Wireless WANs

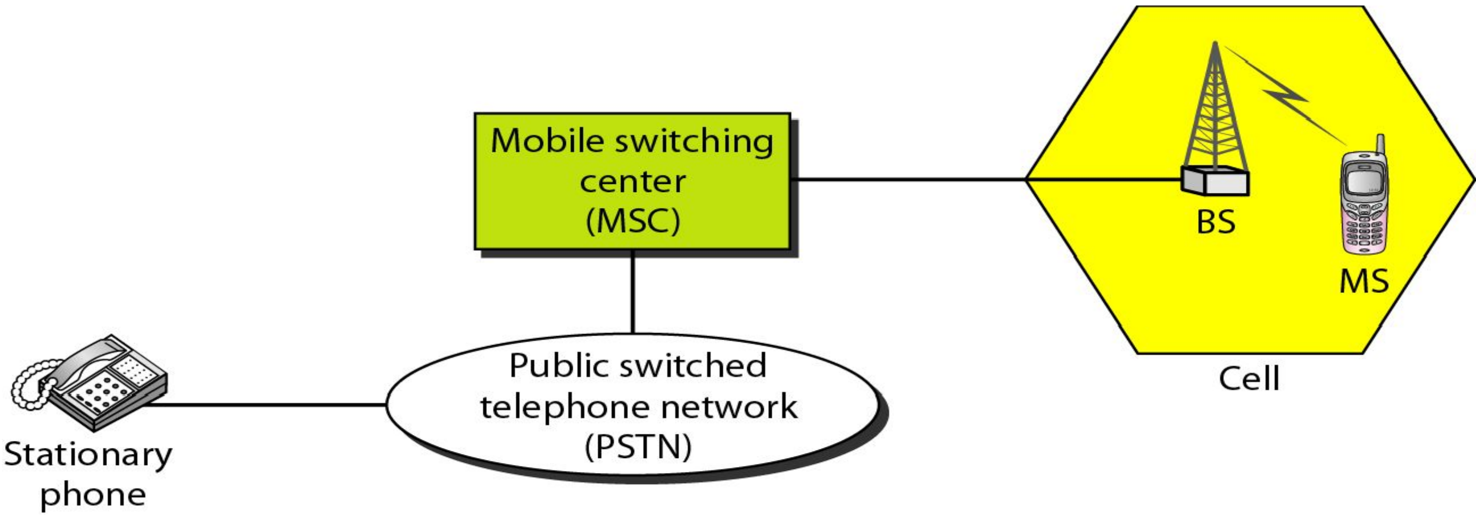
Cellular Telephone and Satellite

Networks

Wireless WAN, Cellular Networks, Mobile IP Management in Cellular Networks, Long-Term Evolution (LTE) Technology, Wireless Mesh Networks (WMNs) with LTE, Characterization of Wireless Channels.

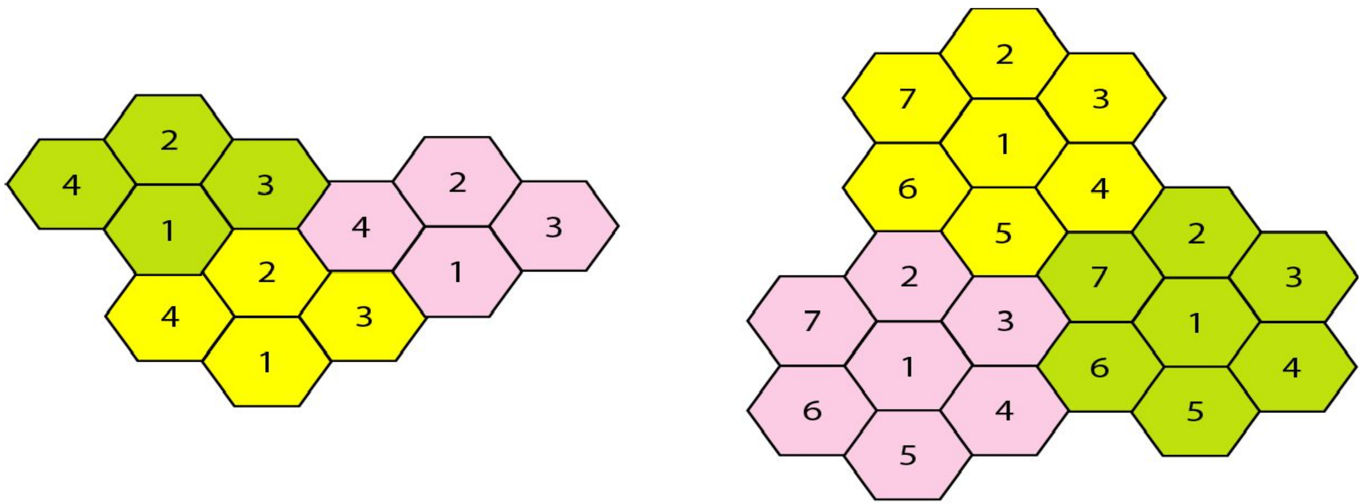
CELLULAR TELEPHONY

- **Cellular telephony** is designed to provide communications between **two moving units,** called **mobile stations (MSs**), or between **one mobile unit** and **one stationary unit**, often called a **land unit**.
- A **service provider** must be able to **locate and track a caller**, **assign a channel to the call**, and **transfer the channel from base station to base station** as the caller moves out of range.
- To make this tracking possible, each cellular service area is divided into small regions called **cells.**
- Each **cell** contains an **antenna** and is controlled by a **solar or AC powered network station**, called the **base station** (BS).
- Each base station, in tum, is controlled by a switching office, called a **mobile switching center** (MSC).
- The MSC coordinates **communication between all the base stations** and the **telephone central office**. It is a computerized center that is responsible for connecting calls, recording call information, and billing.



Frequency-Reuse Principle

- In general, **neighboring cells cannot use the same set of frequencies for communication** because it may create interference for the users located near the cell boundaries.
- However, the set of frequencies available is limited, and frequencies need to be reused.
- A **frequency reuse pattern** is a configuration of *N* cells, *N* being the **reuse factor,** in which each cell uses a unique set of frequencies.
- When the pattern is repeated, the frequencies can be reused. There are several different patterns.
- The numbers in the cells define the pattern. The cells with the same number in a pattern can use the same set of frequencies. We call these cells ***the reusing cells***.
- In a pattern with reuse factor 4, only one cell separates the cells using the same set of frequencies.
- In the pattern with reuse factor 7, two cells separate the reusing cells.



a. Reuse factor of 4

b. Reuse factor of 7

Transmitting & Receiving

Transmitting

- To place a call from a mobile station, the caller enters a code of 7 or 10 digits (a phone number) and presses the send button. The mobile station then scans the band, seeking a setup channel with a strong signal, and sends the data (phone number) to the closest base station using that channel.
- The base station relays the data to the MSC.
- The MSC sends the data on to the telephone central office.
- If the called party is available, a connection is made and the result is relayed back to the MSC.
- At this point, the MSC assigns an unused voice channel to the call, and a connection is established.
- The mobile station automatically adjusts its tuning to the new channel, and communication can begin.

Receiving

- When a mobile phone is called, the telephone central office sends the number to the MSC.
- The MSC searches for the location of the mobile station by sending query signals to each cell in a process called ***paging.***
- Once the mobile station is found, the MSC transmits a ringing signal and, when the mobile station answers, assigns a voice channel to the call, allowing voice communication to begin.

Handoff

- It may happen that, during a conversation, the mobile station moves from one cell to another.
- When it does, the signal may become weak. To solve this problem, the MSC monitors the level of the signal every few seconds.
- If the strength of the signal diminishes, the MSC seeks a new cell that can better accommodate the communication.
- The MSC then changes the channel carrying the call (hands the signal off from the old channel to a new one).

Hard Handoff

- Early systems used a hard handoff. In a hard handoff, **a mobile station only communicates with one base station.**
- When the MS moves from one cell to another, communication must first be broken with the previous base station before communication can be established with the new one. This may create a rough transition.

Soft Handoff

- New systems use a soft handoff.
- In this case, **a mobile station can communicate with two base stations at the same time**.
- This means that, during handoff, a mobile station may continue with the new base station before breaking off from the old one.

Roaming

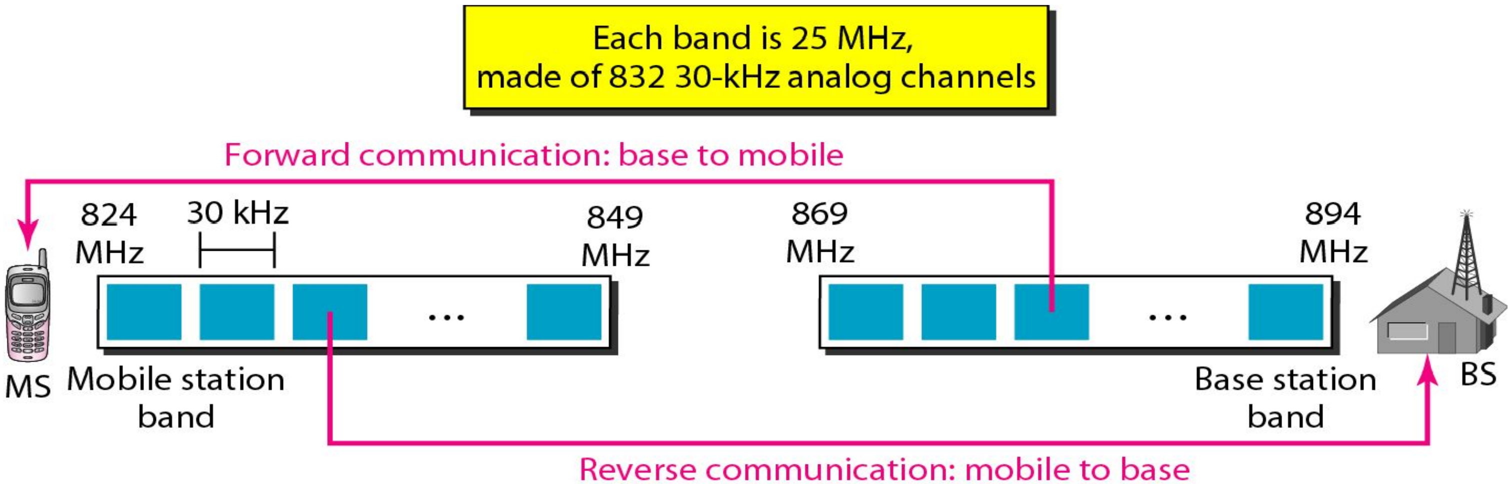
- One feature of cellular telephony is called **roaming**.
- Roaming means, in principle, that a user can have access to communication or can be reached where there is coverage.
- A service provider usually has limited coverage.
- Neighboring service providers can provide extended coverage through a roaming contract.
- The situation is similar to snail mail between countries.
- The charge for delivery of a letter between two countries can be divided upon agreement by the two countries.

AMPS – First Generation

- Advanced **Mobile Phone** System (AMPS) is one of the leading analog cellular systems in North America.
- It uses FDMA to separate channels in a link.

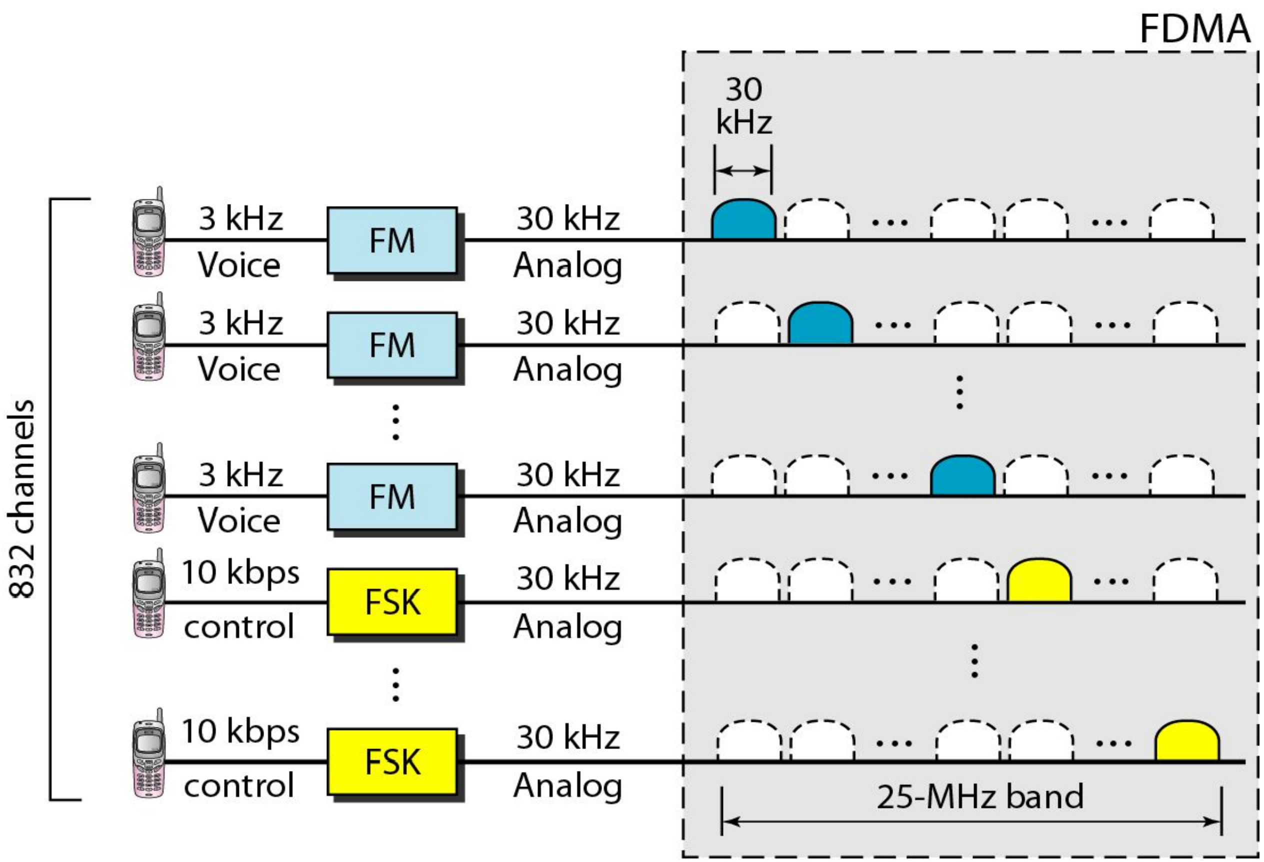
Bands

- AMPS operates in the **ISM 800-MHz band**.
- The system uses **two separate analog channels**, one for **forward** (base station to mobile station) communication and one for **reverse** (mobile station to base station) communication.
- The band between **824 and 849 MHz** carries **reverse communication**; the band between **869 and 894 MHz** carries **forward communication.**
- Each **band** is divided into **832 channels**. However, **two providers** can share an area, which means **416 channels** in each cell for each provider. Out of these 416, **21 channels are used for control**, which leaves 395 channels. AMPS has a frequency reuse factor of 7; this means only one-seventh of these 395 traffic channels are actually available in a cell.



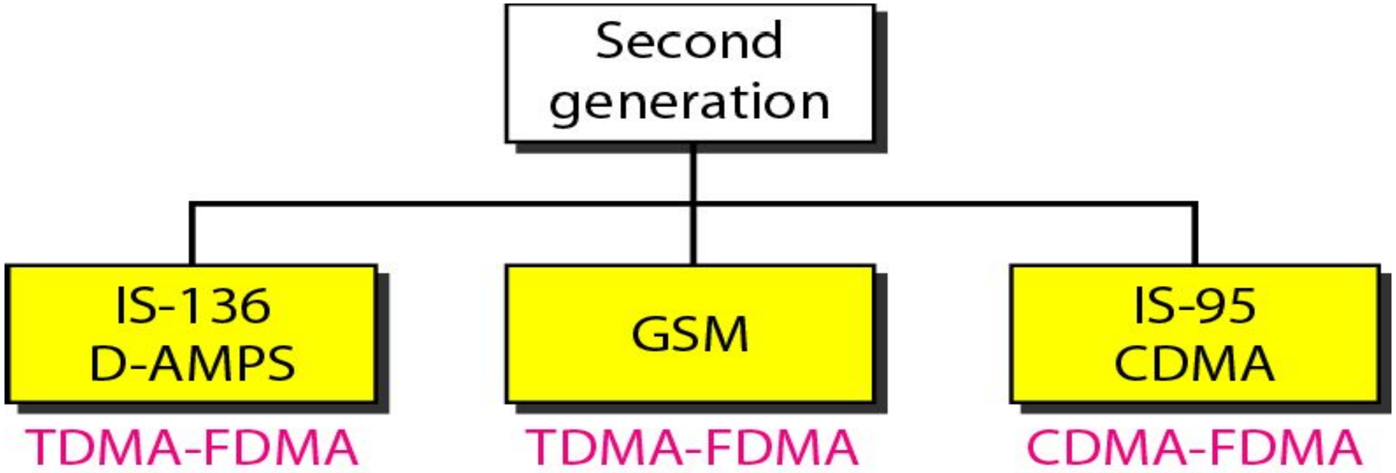
Transmission

- AMPS uses **FM and FSK for modulation**.
- **Voice channels** are modulated using **FM**, and **control channels** use **FSK** to create **30-kHz analog signals**.
- AMPS uses **FDMA** to divide each **25-MHz band into 30-kHz channels**.



Second Generation

- To provide **higher-quality (less noise-prone) mobile voice communications**, the **second generation** of the cellular phone network was developed.
- While the **first generation** was designed for **analog voice communication**, the **second generation** was mainly designed for **digitized voice**.



D-AMPS

- The product of the evolution of the analog AMPS into a digital system is **digital AMPS** (D-AMPS).
- D-AMPS was designed to be backward-compatible with AMPS. This means that in a cell, one telephone can use AMPS and another D-AMPS.
- D-AMPS was first **defined** by **IS-54** (Interim Standard 54) and later **revised** by **IS-136**.

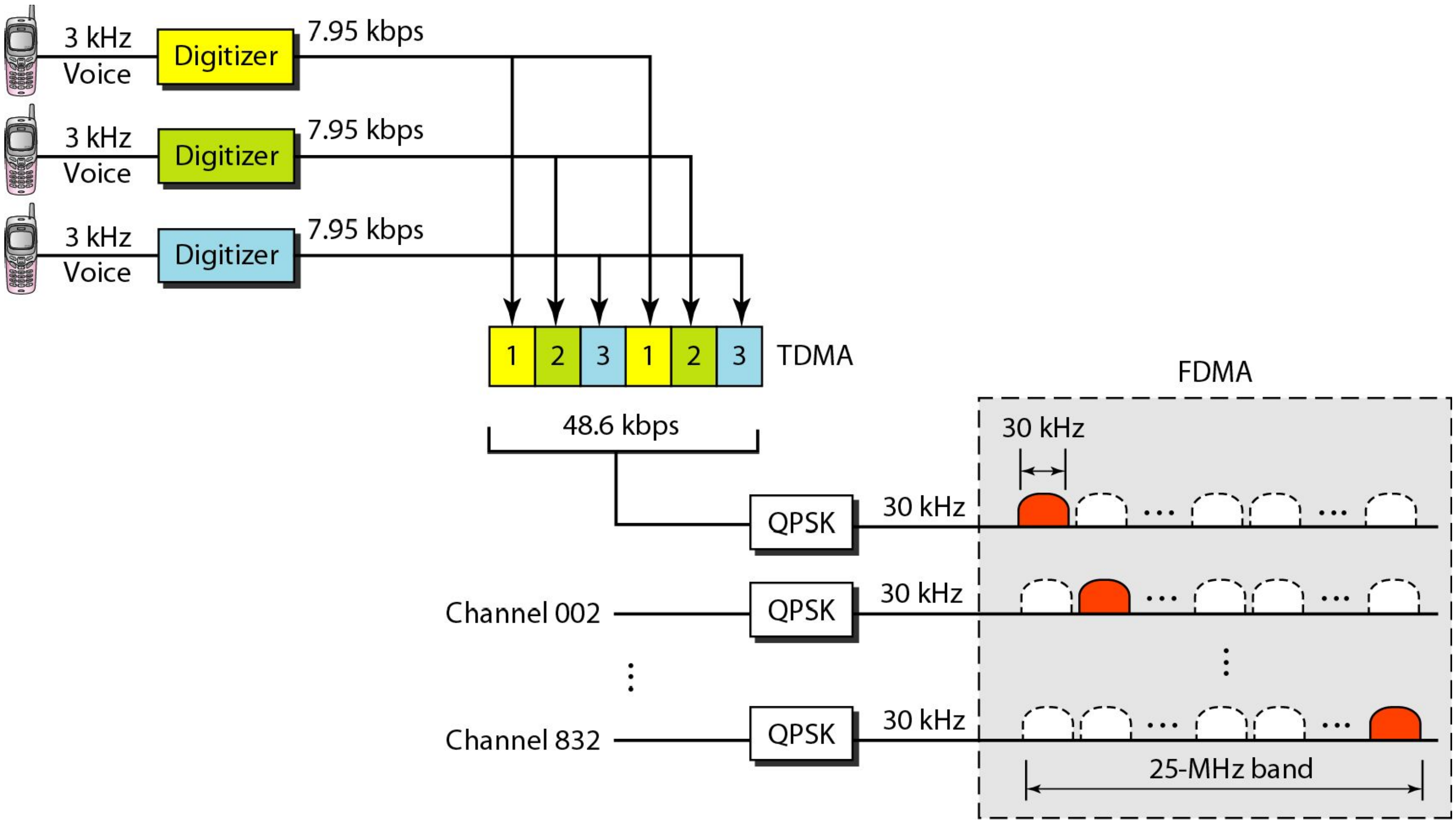
Band

- D-AMPS uses **the same bands and channels** as AMPS.

Transmission

- Each **voice channel is digitized** using a very complex **PCM and compression technique**.
- A voice channel is digitized to **7.95 kbps**.
- **Three 7.95-kbps digital voice channels** are combined using **TDMA**. The result is 48.6 kbps of digital data; much of this is overhead.
- The system sends **25 frames per second**, with **1944 bits per frame**.
- Each frame lasts **40 ms (1/25)** and is divided into **six slots** shared by three digital channels; each channel is allotted two slots.
- Each slot holds **324 bits**. However, only **159 bits** comes from the **digitized voice**; **64 bits** are for **control** and **101 bits are for error correction**.
- The system adds 64 control bits and 101 error-correcting bits.
- The resulting **48.6 kbps of digital data** modulates a carrier using **QPSK;** the result is a **30-kHz analog signal.**
- The **30-kHz analog signals** share a **25-MHz band (FDMA).** D-AMPS has a **frequency reuse factor of 7.**
- **D-AMPS is a digital cellular phone system using TDMA & FDMA.**

D-AMPS



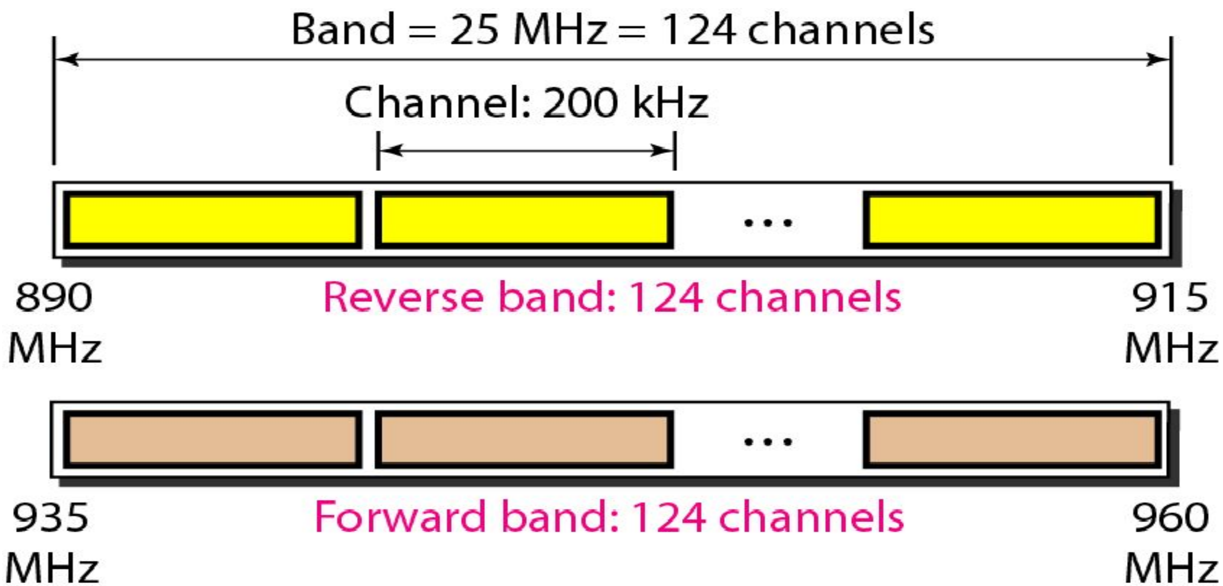
3 kHz
Voice
Digitizer
7.95 kbps
3 kHz
Voice
Digitizer
7.95 kbps
3 kHz
Voice
Digitizer
7.95 kbps
1 2 3 1 2 3
TDMA
48.6 kbps
QPSK
30 kHz
Channel 002
QPSK
30 kHz
Channel 832
QPSK
30 kHz
FDMA
30 kHz
25-MHz band

GSM

- The **Global System for Mobile Communication** (GSM) is a European standard that was developed to provide a common second-generation technology for all Europe.
- The aim was to replace a number of incompatible first-generation technologies.
- GSM is a digital cellular phone system using **TDMA & FDMA**.

Bands

- **GSM** uses **two bands** for **duplex communication**.
- Each band is **25 MHz** in **width**, shifted toward **900 MHz**.
- Each band is divided into **124 channels of 200 kHz** separated by **guard bands**.



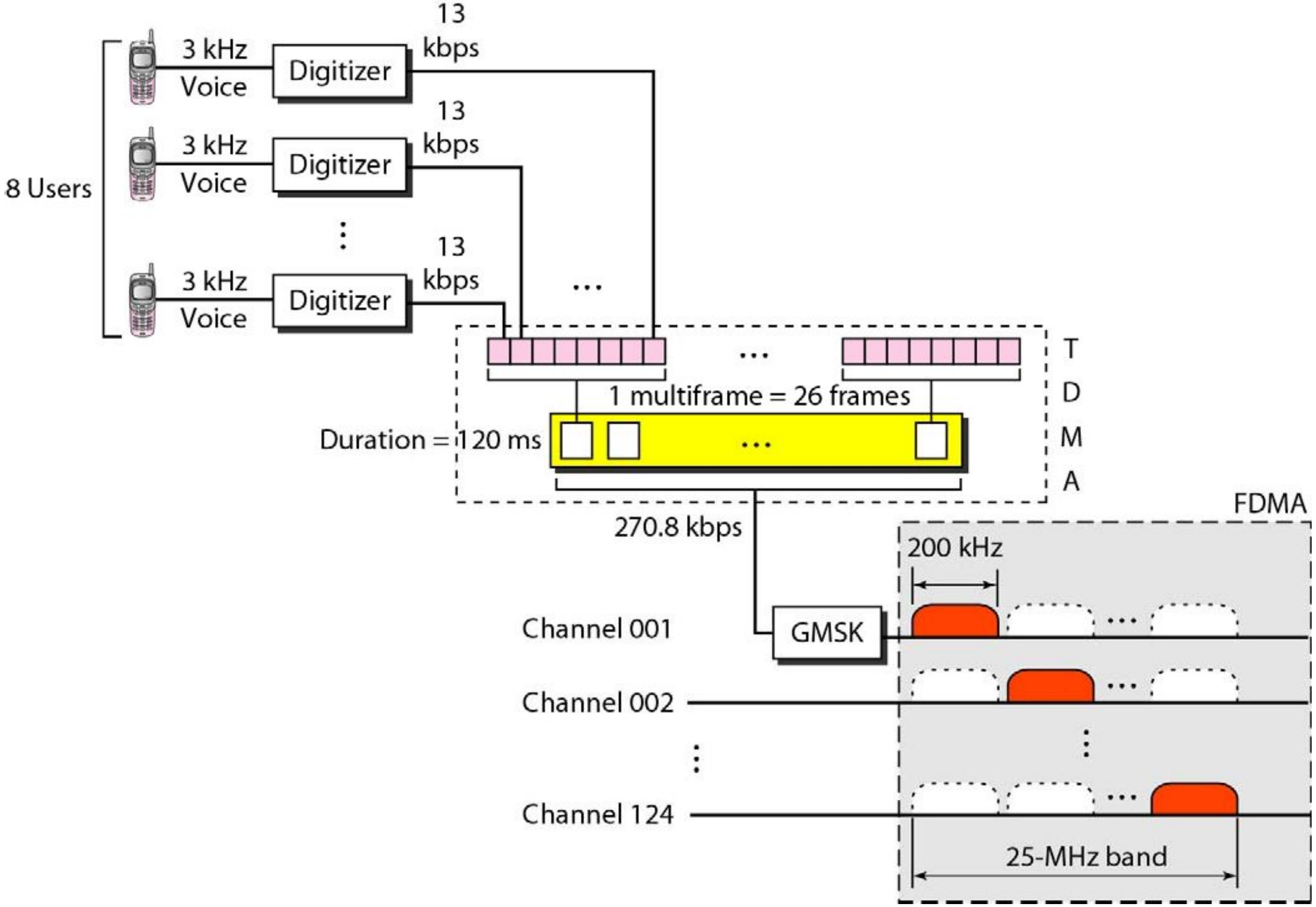
Transmission

- 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).
- 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.
- 124 analog channels of 200 kHz are combined using FDMA. The result is a 25-MHz band.
- The user data are only 65 bits per slot. The system adds extra bits for error correction to make it 114 bits per slot. To this, control bits are added to bring it up to 156.25 bits per slot.
- Eight slots are encapsulated in a frame. Twenty-four traffic frames and two additional control frames make a multiframe.
- A multiframe has a duration of 120 ms.

Reuse Factor

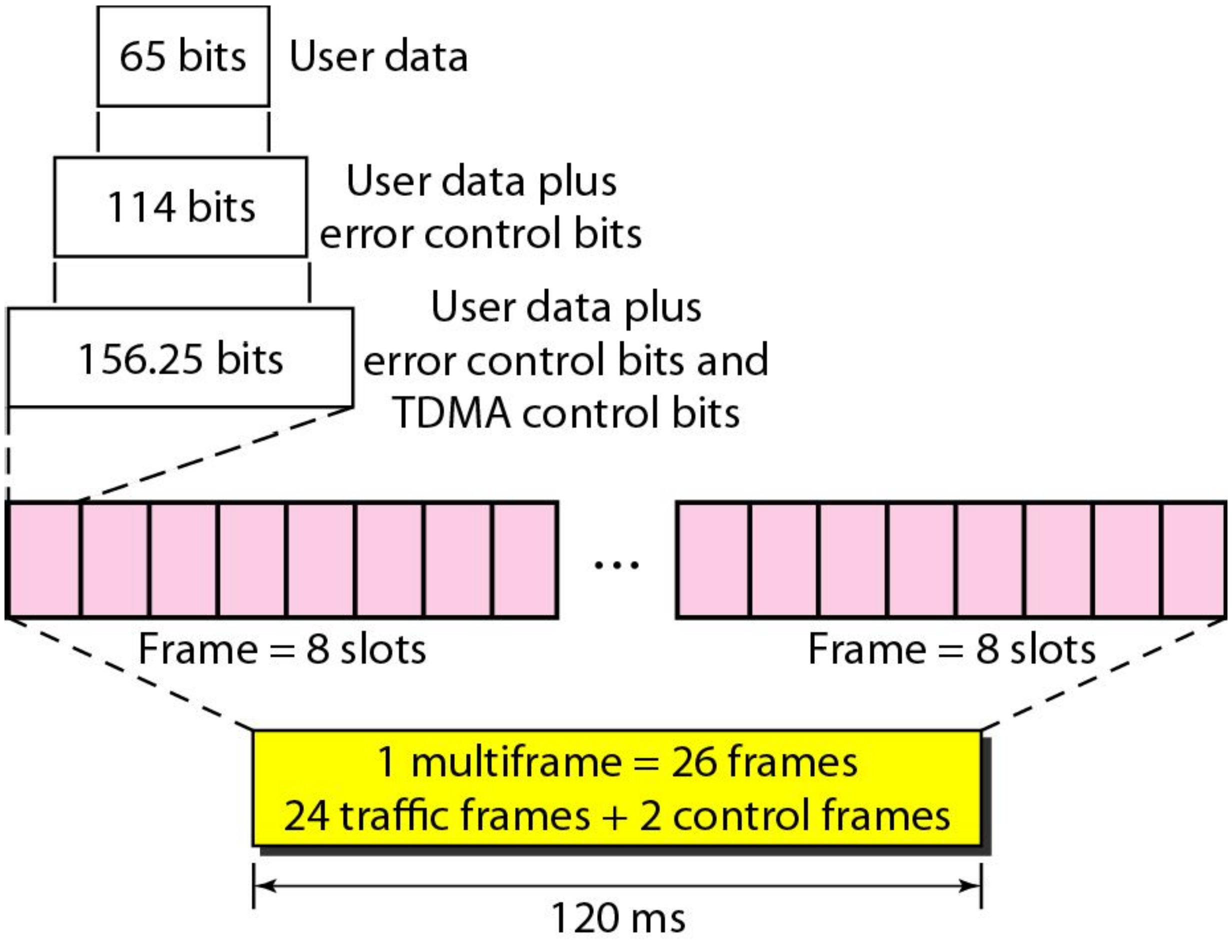
Because of the complex error correction mechanism, GSM allows a **reuse factor as low as 3.**

GSM



8 Users
3 kHz
Voice
Digitizer
13
kbps
3 kHz
Voice
Digitizer
13
kbps
3 kHz
Voice
Digitizer
13
kbps
1 multiframe = 26 frames
Duration = 120 ms
T
D
M
A
270.8 kbps
FDMA
200 kHz
GMSK
Channel 001
Channel 002
Channel 124
25-MHz band

Multiframe components



IS-95

- One of the dominant second-generation standards in North America is Interim Standard 95 (IS-95).
- It is based on CDMA and DSSS.

Bands and Channels

- IS-95 uses two bands for **duplex communication**.
- The bands can be the **traditional ISM 800-MHz band** or the **ISM 1900-MHz band**.
- Each band is divided into **20 channels** of 1.228 MHz separated by guard bands.
- Each **service provider** is allotted **10 channels**.
- **IS-95** can be used **in parallel with AMPS**. Each **IS-95 channel is equivalent to 41 AMPS channels** (41 x 30 kHz=1.23 MHz).

Synchronization

- All base channels need to be synchronized to use CDMA.
- To provide synchronization, bases use the services of GPS (Global Positioning System), a satellite system.

Two Data Rate Sets

- IS-95 defines **two data rate sets**, with **four different rates** in each set.
- The **first set** defines 9600, 4800, 2400, and 1200 bps.
- The **second set** defines 14,400, 7200, 3600, and 1800 bps.
- This is possible by reducing the number of bits used for error correction.
- The bit rates in a set are related to the activity of the channel.
- If the channel **is silent**, only **1200 bits** can be transferred, which improves the spreading by repeating each bit 8 times.
- Frequency-Reuse Factor In an IS-95 system, the **frequency-reuse factor is normally 1** because the interference from neighboring cells cannot affect CDMA or DSSS transmission.

Transmission

IS-95 has two different transmission techniques: one for use in the forward (base to mobile) direction and another for use in the reverse (mobile to base) direction.

Soft Handoff

Every base station continuously broadcasts signals using its pilot channel.

This means a mobile station can detect the pilot signal from its cell and neighboring cells.

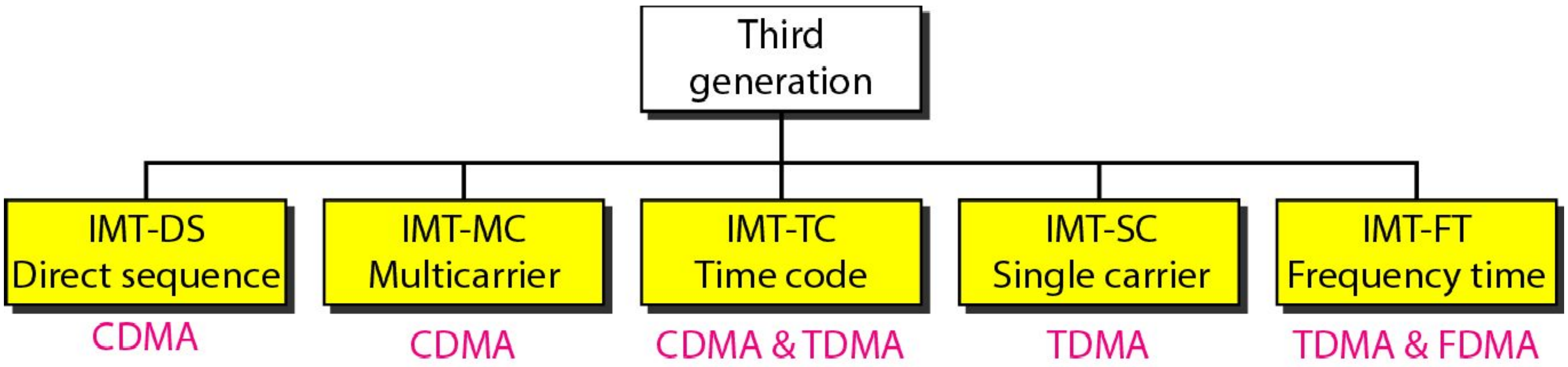
This enables a mobile station to do a soft handoff in contrast to a hard handoff.

Third Generation

- The third generation of cellular telephony refers to a combination of technologies that provide a variety of services.
- The third generation can provide both **digital data and voice communication**.
- Using a small portable device, a person should be able to talk to anyone else in the world with a voice quality similar to that of the existing fixed telephone network.
- A person can download and watch a movie, can download and listen to music, can surf the Internet or play games, can have a video conference, and can do much more.
- One of the interesting characteristics of a third generation system is that the portable device is always connected; you do not need to dial a number to connect to the Internet.
- 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**.
    - Interface to the Internet.

IMT-2000 radio interfaces

- **IMT-DS** This approach uses a version of **CDMA called wideband CDMA** or **W-CDMA**. W-CDMA uses a **5-MHz bandwidth**. It was developed in Europe, and it is compatible with the CDMA used in IS-95.
- **IMT-MC** This approach was developed in North America and is known as **CDMA 2000**. It is an evolution of CDMA technology used in IS-95 channels. It combines the new wideband (I5-MHz) spread spectrum with the narrowband (l.25-MHz) CDMA of IS-95. It is backward-compatible with IS-95. It allows communication on multiple 1.25-MHz channels (l, 3, 6, 9, 12 times), up to 15 MHz. The use of the wider channels allows it to reach the 2-Mbps data rate defined for the third generation.
- **IMT-TC** This standard uses a combination of **W-CDMA and TDMA**. The standard tries to reach the IMT-2000 goals by adding TDMA multiplexing to W-CDMA.
- **IMT-SC** This standard only uses **TDMA.**
- **IMT-FT** This standard uses a combination of **FDMA and TDMA.**

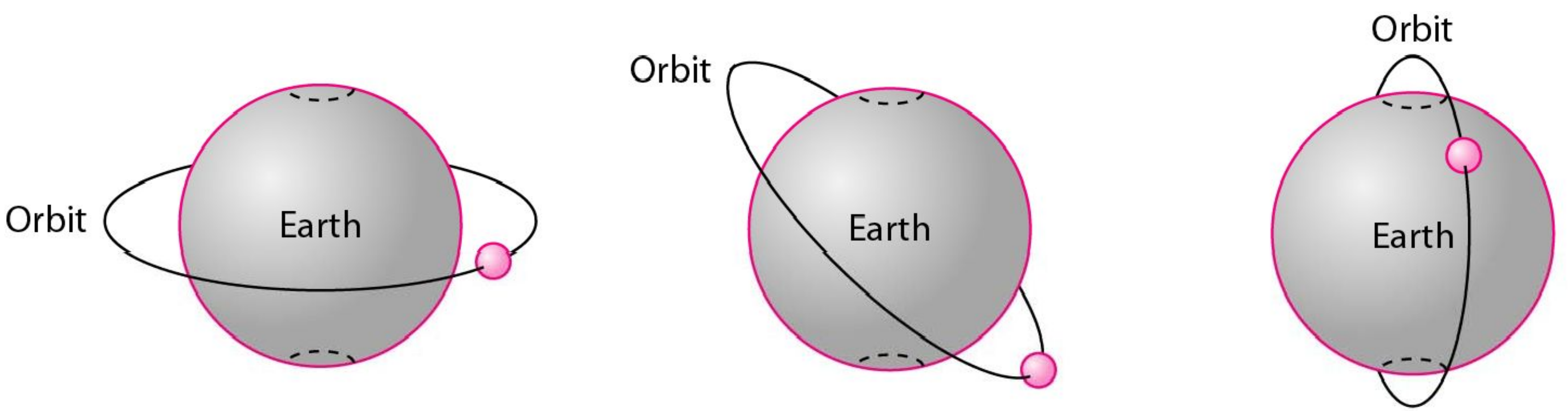


SATELLITE NETWORKS

- A **satellite network** is a combination of nodes, some of which are satellites, that provides communication from one point on the Earth to another..
- A node in the network can be a **satellite, an Earth station, or an end-user terminal or telephone.**
- Satellite networks are like **cellular networks** in that they divide the planet into cells.
- Satellites can provide **transmission capability** to and from any location on Earth, no matter how **remote**.
- This advantage makes **high-quality communication** available to **undeveloped parts of** the world **without requiring a huge investment in ground-based infrastructure**.

Orbits

- An artificial satellite needs to have an orbit, the path in which it travels around the Earth.
- The orbit can be **equatorial, inclined, or polar**.
- The **period of a satellite**, the time required for a satellite to make a complete trip around the Earth, is determined by **Kepler's law**, which defines the period as a function of the **distance** of the **satellite from the center of the Earth**.



a. Equatorial-orbit satellite b. Inclined-orbit satellite c. Polar-orbit satellite

What is the period of the Moon, according to Kepler's law?

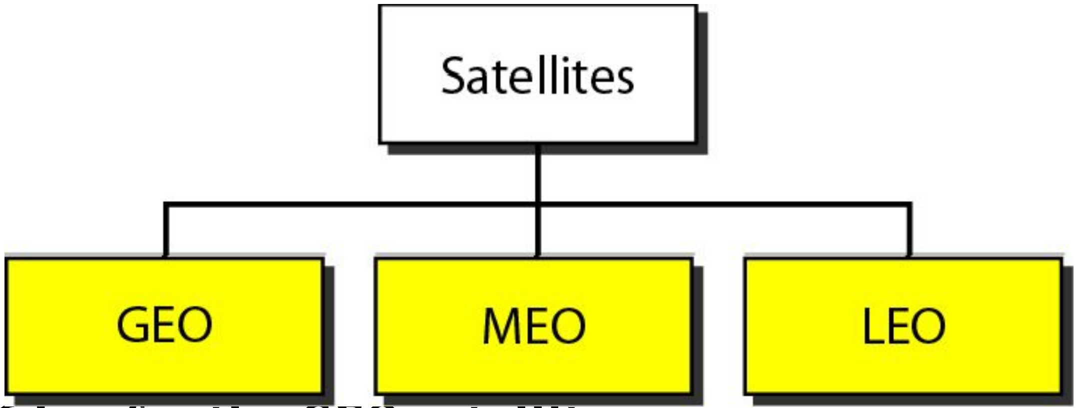
$$\boxed{\text{Period} = C \times \text{distance}^{1.5}}$$

Here C is a constant approximately equal to 1/100. The period is in seconds and the distance in kilometers. The Moon is located approximately 384,000 km above the Earth. The radius of the Earth is 6378 km.

$$\boxed{\text{Period} = \frac{1}{100}(384{,}000 + 6378)^{1.5} = 2{,}439{,}090 \text{ s} = 1 \text{ month}}$$

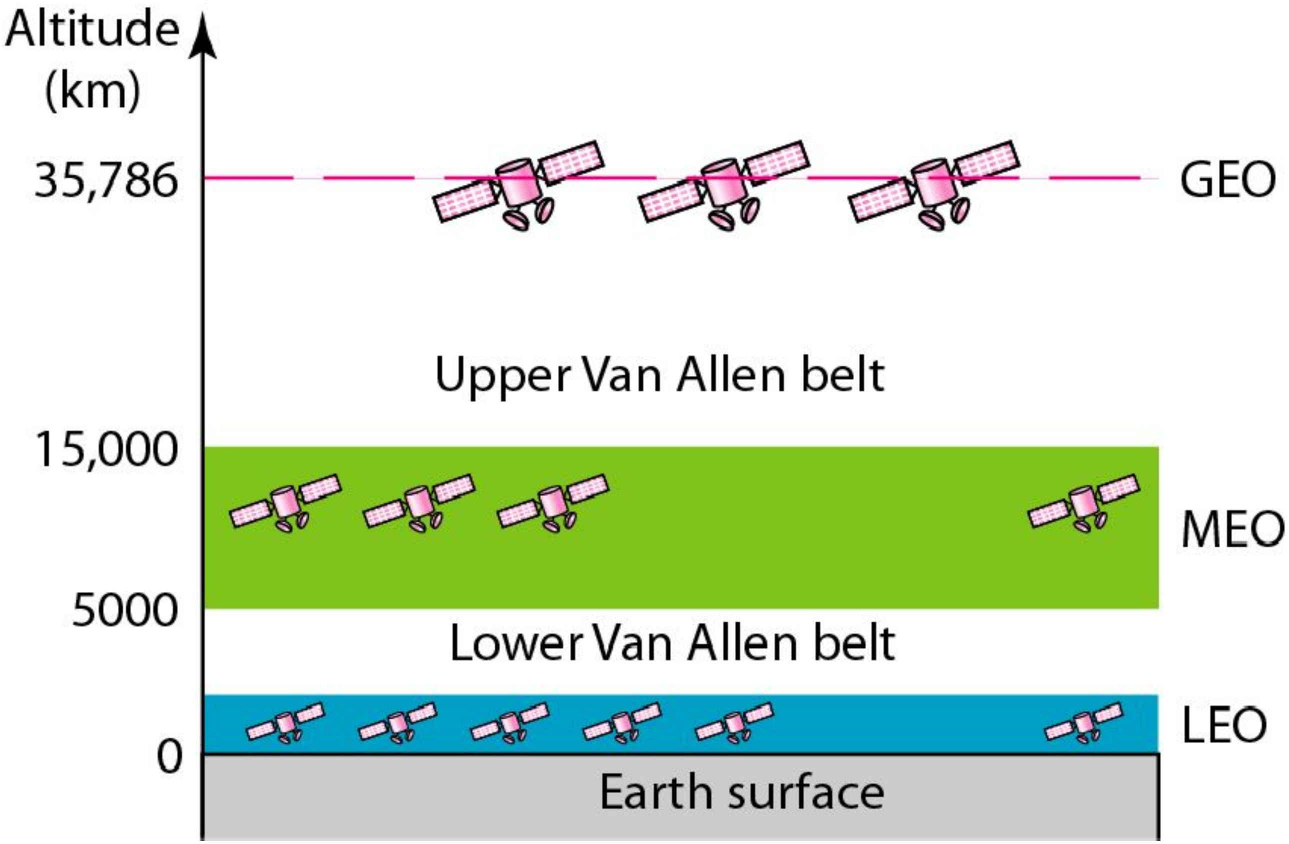
Footprint

- Satellites process microwaves with **bidirectional antennas** (line-of-sight).
- Therefore, the signal from a satellite is normally aimed at a specific area called the **footprint**.
- The signal power at the center of the footprint is **maximum**.
- The power decreases as we move out from the footprint center.
- The boundary of the footprint is the location where the power level is at a predefined threshold.
- **Three Categories of Satellites:**
  - Geostationary Earth orbit (GEO)
  - low-Earth-orbit (LEO)
  - middle-Earth-orbit (MEO)



- There is only one orbit, at an altitude of **35,786 km for the GEO satellite**.
- MEO satellites are located at altitudes between **5000 and 15,000 km.**
- LEO satellites are normally below an altitude of **2000 km.**

Satellite orbit altitudes



Frequency Bands for Satellite Communication

The frequencies reserved for satellite microwave communication are in the gigahertz (GHz) range.

Each satellite sends and receives over two different bands.

Transmission from the **Earth to the satellite** is called the **uplink**.

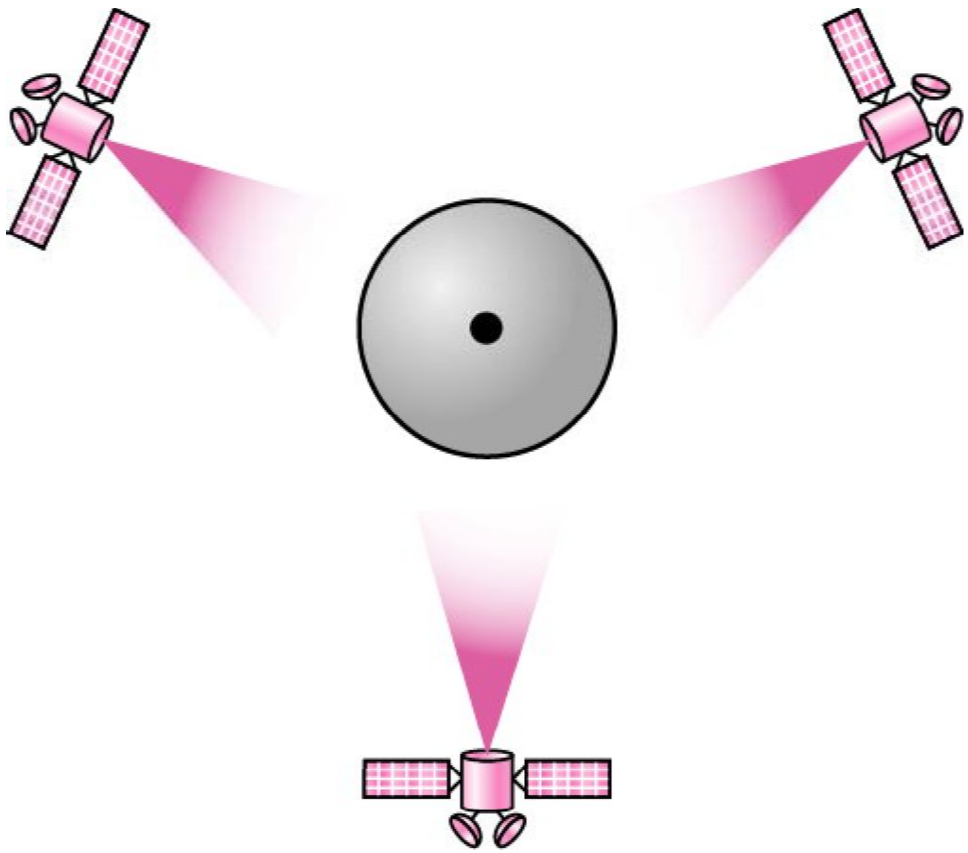
Transmission from the **satellite to the Earth** is called the **downlink.**

Band	*Downlink, GHz*	*Uplink, GHz*	*Bandwidth, MHz*
L	1.5	1.6	15
S	1.9	2.2	70
C	4.0	6.0	500
Ku	11.0	14.0	500
Ka	20.0	30.0	3500

GEO Satellites

- To ensure constant communication, the satellite must move at the same speed as the Earth so that it seems to remain fixed above a certain spot. Such satellites are called ***geostationary.***
- Because orbital speed is based on the distance from the planet, only one orbit can be geostationary.
- This orbit occurs at the equatorial plane and is approximately 22,000 miles from the surface of the Earth.
- But one geostationary satellite cannot cover the whole Earth. One satellite in orbit has line-of-sight contact with a vast number of stations, but the curvature of the Earth still keeps much of the planet out of sight.
- It takes a minimum of three satellites equidistant from each other in geostationary Earth orbit (GEO) to provide full global transmission.

Satellites in geostationary orbit

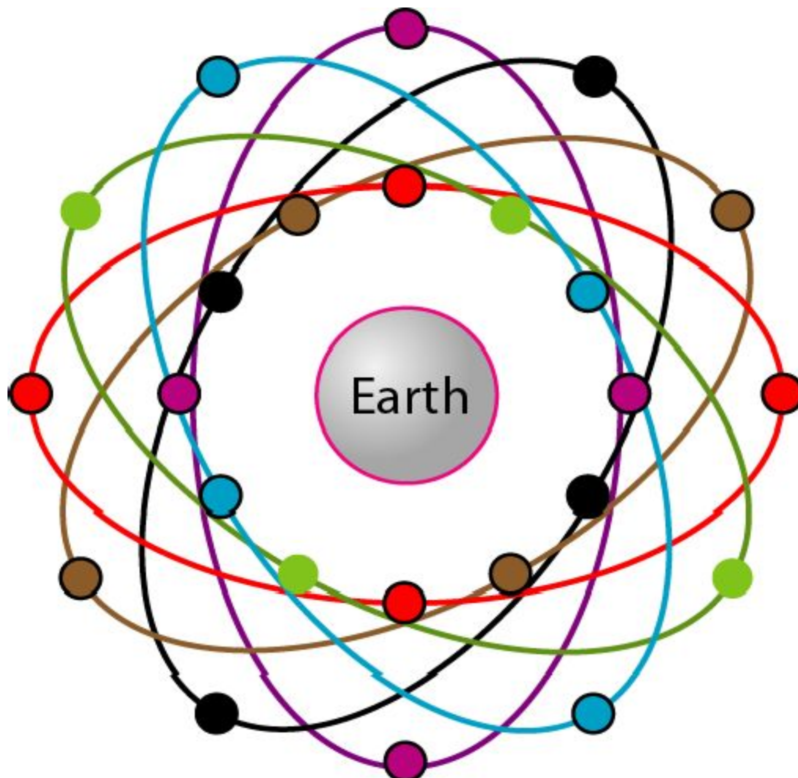


MEO Satellites

- Medium-Earth-orbit (MEO) satellites are positioned between the two Van Allen belts.
- A satellite at this orbit takes approximately 6-8 hours to circle the Earth.

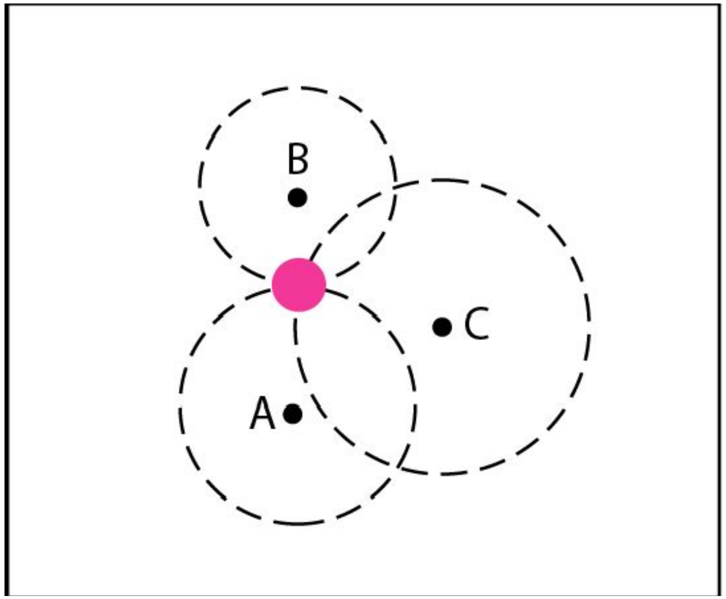
Global Positioning System

- One example of a MEO satellite system is the **Global Positioning System (GPS),** operated by the US Department of Defense, orbiting at an altitude about 18,000 km above the Earth.
- The system consists of **24 satellites** and is used for land, sea, and air navigation to provide time and locations for vehicles and ships.
- GPS uses **24 satellites in six orbits**.
- The orbits and the locations of the satellites in each orbit are designed in such a way that, at any time, four satellites are visible from any point on Earth.
- A GPS receiver has an almanac that tells the current position of each satellite.



Trilateration

- GPS is based on a principle called **trilateration**.
- On a plane, if we know our distance from three points, we know exactly where we are.
- Let us say that we are 10 miles away from point A, 12 miles away from point B, and 15 miles away from point C. If we draw three circles with the centers at A, B, and C, we must be somewhere on circle A, somewhere on circle B, and somewhere on circle C. These three circles meet at one single point (if our distances are correct), our position.



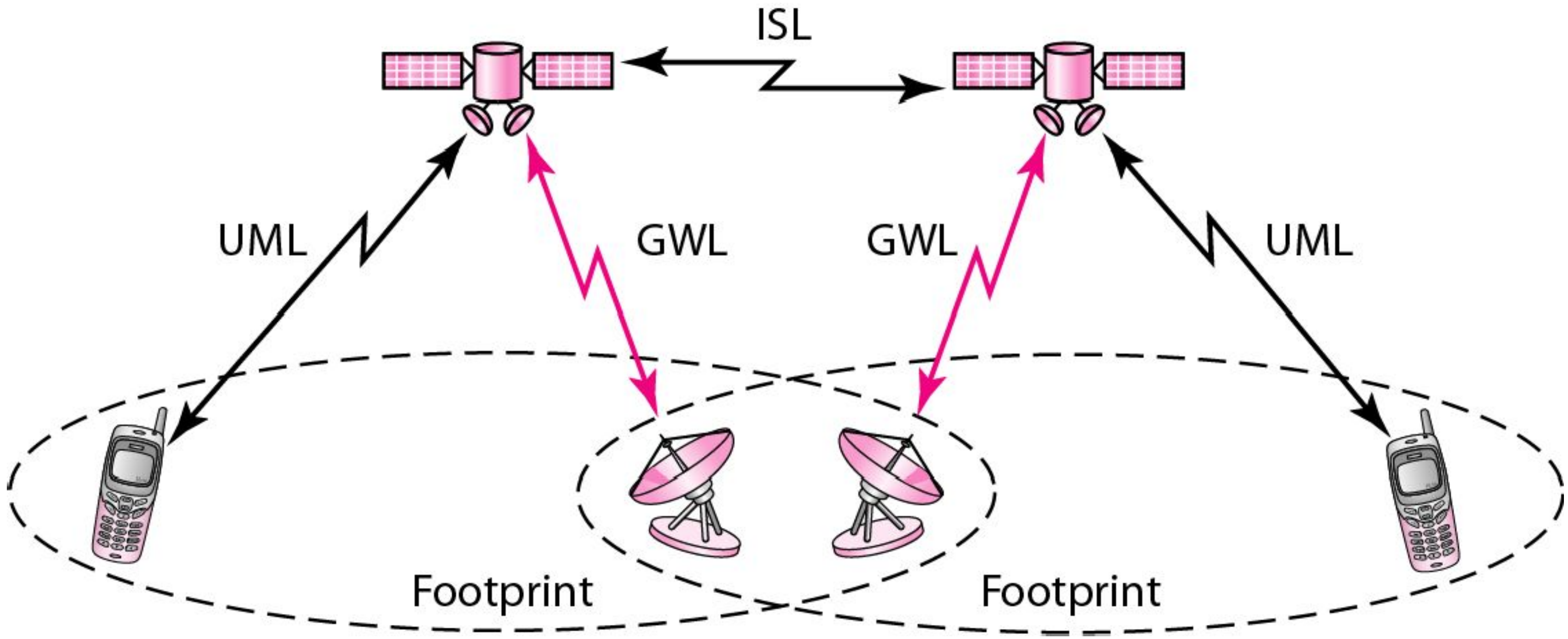
Applications

- GPS is used by **military forces**. For example, thousands of portable GPS receivers were used during the Persian Gulf war by foot soldiers, vehicles, and helicopters.
- Another use of GPS is in **navigation**. The driver of a car can find the location of the car. The driver can then consult a database in the memory of the automobile to be directed to the destination. **In** other words, GPS gives the location of the car, and the database uses this information to find a path to the destination.
- A very interesting application is **clock synchronization**. The IS-95 cellular telephone system uses GPS to create time synchronization between the base stations.

LEO Satellites

- Low-Earth-orbit (LEO) satellites have polar orbits. The altitude is between 500 and 2000 km, with a rotation period of 90 to 120 min.
- The satellite has a speed of 20,000 to 25,000 km/h.
- An LEO system usually has a cellular type of access, similar to the cellular telephone system.
- The footprint normally has a diameter of 8000 km. Because LEO satellites are close to Earth, the round-trip time propagation delay is normally less than 20 ms, which is acceptable for audio communication.
- An LEO system is made of a **constellation of satellites** that work together as a network; each satellite acts as a **switch**.
- **Satellites** that are close to each other are connected through **intersatellite links (ISLs)**.
- A **mobile system communicates with the satellite** through a **user mobile link (UML).**
- A **satellite can also communicate with an Earth station** (gateway) through a **gateway link (GWL).**

LEO satellite system

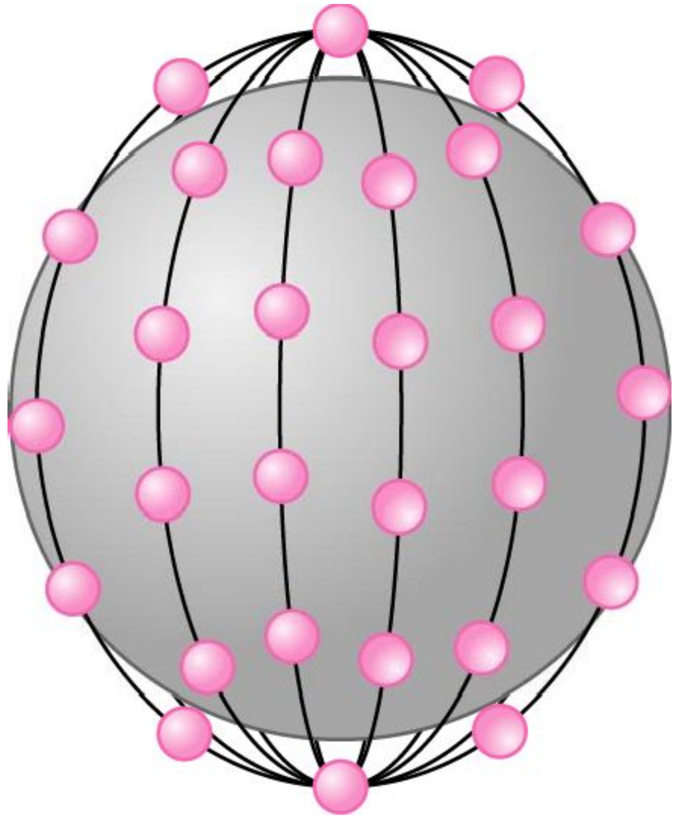


LEO satellites categories

- LEO satellites can be divided into three categories: little LEOs, big LEOs, and broadband LEOs.
- The **little LEOs** operate under **1 GHz.** They are mostly used for **low-data-rate messaging**.
- The **big LEOs** operate between **1 and 3 GHz. Globalstar and Iridium systems** are examples of big LEOs.
- The **broadband LEOs** provide **communication** similar to **fiberoptic networks**. The first broadband LEO system was **Teledesic**.

Iridium System

- The concept of the Iridium system, a **77-satellite network**, was started by Motorola in 1990.
- The project took eight years to materialize. During this period, the number of satellites was reduced.
- Finally, in 1998, the service was started with 66 satellites. The original name, Iridium, came from the name of the 77th chemical element; a more appropriate name is Dysprosium (the name of element 66).
- Iridium has gone through rough times.
- The system was halted in 1999 due to financial problems;
- it was sold and restarted in 2001 under new ownership.
- The system has **66 satellites divided into six orbits, with 11 satellites in each orbit**.
- The orbits are at an altitude of **750 km**.
- The satellites in each orbit are separated from one another by **approximately 32° of latitude**.



- Since each satellite has **48 spot beams**, the system can have up to **3168 beams**.
- However, some of the beams are turned off as the satellite approaches the pole.
- The number of **active spot beams** at any moment is approximately **2000.**
- Each spot beam covers a cell on Earth, which means that Earth is divided into approximately 2000 (overlapping) cells.
- In the Iridium system, communication between two users takes place through satellites.
- When a user calls another user, the call can go through several satellites before reaching the destination. This means that relaying is done in space and each satellite needs to be sophisticated enough to do relaying. This strategy eliminates the need for many terrestrial stations.
- The whole purpose of Iridium is to **provide direct worldwide communication** using **handheld terminals (same concept as cellular telephony).**
- The system can be used for **voice, data, paging, fax, and even navigation.**
- The system can provide connectivity between users at locations where other types of communication are not possible.
- The system provides **2.4- to 4.8-kbps voice and data transmission** between portable telephones.
- Transmission occurs in the **1.616- to 1.6126-GHz frequency band**.
- **Intersatellite communication** occurs in the **23.18- to 23.38-GHz frequency band**.

Globalstar

- Globalstar is another LEO satellite system.
- The system uses **48 satellites in six polar orbits** with each orbit hosting **eight satellites**.
- The orbits are located at an **altitude of almost 1400 km.**
- The Globalstar system is similar to the Iridium system; the main difference is the relaying mechanism.
- Communication between two distant users in the Iridium system requires relaying between several satellites;
- Globalstar communication requires **both satellites and Earth stations**, which means that ground stations can create more powerful signals.

Teledesic

- Teledesic is a system of satellites that provides **fiber-optic-like** (broadband channels, low error rate, and low delay) communication.
- Its main purpose is to **provide broadband Internet access** for users allover the world. It is sometimes called "**Internet in the sky**."
- The project was started in 1990 by Craig McCaw and Bill Gates; later, other investors joined the consortium.
- **Constellation** Teledesic provides **288 satellites in 12 polar orbits** with each orbit hosting **24 satellites.** The orbits are at an **altitude of 1350 km.**

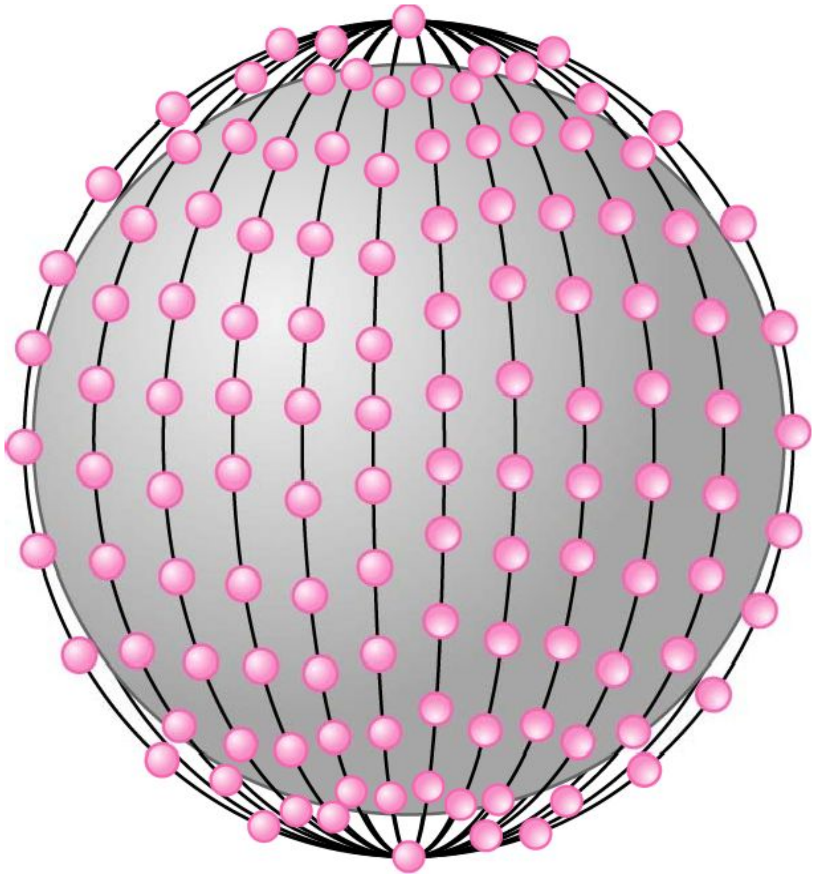
Communication The system provides three types of communication. **Intersatellite communication** allows **eight neighboring satellites** to communicate with one another. Communication is also possible between **a satellite and an Earth gateway s**tation. Users can communicate directly with the **network using terminals**.

Earth is divided into tens of thousands of cells. Each cell is assigned a time slot, and the satellite focuses its beam to the cell at the corresponding time slot. The terminal can send data during its time slot. A terminal receives all packets intended for the cell, but selects only those intended for its address.

Bands Transmission occurs in the Ka bands.

Data Rate The data rate is up to **155 Mbps for the upli**nk and up to **1.2 Gbps for the downlink**.

Teledesic



Wireless Mesh Networks

Wireless Mesh N/ws:

* WMNs is a dynamically self-organised wireless nwk. that maintains mesh connectivity.
* WiMax – Worldwide Interoperability for Microwave Access is a certification mark for IEEE 802.16 std.
* This std. is implemented for point-to-multipoint broadband wireless access.
* WiMax is a WAN technology that can connect IEEE 802.11 WiFi hotspots with one another & to other parts of the Internet.
* WiMax is similar to WiFi technology
* Two types of nodes perform the routing:
  (i) mesh routers
  (ii) mesh users.
* A WiFi nwk, cellular nwk., WiMax nwk. are connected through mesh routers with gateway bridges.
* A router with gateway bridge capability enables the integration of WMNs with other types of nwks.
* Mesh users operate as routers for mesh networking making the connection simpler & faster than conventional wireless nwks. with base station.

Benefits of mesh nwk :

1) Scalability : WMN infrastructure is designed to be scalable as the need of nwk. access increases.

2) Adhoc nwking support : capability to reorganize and get connected for a short period of time.

3) Mobility support of end nodes : End nodes are supported through wireless infra structure.

4) Connectivity in wired infrastructure : Gateway mesh routers integrate networks in both wired & wireless fashions.

Physical & MAC layers of WMNs :

* Physical layer of wireless mesh networks benefits from existing modulation & coding rates.
* Orthogonal Frequency Multiple Access (OFDM) & Ultrawide Band (UWB) → support high speed wireless communication.
* WMN communication & system capacity have been improved through use of multi antenna system → antenna diversity, smart antenna & MIMO systems.
* MIMO algs. send info. over 2 or more antennae.
* Radio signals reflect objects making multiple paths causing interference & fading.

- It uses the cognitive radios which capture unoccupied spectrum. (programmed & configured dynamically to use the best wireless channels.)

Unique feature → all components of the radio, - RF bands, channel access modes, channel modulations are programmable.

MAC layer:

* In WMNs, MAC layer
  (i) designed to face more than one hop communication.
  (ii) distributed to support multipoint-to-multipoint communication.
  (iii) has self-organization features.
  (iv) has moderately lower mobility than classical wireless networks.

* Wireless mesh protocols are designed to use single channel or multiple channels or to operate simultaneously.

* ~~A~~ multiple-channel MAC setup improves network performance by increasing network capacity.

* uses enhanced versions of TDMA & CDMA.

* In multichannel single transceiver MAC, only one channel can be active at a time in each nwk. node, as one transceiver is available.

* In multichannel multi transceiver MAC, several channels are active simultaneously and only one MAC layer module is assigned to coordinate all channels.

* With multiradio MAC, each node has multiple radios and each radio has its own MAC layer and physical layer.

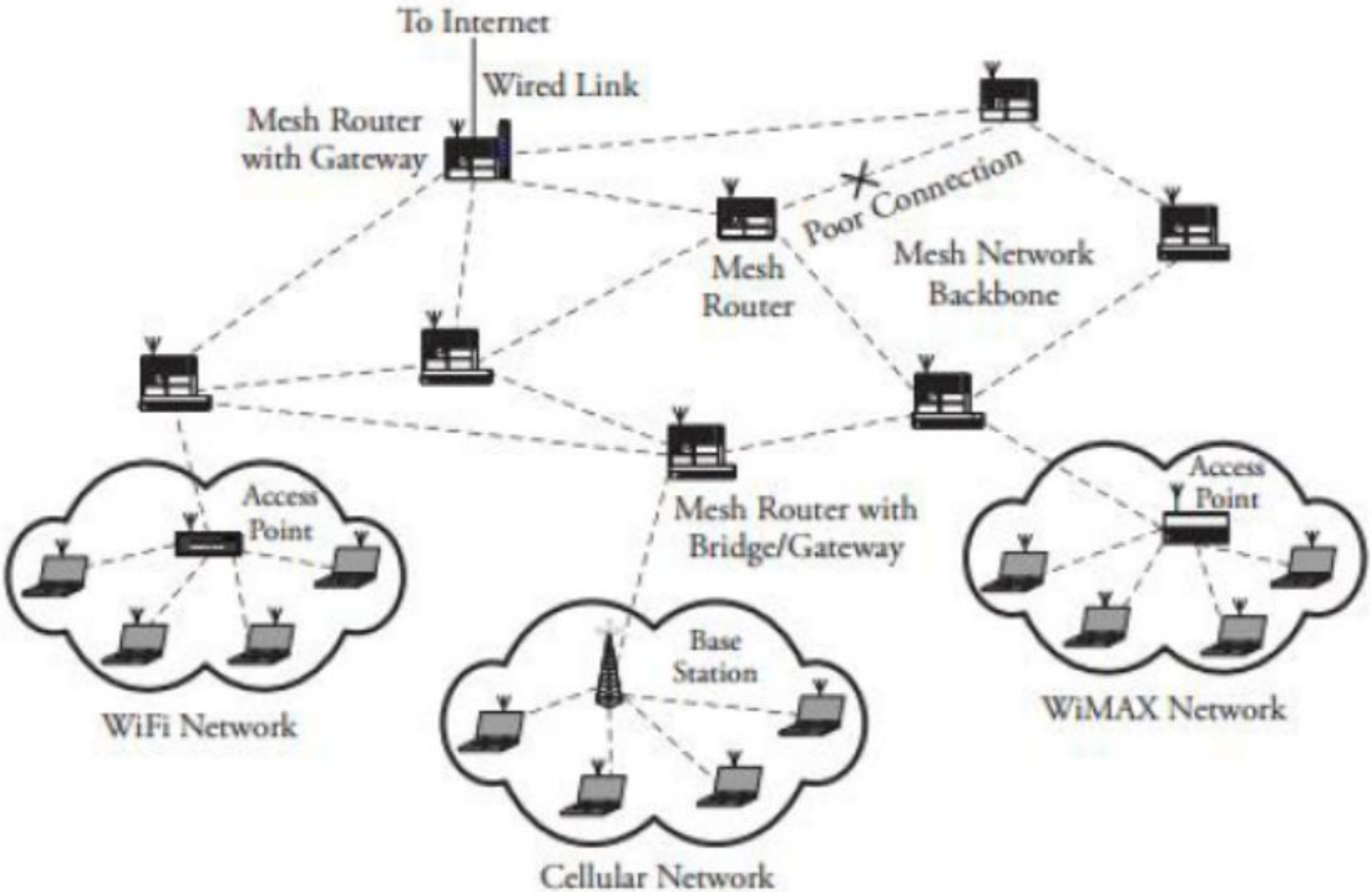


Figure 6.19 Overview of a backbone mesh network and connections to WiFi, WiMAX, and wireless cellular networks