Wireless Network

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1

Protocol & MAC (Medium Access Control)

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Protocol

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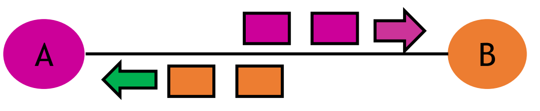
- Communications involve with two or more devices
- Suppose A and B communicate each other
  - Should A and B use the same program?
  - If A and B use Windows and Linux OS, respectively, how they communicate?
- Note that communication is exchanges of messages (packets)
- Protocol
  - Rules that communicating entities should abide to understand and properly process messages received
  - Protocol specifies the meaning (semantics) and syntax of messages
  - And timing of messages



Protocol – Example 1

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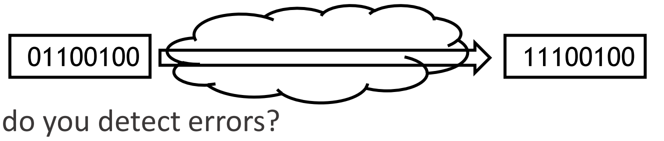
- Error detection
  - Communication links are not 100 % reliable
  - Errors may change, add, delete bits in the original message
  - An Internet bank user C requests to transfer $100 from account A1 to A2
  - If the first bit is changed to 1, then you transfer $228



- How do you detect errors?
  - There are many solutions
    - Parity bit
    - One's complement addition
    - CRC

Protocol – Example 2

- We need to agree
  - Use the same method (Algorithm)
  - How to apply the method
  - How to represent additional data
- Assume we agreed to
  1. Even parity bit
  2. Apply parity to every bytes
  3. Attach parity bits to the end of the original message as a byte stream

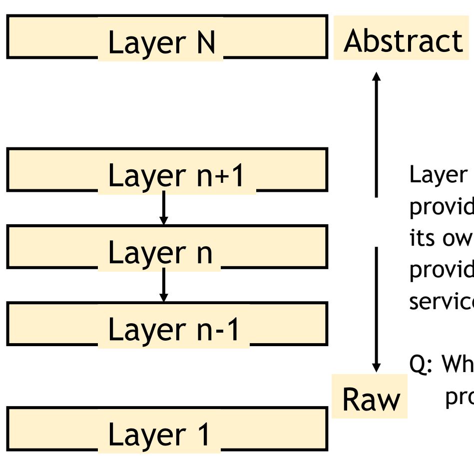
01001100 11100111 10101100 00010010

↓

01001100 11100111 10101100 00010010	00001000

Layered Architecture

- Layered architecture
  - Keep the interaction simple

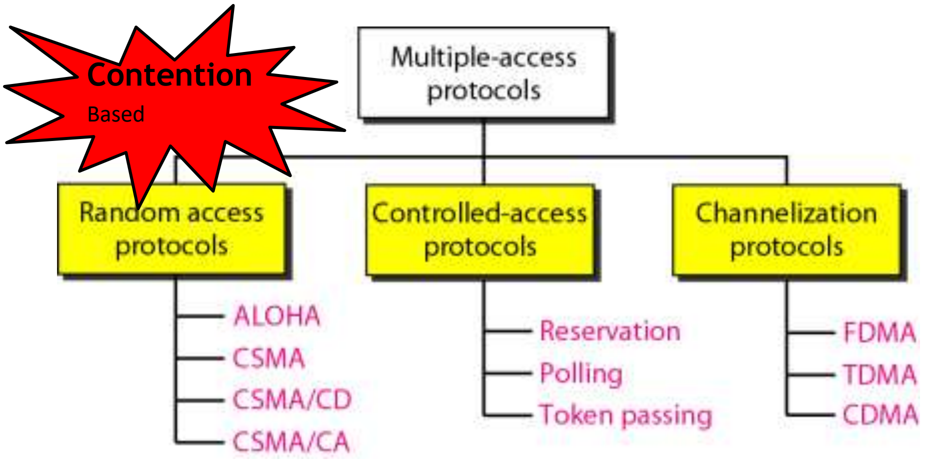


Layer n uses service provided by layer n-1, adds its own functions and provide more abstract service to layer n+1

Q: What functions layer 1 provides? And Layer N?

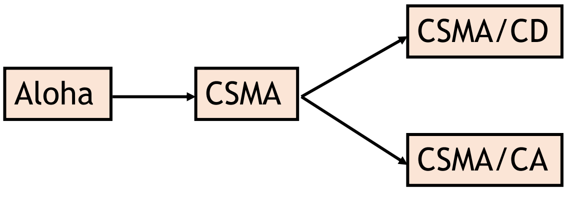
Taxonomy of Medium Access Methods

- Sharing of wired/wireless multi-point links
  - MAC protocols can be considered as distributed ATDM



Contention Based Method

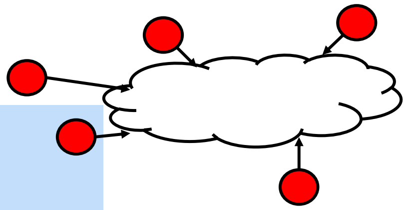
- Every station is a peer
  - No master-slave relation
- Fully distributed, non-coordination method
  - Judge & behave based on locally available information
- Stations use care not to interfere others
  - But should be aggressive to earn the fair share
- ***Collisions*** still can occur



ALOHA - 1

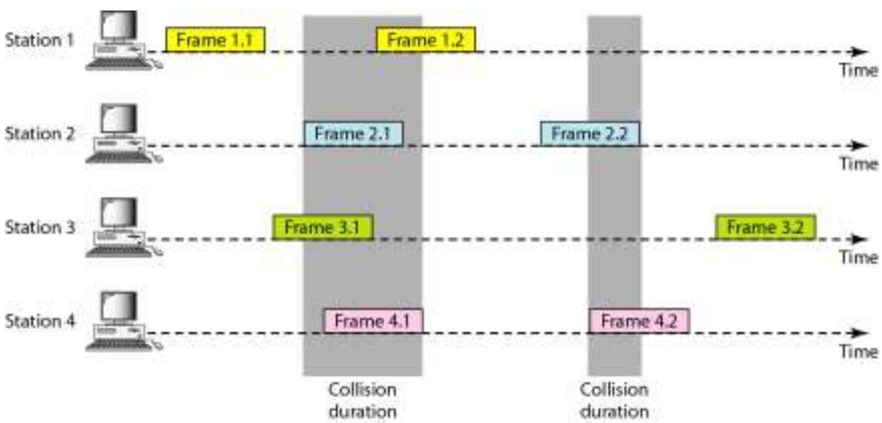
- Developed by Abramson in 1970
- Implemented and used at the Univ. of Hawaii

U. Hawaii campuses are scattered over several islands



ALOHA - 2

- Transmit a frame and check if the frame is transmitted correctly
  - ACK
  - Retransmit in case of no ACK
- Examples of ***Success*** & ***Collision***



ALOHA – Performance Analysis

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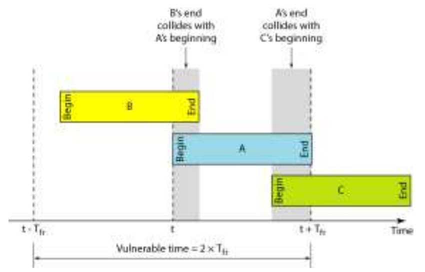
T_{fr} = 1(unit time)

- Frame A during [t, t+1]is **success** if
  - No attempt in (t-1, t) &&
    (t, t+1)



- n stations each with p attempt rate

Total attempt rate = n·p

➔ A frame sent at time t is successful if only one attempt in (t, t+1) and no attempt in (t-1, t)

- Binomial distribution, Bin(x; n, p) = $_nC_x \cdot p^x \cdot (1-p)^{n-x}$

P(success) = b(1; n, p)·b(0; n, p) = $_nC_1\, p(1-p)^{n-1} \cdot {}_nC_0\, (1-p)^n$

$= \boldsymbol{n \cdot p} \cdot (1-p)^{\mathbf{2n-1}}$

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ALOHA – Performance Analysis

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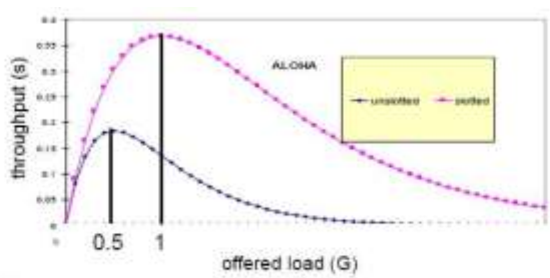
- Note b(x; n, p) ≈ Po(x; G) where G = n·p if n is large and p is small

The throughput for pure ALOHA is
$S = G \times e^{-2G}$.
The maximum throughput
S_{max} = 0.184 when G = (1/2)



What happens if G=n·p is too small OR too large?

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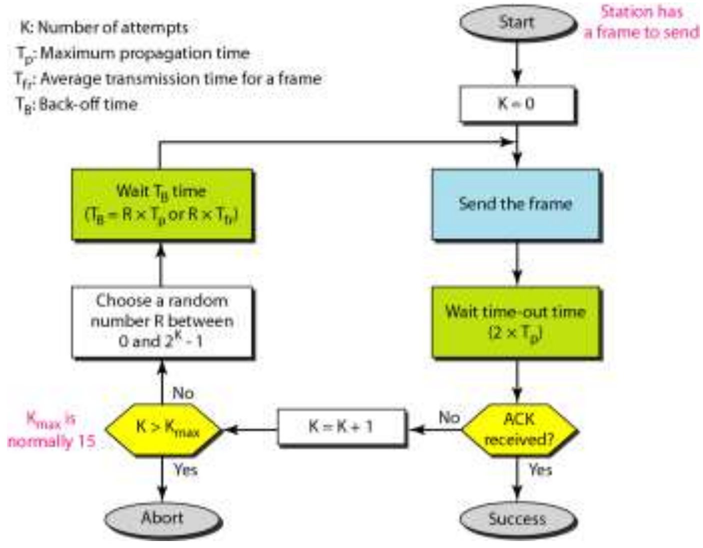
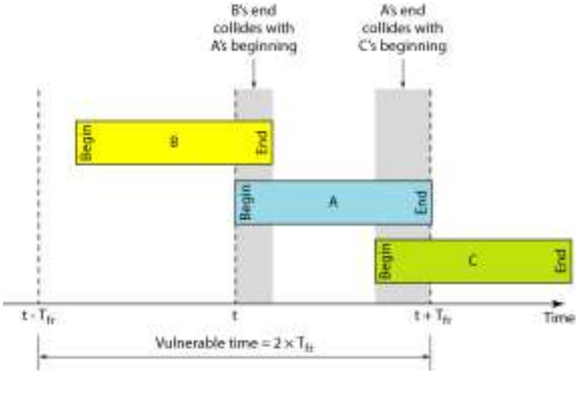
ALOHA - 3

- Procedure



Slotted ALOHA

- Problem with Pure (Unslotted) Aloha
  - An attempt may be interfered by later attempts
  - Vulnerable time is long



Time Synchronization

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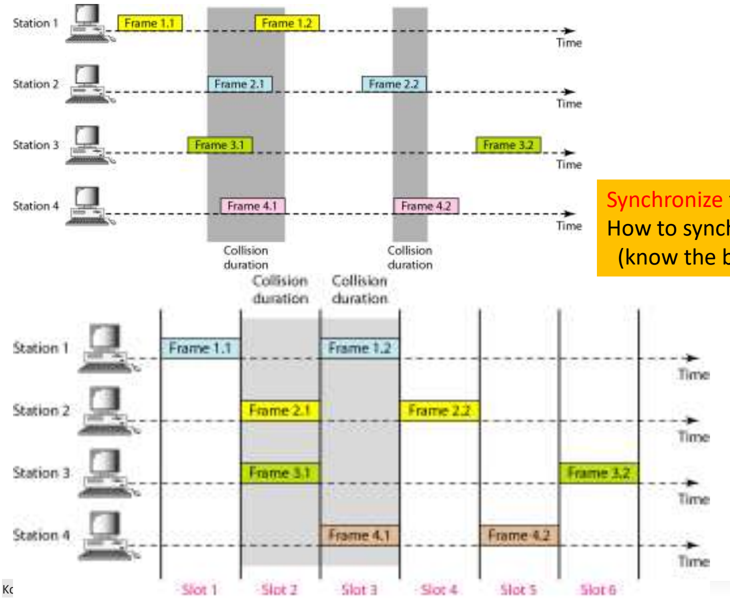

Synchronize the transmissions
How to synchronize stations?
(know the beginning of slots)

Slots

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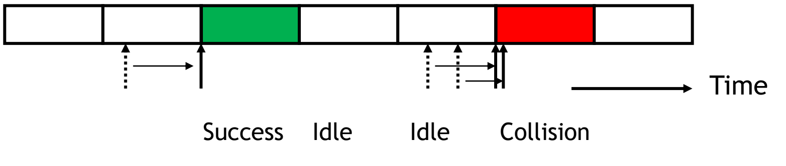
- A station, that has a packet to send, waits until the next slot



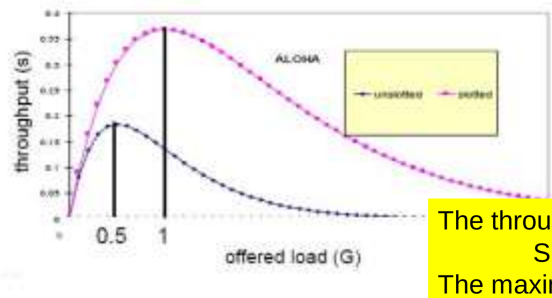
- A slot is either Idle, Success or Collision
  - **Idle**: No arrival during the previous slot time
  - **Success**: Exactly one arrival
  - **Collision**: More than one arrival

Performance of Slotted Aloha

AI

- A slot is successful if
  - There is exactly one attempt during the previous slot

- Pr(1 arrival in a unit time) = $G \times e^{-G}$



The throughput for slotted ALOHA is
$S = G \times e^{-G}$.
The maximum throughput
$S_{max} = 0.368$ when $G = 1$

Wireless Links & WLAN (Wireless Local Area Network)

Name: Chong-Kwon Kim

Wireless Characteristics

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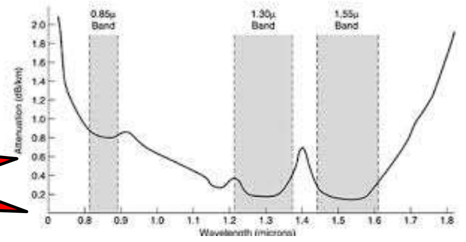
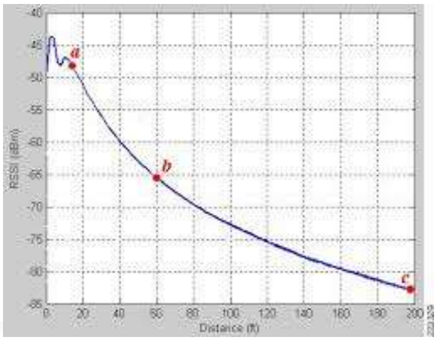
- Signal quality of wireless links is much worse than that of wired links

WHY?
Attenuation





- Root cause:

  Attenuation of wireless medium is large

  Signal strength (r) ∝ $r^{-3} \sim r^{-4}$

IEEE 802.11 WLAN Standard

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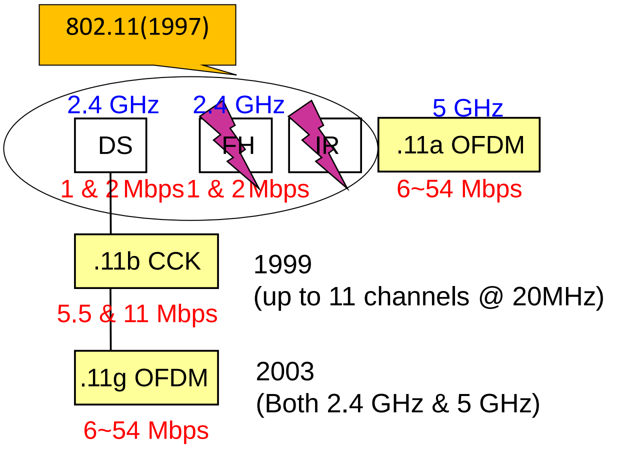
- IEEE 802.11 a/b/g



TCP IP
LLC
MAC
PLCP
PMD

802.11 PHY - 1

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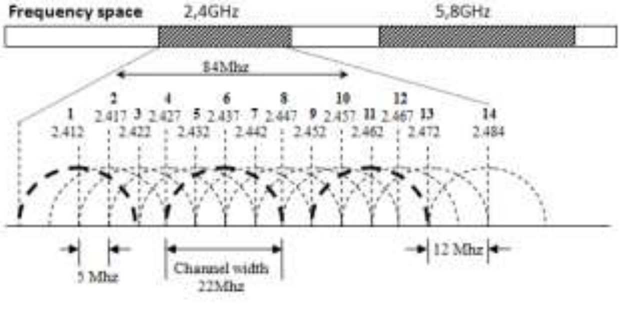
- 802.11 - 1997
  - Three physical layer specifications operating at 1 and 2 Mbps
- Two additional parts in 1999 - 802.11a and 802.11b
- IEEE 802.11b
  - 2.4-GHz band at 5.5 and 11 Mbps
  - Complementary code keying (CCK) modulation
  - Input data treated in blocks of 8 bits at 1.375 MHz
    - 8 bits/symbol × 1.375 MHz = 11 Mbps



802.11 PHY - 2

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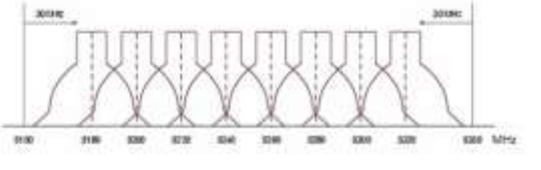
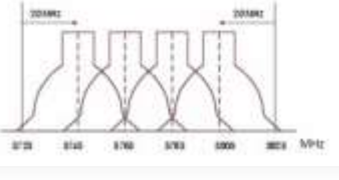
- 802.11a
  - 5-GHz band up to 54 Mbps
  - Uses orthogonal frequency division multiplexing (OFDM)
  - Multiple carrier signals at different frequencies
  - Data rates 6, 9, 12, 18, 24, 36, 48, and 54 Mbps
- IEEE 802.11g (2002)
  - Extends IEEE 802.11b to higher data rates
  - Combines 802.11a and b



- IEEE 802.11n (2006)
  - 100 Mbps



- 802.11ac, 802.11ax, …
  - > Gbps, mmWAVE

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Transmission Rates

AMC: Adaptive Modulation & Coding

Learn: Performance Anomaly Problem

Table 4 Comparative Ranges in an Open Indoor Office Environment Through Cubicle Walls

Data Rate (Mbps)	802.11a (40 mW with 6 dBi gain diversity patch antenna) Range	802.11g (30 mW with 2.2 dBi gain diversity dipole antenna)	802.11b (100 mW with 2.2 dBi gain diversity dipole antenna)
54	45 ft (13 m)	90 ft (27 m)	-
48	50 ft (15 m)	95 ft (29 m)	-
36	65 ft (19 m)	100 ft (30 m)	-
24	85 ft (26 m)	140 ft (42 m)	-
18	110 ft (33 m)	180 ft (54 m)	-
12	130 ft (39 m)	210 ft (64 m)	-
11	-	160 ft (48 m)	160 ft (48 m)
9	150 ft (45 m)	250 ft (76 m)	-
6	165 ft (50 m)	300 ft (91 m)	-
5.5	-	220 ft (67 m)	220 ft (67 m)
2	-	270 ft (82m)	270 ft (82m)
1	-	410 ft (124 m)	410 ft (124 m)

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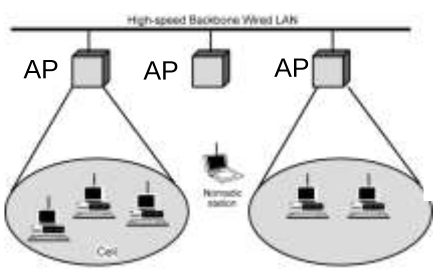
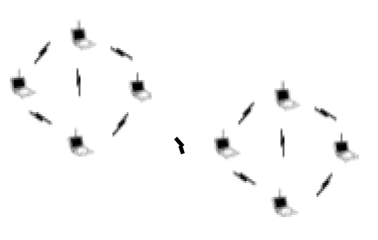
Topology

- Infrastructure Mode
  - All packets pass through the **Access Point (AP)**
  - No direct communications between **Mobile Stations (MS**, or client/host)
- Ad-hoc mode
  - Peer-to-peer (station-to-station) direct communications



(a) Infrastructure Wireless LAN



IEEE 802.11 – BSS / ESS

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- Smallest building block is **Basic Service Set (BSS)**
  - One AP and multiple stations
  - Compete to access the same shared wireless medium
  - **BSSID (= MAC addr. of the AP)**

- ESS (Extended Service Set)
  - Two or more BSSes interconnected by DS
  - Appears as a single logical LAN to LLC
- AP
  - Logic within station that provides access to DS
  - Provides DS services in addition to acting as station
- Portal
  - Integrate IEEE 802.11 architecture with wired LAN

Wireless Links

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- Abrupt degradation of signal strength

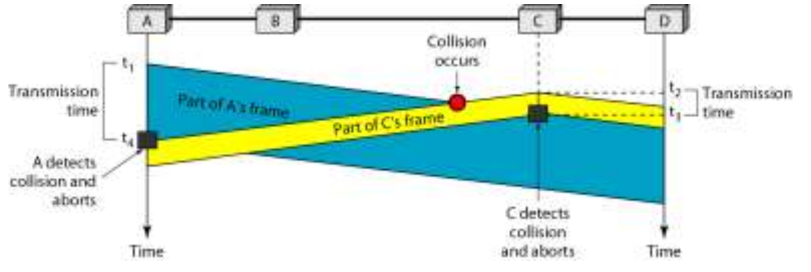
  ➔ Large error rate

  ➔ Carrier sense?

  ➔ Collision detection

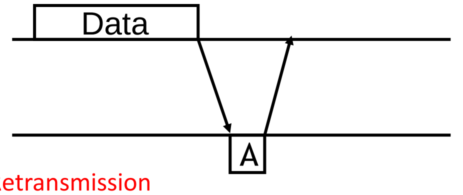
Collision Detection

- In wired links, we can be almost sure that a frame is delivered successfully in case of no collision
  - ➔ ACK is not necessary if CD is equipped
- Wireless CD is impossible. Why???



Reliability & ACK

1. How do you know a frame is successfully transmitted?
   ➔ Use ACK



2. No ACK ➔ Retransmission

ACK should be transmitted before any other frames
How??

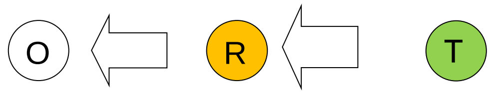
How about SWS?

Carrier Sensing

CS: Channel Status
Strength and quality of signal and noise

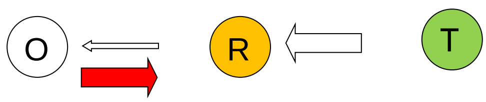
- Wired links,

Transmitter’s CS ≈ Receiver’s CS ≈ Others’ CS



- Wireless links,

Transmitter’s CS >> Receiver’s CS >> Others’ CS

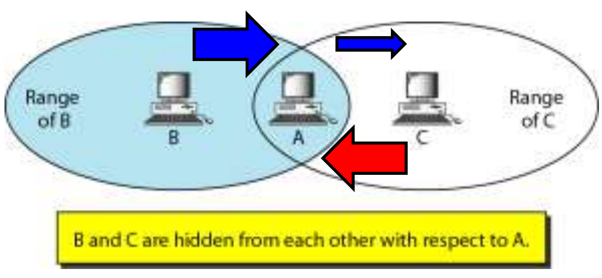


The other thinks the medium is clear and starts to transmit

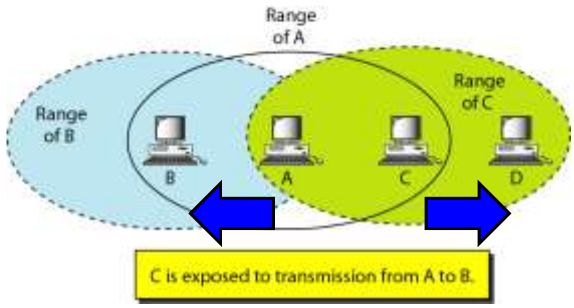
- How do you know the receiver’s channel status?

Hidden / Exposed Terminal

- **Hidden Terminal** Problem
  - C cannot sense B➔A transmission and attempts to send a frame



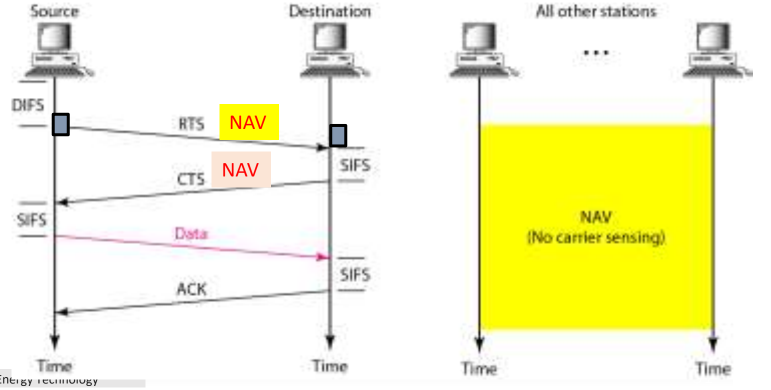
- Exposed Terminal Problem
  - C can send to D without disturbing A➔B transmission
  - However, C thinks the medium is busy



RTS/CTS & Virtual CS

AI

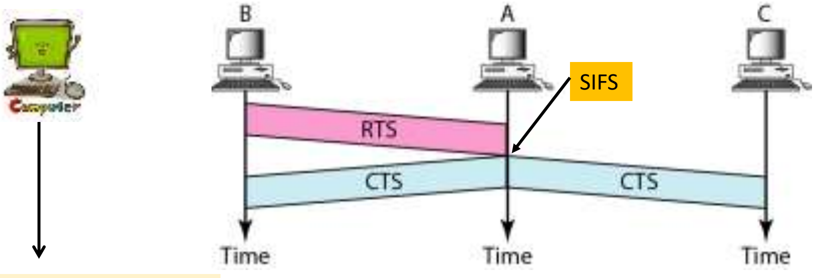
- **Request To Send (RTS) & Clear To Send (CTS)**
  - ***Short*** control frames that specifies the intention to transmit (RTS) and willingness to receive (CTS)
- Specifies the remaining time of the transaction in RTS/CTS frames
- **Network Allocation Vector(NAV)**



RTS/CTS & Hidden Terminal

AI

- RTS/CTS can mitigate the hidden terminal problem



Suppose you hear an RTS but not a CTS, what will you do?

Suppose you hear a CTS without RTS, what will you do?

How long should you wait before sending your frame?

RTS/CTS & Exposed Terminal

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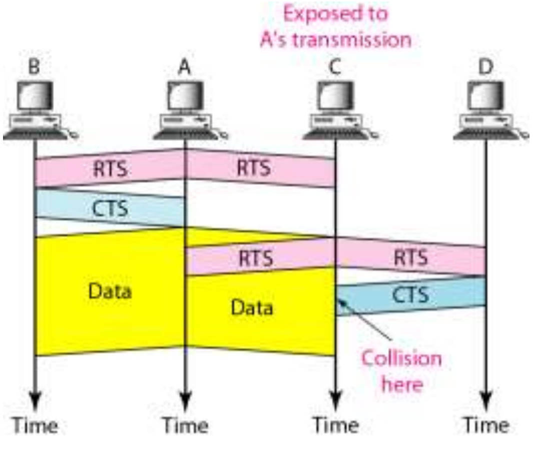

RTS/CTS exchange cannot solve the exposed terminal problem

Atomicity

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- DATA & Control frames
  - ACK, RTS, CTS
- Atomic transaction
  - Transmissions including both DATA and its ACK
  - RTS-CTS-DATA-ACK
- How to guarantee Atomicity?
  - Use **different CS (Carrier Sense) time**

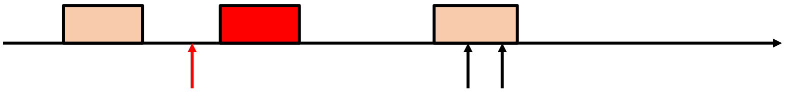
Inter- Frame Space (IFS)

- Importance of ACK > Data
- How to prioritize ACK transmissions?

- IFS: Minimum time that the medium should be idle to trigger frame transmission
- **SIFS** (short IFS):
  - For all immediate response actions (CTS, ACK, Poll response)
- **DIFS** (distributed coordination function IFS):
  - Used as minimum delay for DATA, RTS frames contending for access
- PIFS (point coordination function IFS):
  - Used by the centralized controller in PCF scheme when issuing polls

- If SIFS < DIFS, then data frames cannot intervene DATA-ACK transaction

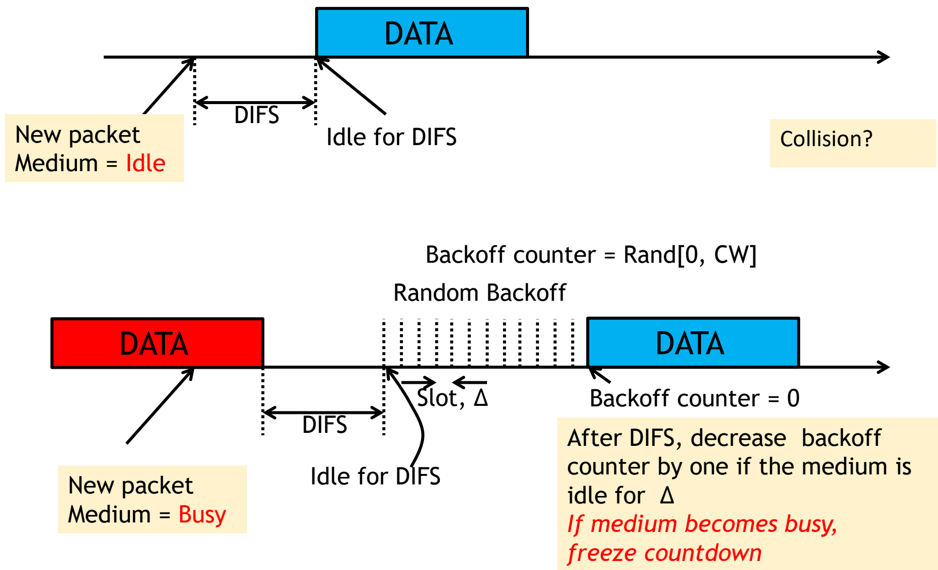
DCF Design



- First Carrier Sensing
  - A new Data frame arrives and the first Carrier Sensing
- First CS = IDLE
  - Should wait at least DIFS to protect ACK, CTS and etc
- First CS = BUSY
  - Should wait extra in addition to DIFS
  - The extra waiting time should be randomized

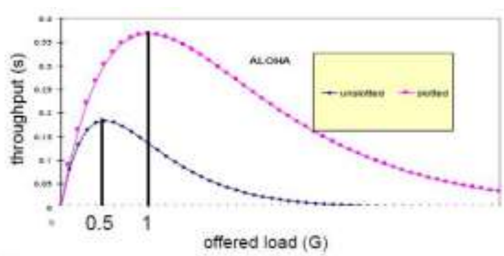
- Transmission result
  - Success or Collision
- In the case of collision, should reduce attempt rate, repeatedly
  ➔ How??

DCF Basic



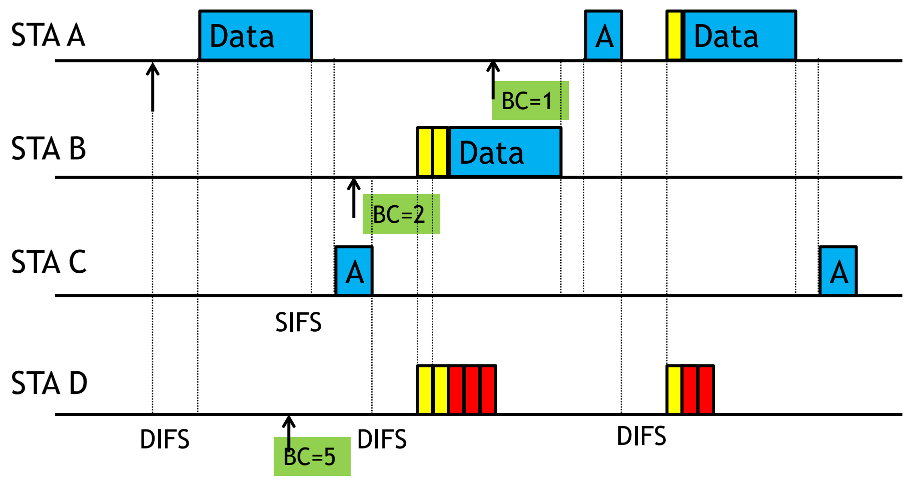
BEB (Binary Exp. Backoff)

- **Collision = Overloaded**
- Contention Window (CW)
- Backoff delay = Random (0 .. CW)
- At the beginning, CW = CW_{min}
- For each unsuccessful transmission, double CW up to CW_{max}



Example

Scenario
1: A→C
2: D→B
3: B→A
4: A→C

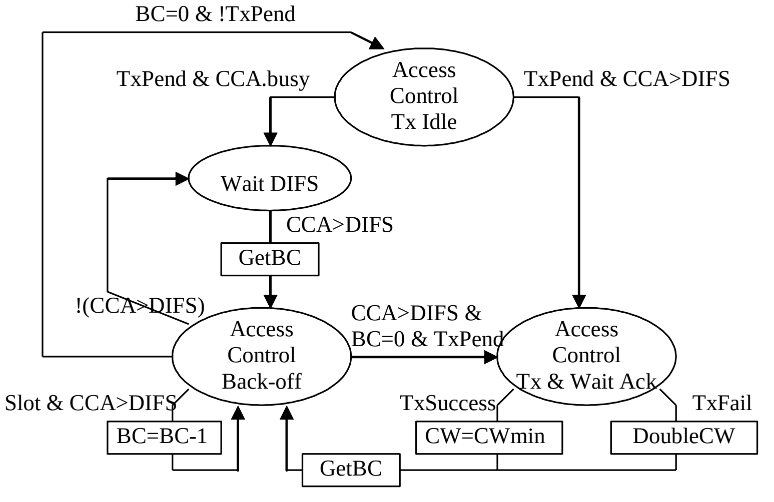


AI

DCF – CSMA/CA

RTS/CTS exchange is optional

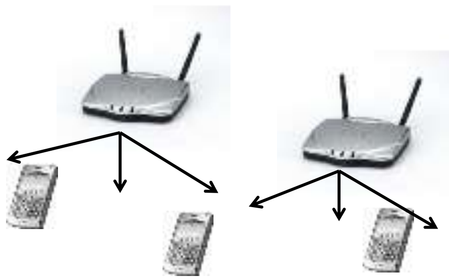
CA (Collision Avoidance)



AP Discovery

AI

- To use AP
  1. Discovery
  2. Authentication
  3. Association
- Scan
  - Discover APs in transmission range
  - Active scan, Passive scan



- Passive scan
  - Clients listen for **"Beacon"** frames that AP transmits periodically
- Active scan
  - Clients probe APs by sending **"Probe request"** frames
  - AP replies with **"Probe response"** frame
  - "Probe response" frame is approximately same as a Beacon frame

Power Saving

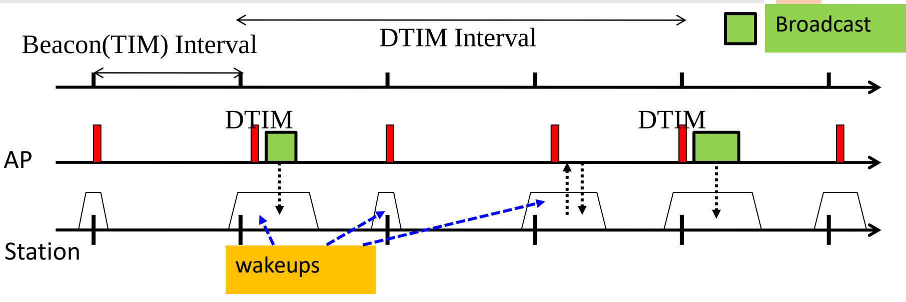
AI

- Energy is a scarce resource in battery powered devices
- Network interfaces consume sizable amount of energy

How to Conserve Energy?

- Turn off idle network interfaces
- **PSM (Power Saving Mode)**
  - Sleep state
  - Listen
- To sleep
  - Signals to the AP not to send frames
- How to resume communication (Wakeup)?
  - Transmission (Station → AP)
  - Reception (AP → Station)

Packet Reception - PSM



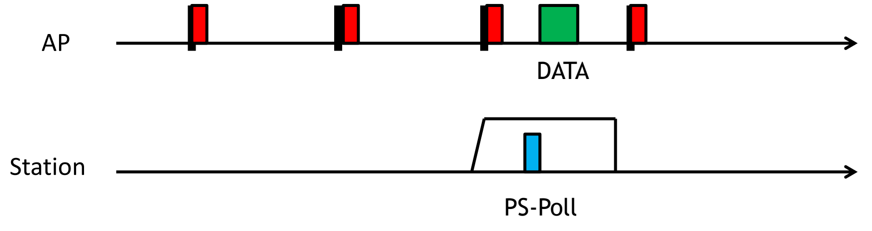
AP transmits beacons every beacon interval (~100msec)
- Defer if channel is busy
- All PS nodes wake up for beacon reception

TIM(Traffic Indication Map)
- Indicate the existence of backlogged unicast traffic to PS nodes
- PS node may request packet transmission

Broadcast packets are announced by a Delivery TIM(DTIM) and are sent immediately afterwards
- DTIM interval is a multiple of TIM interval

Delivery in PS Mode

- If TIM indicates frames buffered
  - STA sends PS-Poll to AP and stays awake to receive data



- Learn
  - U-APSD (Unscheduled Automatic Power Saving Delivery)

802.11e QoS

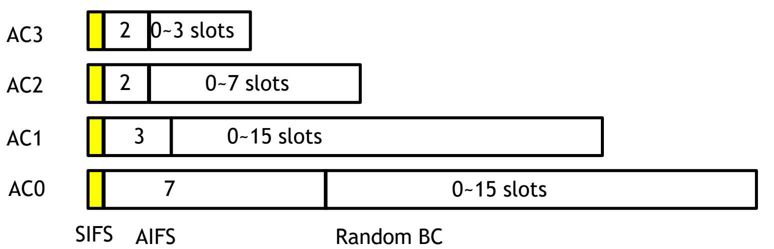
AI

- **Priority** and Parameterized QoS
- Priority scheme
  - **EDCA** (Enhanced DCF Channel Access)
  - Four access classes
  - Different CW and AIFS
- Parameterized QoS scheme
  - HCCA(Hybrid Coordination Function Channel Access)
  - PCF based resource allocation

Access Classes

AI

AC	Description	CW Min.	AIFS
0	Background	15	7
1	Best Effort	15	3
2	Video	7	2
3	Voice	3	2



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