

# EEEN 474

# Wireless Communication

Spring 2020

*Introduction to Wireless Systems*

# Mobile Communication

- 1897: First demonstrated by Guglielmo Marconi, for continuous contact with ships sailing in the English channel
- By the beginning of 1930s: AM for police radio systems
- 1935: Edwin Armstrong demonstrated FM for the first time, then FM has been the primary modulation technique used for mobile communication systems throughout the world
- World War II accelerated the improvements
- 1946: Year of introduction of mobile telephone

# Car Phones



# Growth of Mobile Communication

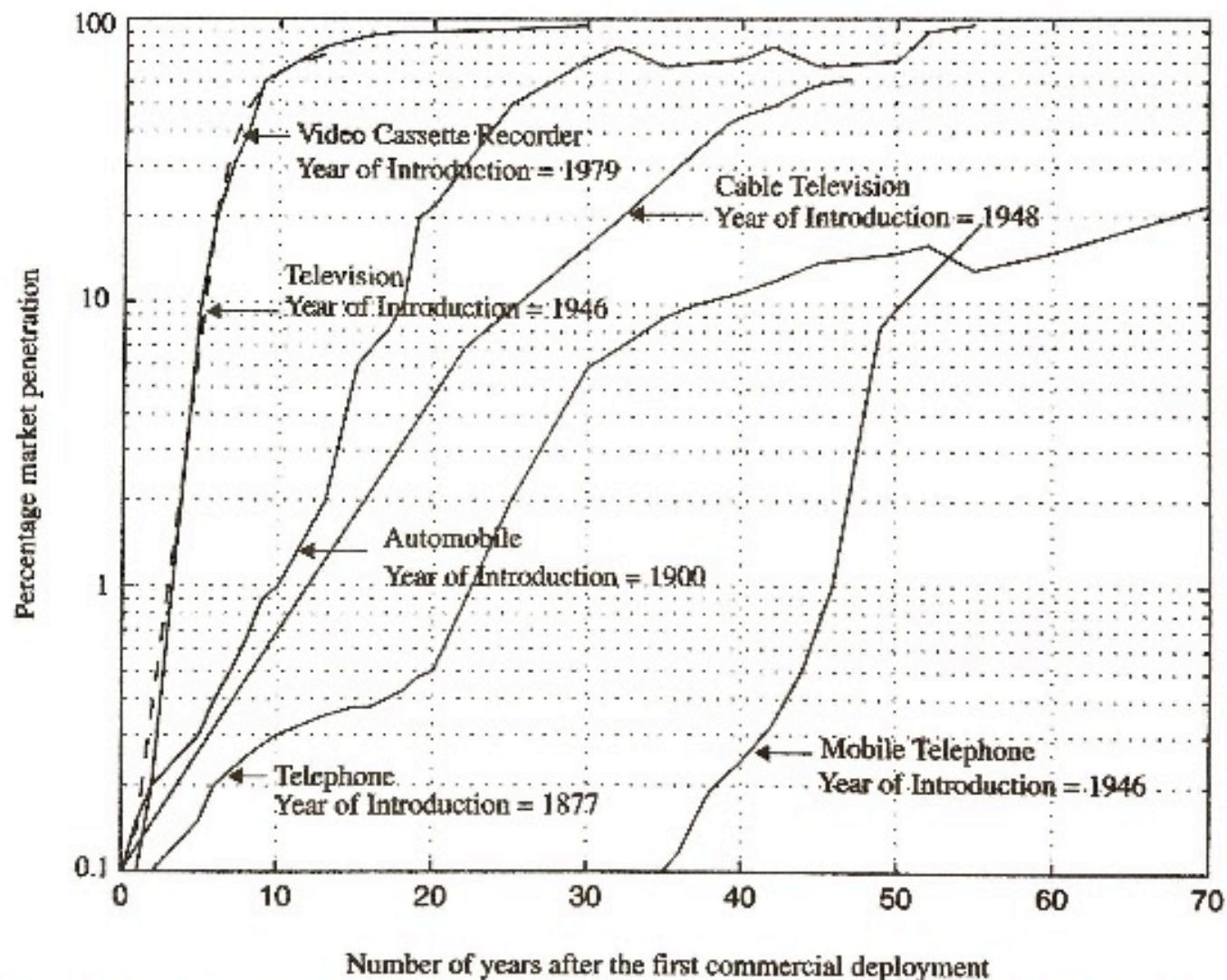
- Slow at the beginning (coupled closely to technological improvements)
- Usage by the entire population started with the development of the cellular concept by AT&T Bell Laboratories in the 1960s and 1970s
- Gained speed with the development of highly reliable, miniature, solid-state radio frequency hardware in 1970s
- Now enjoying its fastest growth period in history
- Future growth will be tied more closely to radio spectrum allocations and regulatory decisions

- Techno-politics are a fundamental driver in the evolution of new technology and services
  - Radio spectrum usage is controlled by governments, not by service providers, equipment manufacturers, entrepreneurs, or researchers
  - Governments want to keep its own country competitive in the rapidly changing field of wireless communications



Martin Cooper (a Motorola researcher and executive) photographed in 2007 with his 1973 handheld mobile phone prototype (*photo taken from Wikipedia*)





**Figure 1.1** The growth of mobile telephony as compared with other popular inventions of the 20th century.

*(Figure 1.1 from the book by Rappaort)*

# Examples of Wireless Communication Systems

- Garage door openers
- Remote controllers for home entertainment equipment
- Cordless telephones
- Hand-held walkie-talkies
- Pagers (a.k.a. paging receivers or “beepers”)
- Cellular telephones



# Pager



# Terminology

- **Historically:**
  - **Mobile** → Any radio terminal that could be moved during operation
- **More recently:**
  - **Mobile** → A radio terminal that is attached to a high speed mobile platform (e.g., a cellular telephone in a fast moving vehicle)
  - **Portable** → A radio terminal that can be hand-held and used by someone at walking speed (e.g., a walkie-talkie or cordless telephone inside a home)

# Some Definitions

- Subscriber: A mobile or portable user
- Subscriber unit: The user's communication device
- Users / mobiles: The collective group of users in a wireless system (even if many of the users may actually use portable terminals)
- ...

**Table 1.4 Wireless Communications System Definitions**

|                                |   |
|--------------------------------|---|
| <b>Base Station</b>            | 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. |
| <b>Control Channel</b>         | Radio channels used for transmission of call setup, call request, call initiation, and other beacon or control purposes.  |
| <b>Forward Channel</b>         | Radio channel used for transmission of information from the base station to the mobile.   |
| <b>Full Duplex Systems</b>     | 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.  |
| <b>Half Duplex Systems</b>     | 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.   |
| <b>Handoff</b>                 | The process of transferring a mobile station from one channel or base station to another.   |
| <b>Mobile Station</b>          | 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).  |
| <b>Mobile Switching Center</b> | 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).         |
| <b>Page</b>                    | A brief message which is broadcast over the entire service area, usually in a simulcast fashion by many base stations at the same time.   |
| <b>Reverse Channel</b>         | Radio channel used for transmission of information from the mobile to base station.   |
| <b>Roamer</b>                  | A mobile station which operates in a service area (market) other than that from which service has been subscribed.  |
| <b>Simplex Systems</b>         | Communication systems which provide only one-way communication.   |
| <b>Subscriber</b>              | A user who pays subscription charges for using a mobile communications system.  |
| <b>Transceiver</b>             | A device capable of simultaneously transmitting and receiving radio signals.  |

# Mobile Radio Transmission Systems

- **Simplex**

communication is possible in only one direction (e.g., paging systems)

- **Half-duplex**

allows two-way communication, but use the same radio channel for both transmission and reception, i.e., user can only transmit or receive information at any given time (push-to-talk & release-to-listen)

- **Full-duplex**

simultaneous radio transmission and reception between a subscriber and a base station, using frequency division duplex (FDD) or time division duplex (TDD)

*Half-duplex and full-duplex systems use **transceivers***

# Frequency Division Duplex (FDD)

- In the same time interval, but different frequency bands for transmit and receive
  - **At the base station:** Separate transmit and receive antennas
  - **At the subscriber unit:**
    - A single antenna for both
    - And a duplexer (to enable the same antenna to be used)

*In FDD, it is necessary to separate the transmit and receive frequencies by about 5% of the nominal RF frequency, so that the duplexer can provide sufficient isolation while being inexpensively manufactured*

From the base station to the mobile user: **Forward channel**

From the mobile user to the base station: **Reverse channel**

# Time Division Duplex (TDD)

- In the same frequency channel, but different time portions for transmit and receive  
(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 base station)
- Only possible with digital transmission formats and digital modulation, very sensitive to timing  
→ has only recently been used and only for indoor or small area wireless applications

*Because the physical coverage distances (and thus the radio propagation time delay) are much smaller than the many kilometers used in conventional cellular telephone systems)*



**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                | $\pi/4$ -DQPSK | 30 kHz            |
| CDPD              | Cellular         | 1993                 | FH/<br>Packet   | 824-894 MHz                | GMSK           | 30 kHz            |
| IS-95             | Cellular/<br>PCS | 1993                 | CDMA            | 824-894 MHz<br>1.8-2.0 GHz | QPSK/<br>BPSK  | 1.25 MHz          |
| GSC               | Paging           | 1970's               | Simplex         | Several                    | FSK            | 12.5 kHz          |
| POCSAG            | Paging           | 1970's               | Simplex         | Several                    | FSK            | 12.5 kHz          |
| FLEX              | Paging           | 1993                 | Simplex         | Several                    | 4-FSK          | 15 kHz            |
| DCS-1900<br>(GSM) | PCS              | 1994                 | TDMA            | 1.85-1.99 GHz              | GMSK           | 200 kHz           |
| PACS              | Cordless/<br>PCS | 1994                 | TDMA/<br>FDMA   | 1.85-1.99 GHz              | $\pi/4$ -DQPSK | 300 kHz           |
| MIRS              | SMR/PCS          | 1994                 | TDMA            | Several                    | 16-QAM         | 25 kHz            |

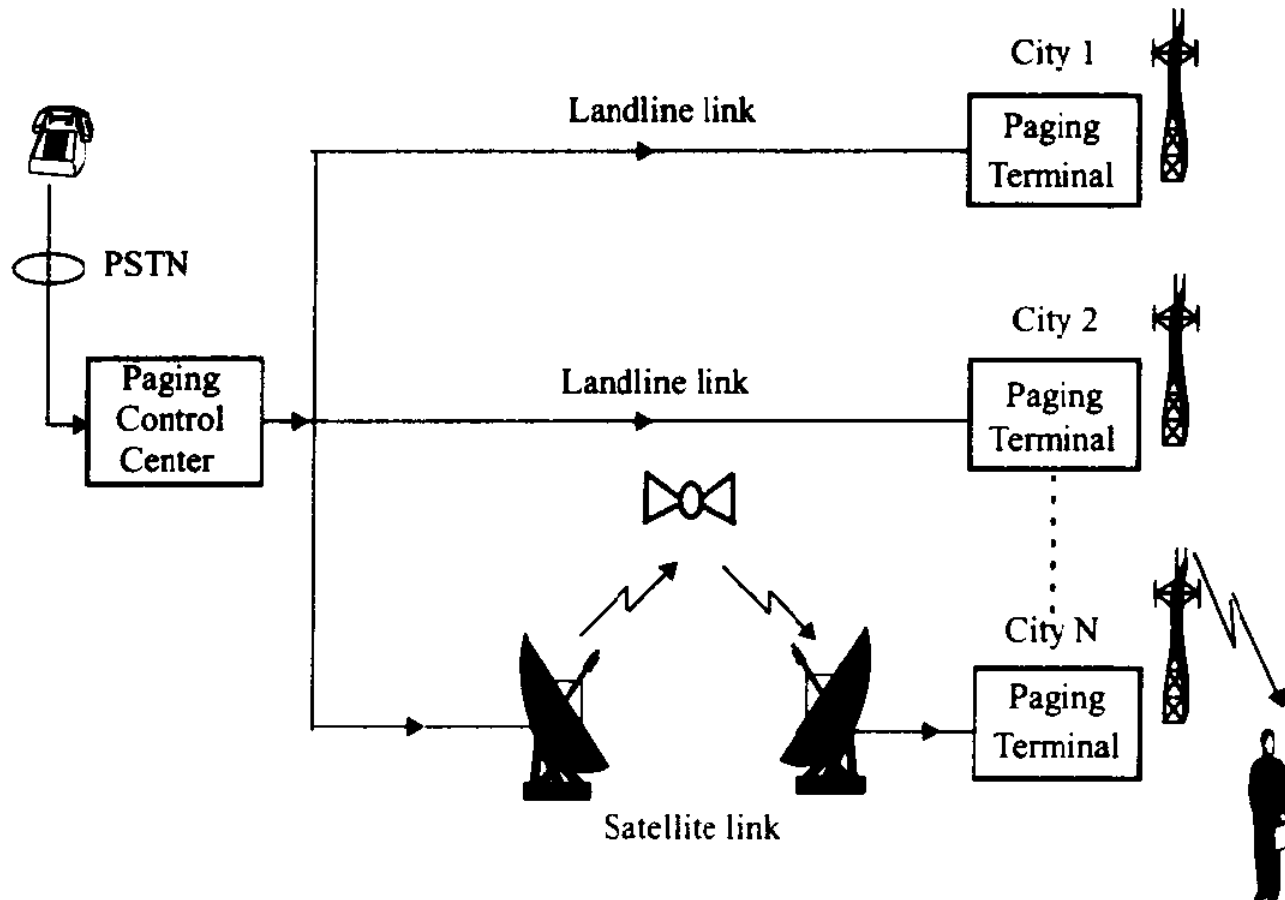
**Table 1.2 Major Mobile Radio Standards in Europe**

| Standard | Type             | Year of Introduction | Multiple Access | Frequency Band   | Modulation | Channel Bandwidth |
|----------|------------------|----------------------|-----------------|------------------|------------|-------------------|
| E-TACS   | 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<br>/PCS | 1990                 | TDMA            | 890-960 MHz      | GMSK       | 200 kHz           |
| C-450    | Cellular         | 1985                 | FDMA            | 450-465 MHz      | FM         | 20 kHz/<br>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<br>MHz | GFSK       | 1.728 MHz         |
| DCS-1800 | Cordless<br>/PCS | 1993                 | TDMA            | 1710-1880<br>MHz | GMSK       | 200 kHz           |

**Table 1.3 Major Mobile Radio Standards in Japan**

| Standard | Type     | Year of Introduction | Multiple Access | Frequency Band | Modulation     | Channel Bandwidth |
|----------|----------|----------------------|-----------------|----------------|----------------|-------------------|
| JTACS    | Cellular | 1988                 | FDMA            | 860-925 MHz    | FM             | 25 kHz            |
| PDC      | Cellular | 1993                 | TDMA            | 810-1501 MHz   | $\pi/4$ -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  | $\pi/4$ -DQPSK | 300 kHz           |

# Paging Systems



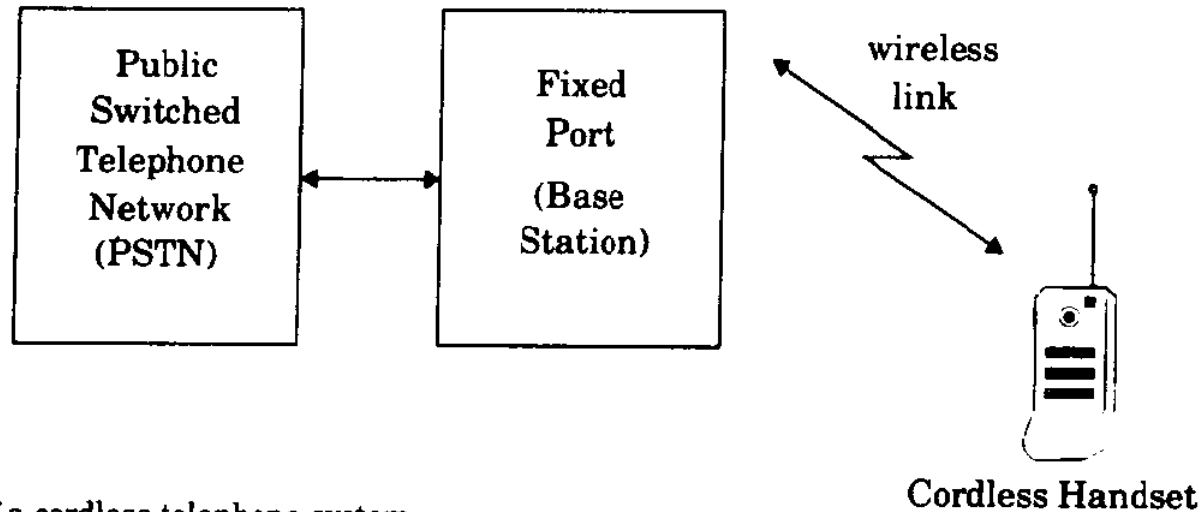
**Figure 1.3**

**Diagram of a wide area paging system. The paging control center dispatches pages received from the PSTN throughout several cities at the same time.**

# Paging Systems

- Simplex
- Simple paging systems may cover a limited range of 2 to 5 km, may even be confined to within individual buildings
- Wide area paging systems can provide worldwide coverage
- Paging receivers are simple and inexpensive, but the transmission system required is quite sophisticated

# Cordless Telephone Systems



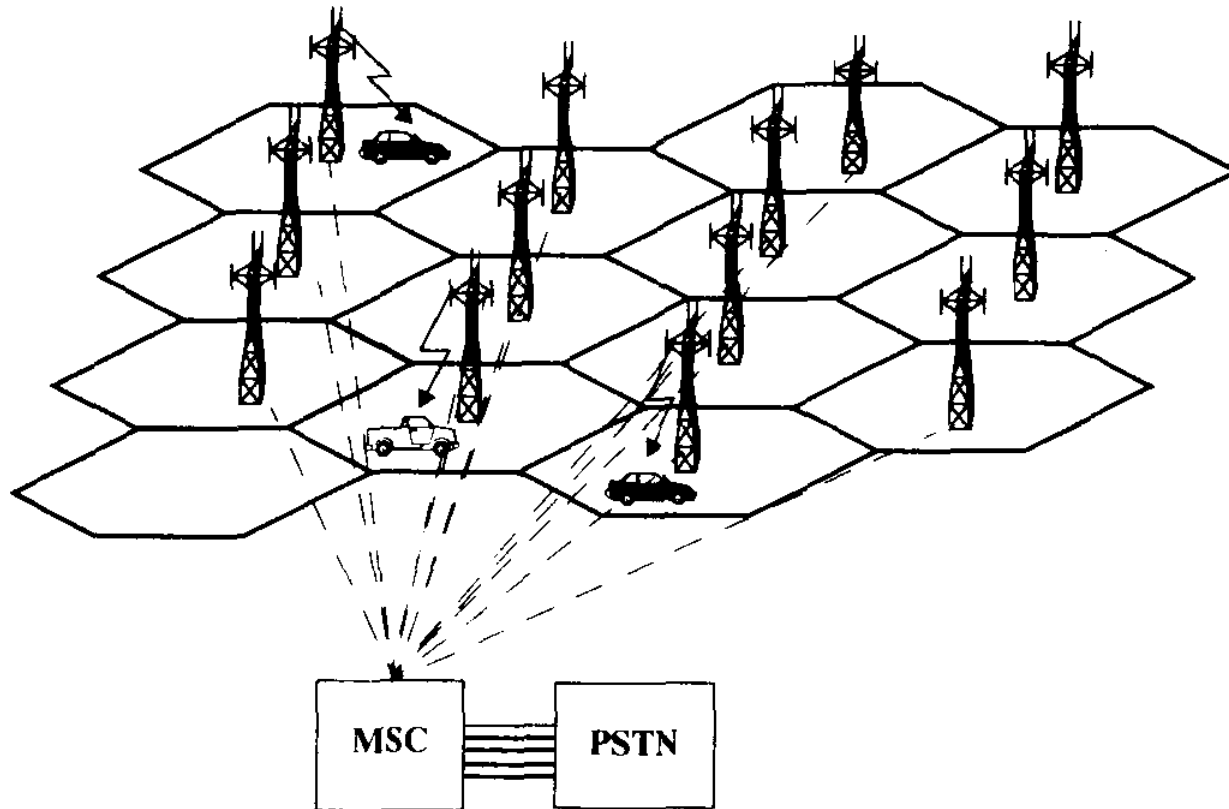
**Figure 1.4**  
Diagram of a cordless telephone system.

# Cordless Telephone Systems

- Full-duplex
- A portable handset is connected to a dedicated base station → which is connected to a dedicated telephone line with a specific telephone number on the public switched telephone network (PSTN)
- First generation: Portable unit communicates only to the dedicated base unit and only over distances of a few tens of meters
- Second generation: (Recently been introduced) Allows subscribers to use their handsets at many outdoor locations, combined with paging receivers, coverage ranges up to a few hundred meters



# Cellular Telephone Systems



**Figure 1.5**

An illustration of a cellular system. The towers represent base stations which provide radio access between mobile users and the Mobile Switching Center (MSC).

# Cellular Telephone Systems

- Full-duplex
- High capacity is achieved by limiting the coverage of each base station transmitter to a small geographic area called a **cell**
- So that the same radio channels may be **reused** by another base station located some distance away
- A sophisticated switching technique called **handoff** enables a call to proceed uninterrupted when the user moves from one cell to another

# Cellular Telephone Systems (cont'd)

- Mobile station contains:
  - A transceiver
  - An antenna
  - Control circuitry
  - May be mounted in a vehicle or used as a portable hand-held unit
- Base station consists of:
  - Several transmitters and receivers which simultaneously handle full-duplex communications
  - Towers which support several transmitting and receiving antennas
- MSC coordinates the activities of all the base stations and connect the entire cellular system to PSTN

A typical MSC handles 100,000 subscribers and 5,000 simultaneous conversations at a time

# Cellular Telephone Systems (cont'd)

- Communication between the base station and the mobiles is defined by a standard *common air interface* (CAI) that specifies four different channels
  - Forward voice channels (FVC)
  - Reverse voice channels (RVC)
  - Forward control channels (FCC)
  - Reverse control channels (RCC)

Control channels are often called *setup channels* (because they are only involved in setting up a call and moving it to an unused voice channel)

Control channels: 5% of the total number of channels available in the system

Voice and data traffic: The remaining 95%

|              |     |  |   |   |   |  |  |   |
|--------------|-----|--|---|---|---|--|--|---|
| 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 message 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

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

MIN: Mobile identification number  
ESN: Electronic serial number

|              |     |  |  |   |  |  |                           |
|--------------|-----|--|--|---|--|--|---------------------------|
| 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

Timing diagram illustrating how a call initiated by a mobile is established

MIN: Mobile identification number  
ESN: Electronic serial number

**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           | Infra-red         | 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           | < 100 MHz         | Transceiver   |
| Cellular Phone     | High           | High                     | High       | Moderate      | < 1 GHz           | Transceiver   |

**Table 1.6 Comparison of Mobile Communication Systems — Base Station**

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