Lecture 9-10
WIRELESS NETWORKS

Reference
"INTRODUCTION TO WIRELESS AND MOBILE SYSTEMS", *DHARMA ARAWAL"*

Contents

- *Multiple Radio Access Protocols*
- *Contention-based Protocols*
  - *Pure Aloha*
  - *Slotted Aloha*
  - *CSMA – with CD and with CA*

Multiple Radio Access

- Multiple users access the wireless medium (Multiplexing principle)
- We need a control channel to organize use of data channels among multiple users
- Users use the control channel at random times and for random periods

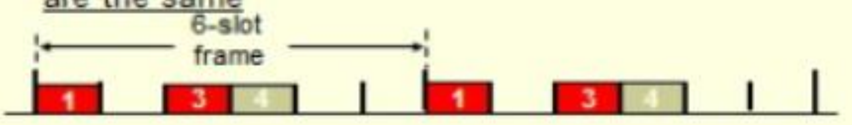
TDMA, FDMA, CDMA, OFDM, SDMA

Continued

- Frequency Division Multiple Access (FDMA)
  - Allocated frequency band is divided into sub-bands (channels), and each user is assigned a channel
- Time Division Multiple Access (TDMA)
  - One channel is used by many users. BS assigns time slots for users in a round-robin fashion
- Code Division Multiple Access (CDMA)
  - AKA spread-spectrum. Each user is assigned a unique code. Code is mixed with each bit before transmission
- Orthogonal Frequency Division Multiplexing (OFDM)
  - One signal is composed of a number of closely-spaced modulated orthogonal carriers

TDMA: time division multiple access

- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle
- A TDMA system may be in either of two modes
  - Frequency Division Duplexing (FDD) – uplink/downlink frequencies differ
  - Time Division Duplexing (TDD) - uplink/downlink frequencies are the same

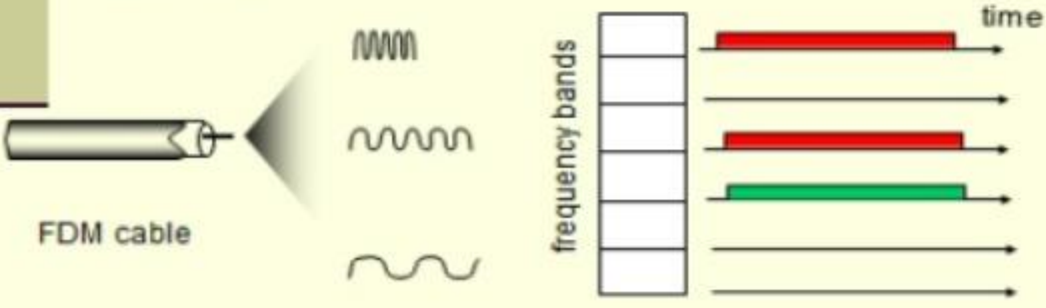


Time Division Multiple Access

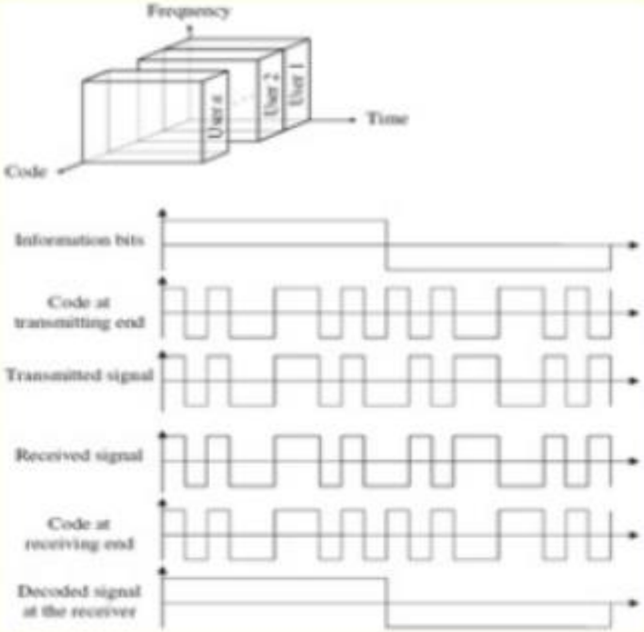
- A TDMA system may be in either of two modes
  - Frequency Division Duplexing (FDD) – uplink/downlink frequencies differ
  - Time Division Duplexing (TDD) - uplink/downlink frequencies are the same

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



Code Division Multiple Access

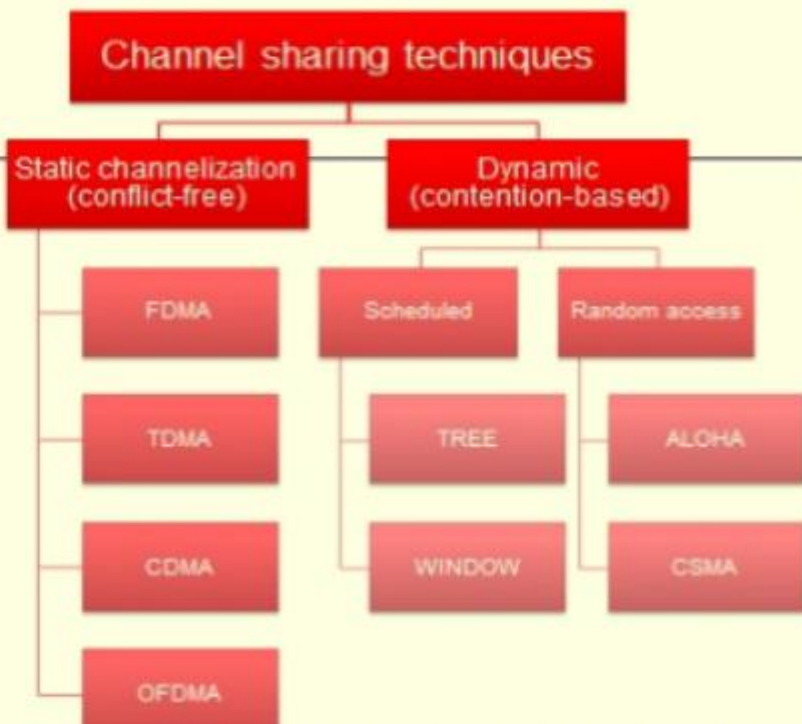


continued

- OFDM is a broadband multicarrier modulation method that offers superior performance and benefits over traditional single-carrier modulation methods.
- OFDMA allows multiple users to access the same channel at the same time.
- Current WLANs such as IEEE 802.11a/g/n and IEEE 802.16d (fixed service) are based on OFDM, while WiMAX such as IEEE 802.16e (mobile service) uses OFDMA.

Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes ➔ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA



Channel Sharing Techniques

- Channelization methods (conflict-free) – channel allocation and assignment is done in a pre-defined way and does not change
- Dynamic MAC (contention-based) – channel is allocated as needed and allocation changes with time

Slotted ALOHA

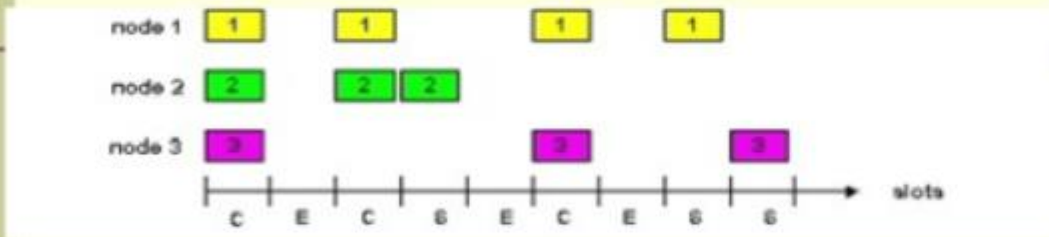
Assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros
- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons
- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted Aloha efficiency

Efficiency : long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose*: N nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

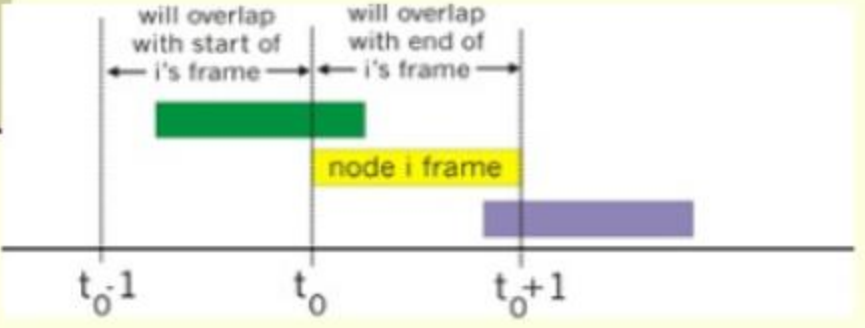
Max efficiency = 1/e = .37

At best: channel used for useful transmissions 37% of time!

!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure Aloha efficiency

P(success by given node) = P(node transmits) ·

P(no other node transmits in $[p_0-1, p_0]$ ·

P(no other node transmits in $[p_0-1, p_0]$

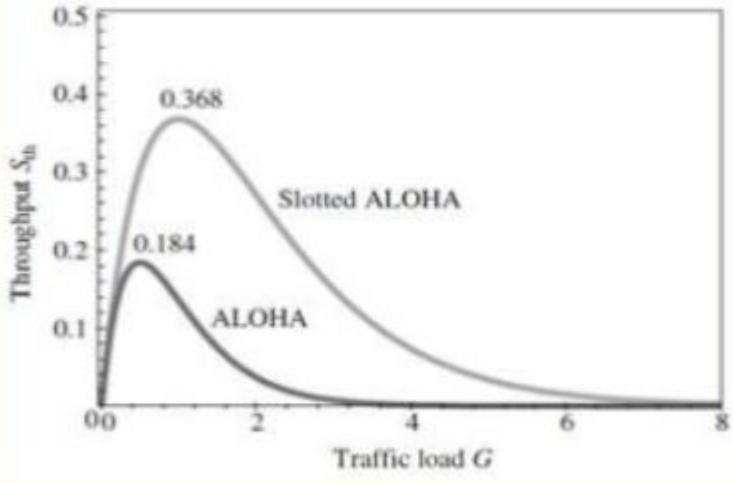
$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$

$= p \cdot (1-p)^{2(N-1)}$

... choosing optimum p and then letting n -> infty ...

= 1/(2e) = .18

even worse than slotted Aloha!



CSMA (Carrier Sense Multiple Access)

- MSs compete for control channel access
- If more than one MS attempts to use the same channel at one time to transmit information, **collision** occurs

Receiver cannot interpret signal

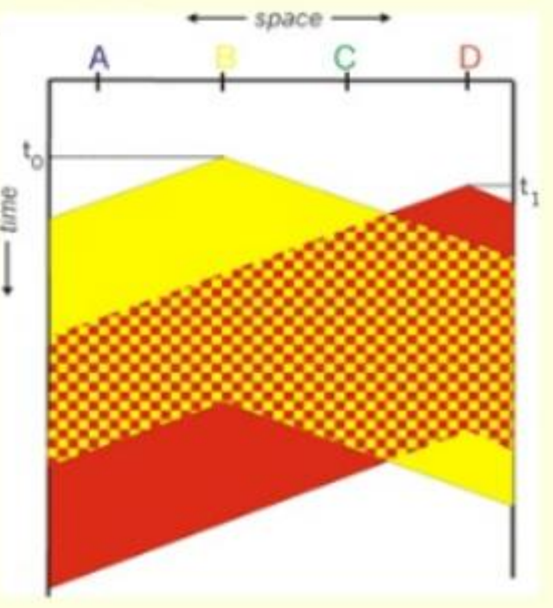
CSMA: listen before transmit:

If channel sensed idle: transmit entire frame

- If channel sensed busy, defer transmission
- Improve throughput of ALOHA and slotted ALOHA

CSMA collisions

spatial layout of nodes



collisions can still occur:
propagation delay means two nodes may not hear each other's transmission

collision:
entire packet transmission time wasted

note:
role of distance & propagation delay in determining collision probability

Collision detection

Collision prevention

Contention-based Methods

- **Random access protocols** allow an MS to retransmit a collided message only after a <u>random delay</u>

  (Nonpersistent CSMA)

- **Scheduled protocols** follow <u>scheduling</u> schemes to control retransmission of collided messages

  (Persistent CSMA)

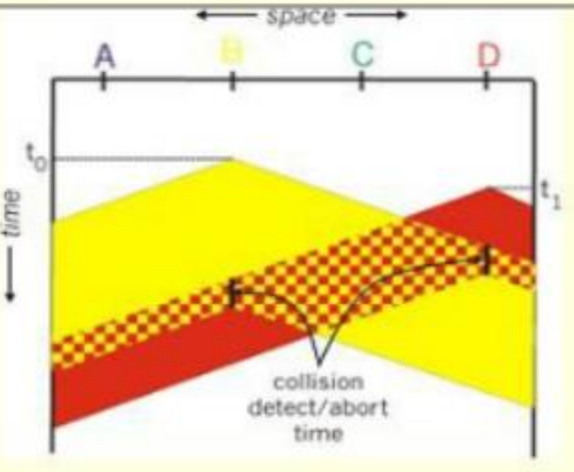
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength
- human analogy: the polite conversationalist

CSMA/CD collision detection



"Taking Turns" MAC protocols

channel partitioning MAC protocols:

- share channel *efficiently* and *fairly* at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

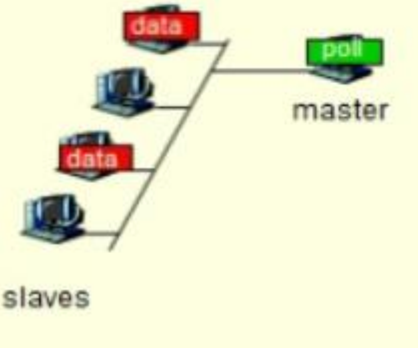
"taking turns" protocols

look for best of both worlds!

"Taking Turns" MAC protocols

Polling:

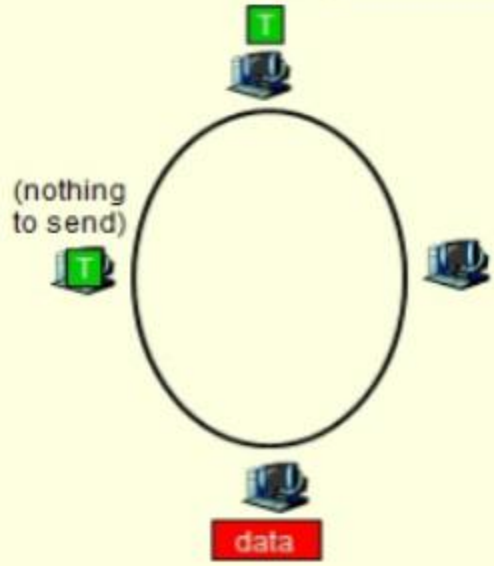
- master node "invites" slave nodes to transmit in turn
- typically used with "dumb" slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)



"Taking Turns" MAC protocols

Token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



1-persistent CSMA

1. When MS has packet to send, it senses channel
2. If channel is busy, MS keeps listening to the medium and transmits packet immediately after channel becomes idle

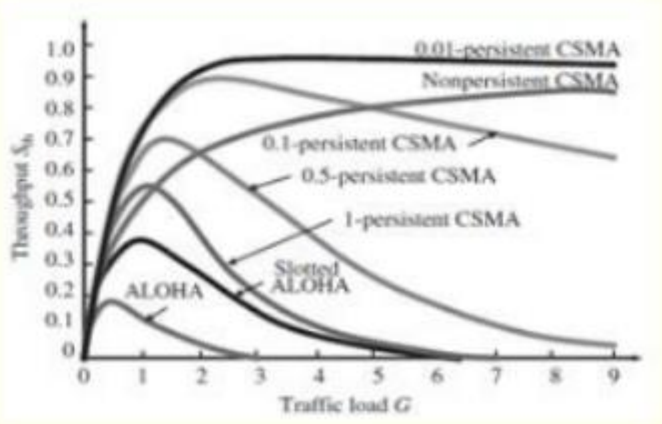
- **MS transmits with a probability of 1 when medium idle**
- Collision will happen if two or more MSs have ready packets and are waiting for channel to become free

p-persistent CSMA

1. When MS has packet to send, it senses channel
2. If channel is busy, MS waits until next time slot and checks channel again
3. If channel is idle, MS transmits packet with probability p or defers transmission to next time slot with probability $1 - p$
4. If collision occurs, MS waits for a random amount of time then starts again

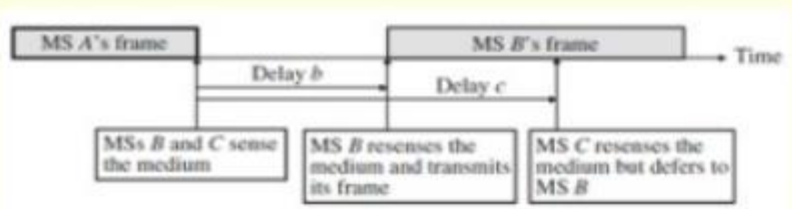
- **Selection of p is crucial**

p-persistent CSMA



CSMA/CA

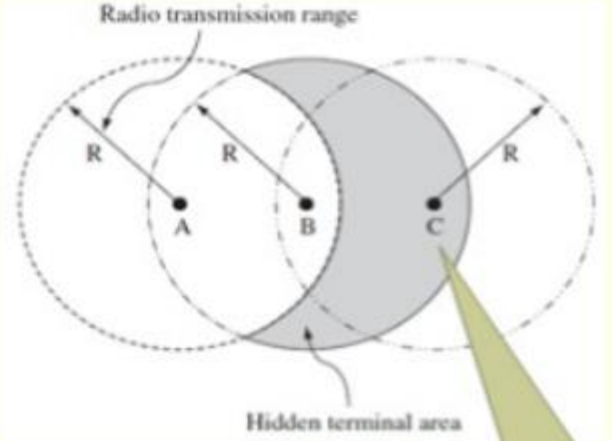
- **CSMA with Collision Avoidance**



Hidden Terminal Problem

- **MSs that are out of each other's radio transmission range**, and thereby carrier sensing range
- Happens when two or more hidden terminals send packets simultaneously

Hidden Terminal Problem



node C is node A's hidden terminal

Hidden Terminal Problem

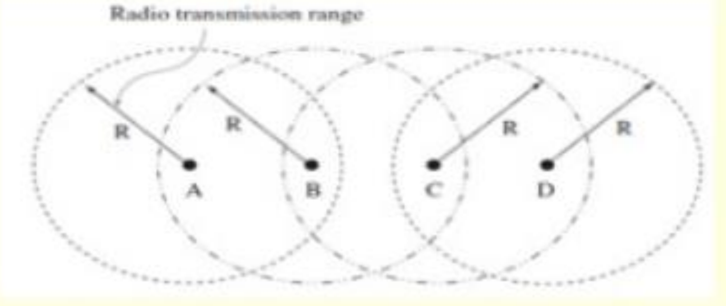
- When A and C start transmitting to node B simultaneously, collision is undetected
  - Neither A nor C can sense the ongoing transmission on the other side
- Solution: **CSMA/CA with RTS/CTS**
  - **CSMA/CA with Request to Send/Clear to Send**
- Uses handshake frames exchange at the beginning of transmission

CSMA/CA with RTS/CTS

- If A is ready for transmission to B, it broadcasts a RTS frame
- B receives the RTS frame and replies with a CTS frame to A
- Since C is in the transmission range of B, C can also receive the CTS packet
- Now C knows that B is in communication with another node and it will refrain from transmission

Exposed Terminal Problem

- CSMA/CA with RTS/CTS solves hidden terminal problem but creates **exposed terminal problem**!



Exposed Terminal Problem

- A and B can communicate with each other. So are B and C, and C and D
- A cannot hear C and D, while node D cannot hear B and A
- B requests sending data to A by broadcasting an RTS packet
- Although the RTS packet is not for C, C will receive the packet because it's within B's range
- C will enter a delayed access state and refrain from transmitting to D
  - Although transmission between C and D will not interfere with data reception at A!

Summary of MAC protocols

- *channel partitioning,* by time, frequency or code
  - Time Division, Frequency Division
- *random access* (dynamic),
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
  - carrier sensing: easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
  - CSMA/CA used in 802.11
- *taking turns*
  - polling from central site, token passing
  - Bluetooth, FDDI, IBM Token Ring

Thanks- Questions !