

# EEC 687/787 Mobile Computing (Spring, 2009)

## Medium Access Control

Prof. Chansu Yu

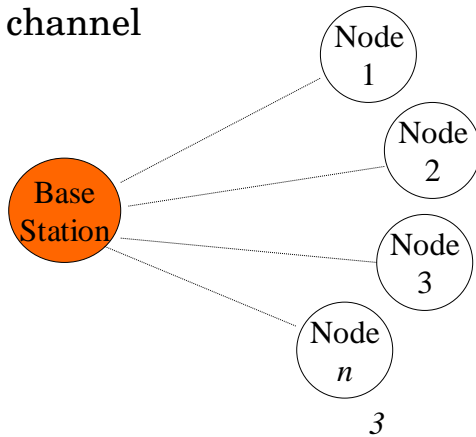
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## Simplified Reference Model...

<input type="checkbox"/> Application layer	<ul style="list-style-type: none"><li>➤ <u>Location/context-sensitive services</u></li><li>➤ <u>Multimedia applications</u></li></ul>
<input type="checkbox"/> Transport layer	<ul style="list-style-type: none"><li>➤ <u>congestion and flow control</u></li><li>➤ <u>quality of service</u></li></ul>
<input type="checkbox"/> Network layer	<ul style="list-style-type: none"><li>➤ <u>addressing, routing, device location</u></li><li>➤ <u>hand-over</u></li></ul>
<input type="checkbox"/> Data link layer	<ul style="list-style-type: none"><li>➤ <u>Authentication</u></li><li>➤ <u>Multiplexing of multiple data streams</u></li><li>➤ <u>Correction of transmission errors</u></li><li>➤ <u>Media access control</u></li></ul>
<input type="checkbox"/> Physical layer	<ul style="list-style-type: none"><li>➤ <u>Modulation</u></li><li>➤ <u>Generation of carrier frequency</u></li><li>➤ <u>Frequency selection</u></li><li>➤ <u>Signal detection</u></li></ul>

## 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

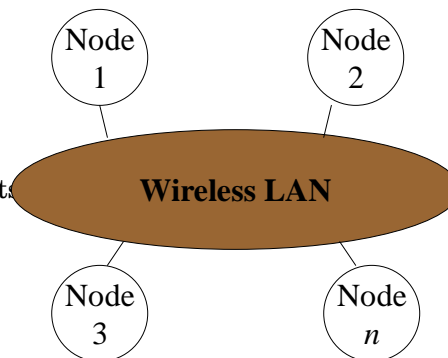
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## Distributed Protocols

- ❑ All nodes have identical responsibilities

- ❑ Arbitration difficulty

- Random access mechanism
- May incur many conflicts
- Performs "carrier sensing" before actually transmitting



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## Two medium access methods

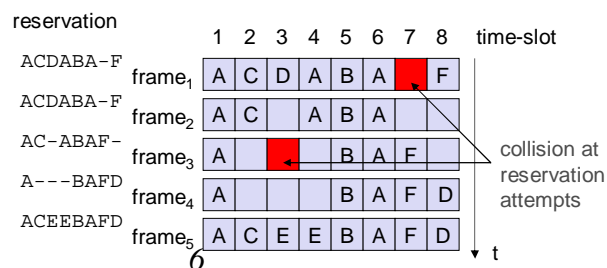
- ❑ TDMA-based fixed allocation methods
  - TDMA assigns frequencies to channels for a certain amount of time
  - Requires sender-receiver synchronization
  
- ❑ Contention-based random access methods
  - Aloha - classical and slotted
  - Carrier Sense Multiple Access (CSMA)
  - Demand Assigned Multiple Access (DAMA)
  - Multiple Access with Collision Avoidance (MACA)

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## TDMA Method – PRMA (Packet Reservation Multiple Access)

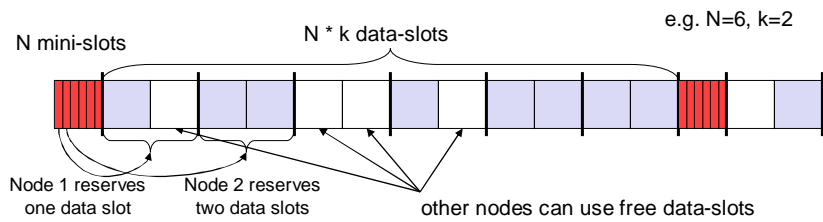
- ❑ AP broadcasts the reservation status (e.g., 7<sup>th</sup> slot is empty)
- ❑ Nodes compete for empty slots according to the Slotted Aloha principle
  
- ❑ Once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
- ❑ Competition for this slots starts again as soon as the slot was empty in the last frame



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# Reservation TDMA

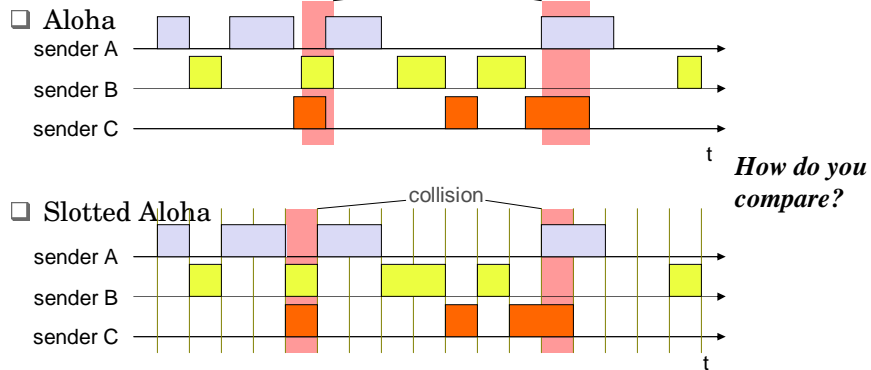
- ❑ Every frame consists of  $N$  mini-slots and  $x$  data-slots
- ❑ Every node has its own mini-slot and can reserve up to  $k$  data-slots using this mini-slot (i.e.  $x = N * k$ )
- ❑ Other nodes can send data in unused data-slots based on round-robin or Aloha scheme



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# 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

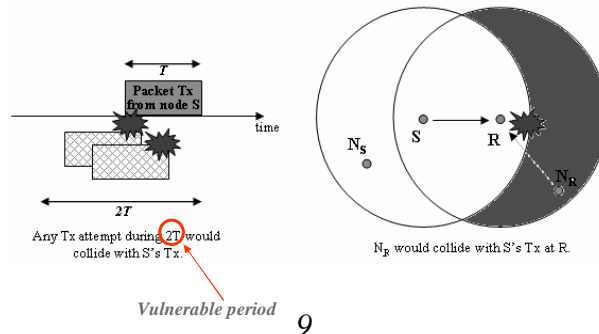


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## MAC Analysis: ALOHA (No CS)

### □ Parameters

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



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## MAC Analysis: ALOHA

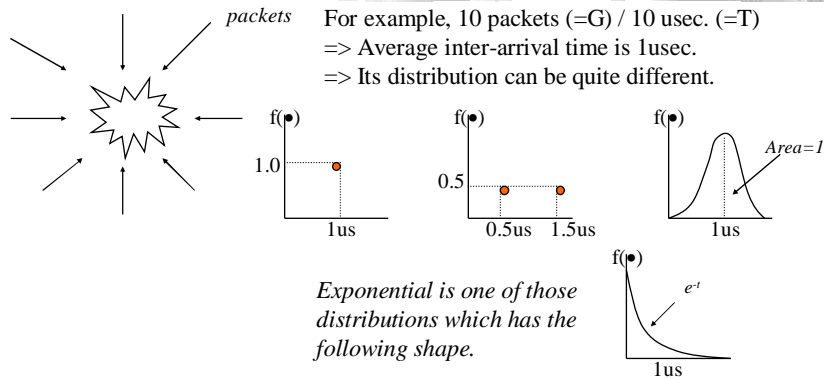
### □ How often and in which intervals are packets transmitted?

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

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## \*Exponential Distribution



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:  $e^{-\lambda t}$

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## 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,  $\lambda = G/T$ )

### ❑ Channel throughput $S$ for slotted ALOHA

- Vulnerable period = ???
- Thus,  $S = G * f(0, ???) = Ge^{-???}$

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## MAC Analysis: ALOHA Efficiency Plot

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

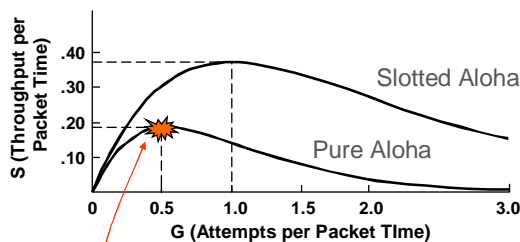
Pure ALOHA max performance with large number of users = 180Kbps

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

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## 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 = ???

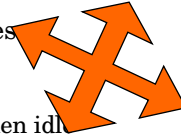
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## Basic Carrier Sense Approach

### ❑ 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

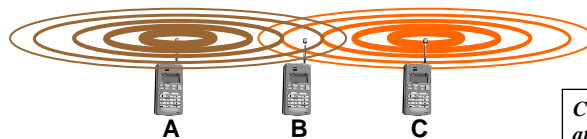


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## CSMA in Wireless Networks

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) !!*

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# CSMA in Wireless Networks

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## ❑ 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

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# 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

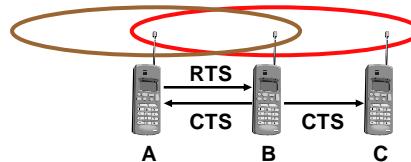
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## RTS/CTS Solves Hidden & Exposed Terminal Problems

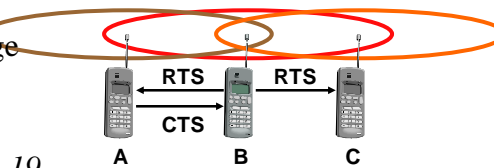
### Hidden Terminal

- 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



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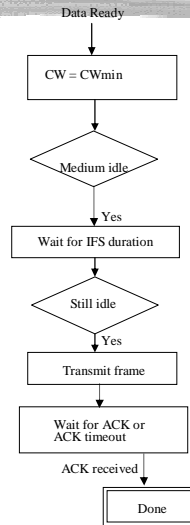
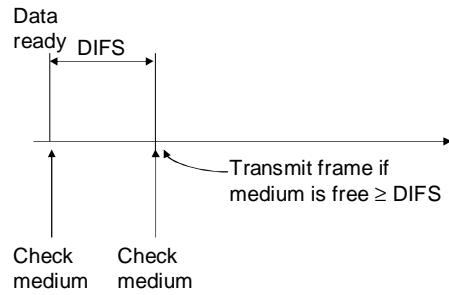
## Contention & Backoff Algorithm to Further Reduce Collisions

- 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

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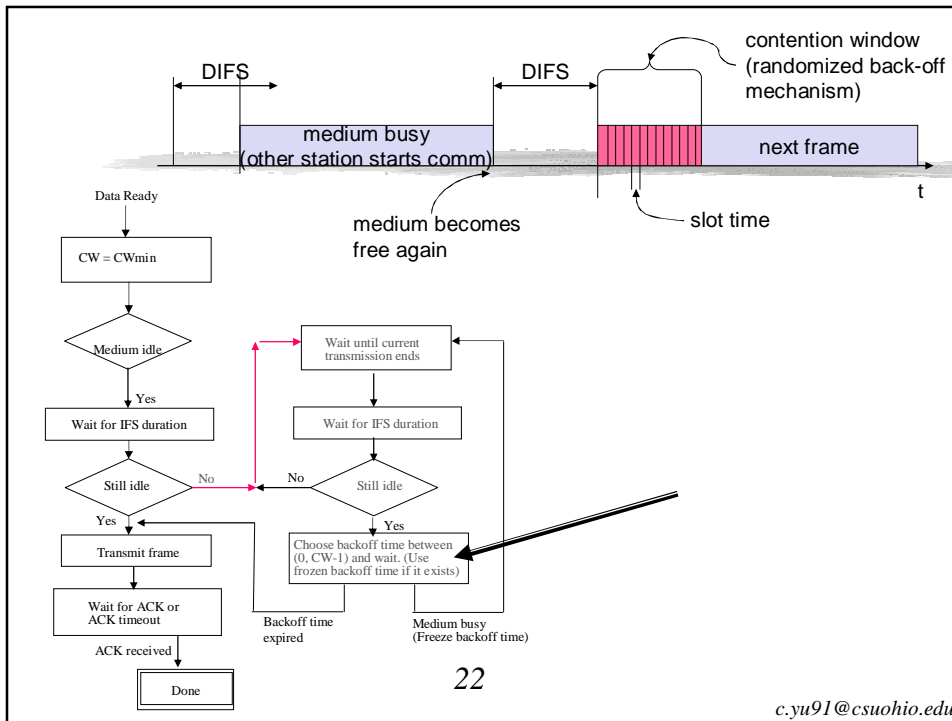
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# Example: 802.11 MAC



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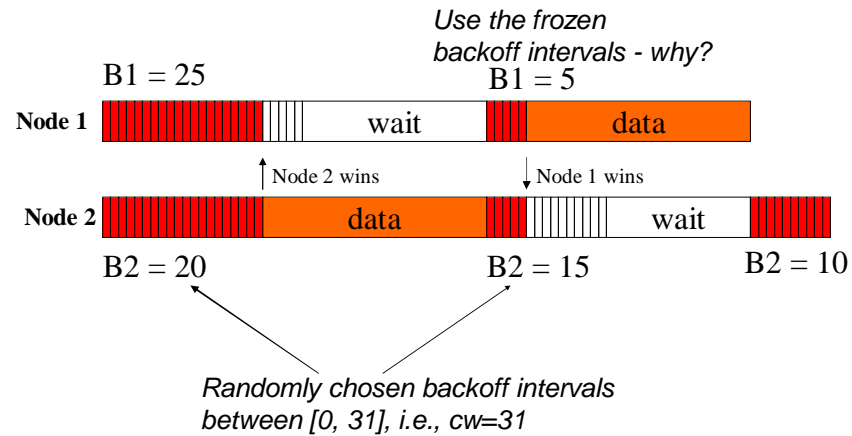
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## Example: IEEE 802.11 MAC



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## Other MAC Protocols Issues

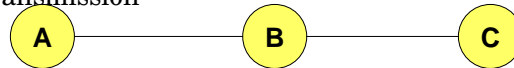
- Hidden Terminal Problem and Collision avoidance
- Reliability
- Congestion control
- Energy efficiency
- Fairness

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## (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

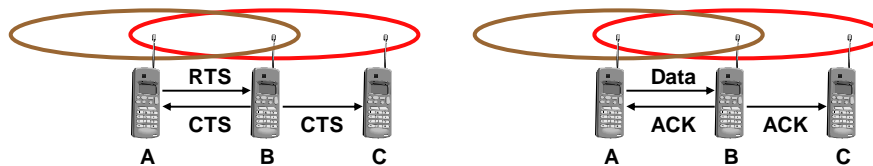


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## Example: IEEE 802.11 MAC

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

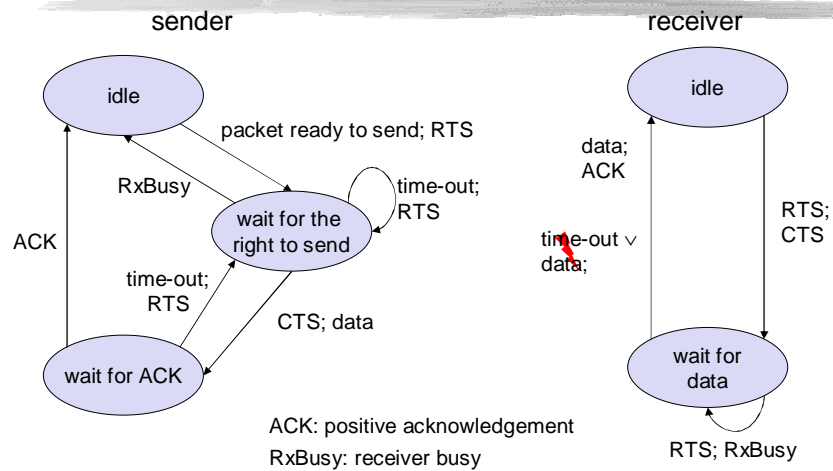


What makes C from causing interference?  
⇒ NAV (Network Allocation Vector) in RTS and CTS

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



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## 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

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### (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)

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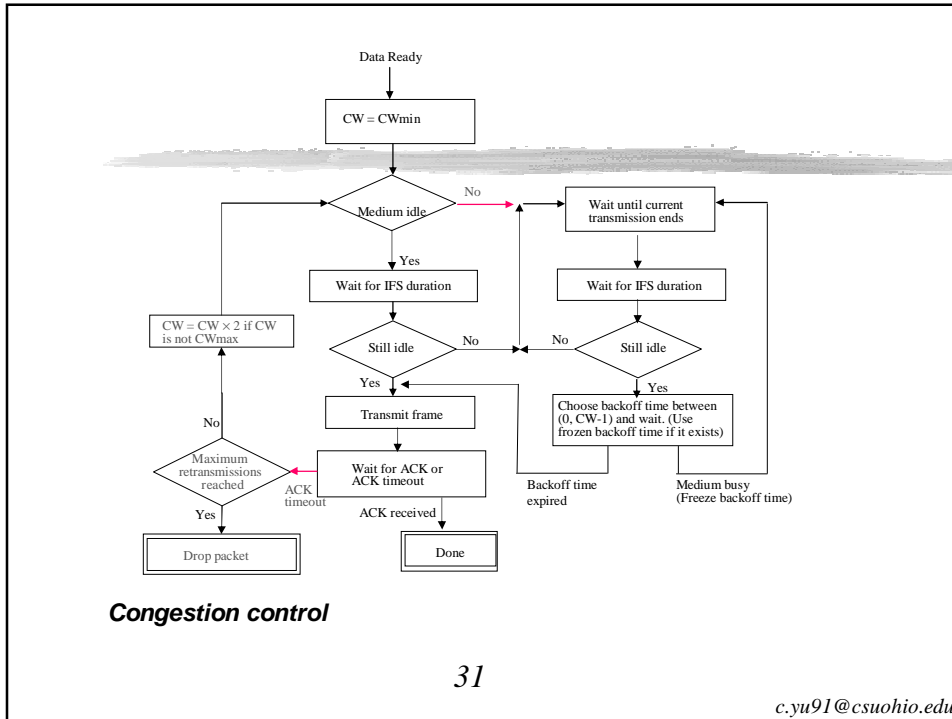
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### Example: Binary Exponential Backoff in 802.11 MAC

- ❑ 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  $CW_{min}$

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## 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  $Cw_{min}$
  - 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

## Reading Assignment

**\* See ns-2 manual**

**Chap. 16**

**Chap. 18**

**\* See 802.11 standard**

**Section 5.1~4**

**Section 7**

**Section 9.1~2**

**Section 11.1~3**