Chapter-1: Introduction to Wireless Communication Systems

Evolution of Wireless Communication

- **1897: Guglielmo Marconi** demonstrated radio's ability to maintain continuous contact with ships in the **English Channel**, marking the birth of wireless communication.
- First proof of **mobile wireless communication**, enabling continuous contact with moving entities.
- Since then, wireless communication methods have been **globally adopted**, revolutionizing how people interact.

Evolution of Wireless Communication

- The mobile radio industry has grown exponentially, driven by:

1. **Digital & RF Circuit Fabrication Improvements**
   - Enhanced signal processing capabilities.
   - Better power efficiency and noise reduction.
2. **Large-Scale Circuit Integration**
   - Enabled complex functionalities in compact devices.
   - Reduced manufacturing costs.

Evolution of Wireless Communication

3. **Miniaturization Technologies**
   - Smaller, lightweight, and more portable devices.
   - Increased reliability and battery efficiency.
4. **Digital Switching Techniques**
   - Facilitated the deployment of large-scale, cost-effective networks.
   - Supported the rise of cellular networks, WiFi, and IoT.

Evolution of Mobile Radio Communications

Why Study the Evolution of Mobile Communications?

- Understanding the historical progression helps appreciate the impact of cellular radio & Personal Communication Services (PCS) on future decades.
- Government regulations & industry competition play a critical role in shaping wireless systems.
  - Radio spectrum is controlled by governments, not by corporations or researchers.
  - National competitiveness depends on progressive policies and R&D investments.
- Techno-politics (regulation vs. innovation) drives new technologies, even if not the focus of this course.

Key Phases of Mobile Communication Growth

1. **Pre-1960s:**
   1. Limited by technology gaps (e.g., high cost, hardware limitations).
   2. No concept of universal wireless coverage until Bell Labs' cellular concept.
2. **1970s Breakthroughs:**
   1. Solid-state RF hardware → Birth of modern wireless era.
   2. Mature technologies enabled cellular networks (e.g., AMPS).
3. **1980s–2000s:**
   1. Digital switching & miniaturization --> Mass adoption.
   2. Spectrum allocation decisions became critical for growth.
4. **21st Century:**
   1. Wireless growth tied to consumer demand, signal processing advances, and regulatory support.

Switching

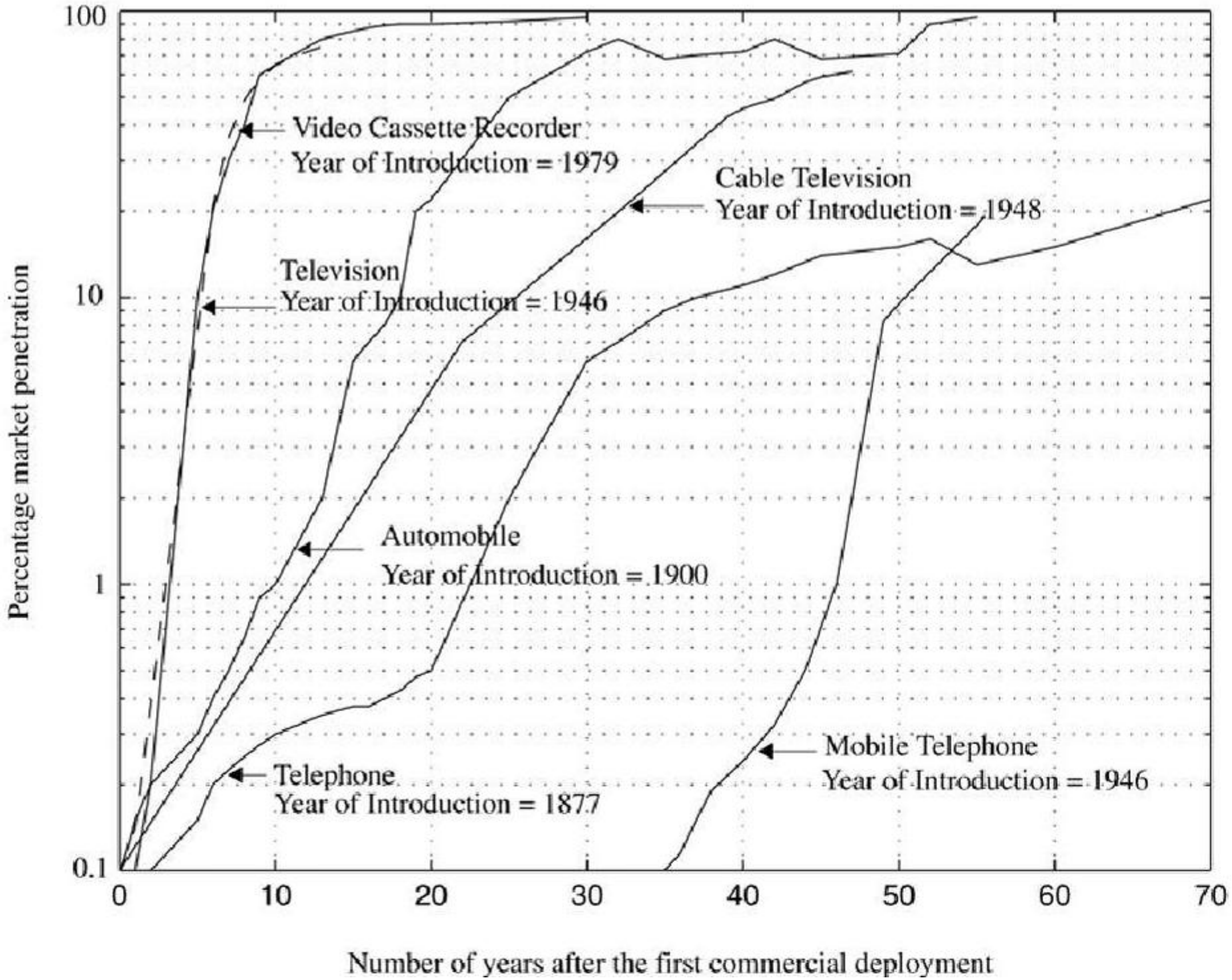
- A switch transfers signals from one input port to an appropriate output.
- A basic problem is then how to transfer traffic to the correct output port.
- In the early telephone network, operators closed circuits manually. In modern circuit switches this is done electronically in digital switches.
- If no circuit is available when a call is made, it will be blocked (rejected). When a call is finished a connection teardown is required to make the circuit available for another user.

Early Mobile Systems (1930s–1960s)

- **1930s:**
  - Amplitude Modulation (AM)-based systems for police/emergency vehicles (~5,000 users by 1935).
  - Challenges: Ignition noise, limited range.
- **1935:** Edwin Armstrong demonstrated Frequency Modulation (FM) → Became the standard for mobile communication systems.
- **Post-WWII (1940s–50s):**
  - Manufacturing advancements → FM two-way radios.
  - User growth:
    - 1940: Few thousand → 1962: **1.4 million** (mostly non-public switched telephone network (PSTN) connected).

Explosive Growth (1980s–2000s)

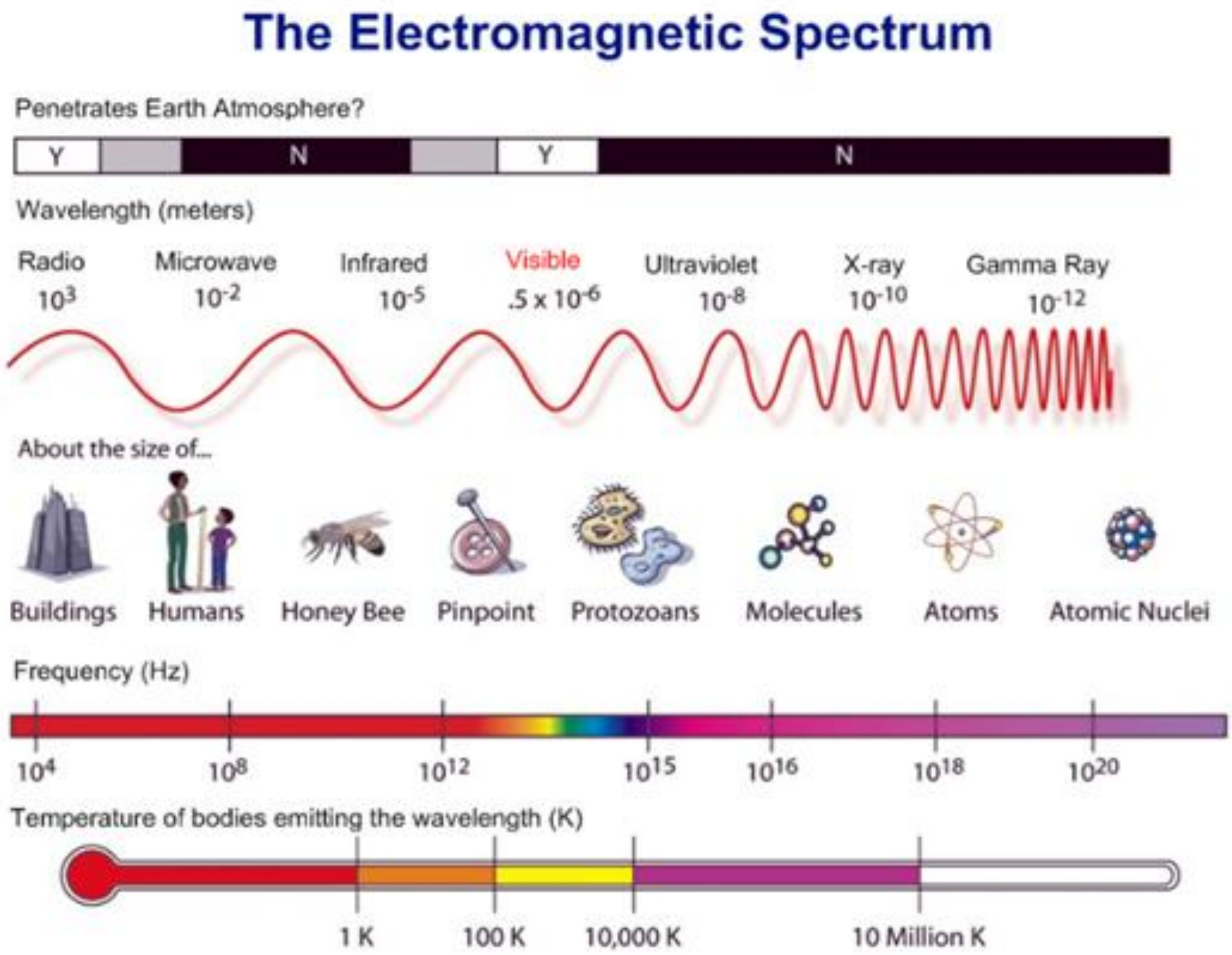
- **1980s–90s:**
  - Cellular users: 25,000 (1984) → 25M (1993) → 630M (2001).
  - Non-cellular radio (paging, CB, cordless phones):
    - 1990: 12M U.S. users (vs. 5M cellular).
    - 1995: 100M U.S. users (37% population).
- **Cordless phones**:
  - 1991: 25–40M → 2001: Over 100M in U.S.
- **21st Century Trend**:
  - Wireless subscriptions surpassed wired lines (~1B each by 2001).
  - 1% of global users abandoned wired phones for cellular-only service.



The growth of mobile telephony as compared with other popular inventions of the 20th century.

The Electromagnetic Spectrum

The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation.



The Electromagnetic Spectrum

- The graphic below shows you several things about the electromagnetic spectrum—wavelength, energies, and the names of the different types of waves. (Wavelengths are measured in nanometers—which are 1/1,000,000,000 of a meter.)
- Radio waves are shown on the left as having the longest wavelengths and lowest energy and frequency.
- Moving left to right increasing in energy and frequency, and decreasing in wavelength are, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays, and cosmic rays.

Introduction of Mobile telephone

- On 17 June 1946, a driver in St. Louis pulled out a handset from under his car's dashboard, placed a phone call and made history. It was the first mobile telephone call, placed on a system inaugurated by Southwestern Bell, one of AT&T's local operating companies.

A Southwestern Bell foreman testing mobile telephone service, St. Louis, 1946 (Courtesy AT&T Archives and History Center.)

Mobile Radiotelephony in the U.S.

Early Mobile Telephony (1940s–1950s)

- **1946:** First U.S. mobile telephone service launched in 25 major cities.
  - Single high-power transmitter per city --> Coverage up to 50 km.
  - Technology Limitations:
    - 120 kHz RF bandwidth (half-duplex FM push-to-talk).
    - Inefficient spectrum use (speech needs only 3 kHz baseband).
- **1950:** Federal Communications Commission (FCC) doubled the number of channels without new spectrum by halving bandwidth to 60 kHz.
- **1960s:** Bandwidth further reduced to 30 kHz (4x efficiency gain vs. 1946).

The Rise of Consumer Mobile Radio (1960s–1990s)

- 1960s–1970s:
  - CB Radio Boom: Citizen’s Band (CB) became popular for personal/trucker communications.
  - Cordless Appliances: Garage door openers, cordless phones (25–40M U.S. units by 1991).
- 1980s–1990s:
  - Cellular Era Begins:
    - 1983: First U.S. cellular network (AMPS) launched.
    - Subscriber growth: 25,000 (1984) → 25M (1993).
  - Non-Cellular Radio:\
    - 1990: 12M U.S. users (paging, dispatch, etc.) vs. 5M cellular users.
    - 1995: 100M+ mobile radio users (37% of U.S. population).

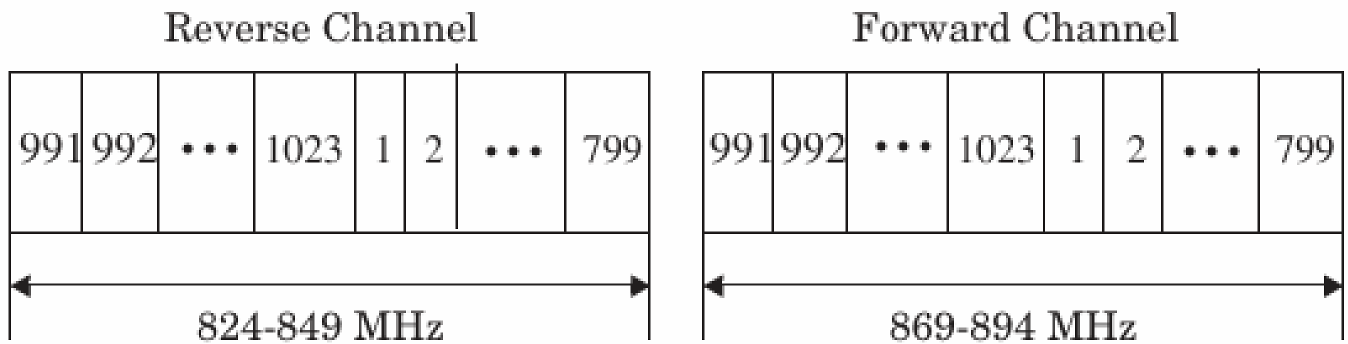
Improved Mobile Telephone Service (IMTS)

- **1960s**: IMTS introduced full-duplex, auto-dial, and trunking (providing service to multiple clients at the same time).
- Critical Flaws:
  - Severe congestion: Example: 1976 NYC market (10M people):
    - 12 channels → 543 users; 3,700+ waitlist.
  - Spectral inefficiency compared to cellular.
- Legacy: IMTS still used in niche applications but obsolete for mass markets.

The Cellular Revolution

- **1950s–60s**: Bell Labs developed cellular concept --> Frequency reuse via small cells.
  - Inspired by TV/radio channel allocation across regions.
- **1968**: AT&T proposed cellular to FCC; technology lagged until 1970s.
- **1983**: FCC allocated 40 MHz (666 channels @ 30 kHz each) for AMPS (Analog Mobile Phone System).
  - Duopoly markets: Two carriers per city to ensure competition.
- **1989**: Added 10 MHz (166 channels) due to demand.

This figure illustrates the channel numbering and frequency allocation scheme for the U.S. Advanced Mobile Phone System (AMPS), the first-generation (1G) cellular system standardized in 1983. Here's a detailed breakdown:



	Channel Number	Center Frequency (MHz)
Reverse Channel	$1 \le N \le 799$	$0.030N + 825.0$
	$991 \le N \le 1023$	$0.030(N - 1023) + 825.0$
Forward Channel	$1 \le N \le 799$	$0.030N + 870.0$
	$991 \le N \le 1023$	$0.030(N - 1023) + 870.0$

(Channels 800–990 are unused)

1. Spectrum Bands

- **Reverse Channel (Uplink): 824–849 MHz**
  - Mobile device → Base station transmission.
- **Forward Channel (Downlink): 869–894 MHz**
  - Base station → Mobile device transmission.
- **Total Bandwidth:** 25 MHz for each direction (duplex operation).

2. Channel Numbering

- **Valid Channel Numbers:**
  - **1–799** and **991–1023** (Channels 800–990 are **unused**).
  - **Example:**
    - Channel 1: Reverse = 825.03 MHz, Forward = 870.03 MHz.
    - Channel 1023: Reverse = 849.99 MHz, Forward = 894.99 MHz.

Digital Transition (1990s)

1. **USDC (IS-54/IS-136):**
   1. 1991: First U.S. digital cellular (USDC).
   2. 3 users per 30 kHz channel (vs. 1 in AMPS) using TDMA.
   3. Future: 6 users/channel with advanced speech coding.
2. **CDMA (IS-95):**
   1. Qualcomm’s innovation: Spread spectrum in 1.25 MHz channels.
   2. Interference-resistant: Reuse frequencies in every cell.
   3. Variable-rate vocoder --> Battery efficiency.
3. **Specialized mobile radio service (SMR)/Personal Communication Service (PCS) Competition**:
   1. Nextel/Motorola’s integrated digital enhanced network (iDEN): Combined dispatch, cellular, and data (800 MHz).
   2. PCS (1800/1900 MHz): Auctioned in 1995; 5 licenses per city.

Mobile Radio Systems Around the World

Global Mobile Radio Standards Overview

- **North America (AMPS → Digital):**
  - AMPS (1983): Analog, 30 kHz channels → IS-136 (TDMA) & IS-95 (CDMA).
  - Regulatory Impact: FCC's duopoly model (2 carriers per market).
- **Europe (GSM Dominance):**
  - GSM (1991): Pan-European digital standard (900/1800 MHz).
  - Key Features: SIM cards, international roaming, TDMA/FDMA.
- **Japan**:
  - 1G (1979): Analog (NTT's system) → 2G PDC (1993): Digital, Japan-exclusive.

European Unification via GSM

- **Pre-GSM Fragmentation**: Incompatible analog systems (e.g., UK's TACS, Germany's C-Netz).
- **GSM Development (1982–1991):**
  - ETSI-led to unify Europe.
  - Digital TDMA: 200 kHz carriers, 8 users per channel.
- **Why It Succeeded:**
  - Roaming: SIM cards enabled cross-border use.
  - Scalability: Adopted in >200 countries by 2000s.
- Note: GSM's 900 MHz band → Later expanded to 1800 MHz (DCS-1800).

Asia's Divergent Paths

- **Japan's Pacific Digital Cellular (PDC) (1993):**
  - TDMA-based, but incompatible with GSM.
  - Limited export success due to isolation.
- **China's Late Entry:**
  - 1990s: Relied on GSM imports → Later developed TD-SCDMA.
- **India's Rapid Growth**:
  - 2000s: Leapfrogged to GSM, avoiding analog systems.
- **Data Point:** By 2001, Japan had 70M mobile users (PDC + early 3G).

Table 1.1 Major Mobile Radio Standards in North America

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
AMPS	Cellular	1983	FDMA	824-894 MHz	FM	30 kHz
NAMPS	Cellular	1992	FDMA	824-894 MHz	FM	10 kHz
USDC	Cellular	1991	TDMA	824-894 MHz	π/4-DQPSK	30 kHz
CDPD	Cellular	1993	FH/ Packet	824-894 MHz	GMSK	30 kHz
IS-95	Cellular/ PCS	1993	CDMA	824-894 MHz 1.8-2.0 GHz	QPSK/ BPSK	1.25 MHz
GSC	Paging	1970s	Simplex	Several	FSK	12.5 kHz
POCSAG	Paging	1970s	Simplex	Several	FSK	12.5 kHz
FLEX	Paging	1993	Simplex	Several	4-FSK	15 kHz
DCS-1900 (GSM)	PCS	1994	TDMA	1.85-1.99 GHz	GMSK	200 kHz
PACS	Cordless/ PCS	1994	TDMA/ FDMA	1.85-1.99 GHz	π/4-DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
iDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

Table 1.2 Major Mobile Radio Standards in Europe

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
ETACS	Cellular	1985	FDMA	900 MHz	FM	25 kHz
NMT-450	Cellular	1981	FDMA	450-470 MHz	FM	25 kHz
NMT-900	Cellular	1986	FDMA	890-960 MHz	FM	12.5 kHz
GSM	Cellular /PCS	1990	TDMA	890-960 MHz	GMSK	200 kHz
C-450	Cellular	1985	FDMA	450-465 MHz	FM	20 kHz/ 10 kHz
ERMES	Paging	1993	FDMA	Several	4-FSK	25 kHz
CT2	Cordless	1989	FDMA	864-868 MHz	GFSK	100 kHz
DECT	Cordless	1993	TDMA	1880-1900 MHz	GFSK	1.728 MHz
DCS-1800	Cordless /PCS	1993	TDMA	1710-1880 MHz	GMSK	200 kHz

Table 1.3 Major Mobile Radio Standards in Japan

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modula-tion	Channel Bandwidth
JTACS	Cellular	1988	FDMA	860-925 MHz	FM	25 kHz
PDC	Cellular	1993	TDMA	810-1501 MHz	π/4-DQPSK	25 kHz
NTT	Cellular	1979	FDMA	400/800 MHz	FM	25 kHz
NTACS	Cellular	1993	FDMA	843-925 MHz	FM	12.5 kHz
NTT	Paging	1979	FDMA	280 MHz	FSK	12.5 kHz
NEC	Paging	1979	FDMA	Several	FSK	10 kHz
PHS	Cordless	1993	TDMA	1895-1907 MHz	π/4-DQPSK	300 kHz

Comprehensive list of all full forms

- **RF** – Radio Frequency
- **PSTN** – Public Switched Telephone Network
- **PCS** – Personal Communication Services
- **SNR** – Signal-to-Noise Ratio
- **R&D** – Research and Development
- **AMPS** – Advanced Mobile Phone System (1G analog)
- **IMTS** – Improved Mobile Telephone Service (pre-cellular)
- **USDC** – U.S. Digital Cellular (2G, also called **IS-54/IS-136**)
- **IS-54/IS-136** – Interim Standard for TDMA-based digital cellular
- **IS-95** – Interim Standard for CDMA-based digital cellular (by Qualcomm)
- **FCC** – Federal Communications Commission (U.S. regulator)
- **SMR** – Specialized Mobile Radio (e.g., Nextel's iDEN)
- **E-SMR** – Extended SMR (Nextel's network)
- **iDEN** – Integrated Digital Enhanced Network (Motorola's SMR upgrade)

Comprehensive list of all full forms

- **GSM** – Global System for Mobile Communications (2G, Europe/global)
- **ETSI** – European Telecommunications Standards Institute (developed GSM)
- **TACS** – Total Access Communication System (UK analog 1G)
- **PDC** – Personal Digital Cellular (Japan's 2G)
- **DCS-1800** – Digital Cellular System 1800 MHz (GSM variant)
- **FDMA** – Frequency Division Multiple Access
- **TDMA** – Time Division Multiple Access
- **CDMA** – Code Division Multiple Access
- **FM** – Frequency Modulation
- **AM** – Amplitude Modulation
- **LOS** – Line-of-Sight
- **IoT** – Internet of Things

Comprehensive list of all full forms

- **ITU** – International Telecommunication Union (global telecom standards)
- **IMT-2000** – International Mobile Telecommunications-2000 (ITU's 3G framework)
- **UMTS** – Universal Mobile Telecommunications System (3G GSM evolution)
- **MHz** – Megahertz
- **kHz** – Kilohertz
- **DECT** - Digital European Cordless Telephone
- **PHS** - Personal Handyphone System
- **NTT** - Nippon Telephone and Telegraph company
- **NMT** - Nordic Mobile Telephone system
- **ETACS** - European Total Access Cellular System

Examples of Wireless Communication Systems

Types of Mobile Radio Systems

- **Pagers (Beepers)** – Paging Receivers (One-way messaging devices).
- **Walkie-Talkies** – Hand-held Portable Radios (Half-duplex communication).
- **Cordless Phones** – Portable Telephones (Short-range full-duplex via base station).
- **Cellular Phones** – Mobile/Portable Subscriber Units (Full-duplex, long-range).

Duplexing Techniques

Term	Full Form	Definition	Example
Simplex	–	One-way communication (no reverse link).	**Pagers**, TV broadcasts.
Half-Duplex	–	Two-way communication using **same channel** (transmit/receive alternately).	**Walkie-talkies** ("push-to-talk").
Full-Duplex	–	Simultaneous two-way communication.	**Cellular phones**, cordless phones.
FDD	**Frequency Division Duplexing**	Uses **paired channels** (forward/reverse) with a fixed frequency gap (e.g., 45 MHz in AMPS).	Analog cellular (AMPS), GSM.
TDD	**Time Division Duplexing**	Shares **one channel** by alternating transmit/receive times.	

Channel Terminology

- **Forward Channel** (Downlink): Base station → Mobile.
- **Reverse Channel** (Uplink): Mobile → Base station.
  - In AMPS: Reverse channel = Forward channel – 45 MHz.

Table 1.4 Wireless Communications System Definitions

Base Station	A fixed station in a mobile radio system used for radio communication with mobile stations. Base stations are located at the center or on the edge of a coverage region and consist of radio channels and transmitter and receiver antennas mounted on a tower.
Control Channel	Radio channel used for transmission of call setup, call request, call initiation, and other beacon or control purposes.
Forward Channel	Radio channel used for transmission of information from the base station to the mobile.
Full Duplex Systems	Communication systems which allow simultaneous two-way communication. Transmission and reception is typically on two different channels (FDD) although new cordless/PCS systems are using TDD.
Half Duplex Systems	Communication systems which allow two-way communication by using the same radio channel for both transmission and reception. At any given time, the user can only either transmit or receive information.
Handoff	The process of transferring a mobile station from one channel or base station to another.
Mobile Station	A station in the cellular radio service intended for use while in motion at unspecified locations. Mobile stations may be hand-held personal units (portables) or installed in vehicles (mobiles).
Mobile Switching Center	Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connects the cellular base stations and the mobiles to the PSTN. An MSC is also called a mobile telephone switching office (MTSO).
Page	A brief message which is broadcast over the entire service area, usually in a simulcast fashion by many base stations at the same time.
Reverse Channel	Radio channel used for transmission of information from the mobile to base station.
Roamer	A mobile station which operates in a service area (market) other than that from which service has been subscribed.
Simplex Systems	Communication systems which provide only one-way communication.
Subscriber	A user who pays subscription charges for using a mobile communications system.
Transceiver	A device capable of simultaneously transmitting and receiving radio signals.

Frequency division duplexing (FDD)

- FDD provides simultaneous radio transmission channels for the subscriber and the base station, so that they both may constantly transmit while simultaneously receiving signals from one another.
- At the base station, separate transmit and receive antennas are used to accommodate the two separate channels.
- At the subscriber unit, however, a single antenna is used for both transmission to and reception from the base station, and a device called a duplexer is used inside the subscriber unit to enable the same antenna to be used for simultaneous transmission and reception.
- To facilitate FDD, it is necessary to separate the transmit and receive frequencies by about 5% of the nominal RF, so that the duplexer can provide sufficient isolation while being inexpensively manufactured.

Frequency division duplexing (FDD)

- In FDD, a pair of simplex channels with a fixed and known frequency separation is used to define a specific radio channel in the system.
- A **guard band** is a narrow frequency range separating the uplink and downlink frequencies. This guard band is crucial to prevent interference between the two channels and ensure clear, uninterrupted communication.
- The channel used to convey traffic to the mobile user from a base station is called the **forward channel**, while the channel used to carry traffic from the mobile user to a base station is called the **reverse channel.**
- In the U.S. AMPS standard, the reverse channel has a frequency which is exactly 45 MHz lower than that of the forward channel.
- FDD is used exclusively in analog mobile radio systems.
- Frequency bands under FDD: 800MHz, 900 MHz (880-915 MHz/ 925-960 MHz), 1800 MHz

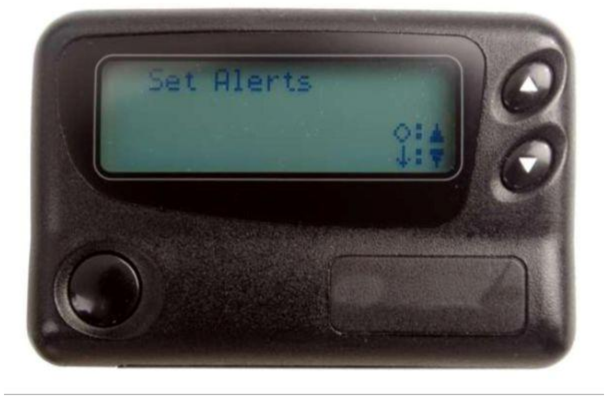
Time division duplexing (TDD)

- Time division duplexing (TDD) uses the fact that it is possible to share a single radio channel in time, so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station.
- If the data transmission rate in the channel is much greater than the end-user's data rate, it is possible to store information bursts and provide the appearance of full duplex operation to a user, even though there are not two simultaneous radio transmissions at any instant.
- TDD is only possible with digital transmission formats and digital modulation, and is very sensitive to timing.
- It is for this reason that TDD has only recently been used, and only for indoor or small area wireless applications where the physical coverage distances (and thus the radio propagation time delay) are much smaller than the many kilometers used in conventional cellular telephone systems.
- In Nepal, the Nepal Telecommunications Authority (NTA) has allocated the 2300 MHz bands for TDD (Time Division Duplex) technology.
- It is spectral efficient.

Paging System

- **Conventional Paging systems** are communication systems that send brief messages to a subscriber.
- Depending on the type of service, the message may be either a numeric message, an alphanumeric message, or a voice message.
- Paging systems are typically used to notify a subscriber of the need to call a particular telephone number or travel to a known location to receive further instructions.
- In modern paging systems, news headlines, stock quotations, and faxes may be sent. A message is sent to a paging subscriber via the paging system access number (usually a toll-free telephone number) with a tele phone keypad or modem.
- The issued message is called a **page**.
- The paging system then transmits the page throughout the service area using base stations which broadcast the page on a radio carrier.

Paging System



Paging System

- Paging systems vary widely in their complexity and coverage area.
- While simple paging systems may cover a limited range of 2 to 5 km, or may even be confined to within individual buildings, wide area paging systems can provide worldwide coverage.
- Though paging receivers are simple and inexpensive, the transmission system required is quite sophisticated.
- Wide area paging systems consist of a network of telephone lines, many base station transmitters, and large radio towers that simultaneously broadcast a page from each base station (this is called **simulcasting**).
- **Simulcast** transmitters may be located within the same service area or in different cities or countries. Paging systems are designed to provide reliable communication to subscribers wherever they are; whether inside a building, driving on a highway, or flying in an airplane.
- This necessitates large transmitter powers (on the order of kilowatts) and low data rates (a couple of thousand bits per second) for maximum coverage from each base station. Figure 1.3 shows a diagram of a wide area paging system.

Paging System

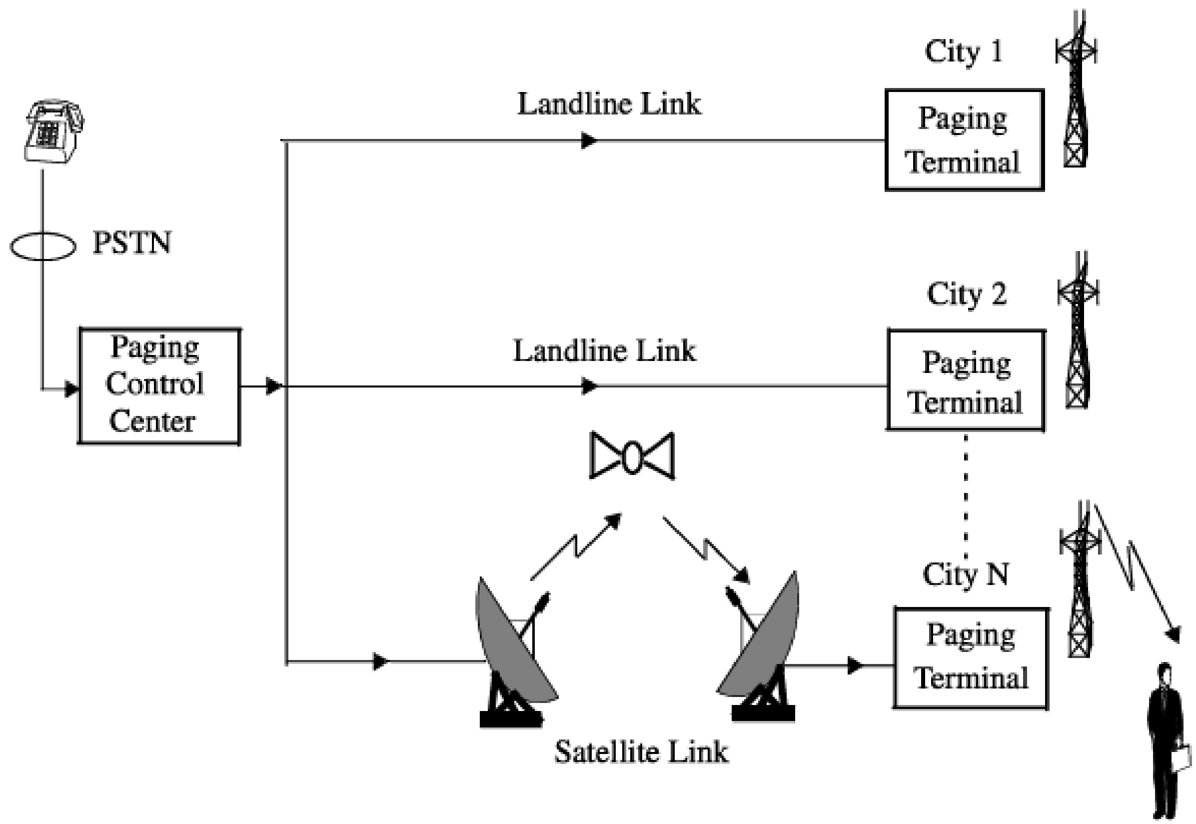


Figure 1.3 A wide area paging system. The paging control center dispatches pages received from the PSTN throughout several cities at the same time.

Q) Why do paging systems need to provide low data rates? How does a low data rate lead to better coverage?

Q) Why do paging systems need to provide low data rates? How does a low data rate lead to better coverage?

Answer: Paging systems are designed to provide ultra-reliable coverage even inside buildings. Since buildings can alternate radio signals by 20 or 30 dB, to maximize the signal-to-noise ratio (SNR) at each paging receiver, we need to reduce the noise level. This can be achieved by reducing the RF bandwidth to which the noise level is proportional. The small RF bandwidth thus result in low data rate.

In a paging system, the signal level in a receiver degrades when the distance between the receiver and the base station becomes large. If the coverage of a paging system is defined by the coverage area at which the signal-to-noise ratio is above a certain threshold, for a lower data rate, the noise level in the receiver will be smaller, thus for a fixed threshold, the coverage will be large.

Cordless Telephone Systems

- Cordless telephone systems are full duplex communication systems that use radio to connect a portable handset to a dedicated base station, which is then connected to a dedicated telephone line with a specific telephone number on the public switched telephone network (PSTN).
- In first generation, cordless telephone systems (manufactured in the 1980s), the portable unit communicates only to the dedicated base unit and only over distances of a few tens of meters.
- Early cordless telephones operate solely as extension telephones to a transceiver connected to a subscriber line on the PSTN and are primarily for in-home use.

Cordless Telephone Systems

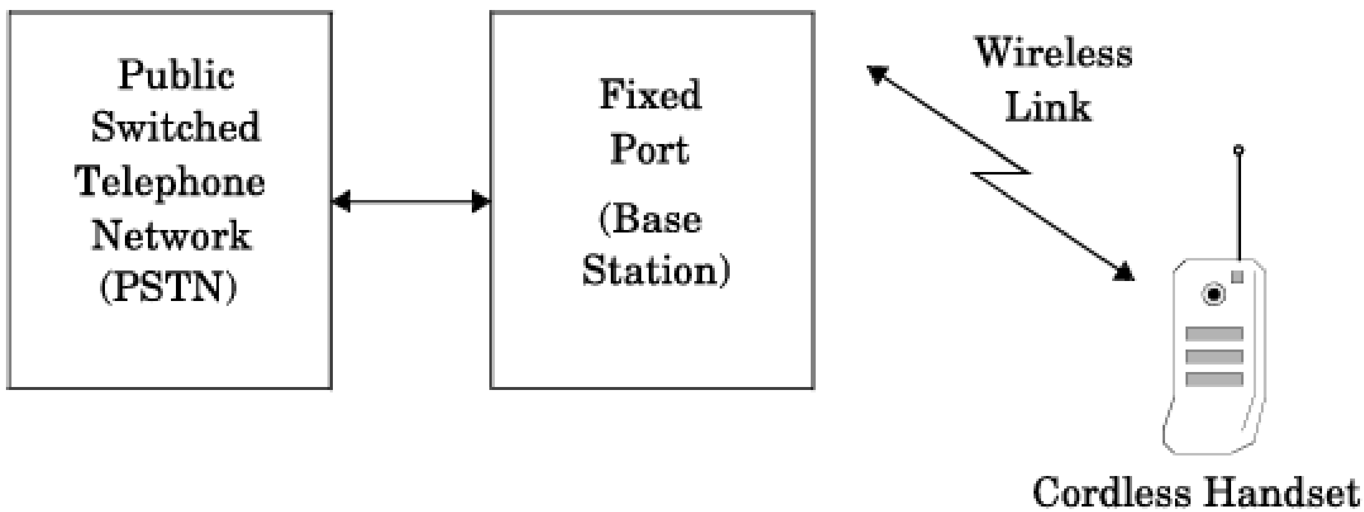


Figure 1.4 A cordless telephone system.

Cordless Telephone Systems

- Second generation cordless telephones have been introduced which allow subscribers to use their handsets at many outdoor locations within urban centers such as London or Hong Kong.
- Modern cordless telephones are sometimes combined with paging receivers so that a subscriber may first be paged and then respond to the page using the cordless telephone.
- Cordless telephone systems provide the user with limited range and mobility, as it is usually not possible to maintain a call if the user travels outside the range of the base station. Typical second-generation base stations provide coverage ranges up to a few hundred meters.

Cellular Telephone Systems

- A cellular telephone system provides a wireless connection to the PSTN for any user location within the radio range of the system.
- Key Features:
  - High capacity via frequency reuse in small geographic areas (cells).
  - Comparable voice quality to landline systems.
- Core Components:
  - Mobile Stations (MS): User devices (handheld/vehicle-mounted).
  - Base Stations (BS): Towers with transceivers, connect mobiles to MSC.
  - Mobile Switching Center (MSC/(Mobile Telephone Switching Office) MTSO): Manages calls, handoffs, and PSTN links.

Cellular Telephone Systems

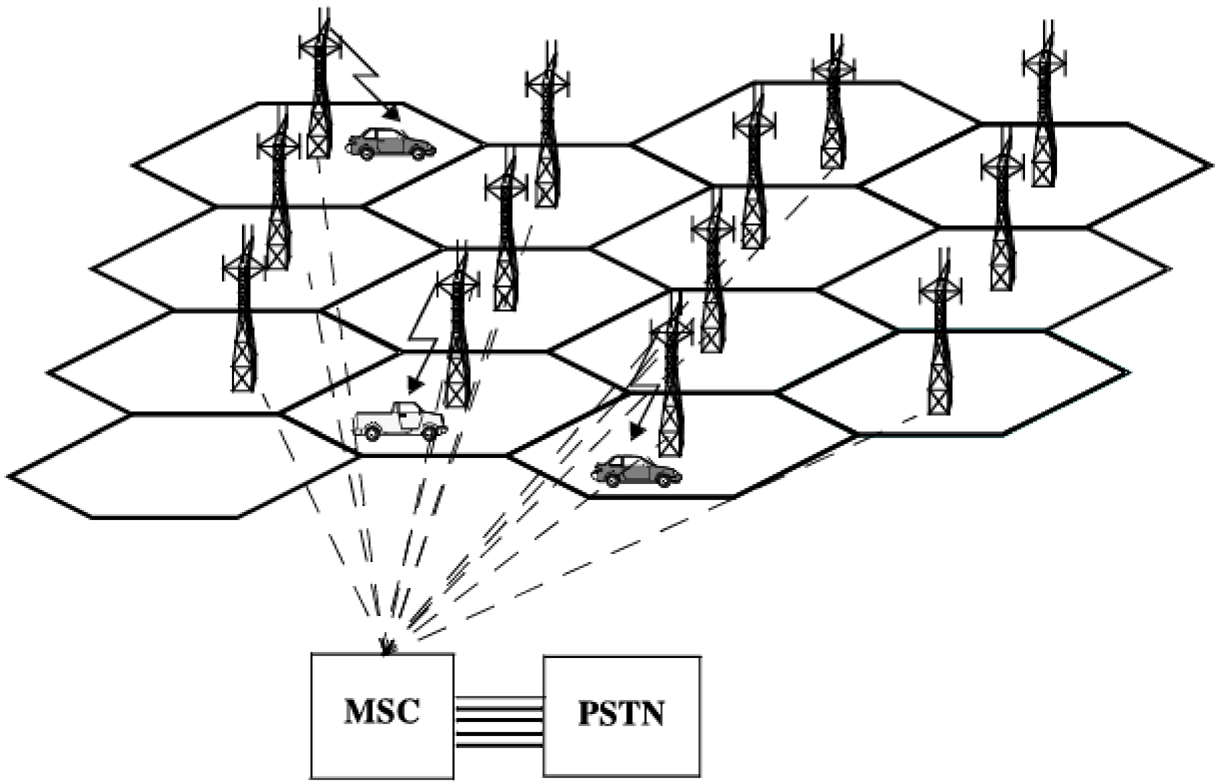


Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

Cellular Telephone Systems: **Frequency Reuse & Handoff**

- **Frequency Reuse**:
  - Same radio channels reused in non-adjacent cells (minimizes interference).
- **Handoff**:
  - Seamless call transfer when a user moves between cells.
  - Controlled by MSC to maintain call quality.
- **Capacity Boost**:
  - Limited spectrum → Efficient reuse enables millions of users.

Cellular Telephone Systems: **System Components & Functions**

1. **Mobile Station (MS)**:
    1. Contains transceiver, antenna, control circuitry.
2. **Base Station (BS)**:
    1. Full-duplex communication; connects mobiles to MSC via landlines/microwave.
3. **MSC/MTSO**:
    1. Handles 100,000+ subscribers, 5,000+ simultaneous calls.
    2. Manages billing, maintenance, and roaming.

- **Data Point**: Large cities use multiple MSCs per carrier.

Cellular Telephone Systems: **Channel Types & Call Setup**

- Communication between the base station and the mobiles is defined by a standard common air interface (CAI) that specifies four different channels.
- **Voice Channels** (used for voice transmission):
  - **FVC (Forward Voice Channel)**: BS → Mobile.
  - **RVC (Reverse Voice Channel)**: Mobile → BS.
- **Control Channels or Setup Channels (**responsible for initiating mobile calls**)**:
  - **FCC (Forward Control Channel)**
  - **RCC (Reverse Control Channel)**
- **Call Setup**:
  - Mobile scans FCC for strongest signal → MIN/ESN authentication → Moves to assigned FVC/RVC.

Cellular Telephone Systems: **Key Terminology**

Term	Full Form/Definition
MIN	Mobile Identification Number (Phone number).
ESN	Electronic Serial Number (Device ID).
SCM	Station Class Mark (Max transmit power level).
HLR	Home Location Register (Billing/auth database).
FDD	Frequency Division Duplexing (Paired channels).

MSC		Receives call from PSTN. Sends the requested MIN to all base stations.			Verifies that the mobile has a valid MIN, ESN pair.	Requests BS to move mobile to unused voice channel pair.		Connects the mobile with the calling party on the PSTN.
Base Station	FCC		Transmits page (MIN) for specified user.				Transmits data message for mobile to move to specific voice channel.	
	RCC			Receives MIN, ESN, Station Class Mark and passes to MSC.				
	FVC							Begin voice transmission.
	RVC							Begin voice reception.
Mobile	FCC		Receives page and matches the MIN with its own MIN.				Receives data messages to move to specified voice channel.	
	RCC			Acknowledges receipt of MIN and sends ESN and Station Class Mark.				
	FVC							Begin voice reception.
	RVC							Begin voice transmission.

time →

Figure 1.6 Timing diagram illustrating how a call to a mobile user initiated by a landline subscriber is established.

MSC			Receives call initiation request from base station and verifies that the mobile has a valid MIN, ESN pair.	Instructs FCC of originating base station to move mobile to a pair of voice channels.		Connects the mobile with the called party on the PSTN.	
Base Station	FCC				Page for called mobile, instructing the mobile to move to voice channel.		
	RCC	Receives call initiation request and MIN, ESN, Station Class Mark.					
	FVC						Begin voice transmission.
	RVC						Begin voice reception.
Mobile	FCC				Receives page and matches the MIN with its own MIN. Receives instruction to move to voice channel.		
	RCC	Sends a call initiation request along with subscribe MIN and number of called party.					
	FVC						Begin voice reception.
	RVC						Begin voice transmission.

time →

Figure 1.7 Timing diagram illustrating how a call initiated by a mobile is established.

Q) If 0 dBm is equal to 1mW (10^{-3} W) over a 50-ohm load; express 10W in units of dBm.

Q) Between a pager, a cellular phone, and a cordless phone, which device will have the longest battery life between charging? Why?

Q) Between a pager, a cellular phone, and a cordless phone, which device will have the longest battery life between charging? Why? 1.8 Between a pager, a cellular phone, and a cordless phone, which device will have the shortest battery life between charging? Why? Between a pager, a cellular phone, and a cordless phone, which device will have the shortest battery life between charging? Why?

Advantages of FM over AM

- FM has superior noise suppression characteristics.
- Low-level modulation can be used with subsequent highly efficient power amplitude.

Comparison of Common Wireless Communication Systems

Table 1.5 Comparison of Mobile Communication Systems—Mobile Station

Service	Coverage Range	Required Infra-structure	Complexity	Hardware Cost	Carrier Frequency	Functionality
TV Remote Control	Low	Low	Low	Low	Infrared	Transmitter
Garage Door Opener	Low	Low	Low	Low	< 100 MHz	Transmitter
Paging System	High	High	Low	Low	< 1 GHz	Receiver
Cordless Phone	Low	Low	Moderate	Low	1–3 GHz	Transceiver
Cellular Phone	High	High	High	Moderate	< 2 GHz	Transceiver

Table 1.6 Comparison of Mobile Communication Systems—Base Station

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Paging System	High	High	High	High	< 1 GHz	Transmitter
Cordless Phone	Low	Low	Low	Moderate	1–3 GHz	Transceiver
Cellular Phone	High	High	High	High	< 2 GHz	Transceiver

Chapter 1 Completed