

Chapter 6

The Link Layer

and LANs

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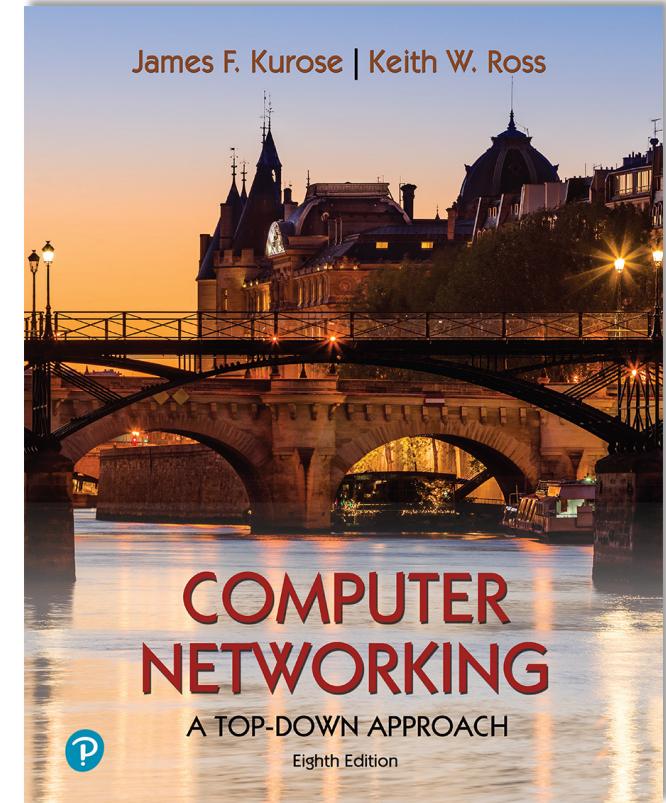
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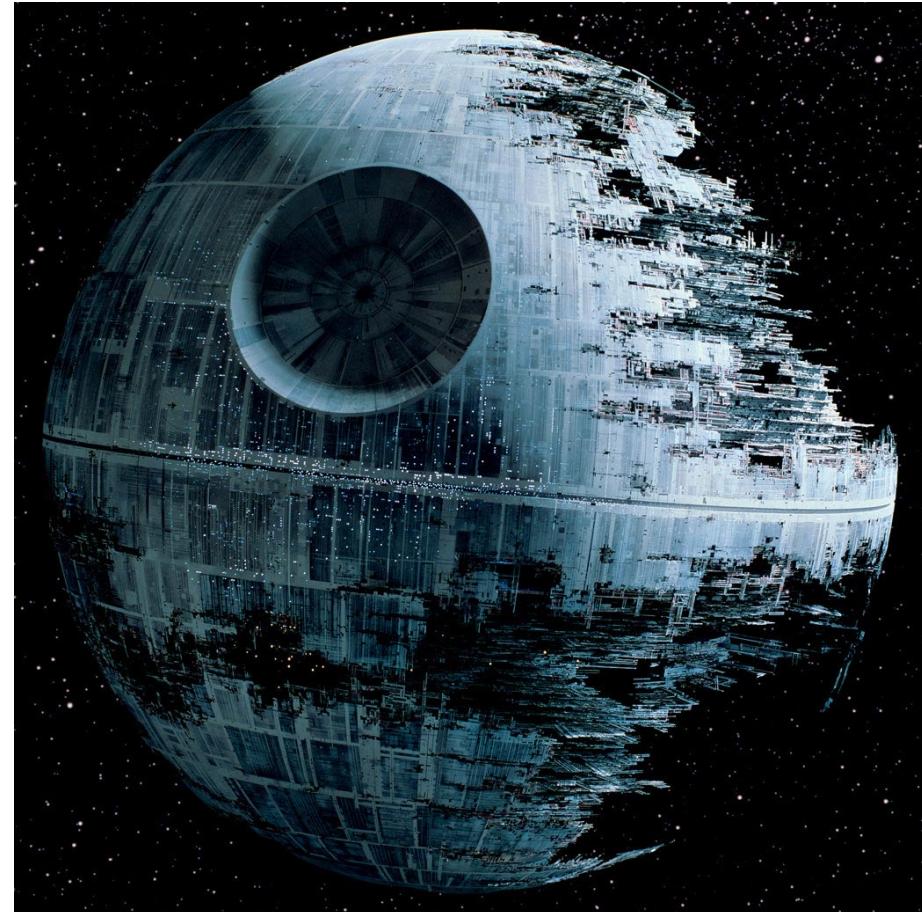
*Computer Networking: A
Top-Down Approach*
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Objective

Build a *system* to transfer data from one node to a physically connected node

We are not quite done yet ...

1. Protocol specification
2. Large local networks
3. Segregation of stakeholders
4. Wireless local networks



Link layer: roadmap

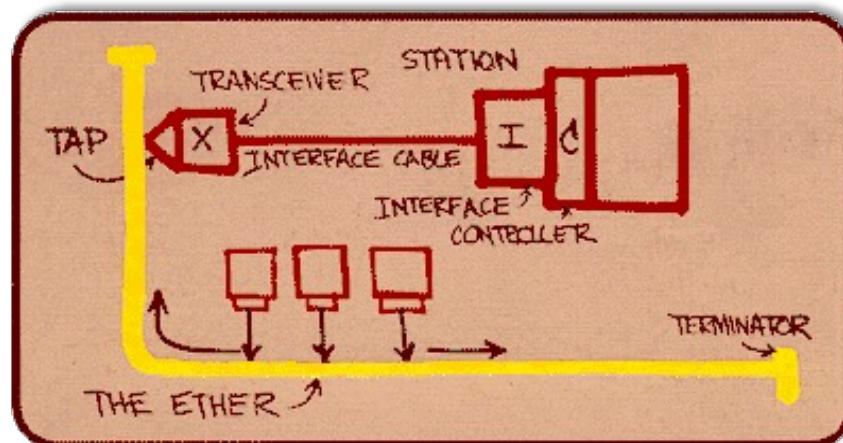
- introduction
- addressing
- error detection, correction
- multiple access protocols
- LANs
 - **Ethernet**
 - Switches
 - VLANs
 - WiFi



Ethernet

“dominant” wired LAN technology:

- first widely used LAN technology
- simple, cheap
- kept up with speed race: 10 Mbps – 400 Gbps
- single chip, multiple speeds (e.g., Broadcom BCM5761)

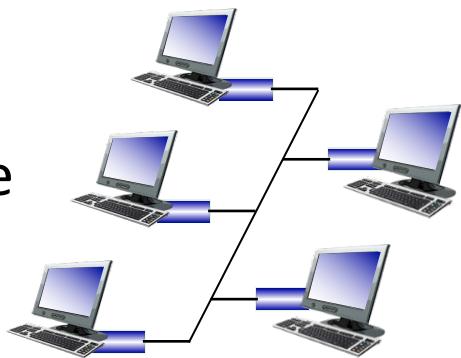


*Metcalfe's Ethernet
sketch*

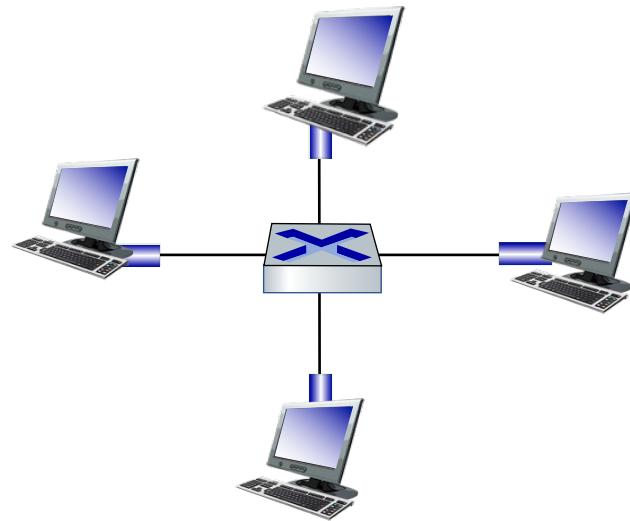
Ethernet: physical topology

- **bus:** popular through mid 90s
 - all nodes in same collision domain (can collide with each other)
- **switched:** prevails today
 - active link-layer 2 *switch* in center
 - each “spoke” runs a (separate) Ethernet protocol (nodes do not collide with each other)

bus: coaxial cable



switched



Ethernet frame structure

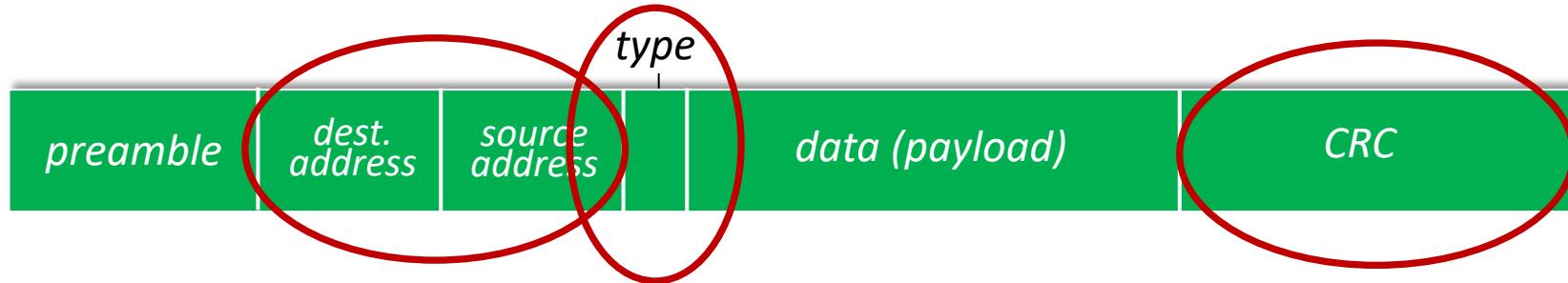
sending interface encapsulates IP datagram (or other network layer protocol packet) in **Ethernet frame**



preamble:

- used to synchronize receiver, sender clock rates
- 7 bytes of 10101010 followed by one byte of 10101011

Ethernet frame structure (more)



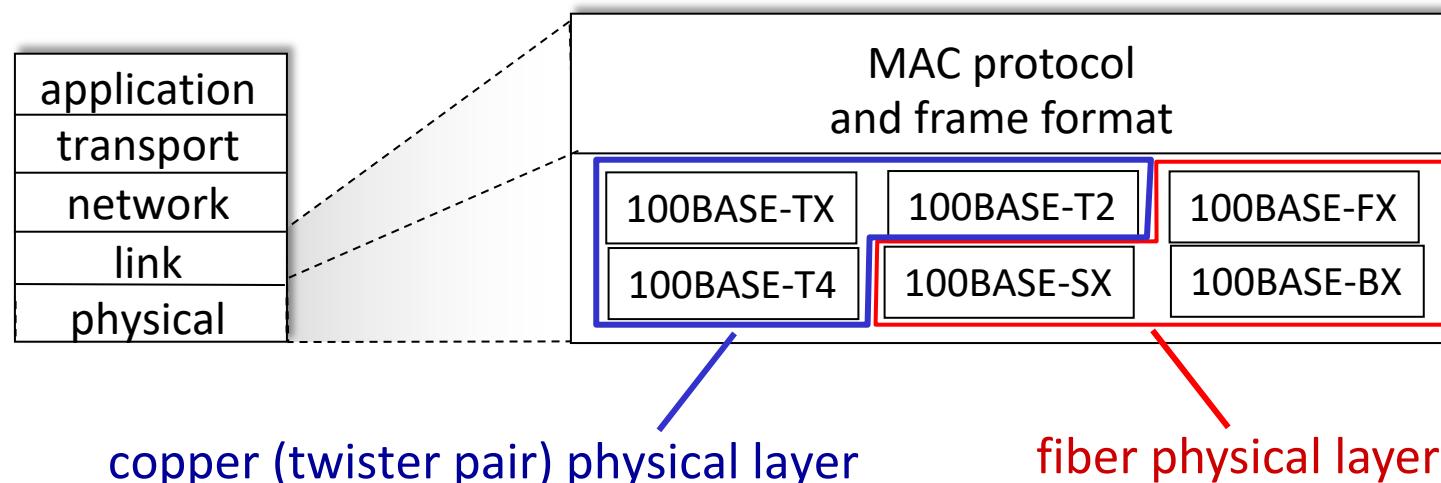
- **addresses**: 6 byte source, destination MAC addresses
 - if adapter receives frame with matching destination address, or with broadcast address (e.g., ARP packet), it passes data in frame to network layer protocol
 - otherwise, adapter discards frame
- **type**: indicates higher layer protocol
 - mostly IP but others possible, e.g., Novell IPX, AppleTalk
 - used to demultiplex up at receiver
- **CRC**: cyclic redundancy check at receiver
 - error detected: frame is dropped

Ethernet: unreliable, connectionless

- **connectionless:** no handshaking between sending and receiving NICs
- **unreliable:** receiving NIC doesn't send ACKs or NAKs to sending NIC
 - data in dropped frames recovered only if initial sender uses higher layer rdt (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol: unslotted **CSMA/CD with binary backoff**

802.3 Ethernet standards: link & physical layers

- *many* different Ethernet standards
 - common MAC protocol and frame format
 - different speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps, 40 Gbps
 - different physical layer media: fiber, cable



Link layer: roadmap

- introduction
- addressing
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- multiple access protocols
- LANs
 - Ethernet
 - **Switches**
 - VLANs
 - WiFi

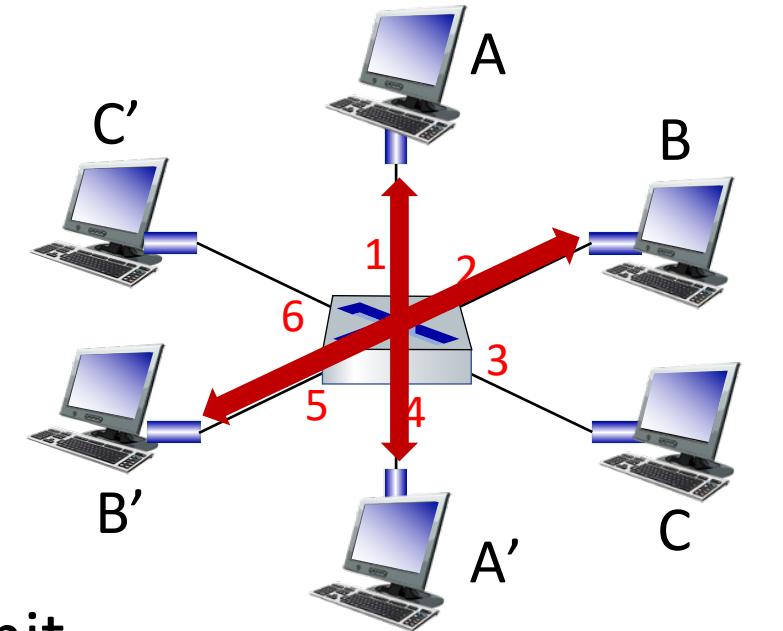


Ethernet switch

- Switch is a **link-layer** device: takes an *active* role
 - store, forward Ethernet frames
 - examine incoming frame's MAC address, *selectively* forward frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- **transparent**: hosts *unaware* of presence of switches
- **plug-and-play, self-learning**
 - switches do not need to be configured

Switch: multiple simultaneous transmissions

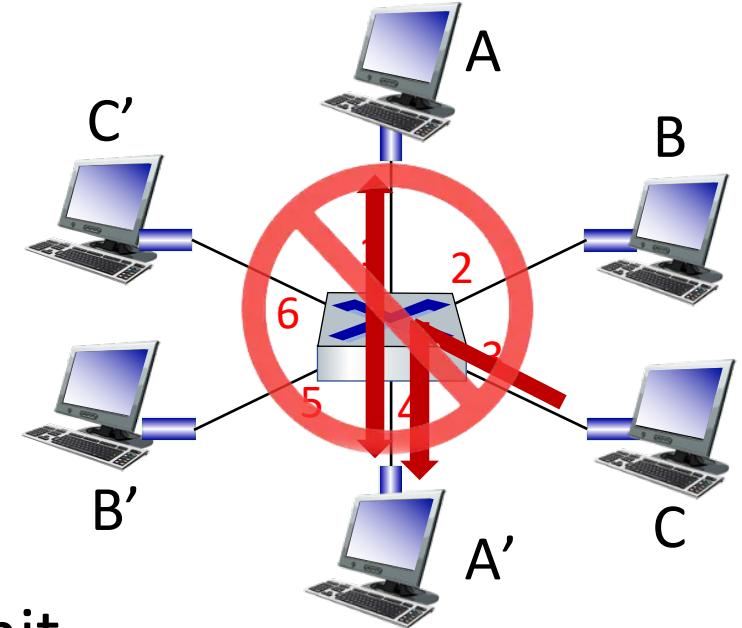
- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
 - no collisions; full duplex
 - each link is its own collision domain
- **switching:** A-to-A' and B-to-B' can transmit simultaneously, without collisions



switch with six
interfaces (1,2,3,4,5,6)

Switch: multiple simultaneous transmissions

- hosts have dedicated, direct connection to switch
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- Ethernet protocol used on *each* incoming link, so:
 - no collisions; full duplex
 - each link is its own collision domain
- **switching:** A-to-A' and B-to-B' can transmit simultaneously, without collisions
 - but A-to-A' and C to A' can *not* happen simultaneously



switch with six
interfaces (1,2,3,4,5,6)

Switch forwarding table

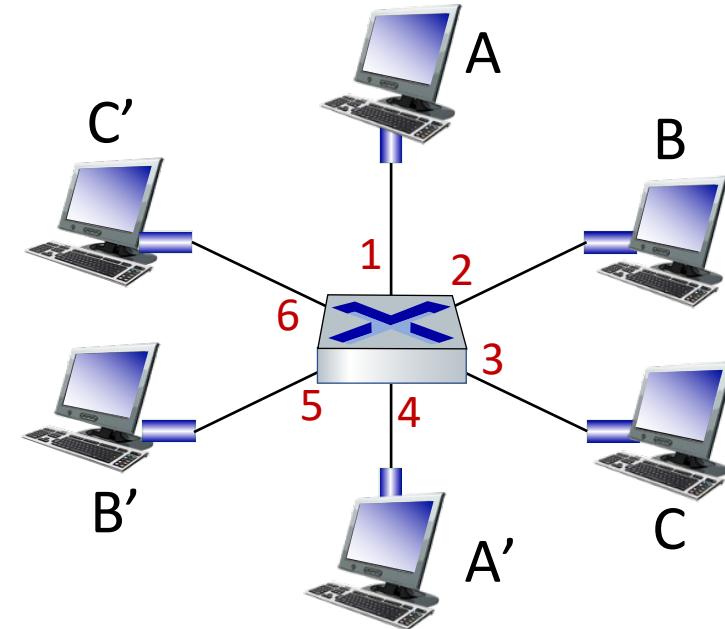
Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

A: each switch has a **switch table**, each entry:

- (MAC address of host, interface to reach host, time stamp)
- looks like a routing table!

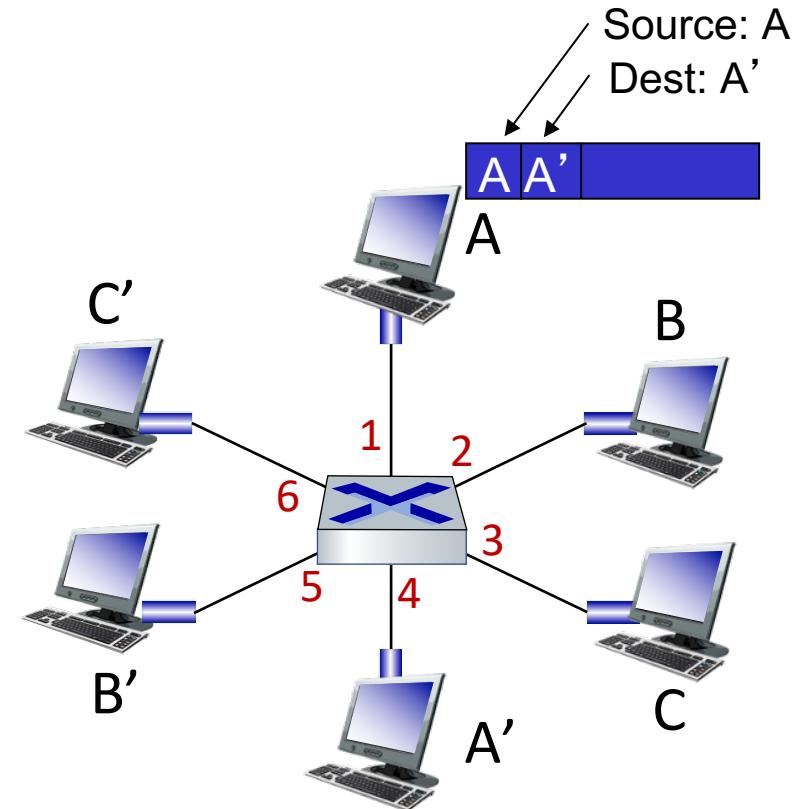
Q: how are entries created, maintained in switch table?

- something like a routing protocol?



Switch: self-learning

- switch *learns* which hosts can be reached through which interfaces
 - when frame received, switch “learns” location of sender: incoming LAN segment
 - records sender/location pair in switch table



MAC addr	interface	TTL
A	1	60

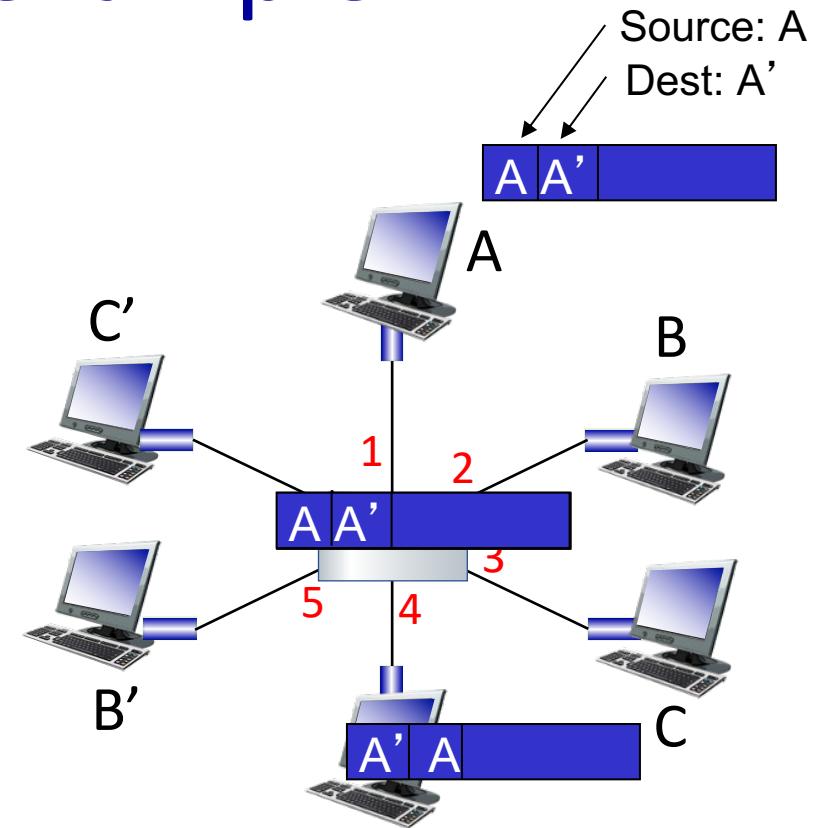
Switch: frame filtering/forwarding

when frame received at switch:

1. record incoming link, MAC address of sending host
2. index switch table using MAC destination address
3. if entry found for destination
 - then {
 - if destination on segment from which frame arrived
 - then drop frame
 - else forward frame on interface indicated by entry
 - }
- else flood /* forward on all interfaces except arriving interface */

Self-learning, forwarding: example

- frame destination, A', location unknown: **flood**
- destination A location known: **selectively send on just one link**

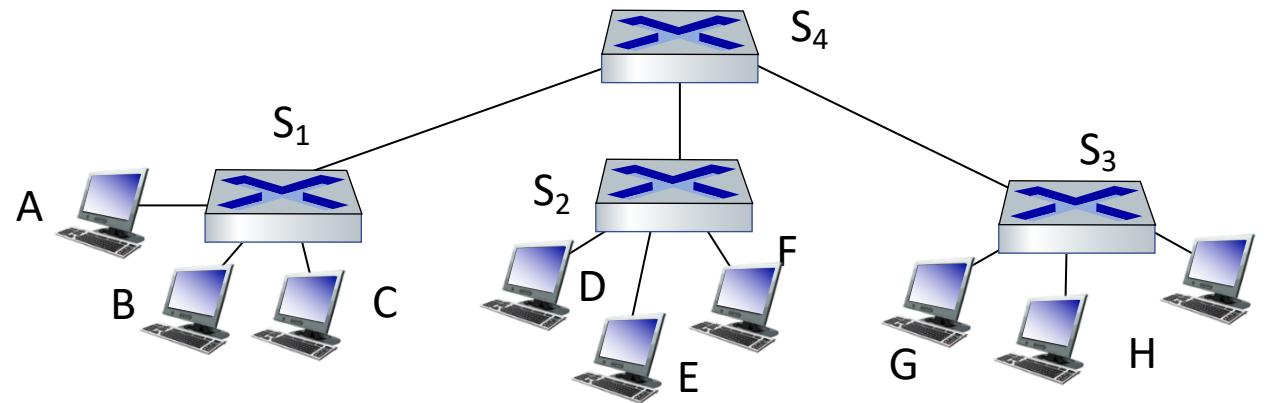


MAC addr	interface	TTL
A	1	60
A'	4	60

*switch table
(initially empty)*

Interconnecting switches

self-learning switches can be connected together:

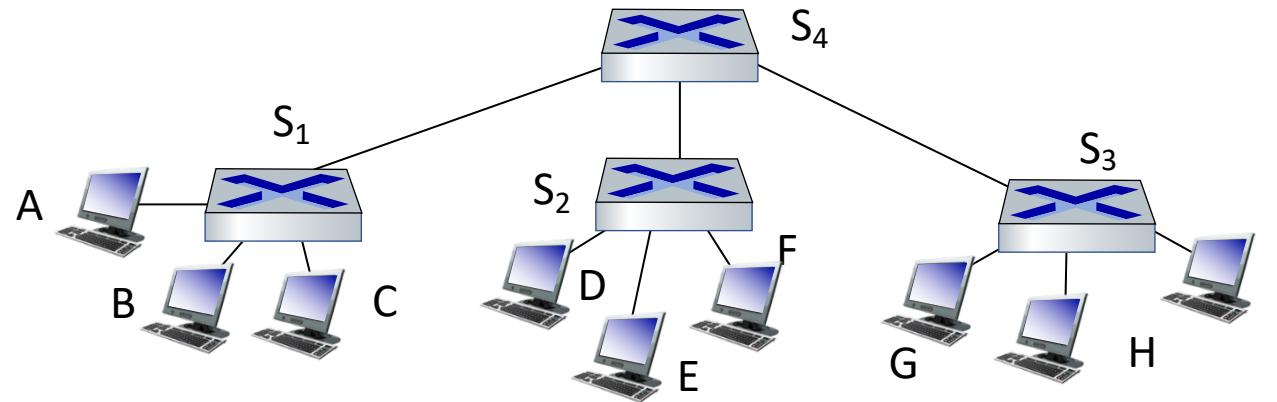


Q: sending from A to G - how does S_1 know to forward frame destined to G via S_4 and S_3 ?

- A: self learning! (works exactly the same as in single-switch case!)

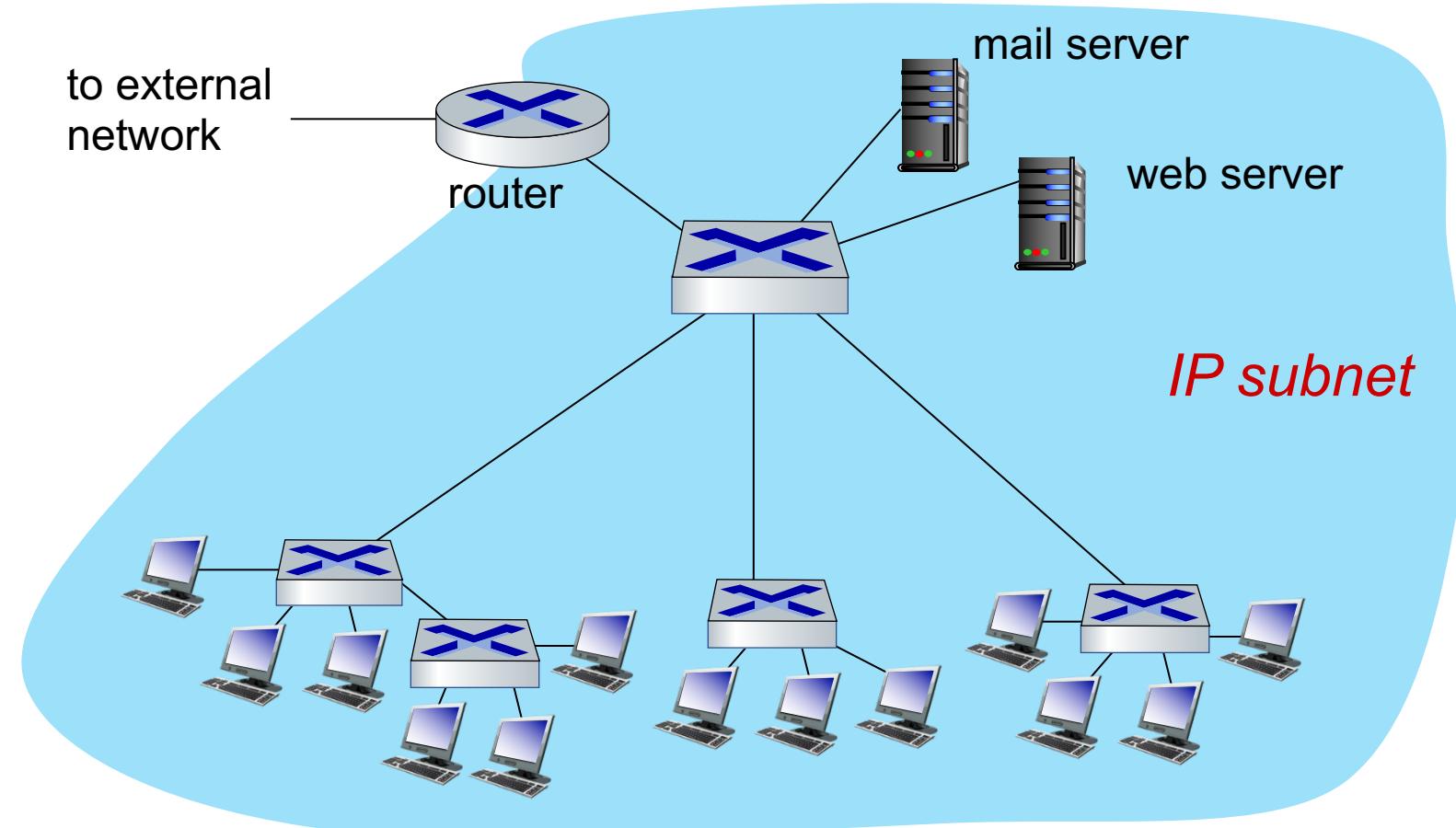
Self-learning multi-switch example

Suppose C sends frame to I, I responds to C



Q: show switch tables and packet forwarding in S_1, S_2, S_3, S_4

Small institutional network



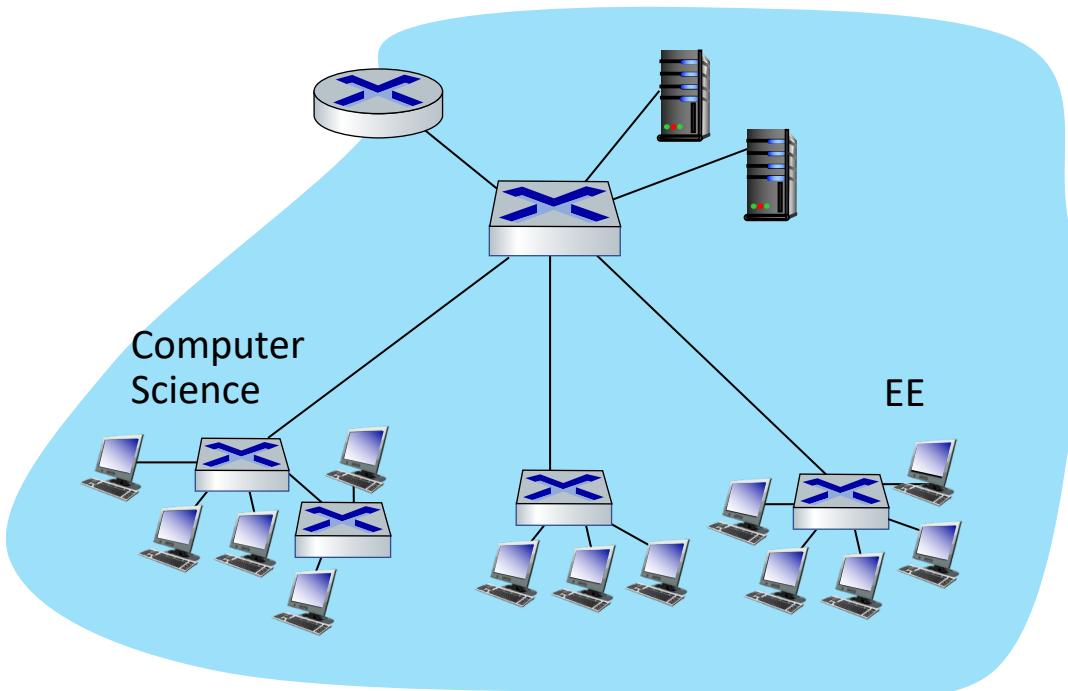
Link layer: roadmap

- introduction
- addressing
- error detection, correction
- multiple access protocols
- LANs
 - Ethernet
 - Switches
 - **VLANs**
 - WiFi



Virtual LANs (VLANs): motivation

Q: what happens as LAN sizes scale, users change point of attachment?

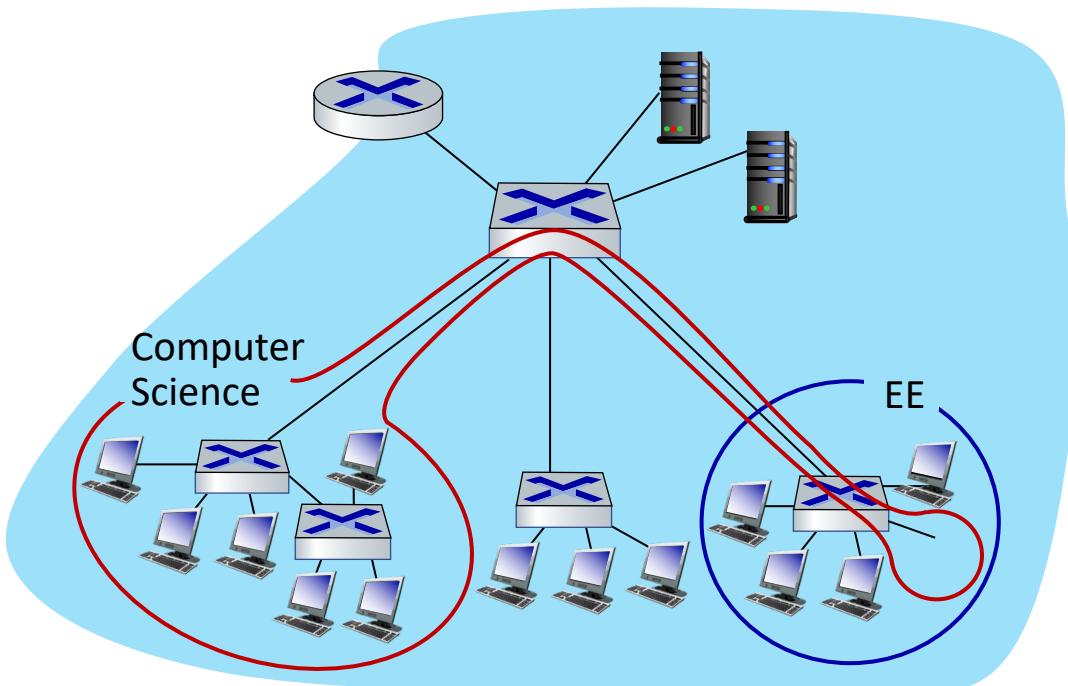


single broadcast domain:

- *scaling:* all layer-2 broadcast traffic (ARP, DHCP, unknown MAC) must cross entire LAN
- efficiency, security, privacy issues

Virtual LANs (VLANs): motivation

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single broadcast domain:

- *scaling:* all layer-2 broadcast traffic (ARP, DHCP, unknown MAC) must cross entire LAN
- efficiency, security, privacy, efficiency issues

administrative issues:

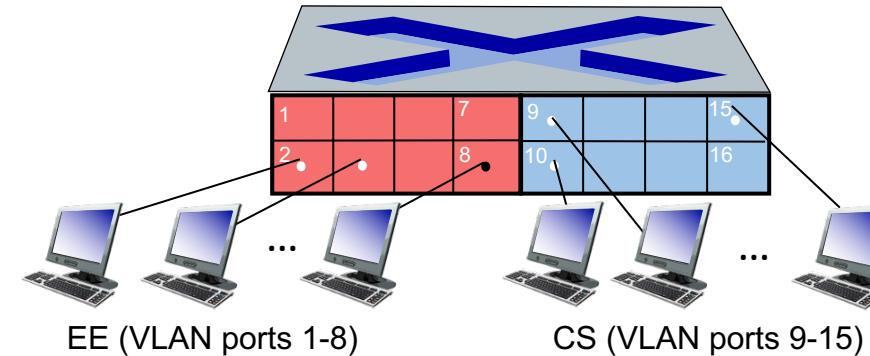
- CS user moves office to EE - *physically* attached to EE switch, but wants to remain *logically* attached to CS switch

Port-based VLANs

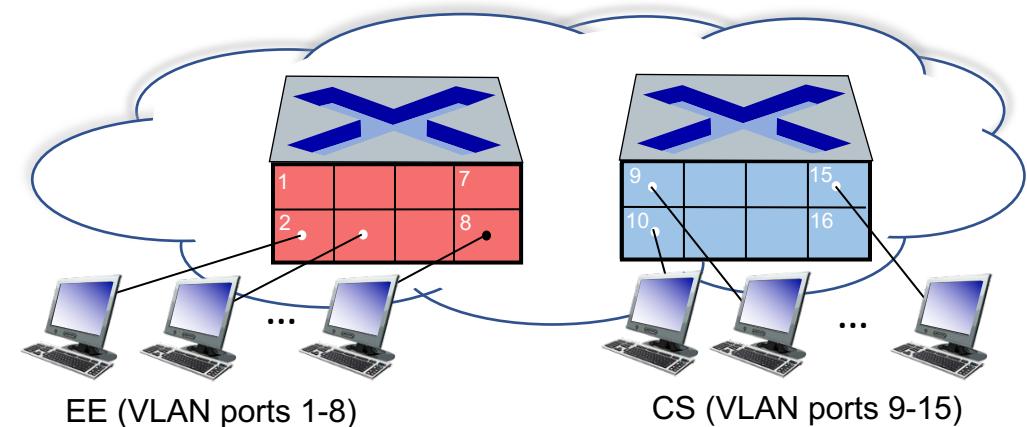
Virtual Local Area Network (VLAN)

switch(es) supporting VLAN capabilities can be configured to define multiple *virtual* LANS over single physical LAN infrastructure.

port-based VLAN: switch ports grouped (by switch management software) so that *single* physical switch

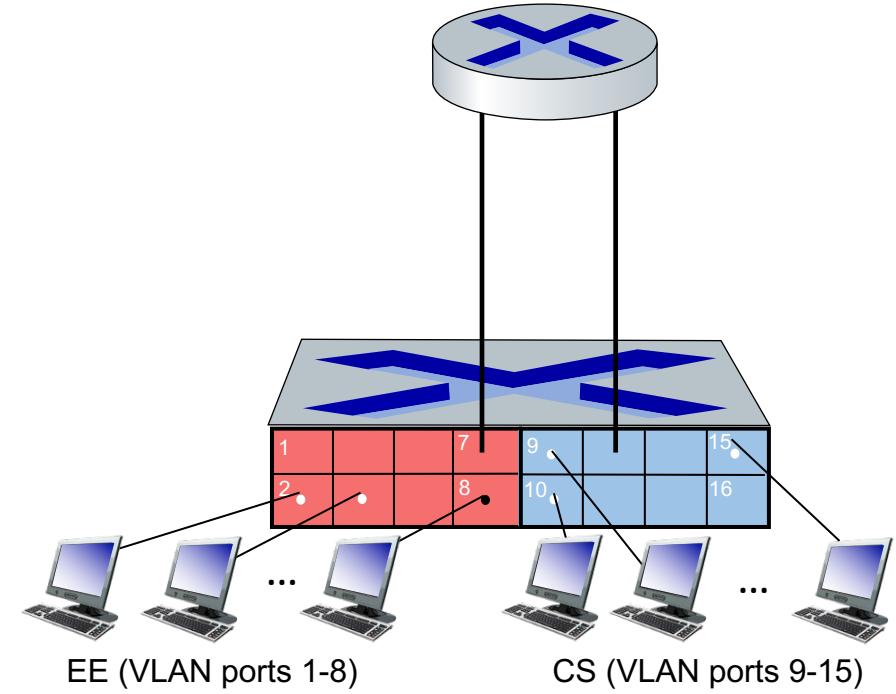


... operates as *multiple* virtual switches

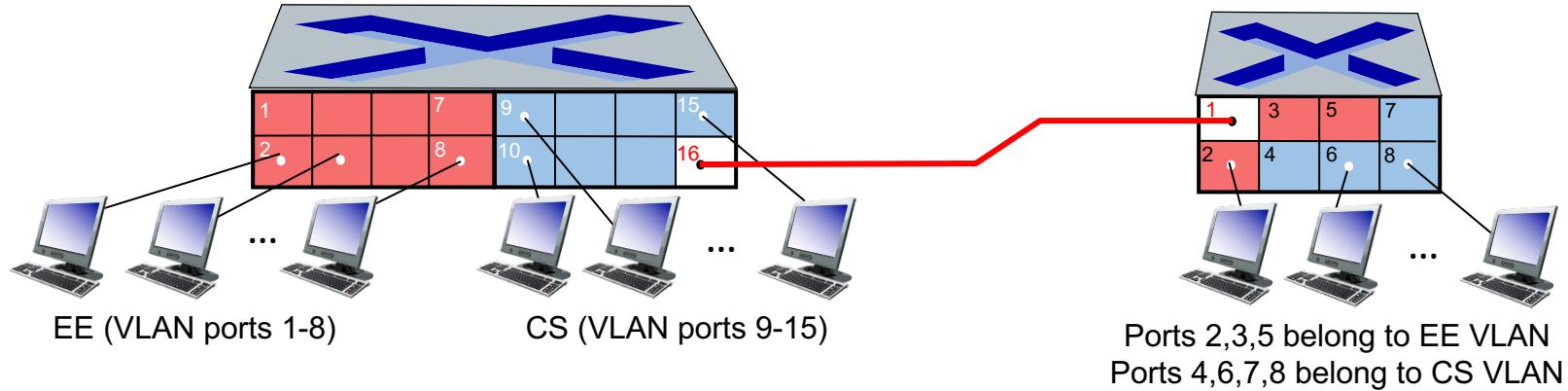


Port-based VLANs

- **traffic isolation:** frames to/from ports 1-8 can *only* reach ports 1-8
 - can also define VLAN based on MAC addresses of endpoints, rather than switch port
- **dynamic membership:** ports can be dynamically assigned among VLANs
- **forwarding between VLANS:** done via routing (just as with separate switches)
 - in practice vendors sell combined switches plus routers



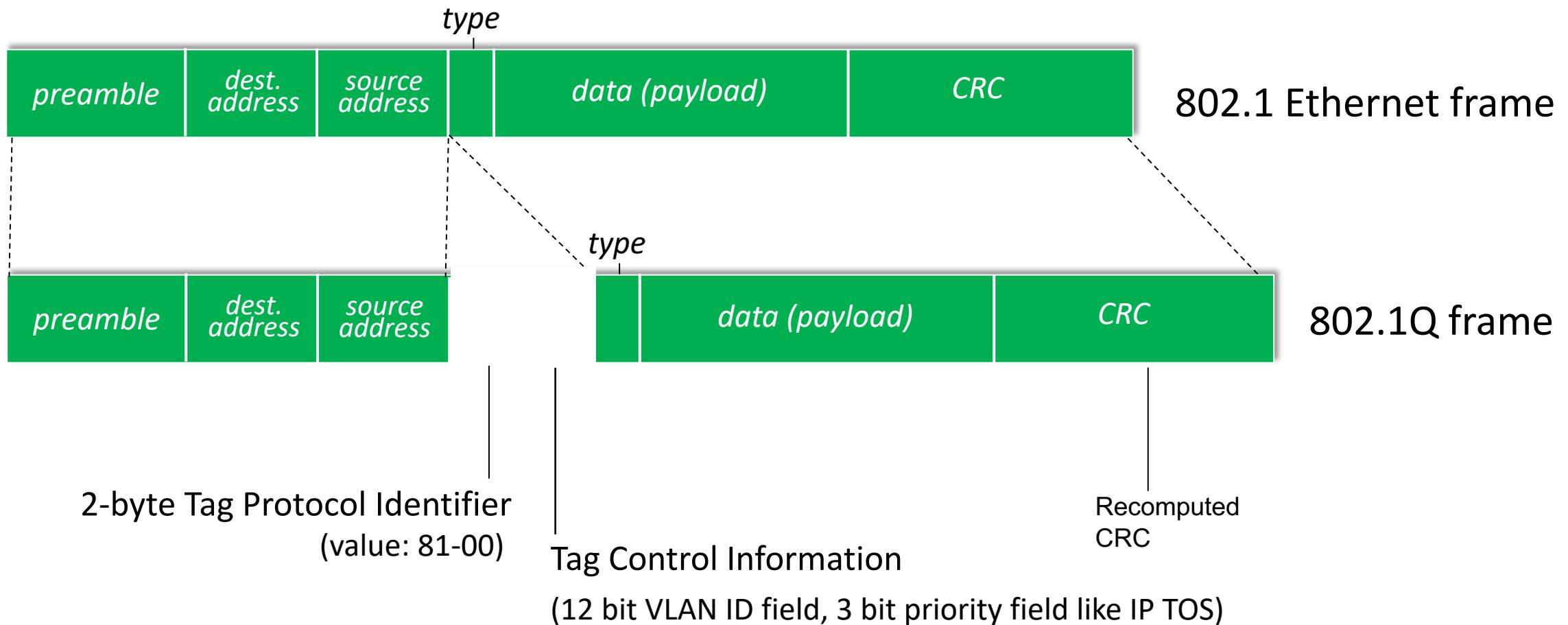
VLANs spanning multiple switches



trunk port: carries frames between VLANs defined over multiple physical switches

- frames forwarded within VLAN between switches can't be vanilla 802.1 frames (must carry VLAN ID info)
- 802.1q protocol adds/removed additional header fields for frames forwarded between trunk ports

802.1Q VLAN frame format

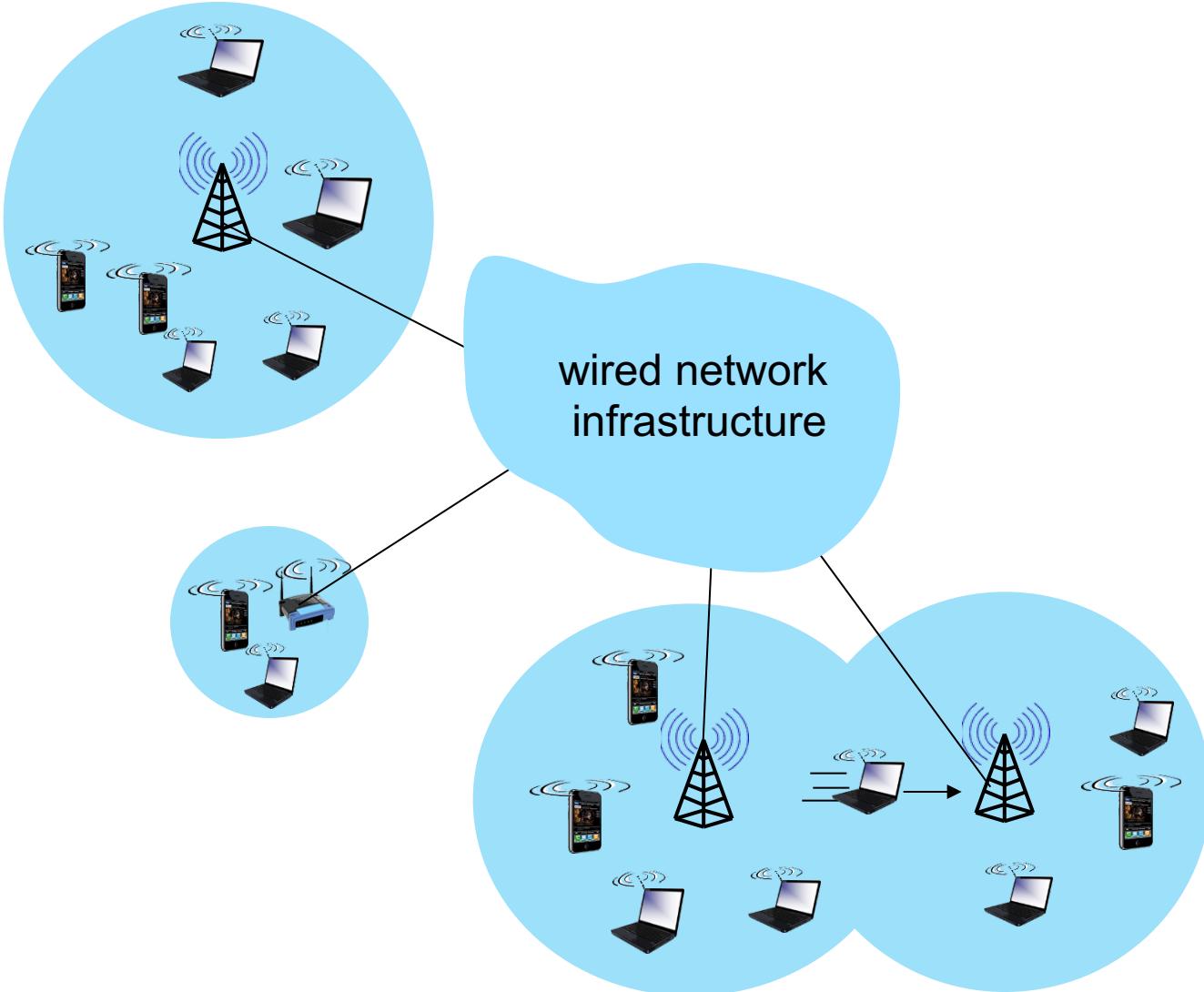


Link layer: roadmap

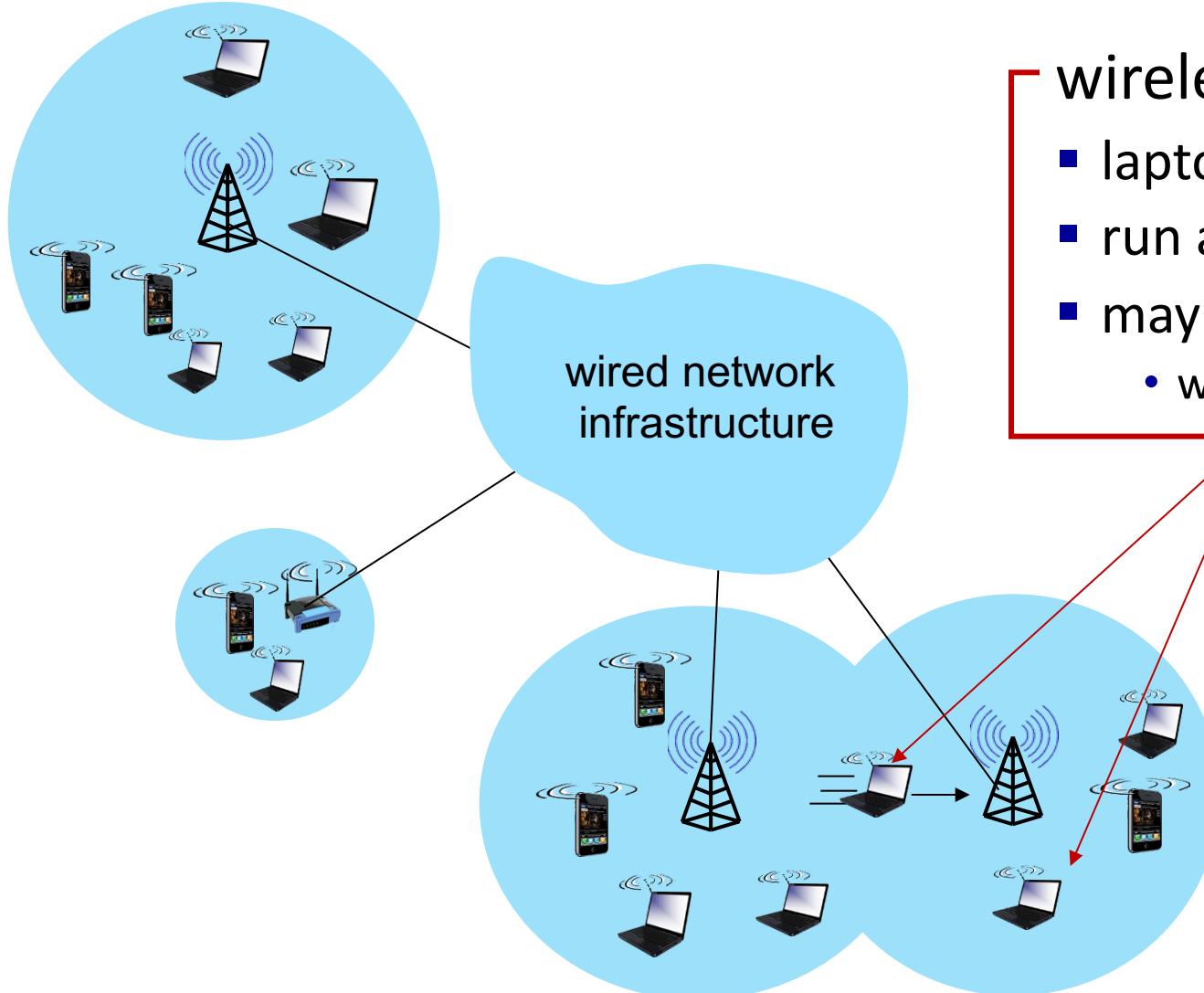
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Elements of a wireless network



Elements of a wireless network

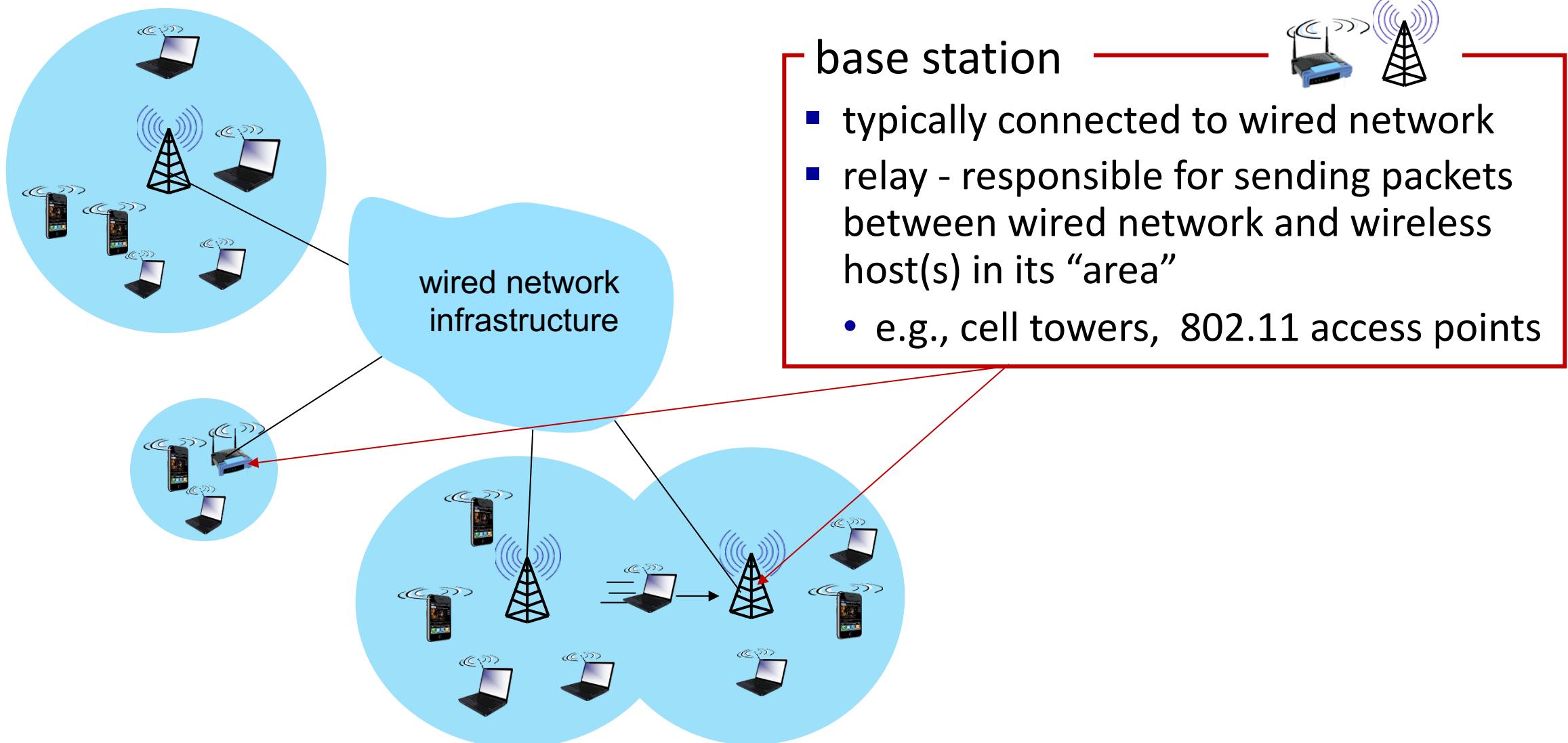


wireless hosts

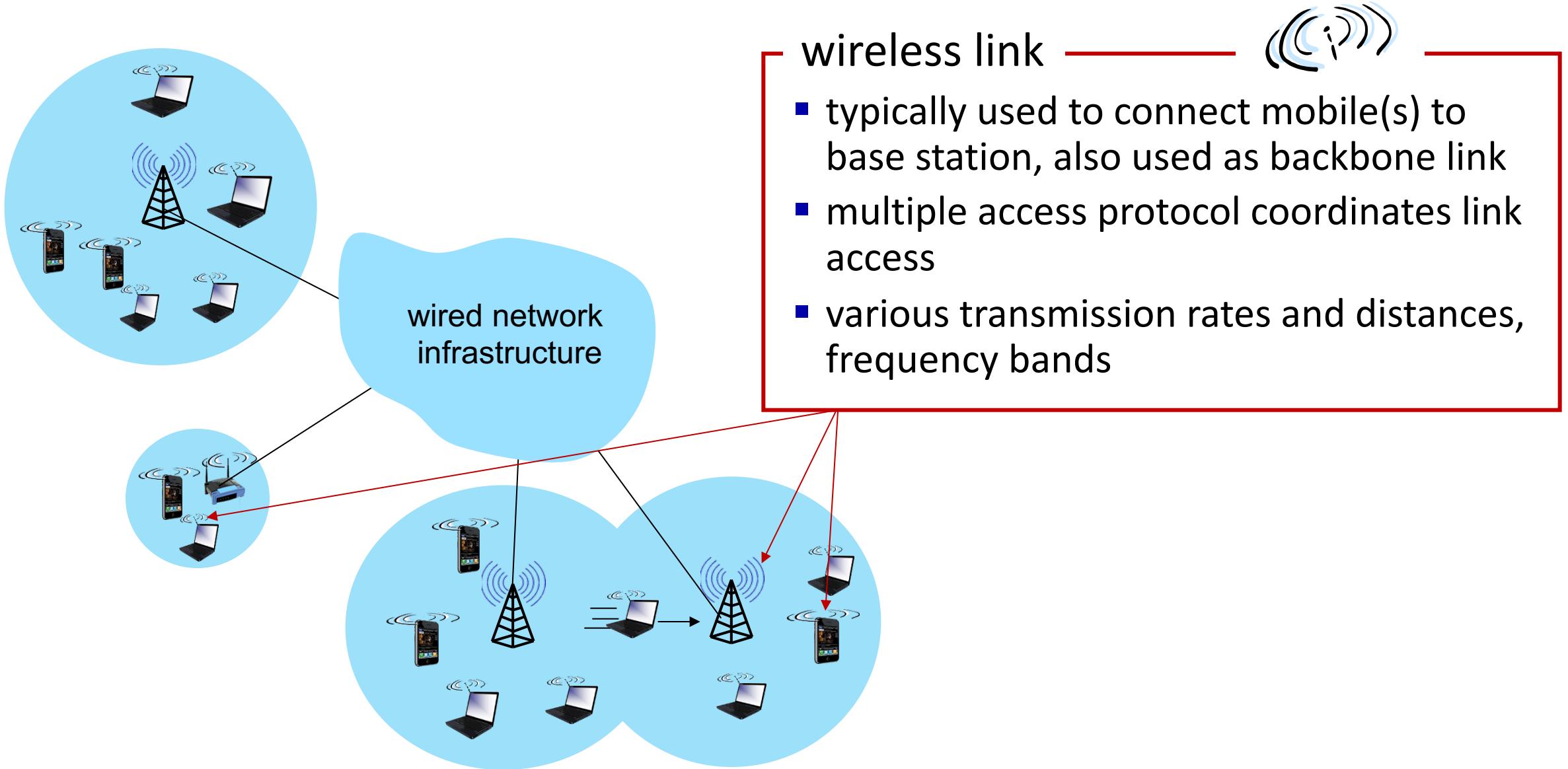
- laptop, smartphone, IoT
- run applications
- may be stationary (non-mobile) or mobile
 - wireless does *not* always mean mobility!



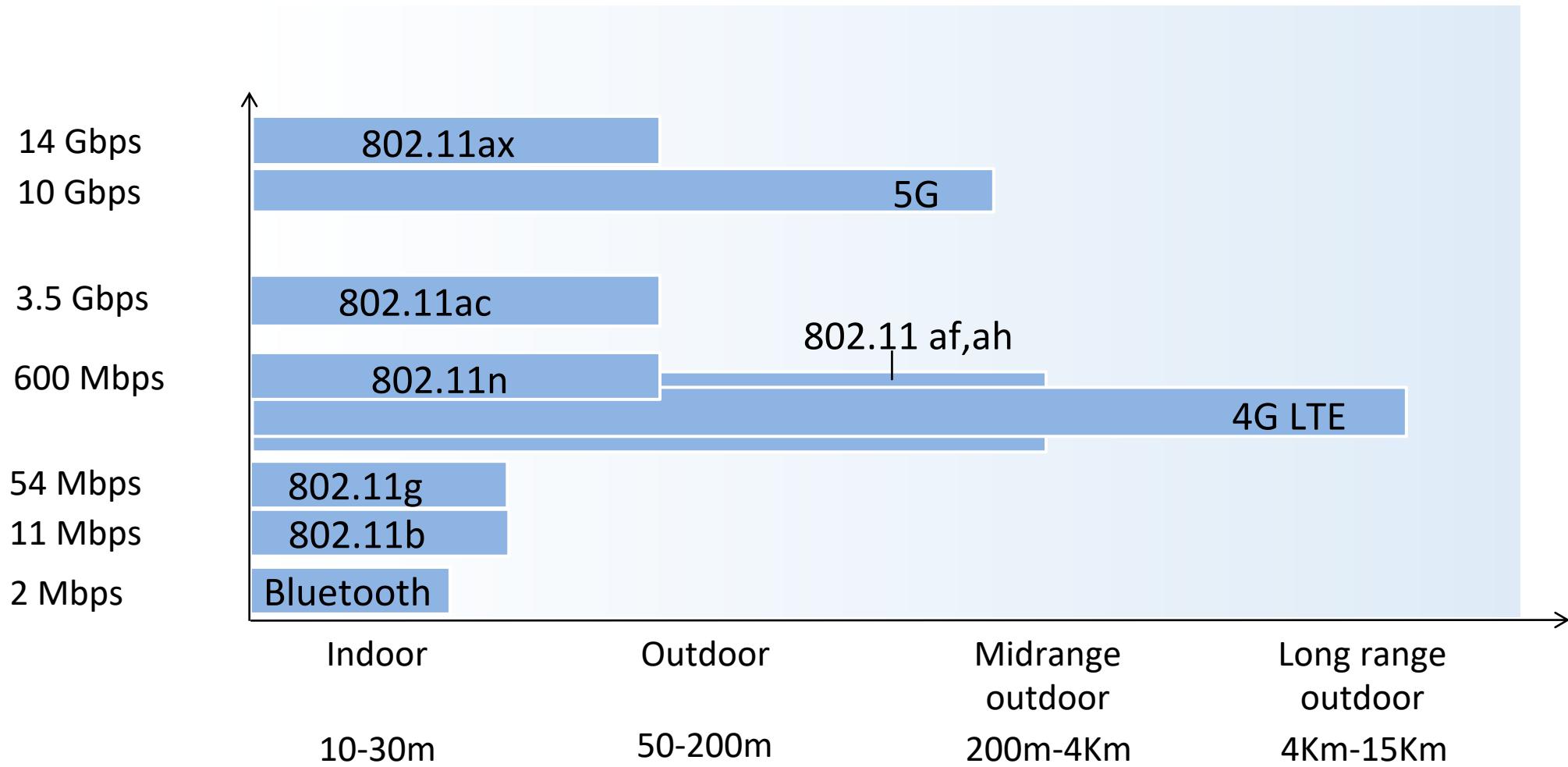
Elements of a wireless network



Elements of a wireless network



Characteristics of selected wireless links

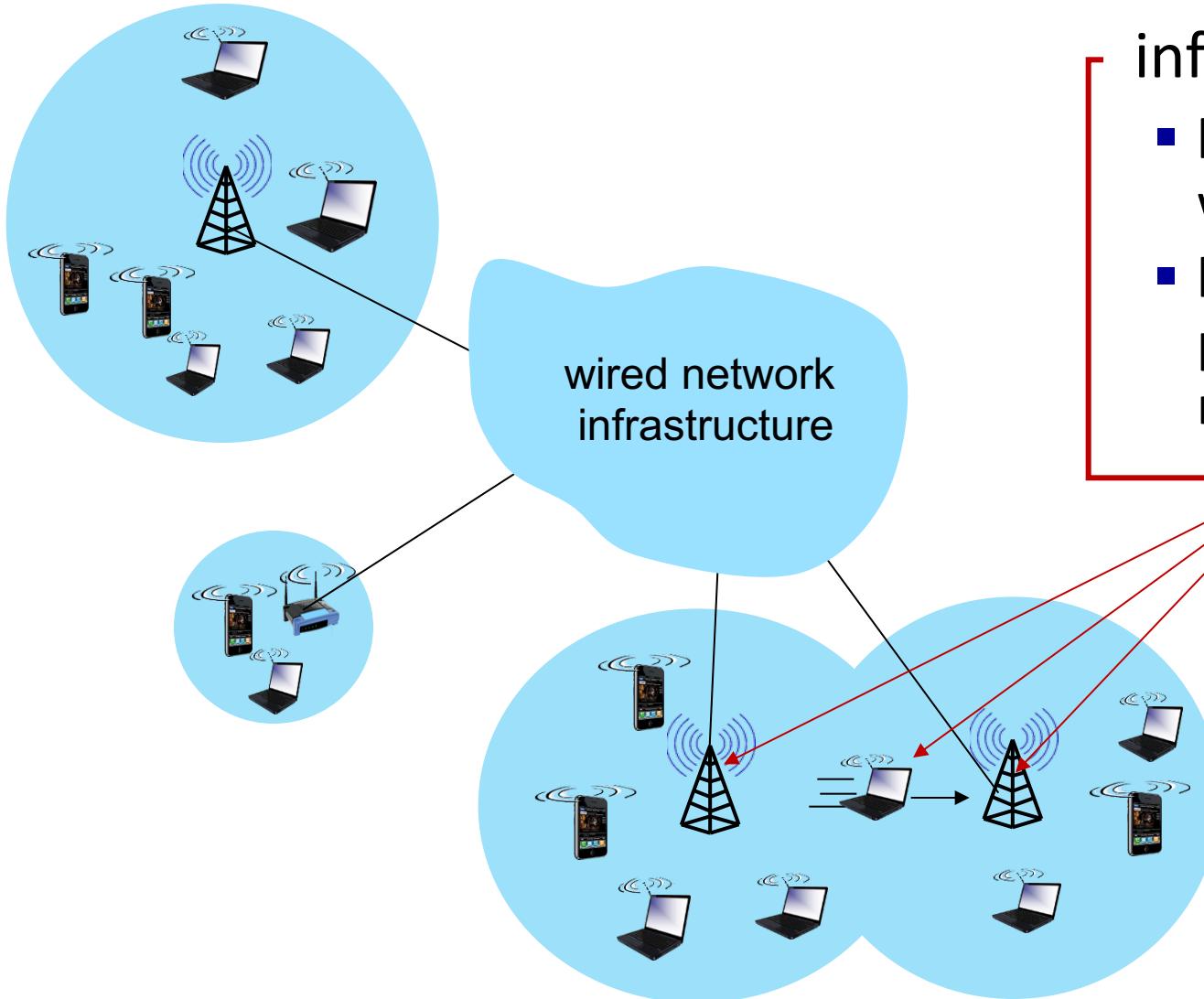


IEEE 802.11 Wireless LAN

IEEE 802.11 standard	Year	Max data rate	Range	Frequency
802.11b	1999	11 Mbps	30 m	2.4 Ghz
802.11g	2003	54 Mbps	30m	2.4 Ghz
802.11n (WiFi 4)	2009	600	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2020	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347Mbps	1 Km	900 Mhz

- all use CSMA/CA for multiple access, and have base-station and ad-hoc network versions

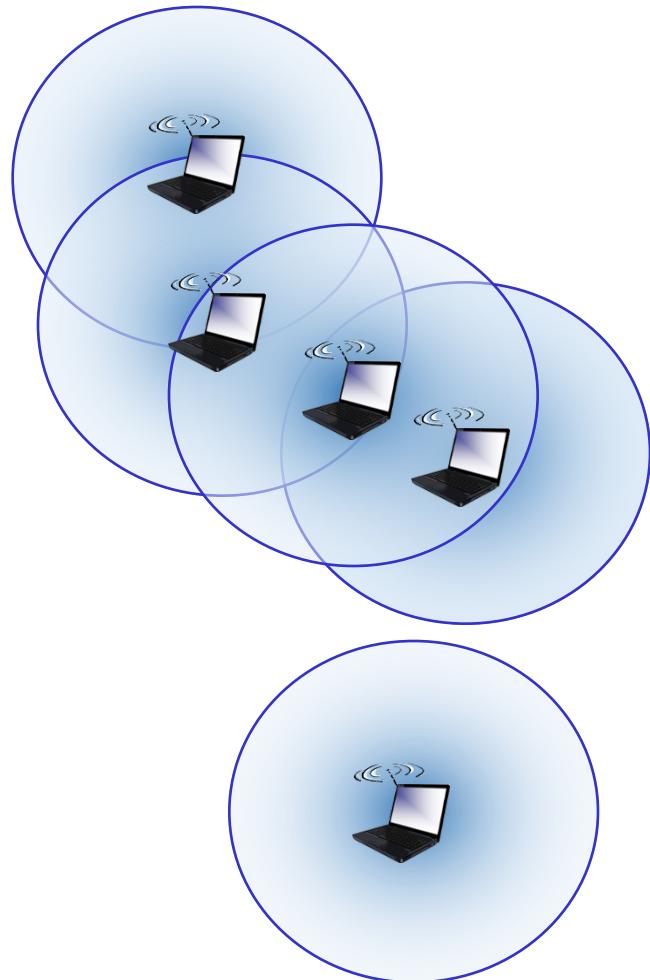
Elements of a wireless network



infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Elements of a wireless network



ad hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, cellular) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: <i>mesh net</i>
<i>no infrastructure</i>	no base station, no connection to larger Internet (Bluetooth, ad hoc nets)	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

Wireless link characteristics (1)

important differences from wired link

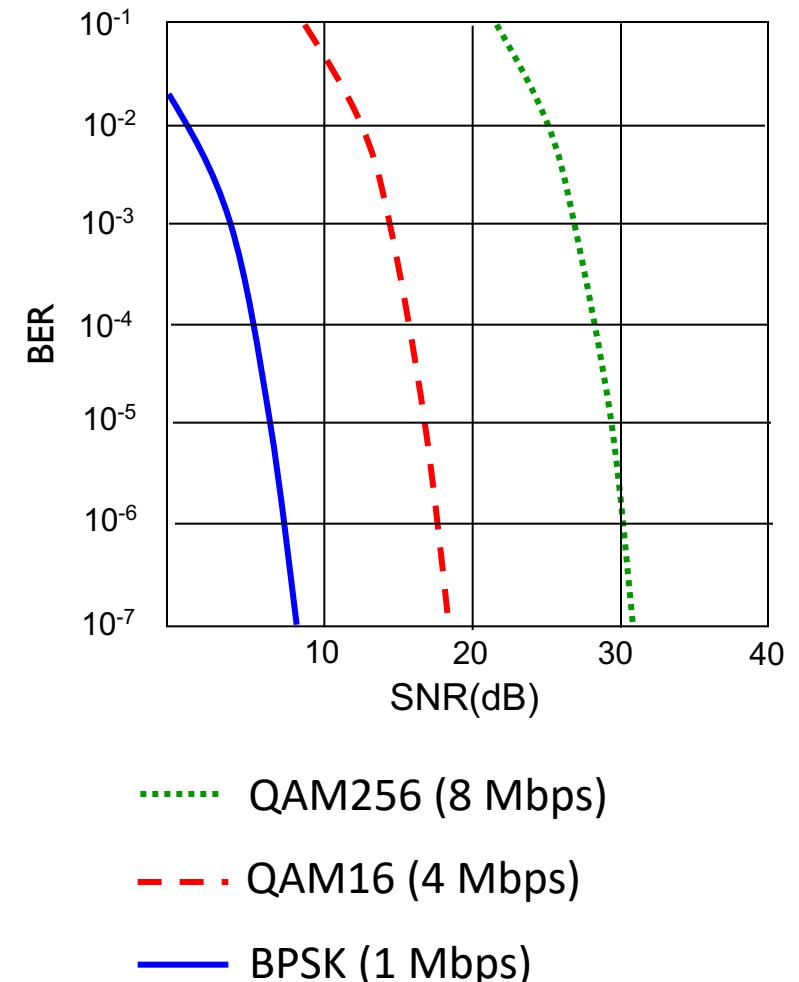
- **decreased signal strength:** radio signal attenuates as it propagates through matter (path loss)
- **interference from other sources:** wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., WiFi, cellular, motors): interference
- **multipath propagation:** radio signal reflects off objects ground, arriving at destination at slightly different times

.... make communication across (even a point to point) wireless link much more “difficult”



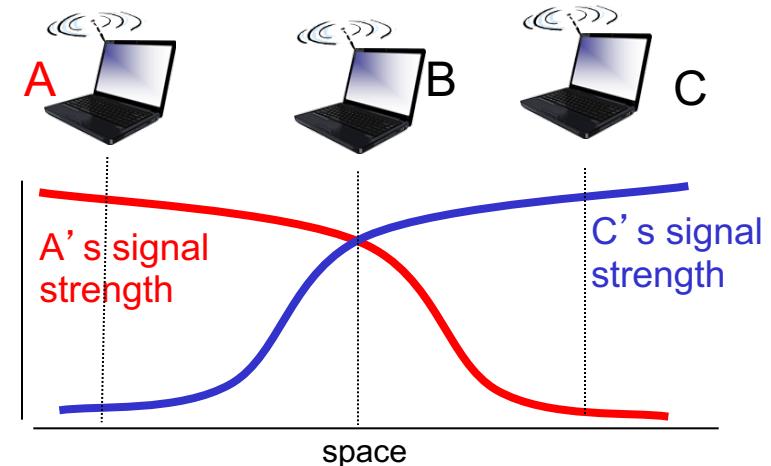
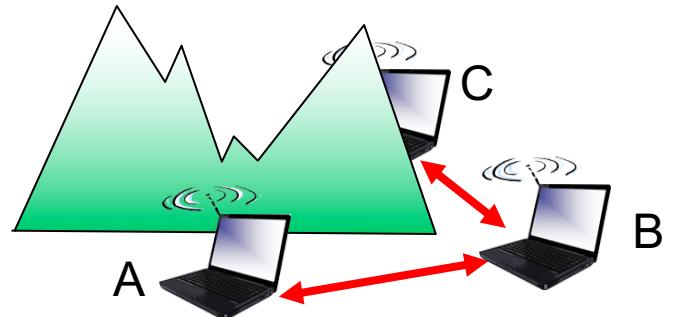
Wireless link characteristics (2)

- SNR: signal-to-noise ratio
 - larger SNR – easier to extract signal from noise (a “good thing”)
- SNR versus BER tradeoffs
 - *given physical layer*: increase power -> increase SNR->decrease BER
 - *given SNR*: choose physical layer that meets BER requirement, giving highest throughput
 - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



Wireless link characteristics (3)

Multiple wireless senders, receivers create additional problems (beyond multiple access):



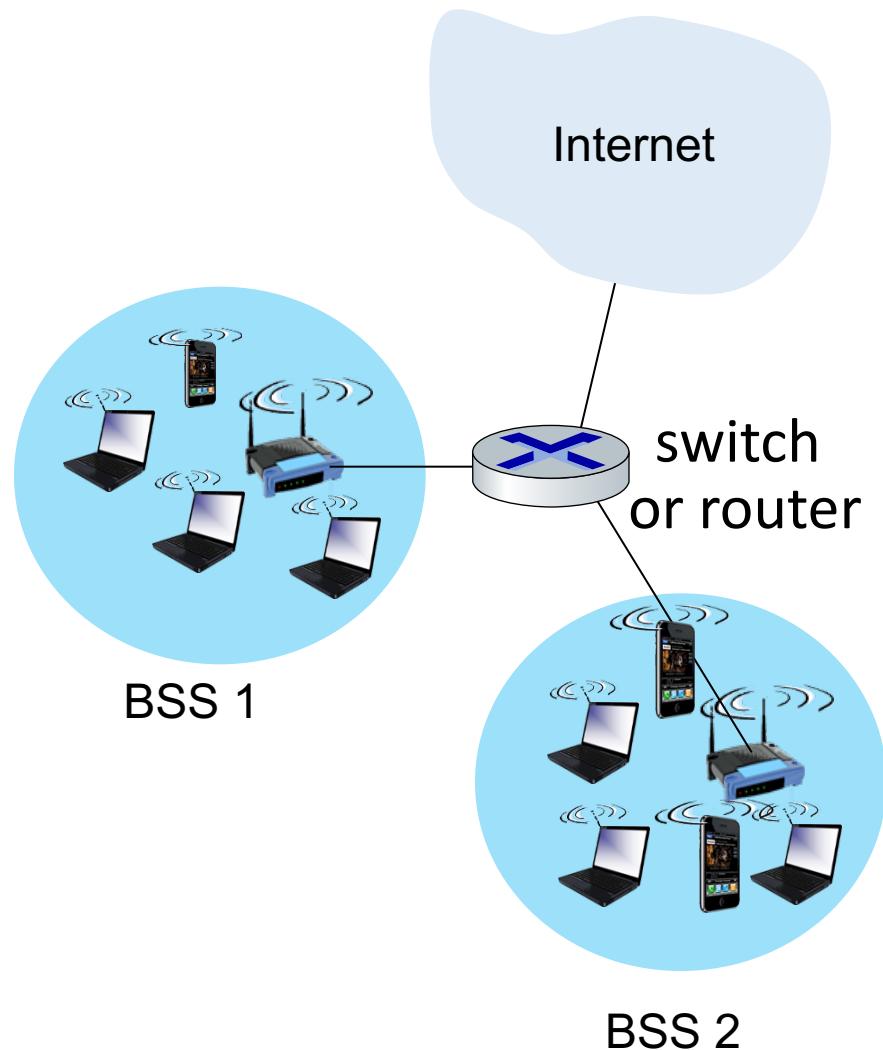
Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

802.11 LAN architecture



- wireless host communicates with base station
 - **base station = access point (AP)**
- **Basic Service Set (BSS) (aka “cell”)** in infrastructure mode contains:
 - wireless hosts
 - access point (AP): base station
 - ad hoc mode: hosts only

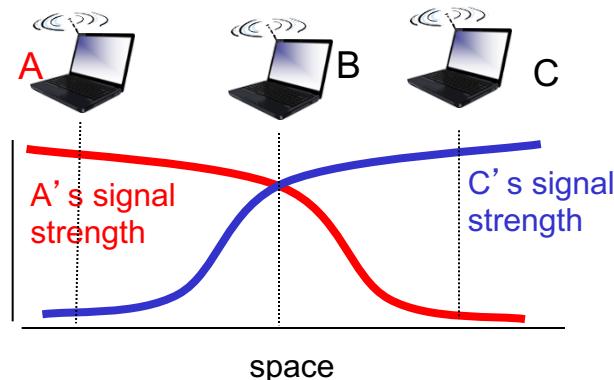
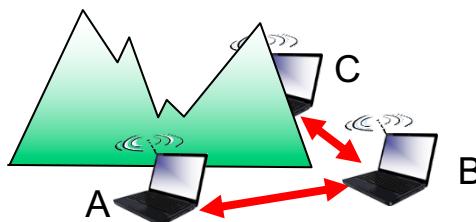
802.11: Channels, association

- spectrum divided into channels at different frequencies
 - AP admin chooses frequency for AP
 - interference possible: channel can be same as that chosen by neighboring AP!
- arriving host: must **associate** with an AP
 - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
 - selects AP to associate with
 - then may perform authentication [Chapter 8]
 - then typically run DHCP to get IP address in AP's subnet



IEEE 802.11: multiple access

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
 - don't collide with detected ongoing transmission by another node
- 802.11: *no collision detection!*
 - difficult to sense collisions: high transmitting signal, weak received signal due to fading
 - can't sense all collisions in any case: hidden terminal, fading
 - goal: *avoid collisions*: CSMA/Collision Avoidance



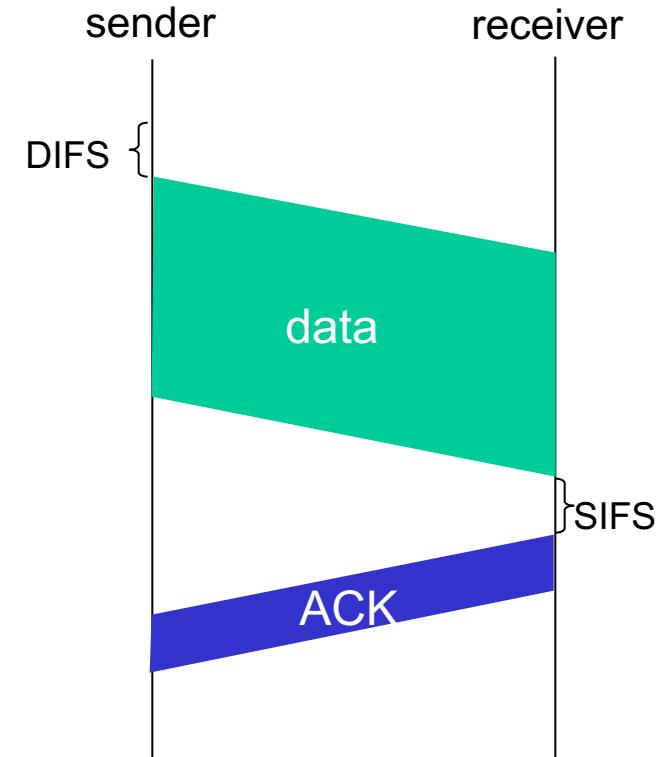
IEEE 802.11 MAC Protocol: CSMA/CA

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)

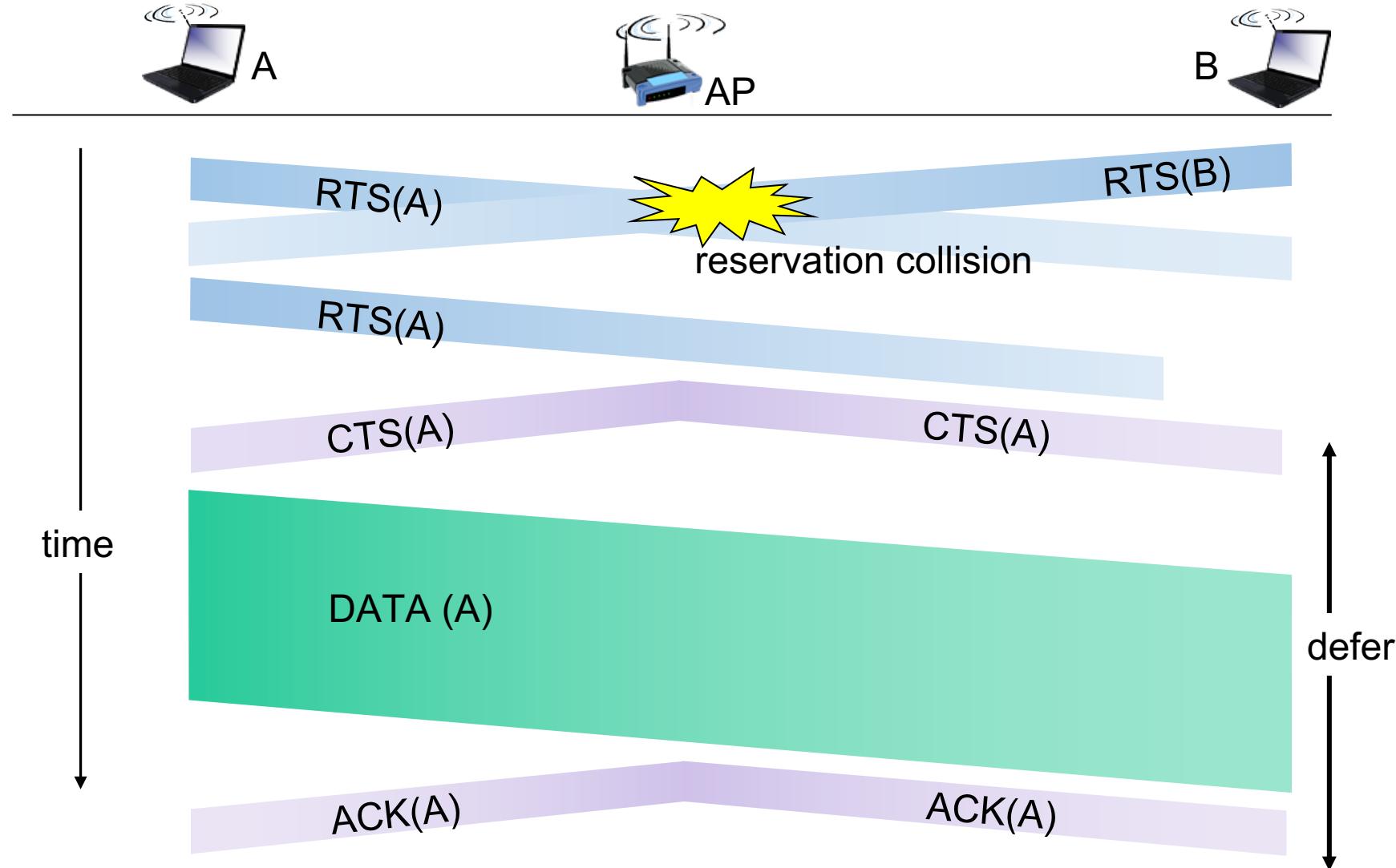


Avoiding collisions (more)

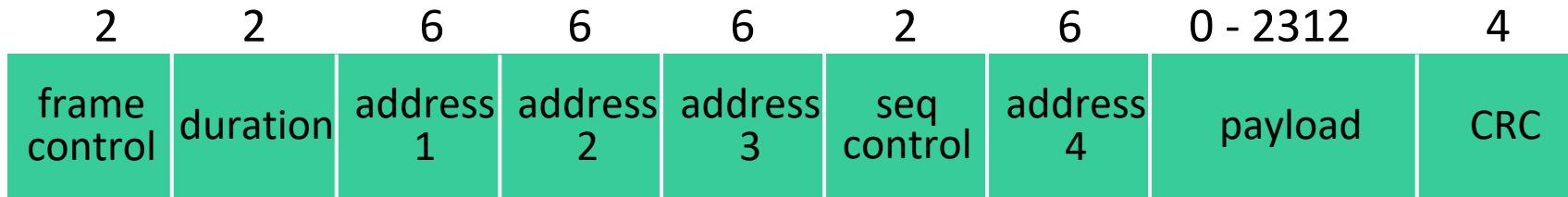
idea: sender “reserves” channel use for data frames using small reservation packets

- sender first transmits *small* request-to-send (RTS) packet to 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

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing



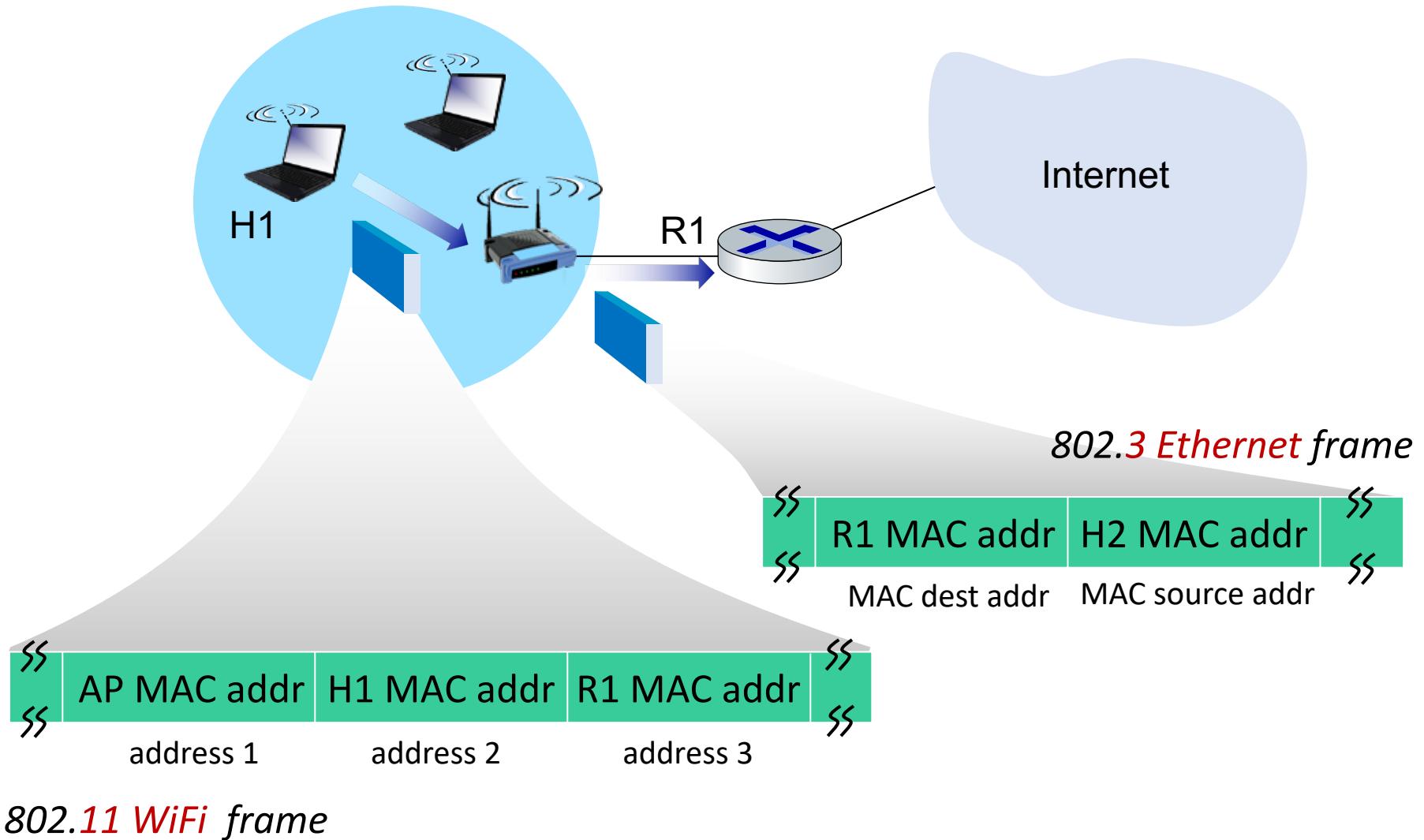
Address 1: MAC address of wireless host or AP to receive this frame

Address 2: MAC address of wireless host or AP transmitting this frame

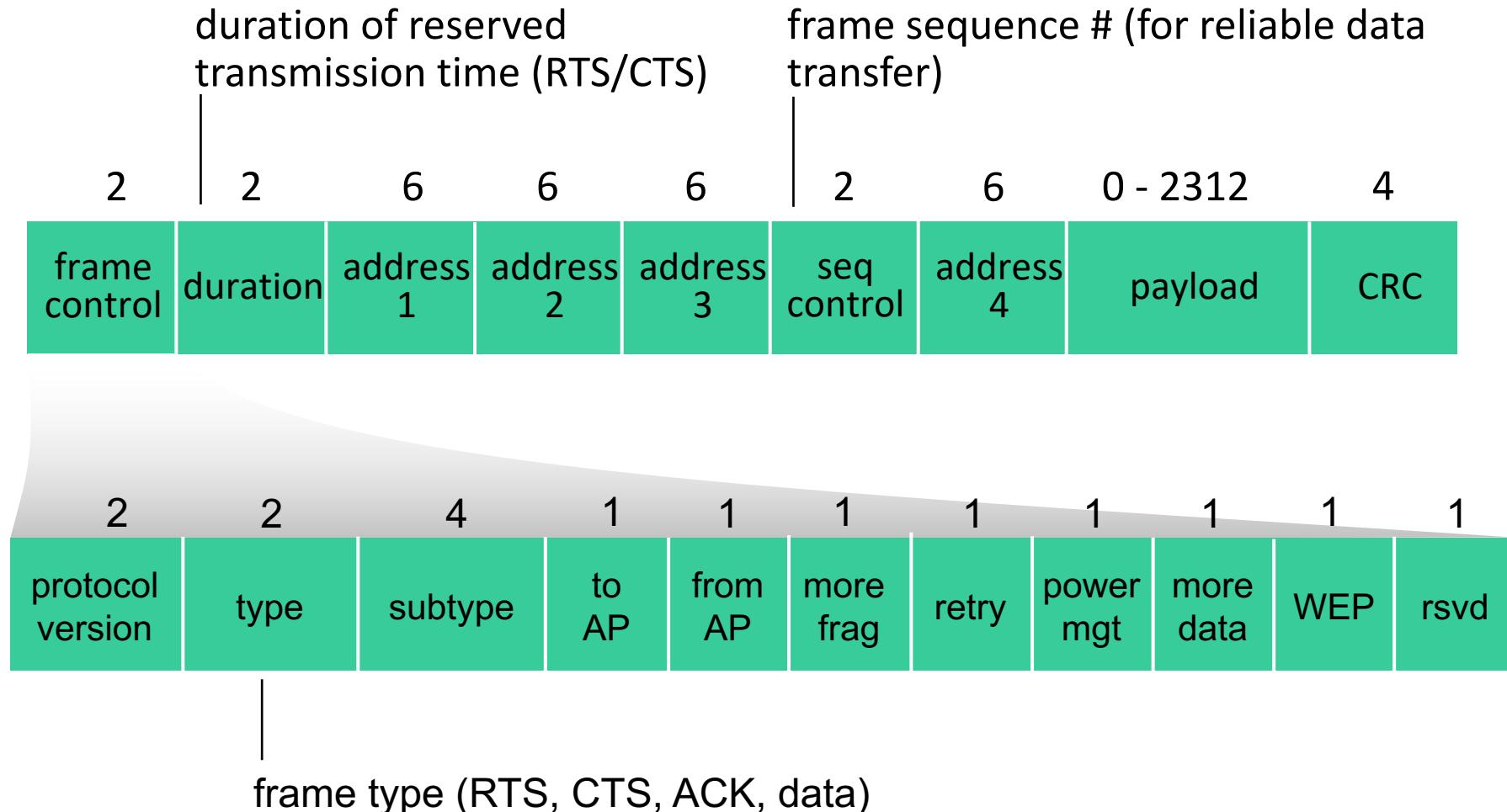
Address 4: used only in ad hoc mode

Address 3: MAC address of router interface to which AP is attached

802.11 frame: addressing



802.11 frame: addressing



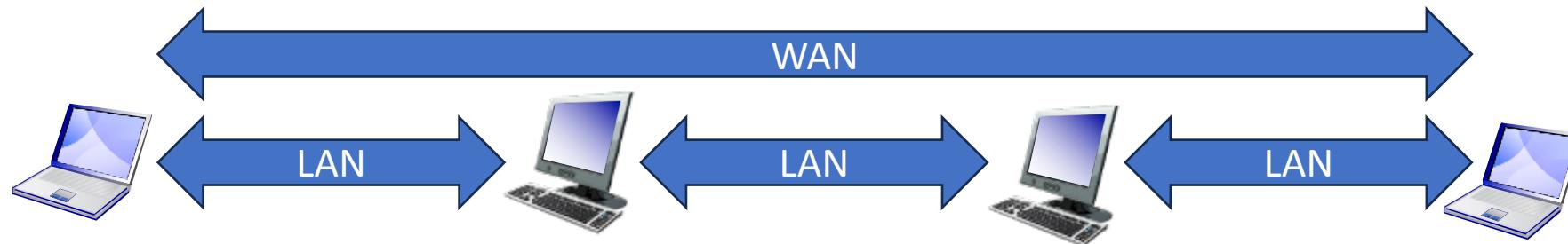
Chapter 6: Summary

- principles behind data link layer services:
 - error detection, correction
 - sharing a broadcast channel: multiple access
 - link layer addressing
- instantiation, implementation of various link layer technologies
 - Ethernet
 - switched LANS, VLANs
 - WiFi

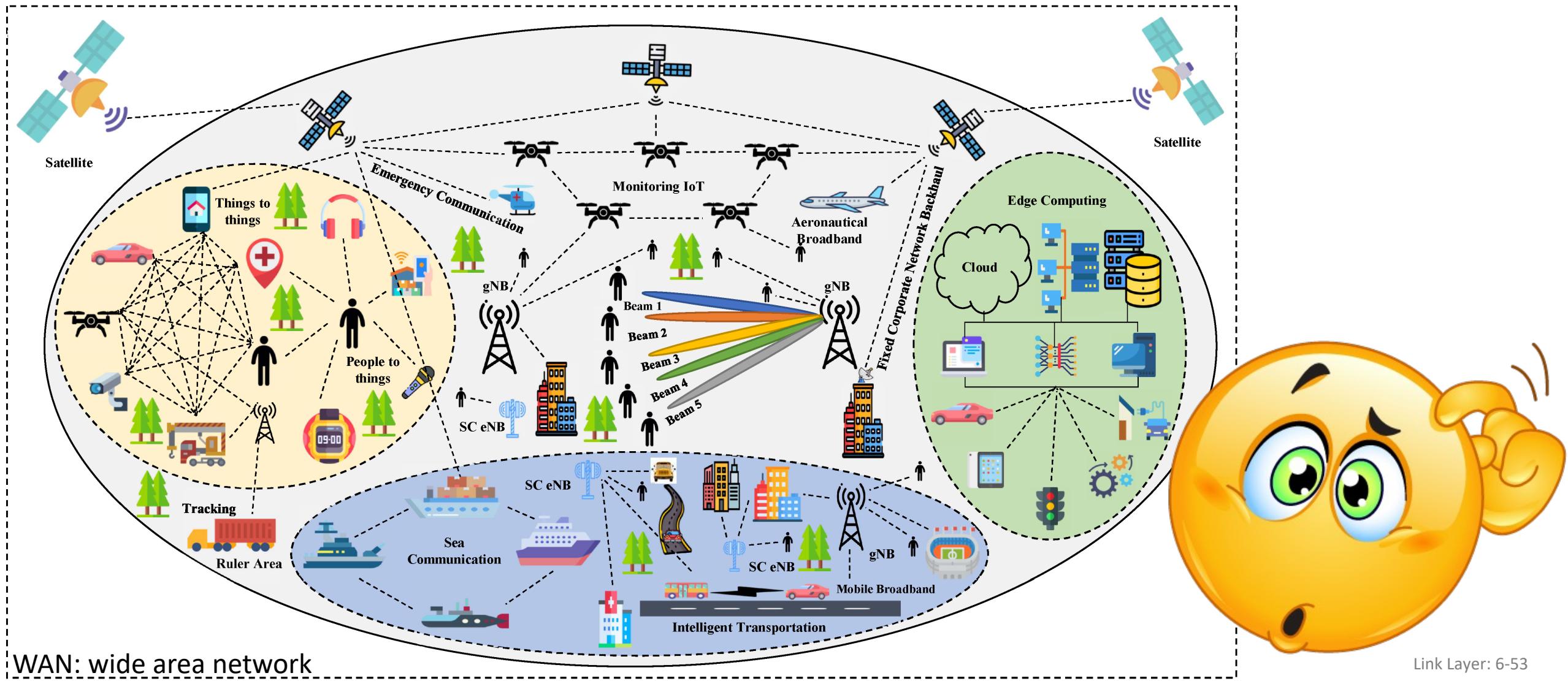
Time for the next step

- What can be achieved with the technologies discussed?
- What should be the next steps?
 - Discussion in small groups (10 minutes)

Real world application – building even larger networks



Real world application – finding the best path



Time for the next step

- What can be achieved with the technologies discussed?
- What should be the next steps?
 - Discussion in small groups (10 minutes)
- Brainstorm ideas to solve the problems
 - Group discussions (20 minutes)

Topics for next lecture

1. WAN addressing
2. Forwarding
3. Address aggregation