GSM: Pan-European Digital Cellular System

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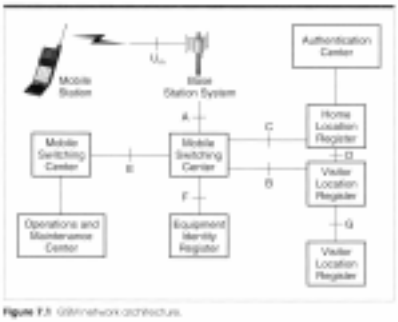
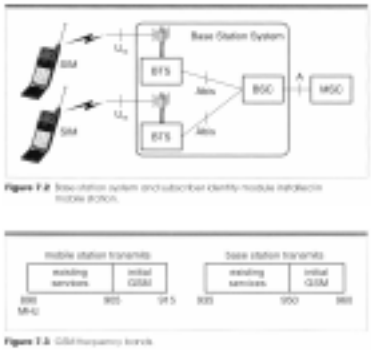
Architecture

- The GSM terminology for three essential network elements is mobile station (terminals), base station, and mobile switching center (switches).
- In addition, GSM specifies three databases: home location registers (HLR), visitor location registers (VLR), and equipment identity register (EIR).
- A base station system contain two elements: a base transceiver station (BTS) and a base station controller (BSC), connected by a standard interface, Abis.
- A BTS consists primarily of radio equipment.
- A BSC performs network control operations and signal processing functions.





Identifier

- Every terminal contain a subscriber identity module (SIM).
- The SIM is a removable card that store essential subscriber information, including identification numbers, detail of the subscriber's service plan, and abbreviated dialing codes selected by the subscriber.

Identifiers (cont.)

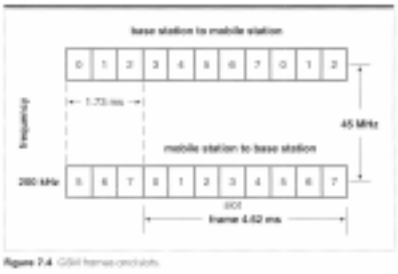
Notation	Name	Size	Description
IMSI	International mobile subscriber identity	15 digits	Directory number assigned by operating company to a subscriber
TMSI	Temporary mobile subscriber identity	32 bits	Assigned by VLR to a subscriber
IMEI	International mobile equipment identifier	15 digits	Unique serial number assigned by manufacturer to a terminal
Ki	Authentication key		Secret key assigned by operating company to a subscriber
Kc	Cipher key	64 bits	Computed by network and by MS
-	Mobile station classmark	32 bits	Indicates properties of a MS
BSIC	Base station identity code	6 bits	Assigned by operating company to a BTS
-	Training sequence	26 bits	Assigned by operating company to BTS
LAI	Location area identity	40 bits	Assigned by operating company to BTS

Radio Transmission

- Tjere are two 25 MHz bands separated by 45 MHz, with the lower band used for transmissions from terminals to BSs and the upper band for transmissions from BSs to terminals.
- The systems operating in the European 1800 MHz bands are disignated DCS1800 and the North American 1900 MHz bands DCS1900.

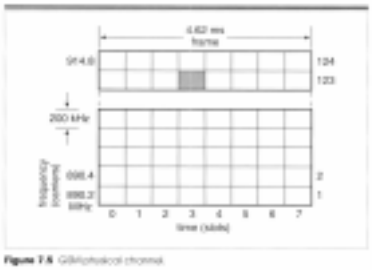
Physical Channels

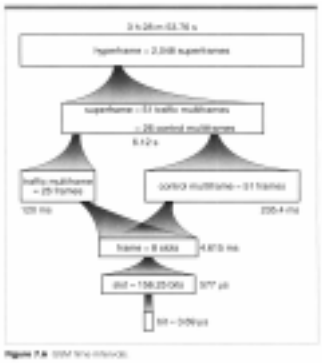
- Each GSM band has carriers spaced at 200 kHz.
- The frame duration in GSM is 4.62 (120/26) ms, derived from the definition of a 120 ms traffic multiframe, devided into 26 frames.
- Each frame contains 8 time slots.
- The time reference for a reverse-direction frame is retarded by 3 time slots relative to the time reference for a forward-direction frame.



Physical Channels (cont.)

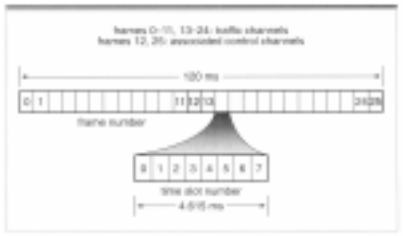
- With the 200 kHz carrier spacing, the frequency allocation of 25 MHz perdirection admits the possibility of 25MHz/200KHz=125 carriers per direction.
- GSM specifies only 124 carriers, leaving unoccupied guard bands at the edges of the GSM spectrum allocation.





Physical Channels (cont.)

- The logical channel that carries telephone speech in GSM is a full-rate traffic channel (TCH/F), which occupies one time slot in 24 of the 26 frames in every multiframe.
- A SACCH (slow associated control channel) with a full-rate traffic channel alternatively occupies one slot in frame 12 and one slot in frame 25.
- Each GSM carrier can convey 8 full-rate traffic channels together with their associated control channels.

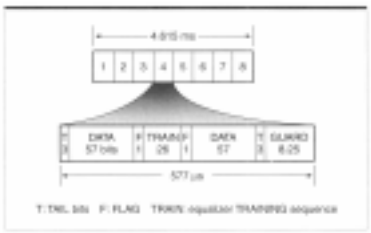


Physical Channels (cont.)

- In GSM, a half-rate traffic channel (TCH/H) occupies a specific time slot in 12 of the 26 frames in every multiframe. Another TCH/H occupies the other 12 frames available for user information.
- Each carrier can carry up to 16 half-rate traffic channels, which together fill all time slots in 24 frames per multiframe.

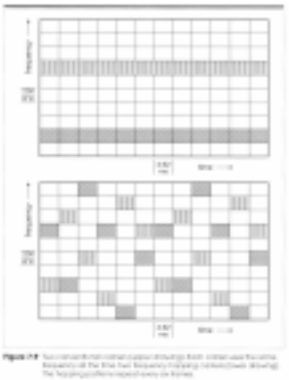
GSM Bit Stream

- GSM documentation refers to the signal transmitted in one time slot as a burst.
- 26-bit TRAINING sequence:
  - Performs the function of the AMPS SAT and NA-TDMA DVCC.
  - It enables terminals and BSs to confirm that the received signal comes from the correct transmitter and not a strong interfering transmitter.
- 2 57-bit DATA fields:
  - Each of these fields is accompanied by a 1-bit FLAG and 3 TAIL bits.
  - The FLAG indicates whether the DATA field contains user information or network control information.
  - The TAIL bits, all set to 0, can be used to enhance equalizer performance.
- 30.5 μs GUARD time:
  - Ramp time for the transmitter to turn off at the end of one time slot and turn on at the beginning of the next slot.
  - It also prevents signals assigned to adjacent time slots from arriving simultaneously at a BS receiver.



Slow Frequency Hopping

- GSM has 2 definitions of radio carrier:
  - The conventional definition of a sine wave at a single frequency.
  - A frequency hopping pattern consists of a repetitive sequence of frequencies occupied by a signal.
- The purpose of frequency hopping is to reduce the vulnerability of GSM signals to transmission impairments.
- Frequency hopping can also reduce harmful effects of co-channel interference between signals in nearby cells.



Radiated Power

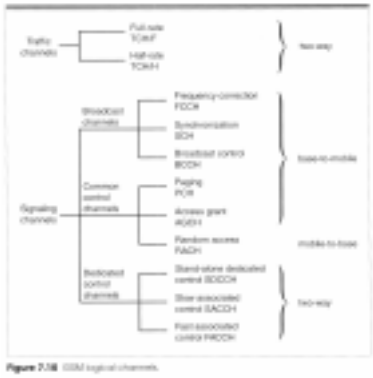
- GSM specifies 5 classes of MSs distinguished by maximum transmitter power, ranging from 20 W (43 dBm) to 0.8 W (29 dBm).
- When a terminal transmits in a full-rate channel, the transmitter is active during only one time slot per frame (one-eighth of the time).
- The maximum power capability of vehicle-mounted terminals is 8 W.
- Portable terminals typically have 2 W maximum transmitter power (250 mW average).

Spectrum Efficiency

- The system can meet signal-quality objectives with a signal-to-interference ratio as low as 7dB.
- This allows networks to operate with a reuse factor of N=3 or N=4.
- The efficiency of GSM is E=124*8/(4*50)=4.96 conversations/cell/MHz for N=4 and E=992*8/(3*50)=6.61 conversations/cell/MHz for N=3.
- Even though NA-TDMA has many more physical channels (up to 2500 channels in 50 MHz) than GSM, its efficiency is not substantially higher because of its efficiency is not substantially higher because of its greater vulnerability to interference.

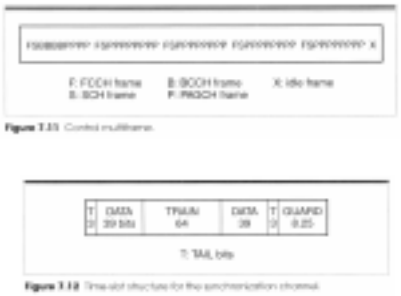
Logical Channels

- The traffic channels are both two-way channels with identical transmission formats in the two directions.
- There are 3 categories of control channel.
  - A BS uses broadcast channels to transmit the same information to all terminals in a cell.
  - The common control channels carry information to and from specific terminals.
  - The dedicated control channels use physical channels that are assigned to specific terminals.



Broadcast Channels

- GSM multiplexes the broadcast and common control channels on the same carrier.
  - The broadcast channels always occupy time slot 0 in repetitive frame patterns on the carrier.
  - The common control channels also occupy time slot 0, and if they need more capacity than time slot 0 can provide, they can occupy time slots 2, 4, or 6 of the same carrier.
- For forward direction, in each multiframe (51 frames) there are 5 groups of frames, each containing 10 frames beginning with a FCCH frame and a SCH frame.
- In the reverse direction, time slot 0 of the corresponding carrier is assigned to a random access channel in all 51 frames of the multiframe.
- The other 7 time slots on the carrier carry traffic channels or stand-alone dedicated control channels.

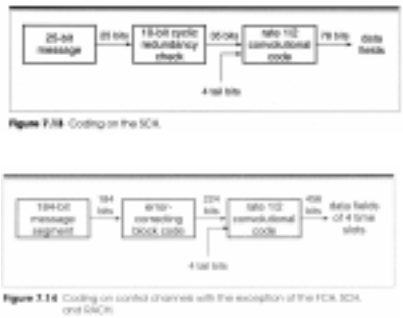


Frequency Correction Channel (FCCH)

- After detecting this FCCH, each terminal adjusts its frequency reference to match that of the BS.
- After a terminal detects the FCCH (in time slot 0), it can keep track of the number of each successive time slots.
- After finding an FCCH, a terminal obtains timing information from a synchronization channel that arrives 8 slots after the arrival of the FCCH.

Synchronization Channel (SCH)

- A BS transmits SCH information in time slot 0 of every frame that follows a frame containing an FCCH.
- To help terminals synchronize their operation to a new BS, the SCH contains a long TRAINING sequence (64 bits) that is the same in all cells.
- The DATA fields in the SCH contain the BS identity code (BSIC) and the present frame number.
  - The frame number is the position of the current frame within the 3.5-hour GSM hyperframe.
- Each SCH transmission consists of one message containing 25 bits.
- It is protected with an error-detecting code that adds 10 parity bits and by a rate ½ convolutional code.



Broadcast Control Channel (BCCH)

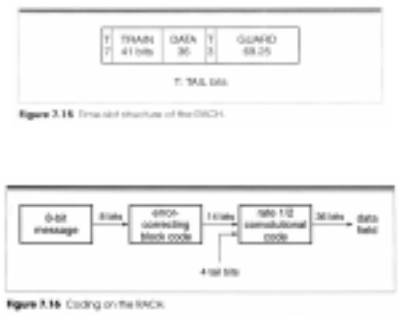
- BSs use the BCCH to transmit the information that terminals need to set up a call.
- The BCCH transmits one message segment, of length 184 bits, in every control multiframe.
- The BCCH sends one message segment every 235 ms, the duration of a 51-frame control multiframe.

Paging Channel (PCH) and Access Grant Channel (AGCH)

- The purpose of the PCH is to notify terminals of arriving calls.
- The purpose of the AGCH is to direct a terminal to a stand-alone dedicated control channel (SDCCH).
- With each message occupying 4 frames, one time slot has a capacity to send nine messages in every 235-ms multiframe.
- To coordinate sleep-mode operation, a BS assigns each block of 4 frames to either PCH operation or AGCH operation.

Random Access Channel (RACH)

- GSM terminals send messages on the random access channel to originate phone calls, initiate transmissions of short messages, respond to paging messages, and register their locations.
- In GSM, the contention is simpler than in other systems and the information transmitted on the RACH is far more restricted.
- A RACH occupies all of the reverse direction time slots of a common control channel.
- A terminal, after transmitting a RACH message, wait for a fixed time interval for an acknowledgment.



Random Access Channel (RACH) (cont.)

- The 36-bit field labeled DATA carries a simple 8-bit message protected with an error-detecting code and an error-correcting code.
  - 3 of 8 message bits indicate the purpose of the access attempt.
  - The other 5 bits are part of RACH access protocol.
  - These 5 bits are produced by a random number generator for the purpose of distinguishing messages from two terminals that transmit in the same time slot.
- Compared with other systems, GSM transmits very little information on the RACH.

Stand-Alone Dedicated Control Channel (SDCCH)

- The physical channel used by an SDCCH is a set of four time slots in each 51-frame control multiframe.
- The data rate of the SDCCH is 4*114*26/6.12=1937.25 b/s. This is less than 10% of the data rate of a full-rate traffic channel.
- The SDCCH is an efficient alternative to using a RACH or a traffic channel to perform network control.
- To transfer all the information necessary to set up a call, GSM assigns a terminal to a SDCCH. After performing the necessary transfer of network control information, the system commands the terminal to move to a traffic channel.

Traffic Channel (TCH)

- A full-rate channel (TCH/F) occupies 24 time slots in every 26-frame traffic multiframe. The bit rate is 24*114/0.120=22800 b/s.
- A half-rate channel (TCH/H) occupies 12 time slots in every multiframe. The bit rate is 11400 b/s.
- The original speech coding technique of GSM is referred to as linear prediction coding with regular pulse excitation (LPC-RPE).
- The LPC-RPE coder uses 36+188+36=260 bits to represent each block of 20 ms of speech. The speech coding rate is 13000 b/s.

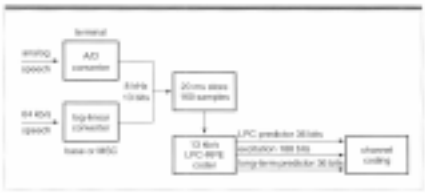


Figure 7.18 Linear prediction coding with regular pulse-excitation.

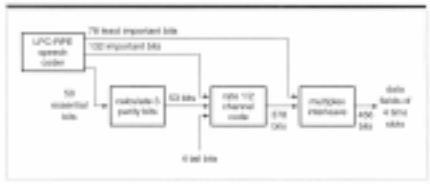


Figure 7.19 Channel coding for speech signals.

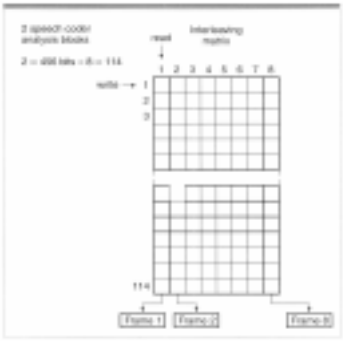


Figure 7.20 GSM interleaving

Slow Associated Control Channel (SACCH)

- When GSM assigns a TCH or an SDCCH to a terminal, it also allocates resources for an SACCH.
- The multiplexing of SACCH information in the transmitted bit stream is different in GSM and NA-TDMA.
  - NA-TDMA places SACCH information in each traffic time slot.
  - GSM establishes separate time slots that contain only SACCH information.
- With 114 information bits per time slot, the transmission rate is 114*1/0.12=950 b/s.
- With 456 bits transmitted per message, a message spans 4 traffic multiframes, a time interval of 480 ms.

Fast Associated Control Channel (FACCH)

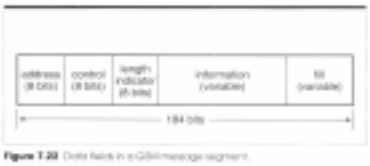
- GSM transmits the messages on an FACCH, which is an in-band signaling channel created by interrupting user information on a TCH or an SDCCH.
- Each FACCH message is multiplexed with user information and interleaved over 8 frames.
- For a traffic channel, the transmission of an FACCH message spans 8 frames, approximately 40 ms.

Messages

- IS-41 deals mainly with communications between MSC and databases.
- A substantial fraction of the GSM specification covers the A interface between a BSC and MSC and the Abis interface between a BSC and a BTS.
  - The A interface uses SS7 protocols
  - The Abis interface uses LAPD, the ISDN data link layer protocol.
- On the air interface, the corresponding protocol is $LAPD_m$.

Message Structure

- The physical layer carries these messages in segments of 184 bits. Most messages fit into a single segment that spans 4 physical layer time slots.
- There are 5 information fields in $LAPD_m$ messages.
- Although every message contains a length indicator field, the presence of the other fields depends on the message type and the channel carrying the message.
- Following LAPD, $LAPD_m$ classifies each message as either a command (C) or a response (R). One C/R bit in the address field indicates the nature of the message.
- The remainder of the address consists of a 3-bit protocol discriminator, a 1-bit extended address indicator, and a 3-bit service access point identifier (SAPI).



Message Structure (cont.)

- Following the ISDN convention, GSM specifies 3 message types:
  - Information (I)
  - Supervisory (S)
  - Unnumbered (U)
- Message flow is also controlled by 2 message sequence numbers in the control field of each information message.
  - N(S) is the 3-bit sequence number of the current message.
  - N(R) is the sequence number of a message received by the network element that is sending the current message.

Data Link Control Messages

Message Name	Function	Type	Purpose
SET ASYNCHRONOUS BALANCED MODE (SABM)	Command	Unnumbered	Initiate transfer of information messages
DISCONNECT	Command	Unnumbered	Terminate transfer of information messages
UNNUMBERED ACKNOWLEDGMENT (UA)	Response	Unnumbered	Confirm a command
RECEIVE READY	Command or response	Supervisory	Request transmission of information message
RECEIVE NOT READY	Command or response	Supervisory	Request retransmission of information message
REJECT	Command or response	Supervisory	Suspend transmission of information message

Message Content

- The unnumbered messages initiate and terminate exchanges of information messages.
- The SET ASYNCHRONOUS BALANCED MODE (SABM) command begins a flow of I message.
  - The SABM message is confirmed by an UNNUMBERED ACKNOWLEDGMENT (UA) response message.
  - A network element terminates the flow of messages by means of a DISCONNECT command that also stimulates a UA response.
- The three S messages are RECEIVE READY, REJECT, and RECEIVE NOT READY.

Information Field of I message

- The first 16 bits of the information field of each I message contain a protocol discriminator, a transaction identifier, and a message type indicator.
  - The protocol discriminator indicates the category of the network operation controlled by the message: either radio resources management, mobility management, or call management.
  - The messages pertaining to different operations are distinguished by their transaction identifies.
  - The message type indicator specifies the purpose of each message.

Example of Information Field

- ASSIGNMENT COMMAND message appears in handover procedure.
  - The protocol discriminator 0110 identifies a radio resources management message.
  - The message type 00101110 indicate that this is an ASSIGNMENT COMMAND message.
  - The following 24 bits (Channel description) identify the new physical channel that the call will use at the end of the handover procedure.
  - The power command data indicates the initial MS transmitter power on the new channel.
  - An example of optional data is frequency hopping information.

Information Field of an ASSIGNMENT COMMAND Message

Bit Positions	Information Elements
1-4	Protocol discriminator 0110
5-8	Transaction identifier
9-16	Message type 00101110
17-40	Channel description
41-48	Power command
Variable	Optional data

Radio Resources Management Messages

- GSM formally classifies the information messages call management, mobility management, radio resources management.
- On powering up or entering a new cell, a terminal first receives a SYNC CHANNEL INFORMATION message on the SCH.
- After acquiring synchronism, the terminal tunes to the broadcast control channel, which transmits a variety of SYSTEM INFORMATION messages to all of the terminals in a cell.
  - GSM uses this message to transmit local system information to active terminals that move away from the cell in which the call originated.

Radio Resources Management Messages (cont.)

- To move to a dedicated control channel, a terminal first sends a CHANNEL REQUEST message (8 bits) on the RACH.
  - 3 bits indicate the purpose of the request.
  - The other 5 bits are a randomly generated code that helps the BS resolve conflicts when 2 or more MSs transmit CHANNEL REQUEST messages in the same random access channel time slot.

Radio Resources Management Messages (cont.)

- To set up a call to a terminal, the network sends a PAGING REQUEST message on a PCH.
  - After receiving a PAGING REQUEST message, a terminal transmits a CHANNEL REQUEST message.
  - On receiving this message, the BS directs the terminal to an SDCCH by means of a message transmitted on an AGCH.
  - The messages: IMMEDIATE ASSIGNMENT, IMMEDIATE ASSIGNMENT EXTENDED, and IMMEDIATE ASSIGNMENT REJECT messages.
    - An IMMEDIATE ASSIGNMENT message directs one terminal to an SDCCH.
    - An IMMEDIATE ASSIGNMENT EXTENDED message conserves transmission resources on the AGCH by assigning 2 terminals to 2 different physical channels.
    - An IMMEDIATE ASSIGNMENT REJECT message contains negative responses to CHANNEL REQUEST messages from up to 5 terminals.

Radio Resources Management Messages (cont.)

- After moving to an SDCCH, a terminal that received a PAGING REQUEST message transmits a PAGING RESPONSE message to the system.
  - The PAGING RESPONSE message identifies the terminal and stimulates the system to initiate an authentication procedure.

Radio Resources Management Messages (cont.)

- After call management messages on an SDCCH, the network moves the terminal to a TCH by means of an ASSIGNMENT COMMAND message.
  - An ADDITIONAL ASSIGNMENT message allocates an additional traffic channel to a terminal that is already operating on a traffic channel.
  - The MEASUREMENT REPORT message plays a key role in mobile-assisted handover.
  - When there is no need to adjust the timing advance of the terminal, the network transmits an ASSIGNMENT COMMAND message to identify the new physical channel.
  - When it is necessary to adjust the timing of the terminal, the network transmits a HANDOVER COMMAND message.

Radio Resources Management Messages (cont.)

- The CIPHERING MODE message indicates whether or not user information is to be encrypted on the traffic channel.
- 2 messages can command a channel to stop using a traffic channel.
  - The system can send a PARTIAL RELEASE message to a terminal using 2 or more traffic channels.
  - When there is only one active traffic channel, the system sends a CHANNEL RELEASE message to command the terminal to stop using this channel.
- The BS sends a FREQUENCY REDEFINITION message to inform a terminal with a call in progress of a change in the frequency hopping pattern.

Mobility Management Messages

- The mobility management messages travel on an SDCCH.
- The authentication procedure begins with an AUTHENTICATION REQUEST message transmitted from a BS to an MS.
- The IDENTITY REQUEST message and the corresponding IDENTITY RESPONSE authentication procedure, any of three identifiers: IMSI, IMEI, TMSI.
- The network assigns a new TMSI to a terminal by means of a TMSI REALLOCATION COMMAND message.
- 3 LOCATION UPDAING messages:
  - A terminal registers its location by means of a LOCATION UPDATING REQUEST message.
  - The network reports the action it takes in response to this message in either a LOCATION UPDATING ACCEPT or a LOCATION UPDATING REJECT message

Call Management Messages

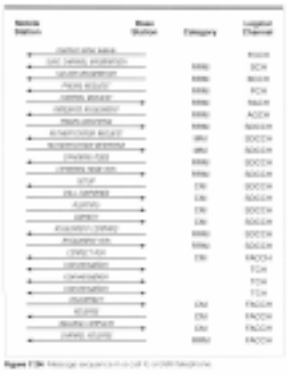
- Call management procedures in GSM conform closely to ISDN procedures.
- At the beginning of a call, messages travel on an SDCCH.
- Call origination
  - A terminal initiates a call by transmitting a SETUP message or an EMERGENCY SETUP message to the BS.
  - The network responds with a CALL PROCEEDING message.
  - The network transmits an ALERTING message to the terminal to indicate that the called party is being alerted.
- Call termination
  - An BS transmits a SETUP message to the terminal.
  - The terminal responds with a CALL CONFIRMED message.
  - An ALERTING message transmitted by the terminal indicates that the terminal is attempting to inform the user that a call has arrived.
  - When the user accepts the call, the terminal transmits a CONNECT message.

Call-clearing Messages

- The mobile subscriber concludes the call
  - The terminal transmits a DISCONNECT message to the base station.
  - The network sends a RELEASE message to the terminal.
  - The terminal responds with a RELEASE COMPLETE message
- The remote subscriber concluding the call
  - The terminal receives a DISCONNECT message.
  - The terminal responds with a RELEASE message.
  - The terminal receives a RELEASE COMPLETE message, indicating that the call is over

Call to a GSM Terminal

- When the terminal arrives in a cell and tunes to a carries that contains a broadcast control channel.
- It uses the FCCH to synchronize its local oscillator.
- It then gains timing information from the synchronization.
- The terminal then obtains other important system information on the broadcast control channel.
- After this initialization procedure is complete, the terminal monitors a PCH.
- The terminal detects a PAGING REQUEST message that contains TMSI.
- The terminal transmit a CHANNEL REQUEST message on the RACH.
- The network transmits an IMMEDIATE ASSIGNMENT message on an AGCH.
- An SDCCH is established
- The terminal moves to the SDCCH and transmits a PAGING RESPONSE message to the BS.



Setup a Call

- The system transmits a SETUP message to the terminal.
- The terminal acknowledges with a CALL CONFIRMED message and then proceeds to alert the subscriber.
- The terminal sends a CONNECT message to the network.
- The network moves the call to a TCH by means of an ASSIGNMENT COMMAND message.
- When the mobile subscriber concludes the conversation, the terminal sends a DISCONNECT message to the network.
- The network responds with a RELEASE command.
- After the terminal acknowledges this command, the network releases the TCH by sending a CHANNEL RELEASE message to the terminal.
- The terminal then returns to monitoring the PCH.

Location-Based Registration

- When a terminal enter a cell and detects a LAI in SYSTEM INFORMATION TYPE 3 message on the BCH.
- To register its location, the terminal requests access to an SDCCH by means of a CHANNEL REQUEST message on the RACH.
- The network sends an IMMEDIATE ASSIGNMENT message to move the terminal to an SDCCH.
- The terminal transmit a LOCATION UPDATING REQUEST message by the SDCCH.
- Two ways to identify the subscriber:
  - Transmit the subscriber's IMSI.
  - Transmit the subscriber's TMSI.
- The network then verifies the identity of the terminal
- After authentication, the network establishes message ciphering and then assigns a new TMSI to the terminal in a LOCATION UPDATING ACCEPT message.
- The terminal acknowledges receipt of the new identity with a TMSI ALLOCATION COMPLETE message.
- The BS transmits a CHANNEL RELEASE message to the terminal.
- The terminal then returns to monitoring the PCH.

Mobile-Assisted Handover

- When the network determines that the call should be moved to another channel, it transmits a HANDOVER COMMAND message to the terminal.
- The MS tunes to the new traffic channel and transmits a sequence of HANDOVER ACCESS messages. These messages have the same form as the CHANNEL REQUEST message transmitted on the RACH.
- To obtain the synchronism, it transmits a PHYSICAL INFORMATION message.
- After performing this adjustment, the terminal sends a HANDOVER COMPLETE message in a normal format.