Wireless Network Topology and Fixed-Assignment Channel-Access Methods

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Content of presentation

- **Wireless network topologies**
  - Differences between wired and wireless networks
  - Wireless network topologies
- **Fixed-assignment channel-access methods**
  - Classifications
    - TDMA
    - FDMA
    - CDMA
  - Characteristics and performance

Wired and wireless network differences

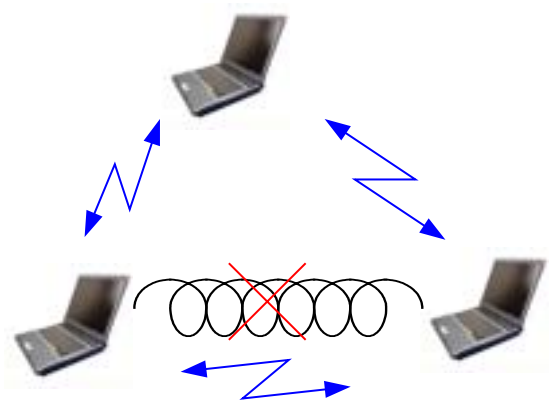
- Wireless network is a broadcast medium fundamentally

Connections

Unexpected receivers

Uncertainty of propagation

Shared transmission medium

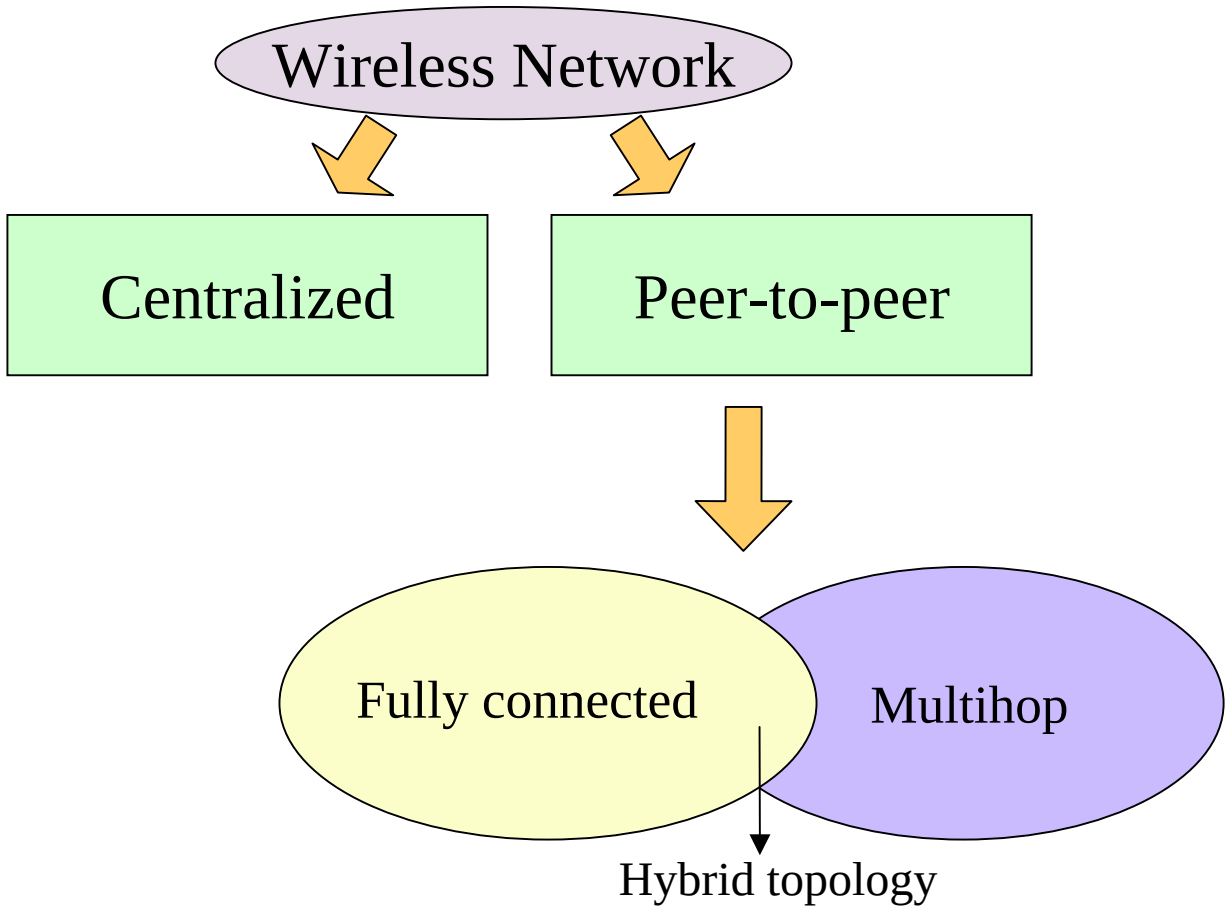


- On consequence, wireless network needs:
  - Utilization mechanism --- Fair and efficient
  - Proper transmission power

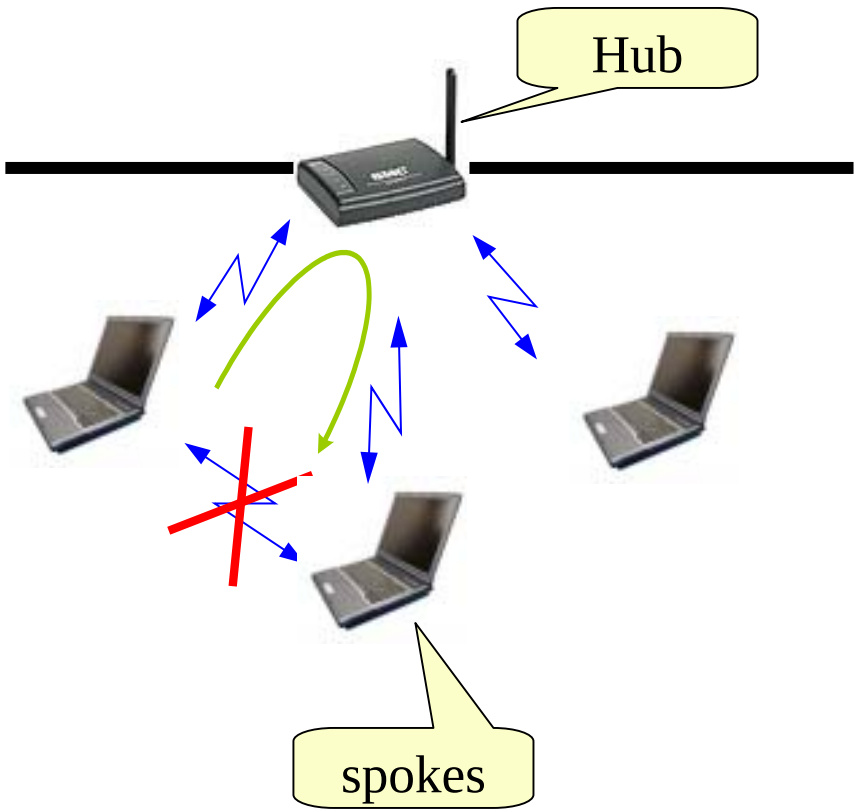
    Too small: *unreliable communications*

    Too large: *Excessive interference*

Wireless network topologies

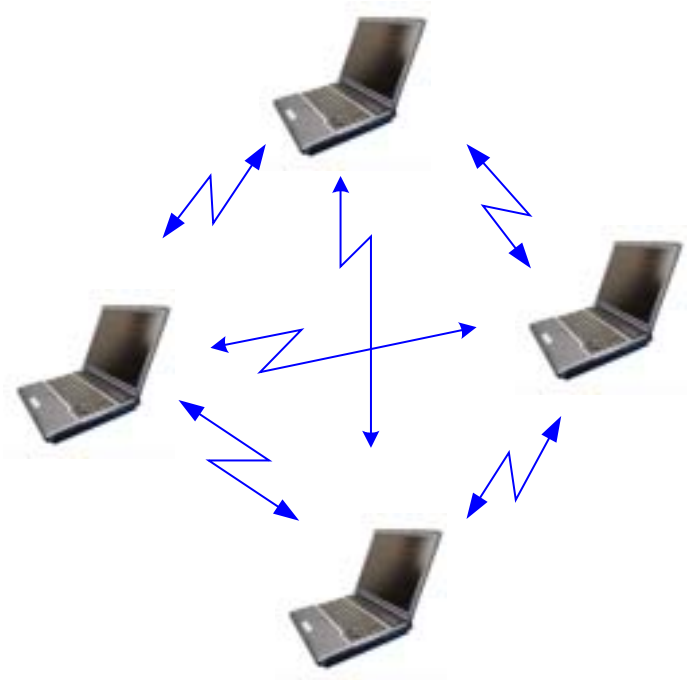


Centralized Network



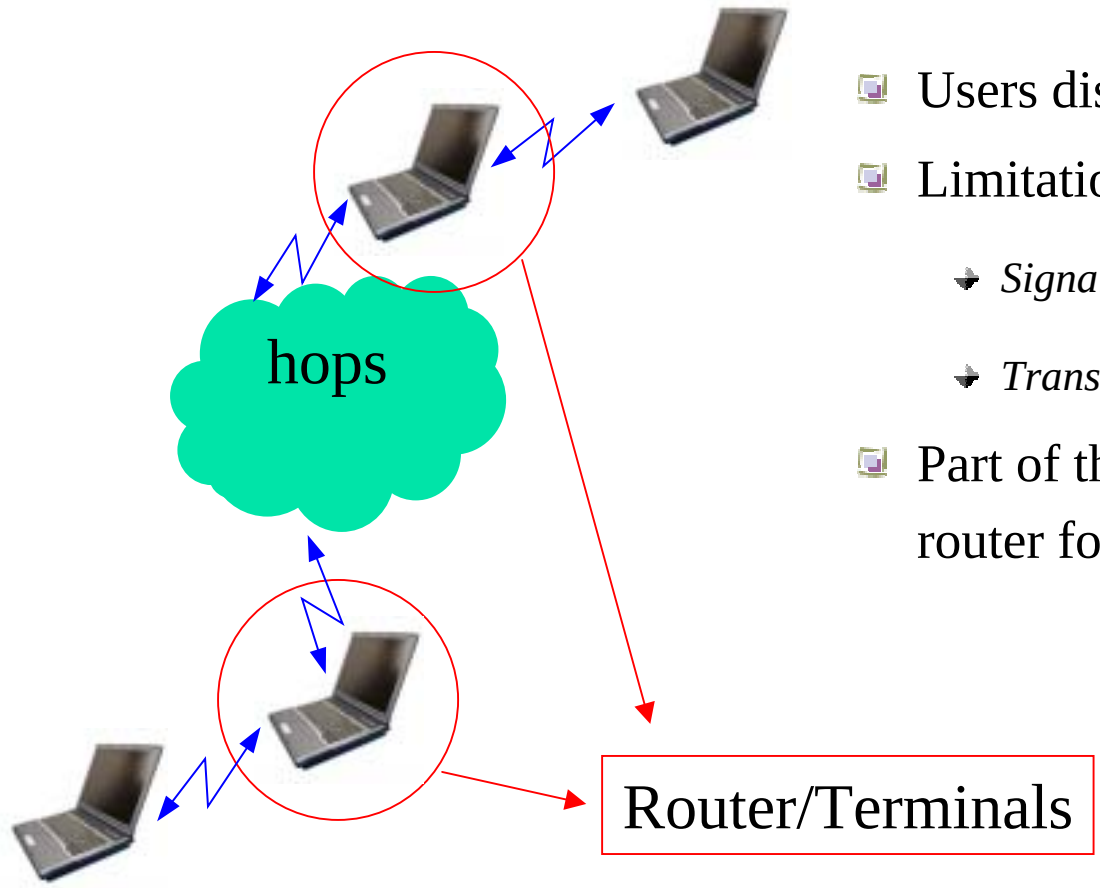
- So called ” hub-and-spoke”
- Structure:
  - *Hub: Control & monitor*
  - *Spokes: Follow*
- No provision for direct peer-to-peer communication
  - *All communication should go through ”hub”*
- Star topology WLAN
- Typical product:
  - *Windata, ALTAIR*

Peer-to-peer (Fully connected)



- Ensured direct connectivity between **ANY** two terminals
- Regardless of the installation site
- Feasible in WLAN, and Ad hoc network.
- Typical Product:
  - *NCR WLAN*

Peer-to-Peer (Multihop)



- Users distributed over wide area
- Limitation:
  - *Signal blockage*
  - *Transmission power*
- Part of the terminals acts as the router for carrying message.

Centralized network characteristics

- Advantages:
  - Transmission power: Efficient!
  - Central station location: Optimized! -- unobstructed propagation
  - Connection to a backbone network: Supported!
  - Applicability: Most of WLANs
  - User terminals functions: Simple!
  - Power control:
    - *Minimize the radiation*
    - *Control interference*
    - *Conserve battery power*
- Disadvantages:
  - Single failure point – Hub
  - Store-and-forward delay
  - No functional flexibility
  - Not suitable for ad hoc network

Full connected network characteristics

- Advantages:
  - No single point of failure
  - No store-and-forward delay
    - *Time delay and channel occupancy are measured halved*
  - No routing: minimized terminal complexity
  - Good alternative in small scale network
- Disadvantages:
  - Additional server needed to connect backbone.
    - *also acts as a bridge or gateway for protocol convert*
  - Implementation complexity & cost:
    - *when many terminal are equipped with backbone connection capability*
  - Enhanced transmitter power is needed when across large networks
  - Near-far problem

Multihop network characteristics

- Advantages:
  - Power efficiency: multiple shorter hops
  - Important role in:
    - *Military radio network*
    - *Public safety communication network*
- Disadvantages:
  - Added complexity in user terminals: routing and control algorithm
  - Accumulated store-and-forward delay
  - Considerable amount of transmission overhead associated
  - Not widely adopted in wireless information network industry

Channel access methods

- Three major categories:
  - Fixed assignment method
    - FDMA
    - TDMA
    - CDMA
    - Hybrid -- TDD-FDMA, TDMA-FDMA, TDMA-TDD-FDMA
  - Random access method
    - Pure ALOHA
    - Slotted ALOHA
    - CSMA (carrier-sense multiple access)
  - Controlled random access
    - Reservation ALOHA
    - Polling techniques
    - Token passing

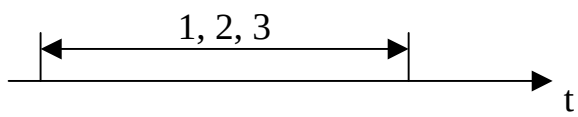
Fixed-assignment channel-access method

- Fixed Assignment:
  - I.e. fixed allocated channel resource
  - Resource can be frequency, or time, or both
  - Predetermined basis to a single user
- Basic access methods:
  - FDMA – Frequency-Division Multiple Access
  - TDMA – Time-division Multiple Access
  - CDMA – Code-Division Multiple access
- Some other formats:
  - Combination of the basic access methods
  - Implemented with various multi-user access algorithm

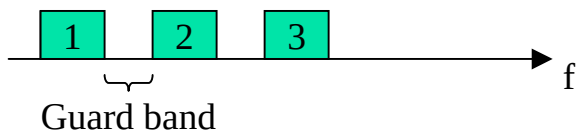
Frequency-Division Multiple Access

- Built upon *Frequency-division multiplexing* scheme
- Simplest and oldest form of multiplexing
- A fixed subchannel is assigned to a user terminal and is retained until released by the user
- At receiver, the user terminal filters the designated channel out if the composite signal

- Currently used in
  - Cellular mobile telephone
  - VHF & UHF land-mobile radio system
  - Satellite networks

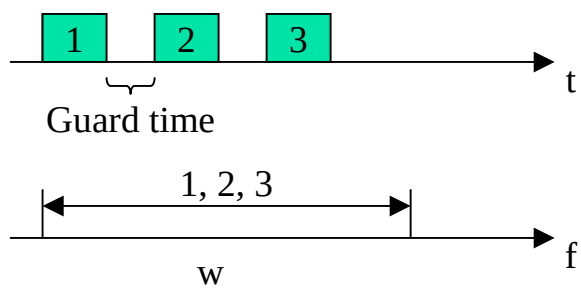


- Characteristics:
  - Efficient when information is steady flow
  - Inefficient when data are sporadic



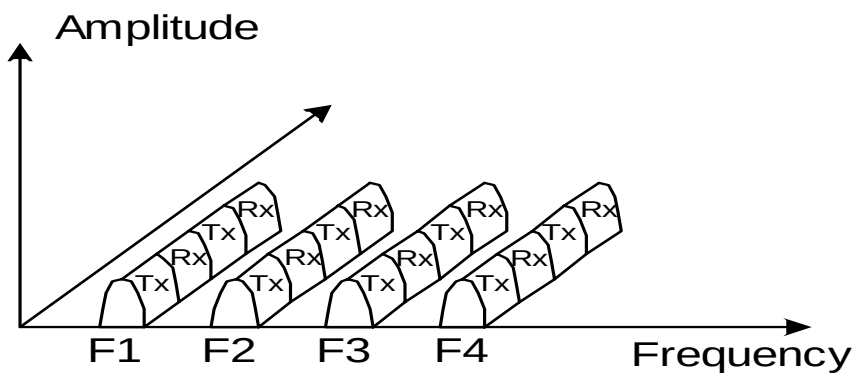
Time-Division Multiple Access

- Built upon *Time-division multiplexing* transmission format
- Deterministic allocation of time interval – *time-slots*
- Time slots are organized into frames
  - T1 channel : 1.544 Mbits/s
  - Multiplexing 24 PCM encoded voice channel
  - Each channel is 64 kbits/s
    - *Each channel sampled at an 8-kHz rate*
    - *Each sample is encoded into 8 bits*
- Used in new digital cellular network
  - Europe (GSM)
  - Japan (JDC)
  - America (IS-54)



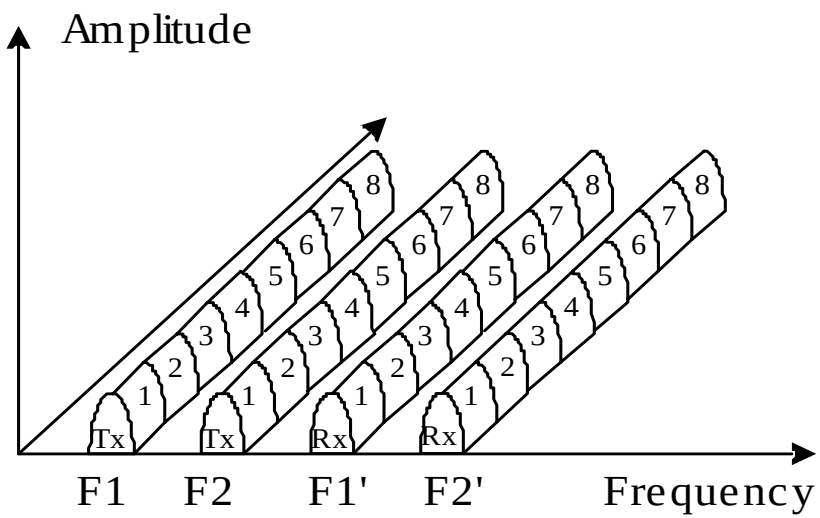
TDD

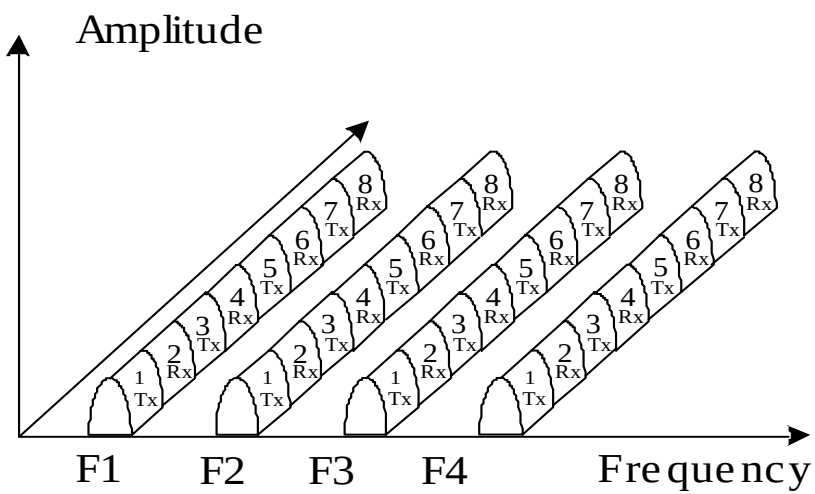
- TDD (time-division duplex)
- Reciprocity of channel:
  - Open loop power control
  - Simultaneous synchronization in forward and reverse channels
- Intend for low-power, local area communications
  - Interference must be carefully controlled
  - Low complexity
  - Low power consumption



Hybrid of TDMA and FDMA

- TDMA and FDMA can be implemented together to get optimized function and performance
- For example
  - TDMA/FDMA
  - TDMA/TDD/FDMA





Comparison between TDMA and FDMA (1)

- **Format Flexibility**
  - TDMA outperforms
  - Fully digital format
  - Flexibility of buffering and multiplexing function
  - Time-slot assignment – easy in providing different access rates
    - Useful for different services
  - evolve over time from one multiplexing format to another
  - More ready to integration of digital voice and data service
  - FDMA is difficult to provide these flexibility , system evolution, and services integration, particularly if channel splitting must be implemented.

Comparison between TDMA and FDMA (2)

- **Significant difference in fading, diversity, and related issues**
  - FDMA divides the bandwidth into smaller sub-channels
    - *Sub-channel bandwidth << coherence bandwidth,*
    - *No need of adaptive equalizer at receiver*
    - *Remove the opportunity for the implicit frequency diversity gains*
  - TDMA normally is close to coherence bandwidth
    - *Adaptive equalizer is needed.*
    - *Provide a form of implicit frequency diversity*
    - *Training sequence is used*
      - Barker code used in 802.11b: **1 0 1 1 1 0 1 0 0 0**
  - Training sequence is needed for channel equalization.
    - $L_{training} << L_{packet}$ *Small overhead*
    - L_{packet} *can not be too long, channel remains stationary*

Comparison between TDMA and FDMA (3)

Bit-rate capability

- Neglect all overhead (guard time or guard band), FDMA and TDMA provide the **same date-rate capability**

Message delay

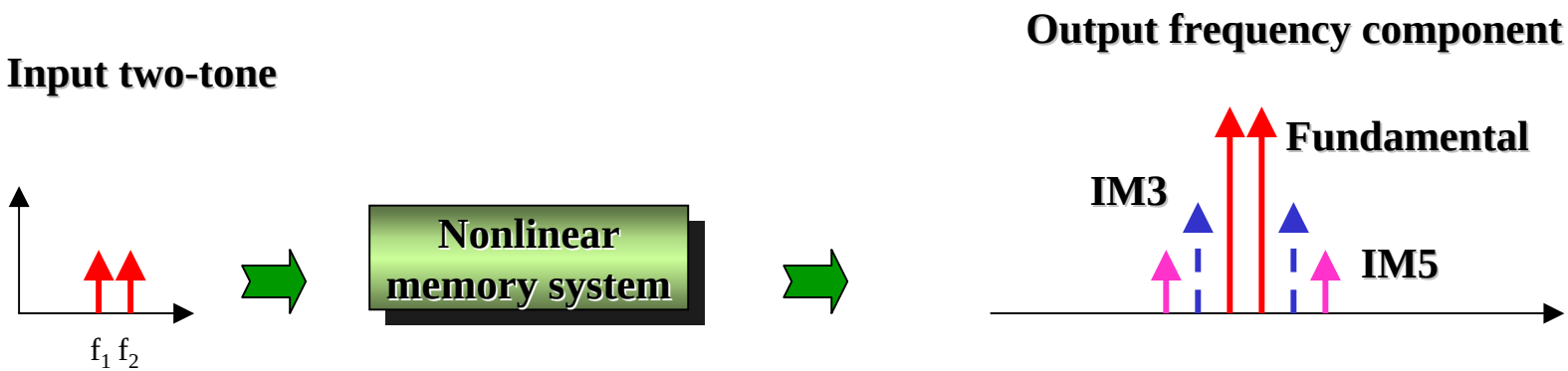
- Average packet delay is different for FDMA and TDMA
- $D_{FDMA} = T$, T is packet waiting and transmission time

$$D_{TDMA} = \frac{T}{2}\left[1 - \frac{1}{M}\right] + \frac{T}{M} = D_{FDMA} - \frac{T}{2}\left[1 - \frac{1}{M}\right]$$

- TDMA is superior to FDMA with respect to average packet delay
- For large number of users, the difference in average packet delay is approximately $\frac{T}{2}$

Comparison between TDMA and FDMA (4)

- **Amplifier backoff**
  - Inter-modulation distortion of amplifier in FDMA
  - Input backoff
    - TDMA in satellite system
    - Not necessarily in terrestrial



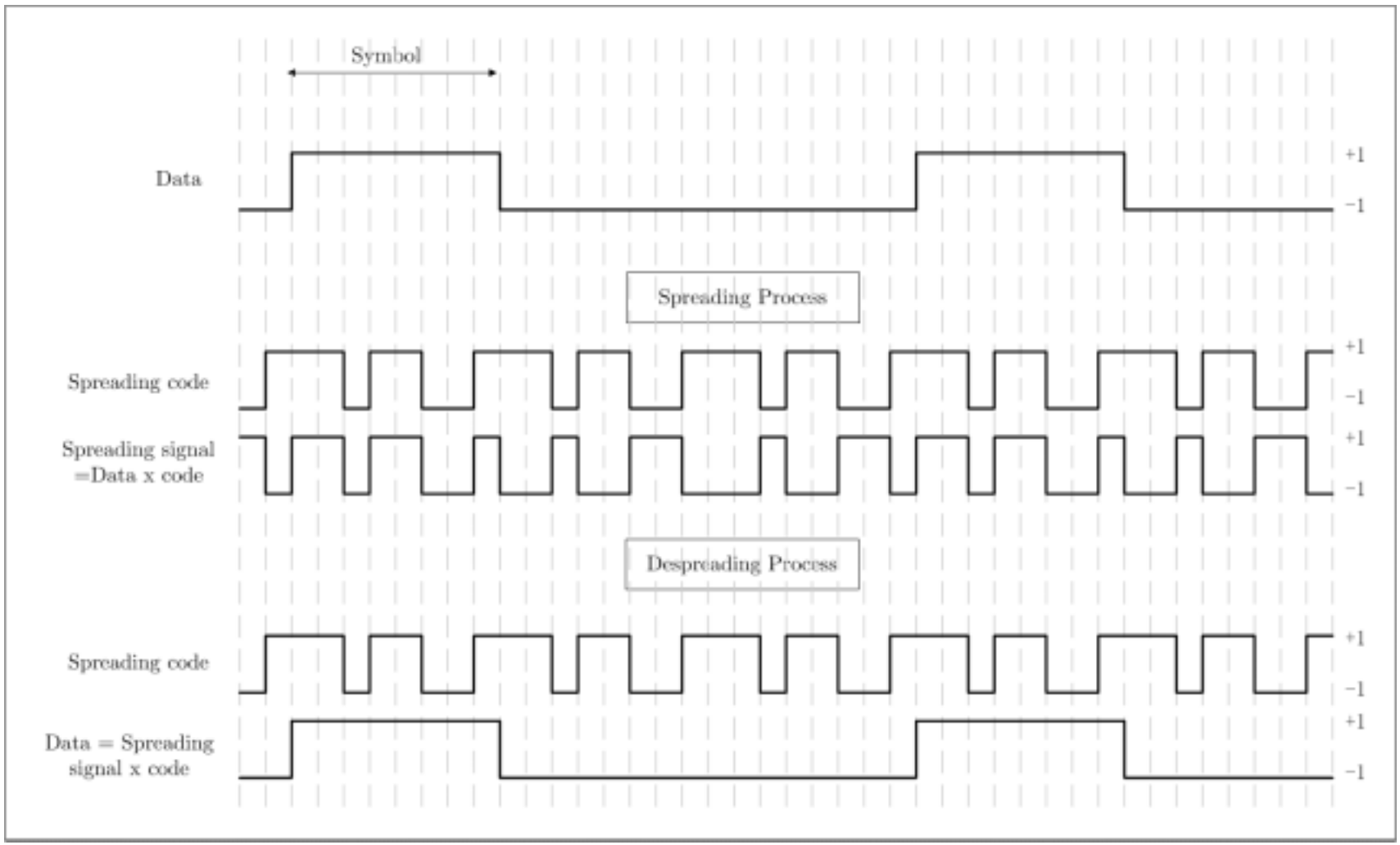
Comparison between TDMA and FDMA (5)

- **Spurious interference**
  - FDMA:
    - One user per channel
    - Narrowband interference only impairs one channel, i.e. one user
  - TDMA:
    - TDMA frame has wider-bandwidth
    - Narrowband interfering signal can affect the performance of all users.

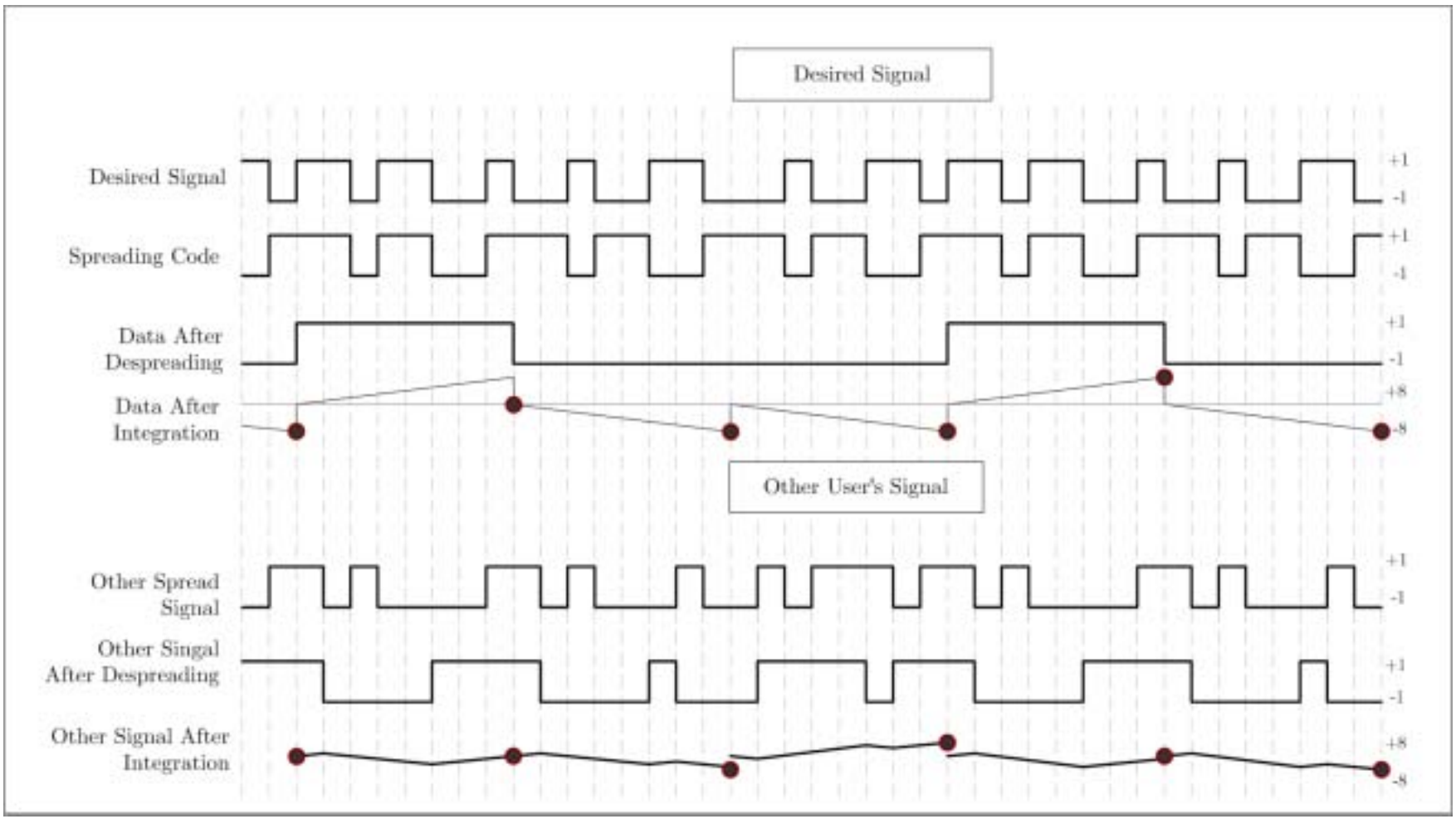
Code-Division Multiple Access

- Hybrids combination of FDMA and TDMA
- Characteristics
  - Multiple users
  - Simultaneously operating
  - Entire bandwidth of time-frequency domain
  - Separated by distinct user-signal codes (Spread spectrum)
- Two common CDMA
  - Direct sequence (DS) CDMA
  - Frequency Hopping (FH) CDMA
- Spreading code
  - ML (Maximum length) code
  - Gold code
  - Walsh-Hadamard code

CDMA --- Spreading



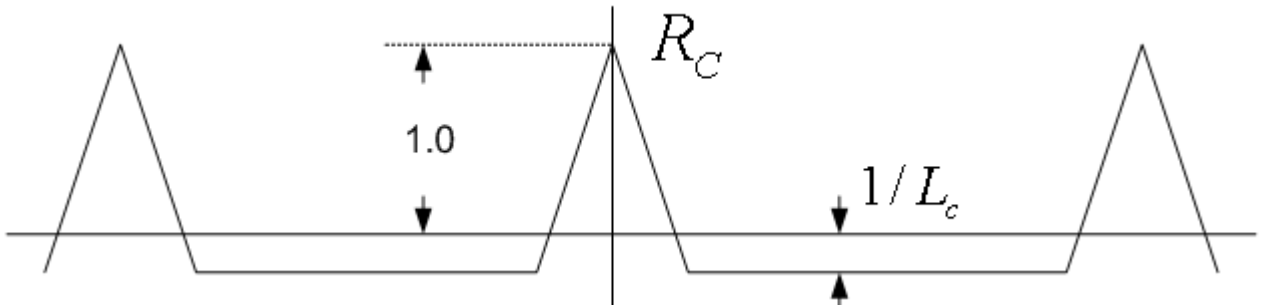
CDMA --- De-spreading



Spreading Code

Gold code:

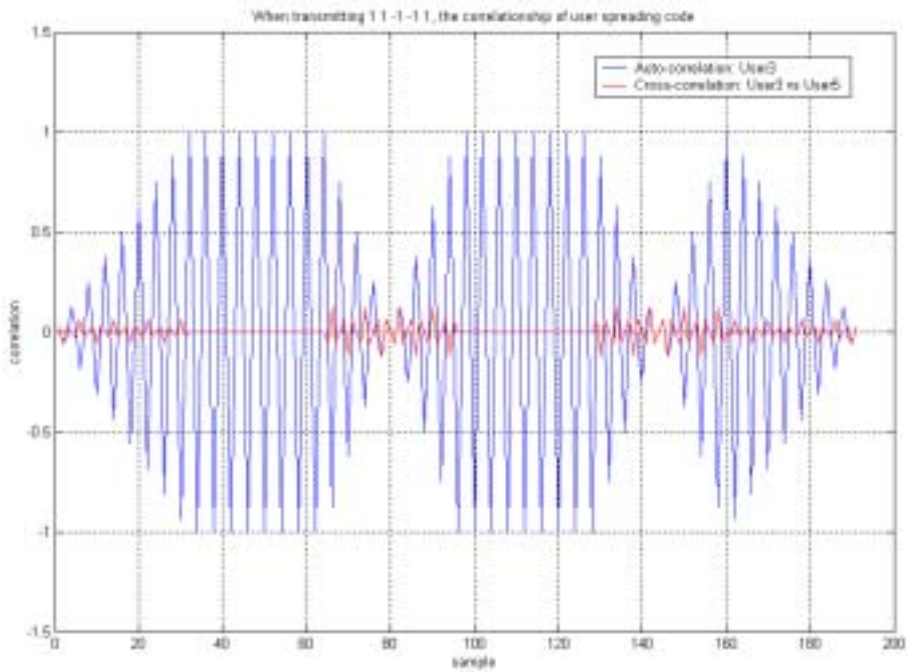
XOR-ing two ML sequences of the same length



Walsh-Hadamard code

$$C^1 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

$$C^l = \begin{bmatrix} C^{l-1} & C^{l-1} \\ C^{l-1} & -C^{l-1} \end{bmatrix}$$



CDMA in portable and mobile radio network

- Who are playing?
  - USA: PCS@2G, IS-95
  - Europe: } Next generation of portable and mobile devices
  - Japan: }
  - Korea: QUALCOMM's spread-spectrum for digital cellular system
- CDMA advantages
  - Timing Flexibility
  - Performance in Frequency selective fading
  - Interference resistance
  - Communication privacy
  - System capacity
  - Soft handoff
  - Soft capacity limit
  - Overlay
  - Interference control with antenna sectorization
  - Time diversity

CDMA advantages (1)

- Timing Flexibility
  - Operate without timing coordination
  - Synchronization can be ensured by the design of codes
  - Unaffected by transmission-time variation
- Performance in Frequency selective fading
  - FH-CDMA:
    - Signal, hopping to the “bad” frequency, attenuates only during the *time interval*. (FDMA: *as long as fade persists*)
    - Distribute the frequency selective fading effects over all users’ signals
    - Error correction and interleaving can improve performance
- Interference resistance
  - Inherent resistance to *intentional* and *unintentional* interference

CDMA advantages (2)

- Communication privacy
  - Transmission pair can be made private
  - Code is known only by transmitter and receiver
  - Used in military communications
- System capacity
  - More user per cell
- Soft handoff
  - Same frequency used in adjacent cells
  - Handoff can be “seamless” by the use of signal combining
  - Rake receiver is used for soft handoff

CDMA advantages (3)

- Soft capacity limit
  - No hard limit on the number of user
  - BUT, each user is a noise source to others
  - No. Users  Performance degradation
- Overlay
  - Overlay the existing analog system
  - Allow the coexisting during the transition

CDMA advantages (4)

- Interference control with antenna sectorization
  - Sectored antennas used to control the interference
  - More users, increasing network capacity
- Time diversity
  - Combatting multipath by RAKE receivers
  - Implicit time diversity

CDMA disadvantages

- Implementation Complexity
  - Two layer modulation techniques --- greater circuit complexity
  - Higher electronic power consumption
  - higher weight and cost for mobile terminal
- Power Control
  - Capacity is extremely limited without power control
  - Power control is essential and key ingredient in maximizing the No. of the users
  - Increasing battery recharging circle
  - Open loop
    - *Keep sum of transmitted and received power at a constant level (-73dBm)*
    - *Monitoring received power, adjusting transmitted power*
  - Close loop
    - *Monitored and commanded by base station*
    - *Qualcomm: 800 times/s, 1 dB/step*

Spread-spectrum for WLAN

- Implementation
  - IEEE 802.11
    - Phsical and MAC control by DSSS and FHSS
    - operate in 2.4 G ISM band
    - Data rate: 1 and 2 Mbps
  - Not fully implemented in WLAN
- Spread-spectrum advantages for WLAN:
  - Can be overlaid onto bands where other system are already operating, with minimal performance impact
  - Anti-multipath characteristics
  - Anti-interference characteristics
  - Convenience of unlicensed operation in ISM band

Summary

- In this presentation, we study the wireless network topologies and fixed-assignment channel access methods
- Wireless network topologies:
  - Centralzied network
  - Peer-to-peer network
    - fully connected
    - multihop
- Fixed-assignment channel access method
  - FDMA
  - TDMA
  - CDMA

Reference

[1] Kaveh Pahlavan & Allen H. Levesque, ”Wireless Information Networks,” John Wiley & Sons, inc 1995.

[2] H. Holma, A. Toskala,” WCDMA for UMTS Radio Access for Third Generation Mobile Communications,”John Wiley&Sons, 2000.

[3] J.Laiho. et. al., ”Radio Network Planning and Optimisation for UMTS,” John Wiley&Sons, 2002

[4] Er Liu, ” MMSE receiver design for multicarier CDMA,” Master thesis, Helsinki University of Technology, 2003

Homework

- Please give a briefly description on the following system:
  - TDD-FDMA
  - OFDM
  - MC-CDMA
  - MC-DS-CDMA
  - MT-CDMA

Please indicate the similarity and differences between these systems with respect to fixed-assginment channel access point of view.

Any questions?

Thanks!