

MOBILE COMPUTING

CHAPTER – THREE Telecommunication Systems

Objective

- ▶ By the end of this lecturer, you should be able to:
 - ✓ Understand telecommunication system
 - ✓ Understand the evolutions of cellular network and what is changed as go from 1G to 5G
 - ✓ Understand the concept of Global System for Mobile Communication
 - ✓ Understand the CDMA IS-95
 - ✓ Understand how GPRS work.

What is Telecommunication Systems?

- ▶ Telecommunication systems are networks of interconnected devices and infrastructure that enable the transmission of information, such as voice, data, and multimedia, **over long distances**.
- ▶ Communication could be:
 - ✓ **Simplex** – in one direction only. E.g. Radio, TV broadcasting
 - ✓ **Half-duplex** – bidirectional but not at the same time. E.g. Walkie-talkie
 - ✓ **Full-duplex** – bidirectional and simultaneously. E.g. Phone

What is Telecommunication Systems?

- ▶ A basic telecommunication system consists of **three primary elements** that are always present in some form.
 - ✓ A **transmitter** that takes information and convert it to a signal.
 - ✓ A **transmission medium**(physical channel) that carries the signal
 - ✓ A **receiver** that takes the signal from the channel and converts it back into usable information.

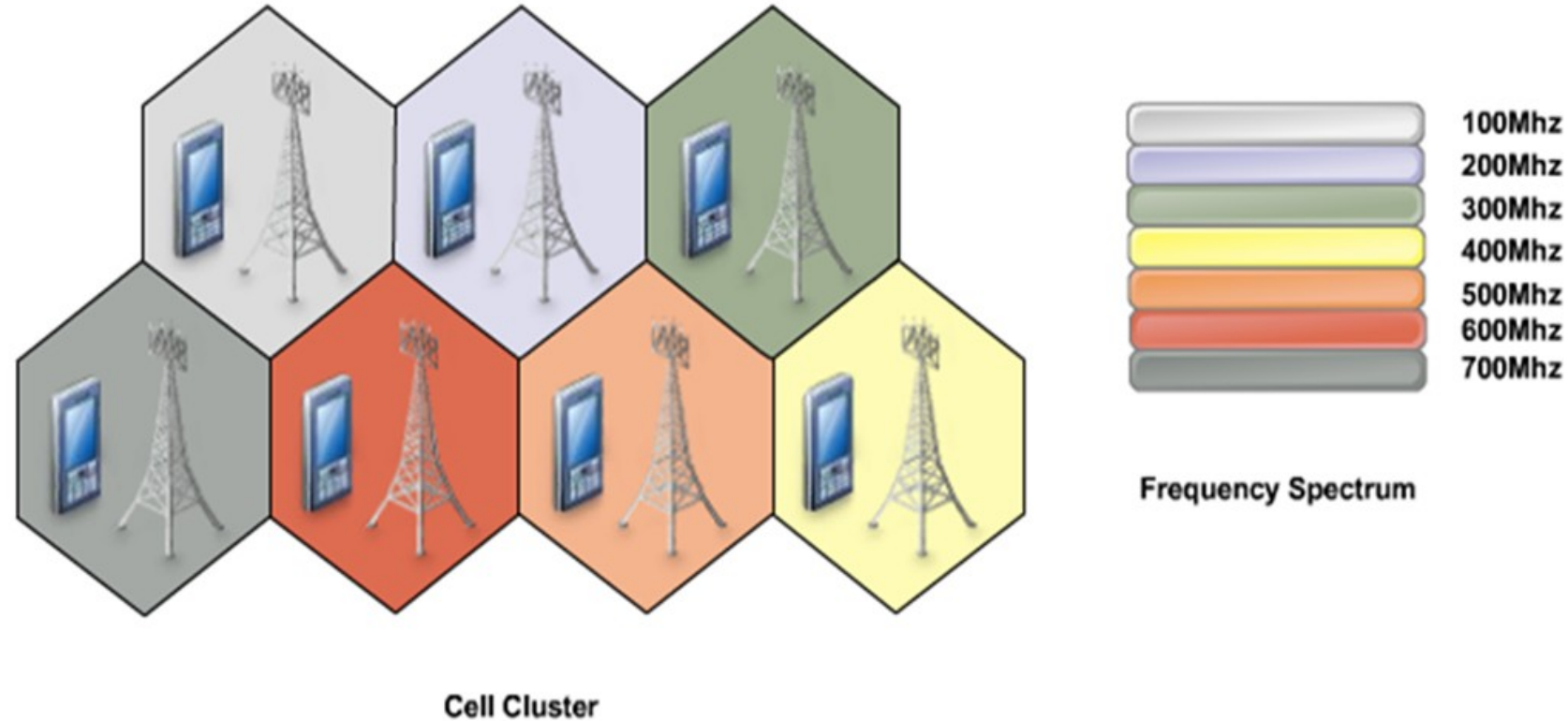
Examples of Telecommunication Systems

- ▶ Telephone system
- ▶ Satellite communication system
- ▶ Mobile cellular system
- ▶ Microwave radio system
- ▶ TV and radio broadcasting systems

Mobile Cellular System

- ▶ Often simply referred to as a **cellular system/network**
- ▶ It is a wireless communication system that allows **mobile devices** to connect to a network and communicate with each other.
- ▶ These systems are designed to provide widespread coverage by dividing a geographic region into **smaller cells**, each served by its own **base station** or cell tower.
- ▶ A cell is a basic geographical unit of cellular system and represented as hexagon (the true shape is not hexagon)

Mobile Cellular System



- The primary goal of a cellular system is to offer **efficient** and **reliable** voice and data communication services to mobile users.

The evolution of cellular networks

► First Generation (1G):

- ✓ Appeared in late 1970s and deployed in early 1980s by AT&T
- ✓ All based on **analog** techniques - primarily used for **voice** calls.
- ✓ It provides **Low-quality** voice transmission
- ✓ It provides **Limited** mobility and coverage.
- ✓ Systems are **incompatible** each other
- ✓ It is **insecure** because an unknown receiver with all-band radio can listen into the conversation.
- ✓ **No Roaming**

The evolution of cellular networks - Cont ...

► **Standards/Technologies used in 1G:**

- ✓ **AMPS** (Advanced Mobile Phone System) - in the Americas
- ✓ **NMT** (Nordic Mobile Telephone) - in the Nordic countries
- ✓ **TACS** (Total Access Communication System) - in Europe

The evolution of cellular networks - Cont ...

► **Second Generation (2G):**

- ✓ Appeared in Late 1980s to early 2000s
- ✓ Based on **digital** – used for **Voice** and some **data**
- ✓ Short Message Service (**SMS**) was a phenomenal success
- ✓ It provides **improved voice quality**, **higher data rates**, and greater **capacity**.
- ✓ Improved security - 2G cellular network is digitally **encrypted**.

The evolution of cellular networks - Cont ...

► Standards/Technologies used in 2G:

- ✓ Global System for Mobile Communications / Groupe Special Mobile (**GSM**)
 - TDMA-based
- ✓ Interim Standard 136 (**IS-136**) – also know as North American Digital Cellular
 - TDMA-based
- ✓ **IS-95** – also know as CDMAONE
 - CDMA-based

The evolution of cellular networks - Cont ...

► 2.5 Generation (2.5 G):

- ✓ Introduced Late 1990s to early 2000s
- ✓ Introduction of technologies like
 - **GPRS** (General Packet Radio Service)
 - **EDGE** (Enhanced Data rates for GSM Evolution).
- ✓ Provide **improved data transmission** with packet-switched networks i.e. connectionless.
- ✓ Support basic mobile **internet** access and **email**.

The evolution of cellular networks - Cont ...

► Third Generation(3G):

- ✓ Founded in Early 2000s to mid-2010s
- ✓ Services associated with 3G provides users with **mobile TV**, **internet access**, **video calls** and all in the environment of mobile.
- ✓ Has **high-speed** data transmission with improved **voice quality**.
- ✓ Introduction of **video calling** and **multimedia messaging (MMS)**.
- ✓ Provide mobile broadband capabilities with higher data rates

The evolution of cellular networks - Cont ...

► Standards/Technologies used in 3G:

- ✓ **UMTS** (Universal Mobile Telecommunications System),
- ✓ **CDMA2000**, and
- ✓ **WCDMA** (Wideband Code Division Multiple Access)

The evolution of cellular networks - Cont ...

►Fourth Generation(4G):

- ✓ Founded in Mid-2010s to present
- ✓ High-speed data transmission (up to 100 Mbps) with low latency.
- ✓ IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television are the applications that are used using 4G
- ✓ Support for high-definition voice calls.
- ✓ Enhanced multimedia streaming and mobile gaming.
- ✓ Most 4G networks offer backward compatibility with 3G and 2G technologies, allowing users with older devices to access basic voice and data services even in areas with 4G coverage.

The evolution of cellular networks - Cont ...

► Standards/Technologies used in 4G:

- ✓ **LTE** (Long-Term Evolution) and
- ✓ **WiMAX** (Worldwide Interoperability for Microwave Access).

The evolution of cellular networks - Cont ...

► **Fifth Generation(5G):**

- ✓ Founded in Mid-2010s to present
- ✓ It is the latest and most advanced generation of mobile telecommunications technology.
- ✓ It offers a wide range of capabilities that enable **faster data speeds, lower latency, increased network capacity**, and support for emerging technologies.

The evolution of cellular networks - Cont ...

► Characteristics of 5G

- ✓ **Ultra-Fast Data Speeds** - between 10 and 20 Gbps, or 100X faster than 4G.
- ✓ **Low Latency** - as low as 1 millisecond or less
 - are ideal for real-time applications like online gaming, augmented reality (AR), virtual reality (VR), and autonomous vehicles.
- ✓ **Massive Device Connectivity** - up to one million devices per square kilometer.

The evolution of cellular networks - Comparison

1G vs. 2G vs. 3G vs. 4G vs. 5G

This slide depicts the difference between 1G, 2G, 3G, 4G, and 5G based on development, technology, frequency, bandwidth, access system, and core network.



	1G	2G	3G	4G	5G
Features					
Start/development	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015
Technology	AMPS, NMT, TACS	GSM	WCDMA	LTE, WiMax	MIMO, mm Waves
Frequency	30KHz	1.8Ghz	1.6 – 2Ghz	2 – 8 Ghz	3 -30 Ghz
Bandwidth	2Kbps	14.4 – 64Kbps	2Mbps	2000 Mbps to 1 Gbps	1 Gbps and higher
Access system	FDMA	TDMA/CDMA	CDMA	CDMA	OFDM/BDMA
Core network	PSTN	PSTN	Packet network	Internet	Internet

Global System for Mobile Communications (GSM)

What is GSM?

- ▶ GSM, is a **digital** cellular communications system

Or

- ▶ GSM is a **second generation** cellular standard developed to cater **voice services** and **data** delivery using digital modulation
- ▶ GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard
- ▶ GSM provides basic to advanced voice and data services including **roaming service**.
- ▶ Roaming is the ability to use your GSM phone number in another GSM network.

Features of GSM

► Increased Capacity

- ✓ The GSM system provides a **greater subscriber capacity** than analogue systems.
- ✓ Digital channel coding and the modulation used makes the signal **resistant to interference** from cells where the **same frequencies are re-used** (co-channel interference);
- ✓ This allows increased **geographic reuse** by permitting a reduction in the number of cells in the reuse pattern.

► Enhanced Range of Services

- ✓ **Speech services** for normal telephony.
- ✓ **Short Message Service** for point to point transmission of text message.
- ✓ **Fax & data services** are provided. Data rates available are 2.4 Kb/s, 4.8 Kb/s & 9.6 Kb/s.
- ✓ Supplementary services like **number identification** , **call barring**, **call forwarding**, **charging display** etc. can be provided

Features of GSM

►Subscriber Identification

- ✓ In a GSM system the mobile station and the subscriber are identified separately.
- ✓ The subscriber is identified by means of a smart card known as a **SIM**.
- ✓ This enables the subscriber to use different mobile equipment while retaining the same subscriber number.

►Cleaner Handovers

- ✓ GSM uses Mobile assisted handover technique.
- ✓ The mobile itself carries out the signal strength and quality measurement of its server and signal strength measurement of its neighbors.
- ✓ This data is passed on the Network which then uses sophisticated algorithms to determine the need of handover.

►Use of Standardized Open Interfaces

- ✓ Different manufacturers can be selected for different parts of the PLMN.
- ✓ There is a high flexibility in where the Network components are situated.

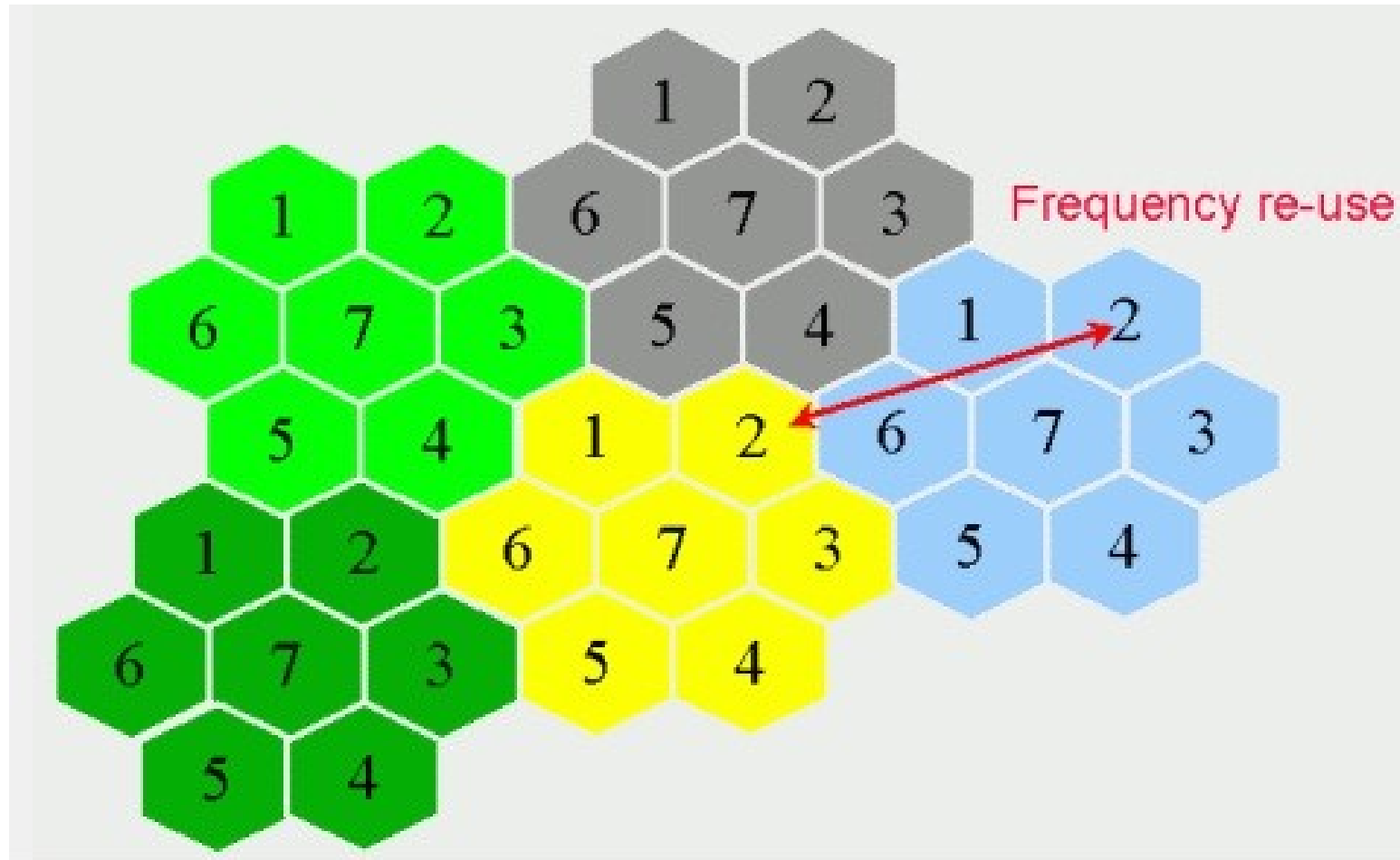
Features of GSM

► Frequency Reuse

- ✓ It is a way of efficiently using **limited frequency resources** and provide reliable mobile communication services to a large number of subscribers.
- ✓ It enables the **simultaneous** use of the same frequencies in different geographic areas, reducing the overall demand for additional spectrum allocations.
- ✓ The radio carriers available are allocated according to a **regular pattern** which repeats over the whole coverage area.
- ✓ The pattern to be used depends on **traffic requirement** and **spectrum availability**.
- ✓ Some typical repeat patterns are 4/12, 7/21 etc.

Features of GSM

► Frequency Reuse



Features of GSM

► Improved Security and Confidentiality

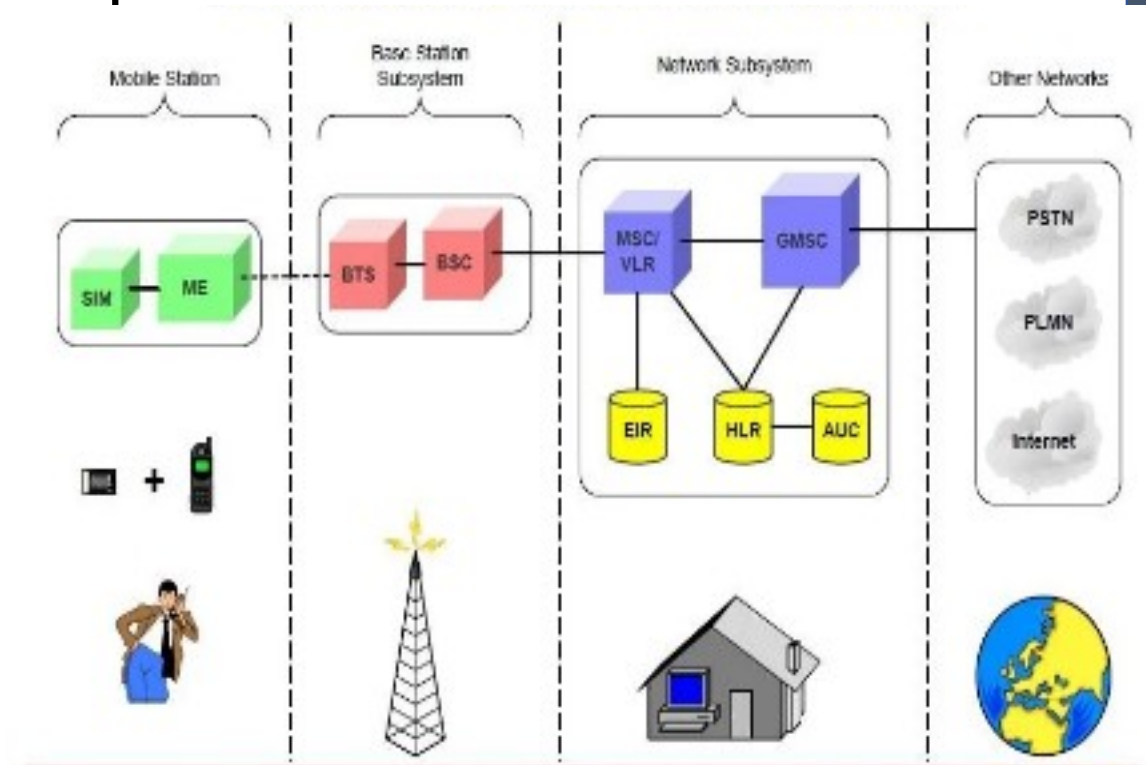
- ✓ GSM offers high **speech and data confidentiality**.
- ✓ Subscriber authentication can be performed by the system to check if a subscriber is a valid subscriber or not.
- ✓ Calls are **encoded** and **ciphered** when sent over air.
- ✓ The mobile equipment can be identified independently from the mobile subscriber. The mobile has a identity number hard coded into it when it is manufactured (**IMEI**).
- ✓ This number is stored in a standard database and whenever a call is made the equipment can be checked to see if it has been reported stolen.

Limitations of GSM

- ▶ There is no perfect system!!
 - ✓ no end-to-end encryption of user data
 - ✓ abuse of private data possible - roaming profiles accessible
 - ✓ high complexity of the system
 - ✓ several incompatibilities within the GSM standards

Architecture of the GSM system

- ▶ It is a hierarchical structure designed to provide efficient and reliable mobile communications
- ▶ It consists of various network elements and components that work together
 - ✓ MS (Mobile Station)-ME and SIM
 - ✓ BSS (Base Station Subsystem)-BTS and BSC
 - ✓ NSS (Network Switching Subsystem)
 - MSC, HLR, VLR, AUC, EIR



Mobile Station : ME and SIM

- ▶ The Mobile Station refers to the mobile device used by the subscriber, such as a mobile phone or a data terminal.
- ▶ It includes two main components:
 - ▶ **Mobile Equipment**
 - ✓ The Mobile Equipment is the hardware used by the subscriber to access the network.
 - ✓ It can be Vehicle mounted, with the antenna physically mounted on the outside of the vehicle or portable mobile unit, which can be handheld.
 - ▶ **Subscriber Identity Module (SIM)**
 - ✓ The SIM is a removable card that plugs into the ME.
 - ✓ It identifies the mobile subscriber and provides information about the service that the subscriber should receive.

Mobile Station : ME and SIM

- ▶ The SIM contains several pieces of information
 - ✓ **International Mobile Subscribers Identity (IMSI)** - This number identifies the mobile subscriber. It is only transmitted over the air during initializing.
 - ✓ **Temporary Mobile Subscriber Identity (TMSI)** - This number also identifies the subscriber. It can be alternatively used by the system. It is periodically changed by the system to protect the subscriber from being identified by someone attempting to monitor the radio interface.
 - ✓ **Location Area Identity (LAI)** - Identifies the current location of the subscriber.
 - ✓ **Subscribers Authentication Key (Ki)** - This is used to authenticate the SIM card.
 - ✓ **Mobile Station International Standard Data Number (MSISDN)** - This is the telephone number of the mobile.

Base Station Subsystem(BSS)

- ▶ BSS is responsible for managing the radio communication between the mobile device (MS) and the cellular network.
- ▶ It consists of two main components:
 - ✓ **Base Transceiver Station (BTS):**
 - It contains the radio transceivers that communicate with the mobile devices within its coverage area.
 - It is responsible for radio signal **transmission** and reception.
 - A BTS is usually placed in the center of a cell.
 - Its transmitting power defines the size of a cell.



Base Station Subsystem(BSS)

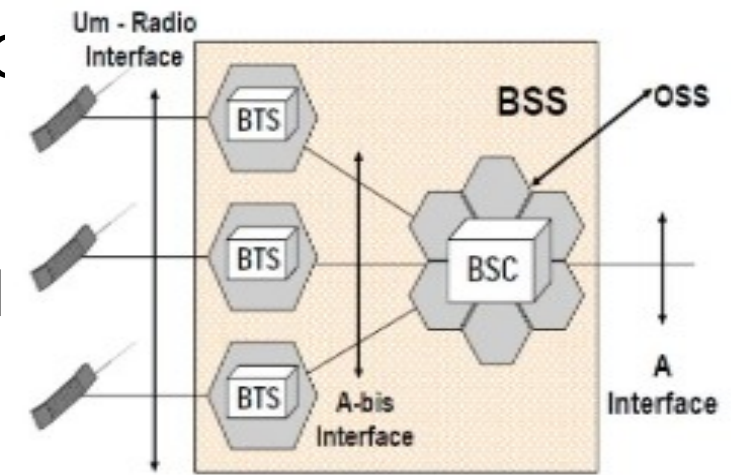
► Components of BSS:

✓ **Base Station Controller (BSC):**

- It manages multiple BTSs and controls their operation.
- It handles functions such as **handovers**, **frequency allocation**, and **power level control** for optimal network performance.
- It provides a physical links between the MSC

► Interfaces

- ✓ **Um** : It is the air interface used between M
- ✓ **Abis** : It is used between BTS and BSC.
- ✓ **A**: It is used between BSC and MSC/VLR



Network Switching Subsystem (NSS)

- ▶ NSS is the main component of the public mobile network GSM
- ▶ It is responsible for call and data routing, switching, and network management.
- ▶ It includes several key components:
 - ✓ Mobile Services Switching Center (MSC)
 - ✓ Different Databases
 - Home Location Register (HLR)
 - Visitor Location Register (VLR)
 - Equipment Identity Register (EIR) and
 - Authentication Center (AuC)

Network and Switching Subsystem: MSC

- ▶ The MSC is a central component that controls the call setup, call routing, and handover management
- ▶ It connects calls within the network and interfaces with external networks, such as the public switched telephone network (PSTN) or other cellular networks.
- ▶ It controls a number of Base Station Sites (BSSs) within a specified geographical coverage area and gives the radio subsystem access to the subscriber and equipment databases.
- ▶ When the MSC provides the interface between PSTN and the BSS in the GSM network it is called the **Gateway MSC(GMSC)**.

Network and Switching Subsystem: MSC

► Key Functions and Features of MSC:

✓ **Call Control and Routing:**

- It is used to manage call setup, call teardown, call hold, call forwarding and routing.
- When a mobile device initiates a call, the MSC is responsible for determining the destination and routing the call appropriately.
- It communicates with other network elements, such as the Base Station Controller (BSC) and other MSCs, to establish the call path.

✓ **Handovers:**

- As mobile devices move between cells while in the middle of a call, the MSC ensures a seamless handover or handoff from one cell to another

Network and Switching Subsystem: MSC

► Key Functions and Features of MSC:

✓ **Location Management:**

- The MSC keeps track of the location of mobile devices within its service area.
- This information is essential for efficient call routing and handovers.
- The VLR stores temporary location information for devices currently within the MSC's coverage area.

✓ **Interconnection:**

- The MSC serves as an interface between the cellular network and external networks, such as the Public Switched Telephone Network (PSTN) and other cellular networks.
- It facilitates call routing and interconnection with these networks.

Network and Switching Subsystem: MSC

► Key Functions and Features of MSC:

✓ **Emergency Services:**

- MSCs are responsible for supporting emergency calls (e.g., 911 or 112) and ensuring that they are appropriately routed to emergency services.

✓ **Billing and Charging:**

- MSCs play a role in call detail record (CDR) generation, which is essential for billing and charging subscribers for their mobile usage.

NSS: Home Location Register (HLR)

- ▶ HLR is a database maintained by the service provider containing **permanent data** about each subscriber (i.e. location, activity status, account status, call forwarding preference, caller identification preference)
- ▶ The data it contains is remotely accessed by all the MSCs and the VLRs in the network.
- ▶ The subscriber data may be accessed by either the IMSI or the MSISDN number.
- ▶ Although the network may contain more than one HLR, there is only one database record per subscriber .

NSS: Home Location Register (HLR)

► Key functions and features of the HLR:

- ✓ **Subscriber Information Storage**: The primary purpose of the HLR is to store subscriber-specific information, including:

- **International Mobile Subscriber Identity (IMSI)**:

- A unique identifier associated with each subscriber's SIM card.
- $IMSI = MCC + MNC + MSIN$

- MCC - Mobile Country Code
- MNC - Mobile Network Code
- MSIN - Mobile Subscriber Identification Number

- **Subscriber Authentication Key**: A secret key used for subscriber authentication and encryption of communication.
- **Subscriber Profile**: Information about the subscriber's services, preferences, and settings, such as call forwarding rules and supplementary services.
- **Current Location**: The HLR keeps track of the current location of the subscriber's mobile device,

NSS: Visitor Location Register (VLR)

- ▶ Is a database that stores **temporary data about a subscriber** (IMSI, MSISDN, current location area, and the subscriber's authentication key (Ki)).
- ▶ The VLR is always integrated with the MSC
- ▶ When a mobile station roams into a new MSC area, the VLR connected to that MSC will request data about the mobile station from the HLR.
- ▶ Later, if the mobile station makes a call, the VLR will have the information needed for call setup without having to interrogate the HLR each time.
- ▶ The data exists for only as long as the subscriber is “**active**” in the particular area covered by the VLR.

NSS: Visitor Location Register (VLR)

- ▶ The VLR plays a key role in **call routing**. When a call is received by the MSC, the VLR is consulted to determine the location of the called subscriber (based on their IMSI).
- ▶ If the called subscriber is within the current MSC's coverage area, the call can be routed directly.
- ▶ If not, the VLR assists in call routing to the appropriate MSC.
- ▶ Mobile subscribers **regularly update** their location information as they move within the network.
- ▶ The VLR tracks these updates and ensures that the MSC always has accurate information about the subscribers within its coverage area.

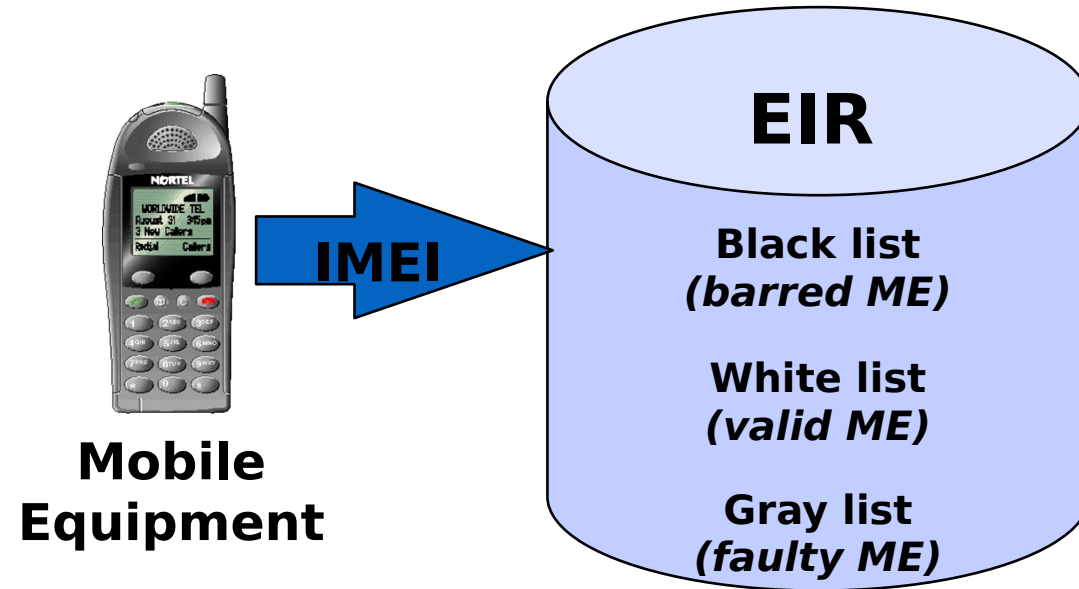
NSS: Equipment Identity Register (EIR)

- ▶ Is a database located near the MSC and containing **information identifying cell phones**
- ▶ The EIR contains a centralized database for validating the **International Mobile Equipment Identity (IMEI)**.
- ▶ This database is concerned solely with **MS equipment** and not with the subscriber
- ▶ The EIR helps in **preventing the stolen or unauthorized** use of mobile devices on the network and ensures network security.

NSS: Equipment Identity Register (EIR)

- The EIR database consists of lists of IMEIs /ranges of IMEIs organized as follows:

- ✓ **White List**
- ✓ **Black List**
- ✓ **Gray List**



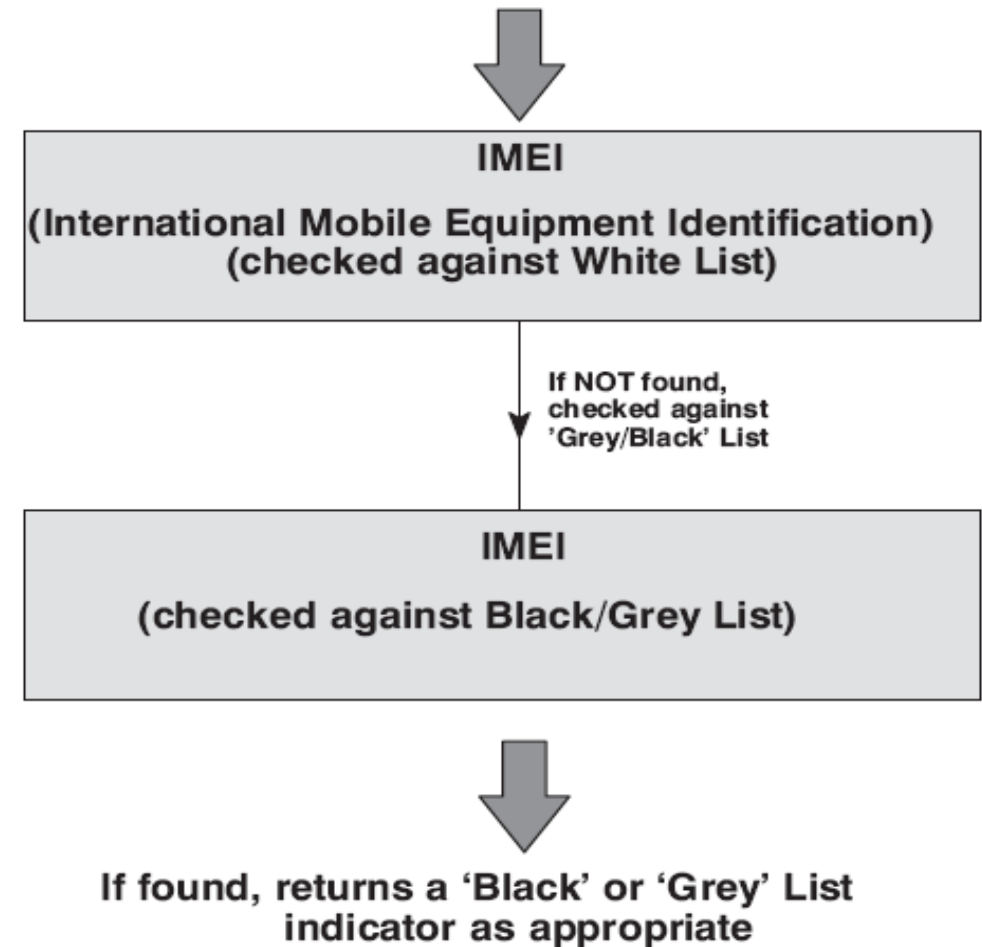
NSS: Equipment Identity Register (EIR)

- ▶ **White List:** IMEI numbers of **authorized** and **legitimate** mobile devices that are allowed to access the network.
- ▶ **Black List:** IMEI numbers of **stolen**, **lost**, or **unauthorized** devices that are barred from network access. Devices on this list are not allowed to connect to the network.
- ▶ **Gray List:** IMEI numbers that require **further inspection**, often due to suspicion of fraudulent activity. These devices may be subject to additional checks before being allowed on the network.

NSS: Equipment Identity Register (EIR)

► IMEI Check During Registration

- ✓ When a mobile device attempts to register on the network (i.e., when a subscriber inserts a SIM card or powers on the device), the network checks the device's IMEI number against the EIR database.
- ✓ If a mobile device's IMEI is found in the EIR's Black List, the network will deny access to that device



NSS: Authentication Center (AUC)

- ▶ It 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** of the radio channel.
- ▶ Authentication is done by **identification and verification of the validity of the SIM**.
- ▶ During authentication, the AUC verifies the subscriber's identity by comparing the provided credentials (e.g., IMSI, Ki) with the stored data.

NSS: Authentication Center (AUC)

- ▶ The AUC performs a **challenge-response authentication procedure** between the subscriber and the network to verify the subscriber's identity.
- ▶ For example, in a GSM network, the AUC generates a random number, which is sent to the subscriber's mobile device.
- ▶ The device then encrypts this number using an authentication key stored in a SIM card and returns the encrypted number to the network.
- ▶ The AUC compares the received response from the mobile device with the expected response based on the provided random number and the stored authentication key.
- ▶ If the responses match, authentication is successful.

NSS: Authentication Center (AUC)

► Why authentication?

- ✓ It helps to ensure that only valid subscribers with correct **credentials** and **authentication keys** can access the network
- ✓ This enhance network **security** and **preventing unauthorized access**.

GSM Services

► GSM offers three basic types of services –

✓ **Telephony services or teleservices**

- Are services provided by the system to the end user
- GSM mainly focuses on **voice-oriented** Teleservices.
- Includes **voice call, SMS, e-mail, Fax**

✓ **Data services or bearer services**

- Using GSM phone to receive and send data is the essential building block leading to widespread mobile Internet access and mobile data transfer.

GSM Services

► GSM offers three basic types of services –

✓ **Supplementary services**

- **Call Waiting:** Notifying users of incoming calls while they are already on a call.
- **Call Hold:** Allowing users to temporarily hold a call and then resume it.
- **Call Forwarding:** Diverting incoming calls to another number or voicemail.
- **Call Barring:** Restricting certain types of calls (e.g., international calls).
- **Call Transfer:** Transferring a call to another user.
- **Conferencing** with multiple participants

IS-136 Networks

- ▶ IS-136, also known as **Digital AMPS** (D-AMPS)
- ▶ It is a second-generation (2G) digital cellular technology that evolved from the original Advanced Mobile Phone System (AMPS).
- ▶ It **introduced digital capabilities** to the existing AMPS analog cellular network.
- ▶ In IS-136 networks, **digital data transmission** is supported alongside voice services, enabling limited data services.
- ▶ IS-136 primarily focuses on providing **digital voice services**, delivering improved **voice quality** and **capacity** compared to the analog AMPS system.

IS-136 Networks

- ▶ Digital voice encoding techniques, such as **time-division multiple access** (TDMA), are used for voice transmission.
- ▶ Data services in IS-136 are relatively **slow** by modern standards, with maximum data rates typically ranging from **9.6 Kbps** to **19.2 Kbps**.
- ▶ IS-136 uses **circuit-switched** data for data transmission(i.e. a dedicated channel is allocated for data sessions)
- ▶ The limited data capabilities of IS-136 networks were primarily used for basic applications, such as **text messaging**, **email**, and **simple web browsing**.
- ▶ IS-136 had **limited global adoption** and was primarily used in North America.

General Packet Radio Service(GPRS) Networks

GPRS Networks

- ▶ It was introduced as an enhancement to the second-generation GSM network by providing an **efficient way to transmit data** over existing GSM networks.
- ▶ GPRS is a **packet-switched** data service, which means that data is broken into packets and transmitted over the network as discrete units.
- ▶ GPRS offered **improved data rates** (from **56 Kbps** to **114 Kbps**) compared to the circuit-switched data capabilities of 2G GSM.

GPRS Networks - Cont ...

- ▶ GPRS offers an "always-on" connectivity model.
- ▶ This allow devices to remain connected to the internet or a data network without needing to establish a new connection for each data transfer.
- ▶ GPRS billing was typically based on the volume of data transmitted and received rather than the duration of the connection.

GPRS Networks – Cont ...

- ▶ GPRS was designed to be **compatible with existing GSM** networks, allowing operators to upgrade their networks without requiring a new infrastructure.
- ▶ GPRS networks supports mobile internet access, Short Message Service (SMS), **email**
- ▶ GPRS served as a stepping stone to more advanced mobile data technologies, including 3G (UMTS) and subsequent generations like 4G (LTE) and 5G.

Universal Mobile Telecommunication s System (UMTS) Networks

UMTS Networks

- ▶ It is a third-generation (3G) mobile cellular technology that was developed to provide **higher data transfer rates** and **improved multimedia** capabilities compared to the earlier 2G technologies like GSM
- ▶ UMTS networks support both **voice** and **data** services, making them versatile for various types of communication.
- ▶ **Voice calls are circuit-switched**, while **data services are packet-switched**.
- ▶ It offers data rates ranging from **384 Kbps** to **several Mbps**, depending on network configuration and user equipment.

UMTS Networks - Cont ...

- ▶ UMTS uses a **wideband Code Division Multiple Access (WCDMA)** radio interface for air interface communication.
- ▶ This technology allows **multiple users** to share the **same frequency band simultaneously**.
- ▶ UMTS networks support a wide range of services, including
 - ✓ **voice, video calls, text messaging (SMS), multimedia messaging (MMS), mobile internet access, and mobile data services like email and browsing.**

UMTS Networks - Cont ...

- ▶ UMTS provide different levels of **service quality**, allowing operators to **prioritize voice calls and real-time applications** while still accommodating best-effort data services.
- ▶ UMTS networks support seamless **handovers** between cells and base stations, allowing mobile users to move while maintaining their connections without interruption.
- ▶ UMTS networks support **global roaming**, enabling users to use their UMTS-enabled devices in various countries with compatible networks.
- ▶ UMTS laid the foundation for the transition to 4G technologies like LTE (Long-Term Evolution) by introducing packet-switched data services and IP-based networking principles.