Internet Protocols EBU5403
The Data Link Layer Part 2
D1

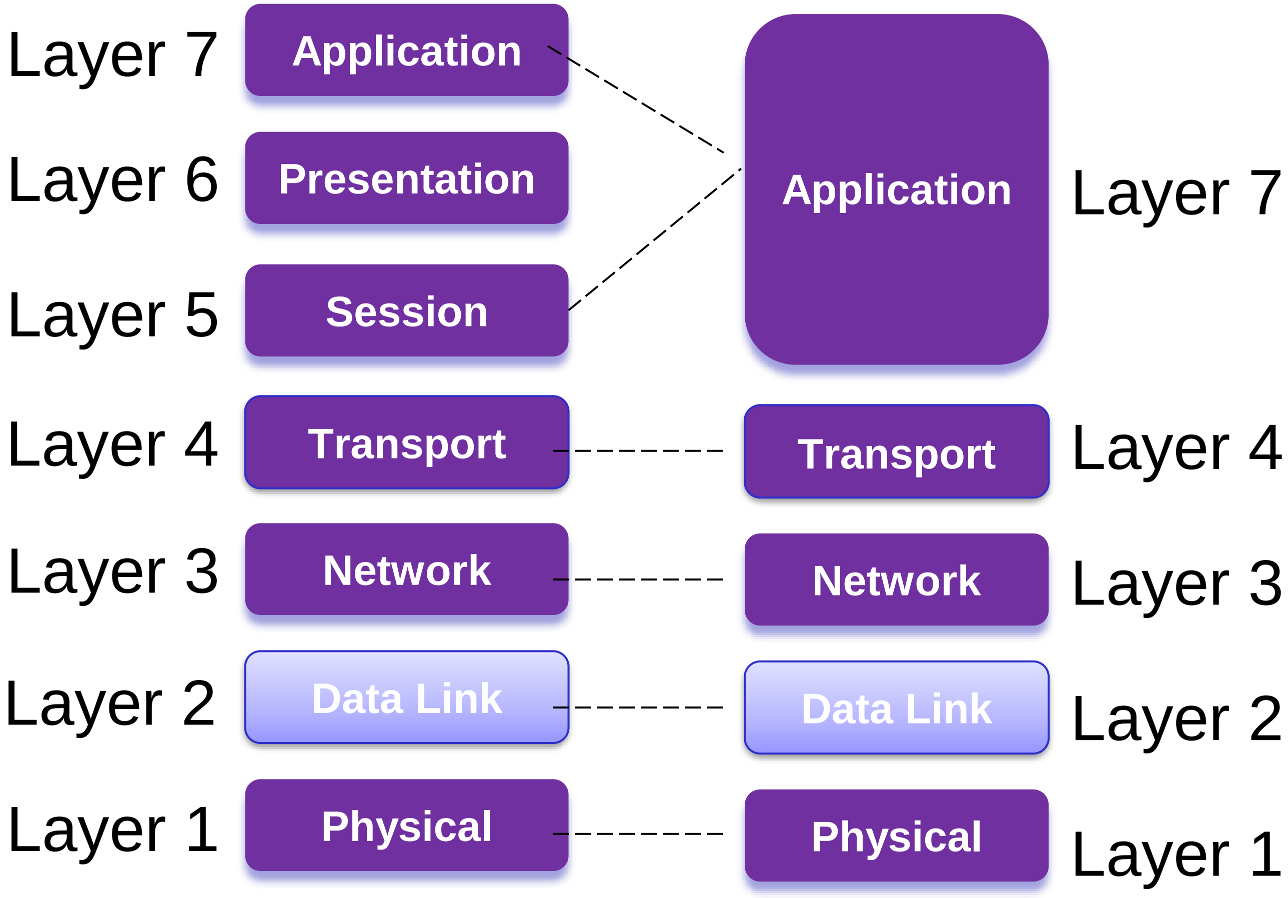
Michael Chai (michael.chai@qmul.ac.uk)
Richard Clegg (r.clegg@qmul.ac.uk)
Cunhua Pan (c.pan@qmul.ac.uk)

<table>
<tr><td></td><td>Part 1</td><td>Part 2</td><td>Part 3</td><td>Part 4</td></tr>
<tr><td>Ecommerce + Telecoms 1</td><td colspan="2">Richard Clegg</td><td colspan="2" rowspan="2">Cunhua Pan</td></tr>
<tr><td>Telecoms 2</td><td colspan="2">Michael Chai</td></tr>
</table>

Structure of course

- Part A
  - Introduction to IP Networks
  - The Transport layer (part 1)
- Part B
  - The Transport layer (part II)
  - The Network layer (part I)
  - Class test (open book exam in class)
- Part C
  - The Network layer (part II)
  - The Data link layer (part I)
- Part D
  - The Data link layer (part II)
  - Security and network management

Data Link Layer



Link layer, LANs: outline

6.1 introduction, services

6.2 error detection, correction

6.3 multiple access protocols

6.4 LANs

- addressing, ARP
- Ethernet
- WiFi
- switches
- VLANS

6.5 link virtualization: MPLS

6.6 a day in the life of a web request

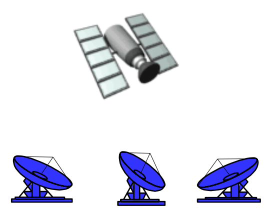
Multiple access links, protocols

two types of "links":

- point-to-point (connect two computers only)
- *broadcast (shared wire or medium)*
  - old-fashioned Ethernet
  - upstream HFC (hybrid fibre coaxial)
  - 802.11 wireless LAN
- Problems: "collision" – 2 or more transmissions at once
- Solution: Multiple access protocol – "share" medium

shared wire (e.g., cabled Ethernet)

shared RF (radio frequency) (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustic)

An ideal multiple access protocol

given: broadcast channel of rate R bps

Desired qualities:

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. Simple

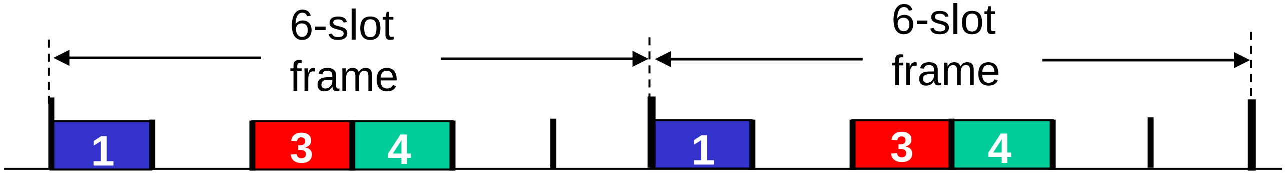
Options:

Partition channel, random access, “take turns”

Channel partitioning MAC protocols: TDMA

TDMA: time division multiple access

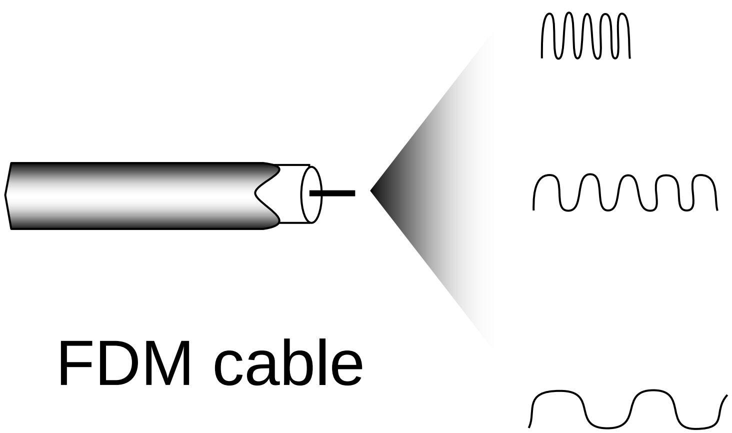
- access to channel in "rounds"
- each station gets fixed length slot (length = packet transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packets to send, slots 2,5,6 idle

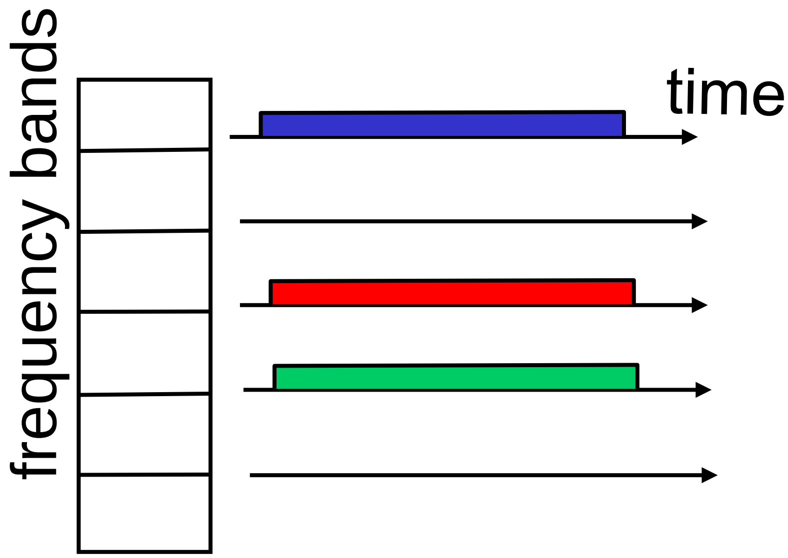


Channel partitioning MAC protocols: FDMA

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 packet to send, frequency bands 2,5,6 idle





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 (not an acronym, means "hello" in Hawaii)
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA
    - Carrier Sense Multiple Access (collision detection/collision avoidance)

Slotted ALOHA

assumptions:

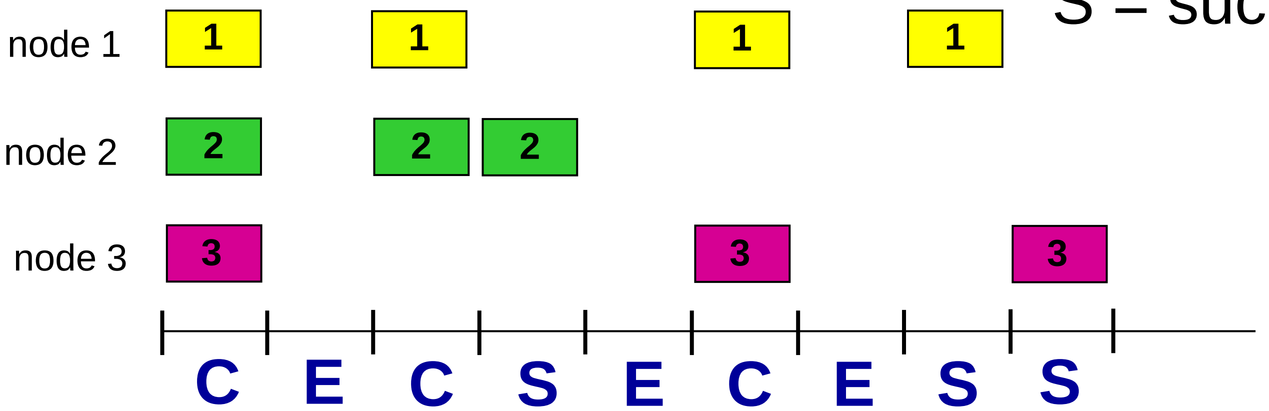
- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

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

C = collision
E = empty
S = successfully sent



Pros:

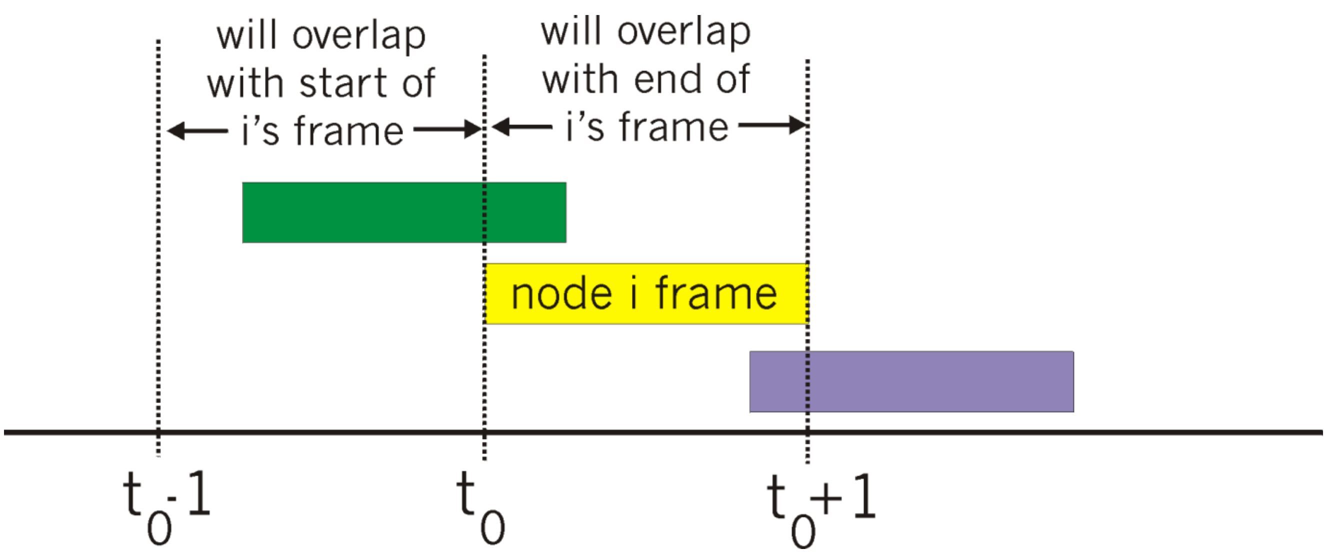
- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons:

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

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 $[t_0-1, t_0+1]$
- Doesn't need unified clock but half as efficient as slotted.



CSMA (carrier sense multiple access)

CSMA: listen before transmit:

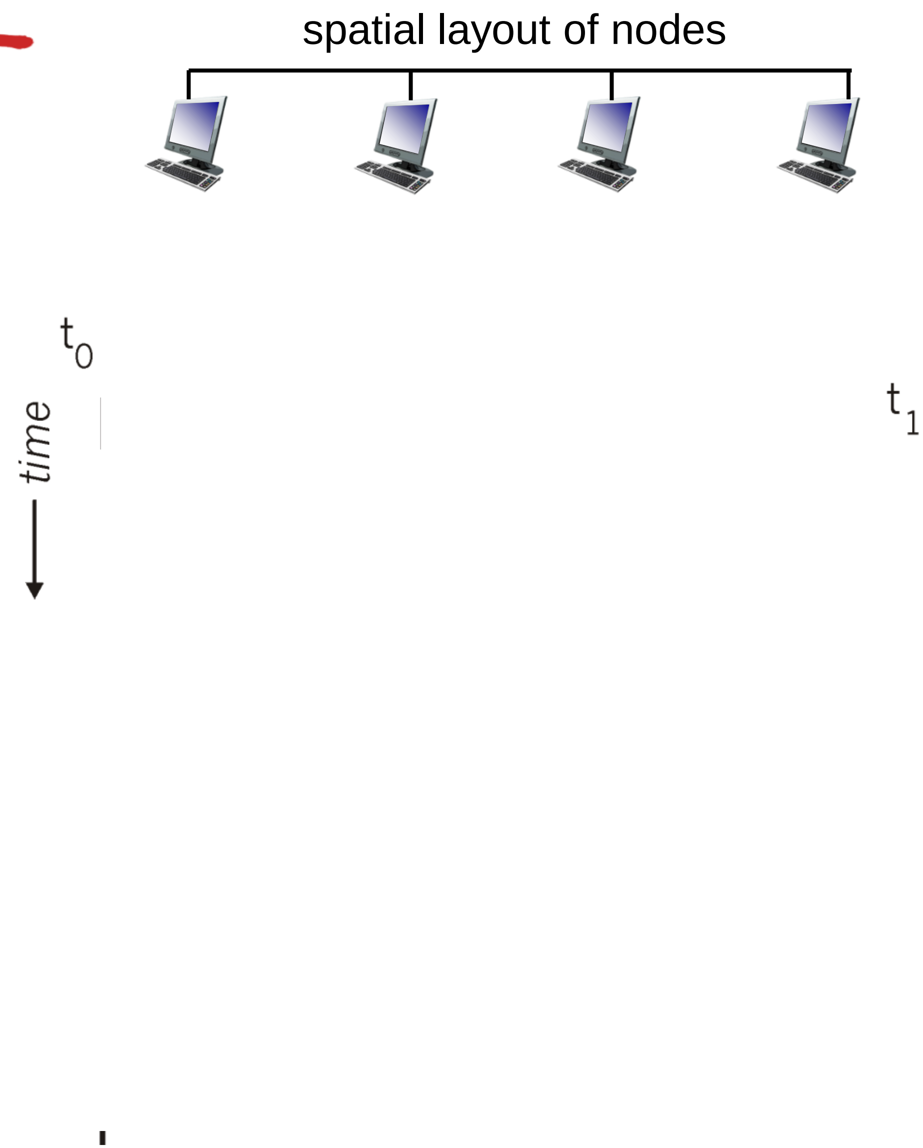
if channel sensed idle: transmit entire frame

- if channel sensed busy, defer transmission

- human analogy: don't interrupt others!

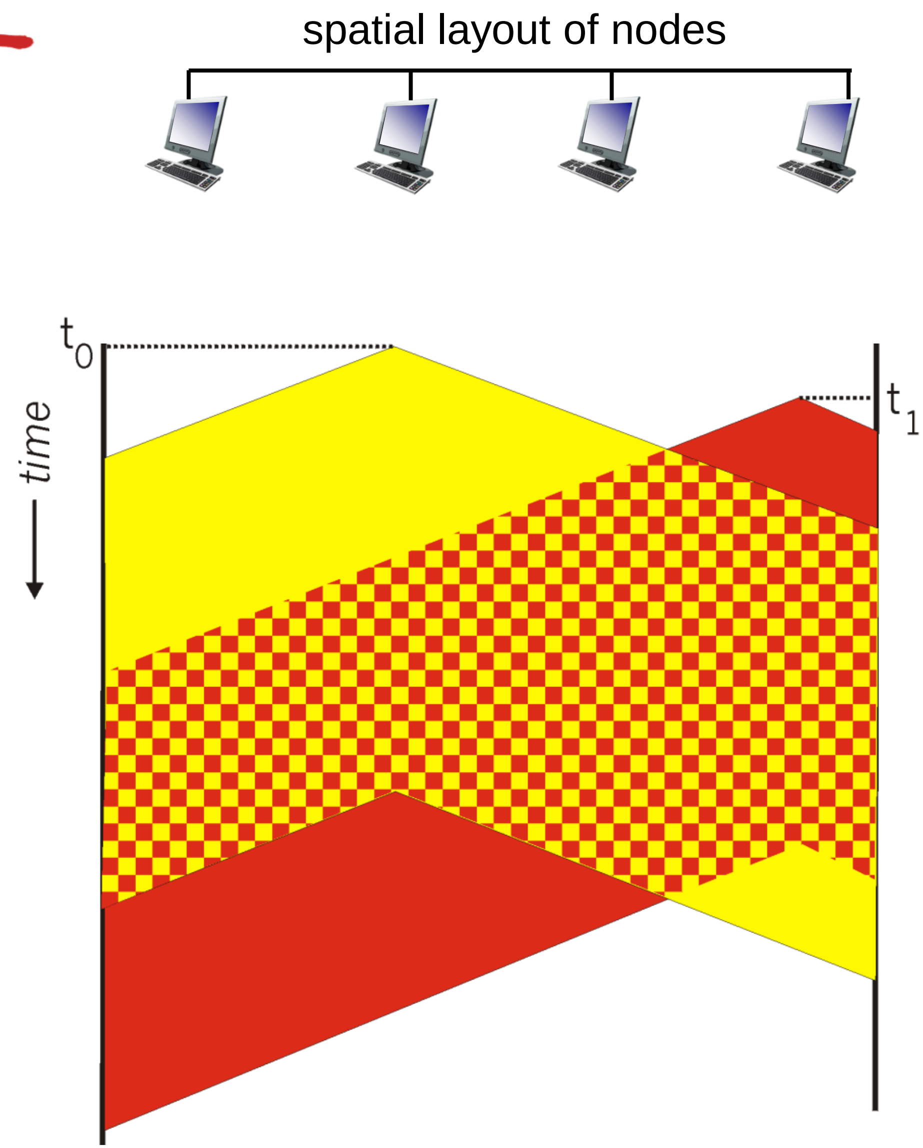
CSMA collisions

- collisions *can* still occur: propagation delay means two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted
  - distance & propagation delay play role in in determining collision probability



CSMA collisions

- collisions *can* still occur: propagation delay means two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted
  - distance & propagation delay play role in in determining collision probability

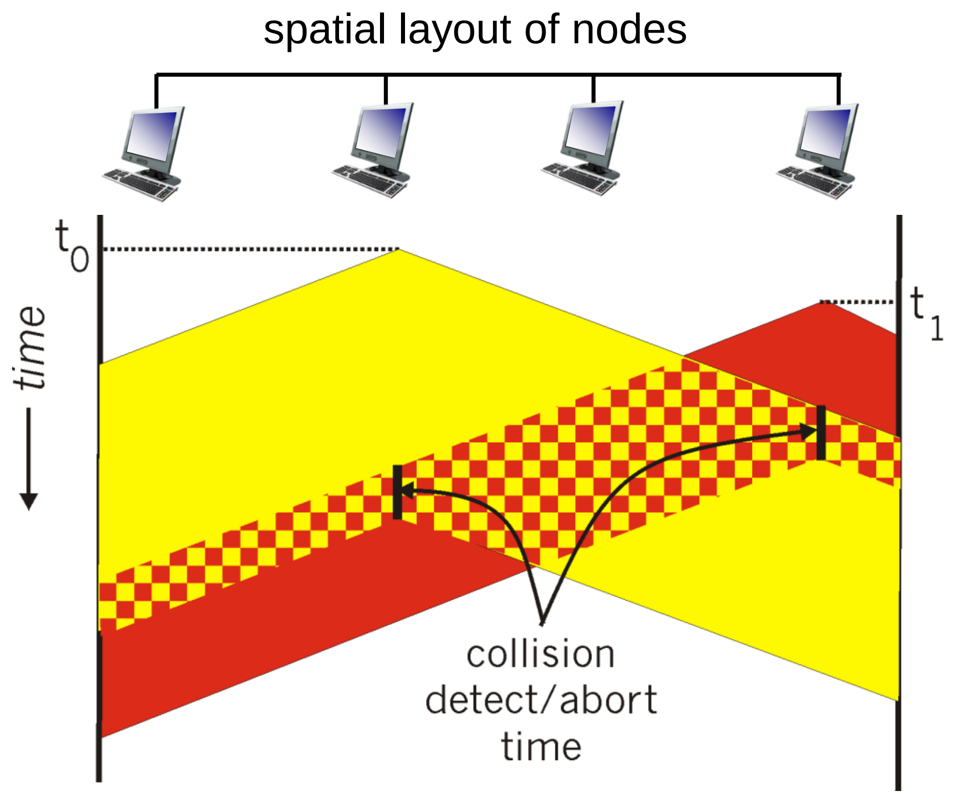


CSMA/CD (collision detection)

CSMA/CD: carrier sensing, deferral (backs off transmission) 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: polite talk where people wait for each other

CSMA/CD (collision detection)



Ethernet CSMA/CD algorithm

1. Network Interface Card (NIC)receives datagram from network layer, creates frame

2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.

3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !

Ethernet CSMA/CD algorithm

4. If NIC detects another transmission while transmitting, aborts and sends jam signal

5. After aborting, NIC enters *binary (exponential) backoff:*
   - after m th collision, NIC chooses K at random from $\{0,1,2, \ldots, 2^m-1\}$. NIC waits K·512 bit times, returns to Step 2
   - longer backoff interval with more collisions

Test your understanding

With Ethernet, if a host experiences two successive collisions it may next backoff for …

A. 0 or 1 time slots

B. 0, 1, 2 or 3 time slots

C. 0, 1, 2, 3, 4 or 5 time slots

D. 0, 1, 2, 3, 4, 5, 6 or 7 time slots

Test your understanding

With Ethernet, if a host experiences two successive collisions it may next backoff for

…

A. 0 or 1 time slots

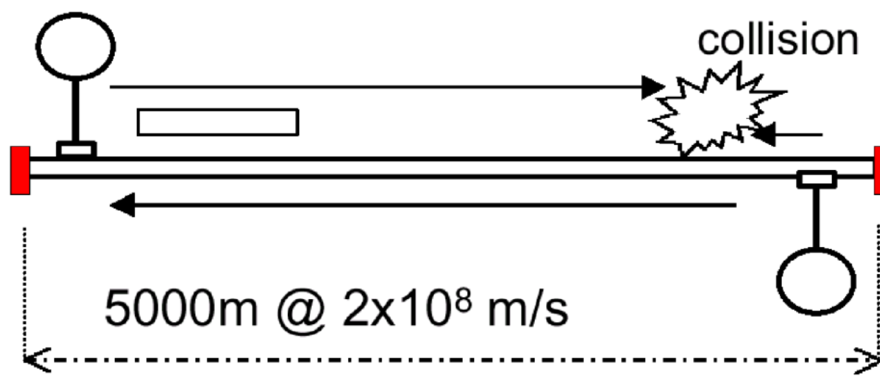
B. 0, 1, 2 or 3 time slots

C. 0, 1, 2, 3, 4 or 5 time slots

D. 0, 1, 2, 3, 4, 5, 6 or 7 time slots

CSMA/CD: Frame size

- Collision Detection
- Collision Window
  - Related to end-to-end propagation delay
- Minimum packet size must be greater than collision window
  - For 5000m (5km) bus @ 10 Mbits/sec,
  - RTT = 2x5000m/2x10^8 m/s = 0.00005s
    min frame size = 0.00005s x 10,000,000 bits/sec
    = (500 bits) ~64 octets



2x10^8 m/s = 2/3 speed of light = speed of signal in copper wire

Test your understanding

With CSMA/CD, a minimum frame size must be imposed to ensure …..

A. The transmitting station is still transmitting long enough for a corrupted signal to be detected
B. The frame overhead is limited
C. Access to the shared medium is fair
D. Stations do not keep hold of the shared medium for too long

Test your understanding

With CSMA/CD, a minimum frame size must be imposed to ensure …..

A. The transmitting station is still transmitting long enough for a corrupted signal to be detected

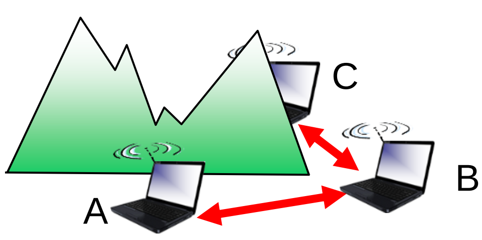
B. The frame overhead is limited

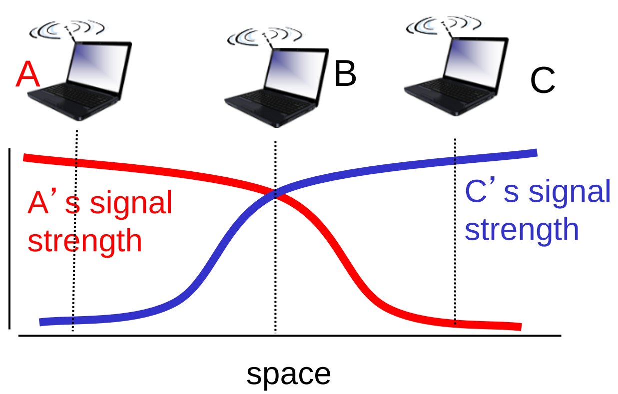
C. Access to the shared medium is fair

D. Stations do not keep hold of the shared medium for too long

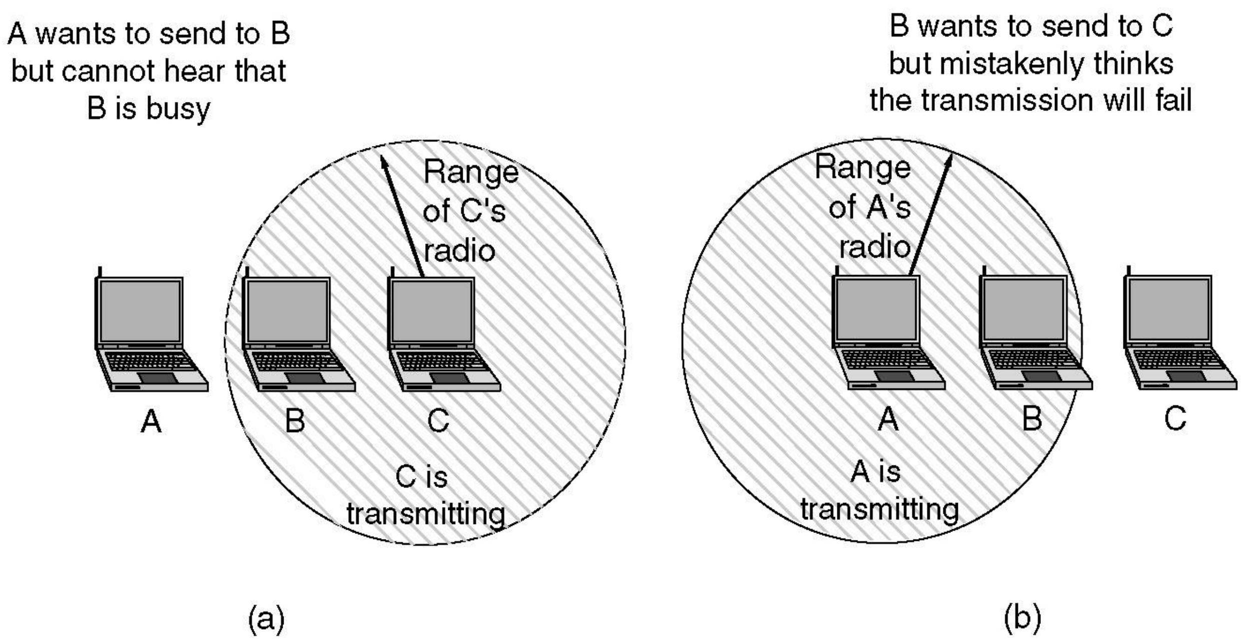
CSMA/CA (Collision Avoidance)

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by other node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





Hidden and Exposed Station problems



(a) The hidden station problem.

A and C are hidden from each other

(b) The exposed station problem.

B is exposed to transmission from A

IEEE 802.11 MAC Protocol: CSMA/CA

802.11 sender

1 if sense channel idle for **DIFS** then

transmit entire frame (no CD)

2 if sense channel busy then

start random backoff time

timer counts down while channel idle

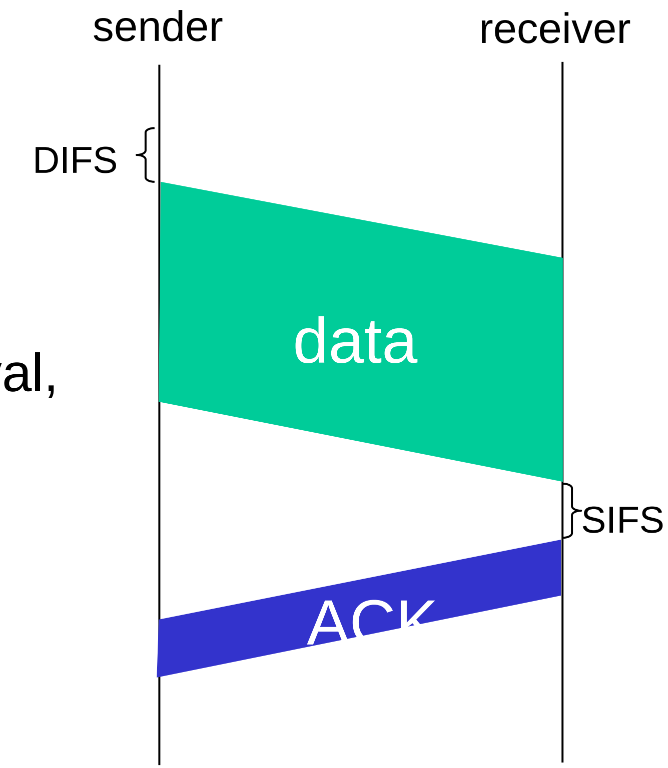
transmit when timer expires

if no ACK, increase random backoff interval, repeat 2

802.11 receiver

- if frame received OK

return ACK after **SIFS** (ACK needed due to hidden terminal problem)



DCF = Distributed Coordination Function

DIFS = DCF InterFrame Space

SIFS = Short InterFrame Space

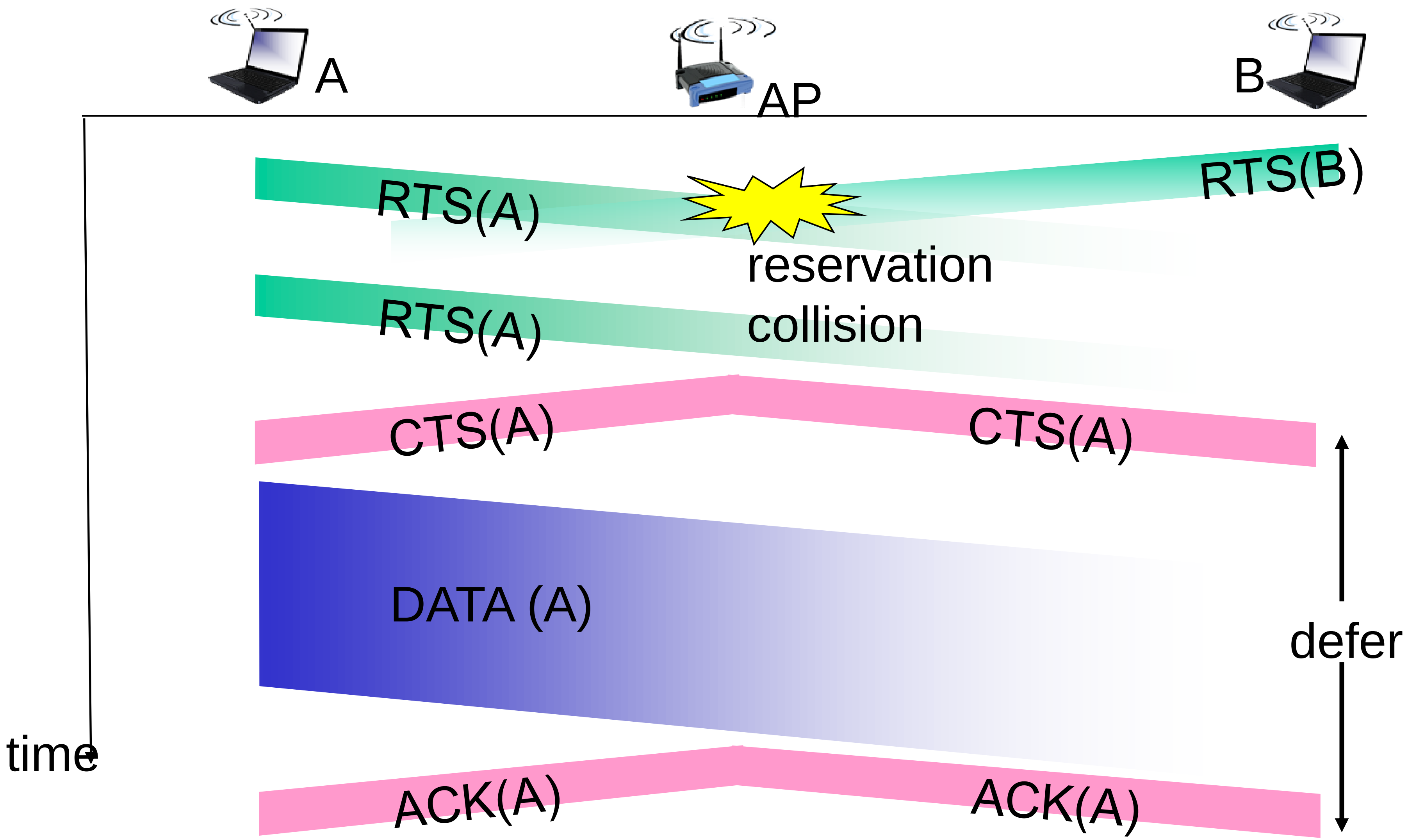
Avoiding collisions (more)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

- sender first transmits *small* request-to-send (RTS) packets to base station (BS) using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts **clear-to-send** CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



What have we learned?

- *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