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
- Peer-to-peer
- Fully connected
- Multihop
- Hybrid topology
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
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

Radio network topology and fixed assignment channel access method
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 \( \ll \) 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.

- \( L_{\text{training}} \ll L_{\text{packet}} \) Small overhead
- \( L_{\text{packet}} \) 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 data-rate capability.

Message delay

Average packet delay is different for FDMA and TDMA.

\[ D_{FDMA} = T, \quad T \text{ is packet waiting and transmission time} \]

\begin{align*}
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]
\end{align*}

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

Input two-tone

Output frequency component

\[ f_1, f_2 \]

Nonlinear memory system

Fundamental

IM3

IM5
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

Symbol

Data

Spreading code

Spreading signal = Data x code

Despreading Process

Spreading code

Data = Spreading signal x code

+1

-1

+1

-1

+1

-1

+1

-1

+1

-1
CDMA --- De-spread
Gold code:
XOR-ing two ML sequences of the same length

Walsh-Hadamard code

\[ C^l = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \]

\[ C'^l = \begin{bmatrix} C'^{l-1} & C'^{l-1} \\ C'^{l-1} & -C'^{l-1} \end{bmatrix} \]
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

<table>
<thead>
<tr>
<th>No. Users</th>
<th>Performance degradation</th>
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- **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
  - Physical 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 systems 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:
- Centralized network
- Peer-to-peer network
  - fully connected
  - multihop

Fixed-assignment channel access method
- FDMA
- TDMA
- CDMA
Reference


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-assignment channel access point of view.
Any questions?

Thanks!