

Problem: physically connecting hosts

Direct link networks:

- point-to-point links
- shared access networks

Shared Access Networks

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Acknowledgement: this lecture is partially based on the slides of Dr. Larry Peterson

Key issue?

Efficient, fair access control

Outline

- Bus (Ethernet)
- Token ring (FDDI)
- Wireless (802.11)

- Discussion

Outline

- Bus (Ethernet)
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- Wireless (802.11)

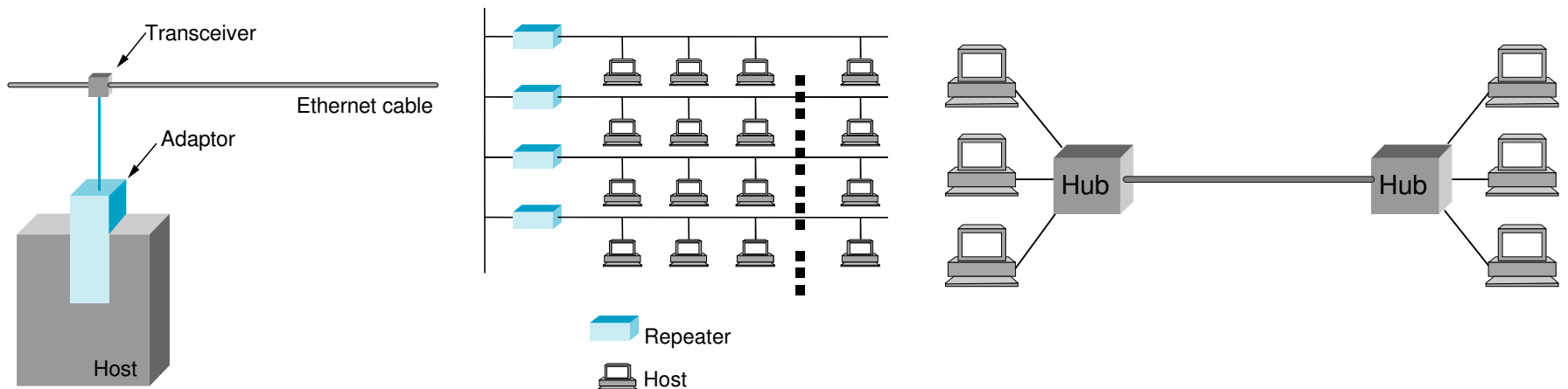
- Discussion

Ethernet Overview

- History

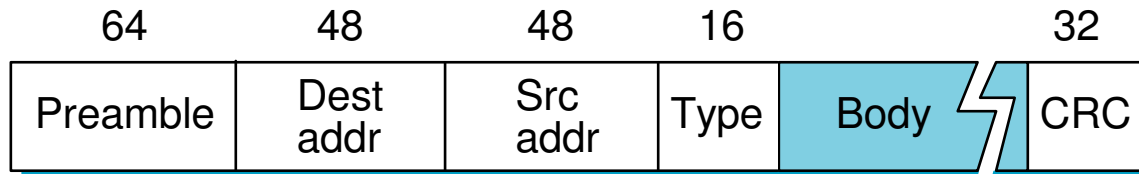
- developed by Xerox PARC in mid-1970s
- roots in Aloha packet-radio network
- standardized by Xerox, DEC, and Intel in 1978
- similar to IEEE 802.3 standard

- Common topologies



Ethernet (contd.)

■ Frame Format



■ Addresses

- unique, 48-bit unicast address assigned to each adapter
 - example: `8:0:e4:b1:2`
- broadcast: all 1s
- multicast: first bit is 1

Ethernet (contd.)

- Bandwidth: 10Mbps, 100Mbps, 1Gbps
- Length: 2500m (500m segments with 4 repeaters)
- CSMA/CD
 - carrier sense
 - multiple access
 - collision detection
- Challenge: how to design distributed algorithm for efficient, fair channel access?

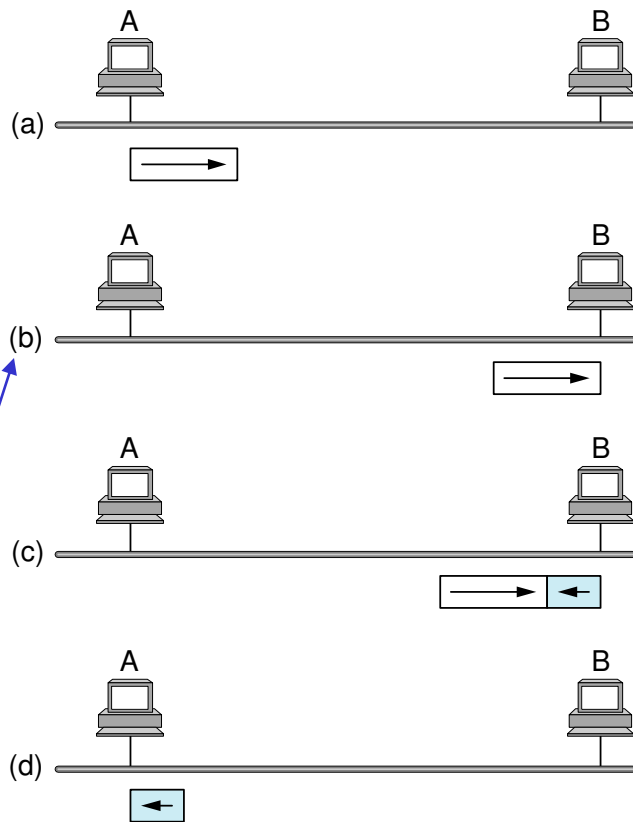
Transmit Algorithm

- If line is idle...
 - send immediately
 - upper bound message size of 1500 bytes
 - must wait 9.6us between back-to-back frames
 - To allow for receiver to be ready for the next reception
 - 96 bits (minimum # of bits transmitted in the presence of collision) time for 10Mbps Ethernet
- If line is busy...
 - wait until idle and transmit immediately
 - called *1-persistent* (special case of *p-persistent*)

Algorithm (contd.)

- If collision...
 - jam for 32 bits, then stop transmitting frame
 - Transmitter will minimally transmits 96 bits in the presence of collision: 32 bit jamming sequence + 64 bits preamble
 - delay and try again: exponential backoff
 - 1st time: 0 or 51.2us
 - 2nd time: 0, 51.2, 102.4, or 153.6 us
 - *n*th time: $k \times 51.2\text{us}$, for randomly selected $k=0..2^n - 1$
 - give up after several tries (usually 16)
 - minimum frame is 64 bytes/512 bits (why?)
 - 14 bytes of header + 46 bytes of data + 4 bytes of CRC

Collision: worst case scenario



B starts to transmit right at the moment that the packet from A arrives at B

- A will not be able to detect the collision until it hears the jamming sequence from B.
- To enable effective collision detection, *network physical length* and *minimum frame size* are carefully designed to ensure that the sender can reliably detect all possible collision

i.e., the time taken to finish transmitting the min-length packet is no less than $2*d$, where d is the max. latency between two nodes

Example: minimum frame size (512bits) for Ethernet

Max. 2500 meters long and up to 4 repeaters
between two hosts =>

51.2 microseconds of max. round-trip delay

+

10M bps Ethernet

=> 512 bits

Outline

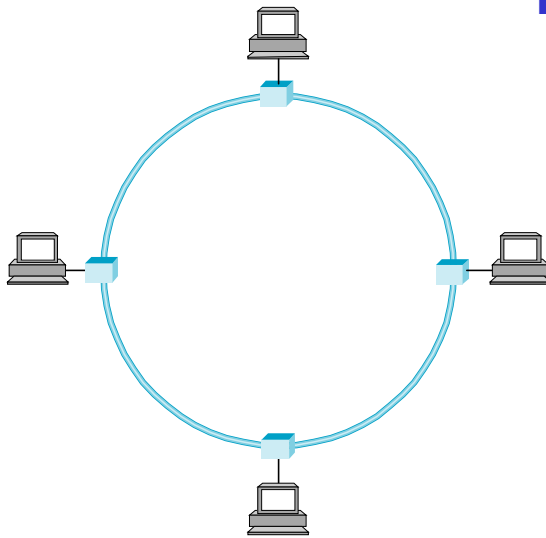
- Bus (Ethernet)
- Token ring (FDDI)
- Wireless (802.11)

- Discussion

Token Ring Overview

- Examples
 - 4Mbps/16Mbps IEEE 802.5 (based on earlier IBM ring)
 - 100Mbps Fiber Distributed Data Interface (FDDI)

Token Ring (contd.)

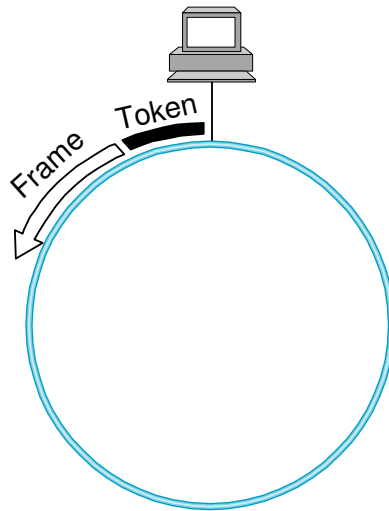


■ Idea

- Frames flow in one direction: upstream to downstream
- *special bit pattern (token)* rotates around ring
- must capture token before transmitting
- release token after done transmitting

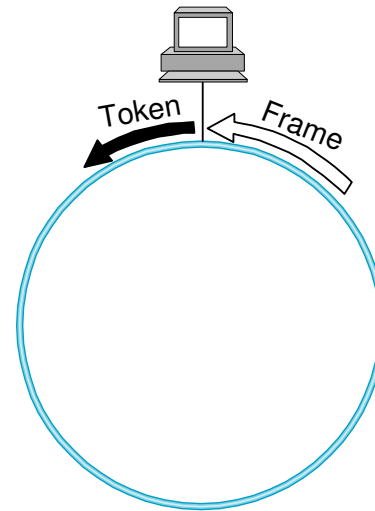
- remove your frame when it comes back around
- stations get round-robin service

Token release



(a)

Early release: allows better
BW utilization

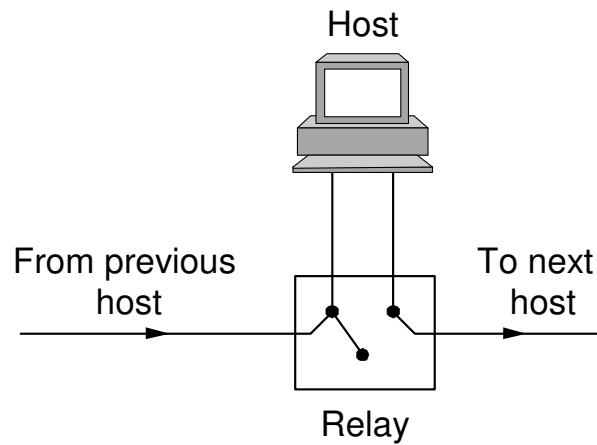


(b)

Delayed release:
originally used

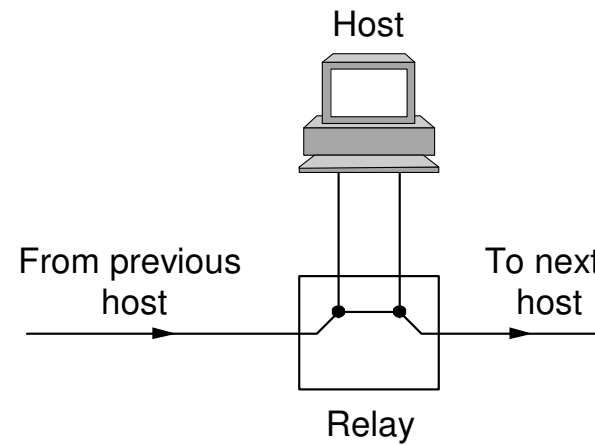
Token Ring: construct

- 802.5 (IBM token ring)



(a)

Relay open – host active

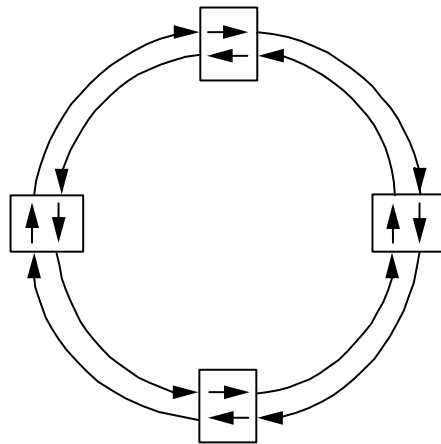


(b)

Relay closed – host bypassed

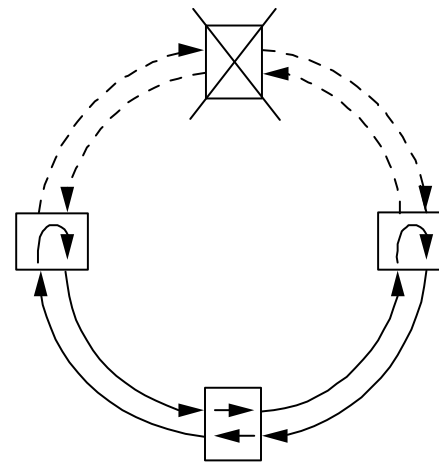
Token Ring: construct (contd.)

- FDDI



(a)

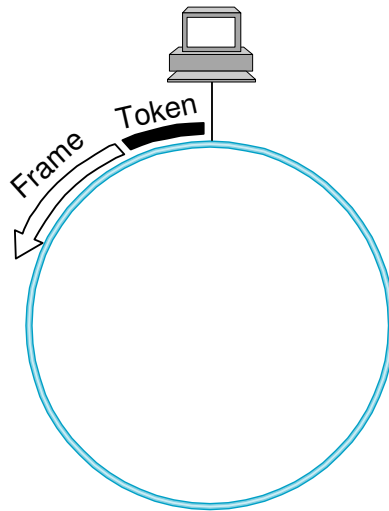
Normal operation: second ring is only used back-up



(b)

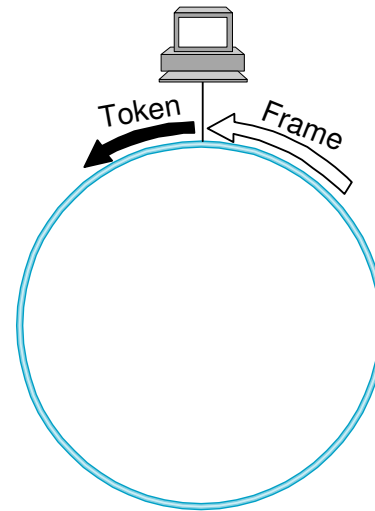
Failure of the primary ring

Token release



(a)

Early release: allows better
BW utilization



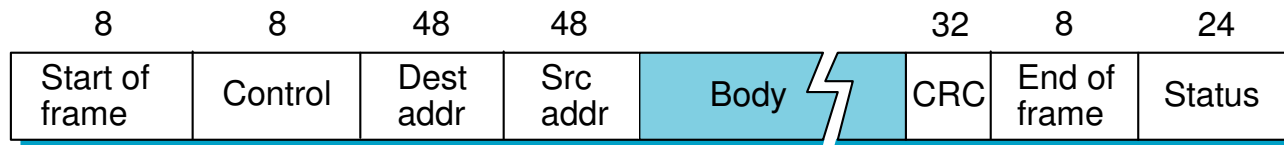
(b)

Delayed release:
originally used

Our discussion here

focuses on FDDI, since 802.5 is pretty much a legacy

Frame format (FDDI)



- “control field”: access control (frame/reservation priority), higher-layer protocol ID ...
- 48-bit MAC address (same as Ethernet)

Timed Token Algorithm (FDDI)

- Token Holding Time (THT)
 - upper limit on how long a station can hold the token
- Token Rotation Time (TRT)
 - how long it takes the token to traverse the ring
 - $TRT \leq \text{ActiveNodes} \times THT + \text{RingLatency}$
- Target Token Rotation Time (TTRT): application requirements
 - agreed-upon upper bound on TRT
 - $TTRT \leq \text{ActiveNodes} \times THT + \text{RingLatency}$

Algorithm (contd.)

- Each node measures TRT between successive tokens
 - if measured-TRT \geq TTRT: token is late so don't send
 - if measured-TRT $<$ TTRT: token is early so OK to send
- Two classes of traffic
 - synchronous: can always send; delay sensitive
 - But total amount of synchronous data that can be sent during one token rotation is bounded from above by TTRT
 - asynchronous: can send only if token is early
- Worst case: $(2 \times \text{TTRT} + \text{RingLatency})$ between seeing token
 - Nodes with asynchronous data consumes one TTRT, and
 - Nodes with synchronous data consumes another TTRT
- Back-to-back $2 \times \text{TTRT}$ rotations not possible?

Token Maintenance (FDDI)

- Lost Token
 - no token when initializing ring
 - bit error corrupts token pattern
 - node holding token crashes

- Monitoring for a Valid Token in the ring
 - should periodically see valid transmissions, whether frame or token
 - maximum gap = ring latency + max frame \leq 2.5ms
 - set timer at 2.5ms and send claim frame if it fires

Maintenance (contd.)

- Generating a Token (and agreeing on TTRT)?
 - execute when join ring or suspect a failure
 - send a *claim frame* that includes the node's TTRT *bid*
 - when receive claim frame, update the bid (i.e., choose the lower TTRT bid) and forward
 - if your claim frame makes it all the way around the ring (when your bid was the lowest), then
 - everyone knows TTRT
 - you insert new token

Outline

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- Token ring (FDDI)
- **Wireless (802.11)**

- Discussion

Wireless LAN (IEEE 802.11?)

- **802.11 (1997)**
 - 2.4-2.485 GHz unlicensed radio spectrum
 - 1Mbps or 2Mbps
 - Physical layer coding: Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS)
- **802.11b (1999)**
 - 2.4-2.485 GHz unlicensed radio spectrum
 - up to 11 Mbps: 1, 2, 5.5, 11M depending on coding scheme
 - DSSS only (at physical layer)
 - all hosts use same chipping code
 - widely deployed, using base stations; ad hoc mode/mesh network at research/prototype stage

Wireless LAN (contd.)

- **802.11a** (1999)
 - 5-6 GHz range
 - up to 54 Mbps
 - Orthogonal Frequency Division Multiplexing (OFDM)
- **802.11g** (2003)
 - 2.4-2.485 GHz range
 - up to 54 Mbps
 - OFDM
- **802.11n** (2009)
 - Multi-input multi-output (MIMO) at physical layer
 - 2.4 GHz or 5 GHz
 - Up to 549 Mbps; ~50meters

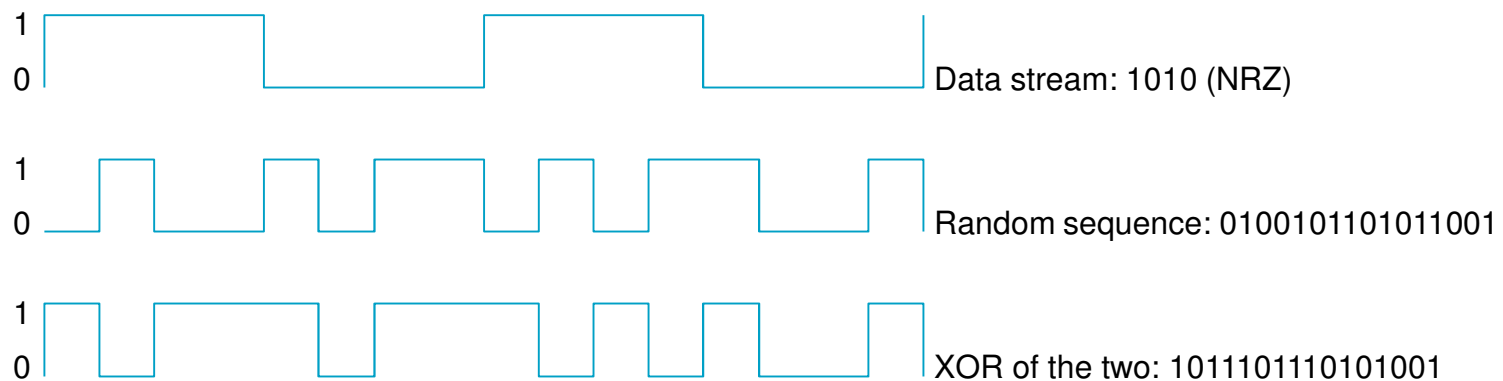
Spread Spectrum

- Idea
 - spread signal over wider frequency band than required
 - originally designed to thwart jamming
- Frequency Hopping
 - transmit over random sequence of frequencies
 - sender and receiver share...
 - pseudorandom number generator
 - seed
 - 802.11 uses 79 x 1MHz-wide frequency bands

Spread Spectrum (cont)

- Direct Sequence

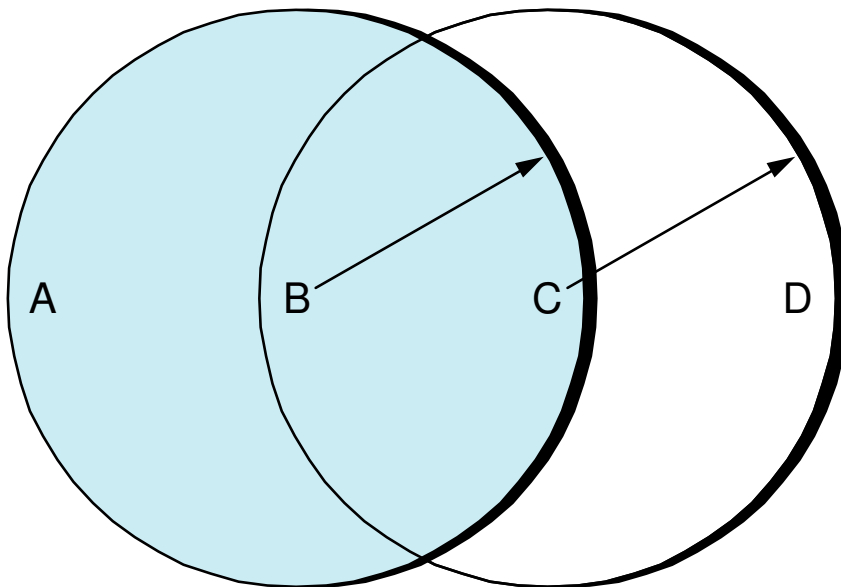
- For each bit, send XOR of that bit and n random bits (also called *chipping sequence*)
 - Random sequence known to both sender and receiver
 - Transmitted values are called n -bit *chipping codes*
- 802.11 defines an 11-bit chipping sequence



Example 4-bit chipping sequence

Collisions Avoidance

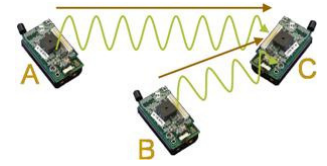
- Similar to Ethernet
- Problem: *hidden* and *exposed* nodes



- *Hidden node problem*: A and C cannot sense and thus are hidden from each other
- *Exposed node problem*: C cannot transmit to D when B is transmitting to A, even though the transmission from C to D may not interfere the transmission from B to A

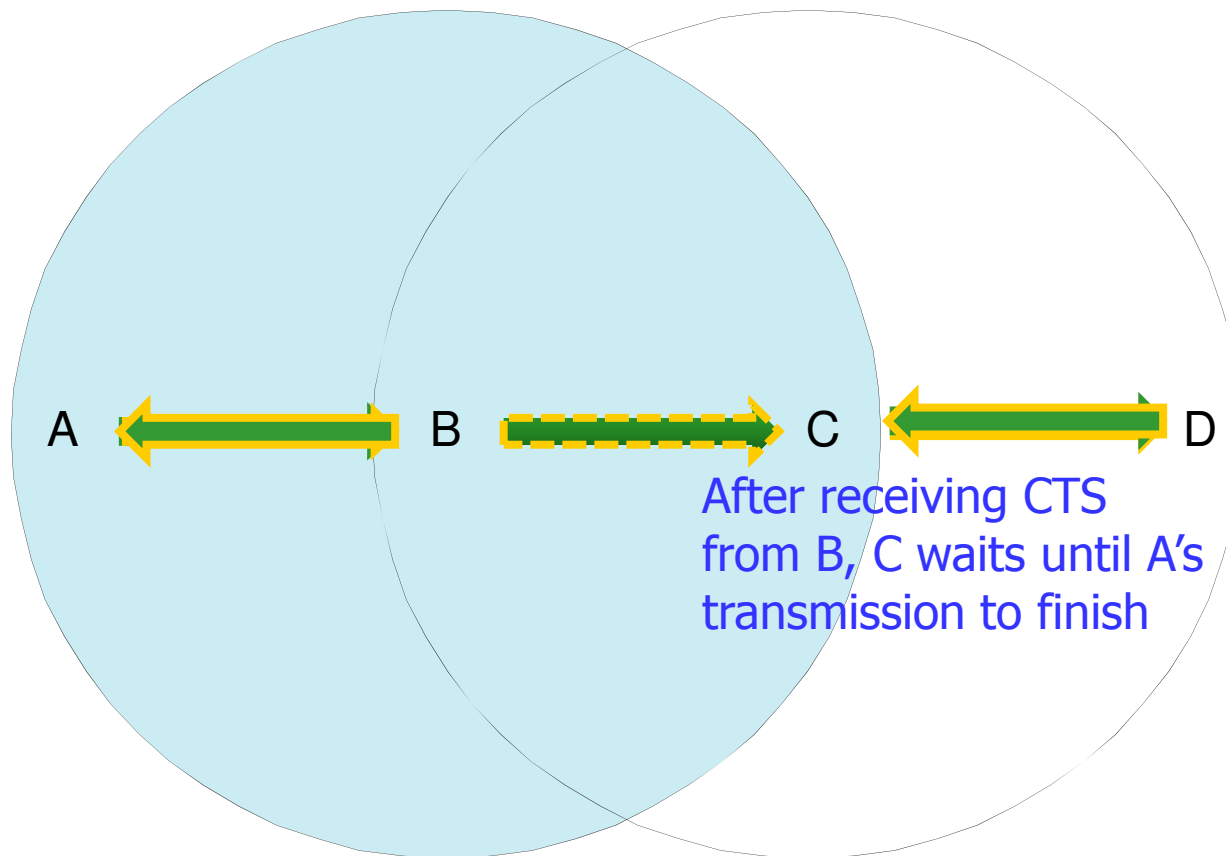
MACAW

- Sender transmits **RequestToSend** (RTS) frame
- Receiver replies with **ClearToSend** (CTS) frame
- Neighbors...
 - see CTS: keep quiet
 - see RTS but not CTS: “ok” to transmit
 - In 802.11: does not transmit if see RTS
- Receiver sends ACK when receives frame
 - neighbors silent until see ACK, or after a timer fires if CTS is lost (and no DATA is sent)
- Collisions: RTS or DATA
 - Unlike in Ethernet, collision detection is hard in wireless networks
 - Becomes known when the sender don't receive CTS or ACK
 - Exponential backoff after collision (as in Ethernet)



RTS-CTS based interference control

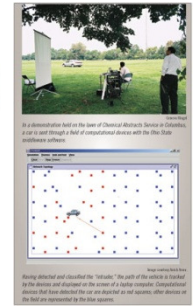
- RTS: request to send CTS: clear to send
- Used in MACAW, S-MAC (WSN), IEEE 802.11 MAC, etc



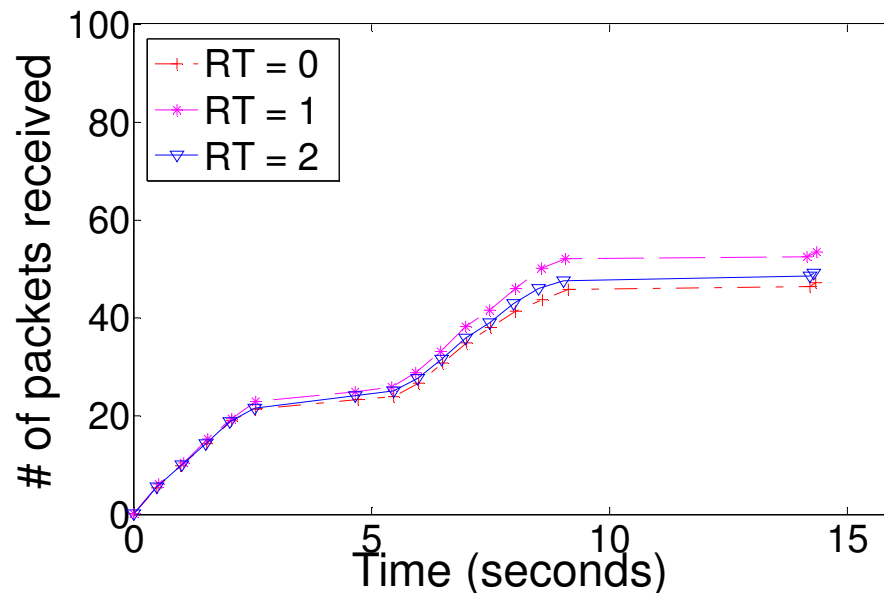
Q: does MACAW eliminate hidden terminal problem?

RTS-CTS may not work well in multi-hop networks

A Line in the Sand:



Metrics	$RT=0$	$RT=1$	$RT=2$
<i>Reliability (%)</i>	51.05	54.74	54.63
<i>Latency (sec)</i>	0.21	0.25	0.26
<i>throughput (pkt/sec)</i>	4.01	4.05	3.63



- RTS-CTS based S-MAC
- Retransmission does not help much, and may even decrease reliability and throughput;

Similar observations when adjusting contention window.

- One major reason: RTS-CTS based approach assumes *equal* comm. & interference ranges

Wireless interference model

- *Predicts* whether a set of concurrent transmissions may interfere with one another
- Ratio-K model (protocol model)
 - Interference range = $K \times$ communication range
 - RTS-CTS based approach implicitly assumed ratio-1 model
 - (+) defined local, pair-wise interference relation
 - (+) good for distributed protocol design
 - (-) approximate model; may lead to bad performance

Interference model (contd.)

- SINR model (physical model)
 - A transmission is successful if the signal-to-interference-plus-noise ratio (SINR) is above a certain threshold
 - (+) high fidelity: based on communication theory
 - (-) interference relation is non-local: explicitly depends on all concurrent transmitters
 - (-) not suitable for distributed protocol design
- Inconsistent observations on the performance of ratio-K- and SINR-based scheduling in literature

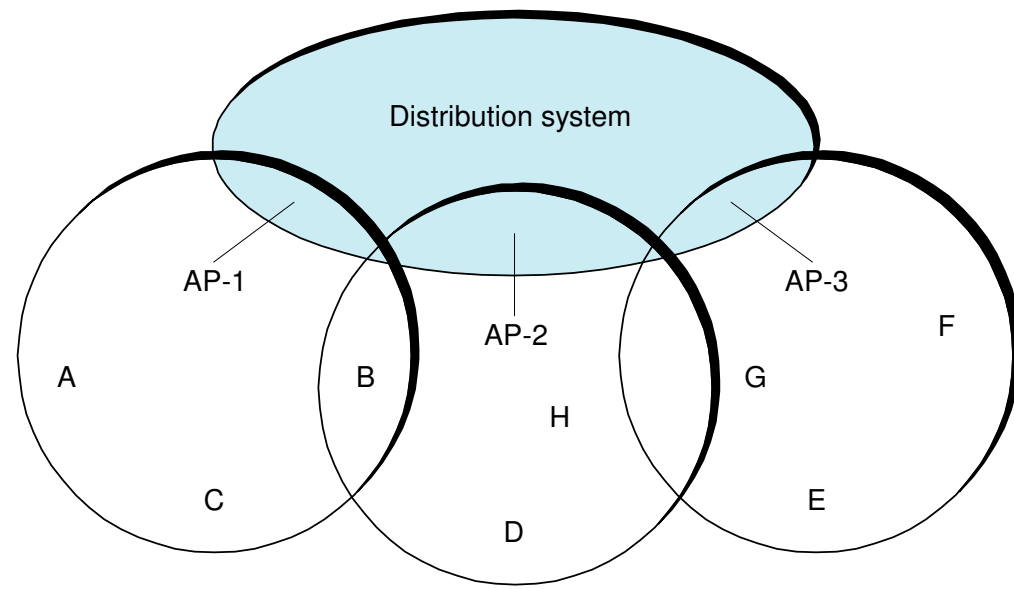
Questions

- Why can ratio-K-based scheduling outperform SINR-based scheduling in network throughput?
- Is it possible to instantiate the ratio-K model so that ratio-K based scheduling consistently achieve a performance close to what is enabled by SINR-based scheduling?

X. Che, X. Liu, X. Ju, H. Zhang, [Adaptive Instantiation of the Protocol Interference Model in Mission-Critical Wireless Networks](#), *7th IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)*, 2010

Supporting Mobility

- Case 1: *ad hoc* networking
- Case 2: *access points (AP)*
 - tethered
 - each mobile node associates with an AP

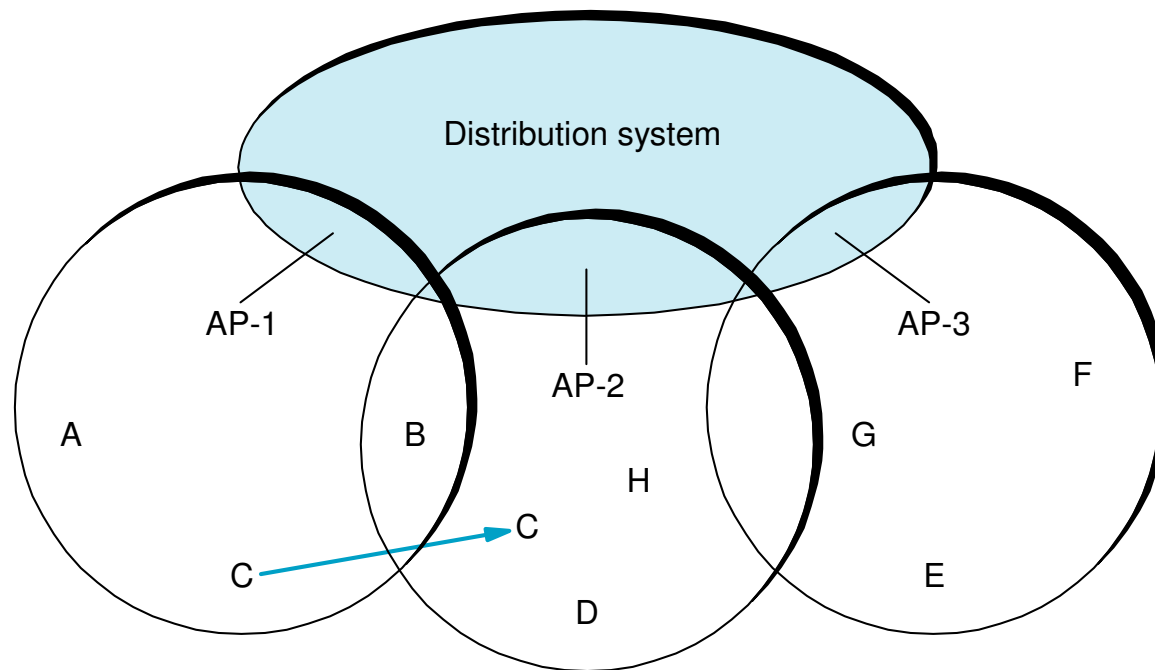


How APs communicate with one another is not specified in 802.11.

Mobility (contd.)

- Active scanning (selecting an AP): when join or move
 - node sends **P**robe frame
 - all AP's w/in reach reply with **P**robeResponse frame
 - node selects one AP; sends it **A**ssociateRequest frame
 - AP replies with **A**ssociationResponse frame
 - new AP informs old AP via tethered network
- Passive scanning: AP periodically sends **B**eacon frame

Q: mobility example



What actions will be taken when C moves as shown in the figure?

Other wireless standards/ technologies

- 802.11e (2005)
 - QoS support in both ad-hoc and AP modes

- 802.11s
 - Mesh networking
 - Not yet approved

Other wireless standards (contd.)

- 802.11p
 - Draft amendment to 802.11 to support ITS (Intelligent Transportation Systems) applications: DSRC (Dedicated Short Range Communication) for vehicle-to-vehicle and vehicle-to-roadside communication
 - Run in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz)
- 802.16 (started in 2001)
 - WirelessMAN, WiMAX
 - Frequency bands not agreed upon yet
 - Up to 75Mbps
- 802.15.4
 - Sensor networks
 - 250Kbps
- Etc.

Outline

- Bus (Ethernet)
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- Wireless (802.11)

- Discussion

Study on low power wireless link properties

- Interference free
 - Jerry Zhao, and Ramesh Govindan, *Understanding Packet Delivery Performance In Dense Wireless Sensor Networks*, ACM SenSys'03
 - Marco Zuniga, Bhaskar Krishnamachari, *Analyzing the Transitional Region in Low Power Wireless Links*, IEEE SECON' 04
- Interference
 - Dongjin Son, Bhaskar Krishnamachari, John Heidemann, *Experimental Analysis of Concurrent Packet Transmissions in Low-Power Wireless Networks*, ACM Sensys' 06
 - Hongwei Zhang, Anish Arora, and Prasun Sinha, *Learn on the Fly: Data-driven Link Estimation and Routing in Sensor Network Backbones*, IEEE INFOCOM'06

Channel access control in wireless networks

- Interference range > communication range
 - Gang Zhou, Tian He, John Stankovic, and Tarek Abdelzaher, *RID: Radio Interference Detection in Wireless Sensor Networks*, IEEE INFOCOM'05
- Energy efficiency
 - Wei Ye, John Heidemann, and Deborah Estrin, *An Energy-Efficient MAC Protocol for Wireless Sensor Networks*, IEEE INFOCOM'02
 - Joseph Polastre, Jason Hill, and David Culler, *Versatile Low Power Media Access for Wireless Sensor Networks*, ACM SenSys'04
 - Hui Cao, Ken Parker, and Anish Arora, *O-MAC: A Receiver Centric Power Management Protocol*, IEEE ICNP'06

Further reading

- Ethernet
 - R. Metcalf and D. Boggs, *Ethernet: Distributed Packet Switching for Local Computer Networks*, Communications of ACM, 19(7):395-403, July 1976
 - D. Boggs, J. Mogul, and C. Kent, *Measured Capacity of an Ethernet*, ACM SIGCOMM'88
- Integrating high-speed network adaptors with system software
 - P. Druschel, M. Abbot, M. Pagels, and L.L. Peterson, *Network Subsystem Design*, IEEE Networks, 7(4):8-17, July 1993

Summary

- Point-to-point links
 - Encoding
 - Framing
 - Error detection
 - Reliable transmission
- Shared access networks
 - Channel access control

Assignment – Chapter 2

- Lab#1 (mandatory)
 - Write a TinyOS program that let a sender continuously transmit packets (with increasing packet sequence number) to a receiver; run the program using TOSSIM
 - Implement the sliding window algorithm in TinyOS, and test it using TOSSIM

- Exercise#1
 - Exercises 1, 5, 18, 26, and 33
 - Exercise 43
 - Hint: 1) the relation between propagation delay, transmission rate, and minimum packet size in CSMA/CD networks; 2) too large a minimum packet size may require padding and thus bandwidth wastage

- Quiz#1