Telephone Services

- The principal information service delivered by personal communications system is voice telephone.
- Supplementary services: voice mail, call forwarding, calling number identification, call waiting, and conference calls.

Short Message Services

- An important advantage of this type of service over paging services is the ability of the terminal to acknowledge receipt of the message.
- Broadcast messages: these are messages available to all terminals in a geographical area designated by the service provider.
- Road traffic reports, winning lottery numbers, and stock market quotations,

Voiceband Data and Facsimile

- In analog radio systems, the principal problems are high interference levels, rapid variations in the strength of received signals, and circuit interruptions during handoffs.
- Digital errors in received radio signals further distort voiceband data signals and cause the remote modem to make errors in detecting the arriving data.
- PCS that allow subscribers to communicate with fax machines and data modems require adapters to move information reliably across radio links,

Direct Digital Access

- Subscriber terminals do not have modems that send and receive digital signals disguised as human voices.
- Data terminals in PCSs require special techniques to deal with high error rates in radio links.
- Two approaches:
  - Transparent data transmission: with forward error correction, information bits flow in and out of the terminal at a constant rate. However, their rates rise and fall as the strength of the arriving signal fluctuates.
  - Nontransparent data services: the PCS retransmits blocks of information where errors have been detected.
Characteristics of Digital Data Services

<table>
<thead>
<tr>
<th>Technique</th>
<th>Transmission Rate</th>
<th>Error Rate</th>
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<tr>
<td>Transparent</td>
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<tr>
<td>Nontransparent</td>
<td>Error detection</td>
<td>Variable</td>
</tr>
<tr>
<td></td>
<td>and retransmission</td>
<td>Constant</td>
</tr>
</tbody>
</table>

Closed User Group

- Within systems, terminals are restricted to communicating with one another.
- It is possible for PCS to offer this type of service to groups of subscribers.
- There are radio versions of the virtual private networks (VPN) offered by public telephone companies.

Telemetry

- PCSs are capable communicating status signals including security alarms, utility meter readings, and vending machine inventory from remote locations to administrative sites.

Wireless Local Loops

- A local loop contains the facilities that link a customer’s premises with the local telephone company.
- In many environments, radio links offer an economically attractive alternative to installing telephone wires in a vast number of customer premises.
- To compete with long-standing telephone monopolies, some companies deploy wireless local loops to provide local telephone service.

Vidio and Other Broadband Services

- The long-term goal of the PSTN is to evolve to a set of B-ISDN.
- B-ISDN offers, in addition to voice, facsimile, and low-speed data services, access to information services with high transmission bit rates.
- Broadband services will be attractive to users of future PCSs.

Design Goals

- Many of the criteria of the design of PCS are contradictory.
- The compromises of PCSs reflect tradeoffs between cost and performance that arise in the creation of most products and services.
- 21 measures of the quality of a PCS are described.
Summary of Personal Communications

Figures of Merit

<table>
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<td>Transmission quality</td>
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<td>Battery life</td>
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<td>Terminal price</td>
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<td>Terminal size and weight</td>
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</table>

Terminal Price

- The systems vary widely in complexity, with direct effects on terminal production costs.
- Ordinary wired telephones are simple information processing devices connected to extremely complex switching equipment.
- Computer networks have opposite characteristics. The communications infrastructure is relatively simple, with most of the complexity appearing in the host terminals, which are sophisticated computers.
- Personal communications sets take intermediate positions between simple telephones and complex computers.

Terminal Size and Weight

- Battery size is proportional to battery life, which is influenced by many details of system design.
- Within the terminal itself, the complexity of the required information processing operations has the strongest influence on size, weight, and power consumption.

Service Price

- Cellular phone conversations incur monthly rental fees and substantial service charges every minute.
- The users of wireless data services pay for every unit of information transferred to or from a terminal.
- Service price depends on the cost of infrastructure equipment and on the network architecture, which places demands on fixed communications links.

Range of Services

- The wider the range of information services it can deliver, the better the system.
- The systems described in this book begin with the principal aim of providing telephone service.
- Some of them also are inherently capable of delivering other services.

Coverage Area

- Enthusiasts speak of ubiquitous or even "universal" service, available everywhere.
- This is clearly worthy goal, it is hard to achieve.
Roaming

- A subscriber who enters the service area of another operating company is roaming.
- The possibility of doing so requires technology for coordinating the operations of the home and visited systems and business arrangements between the two service providers.

User Interface

- The system should be easy to use, especially in view of the special requirements of a person in motion, sometimes driving a car.

Call Blocking

- With limited bandwidth allocations and unpredictable user mobility, personal communications systems are particularly vulnerable to overload.
- Even with traffic channels available, the control channels used to set up new communications are vulnerable to overloads that result in a blocked call.

Setup Time

- Congested control channels and switches, even when they do not cause rejection of service requests, can result in long delays.
- When a request arrives to set up a call or deliver other types of information to a mobile subscriber, the system has to search for the subscriber.

Transmission Quality

- For high-quality telephone, the received voice should sound good.
- It should be free of distortion and background noise.
- It should not experience a long delay traveling from talker to listener.
- A received facsimile should look like the original image.
- Tex and digital data should be error free.

Privacy

- PCS are vulnerable to eavesdropping
- Two privacy issue:
  - Access user information, such as the contents of conversations, electronic mail, facsimiles, and so on.
  - Access network control information, such as the communications behavior of subscribers and the locations of subscribers.
- The level of privacy in a PCS depends on the radio transmission technology and on data encryption techniques introduced to prevent eavesdropping on user information and network control information.
**Mobility**

- A system will maintain communications as its users move at high speed through a diverse set of geographical area.
- It burdens the network control infrastructure by adding complexity to the tasks of tracking user location and performing handoffs.

**Call Dropping**

- Vulnerability to call dropping is usually associated with mobility.

**Battery Life**

- It has two components for the battery life.
  - **Talk time**: the number of hours that a terminal can participate in two-way communications.
  - **Standby time**: the number of hours that a terminal is available to respond to a call request but is not actually engaged in a communication session.
- A third factor that influences battery life is the location of the terminal.
- Battery life is also influenced by various details of system design.
- **Sleep mode**: receivers are turned off for the majority of the time in order to conserve battery power.

**Modes of Operation**

- A telephone might function as a cordless phone when the subscriber is at home, as a cellular phone in a car, and as an office telephone when the person is at work.
- These functions require special terminal capabilities and coordination of different systems.

**Infrastructure Cost**

- Consists of base stations, switches, databases, and the communications links connecting them.
- Base station costs depend on the radio transmission technology and on network architecture.
- Changing the distribution of network control tasks can add to the cost of terminals while creating base station economies.
- The topological organization of system elements affects the cost the communications links among base stations, switching equipment, and external networks.

**Cell Radius**

- The number of base stations necessary to meet radio coverage objectives has a strong influence on start-up costs.
- The number is determined by the geographical range of a base station transmitter.
- The range depends on transmission technology.
Spectrum Efficiency

- At any single location, these frequencies can carry only a small volume of communications.
- PCSs achieve high capacity by means of frequency reuse.
- The system capacity depends on subscriber behavior, the total bandwidth allocation, the radio technology employed, and the number of base stations.
- To meet a growing demand for service, a system operator adds base stations, thus reducing cell size and increasing capacity.
- Efficiency depends on radio technology and on network management operations referred to as radio resources management.

Network Security

- In personal communications, the system has to take far more responsibility for protection against unauthorized use of the network.
- 1G cellular systems are particularly vulnerable to fraudulent use.
- Later systems incorporate more robust authentication technology to prevent unauthorized access to PCSs.

Early Deployment and Adaptability

- An important question for equipment vendors and system operators is when to introduce a new technology.
- Systems that anticipate developments can evolve and absorb new techniques as they become technically and economically feasible.

User Information Transport

- The technology for information transport across the air interface is the most prominent feature of each practical system.
- The nature of the air interface reflects the tradeoffs among a large number of design goals including costs, coverage area, transmission quality, spectrum efficiency, and user mobility.

Mobility Management

- Mobility management procedures influence call setup time, probability of blocking, spectrum efficiency, and infrastructure costs.
- Two key procedures are registration and paging.
  - A terminal registers its location by sending a message to the network.
  - When the network has to send information to a terminal, it initiates a search procedure that involves broadcasting paging messages to cells in the vicinity of the cell where the terminal most recently registered.
- Frequent registration can be costly.
- Infrequent registration adds to the network resource in the paging process.
Authentication and Encryption

- PCSs are far more vulnerable because authentication information travels through the air.
- Digital PCSs employ data encryption techniques to protect user information and sensitive network control information against eavesdropping.
- Together, authentication procedures and encryption procedures are sometimes referred to as network security operations.

Radio Resources Management

- Radio resources management procedures dynamically manage 4 attributes of each communication:
  - A base station
  - A physical channel
  - The power of the signal transmitted by the terminal
  - The power of the signal transmitted to the terminal by the base station.
- The most strongly affected are call blocking, transmission quality, call dropping, mobility, battery life, spectrum efficiency, and infrastructure cost.
- Radio resources management is a very large combinatorial optimization problem with many interdependent objectives.
- Practical systems approach the problem by performing four separate tasks: call admission, base and channel assignment, power control, and handoff.

Call Admission

- Call admission procedures determine whether the system accepts a request to set up a new communication.
- In some cases, the system reserves one or more channels to satisfy potential handoff requests.
- This reflects the tradeoff between call-blocking probability and call dropping.
- Setup requests may also be rejected by call admission procedure when the system determines that the new call would cause too much interference to calls in progress.

Base and Channel Assignment

- When it accepts a call request, the system assigns the call to a base station and a channel.
- There are various ways that base stations are associated with channels:
  - Fixed channel allocation (FCA): taken in cellular systems that use FDMA and TDMA.
  - Dynamic channel allocation (DCA): used in cordless telephone systems.
- CDMA channels correspond to the binary codes assigned to individual calls. All codes can be used at all base stations, regardless of which other codes are already in use.
Power Control

- **Power control procedures** determine the power levels for transmission to and from the terminal.
- If, during a call, the terminal moves closer to the base station it is using, the system may reduce the power levels in order to reduce interference to other calls.

Handoff

- Handoff criteria adopted by the system may determine that the call would be better served by a different channel and/or base station.

Operations, Administration, and Maintenance (OA&M)

- OA&M in telephone industry: monitoring the performance of communications systems, changing system configuration, and responding to malfunctions.
- Operators of PCSs rely heavily on network monitoring techniques and on planning strategies based on measurements and predictions.

A Framework of System Description

- System architecture consists of network elements and interfaces between the elements.
- The air interface is examined in three sections, corresponding to the lowest three layers of the Open Systems Interconnection (OSI) protocol.
- The three topics are radio transmission, corresponding to layer 1; logical channels, corresponding to layer 2; and messages, corresponding to layer 3.

Network Elements

- Some systems use the term standard devices to refer to network elements.
- 3 network elements that are essential to any PCS: a terminal, a base station, and a switch.
- In standards documents, the most common nomenclature for a terminal is mobile station.
- Each terminal communicates with radio equipment in a fixed location. This collection of equipment performs the functions of a base station.
- Information originating at a wireless terminal arrives at a base station enroute to its destination, which is often in an external information network. For telephone calls, the external network is referred to as the Public Switched Telephone Network (PSTN).
- Switches and base stations are components of the personal communications network infrastructure.
Interfaces

- **Interfaces** are the communications protocols for linking network elements.
- If the interface is open, there are published protocols for communication between a pair of network elements. A proprietary interface is private intellectual property available only to the owner and license holders.
- A major trend in cellular communications is the move in 2G systems toward open interfaces.

Cellular Telephone Architecture

- It is hierarchical.
- Each base station communicates with several telephones—a maximum of 57 in most U.S. systems.
- Many base stations, on the order of 100 in large systems, are connected to one switch.

Physical Channels and Logical Channels

- On the air interface, physical channels can be associated with time slots and codes as well as with frequency bands.
- In digital systems, physical channels transfer bits from one network element to another.
- Logical channels are distinguished by the nature of the information they carry and by the way in which they assemble bits into larger data units.
- Paging channels inform terminals that the network has information to transfer to them.
- The purpose of a synchronization channel is to transfer timing information between base stations and terminals.
Radio Transmission

- Obstacles in radio transmission:
  - Limited spectrum
  - Transmission impairments
  - Interrupted connections associated with handoff procedures
  - Limited power of portable terminals
- To meet these challenges, personal communications systems deploy an impressive arsenal of techniques including modulation, source coding, channel coding, interleaving, diversity reception, and channel equalization.

Access Technologies

- Multiple access refers to transmissions from terminals to base stations, multiplex refers to transmissions from base stations to terminals. OSI protocols refer to the access technology as the media access method.
- The three access technologies employed by PCSs for establishing physical channels are FDMA, TDMA, and CDMA.

Access Technologies

Access Technologies

Spectrum Efficiency

- Network costs are heavily influenced by the number of base stations necessary to provide service.
- The amount of traffic that a system can handle is directly proportional to the bandwidth it occupies.
- Spectrum efficiency is the maximum number of simultaneous conversations per base station per MHz of assigned spectrum. 

Spectrum Efficiency

Logical Channels

- To address the fact that different information types have different requirements, systems segregate the information into logical channels.
- The combination of error detection and retransmission is the most prominent layer 2 mechanism for promoting accurate packet delivery.
- Traffic channels are typically “one-to-one”.
- Other channels carry “one-to-many” information, such as synchronization signals transmitted by a base station to all terminals in a cell.
- The logical channel used by terminals to transmit call setup request messages to a base station is “many-to-one”.

Logical Channels

Logical Channels

Messages

- The message structure indicates the nature of the information carried in the message.
- The message type distinguishes a handoff message from a power control message.
- A call setup message contains the phone number of the called party.
- A handoff message indicates the new channel to use and how much power to transmit.