EEC 687/787 Mobile Computing (Spring 2007)

Medium Access Control

Chansu Yu

Cleveland State University

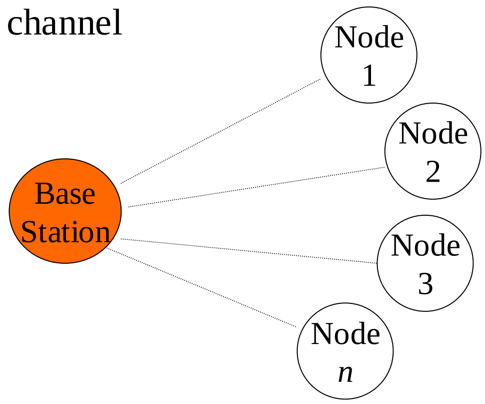
Simplified Reference Model...

Application layer	Location/context-sensitive services; Multimedia applications
Transport layer	congestion and flow control; quality of service
Network layer	addressing, routing, device location; hand-over
Data link layer	Authentication; Multiplexing of multiple data streams; Correction of transmission errors; Media access control
Physical layer	Modulation; Generation of carrier frequency; Frequency selection; Signal detection

c.yu91@csuohio.edu

Centralized Protocols

- Base station coordinates access to the wireless channel



Disadvantages:

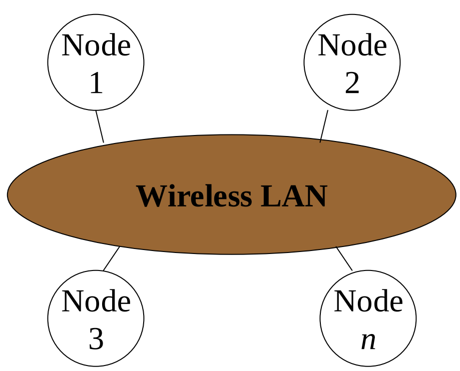
- *If a node cannot talk to the base station, it cannot transmit to any other nodes*
- *Base station needs to keep track of state of other nodes*
- *Hard to use failure-prone nodes as coordinators in centralized protocols*

3

c.yu91@csuohio.edu

Distributed Protocols

- All nodes have identical responsibilities
- Arbitration difficulty
  - Random access mechanism
  - May incur many conflicts
  - Performs "carrier sensing" before actually transmitting



4

c.yu91@csuohio.edu

Two medium access methods

- TDMA-based fixed allocation methods
  - TDMA assigns frequencies to channels for a certain amount of time
  - Requires sender-receiver synchronization

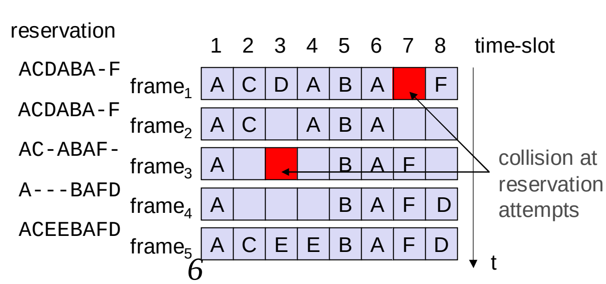
- Contention-based random access methods
  - Aloha - classical and slotted
  - Carrier Sense Multiple Access (CSMA)
  - Demand Assigned Multiple Access (DAMA)
  - Multiple Access with Collision Avoidance (MACA)

TDMA Method – PRMA (Packet Reservation Multiple Access)

- AP broadcasts the reservation status (e.g., 7th slot is empty)
- Nodes compete for empty slots according to the Slotted Aloha principle

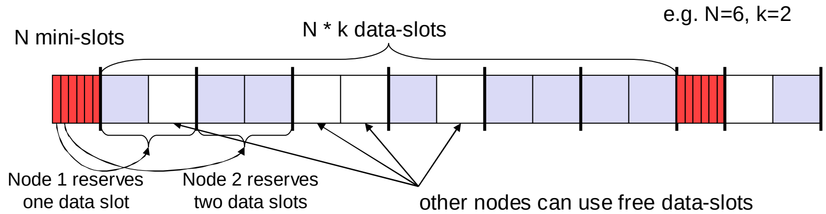
- Once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send

- Competition for this slots starts again as soon as the slot was empty in the last frame



Reservation TDMA

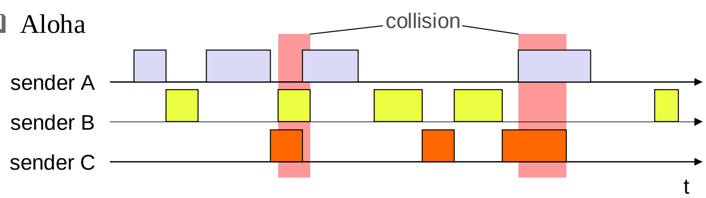
- ❑ Every frame consists of N mini-slots and x data-slots
- ❑ Every node has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k)
- ❑ Other nodes can send data in unused data-slots based on round-robin or Aloha scheme



c.yu91@csuohio.edu

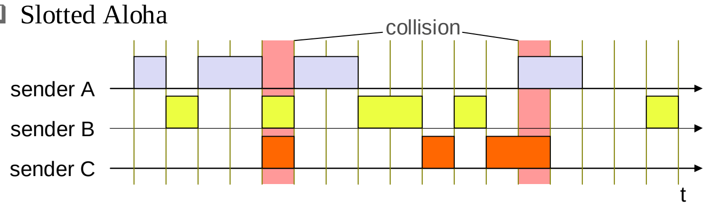
Random access methods: Aloha

- ❑ Mechanism
  - ➢ Simply transmits and waits for ack for some time. Repeats if timeout
  - ➢ Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- ❑ Aloha



How do you compare?

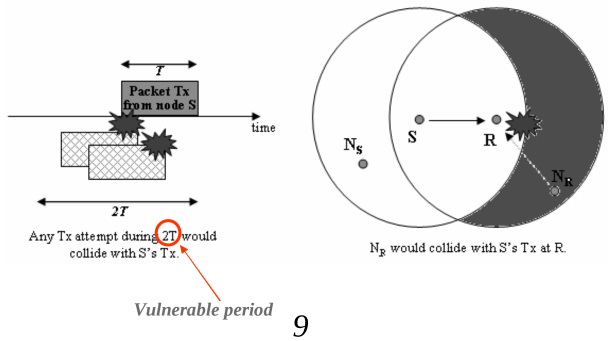
- ❑ Slotted Aloha



c.yu91@csuohio.edu

MAC Analysis: ALOHA (No CS)

- Parameters
  - T = packet transmission time (average)
  - G = number of packets attempted during T (including retransmissions)



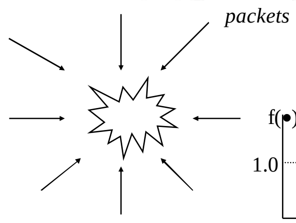
c.yu91@csuohio.edu

MAC Analysis: ALOHA

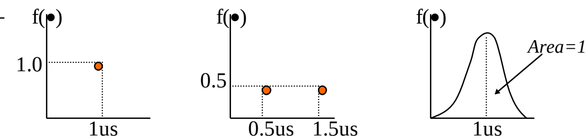
- How often and in which intervals are packets transmitted?
  - Packet inter-arrival time is assumed to be exponentially distributed
  - I.e., F(t) = Prob[inter-arrival time ≤ t] = $e^{-\lambda t}$: exponential function, where λ is average packet rate (G/T)
  - Thus, f(x,t) = Prob[there are x packets during t] = $(\lambda t)^x e^{-\lambda t}/x!$: Poisson distribution

c.yu91@csuohio.edu

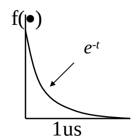
*Exponential Distribution



For example, 10 packets (=G) / 10 usec. (=T)
=> Average inter-arrival time is 1usec.
=> Its distribution can be quite different.



Exponential is one of those distributions which has the following shape.



When inter-arrival time follows exponential distribution,
the number of packets (x) during t follows Poisson: $(\lambda t)^x e^{-\lambda t}/x!$
Thus, zero packet during t follows: $e^{-\lambda t}$

11

c.yu91@csuohio.edu

MAC Analysis: ALOHA

- Channel throughput S
  - No. successful packets during T among G attempts
    = No. attempted packets during T * Prob[no collision]
  - Prob[no collision]
    = Prob[no additional packets during "vulnerable period"]
  - Vulnerable period = 2T
  - Thus, S = G*f(0,2T) = Ge^{-2G} (Because, λ=G/T)
- Channel throughput S for slotted ALOHA
  - Vulnerable period = ???
  - Thus, S = G*f(0,???) = $Ge^{-???}$

12

c.yu91@csuohio.edu

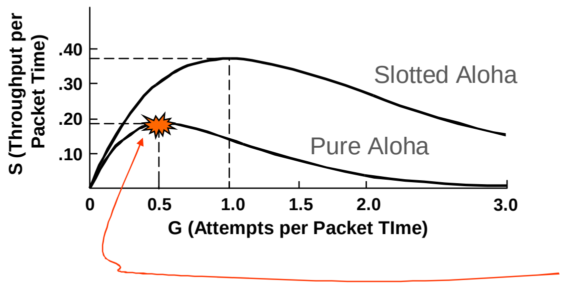
MAC Analysis: ALOHA Efficiency Plot

TDMA max performance with large number of users along a 1Mbps channel = 1Mbps

Pure ALOHA max performance with large number of users = 180Kbps

Pure ALOHA max performance with one user = 1Mbps

S cannot be larger than 1 &
S cannot be larger than G.
How can G be larger than 1: retransmission



0.18 packets were successful out of 0.5 attempted packets. What happen to 0.32 packets? => Retransmission Thus, input rate becomes 0.82

c.yu91@csuohio.edu

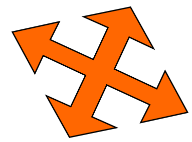
Random access method: CSMA

- Channel efficiency is only 18% for Aloha, 36% for Slotted Aloha
  - It is acceptable when offered traffic is light but generally not acceptable
  - The main problem is collisions
- CSMA (Carrier sense multiple access) algorithm reduces collision probability by first sensing the medium
  - Vulnerable period = ???

c.yu91@csuohio.edu

Basic Carrier Sense Approach

- Carrier Sense Multiple Access with Collision Detect (CSMA/CD)
  - Used in Ethernet
  - Distributed, no central authority granting access

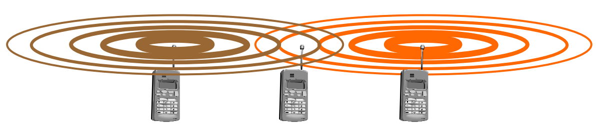


  - When to transmit
    - 1-persistent : start transmission with prob 1 when idle
    - p-persistent : start transmission with prob p when idle
    - non-persistent : wait a random time and check
  - Characteristics
    - Max packet size & Min interpacket gap to reduce starvation probability
    - Collision detection is free
    - Exponential backoff strategy when collision detect

c.yu91@csuohio.edu

CSMA in Wireless Networks

Signal strength decreases with square of distance



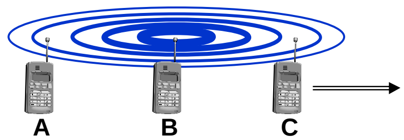
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a "free" medium (CS fails)
  - Collision at B not detected by A (CD fails): C is *hidden* from A

Collision is detected at the receiver but <u>not</u> at the source (unlike Ethernet) !!

c.yu91@csuohio.edu

CSMA in Wireless Networks

Signal strength decreases with square of distance



- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a "free" medium (CS fails)
  - Collision at B not detected by A (CD fails): C is *hidden* from A

Collision is detected at the receiver but not at the source (unlike Ethernet) !!

- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - But waiting is not necessary: C is *exposed* to B

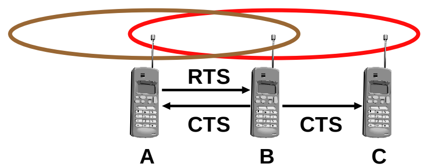
Collision Avoidance instead of Collision Detection

- Reduce collision probability by first sensing the medium
  - Not sufficient, given hidden terminals
- Uses short signaling packets for collision avoidance
  - Request To Send (RTS): a sender first requests the right to send from a receiver
  - Clear To Send (CTS): the receiver grants the right to send as soon as it is ready to receive
- CSMA with Collision Avoidance (CSMA/CA) or Multiple Access with Collision Avoidance (MACA)
- Available in IEEE802.11

RTS/CTS Solves Hidden & Exposed Terminal Problems

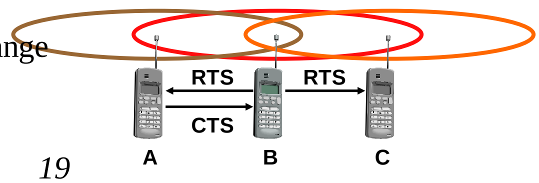
Hidden Terminal

• CTS from B to A is also heard by C, which then waits



Exposed Terminal

• C doesn't hear A's CTS and concludes A is outside its range
• C can start its transmission



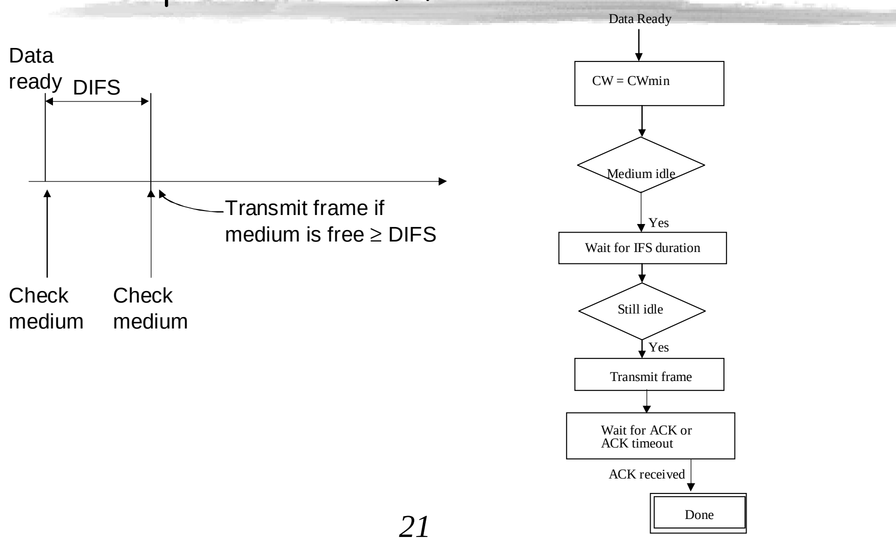
c.yu91@csuohio.edu

Contention & Backoff Algorithm to Further Reduce Collisions

- Carrier sense
  - When a node wishes to transmit a packet, it first waits until the channel is idle
- Collision avoidance
  - RTS/CTS avoids collisions from hidden terminals (Virtual carrier sensing or VCS)
- Further collision avoidance
  - If medium is idle when the packet is ready,
    - just send it
  - However, when the medium was busy and becomes idle,
    - the node waits for a randomly chosen duration before attempting to transmit
    - Contention & backoff algorithm

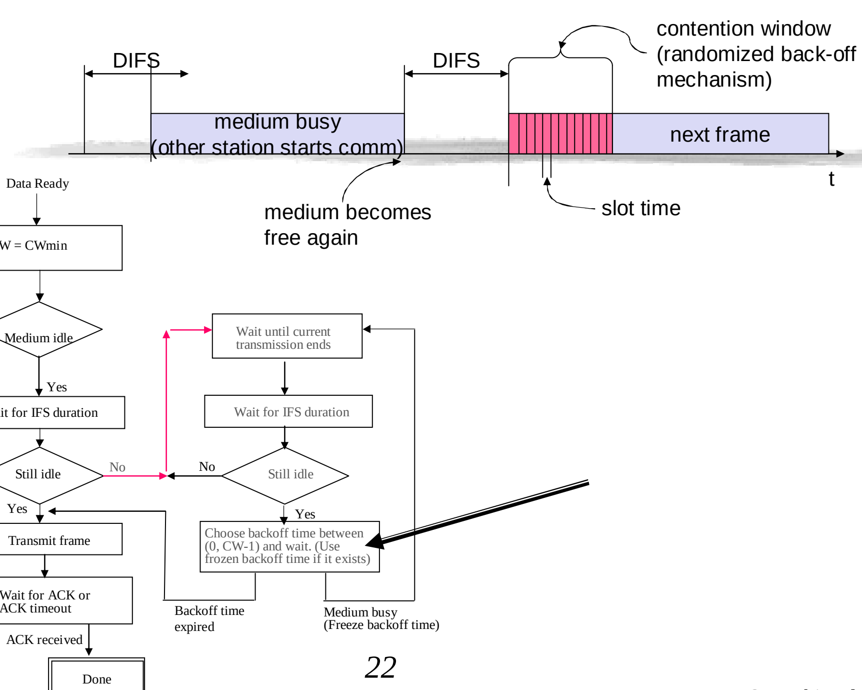
c.yu91@csuohio.edu

Example: 802.11 MAC



21

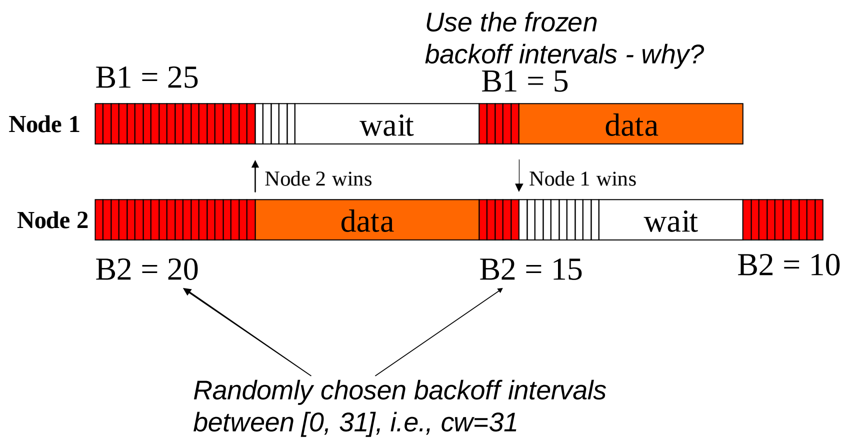
c.yu91@csuohio.edu



22

c.yu91@csuohio.edu

Example: IEEE 802.11 MAC



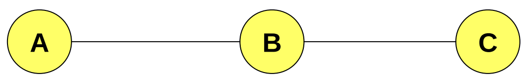
Other MAC Protocols Issues

- Hidden Terminal Problem and Collision avoidance

- Reliability
- Congestion control
- Energy efficiency
- Fairness

(2) Reliability

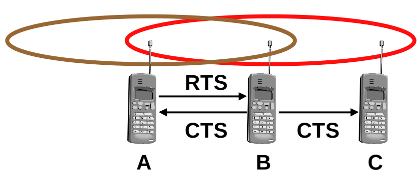
- ❑ Wireless links are prone to errors
  - ➢ High packet loss rate detrimental to transport-layer performance.
  - ➢ Mechanisms needed to reduce packet loss rate experienced by upper layers
- ❑ A simple solution
  - ➢ Acknowledgement (Ack)
  - ➢ Retransmission

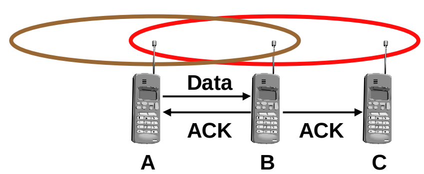


c.yu91@csuohio.edu

Example: IEEE 802.11 MAC

- ❑ Uses ACK to achieve reliability
  - ➢ 2-way handshake: Data-Ack
  - ➢ 4-way handshake: RTS-CTS-Data-Ack

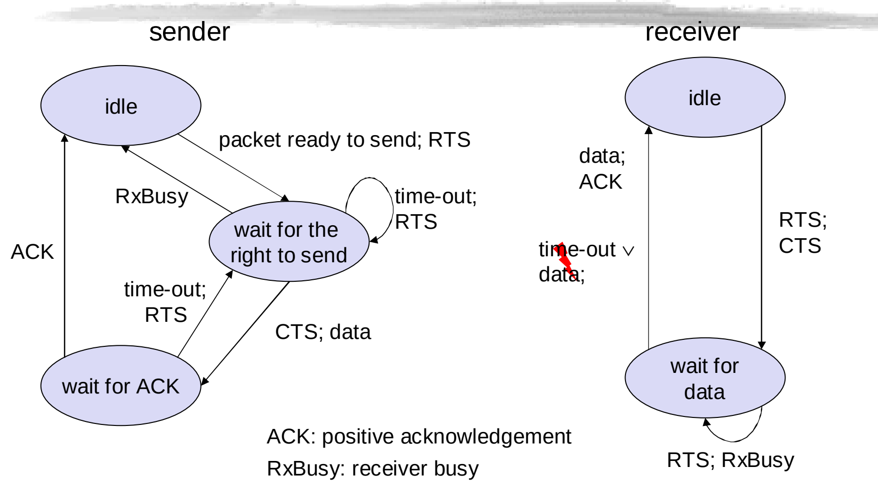




What makes C from causing interference?
⇒NAV (Network Allocation Vector) in RTS and CTS

c.yu91@csuohio.edu

4-Way Handshake (RTS-CTS-Data-Ack)



c.yu91@csuohio.edu

Link-level ACK

- Usually not used in wired networks
- In wired networks,
  - TCP-level ack is used to achieve reliability as well as to alleviate the congestion problem via sliding window protocol
  - Link-level ack is overkilling
- In mobile networks,
  - Link-level ack is used to provide comparable link-level reliability
  - But it competes with Data as well as with TCP-level ack

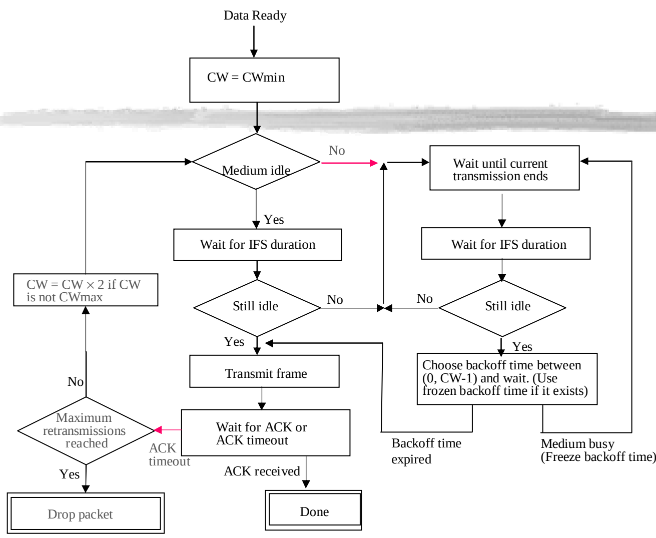
c.yu91@csuohio.edu

(3) Congestion Control

- The time spent counting down backoff intervals is a part of MAC overhead
- Choosing a *large cw* leads to large backoff intervals and can result in larger overhead
- Choosing a *small cw* leads to a larger number of collisions (when two nodes count down to 0 simultaneously)

Example: Binary Exponential Backoff in 802.11 MAC

- Since the number of nodes attempting to transmit simultaneously may change with time, some mechanism to manage congestion is needed
- IEEE 802.11 DCF: Congestion control achieved by dynamically choosing the contention window *cw*
  - When a node fails to receive CTS (ACK) in response to its RTS (Data), it increases the contention window: *cw* is doubled (up to an upper bound)
  - When a node successfully completes a data transfer, it restores *cw* to *CWmin*



Congestion control

c.yu91@csuohio.edu

MILD Algorithm in MACAW

- When a node fails to receive CTS in response to its RTS, it multiplies *cw* by 1.5
  - Similar to 802.11, except that 802.11 multiplies by 2
- When a node successfully completes a transfer, it reduces *cw* by 1
  - Different from 802.11 where cw is restored to Cwmin
  - In 802.11, cw reduces much faster than it increases
  - MACAW: cw reduces slower than it increases

    Exponential Increase Linear Decrease
- MACAW can avoid wild oscillations of cw when congestion is high

c.yu91@csuohio.edu