B, then the base station indicates this signal using paging channel. This paging information may also contain dedicated channel on which further signaling information has to take place. The paging information may contain caller-id. This information will be used the callee to decide whether to proceed for communication or not.

Note: a control channel on some channel(say slot-3) means slot 3 of all frames together. This can be multiplexed with speech channel.

### Call routing

Unlike routing in the fixed network, where a terminal is semi-permanently wired to a central office, a GSM user can roam nationally and even internationally. The directory number dialed to reach a mobile subscriber is called the Mobile Subscriber ISDN (MSISDN), which is defined by the E.164 numbering plan. This number includes a country code and a National Destination Code which identifies the subscriber's operator. The first few digits of the remaining subscriber number may identify the subscriber's HLR within the home PLMN.

An incoming mobile terminating call is directed to the Gateway MSC (GMSC) function. The GMSC is basically a switch which is able to interrogate the subscriber's HLR to obtain routing information, and thus contains a table linking MSISDNs to their corresponding HLR. A simplification is to have a GMSC handle one specific PLMN. It should be noted that the GMSC function is distinct from the MSC function, but is usually implemented in an MSC.

The routing information that is returned to the GMSC is the Mobile Station Roaming Number (MSRN), which is also defined by the E.164 numbering plan. MSRNs are related to the geographical numbering plan, and not assigned to subscribers, nor are they visible to subscribers.

The most general routing procedure begins with the GMSC querying the called subscriber's HLR for an MSRN. The HLR typically stores only the SS<sup>V</sup> address of the subscriber's current VLR, and does not have the MSRN (see the location updating section). The HLR must therefore query the subscriber's current VLR, which will temporarily allocate an MSRN from its pool for the call. This MSRN is returned to the HLR and back to the GMSC, which can then route the call to the new MSC. At the new MSC, the IMSI corresponding to the MSRN is looked up, and the mobile is paged in its current location area (see Figure 4).

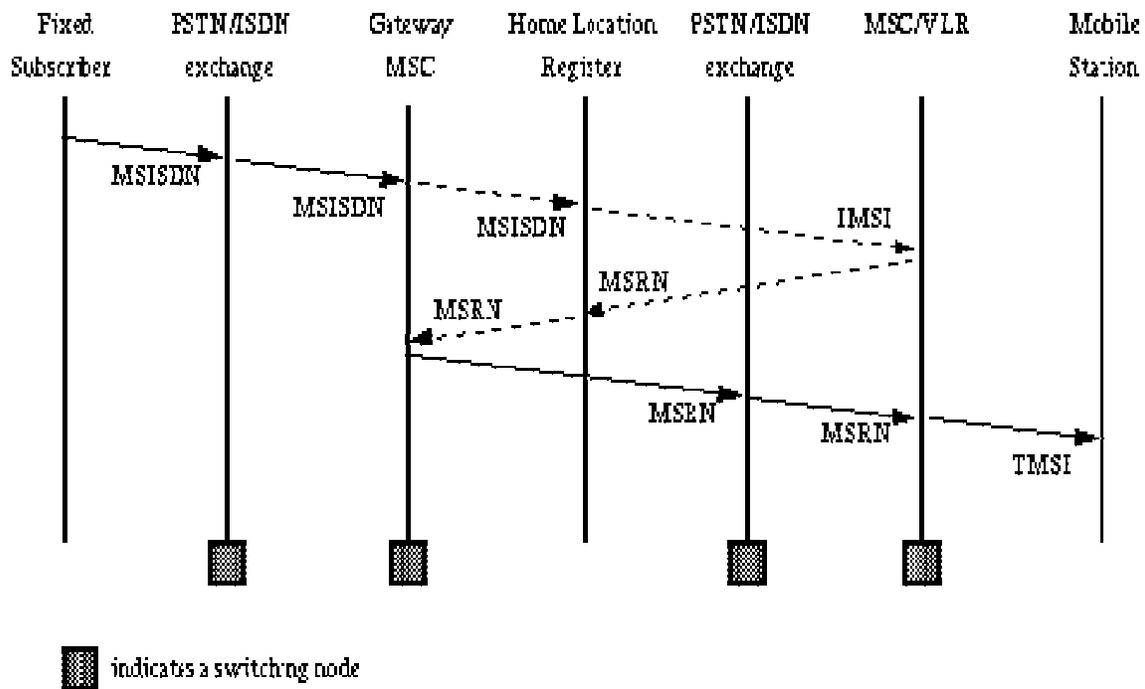


fig 4