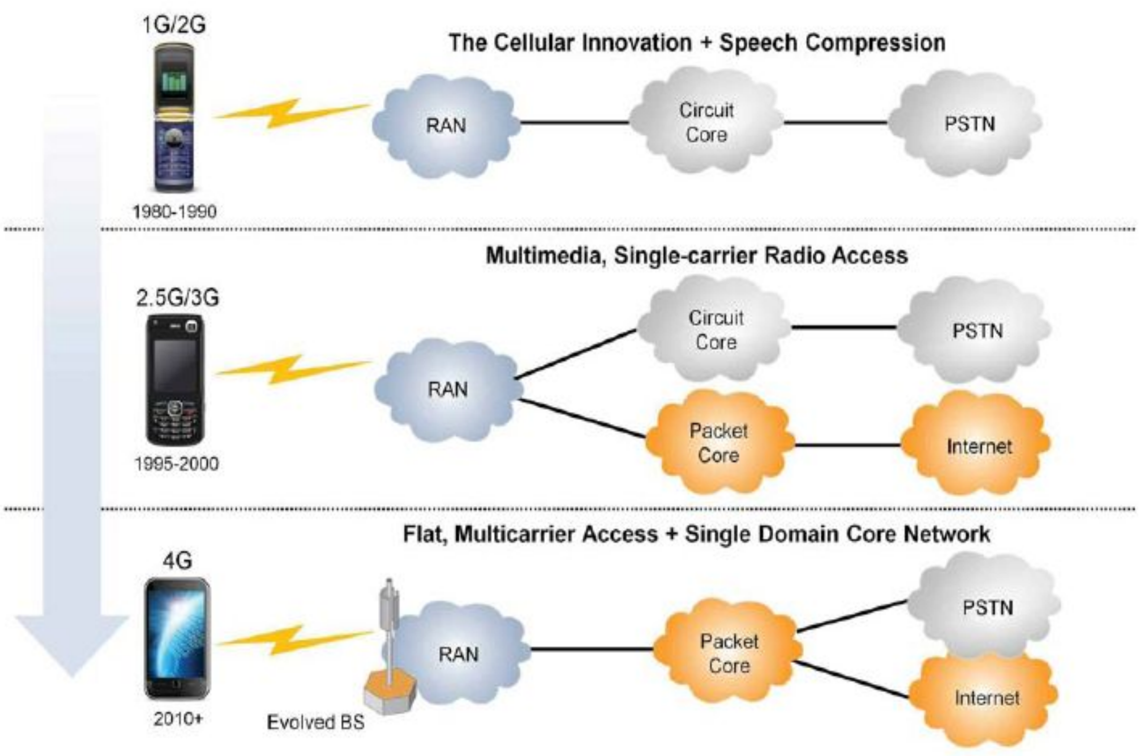
Lecture-9

Generations of Cellular System

1G, 2G, 3G, 4G --The Evolution of Wireless Generations

Evolution in Network Structure

- **1G/2G:** Circuit switching only
- **2.5G/3G:** Both circuit switching and packet switching
- **4G:** Circuit switching eliminated; packet switch only (All-IP)



Source: LTE Network Evolution and Technology Overview, White Paper by Tektronix Communications, USA

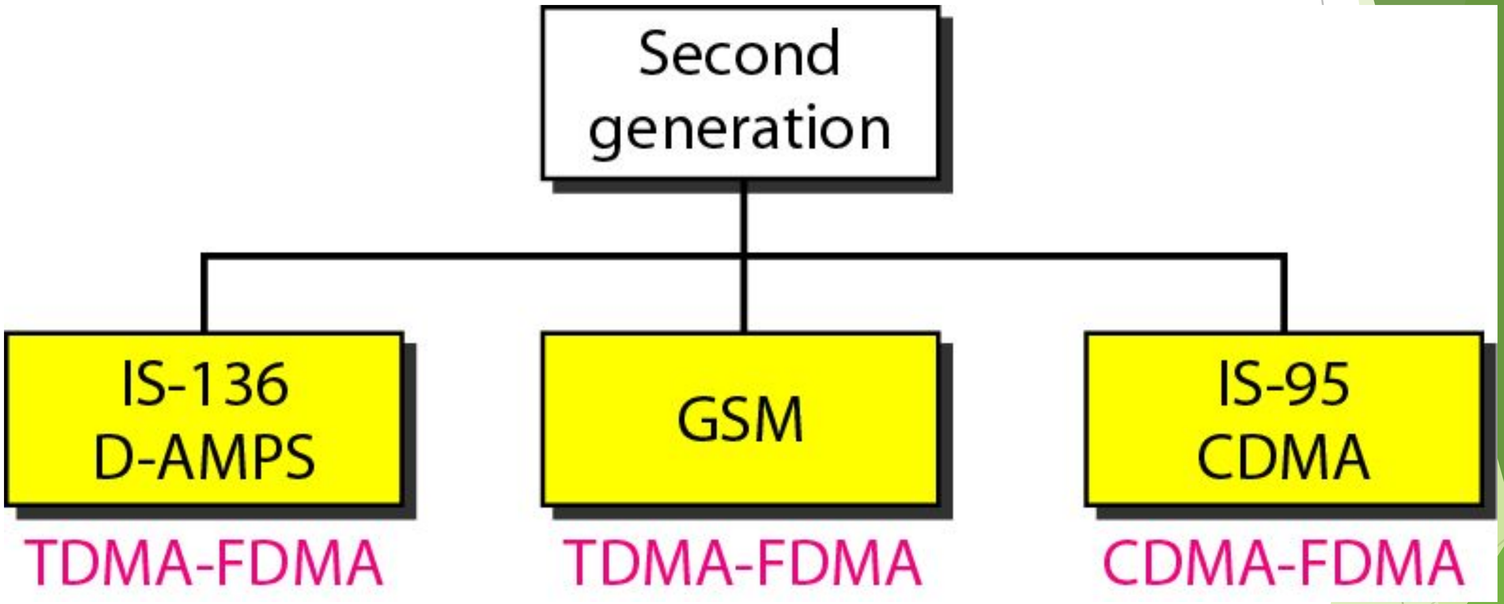
2nd Generation—Digital System

- Introduced in the late 1980s, are based on digital transmission.
- Motivation for 2G is Digital Cellular:
  - Increase System Capacity
  - Add additional services/features (SMS, caller ID, etc..)
  - Reduce Cost
  - Improve Security—Error detection, encryption
  - Interoperability among components/systems (GSM only)
  - Dynamic Channel Allocation

Differences Between First and Second Generation Systems

- Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users

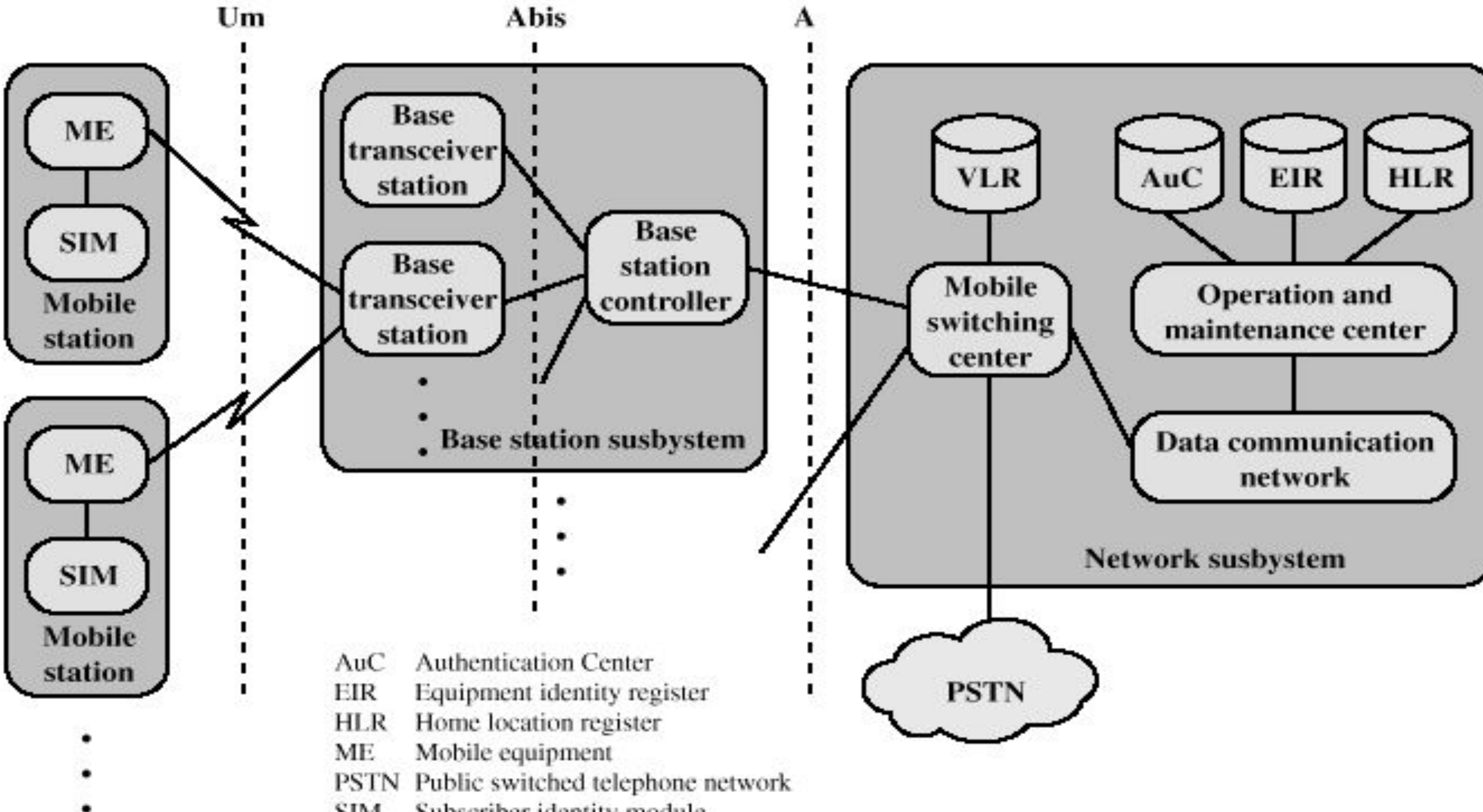
2nd Generation Cellular Systems



2G: GSM

- The Global System for Mobile Communication (GSM) is a digital cellular phone system using TDMA and FDMA.
- Reduced RF transmission power and longer battery life.
- International roaming capability by using SIM
- Better security against fraud (through terminal validation and user authentication).
- Encryption capability for information security and privacy.
- Short Message Service (SMS)
  - up to 160 character alphanumeric data transmission to/from the mobile terminal
- Provide data services for wireless users.

GSM Network Architecture



AuC Authentication Center
EIR Equipment identity register
HLR Home location register
ME Mobile equipment
PSTN Public switched telephone network
SIM Subscriber identity module
VLR Visitor location register

Figure 10.14 Overall GSM Architecture

Mobile Station

- Mobile station communicates across Um interface (air interface) with base station transceiver in same cell in which the mobile unit is located.
- Mobile equipment (ME) – physical terminal, such as a telephone or PCS
  - ME includes radio transceiver, digital signal processors and subscriber identity module (SIM)
- GSM subscriber units are generic until SIM is inserted
  - SIMs roam, not necessarily the subscriber devices
- The Um interface contains all the mechanisms necessary for wireless transmission (TDMA, FDMA etc.).

GSM SIM

- Subscriber Identity Module
- Smart card or plug-in module to activate unit
- Stores
  - subscriber's identification number
  - networks subscriber is authorized to use
  - encryption keys
- Can use any unit anywhere with your SIM

Base Station Subsystem (BSS)

- BSS consists of base station controller and one or more base transceiver stations (BTS)
- Each BTS defines a single cell
  - includes radio antenna, radio transceiver and a link to a base station controller (BSC)
- BSC may control multiple BTS units and hence multiple cells.
  - reserves radio frequencies, manages handoff of mobile unit from one cell to another within BSS, and controls paging.
- The Abis interface consists of 16 or 64 kbit/s connections.

Network Subsystem (NS)

- NS provides link between cellular network and public switched telecommunications networks
  - Controls handoffs between cells in different BSSs
  - Authenticates users and validates accounts
  - Enables worldwide roaming of mobile users
- Central element of NS is the mobile switching center (MSC).
  - Heart of the network which manages communication between GSM and other networks
  - It is supported by four databases that it controls.

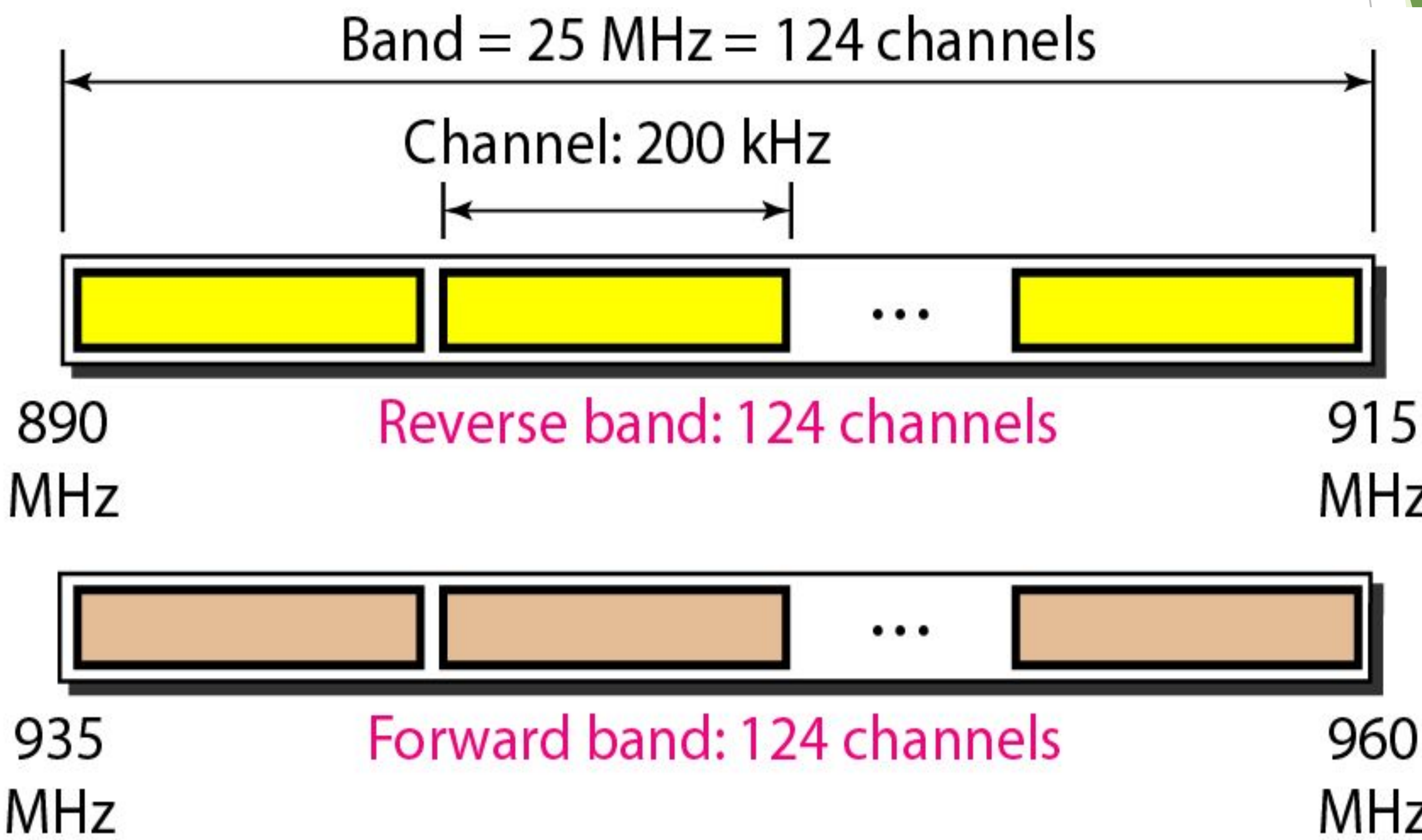
MSC Databases

- **Home location register (HLR) database:** stores information about each subscriber and update the information in HLR as soon as the subscriber leaves its current local area.
- **Visitor location register (VLR) database:** maintains information about subscribers that are currently physically in the region covered by the switching center.
- **Authentication center database (AuC):** used for authentication activities, holds encryption keys.
- **Equipment identity register database (EIR):** Stores all devices identifications registered for this network. Ex-IMEI

GSM-900 Frequency Band:

- Two frequency bands, of 25 MHz each one, have been allocated for the GSM system.
- The band 890-915 MHz has been allocated for the uplink direction (transmitting from the mobile station to the base station).
- The band 935-960 MHz has been allocated for the downlink direction (transmitting from the base station to the mobile station).
- Channel spacing 200 kHz provide 124 channels per cell.
- Each channel can support 8 users through TDMA (maximum 992 users per cell, in practice about 500).

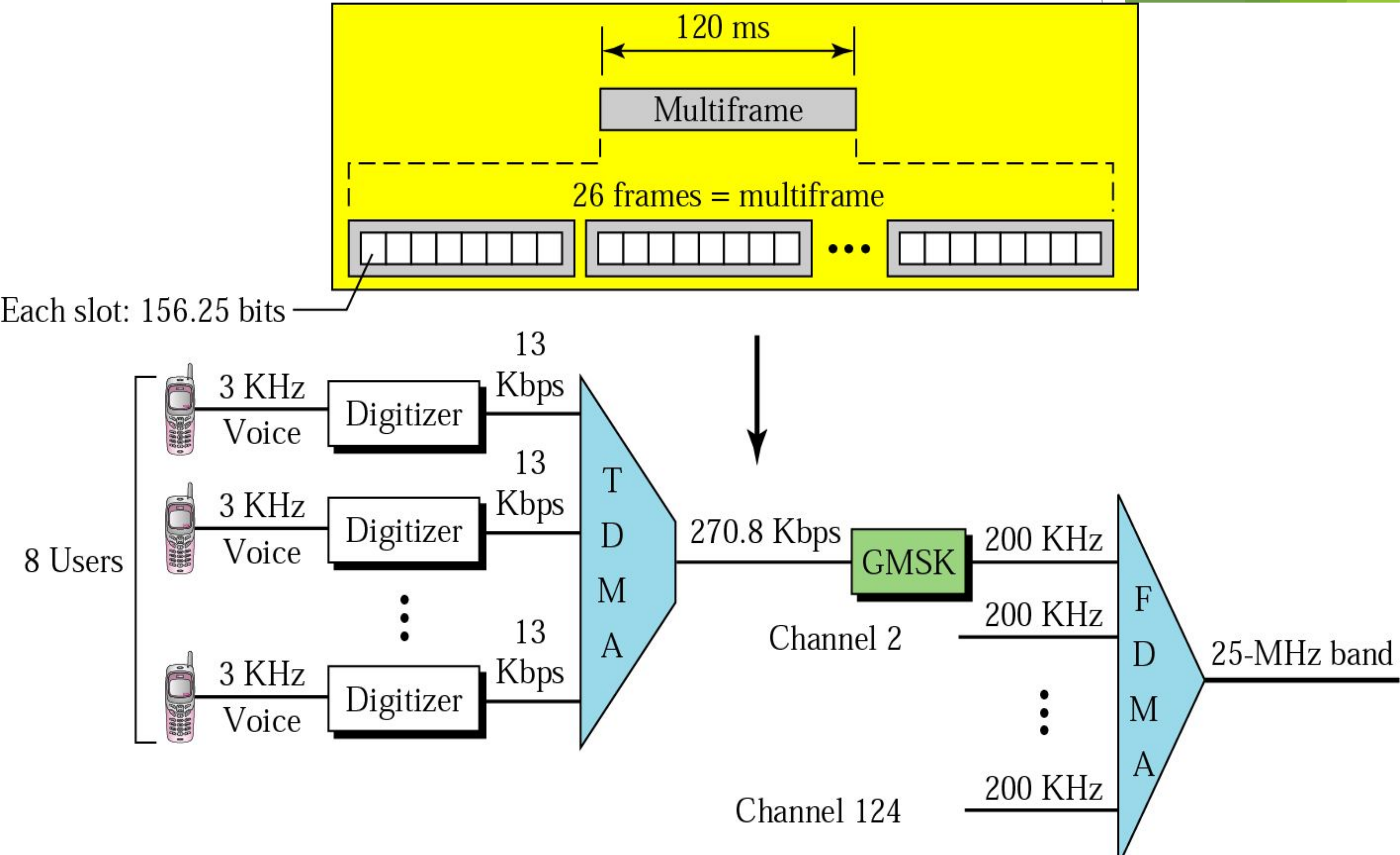
GSM-900 bands



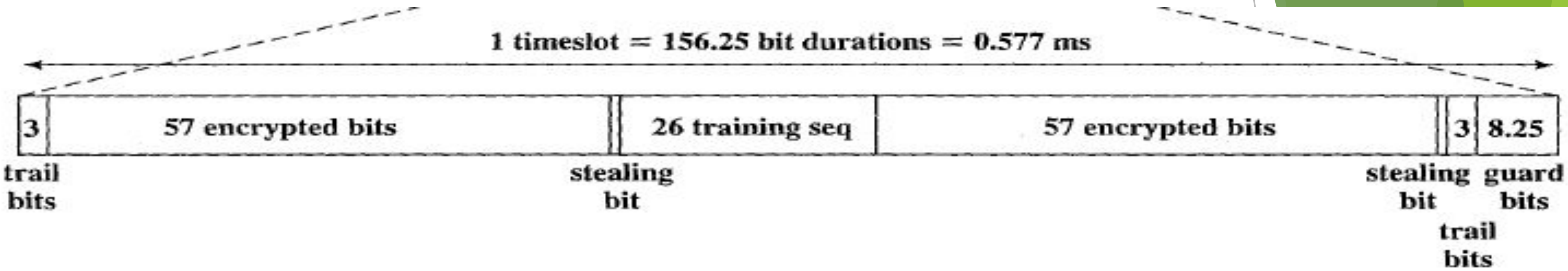
GSM Transmission:

- In a GSM System, each voice channel is digitized and compressed to a 13-kbps digital signal.
- Each slot carries 156.25 bits. Eight slots share a frame (TDMA).
- Twenty-six frames also share a multiframe (TDMA) and each channel takes one multiframe.
- Each 270.8-kbps digital channel modulates a carrier using GMSK (a form of FSK used mainly in European systems); the result is a 200-kHz analog signal.
- Finally 124 analog channels of 200 kHz are combined using FDMA. The result is a 25-MHz band.

GSM Transmission:



GSM Frame Structure



Trail bits: synchronisation between mobile and BS.

Encrypted bits: data is encrypted in blocks, Two 57-bit fields

Stealing bit: this flag indicates the type of data in the data field.

Training sequence: a known sequence that differs for different adjacent cells. It indicates the received signal is from the correct transmitter and not a strong interfering transmitter. It is also used for multipath equalisation. 26 bits.

Guard bits: avoid overlapping, 8.25 bits

GSM Example-1

GSM uses a frame structure where each frame consists of eight time slots, and each time slot contains 156.25 bits and data is transmitted over a channel at 270.833 kbps. Find (i) time duration of a bit, (ii) time duration of a time slot, (iii) time duration of a TDMA frame, and (iv) how long must a user wait when occupying a single time slot between two successive transmissions.

Solution

(i) To find time duration of a bit, T_b

Channel data rate = 270.833 kbps (given)

Time duration of a bit, T_b = 1/data rate

Hence, time duration of a bit, T_b = 1/270.833 kbps = 3.69 us

(ii) To find time duration of a time slot, T_{slot}

Number of bits per time slot = 156.25 bits (given)

Time duration of a time slot, T_{slot} = 156.25 bits · T_b

Time duration of a time slot, T_{slot} = 156.25 bits · 3.69 us = 577 us

(iii) To find time duration of a TDMA frame, T_f

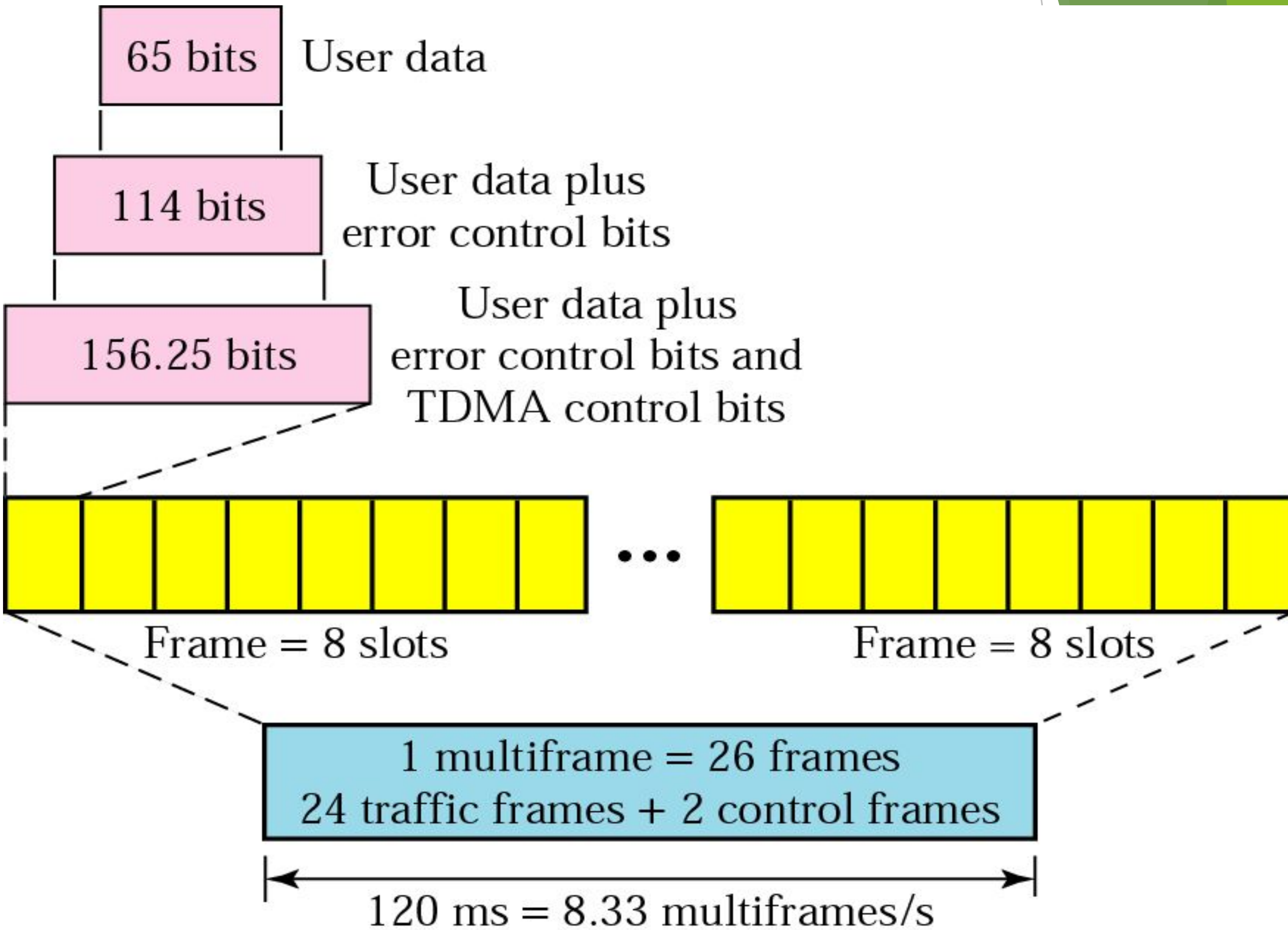
Number of time slots per TDMA frame = 8 (given)

Time duration of a frame, T_f = number of time slots · T_{slot}

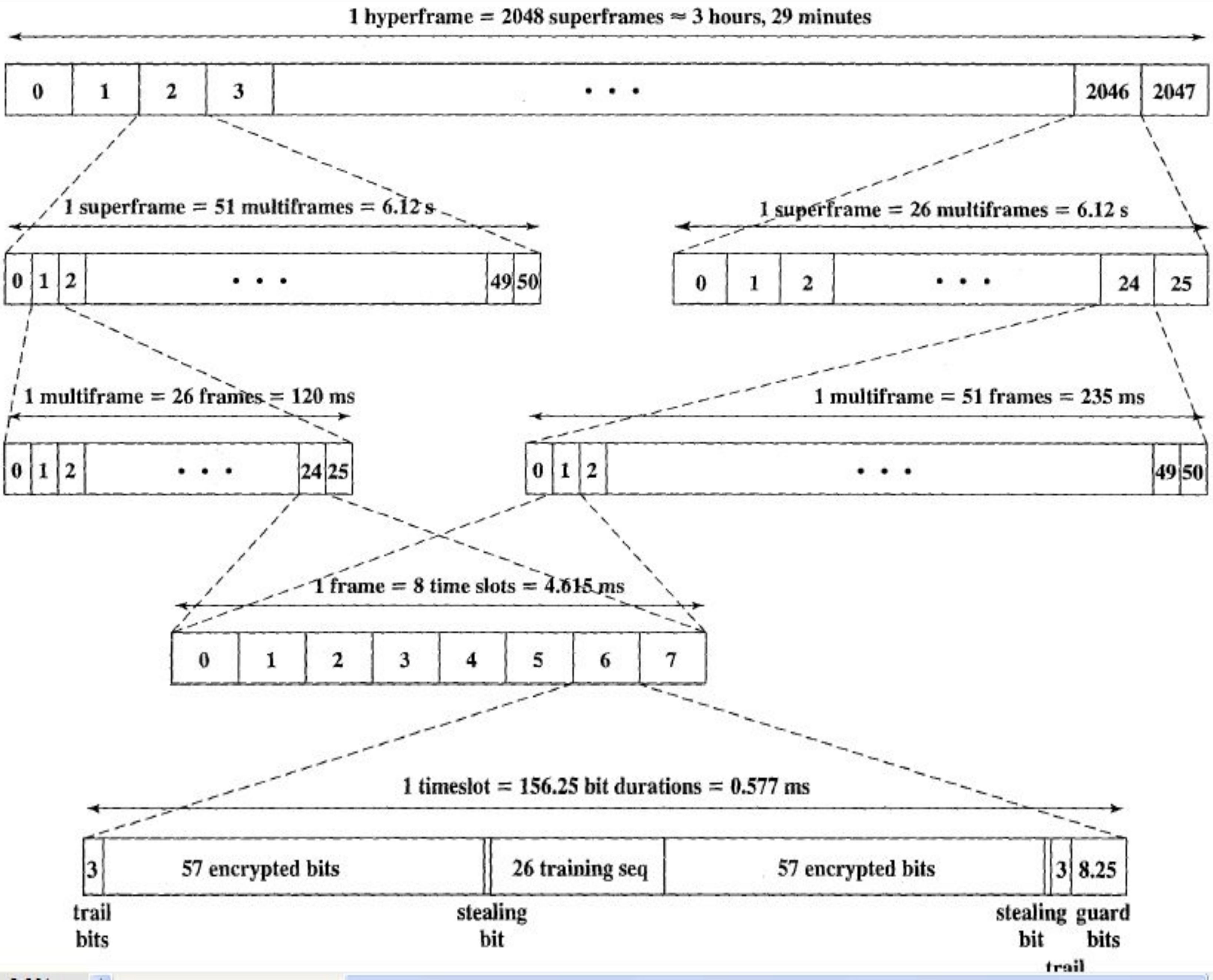
Time duration of a frame, T_f = 8 · 577 us = 4.616 ms

(iv) To find time duration for a user occupying a single time slot between two successive transmissions has to wait for the time duration of a frame. Hence, a user has to wait for 4.616 ms between two successive transmissions.

Multiframe Components:



GSM frame format



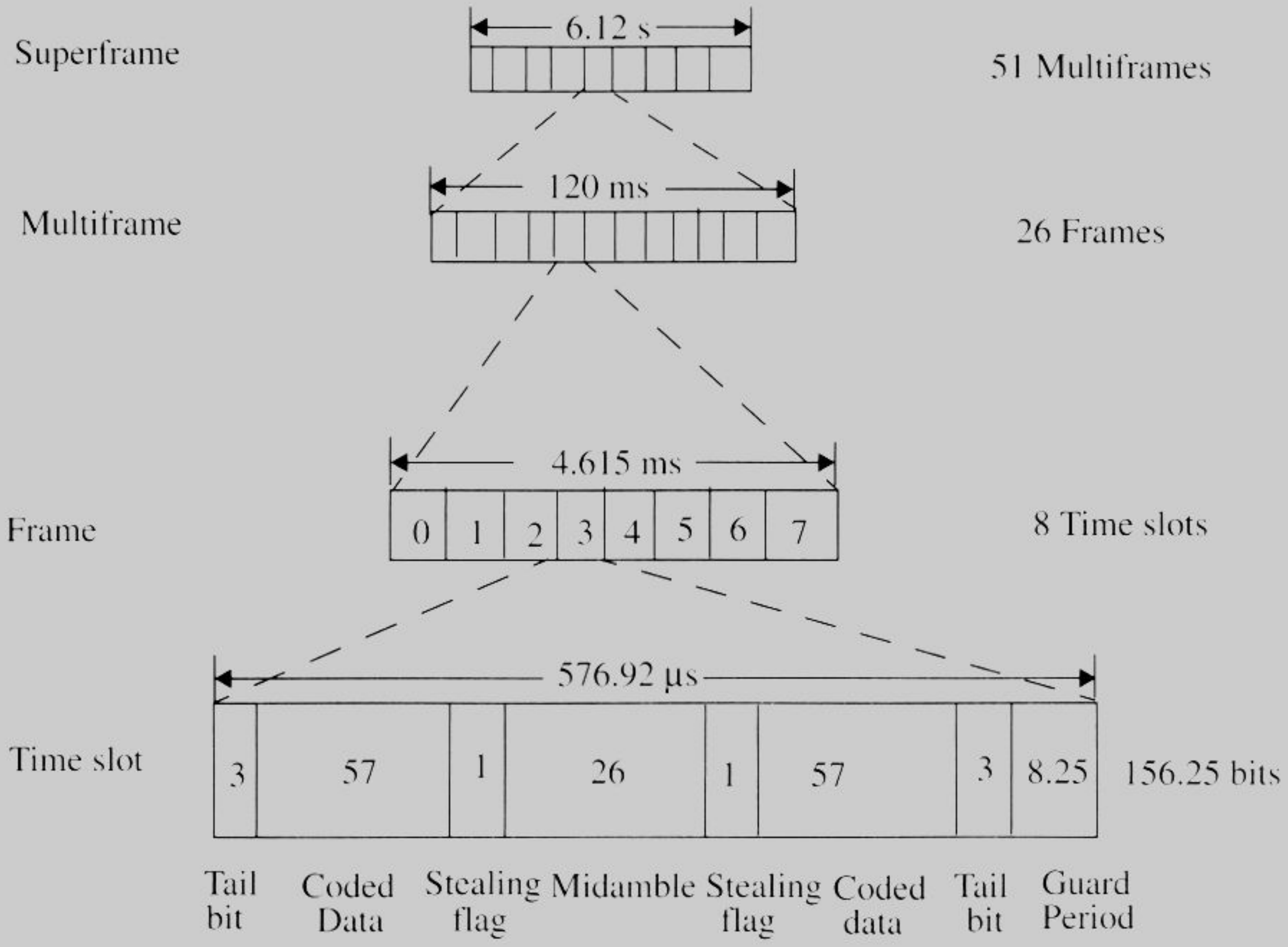


Figure 11.10 GSM frame structure.

GSM Data Rate

Time slot width

114 traffic bits + 42.25 control bits = 156.25 bits

Frame width

8 time slots per frame × 156.25 bits per slot = 1,250 bits per frame

Multiframe width

26 frames × 1,250 bits per frame = 32,500 bits per multiframe

Total transmission rate

32,500 bits per multiframe / 120 ms = 270.833 kbps

User traffic rate

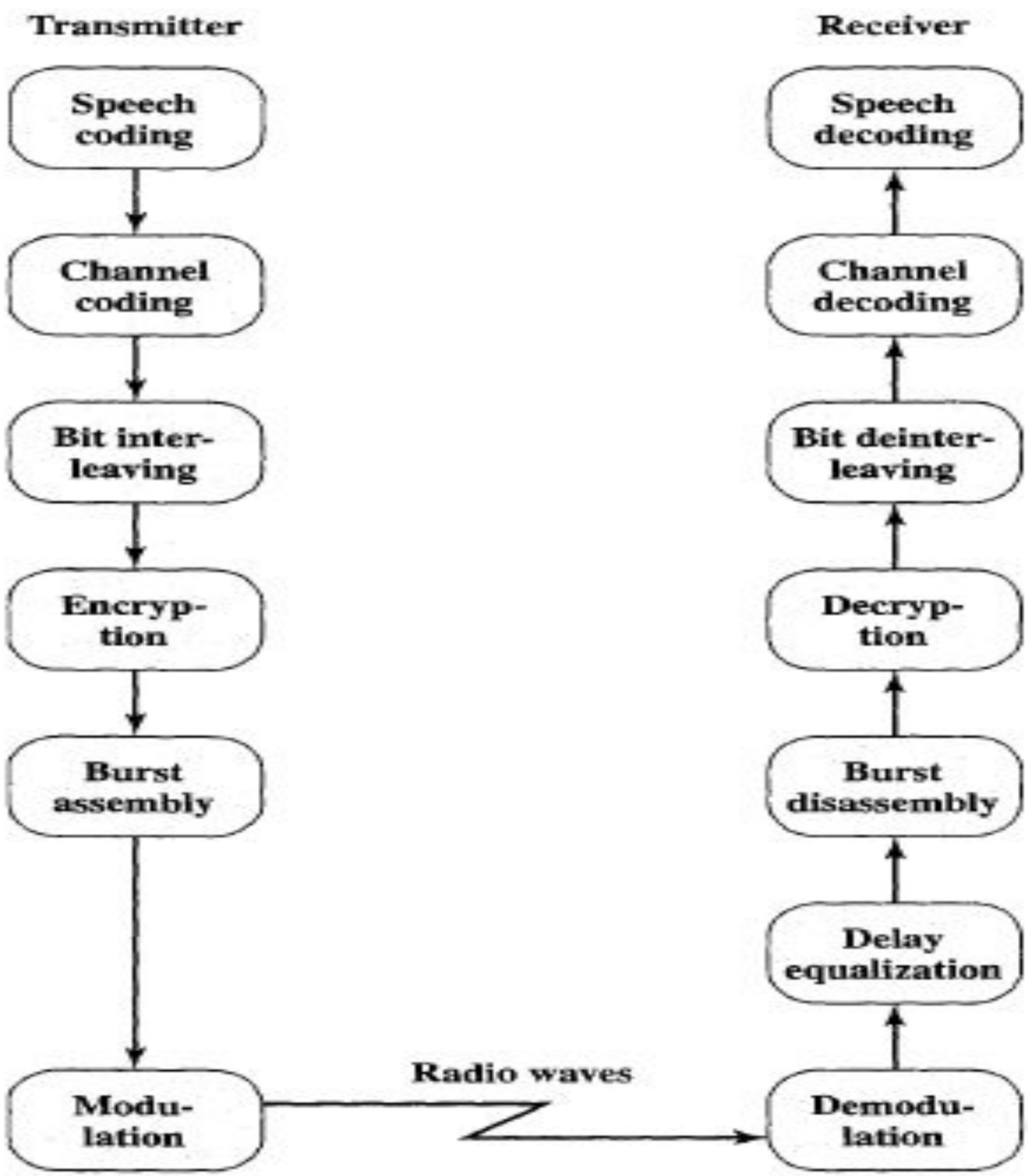
Traffic in 24 frames — frames 12 and 25 carry no traffic

$$\left(\frac{2 \times 57 \text{ bits}}{\text{time slot}} \times \frac{24 \text{ time slots}}{\text{multiframe}}\right) \Big/ \frac{120 \text{ ms}}{\text{multiframe}} = 22.8 \text{ kbps}$$

GSM Control Channel:

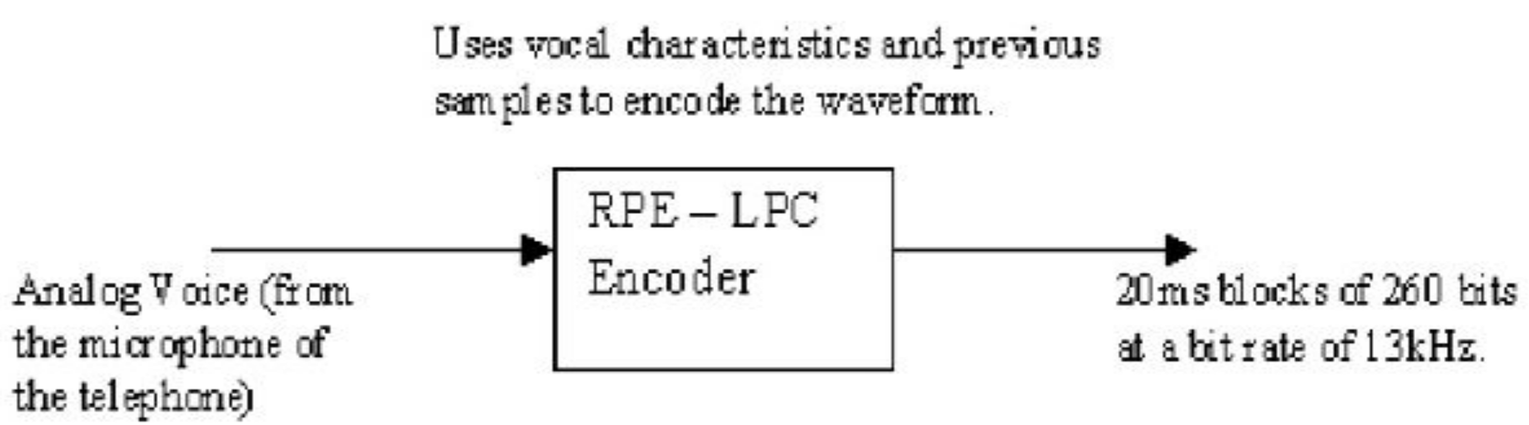
- According to their functions, three different classes of control channels are defined:
  - **Broadcast channels (BCH):** The BCH channels are used, by the base station, to provide the mobile station with the sufficient information it needs to synchronize with the network.
  - **Common control channels (CCCH):** All information regarding connection setup between MS and BS is exchanged via the CCCH.
  - **Dedicated control channels (DCCH):** The DCCH channels are used for message exchange between several mobiles or a mobile and the network.

GSM Speech signal processing



Speech Coding

- The speech signal is compressed using an algorithm known as Regular Pulse Excited - Linear Predictive Coder (RPE-LPC).
- This codec uses the information from previous samples in order to predict the current sample.
- The speech signal is divided into blocks of 20 ms.
- These blocks are then passed to the speech codec, which has a rate of 13 kbps, in order to obtain blocks of 260 bits.



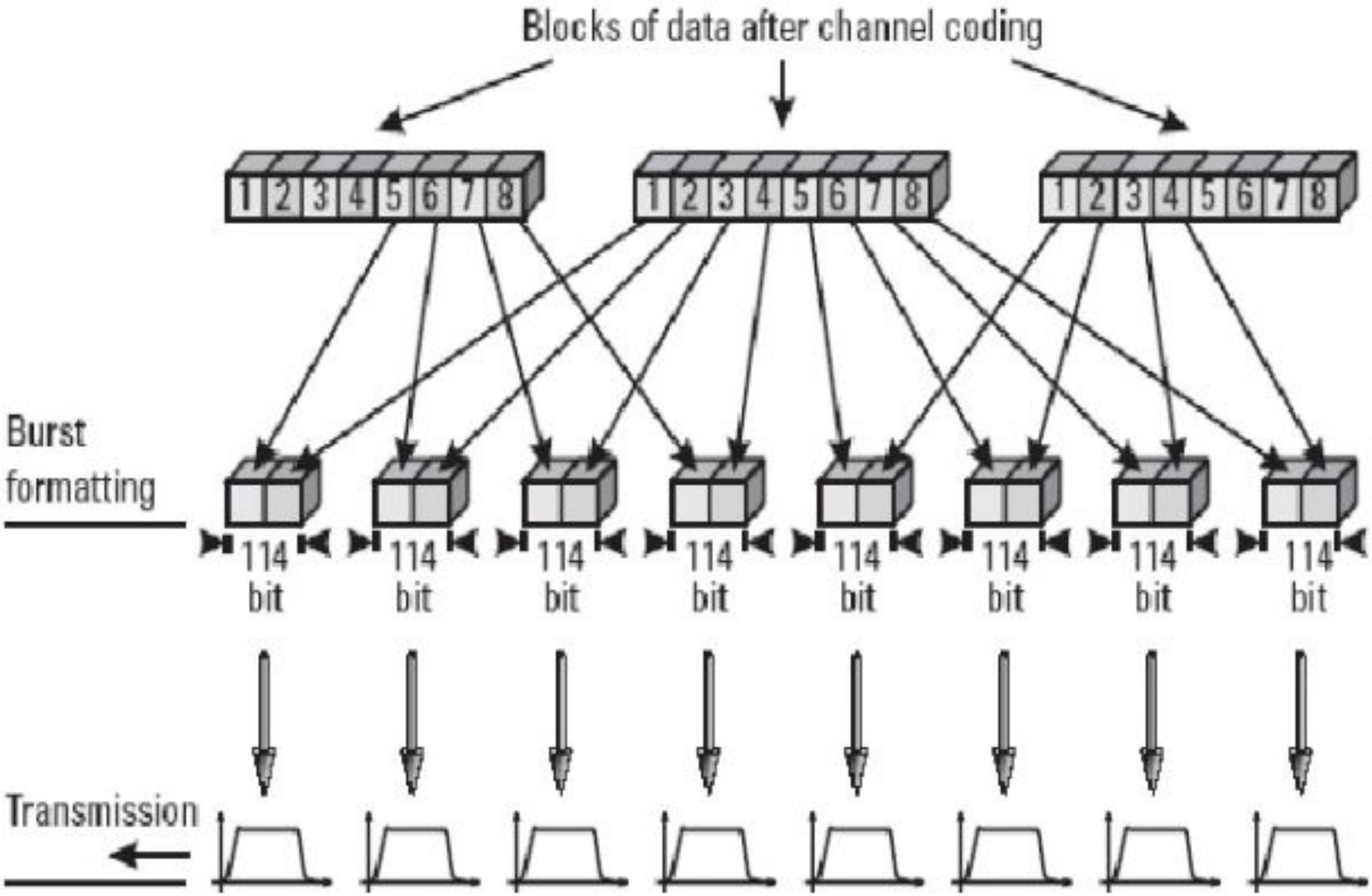
Channel Coding

- GSM speech frame are divided in three different classes according to their function and importance.
  - Class Ia: 50 bits, most sensitive to bit errors
  - Class Ib: 132 bits, moderately sensitive to bit errors
  - Class II: 78 bits, least sensitive to bit errors
- The different classes are coded differently:
  - The first 50 bits are protected by a 3-bit cyclic redundancy check (CRC) error detection code.
  - These 53 bits plus the 132 class 1b bits, plus a 4-bit tail sequence, are then protected by a convolutional (2, 1, 5) error correcting code, resulting in 189 X 2 = 378 bits.
  - The remaining 78 bits are unprotected and appended to the protected bits to produce a block of 456 bits,

Interleaving

- To further protect against the burst errors common to the radio interface, each sample is interleaved.
- This method rearranges a group of bits in a particular way.
- Each 456 bit block are then divided into eight blocks each containing 57 bits.
- The first four blocks will be placed in the even bit positions of the first four bursts.
- The last four blocks will be placed in the odd bit positions of the next four bursts.

Interleaving



Encryption

- It is used to protect signaling and data. This process is done using 3 algorithms :
  - A3 algorithm for authentication
  - A5 algorithm for encryption
  - A8 algorithm for key generation

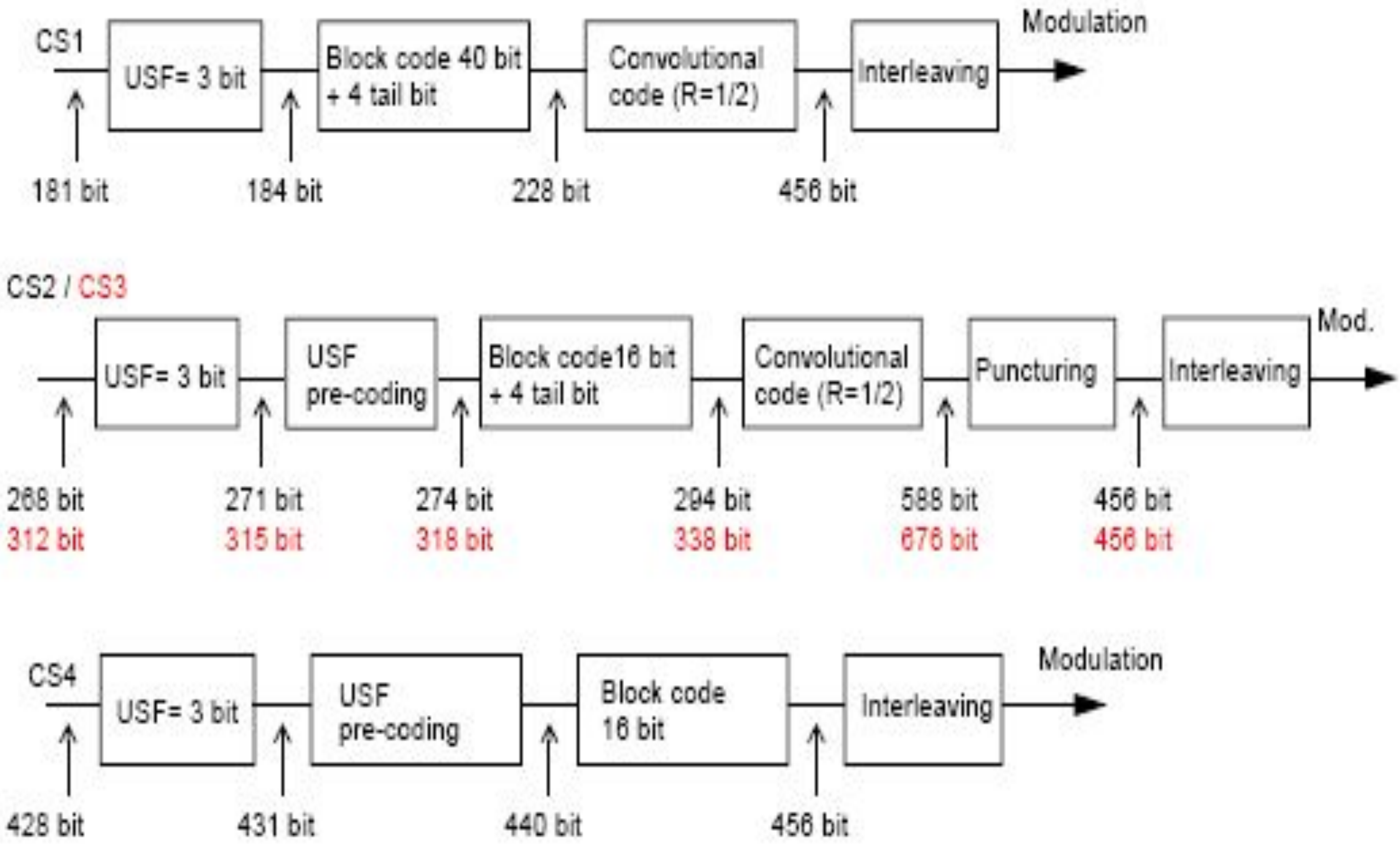
Modulation

- The modulation chosen for the GSM system is the Gaussian Minimum Shift Keying (GMSK).

2.5G – GPRS (General Packet Radio Service)

- GPRS is a packet-switching-based data service for GSM.
- Purpose is to provide increased data rates on existing 2G GSM network.
- GPRS supports the world's leading packet-based Internet communication protocols: Internet protocol (IP) and X.25.
- One to eight time slots can be allocated to a user, or several active users can share a single time slot.
- Theoretically, a GPRS connection can provide a data transmission speed of up to 171.2Kbps if all eight time slots are used.

GPRS Coding Scheme

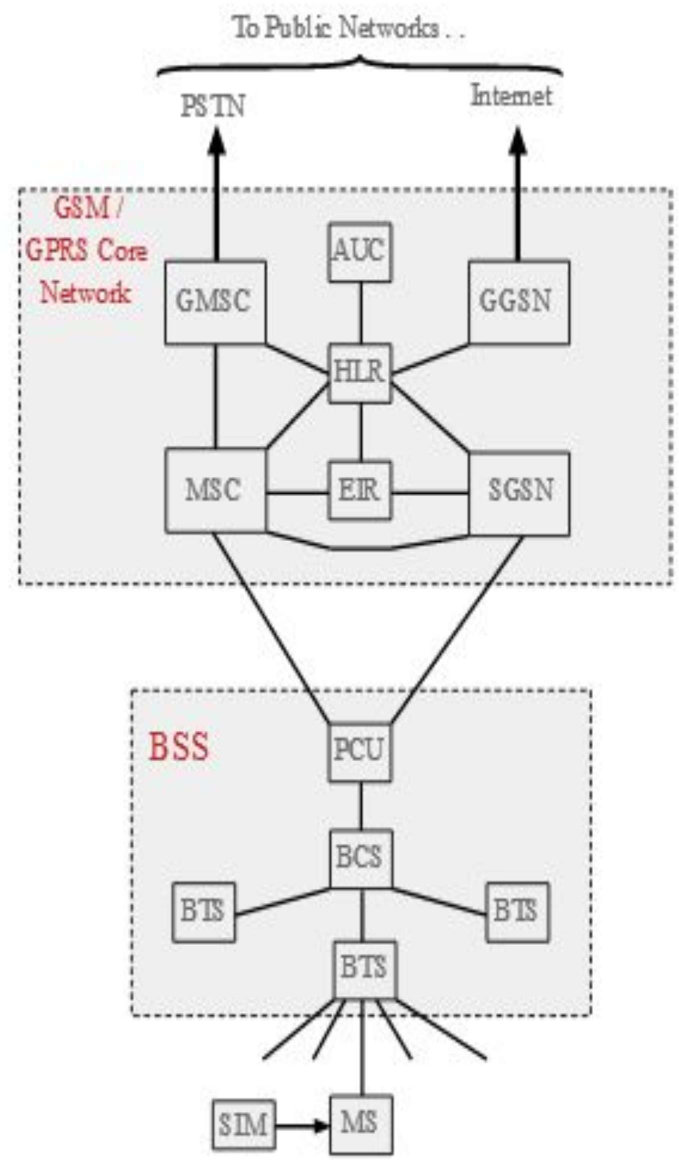


GPRS Coding Scheme

	Duration of radio block	Net number of bits	Preco-ded USF	BCS	Tail bits	Number of coded bits	Punc-tured bits	Net data rate
CS-1	20 ms	181	3	40	4	456	0	9,05 kbit/s
CS-2	20 ms	268	6	16	4	588	132	13,4 kbit/s
CS-3	20 ms	312	6	16	4	676	220	15,6 kbit/s
CS-4	20 ms	428	12	16	0	456	0	21,4 kbit/s

GPRS Architecture

- **PCU:**
  - Packet Control Unit.
  - The PCU detects whether data is to be routed to the packet switched or circuit switched networks.
- **SGSN:**
  - Serving GPRS Support Node.
  - Handles all packet switched data within the network.
  - It also stores the user profiles (e.g., IMSI, packet addresses used) for all the GPRS users
- **GGSN:**
  - Gateway GPRS Support Node.
  - Responsible for the interworking between the GPRS network and external networks.



2.75 – EDGE (Enhanced Data rates for GSM Evolution)

- GSM EDGE cellular technology is an evolutionary upgrade to the existing GSM / GPRS networks, and can be implemented as a software upgrade to existing GSM / GPRS networks.
- EDGE is capable of offering data rates of 384 kbps and theoretically up to 473.6 kbps.
- **Use of 8PSK modulation:**
  - In order to achieve the higher data rates within GSM EDGE, the modulation format was changed from GMSK to 8PSK.
  - This provided a significant advantage in being able to convey 3 bits per symbol, thereby increasing the maximum data rate.
  - Several new coding schemes are introduced that offer net bit rates per time slot of up to 59.2 Kbps. If a subscriber has all the eight time slots of a carrier, the maximal theoretical data rate with EDGE is then

$$59.2 \text{ Kbps} \times 8 \text{ time slots} = 473.6 \text{ Kbps}.$$

3rd Generation

The third-generation concept started in 1992, when ITU issued a blueprint called the Internet Mobile Communication 2000 (IMT-2000). The blueprint defines some criteria for third-generation technology as outlined below:

- Voice quality comparable to that of the existing public telephone network.
- Data rate of 144 kbps for access in a moving vehicle (car), 384 kbps for access as the user walks (pedestrians), and 2 Mbps for the stationary user (office or home).
- Support for packet-switched and circuit-switched data services.
- A band of 2 GHz.
- Bandwidths of 2 MHz.
- Same Network Standard for world wide.

Technologies of 3G

- **W-CDMA :**Wideband Code Division Multiple Access.
- **CDMA 2000:** Code Division Multiple Access.
- **TD-SCDMA**: Time-division Synchronous CDMA
- 3.5G/3.5G+ is enhancement to 3G.
  - High-Speed Downlink Packet Access (HSDPA)
  - High-Speed Packet Access(HSPA)
  - Evolved High-Speed Packet Access (HSPA+)

3rd Generation—Internet System

- 3.5G – HSDPA (High-Speed Downlink Packet Access):
  - Provides a smooth evolutionary path for UMTS-based 3G networks allowing for higher data transfer speeds.
  - HSDPA is a packet-based data service in W-CDMA downlink with data transmission up to 8-10 Mbits over a 5MHz bandwidth in WCDMA downlink.
  - Implementations includes Adaptive Modulation and Coding (AMC), Multiple-Input Multiple-Output (MIMO), Hybrid Automatic Request (HARQ), fast cell search, and advanced receiver design.
- 3.75G – HSUPA (High-Speed Uplink Packet Access)
  - High Speed Uplink Packet Access (HSUPA) is a UMTS / WCDMA uplink evolution technology.
  - HSUPA will enhance advanced person-to-person data applications with higher and symmetric data rates, like mobile e-mail and real-time person-toperson gaming.
  - HSUPA will initially boost the UMTS / WCDMA uplink up to 1.4Mbps and in later releases up to 5.8Mbps.

4th Generation

- The 4G mobile system is an all IP-based network system--Utilizing packet switching environment, LAN or WAN networks via VoIP.
- 4G technology integrate different current existing and future wireless network technologies.
- Provides high quality audio/video streaming over end to end Internet Protocol.
- The first two commercially available technologies considered as 4G were the WiMAX standard and the LTE standard
  - Data Rate: 4G LTE– peak download 100Mbps and peak upload 50 Mbps
  - WiMax—128 Mbps downlink and 56 Mbps uplink
- 4G based on OFDM (Orthogonal Frequency Division Multiplexing), which is the key enabler of 4G technology.

4th Generation

Applications :

Games

Games will be a major application segment in 4G.

Electronic Agents

There will be e-assistance, e-secretaries, e-advisors, e-administrators etc. This kind of control is what home automation applications anticipate.

Broadband Access in Remote Locations

4G networks will provide a wireless alternative for broadband access to residential and business customers. In addition, 4G will provide the first opportunity for broadband access in remote locations without an infrastructure to support cable or DSL access.

Comparison between 3G and 4G

Technology	3G	4G
Frequency band	1.8 - 2.5GHz	2 - 8GHz
Bandwidth	5-20MHz	15-200MHz
Data rate	Up to 2Mbps	100Mbps moving - 1Gbps stationary
Core Network	Wide area concept: Circuit and Packet switching	Broadband, IP based Packet Switching
Technologies	W-CDMA, CDMA-2000	OFDMA, MC-CDMA

5^{th} Generation - Real Wireless World System

- The next (5th) generation wireless network will address the evolution beyond mobile internet to massive IoT (Internet of Things) for the horizon 2020.
- Characteristics
  - 100 Times More Capacity Than 4G
  - Implements Massive MIMO with 96 to 128 antennas
  - Blazing Fast Internet—data rate upto10 Gb/s
  - Very Low Network Latency-- 1 millisecond latency
  - Custom Made Network Slices
  - Better Battery Life for Devices
  - Multiple Services Can Run in Parallel