# Wireless Communication

## Lecture 9

## Cellular Wireless Networks

# Cellular Network Organization

- Use multiple low-power transmitters (100 W or less)
- Areas divided into cells
  - Each served by its own antenna
  - Served by base station consisting of transmitter, receiver, and control unit
  - Band of frequencies allocated
  - Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)

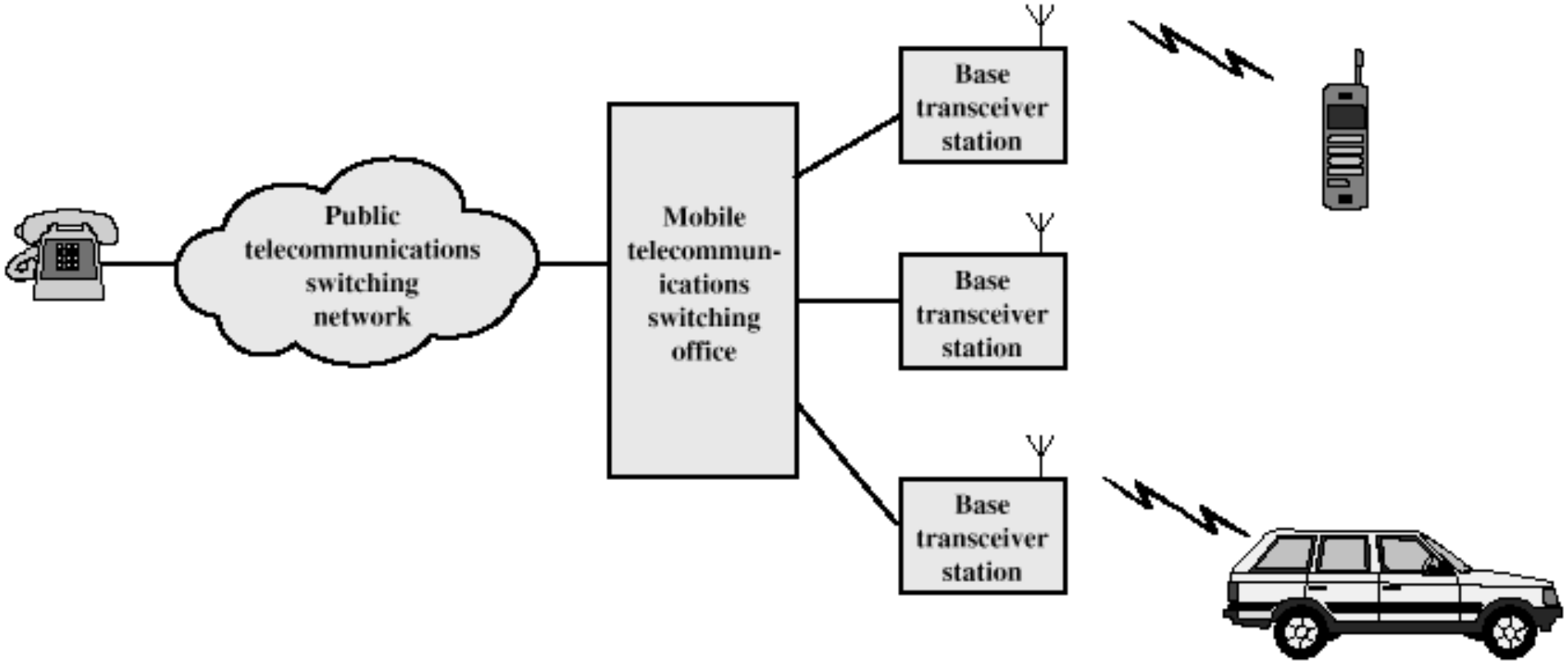
# Frequency Reuse

- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Objective is to reuse frequency in nearby cells
  - 10 to 50 frequencies assigned to each cell
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells
  - The issue is to determine how many cells must intervene between two cells using the same frequency

# Approaches to Cope with Increasing Capacity

- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels
- Microcells – antennas move to buildings, hills, and lamp posts

# Cellular System Overview



# Cellular Systems Terms

- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - Control channels – used to exchange information having to do with setting up and maintaining calls
  - Traffic channels – carry voice or data connection between users

# Steps in an MTSO Controlled Call between Mobile Users

- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff

# Additional Functions in an MTSO Controlled Call

- Call blocking
- Call termination
- Call drop
- Calls to/from fixed and remote mobile subscriber

# Mobile Radio Propagation Effects

- Signal strength
  - Must be strong enough between base station and mobile unit to maintain signal quality at the receiver
  - Must not be so strong as to create too much cochannel interference with channels in another cell using the same frequency band
- Fading
  - Signal propagation effects may disrupt the signal and cause errors

# Handoff Performance Metrics

- Cell blocking probability – probability of a new call being blocked
- Call dropping probability – probability that a call is terminated due to a handoff
- Call completion probability – probability that an admitted call is not dropped before it terminates
- Probability of unsuccessful handoff – probability that a handoff is executed while the reception conditions are inadequate

# Handoff Performance Metrics

- Handoff blocking probability – probability that a handoff cannot be successfully completed
- Handoff probability – probability that a handoff occurs before call termination
- Rate of handoff – number of handoffs per unit time
- Interruption duration – duration of time during a handoff in which a mobile is not connected to either base station
- Handoff delay – distance the mobile moves from the point at which the handoff should occur to the point at which it does occur

# Handoff Strategies Used to Determine Instant of Handoff

- Relative signal strength
- Relative signal strength with threshold
- Relative signal strength with hysteresis
- Relative signal strength with hysteresis and threshold
- Prediction techniques

# Power Control

- Design issues making it desirable to include dynamic power control in a cellular system
  - Received power must be sufficiently above the background noise for effective communication
  - Desirable to minimize power in the transmitted signal from the mobile
    - Reduce cochannel interference, alleviate health concerns, save battery power
  - In SS systems using CDMA, it's desirable to equalize the received power level from all mobile units at the BS

# Types of Power Control

- Open-loop power control
  - Depends solely on mobile unit
  - No feedback from BS
  - Not as accurate as closed-loop, but can react quicker to fluctuations in signal strength
- Closed-loop power control
  - Adjusts signal strength in reverse channel based on metric of performance
  - BS makes power adjustment decision and communicates to mobile on control channel

# Traffic Engineering

- Ideally, available channels would equal number of subscribers active at one time
- In practice, not feasible to have capacity handle all possible load
- For $N$ simultaneous user capacity and $L$ subscribers
  - $L < N$ – nonblocking system
  - $L > N$ – blocking system

# Blocking System Performance Questions

- Probability that call request is blocked?
- What capacity is needed to achieve a certain upper bound on probability of blocking?
- What is the average delay?
- What capacity is needed to achieve a certain average delay?

# Traffic Intensity

- Load presented to a system:

$$A = \lambda h$$

  - $\lambda$ = mean rate of calls attempted per unit time
  - $h$ = mean holding time per successful call
  - $A$ = average number of calls arriving during average holding period, for normalized $\lambda$

# Factors that Determine the Nature of the Traffic Model

- Manner in which blocked calls are handled
  - Lost calls delayed (LCD) – blocked calls put in a queue awaiting a free channel
  - Blocked calls rejected and dropped
    - Lost calls cleared (LCC) – user waits before another attempt
    - Lost calls held (LCH) – user repeatedly attempts calling
- Number of traffic sources
  - Whether number of users is assumed to be finite or infinite

# First-Generation Analog

- Advanced Mobile Phone Service (AMPS)
  - In North America, two 25-MHz bands allocated to AMPS
    - One for transmission from base to mobile unit
    - One for transmission from mobile unit to base
  - Each band split in two to encourage competition
  - Frequency reuse exploited

# AMPS Operation

- Subscriber initiates call by keying in phone number and presses send key
- MTSO verifies number and authorizes user
- MTSO issues message to user's cell phone indicating send and receive traffic channels
- MTSO sends ringing signal to called party
- Party answers; MTSO establishes circuit and initiates billing information
- Either party hangs up; MTSO releases circuit, frees channels, completes billing

# Differences Between First and Second Generation Systems

- Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users

# Mobile Wireless TDMA Design Considerations

- Number of logical channels (number of time slots in TDMA frame): 8
- Maximum cell radius (R): 35 km
- Frequency: region around 900 MHz
- Maximum vehicle speed ($V_m$):250 km/hr
- Maximum coding delay: approx. 20 ms
- Maximum delay spread ($\Delta_m$): 10 $\mu$s
- Bandwidth: Not to exceed 200 kHz (25 kHz per channel)

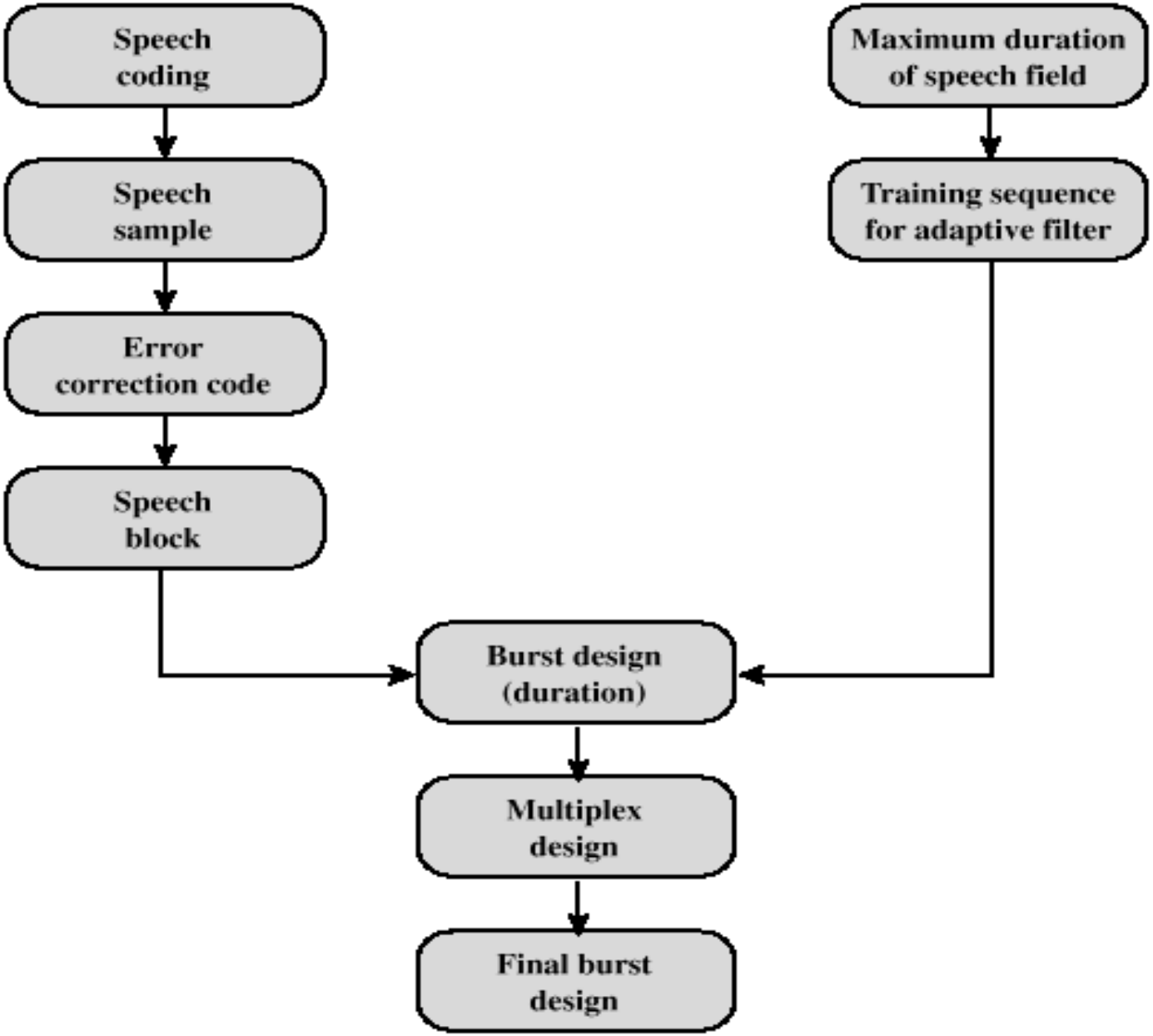



**Figure 10.12 Steps in Design of TDMA Timeslot**

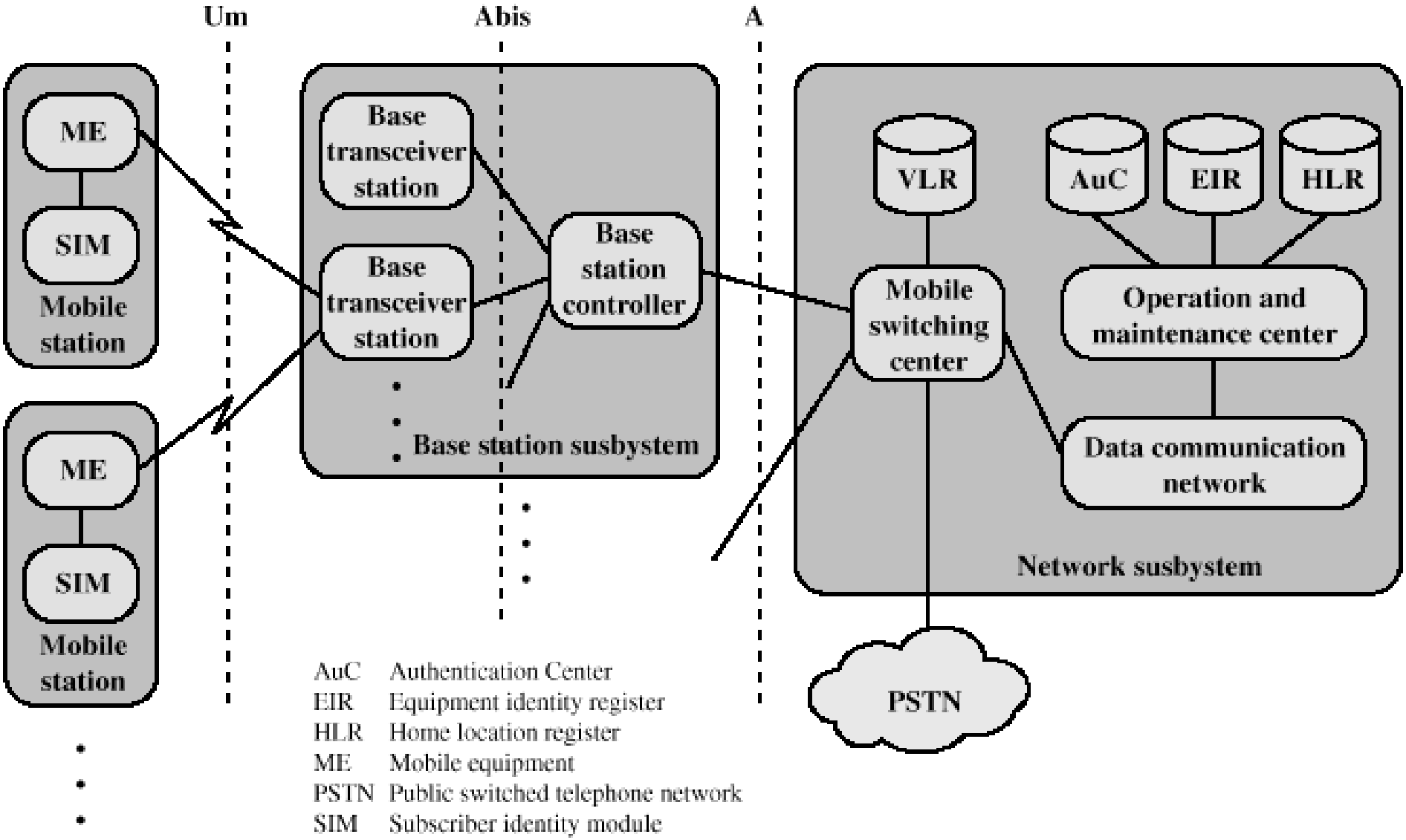



**Figure 10.14 Overall GSM Architecture**

# Mobile Station

- Mobile station communicates across Um interface (air interface) with base station transceiver in same cell as mobile unit
- Mobile equipment (ME) – physical terminal, such as a telephone or PCS
  - ME includes radio transceiver, digital signal processors and subscriber identity module (SIM)
- GSM subscriber units are generic until SIM is inserted
  - SIMs roam, not necessarily the subscriber devices

# Base Station Subsystem (BSS)

- BSS consists of base station controller and one or more base transceiver stations (BTS)
- Each BTS defines a single cell
  - Includes radio antenna, radio transceiver and a link to a base station controller (BSC)
- BSC reserves radio frequencies, manages handoff of mobile unit from one cell to another within BSS, and controls paging

# Network Subsystem (NS)

- NS provides link between cellular network and public switched telecommunications networks
  - Controls handoffs between cells in different BSSs
  - Authenticates users and validates accounts
  - Enables worldwide roaming of mobile users
- Central element of NS is the mobile switching center (MSC)

# Mobile Switching Center (MSC) Databases

- Home location register (HLR) database – stores information about each subscriber that belongs to it
- Visitor location register (VLR) database – maintains information about subscribers currently physically in the region
- Authentication center database (AuC) – used for authentication activities, holds encryption keys
- Equipment identity register database (EIR) – keeps track of the type of equipment that exists at the mobile station

# TDMA Format – Time Slot Fields

- Trail bits – allow synchronization of transmissions from mobile units
- Encrypted bits – encrypted data
- Stealing bit - indicates whether block contains data or is "stolen"
- Training sequence – used to adapt parameters of receiver to the current path propagation characteristics
  - Strongest signal selected in case of multipath propagation
- Guard bits – used to avoid overlapping with other bursts

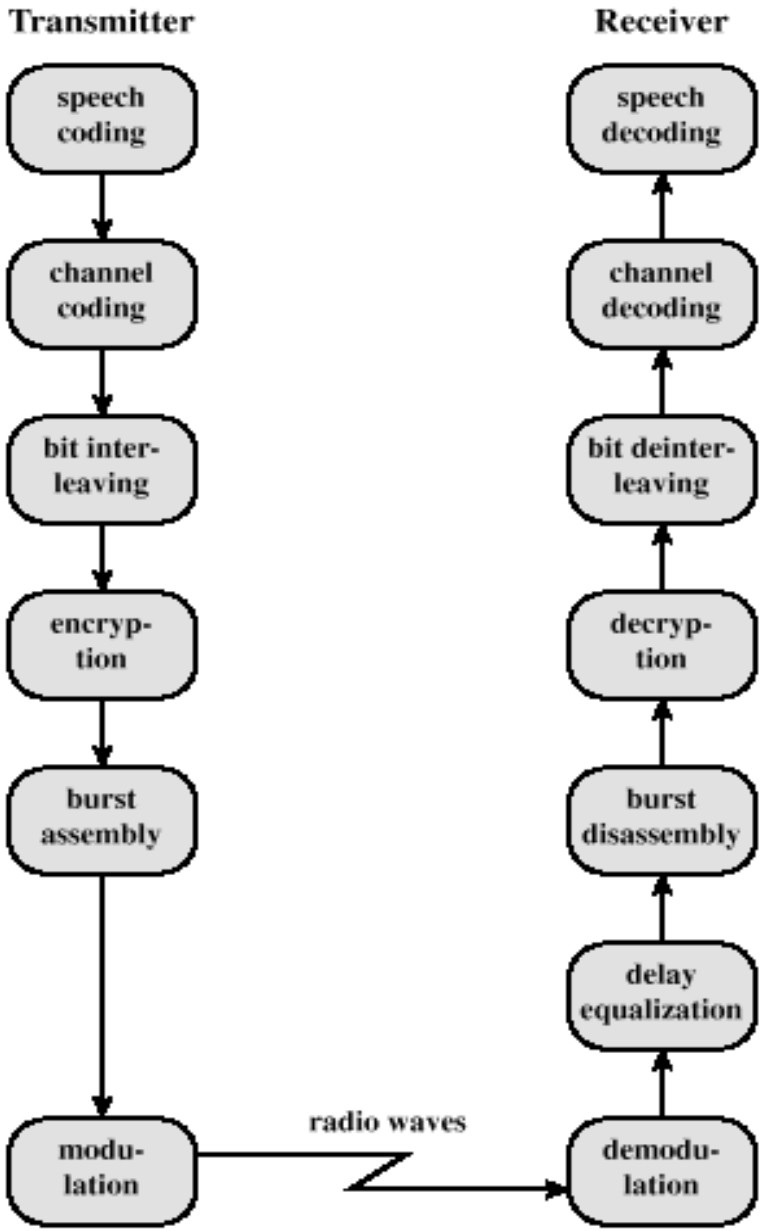
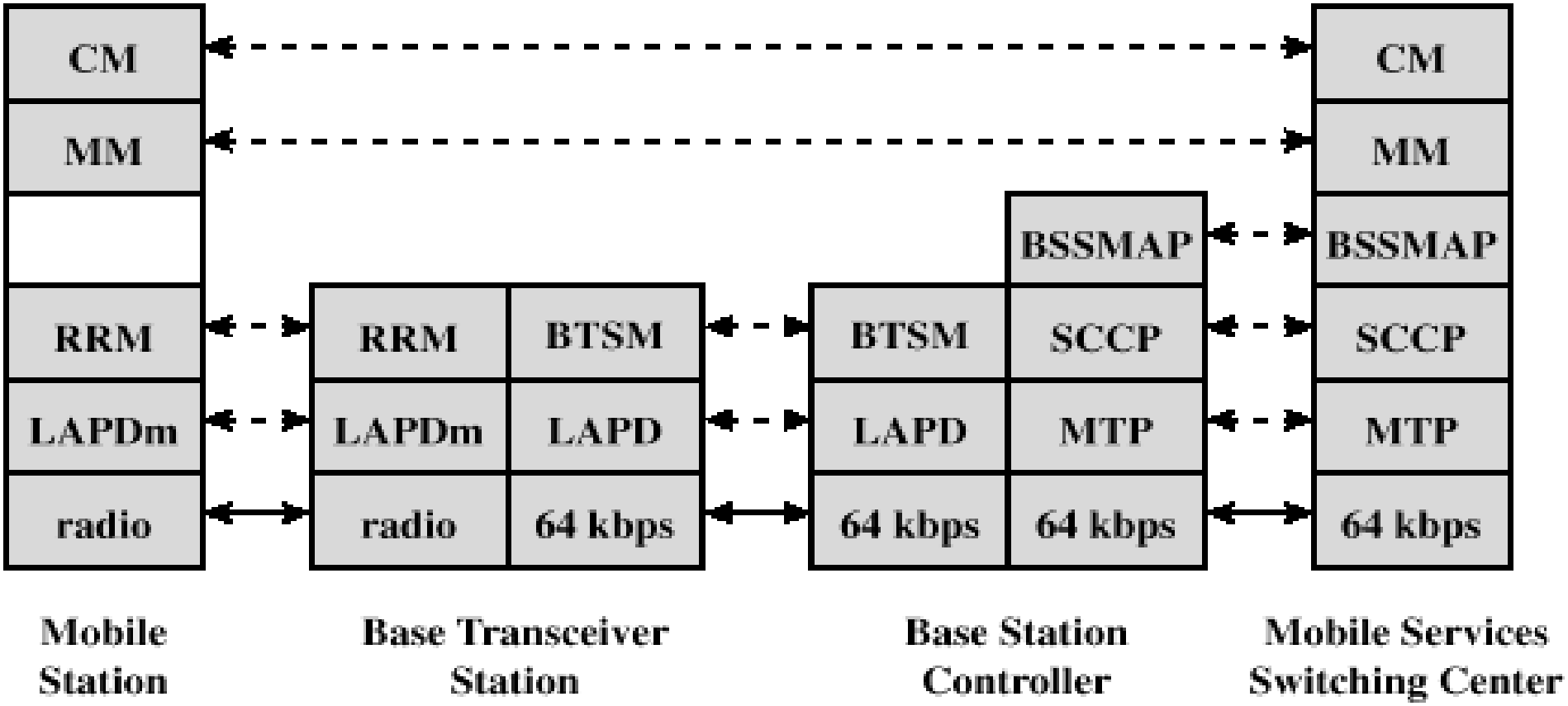



**Figure 10.16 GSM Speech Signal Processing**




BSSMAP = BSS mobile application part
BTSM = BTS management
CM = connection management
LAPD = link access protocol, D channel
MM = mobility management
MTP = message transfer part
RRM = radio resources management
SCCP = signal connection control part

**Figure 10.17 GSM Signaling Protocol Architecture**

# Functions Provided by Protocols

- Protocols above the link layer of the GSM signaling protocol architecture provide specific functions:
  - Radio resource management
  - Mobility management
  - Connection management
  - Mobile application part (MAP)
  - BTS management

# Advantages of CDMA Cellular

- Frequency diversity – frequency-dependent transmission impairments have less effect on signal
- Multipath resistance – chipping codes used for CDMA exhibit low cross correlation and low autocorrelation
- Privacy – privacy is inherent since spread spectrum is obtained by use of noise-like signals
- Graceful degradation – system only gradually degrades as more users access the system

# Drawbacks of CDMA Cellular

- Self-jamming – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized
- Near-far problem – signals closer to the receiver are received with less attenuation than signals farther away
- Soft handoff – requires that the mobile acquires the new cell before it relinquishes the old; this is more complex than hard handoff used in FDMA and TDMA schemes

# Mobile Wireless CDMA Design Considerations

- RAKE receiver – when multiple versions of a signal arrive more than one chip interval apart, RAKE receiver attempts to recover signals from multiple paths and combine them
  - This method achieves better performance than simply recovering dominant signal and treating remaining signals as noise
- Soft Handoff – mobile station temporarily connected to more than one base station simultaneously

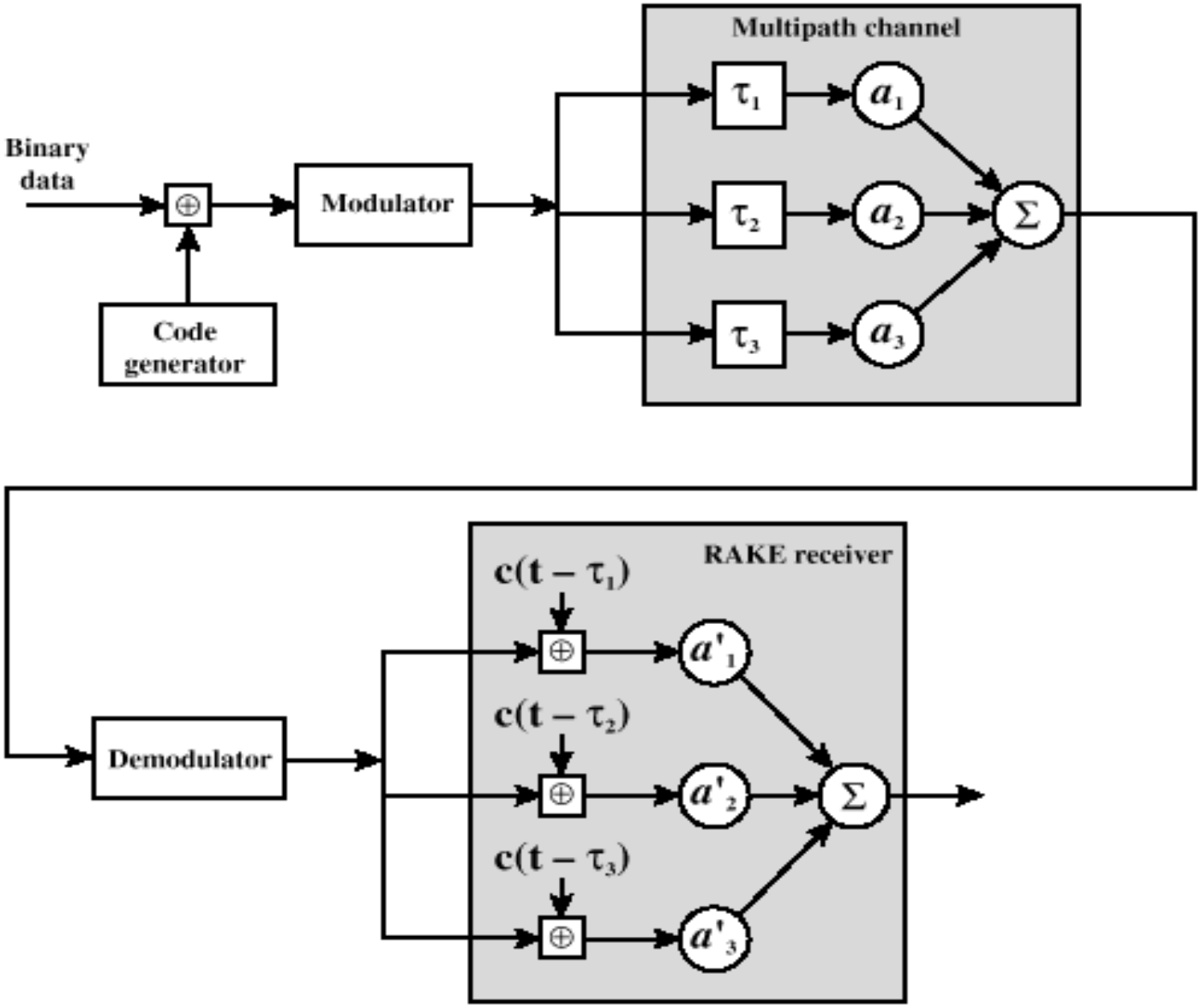



**Figure 10.18 Principle of RAKE Receiver [PRAS98]**

# Types of Channels Supported by Forward Link

- Pilot (channel 0) - allows the mobile unit to acquire timing information, provides phase reference and provides means for signal strength comparison
- Synchronization (channel 32) - used by mobile station to obtain identification information about cellular system
- Paging (channels 1 to 7) - contain messages for one or more mobile stations
- Traffic (channels 8 to 31 and 33 to 63) – the forward channel supports 55 traffic channels

# Forward Traffic Channel Processing Steps

- Speech is encoded at a rate of 8550 bps
- Additional bits added for error detection
- Data transmitted in 2-ms blocks with forward error correction provided by a convolutional encoder
- Data interleaved in blocks to reduce effects of errors
- Data bits are scrambled, serving as a privacy mask

# Forward Traffic Channel Processing Steps (cont.)

- Power control information inserted into traffic channel
- DS-SS function spreads the 19.2 kbps to a rate of 1.2288 Mbps using one row of 64 x 64 Walsh matrix
- Digital bit stream modulated onto the carrier using QPSK modulation scheme

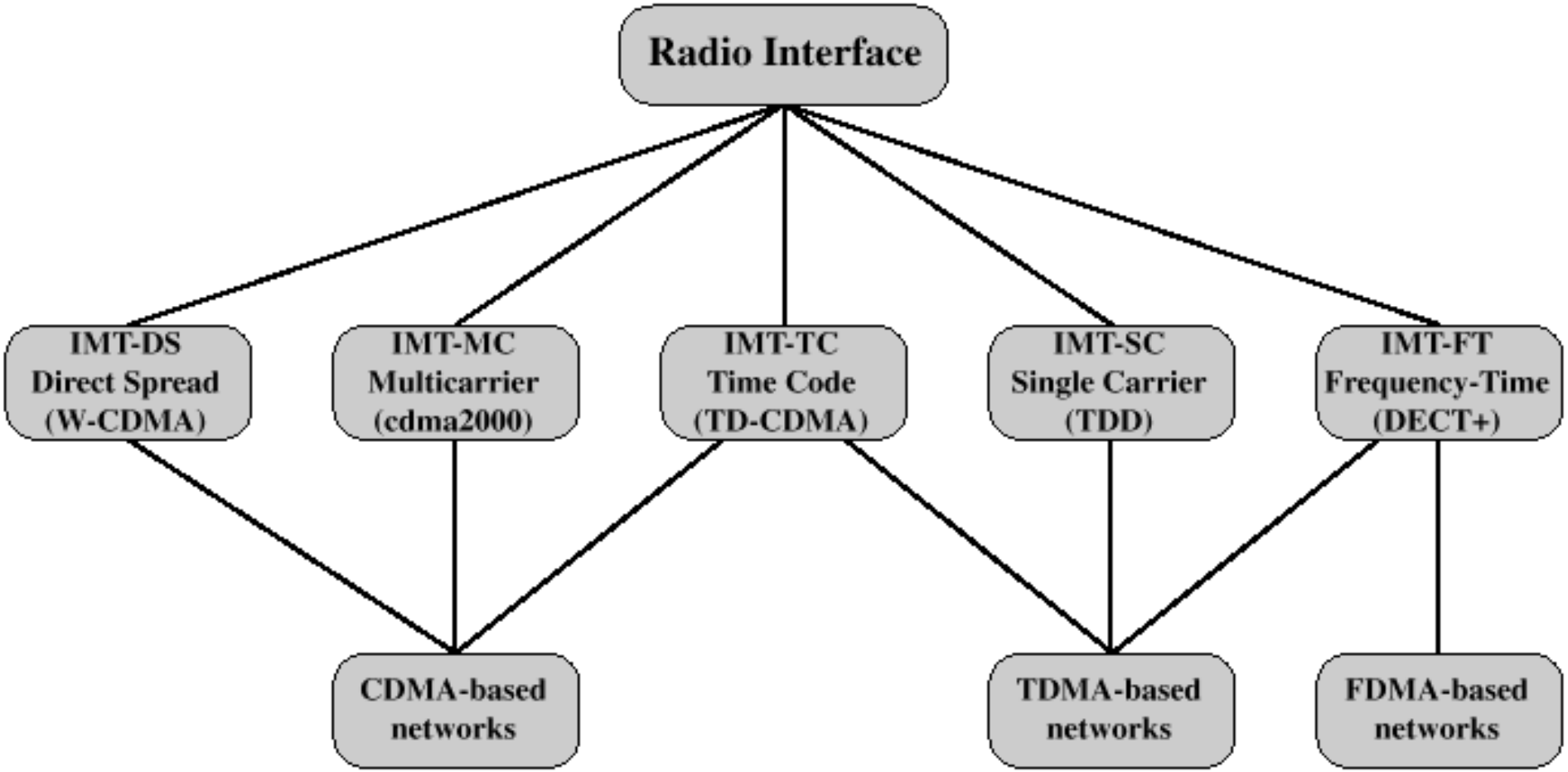
# ITU's View of Third-Generation Capabilities

- Voice quality comparable to the public switched telephone network
- 144 kbps data rate available to users in high-speed motor vehicles over large areas
- 384 kbps available to pedestrians standing or moving slowly over small areas
- Support for 2.048 Mbps for office use
- Symmetrical / asymmetrical data transmission rates
- Support for both packet switched and circuit switched data services

# ITU's View of Third-Generation Capabilities

- An adaptive interface to the Internet to reflect efficiently the common asymmetry between inbound and outbound traffic
- More efficient use of the available spectrum in general
- Support for a wide variety of mobile equipment
- Flexibility to allow the introduction of new services and technologies

# Alternative Interfaces



# CDMA Design Considerations

- Bandwidth – limit channel usage to 5 MHz
- Chip rate – depends on desired data rate, need for error control, and bandwidth limitations; 3 Mcps or more is reasonable
- Multirate – advantage is that the system can flexibly support multiple simultaneous applications from a given user and can efficiently use available capacity by only providing the capacity required for each service