Data and Computer Communications

Chapter 14 – Cellular Wireless Networks

Eighth Edition

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Cellular Wireless Networks

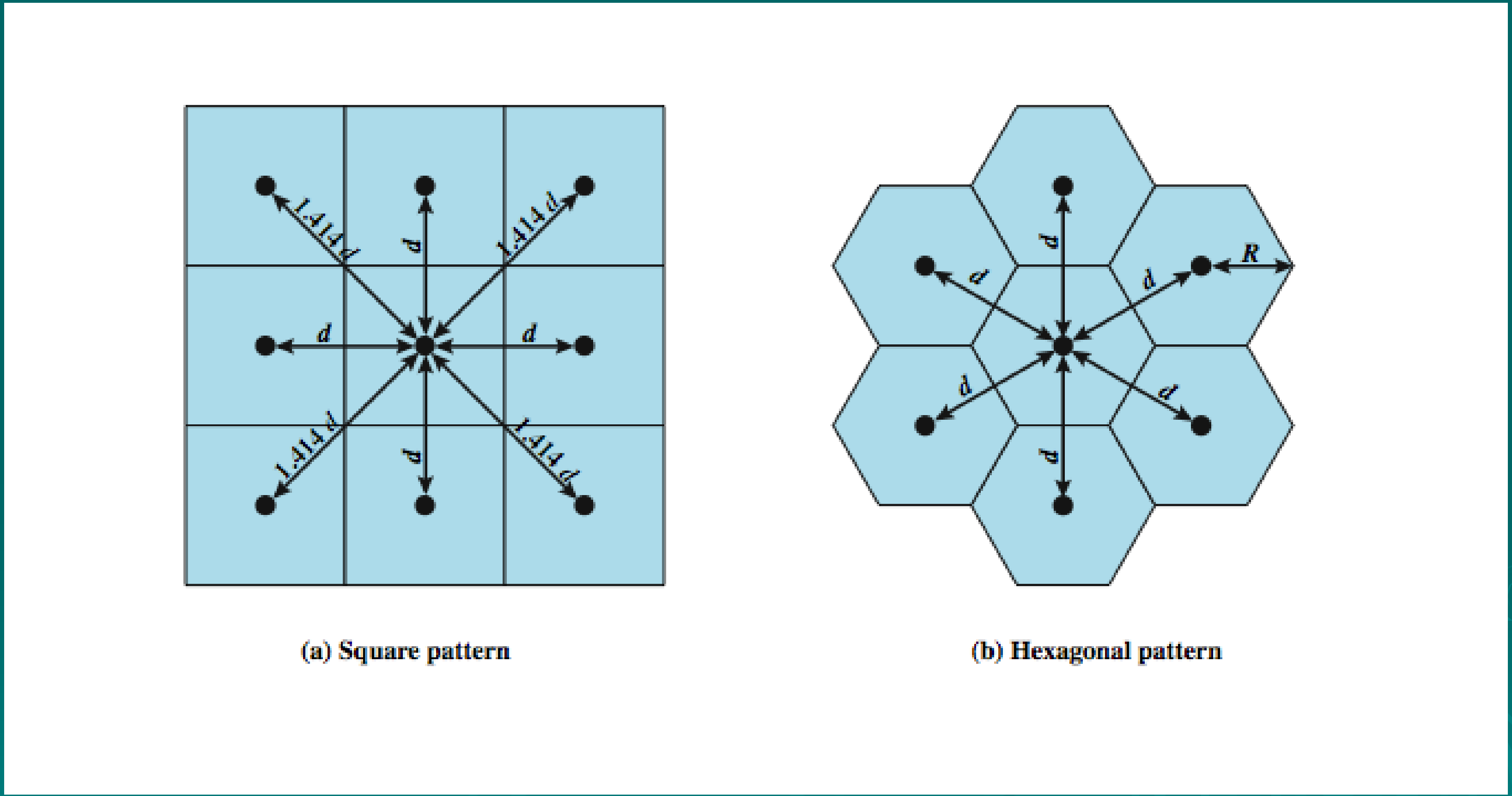
After the fire of 1805, Judge Woodward was the central figure involved in reestablishing the town. Influenced by Major Pierre L'Enfant's plans for Washington, DC, Judge Woodward envisioned a modern series of hexagons with major diagonal avenues centered on circular parks, or circuses, in the center of the hexagons. Frederick Law Olmstead said, "nearly all of the most serious mistakes of Detroit's past have arisen from a disregard of the spirit of Woodward's plan."

—*Endangered Detroit*, Friends of the Book-Cadillac Hotel

Cellular Wireless Networks

- key technology for mobiles, wireless nets etc
- developed to increase mobile phone capacity
- based on multiple low power transmitters
- area divided into cells
  - in a tiling pattern to provide full coverage
  - each with own antenna
  - each with own range of frequencies
  - served by base station
  - adjacent cells use different frequencies to avoid crosstalk

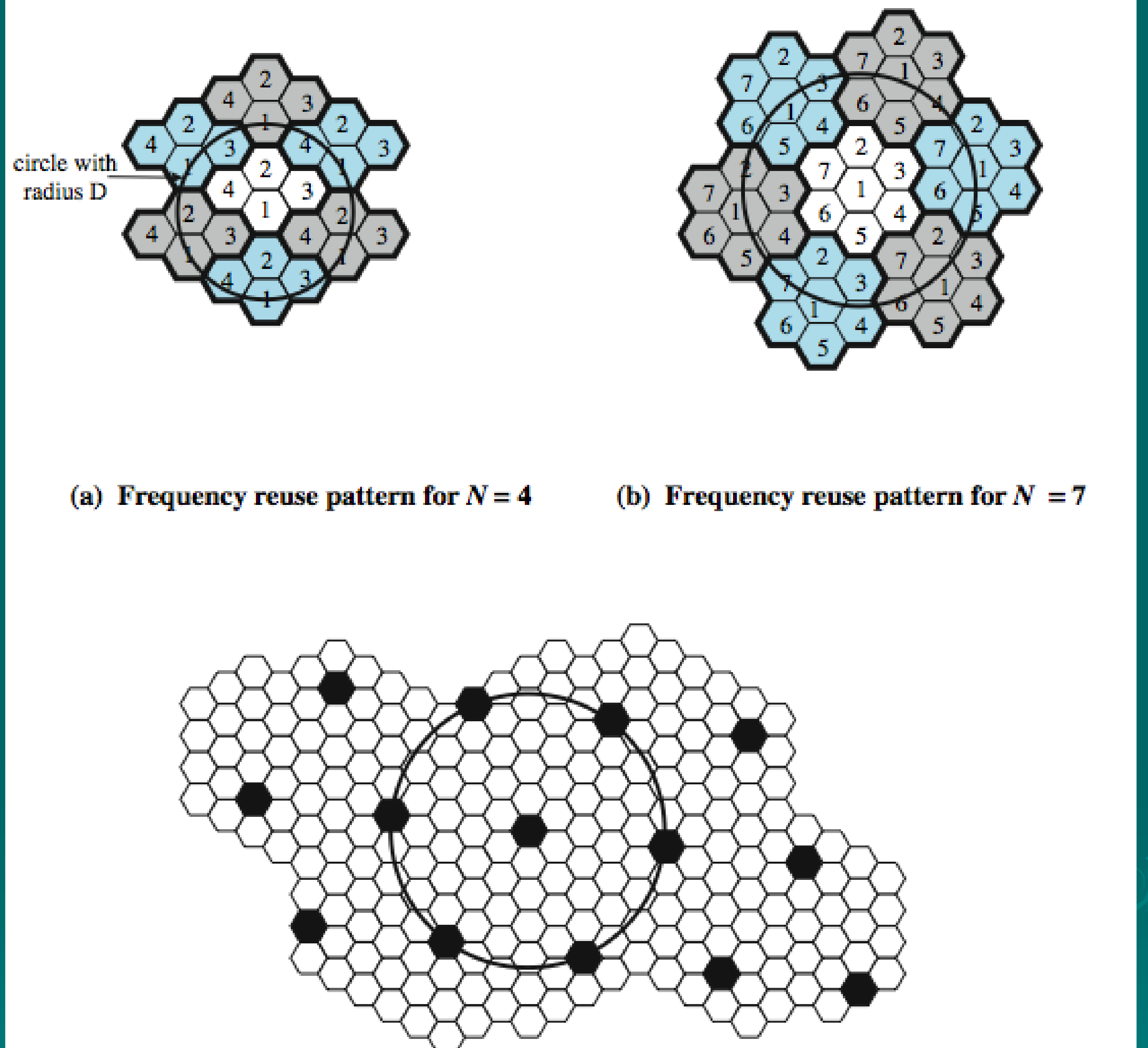
Cellular Geometries



Frequency Reuse

- must manage reuse of frequencies
- power of base transceiver controlled
  - allow communications within cell on given frequency
  - limit escaping power to adjacent cells
  - allow re-use of frequencies in nearby cells
  - typically 10 – 50 frequencies per cell
  - example for Advanced Mobile Phone Service (AMPS)
    - N cells all using same number of frequencies
    - K total number of frequencies used in systems
    - each cell has K/N frequencies
    - K=395, N=7 giving 57 frequencies per cell on average

Frequency Reuse Patterns



(a) Frequency reuse pattern for $N = 4$

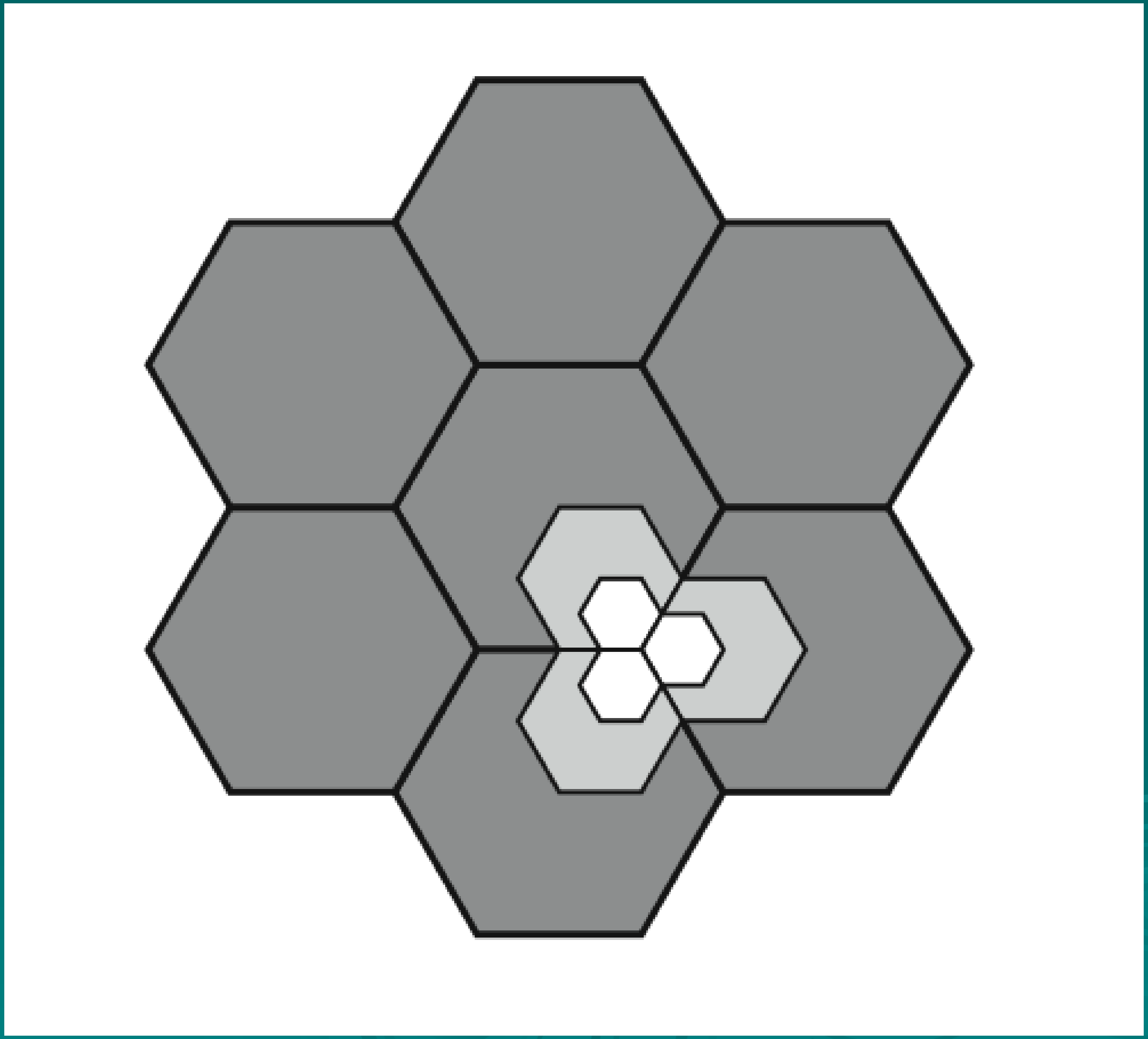
(b) Frequency reuse pattern for $N = 7$

(c) Black cells indicate a frequency reuse for $N = 19$

Increasing Capacity

- add new channels
  - not all channels used to start with
- frequency borrowing
  - taken from adjacent cells by congested cells
  - or assign frequencies dynamically
- cell splitting
  - non-uniform topography and traffic distribution
  - use smaller cells in high use areas

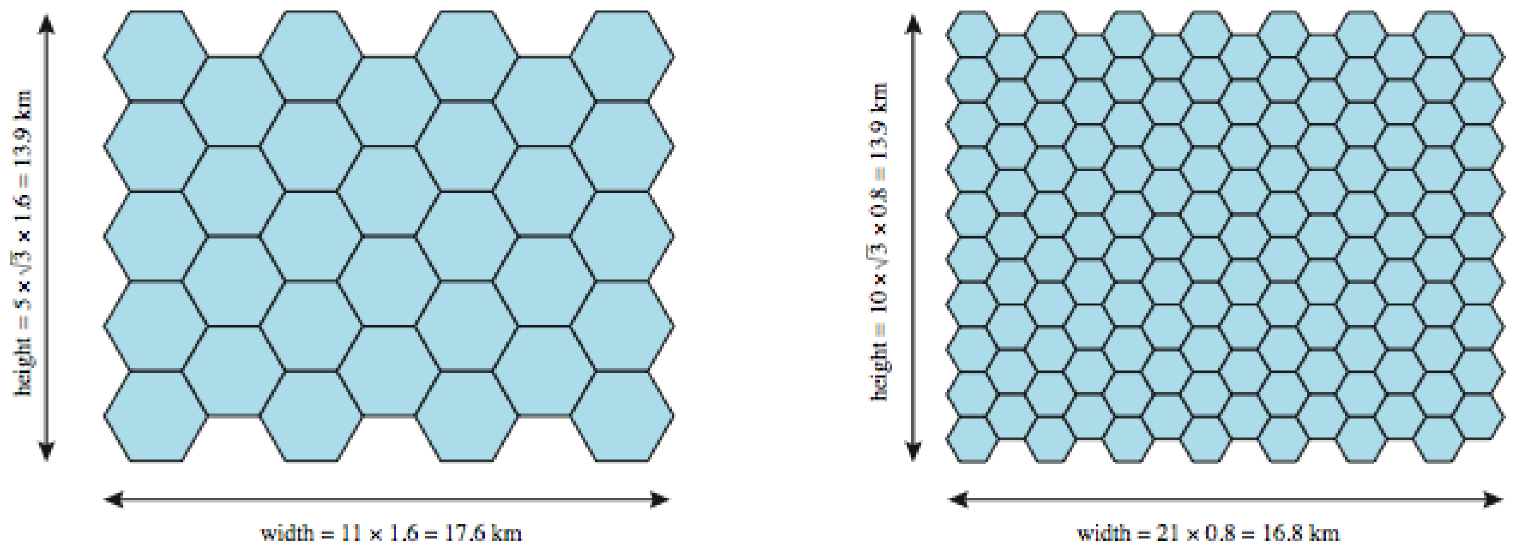
Cell Splitting



Increasing Capacity

- cell sectoring
  - cell divided into wedge shaped sectors (3–6 per cell)
  - each with own channel set
  - directional antennas
- microcells
  - move antennas from tops of hills and large buildings to tops of small buildings and sides of large buildings
  - use reduced power to cover a much smaller area
  - good for city streets, roads, inside large buildings

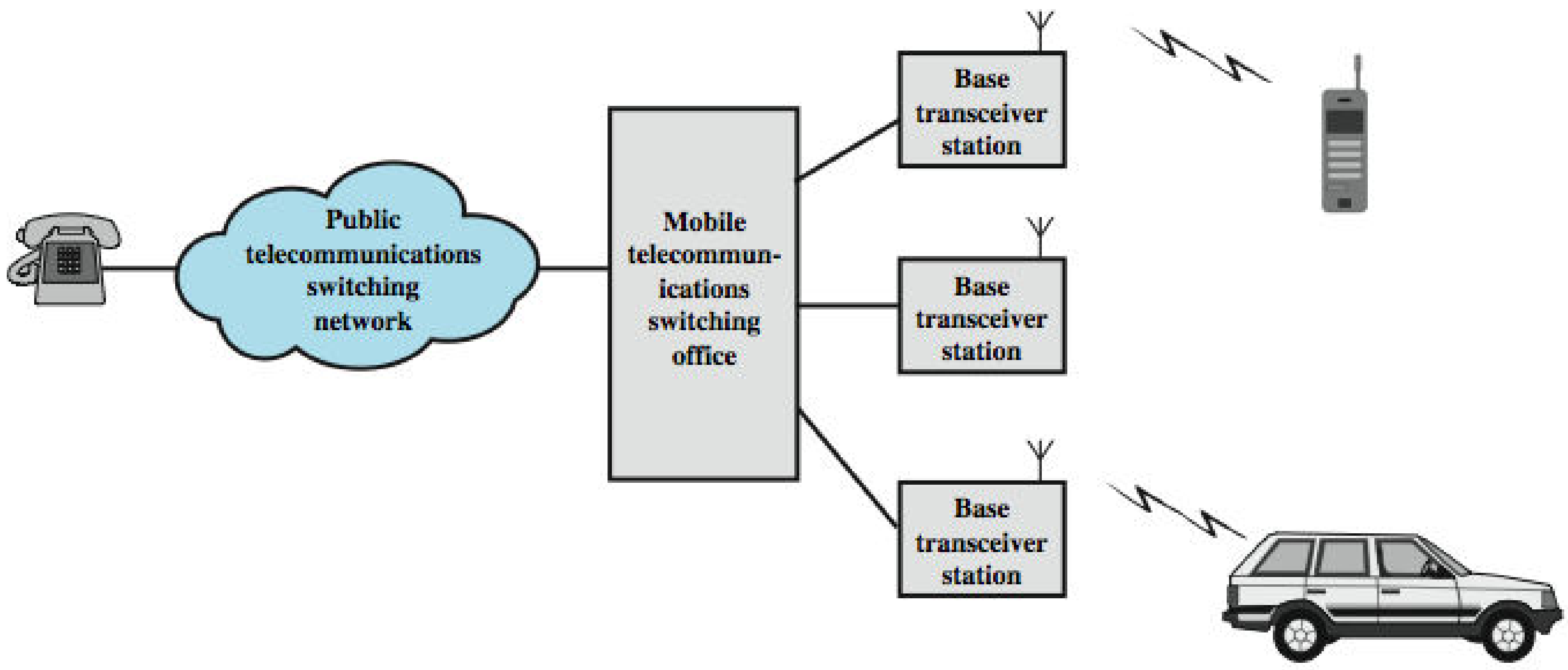
Frequency Reuse Example



(a) Cell radius = 1.6 km

(b) Cell radius = 0.8 km

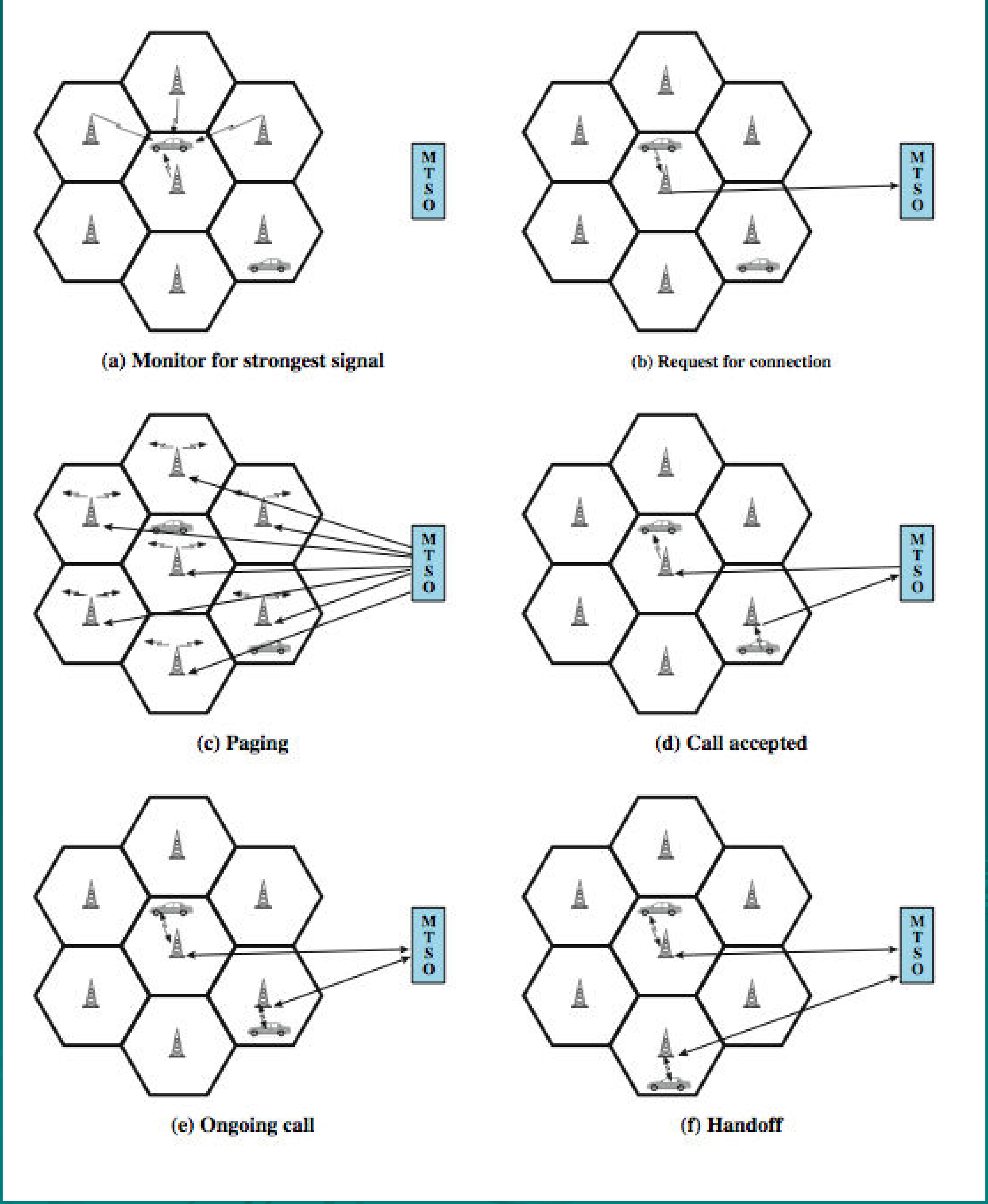
Overview of Cellular System



Cellular System Channels

- system is fully automated
- see two types of channels between mobile and base station (BS)
- control channels
  - set up and maintain calls
  - establish relationship between mobile unit and nearest BS
- traffic channels
  - carry voice and data

Call Stages


MTSO
(a) Monitor for strongest signal
(b) Request for connection
(c) Paging
(d) Call accepted
(e) Ongoing call
(f) Handoff

Other Functions

- call blocking
  - if all traffic channels busy
- call termination
  - when user hangs up
- call drop
  - when BS cannot maintain required signal strength
- calls to/from fixed and remote mobile subscriber
  - MTSO connects mobile user and fixed line via PSTN
  - MTSO connects to remote MTSO via PSTN or dedicated lines

Mobile Radio Propagation Effects

- signal strength
  - strength of signal between BS and mobile unit strong enough to maintain signal quality at the receiver
  - not too strong to create cochannel interference
  - must handle variations in noise
- fading
  - time variation of received signal
  - caused by changes in transmission path(s)
  - even if signal strength in effective range, signal propagation effects may disrupt the signal

Design Factors

- propagation effects
- max transmit power level at BS and mobile units
- typical height of mobile unit antenna
- available height of the BS antenna
- these factors determine size of individual cell
- use model based on empirical data
- eg. model by Okumura et al & refined by Hata
  - detailed analysis of tokyo area
  - produced path loss info for an urban environment
  - Hata's model is an empirical formulation

Multipath Propagation

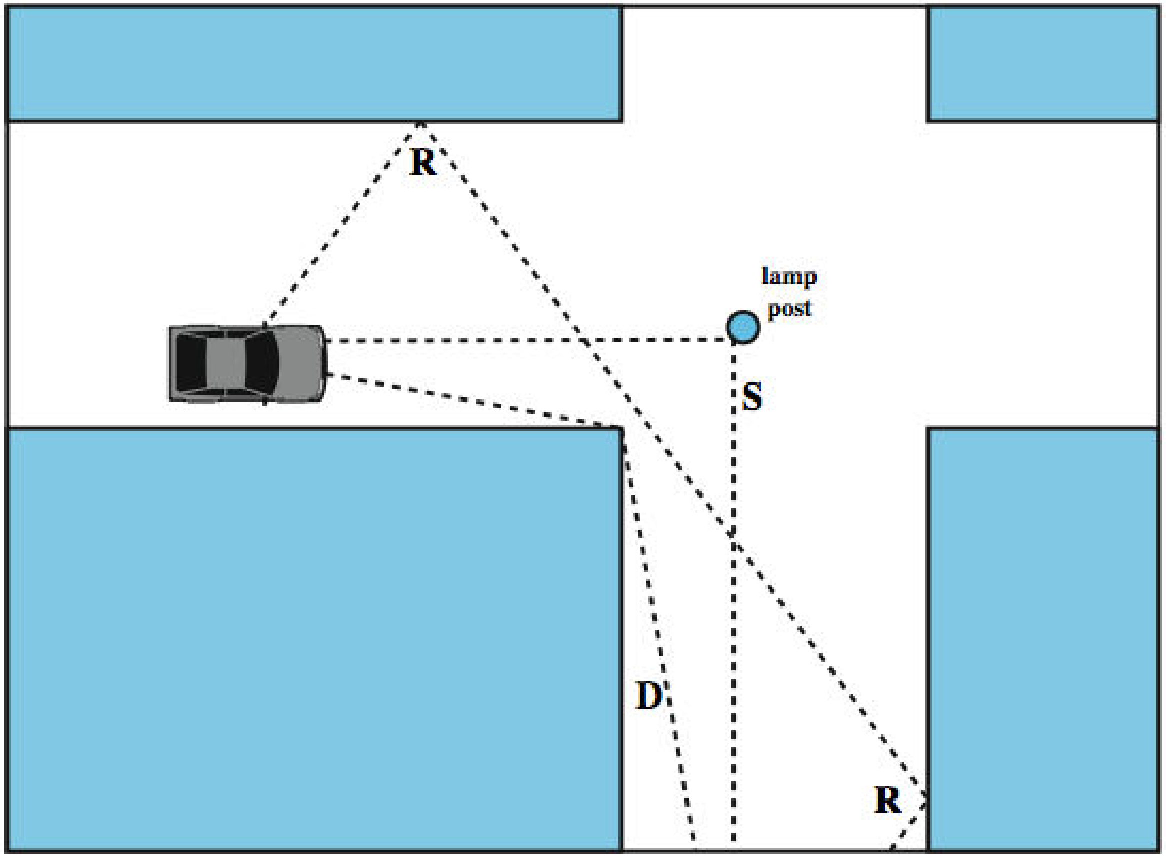
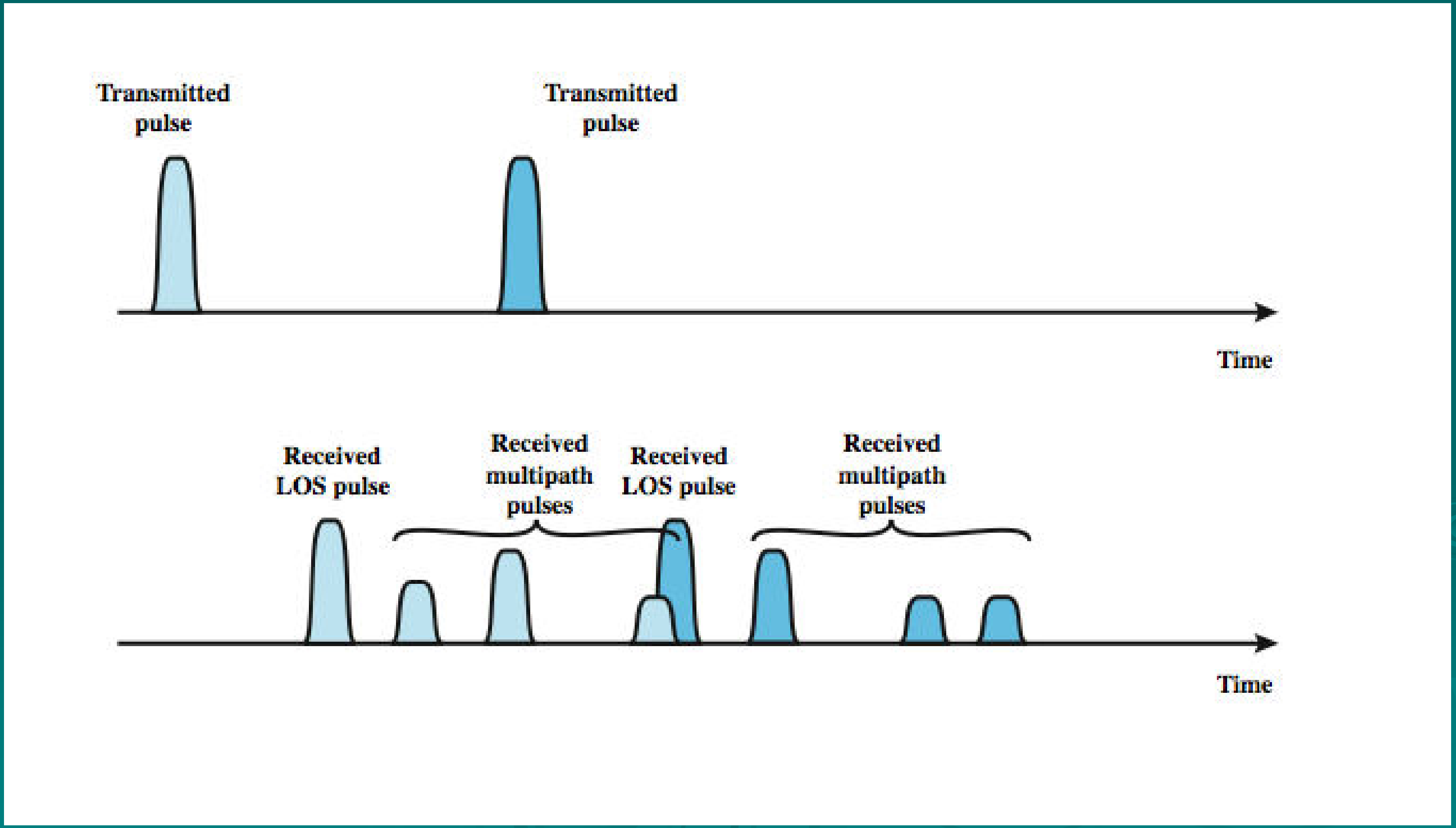


Figure 14.7 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

Effects of Multipath Propagation



Types of Fading

- fast fading
  - rapid changes in strength over half wavelength distances
    - eg. 900MHz wavelength is 0.33m see 20-30dB
- slow fading
  - slower changes due to user passing different height buildings, gaps in buildings etc.
  - over longer distances than fast fading
- flat fading
  - affects all frequencies in same proportion
- selective fading
  - different frequency components affected differently

Error Compensation Mechanisms

- forward error correction
  - applicable in digital transmission applications
  - typically, ratio of total bits to data bits is 2-3
  - has a big overhead
- adaptive equalization
  - applied to transmissions that carry analog or digital information
  - used to combat intersymbol interference
  - gathering the dispersed symbol energy back together into its original time interval
  - techniques include so-called lumped analog circuits and sophisticated digital signal processing algorithms

Error Compensation Mechanisms

- diversity
  - based on fact that individual channels experience independent fading events
  - use multiple logical channels between transmitter and receiver
  - send part of signal over each channel
  - doesn’t eliminate errors
  - reduce error rate
  - equalization, forward error correction then cope with reduced error rate
  - space diversity involves physical transmission paths
  - more commonly refers to frequency or time diversity

First Generation Analog

- original cellular telephone networks
- analog traffic channels
- early 1980s in North America
- Advanced Mobile Phone Service (AMPS)
- also common in South America, Australia, and China
- replaced by later generation systems

AMPS Spectral Allocation In North America

- two 25-MHz bands are allocated to AMPS
  - from BS to mobile unit (869–894 MHz)
  - from mobile to base station (824–849 MHz)
- bands is split in two to encourage competition
- operator is allocated only 12.5 MHz in each direction
- channels spaced 30 kHz apart (416 channels / operator)
- control channels are 10 kbps data channels
- voice channels carry analog using frequency modulation
- control info also sent on voice channels in bursts as data
- number of channels inadequate for most major markets
- for AMPS, frequency reuse is exploited

Operation

- AMPS-capable phone has numeric assignment module (NAM) in read-only memory
  - NAM contains number of phone
  - serial number of phone
  - when phone turned on, transmits serial number and phone number to MTSO
  - MTSO has database of mobile units reported stolen
  - MTSO uses phone number for billing
  - if phone is used in remote city, service is still billed to user's local service provider

AMPS Call Sequence

1. subscriber initiates call keying in number
2. MTSO validates telephone number and checks user authorized to place call
3. MTSO issues message to user's phone indicating traffic channels to use
4. MTSO sends ringing signal to called party
5. when called party answers, MTSO establishes circuit and initiates billing information
6. when one party hangs up MTSO releases circuit, frees radio channels, and completes billing information

AMPS Control Channels

- 21 full-duplex 30-kHz control channels
  - transmit digital data using FSK
  - data transmitted in frames
- control information can be transmitted over voice channel during conversation
  - Mmobile unit or the base station inserts burst of data
    - turn off voice FM transmission for about 100 ms
    - replacing it with an FSK-encoded message
  - used to exchange urgent messages
    - change power level
    - handoff

Second Generation CDMA

- provide higher quality signals, higher data rates, support digital services, with overall greater capacity
- key differences include
  - digital traffic channels
  - encryption
  - error detection and correction
  - channel access
    - time division multiple access (TDMA)
    - code division multiple access (CDMA)

Code Division Multiple Access (CDMA)

- have a number of 2nd gen systems
  - for example IS-95 using CDMA
- each cell allocated frequency bandwidth
- is split in two
  - half for reverse, half for forward
  - uses direct-sequence spread spectrum (DSSS)

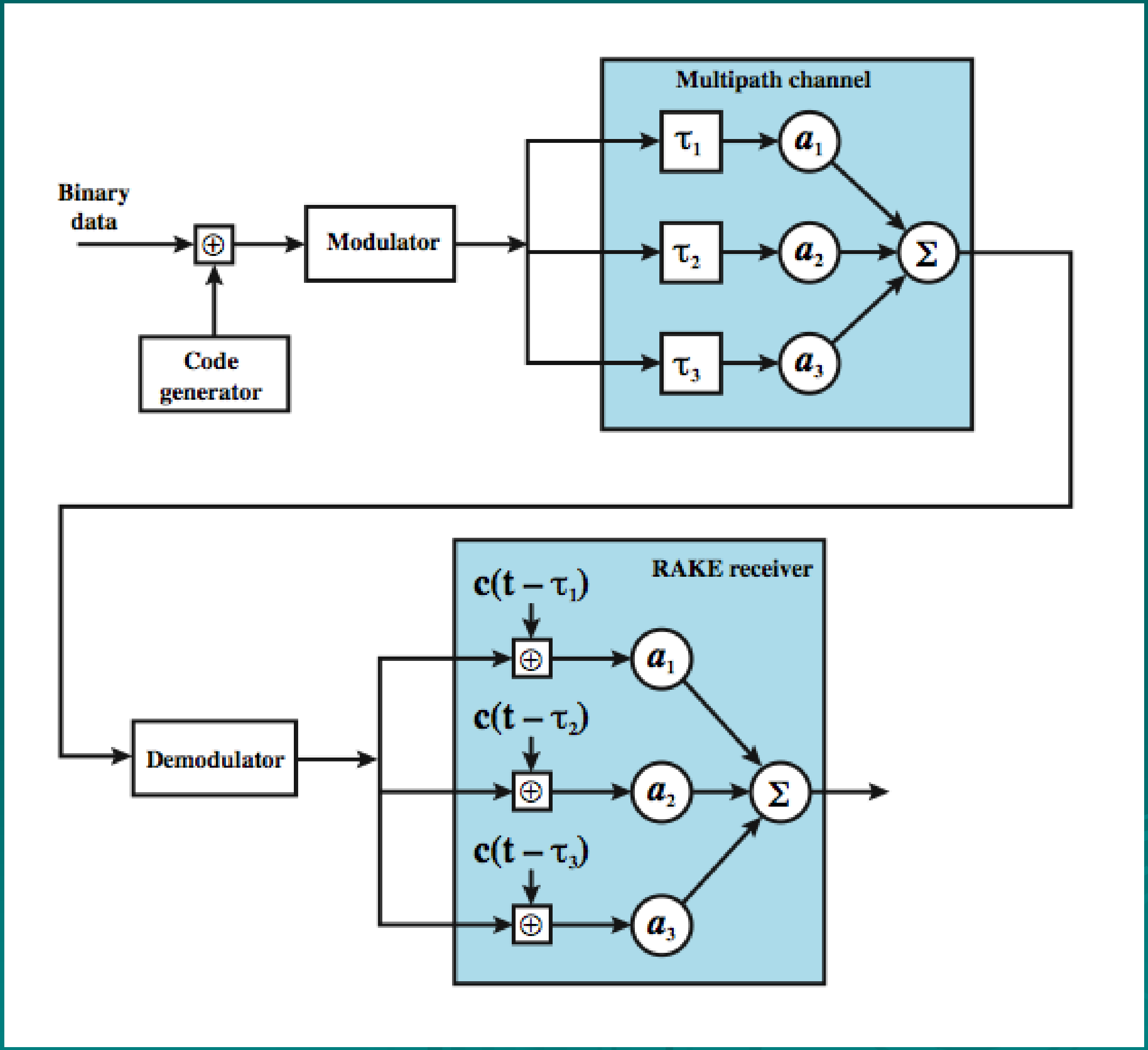
Code Division Multiple Access (CDMA) Advantages

- frequency diversity
  - noise bursts & fading have less effect
- multipath resistance
  - chipping codes have low cross & auto correlation
- privacy
  - inherent in use of spread-spectrum
- graceful degradation
  - more users means more noise
  - leads to slow signal degradation until unacceptable

Code Division Multiple Access (CDMA) Disadvantages

- self-jamming
  - some cross correlation between users
- near-far problem
  - signals closer to receiver are received with less attenuation than signals farther away

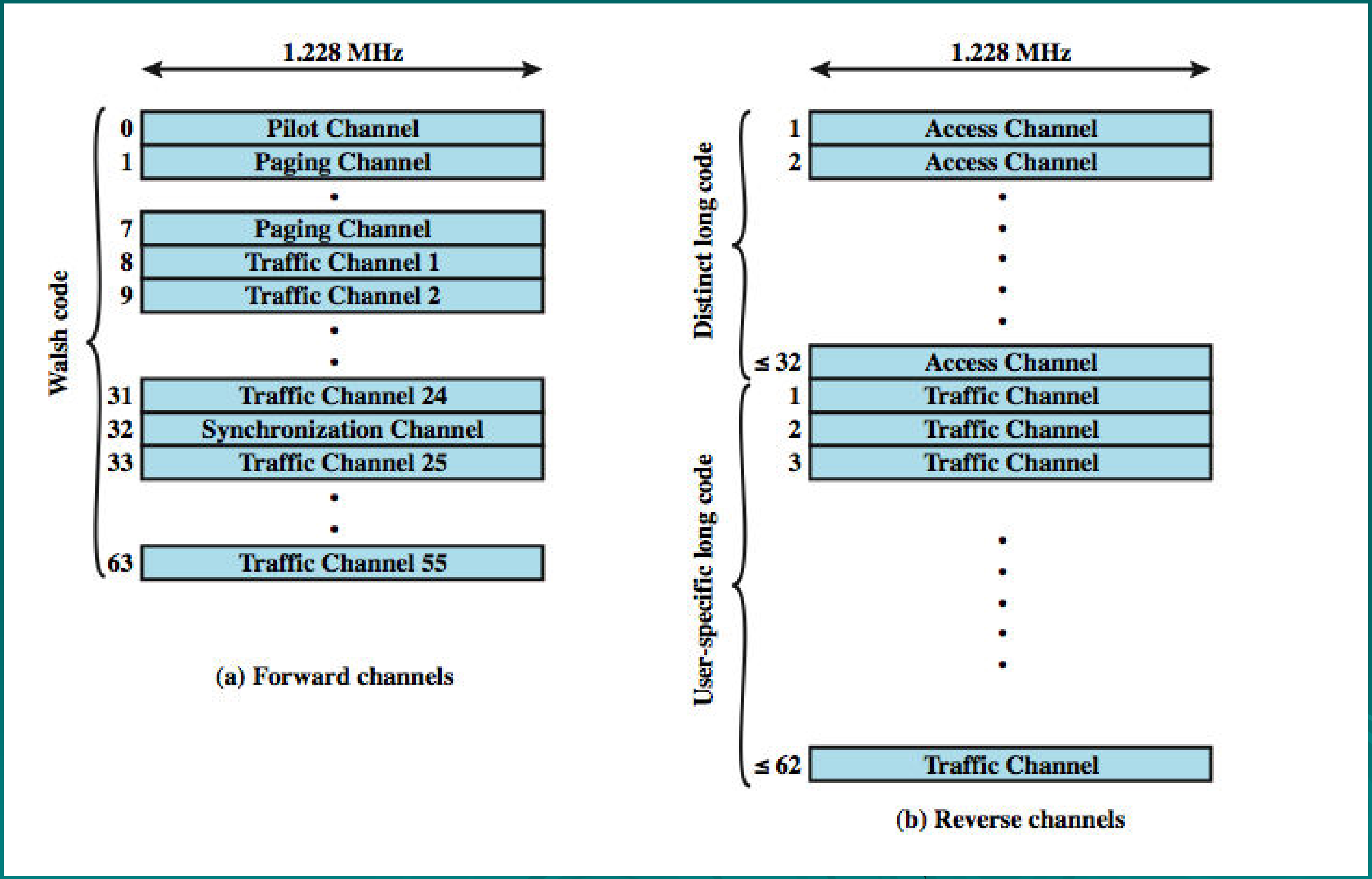
RAKE Receiver



IS-95

- second generation CDMA scheme
- primarily deployed in North America
- transmission structures different on forward and reverse links

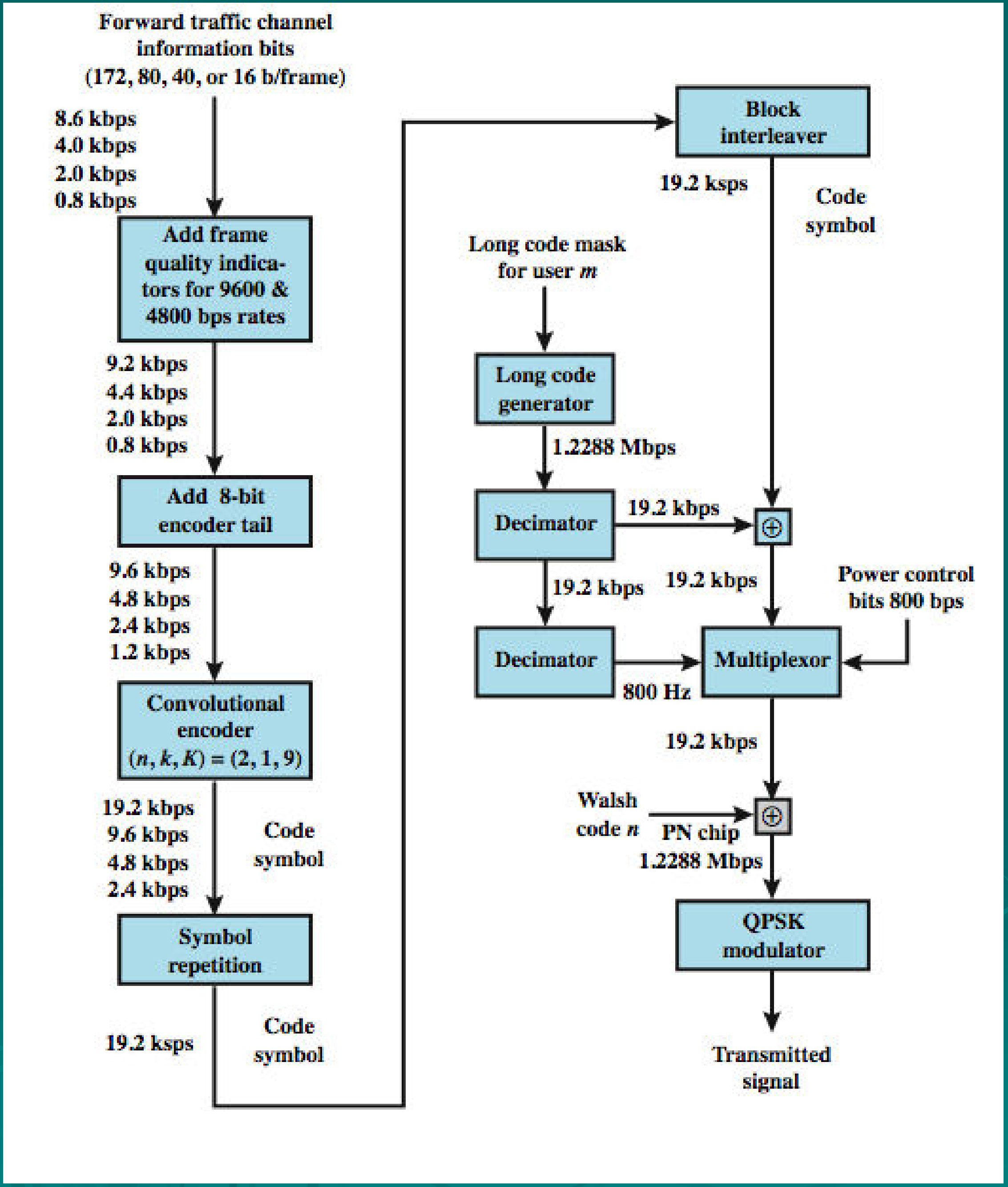
IS-95 Channel Structure



IS-95 Forward Link

- four types of channels
  - Pilot (channel 0)
    - allows mobile unit to acquire timing information
  - Synchronization (channel 32)
    - 1200-bps channel used by mobile station to obtain identification information about the cellular system
  - Paging (channels 1 to 7)
    - Contain messages for one or more mobile stations
  - Traffic (channels 8 to 31 and 33 to 63)
    - 55 traffic channels
- all channels use same bandwidth

Forward Link Processing



Forward Link - Scrambling

- after interleaver, data scrambled
- privacy mask
- prevent sending of repetitive patterns
  - reduces probability of users sending at peak power at same time
- scrambling done by long code
  - pseudorandom number from 42-bit shift register
  - initialized with user's electronic serial number
  - output at a rate of 1.2288 Mbps

Forward Link - Power Control

- inserts power control info in traffic channel
  - to control the power output of antenna
  - robs traffic channel of bits at rate of 800 bps by stealing code bits
  - 800-bps channel carries information directing mobile unit to change output level
  - power control stream multiplexed to 19.2 kbps

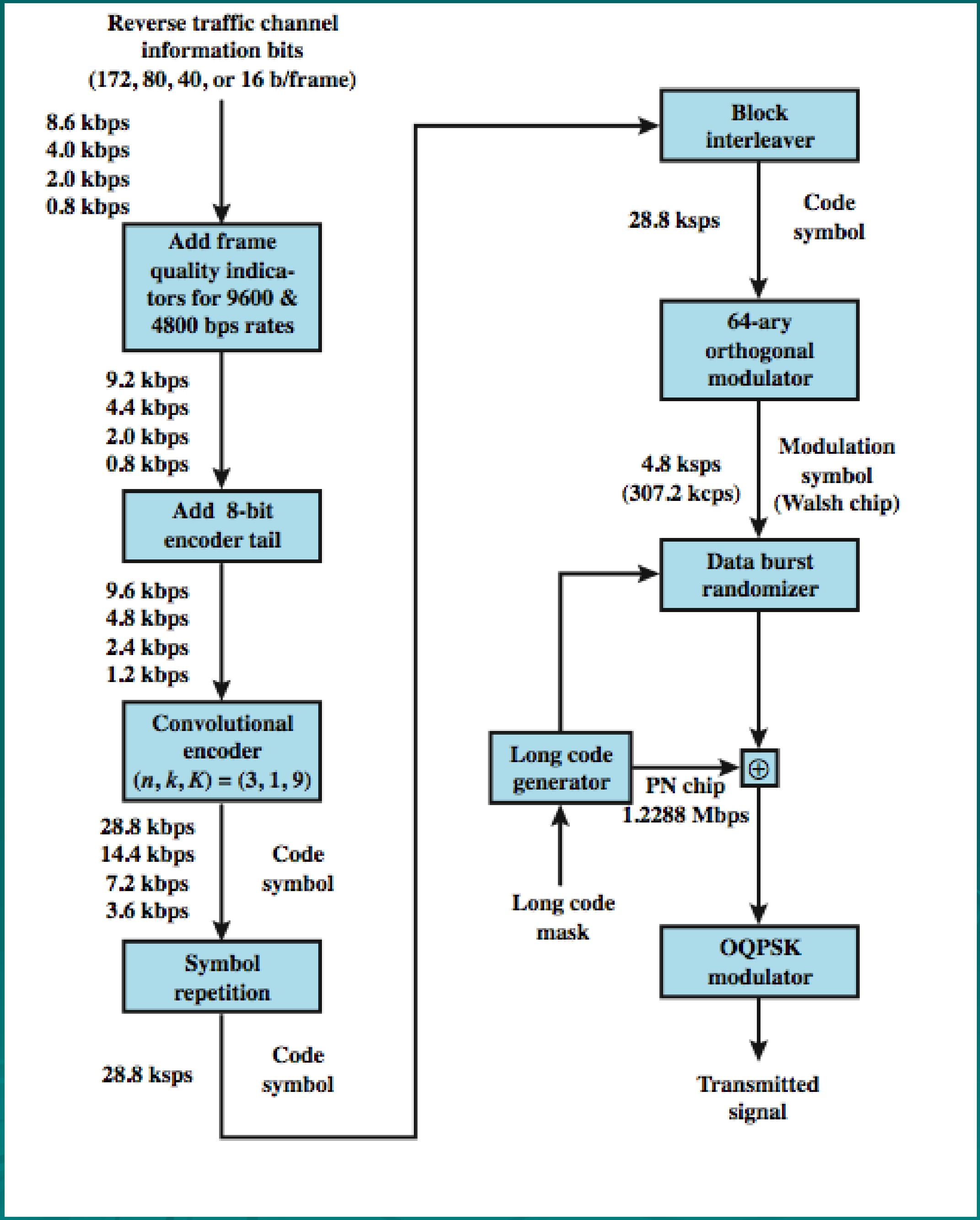
Forward Link - DSSS

- spreads 19.2 kbps to 1.2288 Mbps
- using one row of Walsh matrix
  - assigned to mobile station during call setup
  - if 0 presented to XOR, 64 bits of assigned row sent
  - if 1 presented, bitwise XOR of row sent
- final bit rate 1.2288 Mbps
- bit stream modulated onto carrier using QPSK
  - data split into I and Q (in-phase and quadrature) channels
  - data in each channel XORed with unique short code

IS-95 Reverse Link

- up to 94 logical CDMA channels
  - each occupying same 1228-kHz bandwidth
  - supports up to 32 access and 62 traffic channels
- traffic channels are mobile unique
  - each station has unique long code mask based on serial number
    - 42-bit number, $2^{42} - 1$ different masks
    - access channel used by mobile to initiate call, respond to paging channel message, and for location update

Reverse Link Processing



Reverse Link - DSSS

- long code unique to mobile XORed with output of randomizer
- 1.2288-Mbps final data stream
- modulated using orthogonal QPSK modulation
- differs from forward channel in use of delay element in modulator to produce orthogonality
  - forward channel, spreading codes orthogonal
  - reverse channel orthogonality of spreading codes not guaranteed

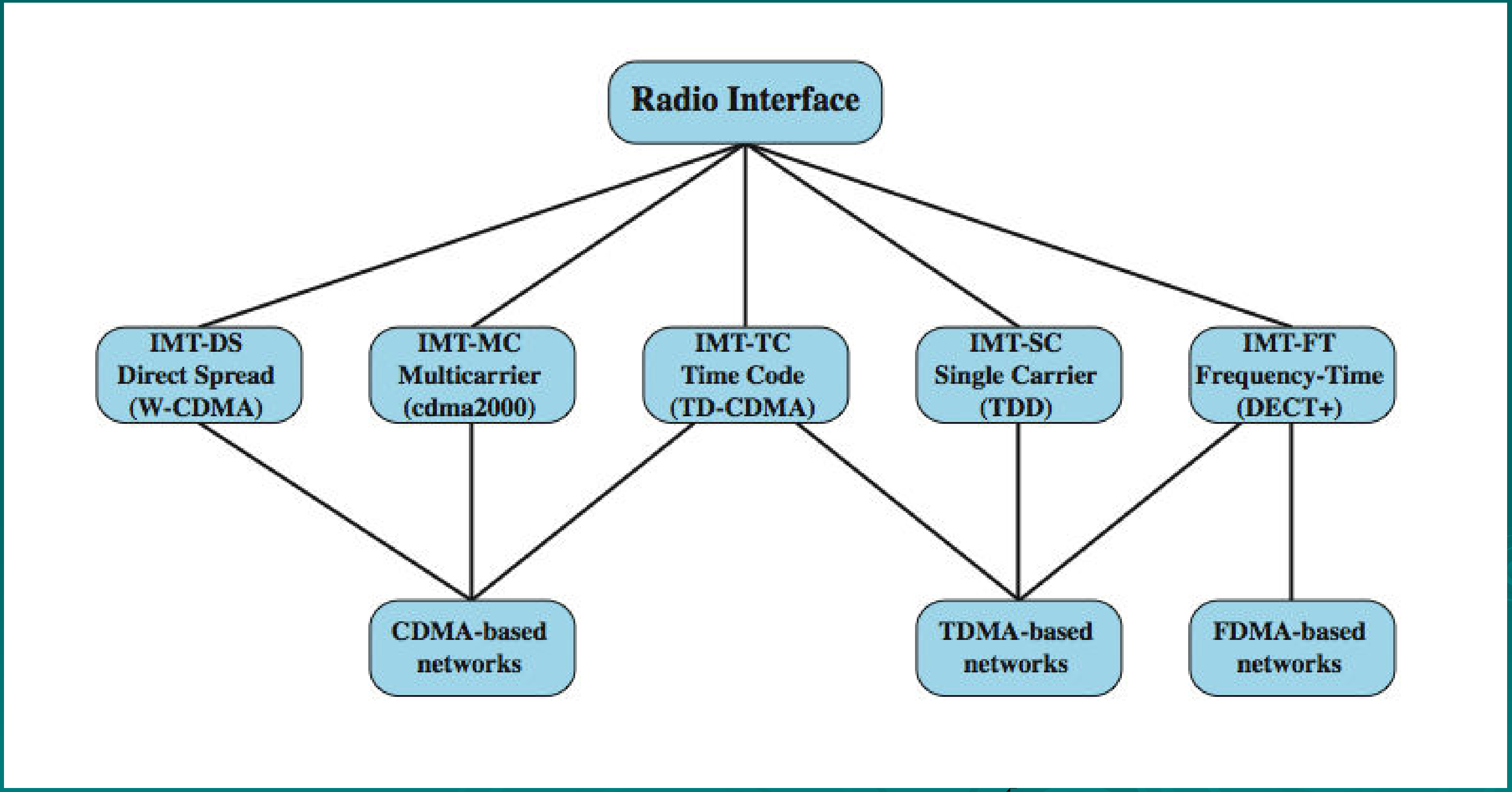
Third Generation Systems

- high-speed wireless communications to support multimedia, data, and video in addition to voice
- 3G capabilities:
  - voice quality comparable to PSTN
  - 144 kbps available to users over large areas
  - 384 kbps available to pedestrians over small areas
  - support for 2.048 Mbps for office use
  - symmetrical and asymmetrical data rates
  - packet-switched and circuit-switched services
  - adaptive interface to Internet
  - more efficient use of available spectrum
  - support for variety of mobile equipment
  - allow introduction of new services and technologies

Driving Forces

- trend toward universal personal telecommunications
- universal communications access
- GSM cellular telephony with subscriber identity module, is step towards goals
- personal communications services (PCSs) and personal communication networks (PCNs) also form objectives for third-generation wireless
- technology is digital using time division multiple access or code-division multiple access
- PCS handsets low power, small and light

IMT-2000 Terrestrial Radio Alternative Interfaces



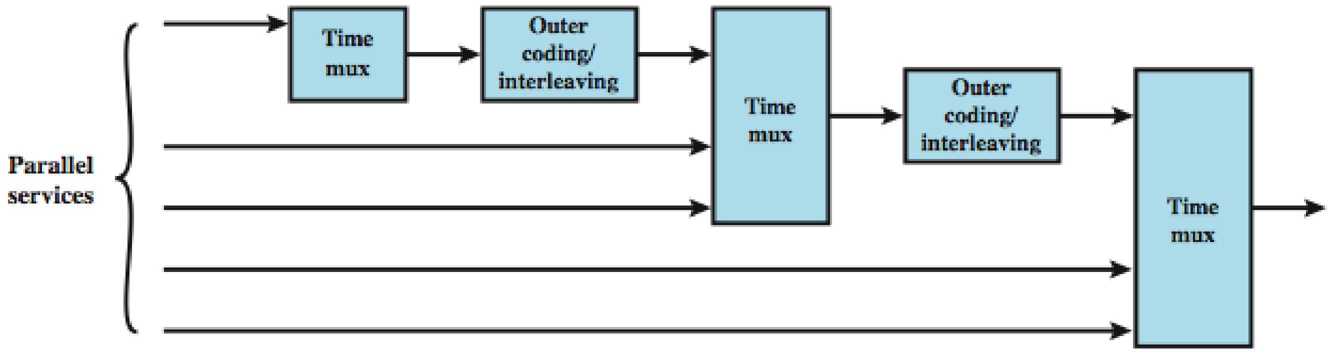
CDMA Design Considerations – Bandwidth and Chip Rate

- dominant technology for 3G systems is CDMA
  - 3 CDMA schemes, share some design issues
- bandwidth (limit channel to 5 MHz)
  - 5 MHz reasonable upper limit on what can be allocated for 3G
  - 5 MHz is enough for data rates of 144 and 384 kHz
- chip rate
  - given bandwidth, chip rate depends on desired data rate, need for error control, and bandwidth limitations
  - chip rate of 3 Mbps or more reasonable

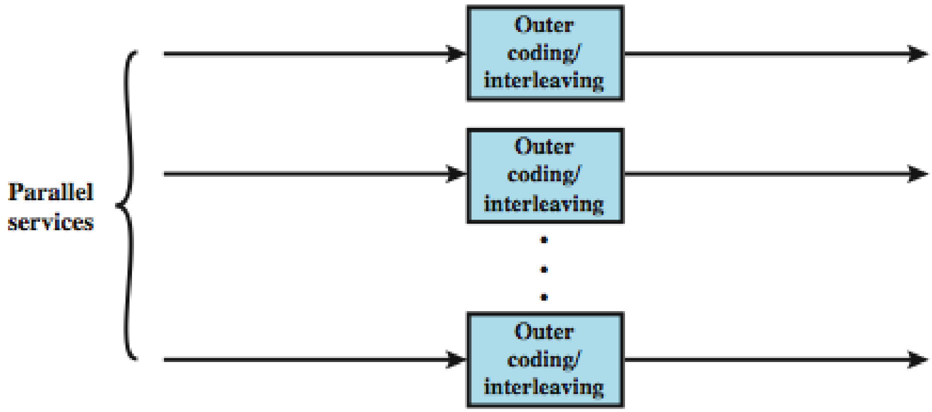
CDMA Design Considerations – Multirate

- provision of multiple fixed-data-rate channels to user
- different data rates provided on different logical channels
- logical channel traffic can be switched independently through wireless fixed networks to different destinations
- flexibly support multiple simultaneous applications
- efficiently use available capacity by only providing the capacity required for each service
- use TDMA within single CDMA channel
- or use multiple CDMA codes

CDMA Multirate
Time and Code Multiplexing



(a) Time multiplexing



(b) Code multiplexing

Summary

- principles of wireless cellular networks
- operation of wireless cellular networks
- first-generation analog
- second-generation CDMA
- third-generation systems