Chapter 7
Wireless and Mobile Networks

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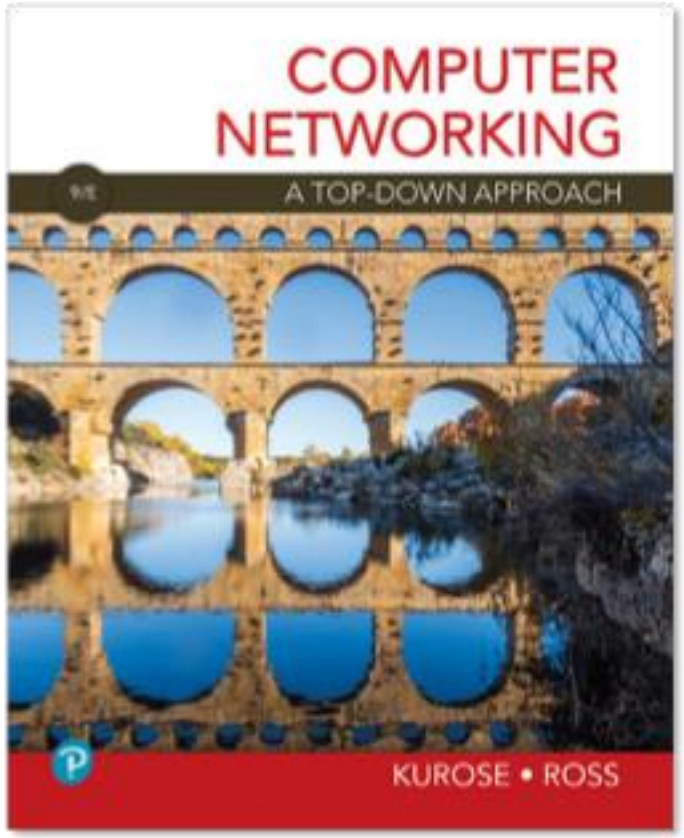
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Thanks and enjoy! JFK/KWR

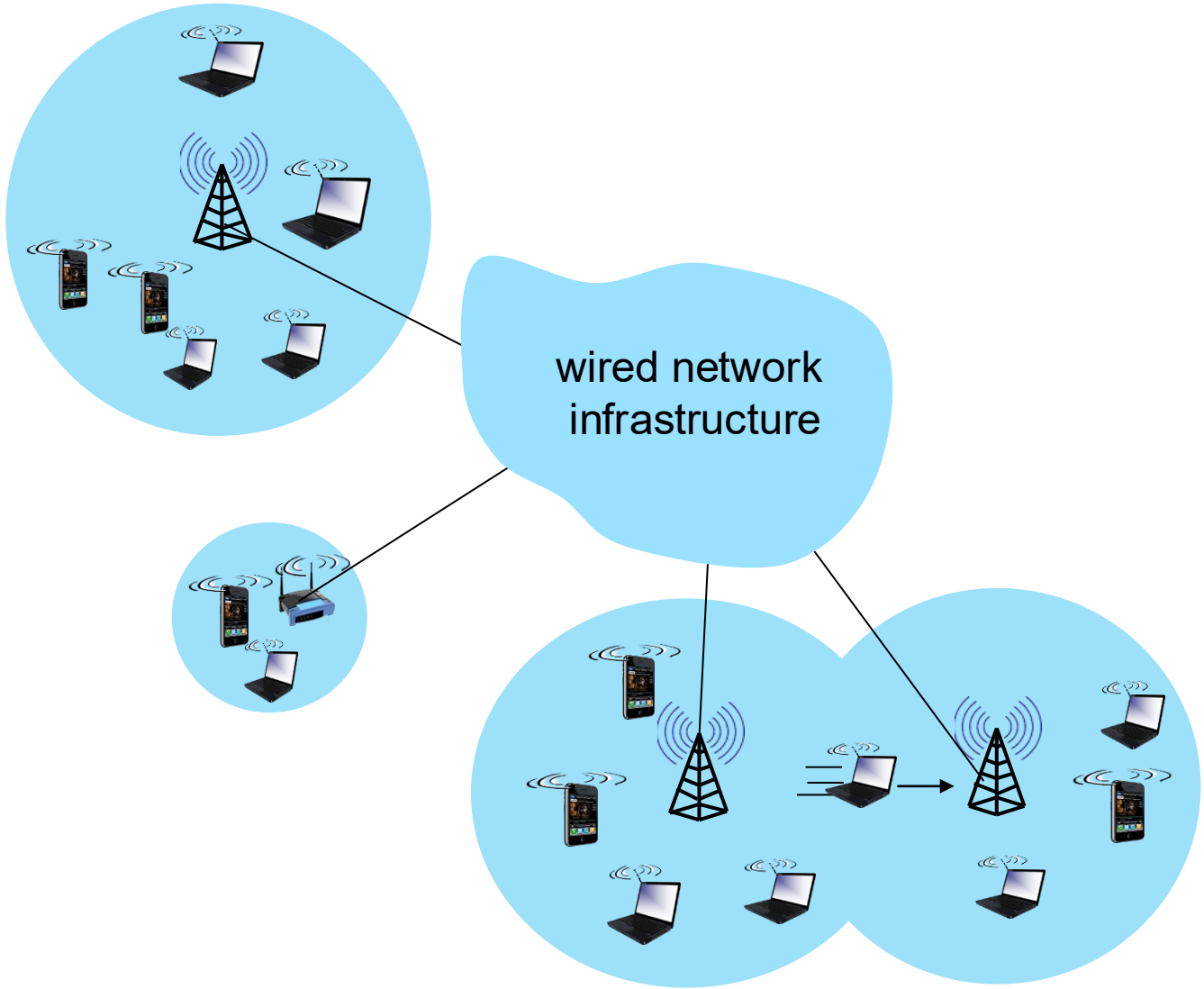
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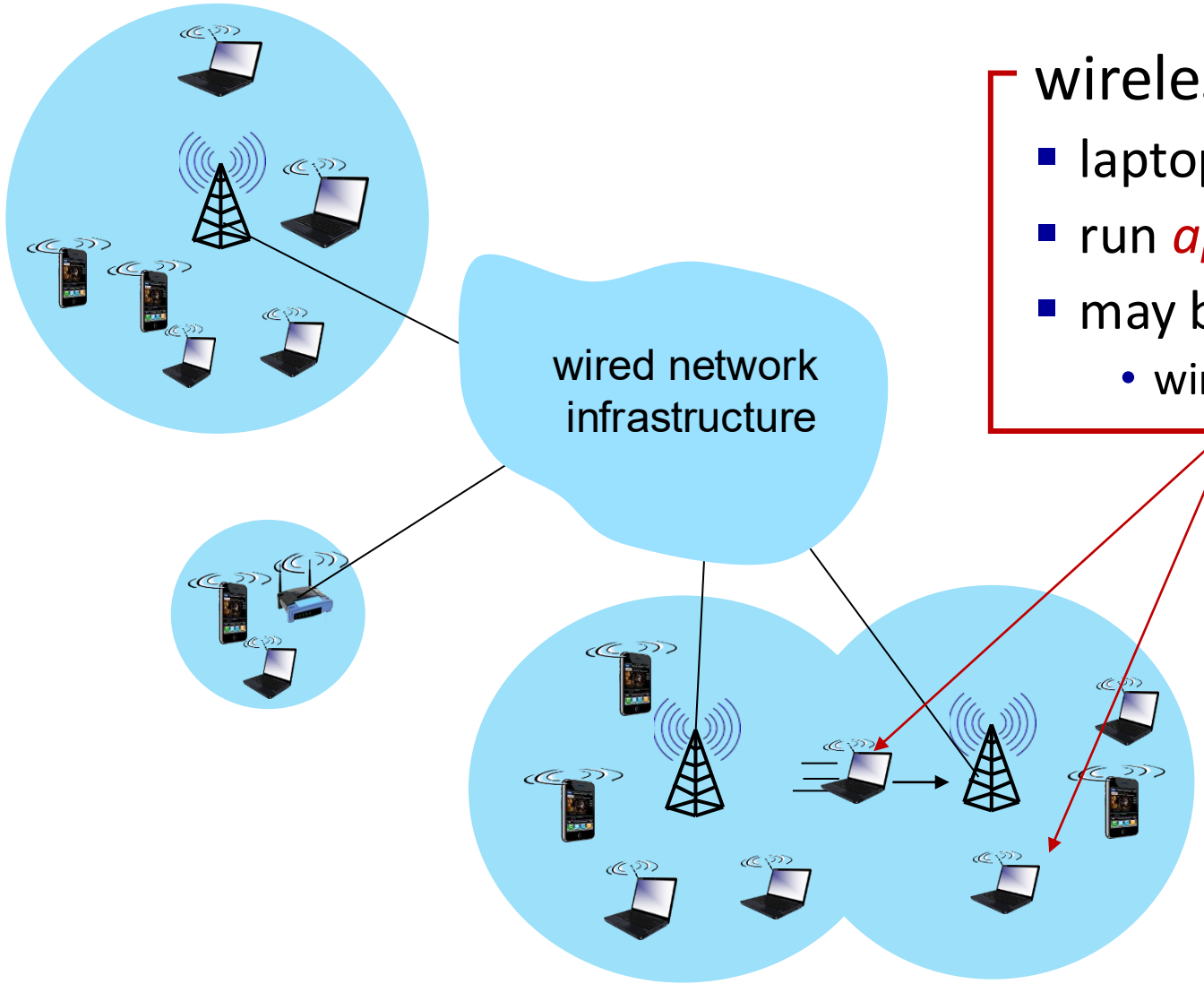
Computer Networking: A Top-Down Approach

9th edition
Jim Kurose, Keith Ross
Pearson, 2025

Elements of a wireless network



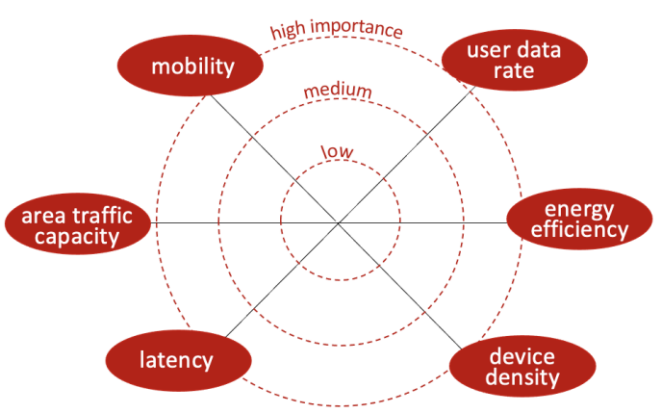
Elements of a wireless network



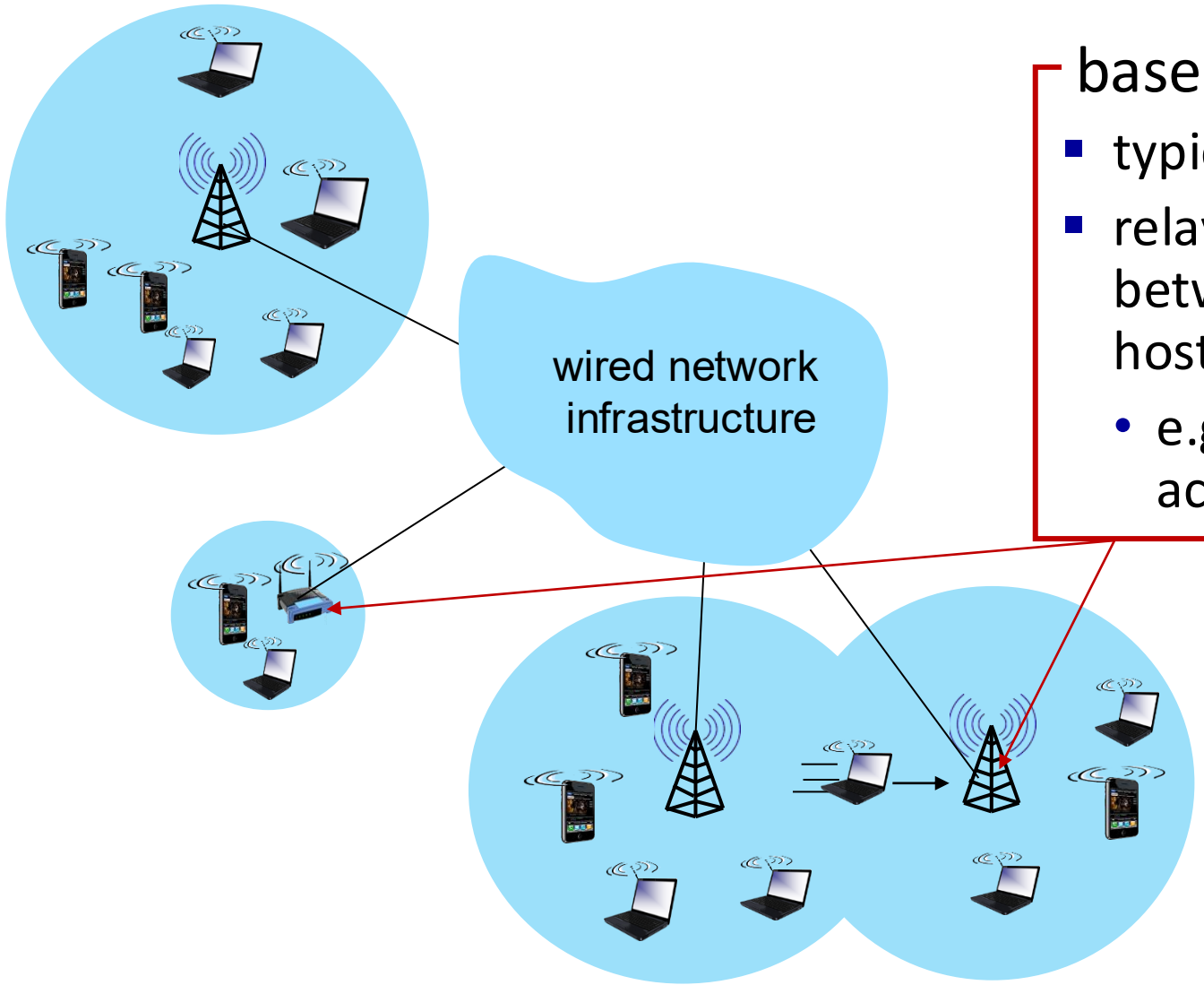
wireless hosts



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



Elements of a wireless network

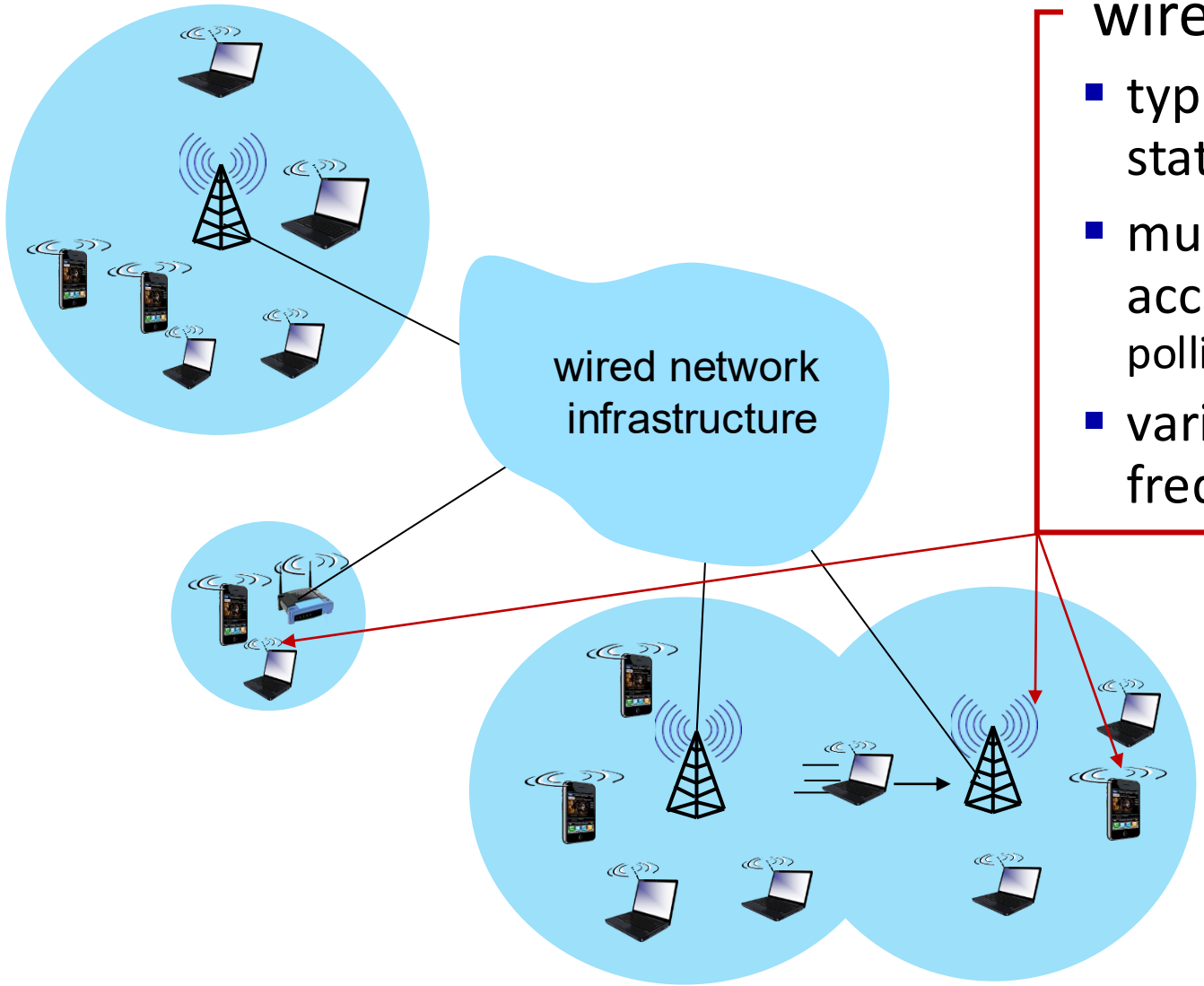


base station



- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., 4G/5G cell towers, 802.11 (WiFi) access points (APs)

Elements of a wireless network



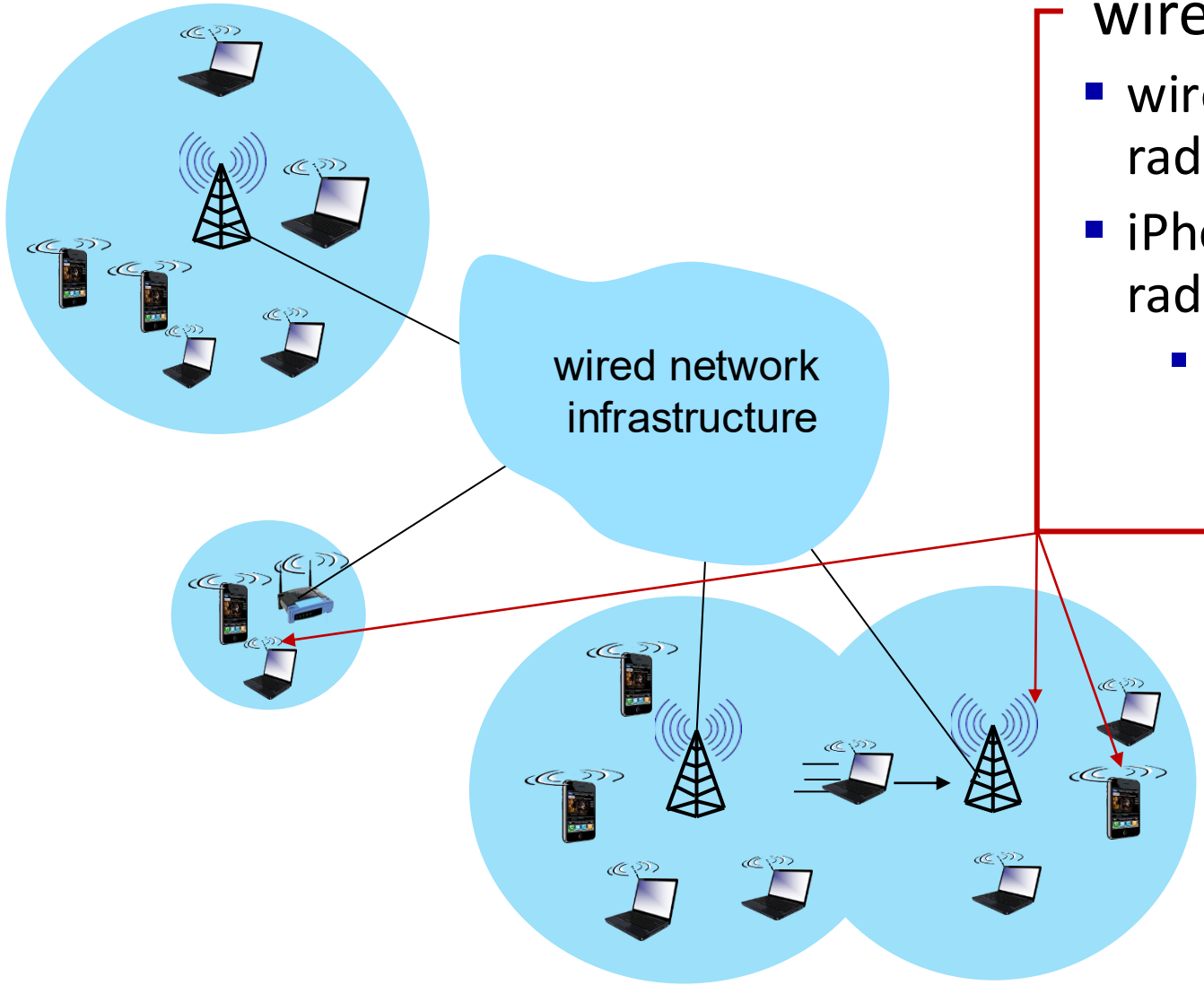
wireless link

- typically used to connect device(s) to base station, also used as backbone link
- multiple access protocol coordinates link access (random access, FDMA, TDMA, CDMA, polling)
- various transmission rates and distances, frequency bands



Ad hoc networks: not all wireless networks are connected into a larger network

Elements of a wireless network



wireless device radio



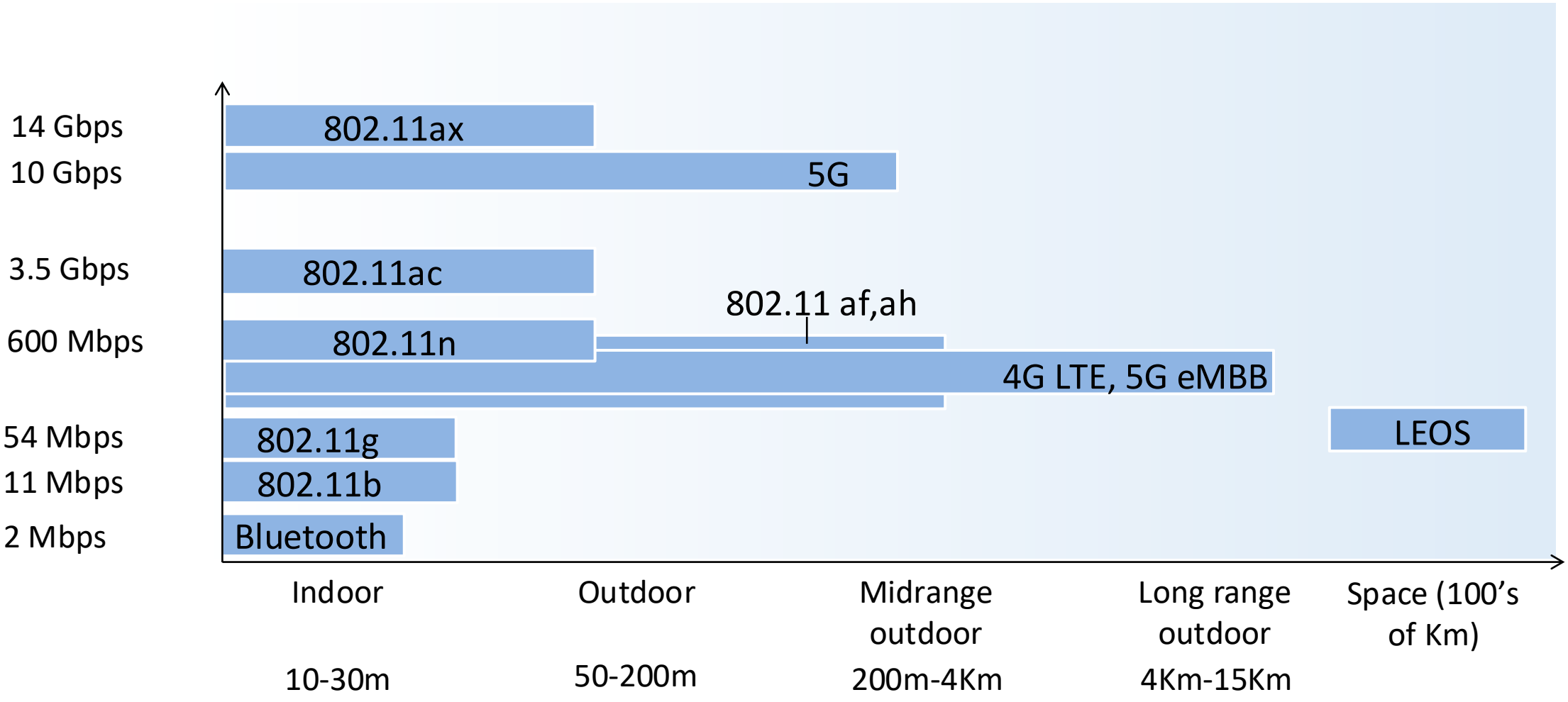
- wireless device has different radios for different networks
- iPhone16: has ~11 different radios, many antennae
  - 5 different cellular radios, WiFi, Bluetooth, UWB, satellite NFC, GPS





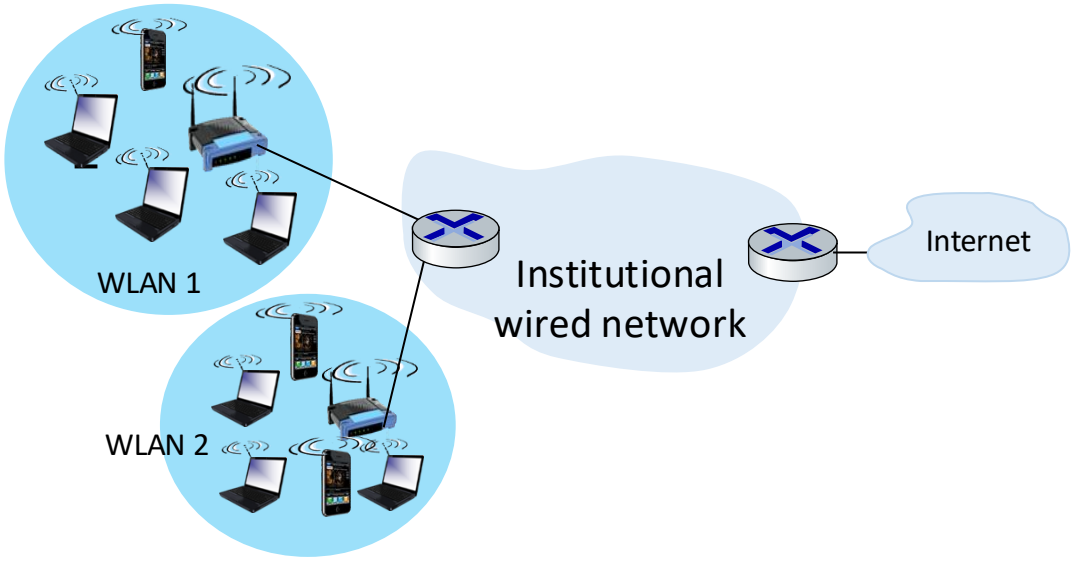
Ad hoc networks: not all wireless networks are connected into a larger network

Characteristics of selected wireless links

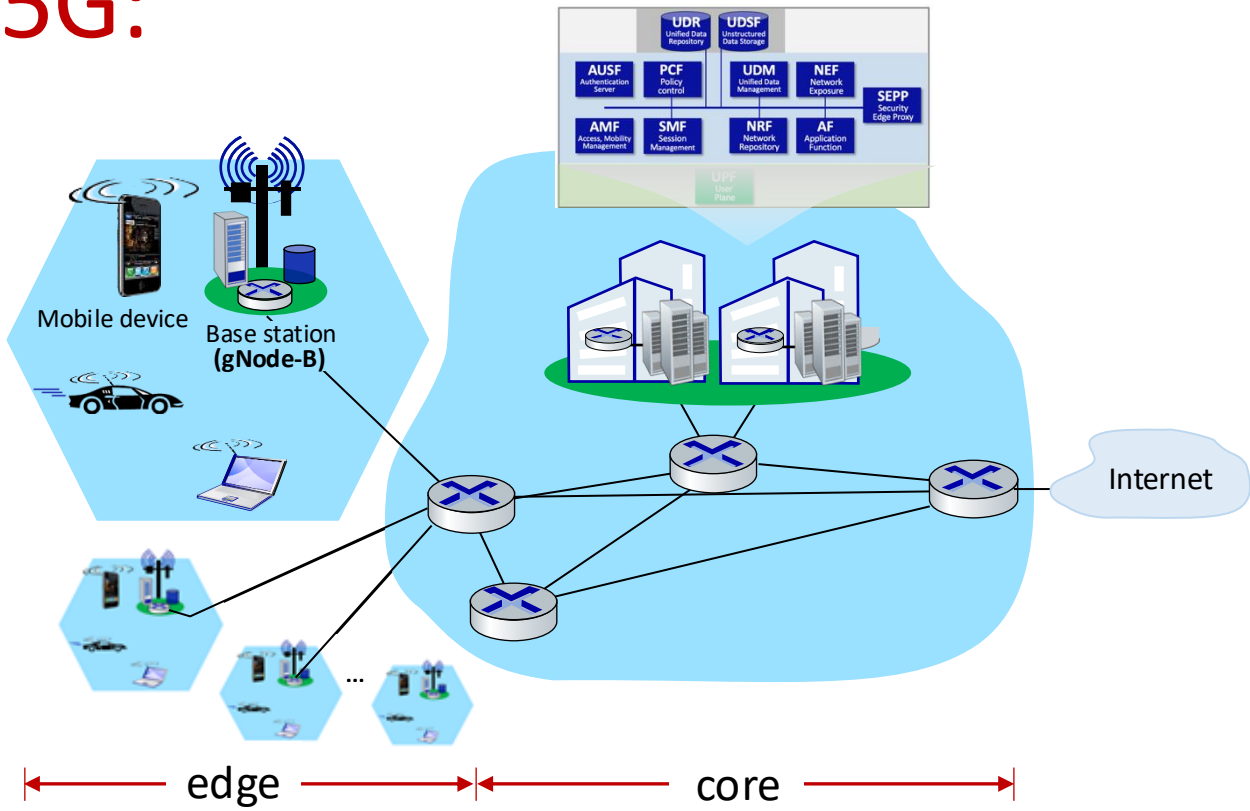


Wireless networks: edge and core networks

WiFi:



5G:



Wireless link characteristics: path loss

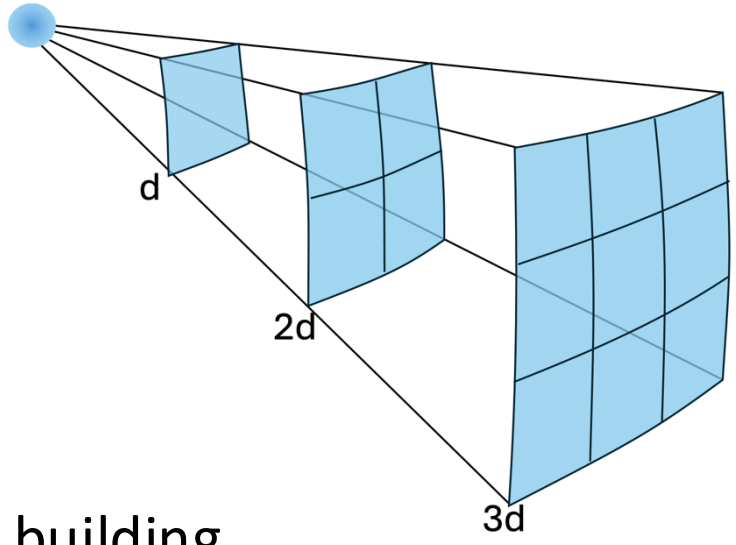
Wireless radio signal attenuates (loses power) as it propagates

path loss

(aka *fading*) reduction in power density (attenuation) of an electromagnetic wave as it propagates from transmitter to receiver

$$\frac{P_{received}}{P_{transmitted}} \sim \frac{1}{(fd)^2}$$

f: frequency
d: distance

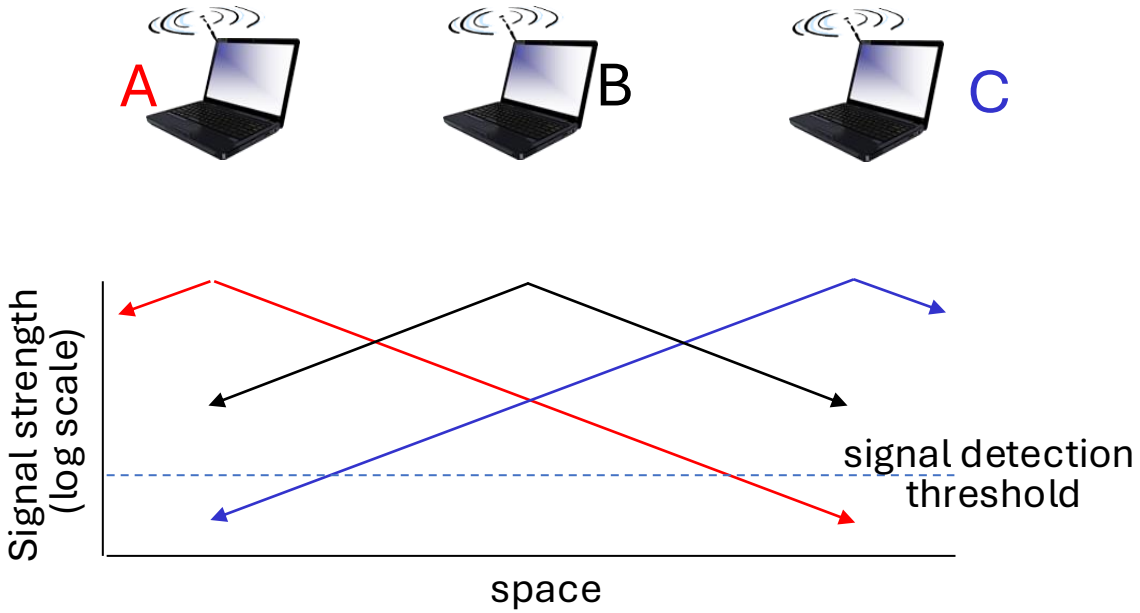


Generalized path loss ~ $(fd)^n$:

- n=2 (free space), n=(2.7,3.5) urban, n= (3,6) in building

"Hidden terminal problem" recalling ~ $(fd)^2$ path loss

Signal fading with~ $(d)^2$ path loss, causes a "hidden terminal" problem:

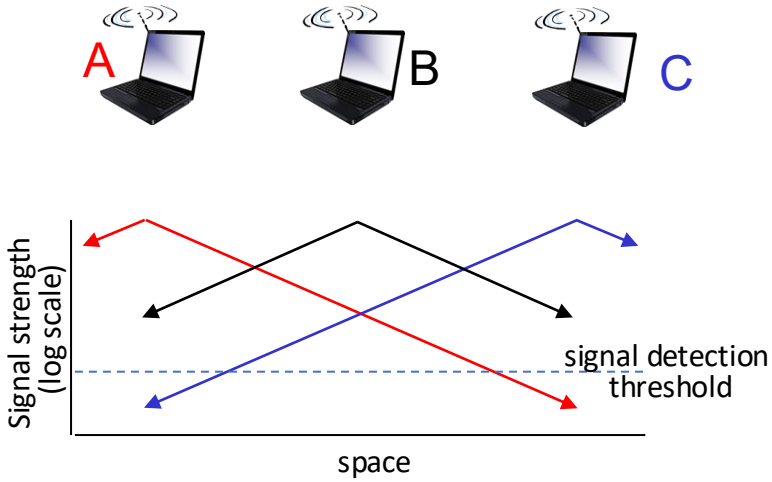


hidden terminals: A and B can hear each other, B and C can hear each other, but A and C can not hear each other

- complicates wireless channel sharing among A, B, C

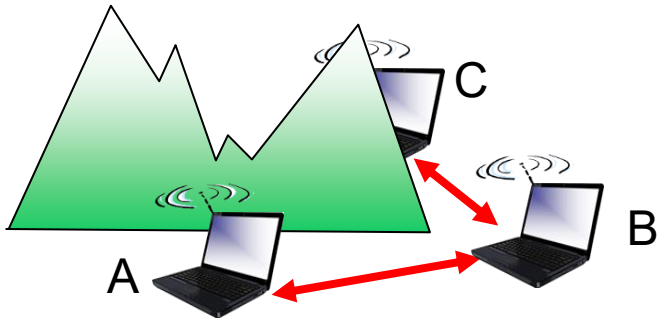
Wireless link characteristics: hidden terminals

Path loss causes “hidden terminals”



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

Objects cause ”hidden terminals”



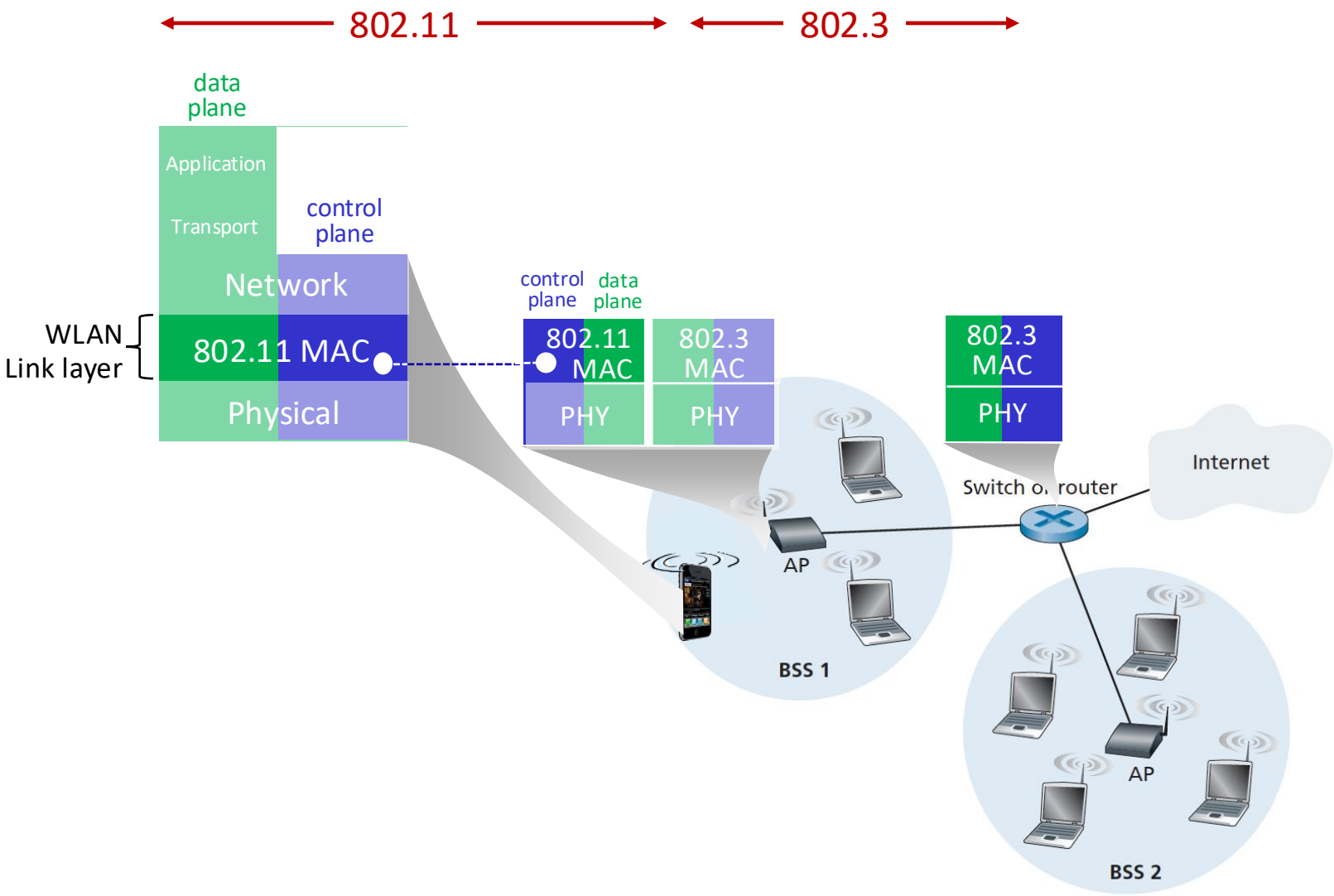
- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

Chapter 7 outline

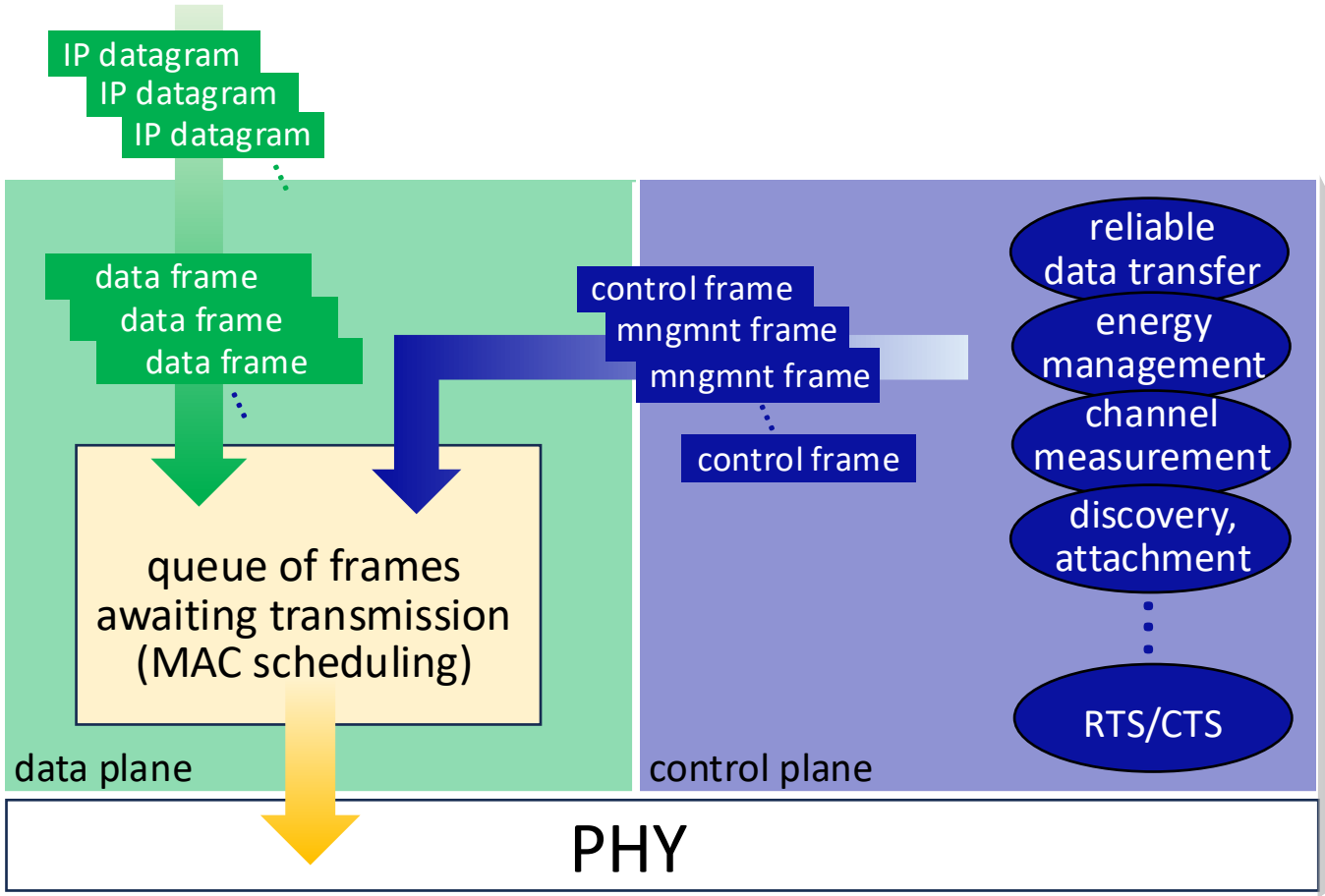
- introduction
- radio: the physical layer
- the wireless *access* network
  - sharing a wireless access channel: OFDMA, CSMA/CA
  - WiFi wireless LAN
  - 5G radio access network
- the wireless core network
  - principles, 5G
- mobility
- Bluetooth, satellite, IoT wireless networks



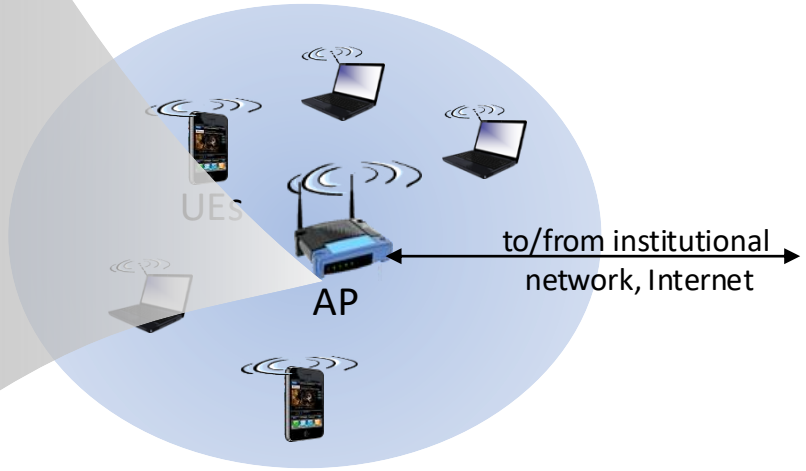
802.11 wireless link layer



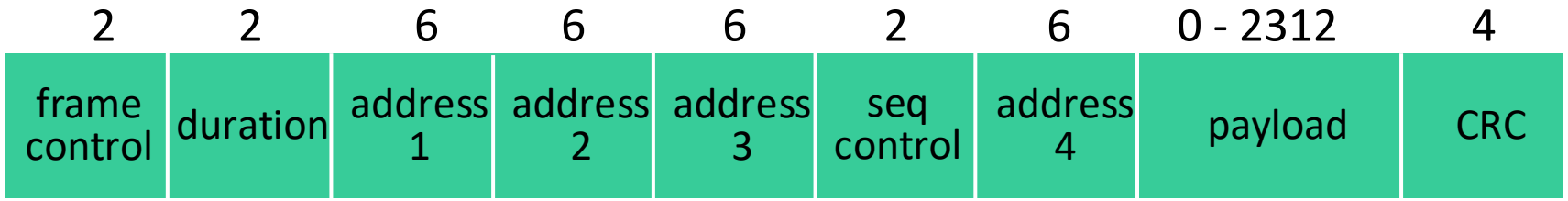
802.11 downlink (AP-to-device) frame flow



- data frames: containing IP datagrams
- Control, management frames



802.11 frame: addressing



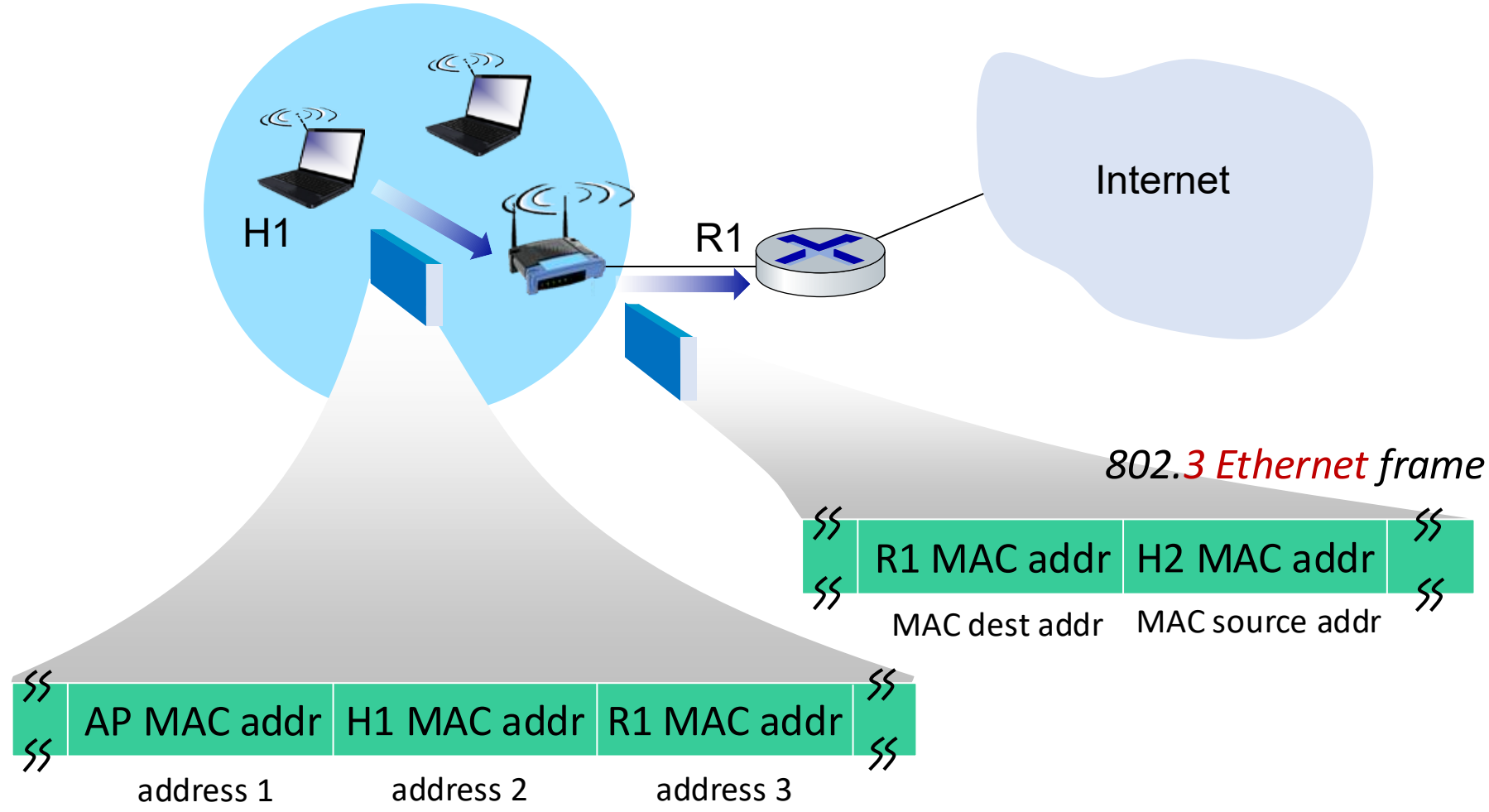
Address 1: MAC address of wireless host or AP to receive this frame

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

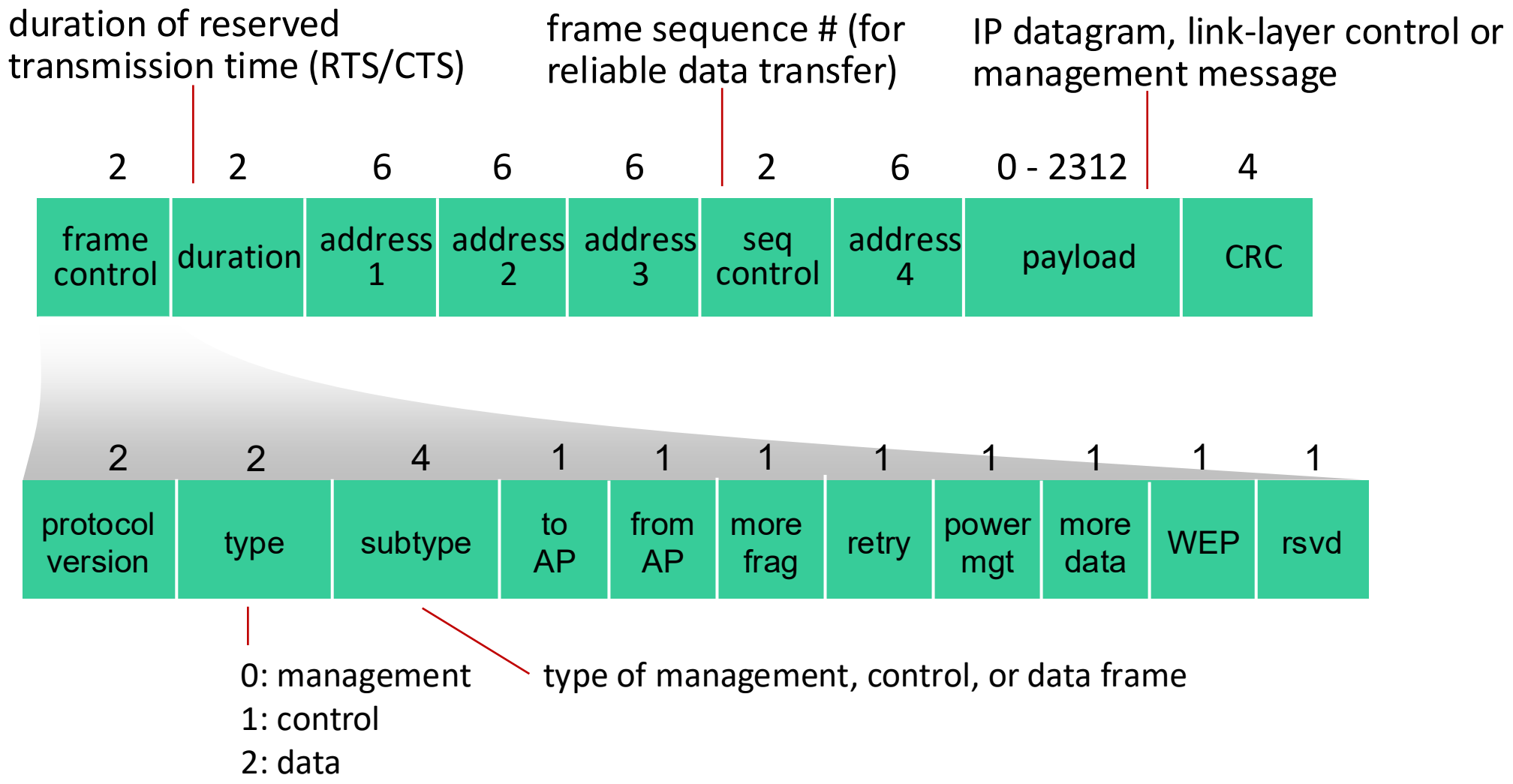
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

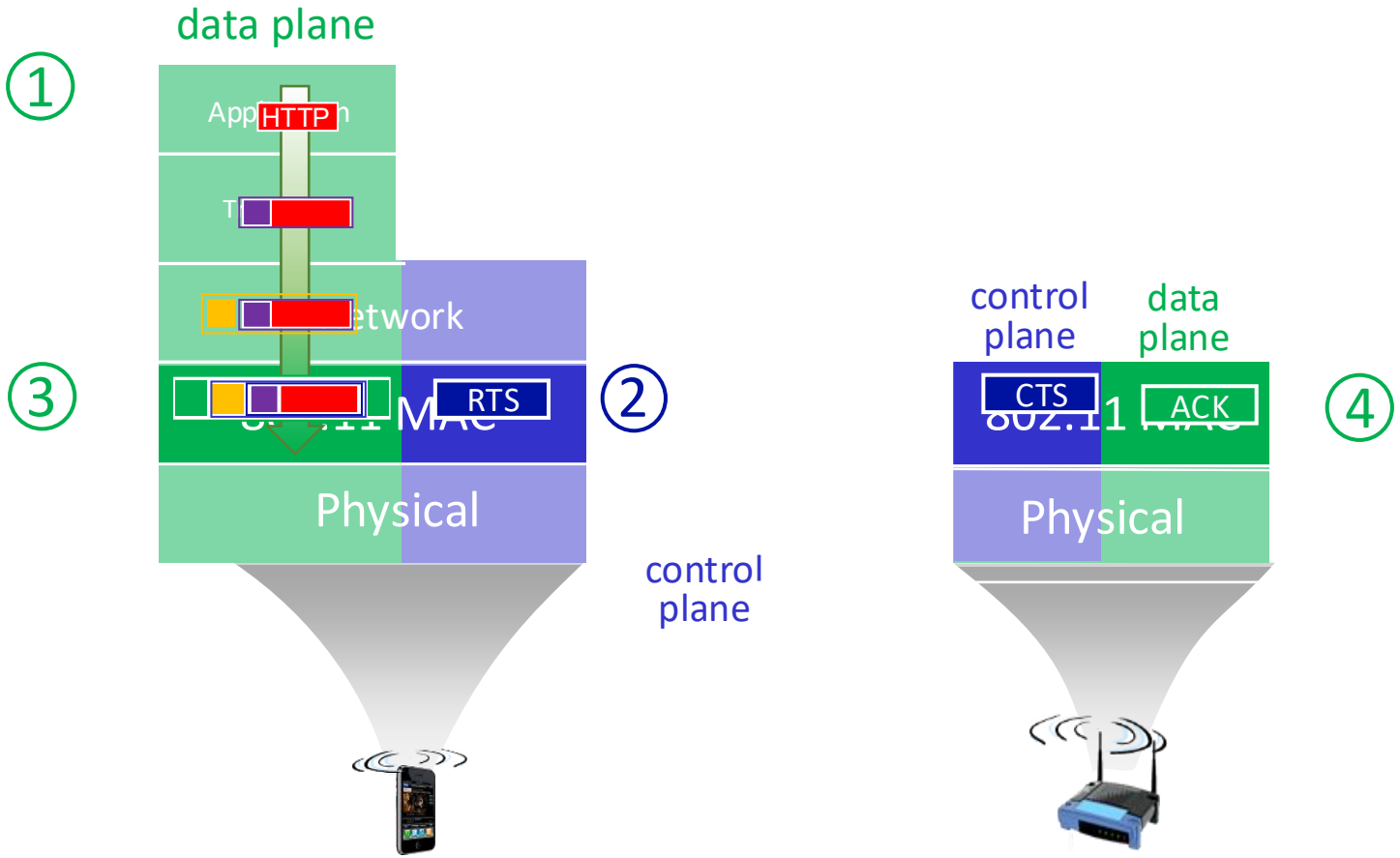
802.11 frame: addressing



802.11 frame


duration of reserved transmission time (RTS/CTS)
frame sequence # (for reliable data transfer)
IP datagram, link-layer control or management message
2
2
6
6
6
2
6
0 - 2312
4
frame control
duration
address 1
address 2
address 3
seq control
address 4
payload
CRC
2
2
4
1
1
1
1
1
1
1
1
protocol version
type
subtype
to AP
from AP
more frag
retry
power mgt
more data
WEP
rsvd
0: management
1: control
2: data
type of management, control, or data frame

Retrospective: "A day in the life"* (WiFi)

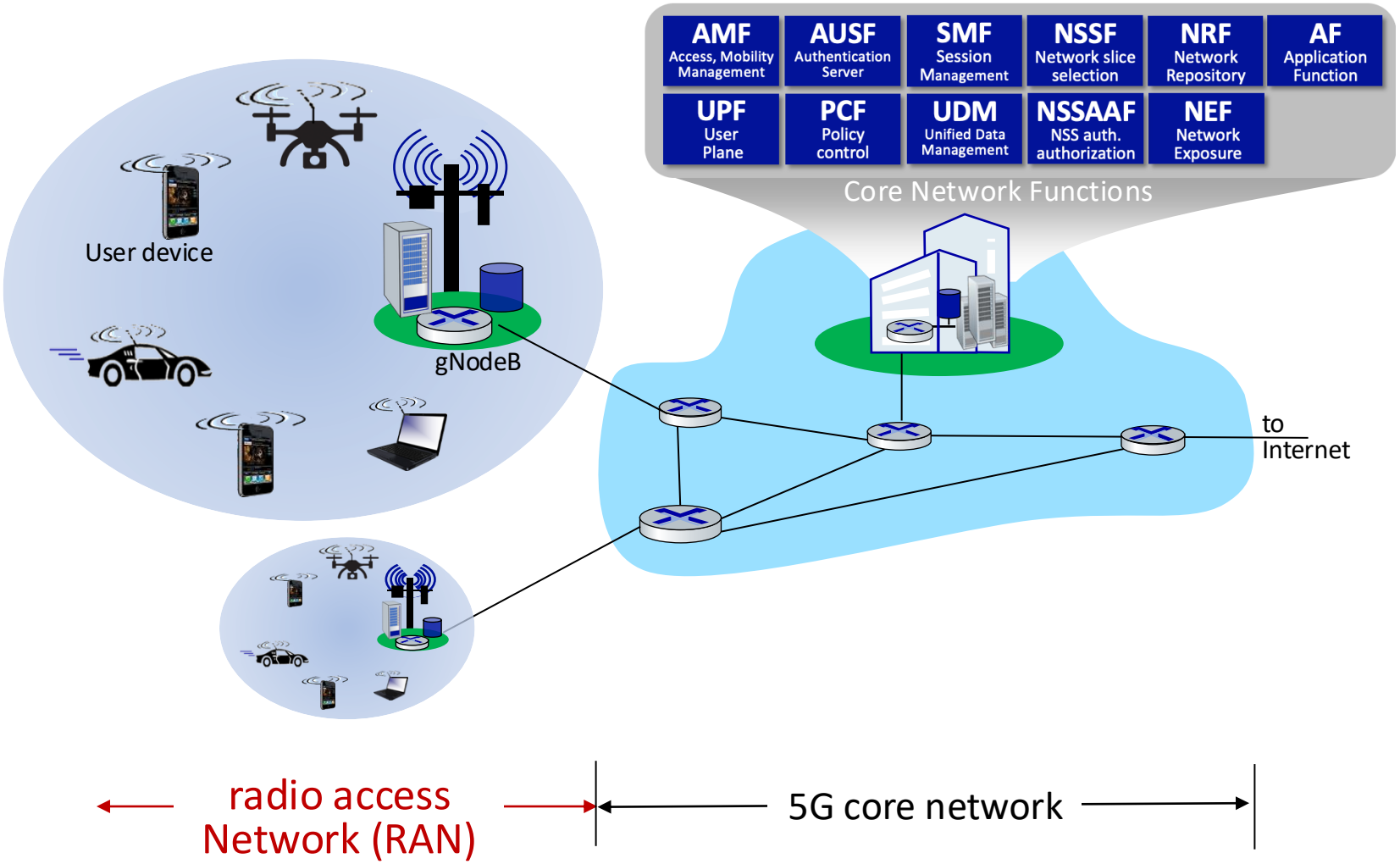


1. HTTP/3 request in UDP segment, in IP datagram, into 802.11 frame. Enter, wait, MAC frame scheduling queue
2. Device sends RTS control frame (using CSMA/CA); AP responds with CTS.
3. Device sends DATA frame to AP. Buffers DATA frame
4. AP responds with ACK, device removes transmitted frame

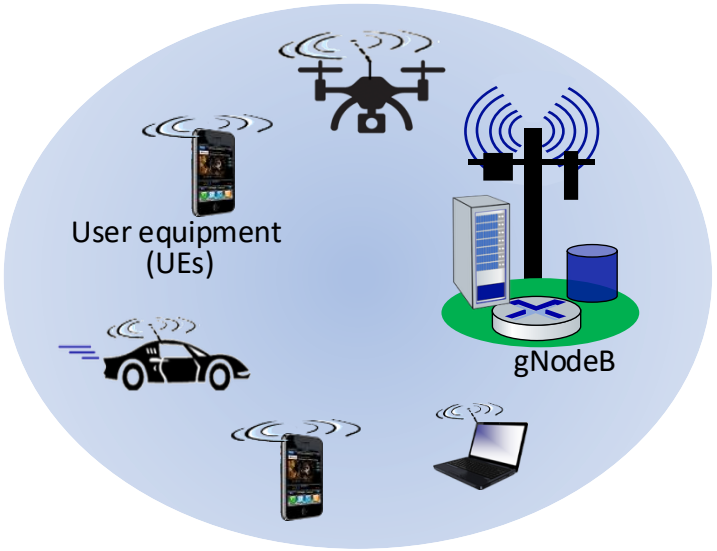
   AP can now forward frame to router

*https://gaia.cs.umass.edu/kurose_ross/videos/6/

Architectural Elements of 5G



5G Radio Access Network (RAN)

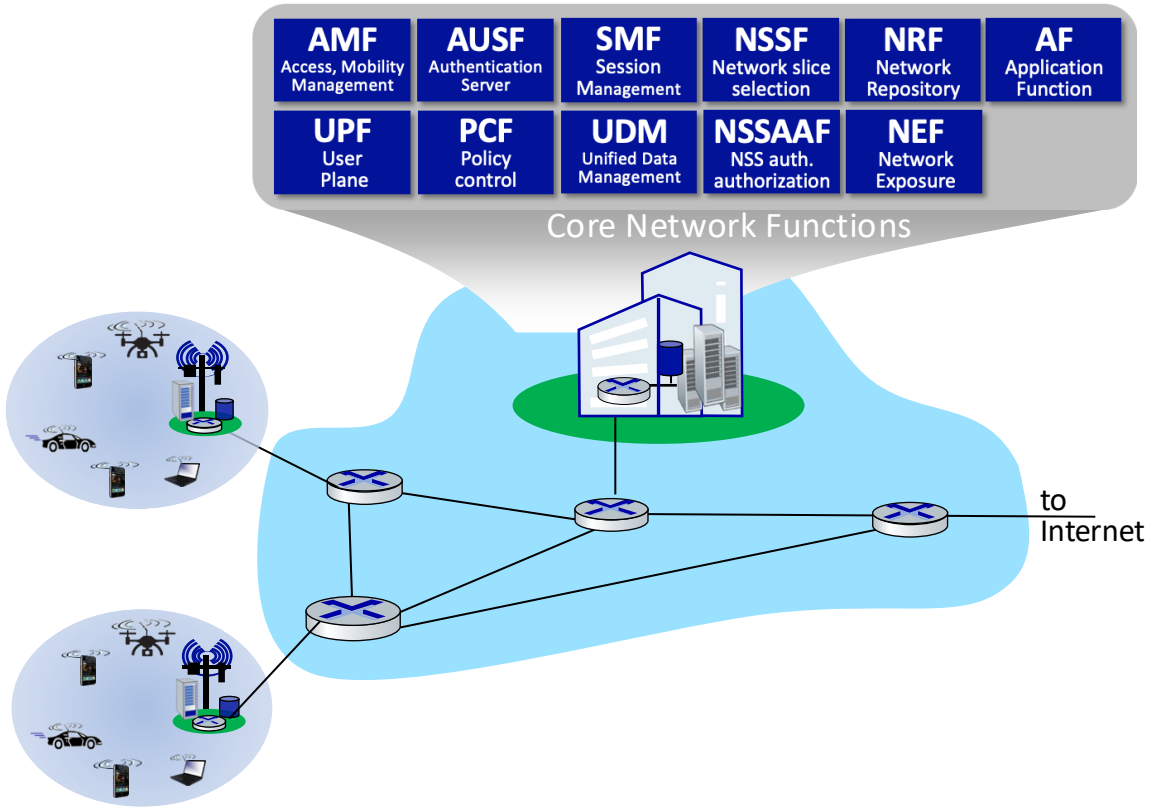


5G RAN: edge network connecting devices to base station

- provides link-layer service, as first hop between devices and larger network
- limited geographic scope
- under control of a single service provider
- somewhat analogous to WiFi LAN
- RAN components:
  - many devices (User Equipment: UE)
  - radio channel (New Radio: NR)
  - one base station (Next Generation Node B: gNodeB, gNB)

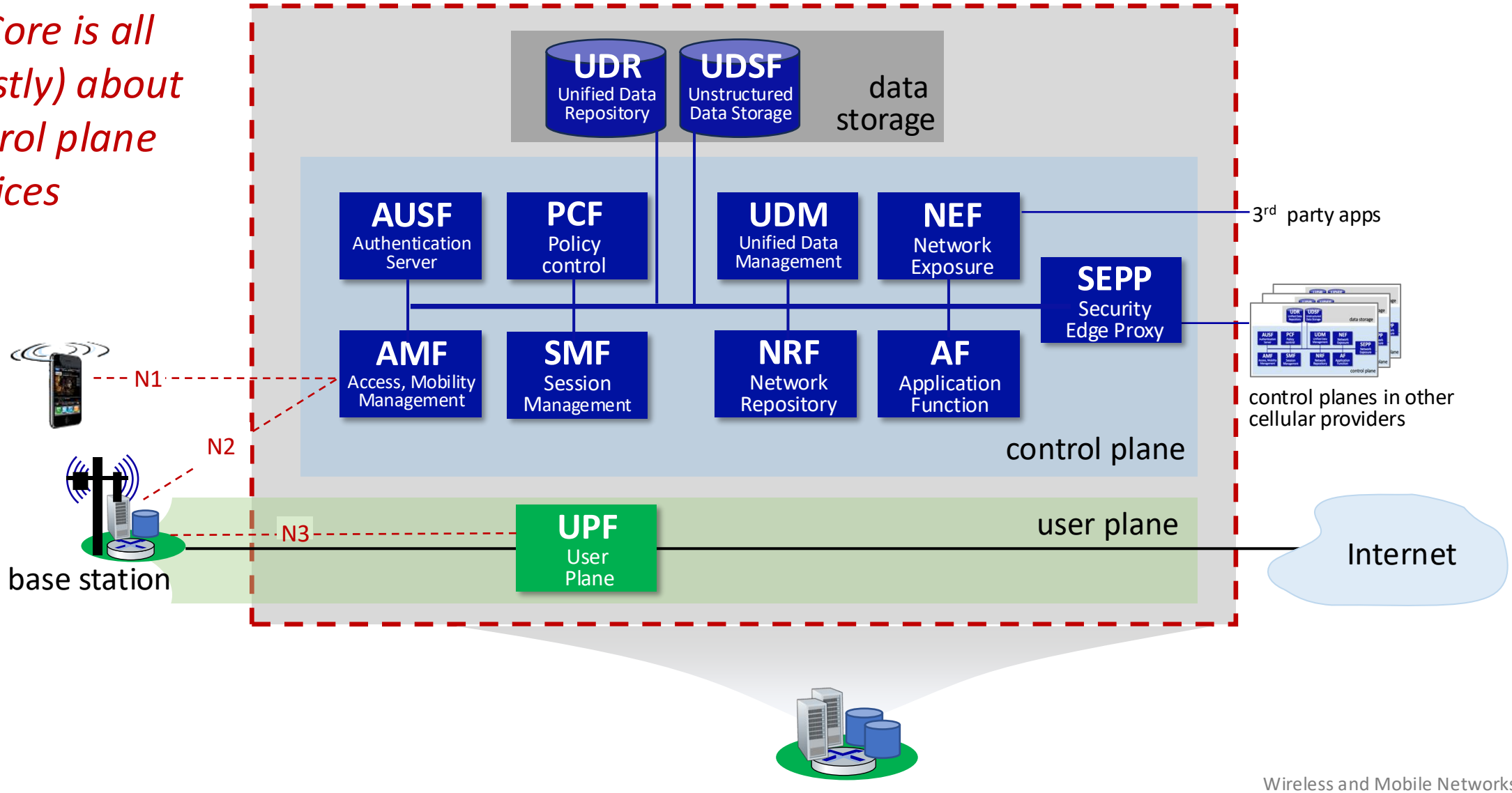
5G Core Network

- Core situated between RAN and other endpoints (Core, larger Internet)
  - single Core; multiple RANs
- consist of links, routers, servers, providing services to devices and base stations
  - "all IP" Core, but very different services than traditional Internet apps
- clear logical separation between control-plane, user plane:
  - *CUPS:* Control-Plane and User-Plane Separation

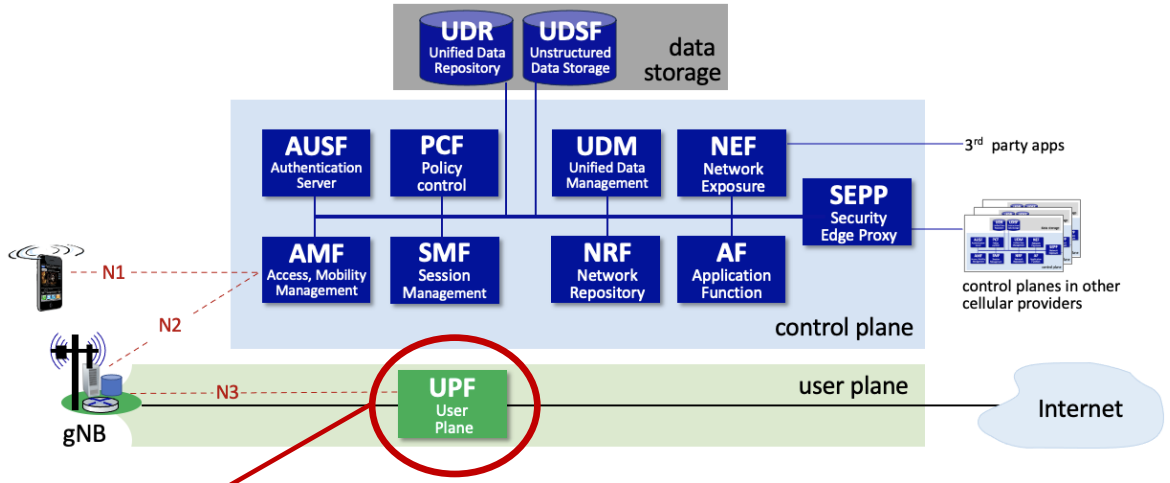


5G Core Functional Components

5G Core is all (mostly) about control plane services



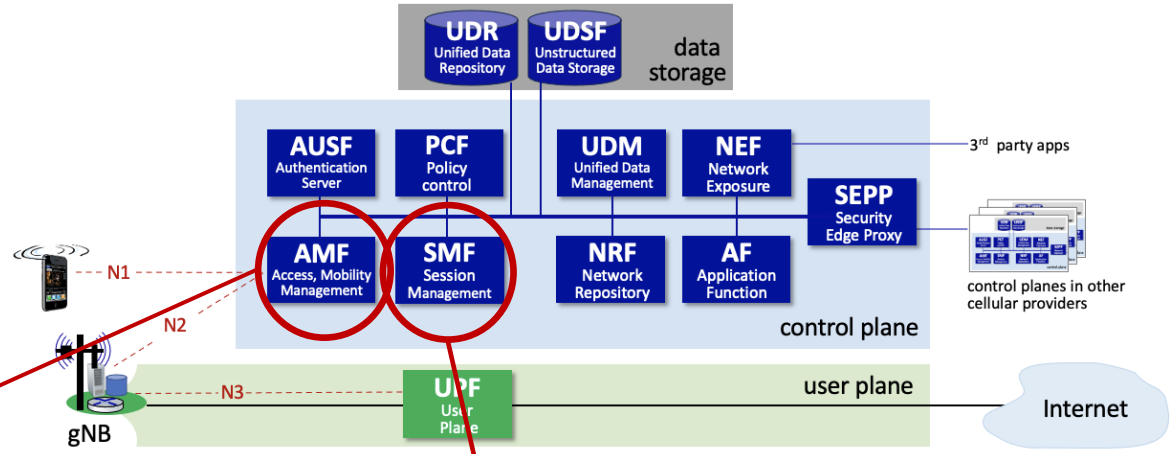
5G Core Functional Components



UPF (User Plane Function)

- each device is assigned to a UPF, which acts as relay, forwarding traffic between UE, Internet
- UPF responsible for policy enforcement, lawful intercept, traffic usage measurement, QoS policing
- responsible for tunneling (i.e., encapsulating, decapsulating) traffic to/from base station over N3 interface

5G Core Functional Components



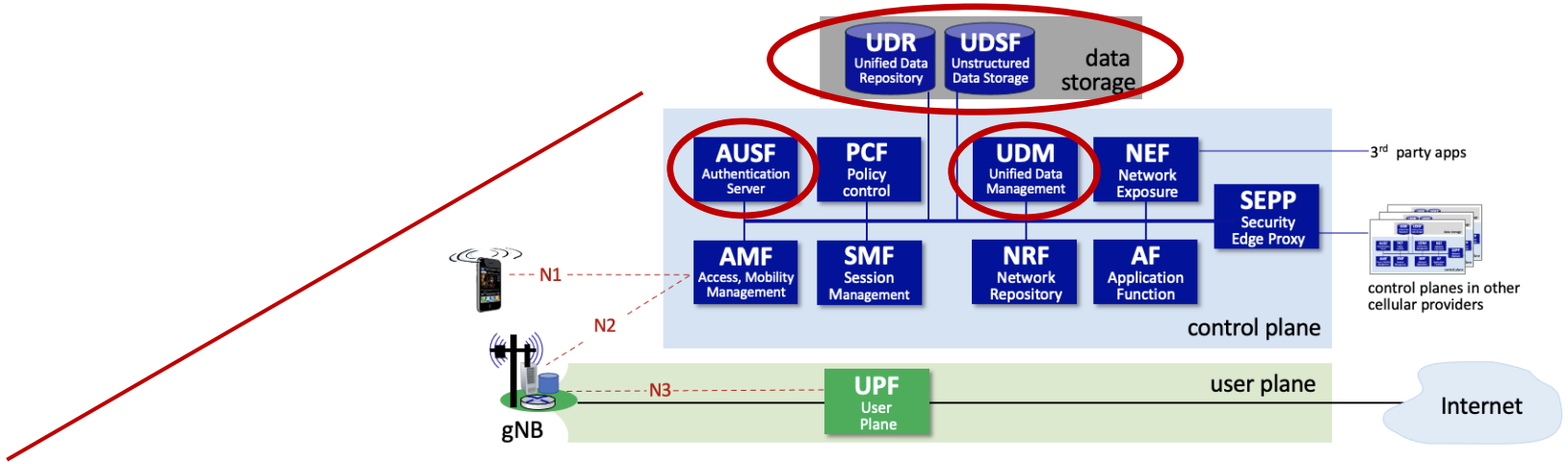
AMF (Access, Mobility Management Function)

- connection, reachability management; mobility management; access authorization; and location services

SMF (Session Management Function)

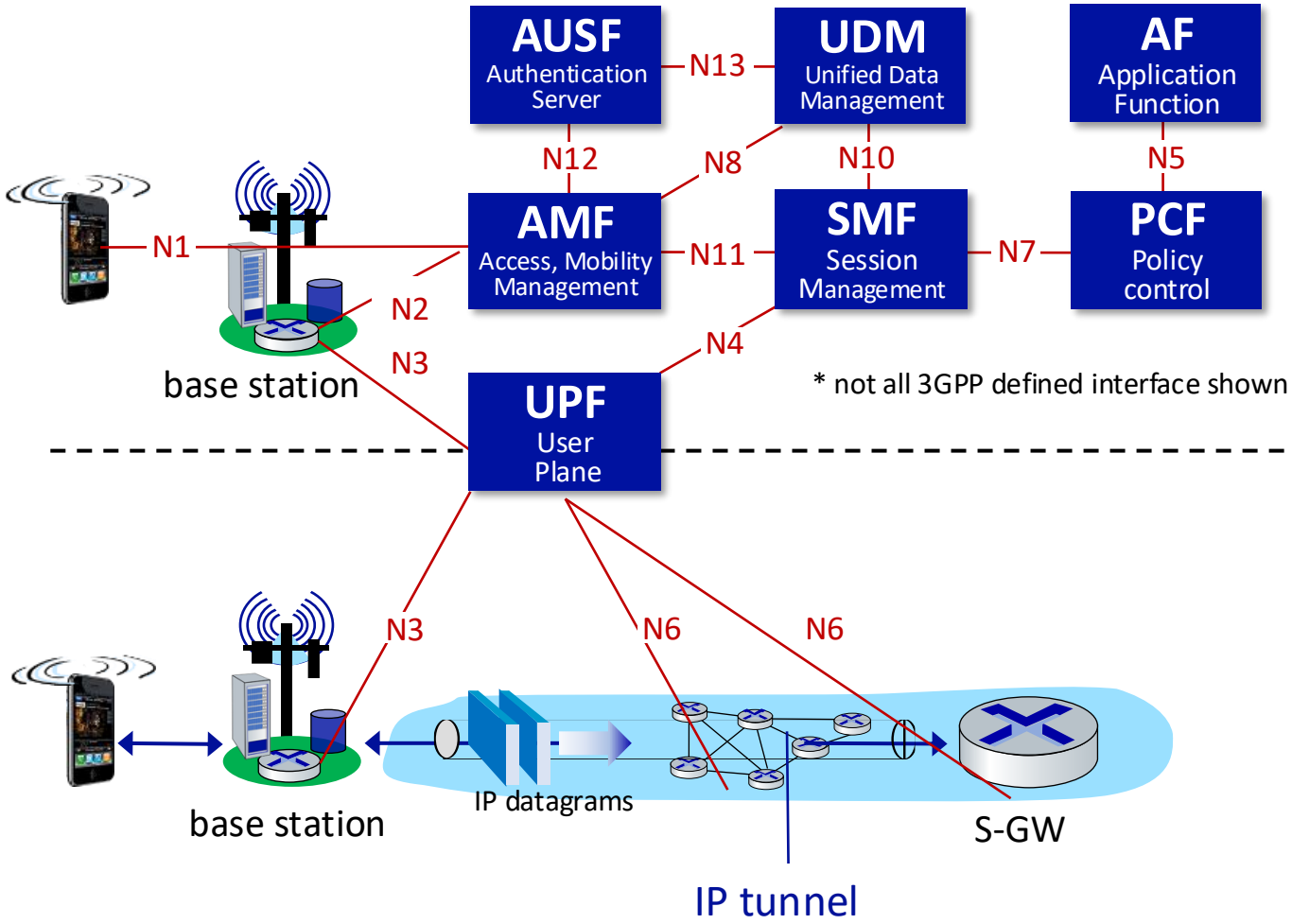
- manages each UE session, including IP address allocation, selection of associated UP function, QoS control, control aspects of UP routing

5G Core Functional Components



- *AUSF (Authentication Server Function):* Authenticates devices.
- *UDM (Unified Data Management):* Manages user identity, including the generation of authentication credentials.
- *UDR (Unified Data Repository):* Manages user static subscriber-related information.
- *UDSF (Unstructured Data Storage Network Function):* Used to store unstructured data, and so is similar to a *Key/Value Store*.

5G interfaces*, control/user -plane separation (CUPS)



control plane

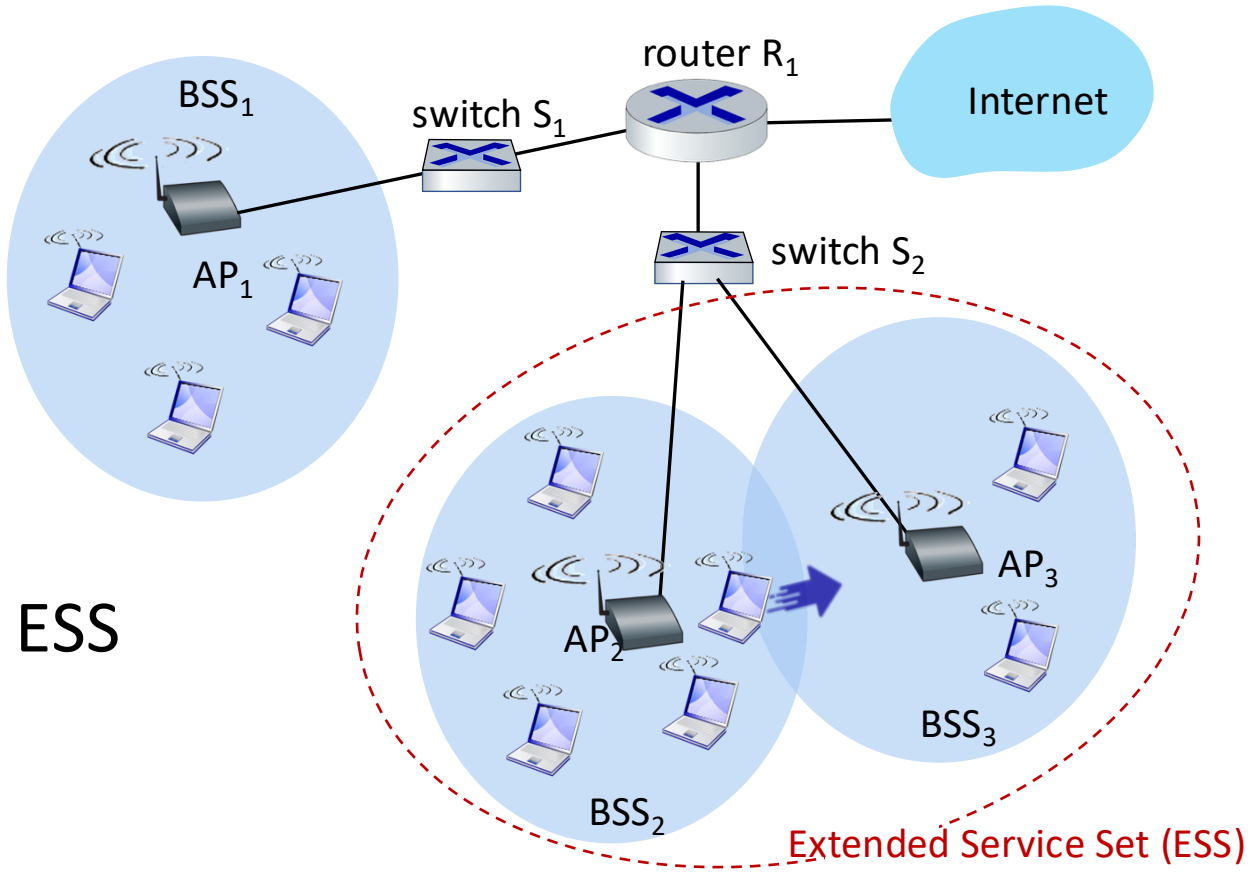
- emphasis on functions and services
- well-defined interfaces defines between services

data plane

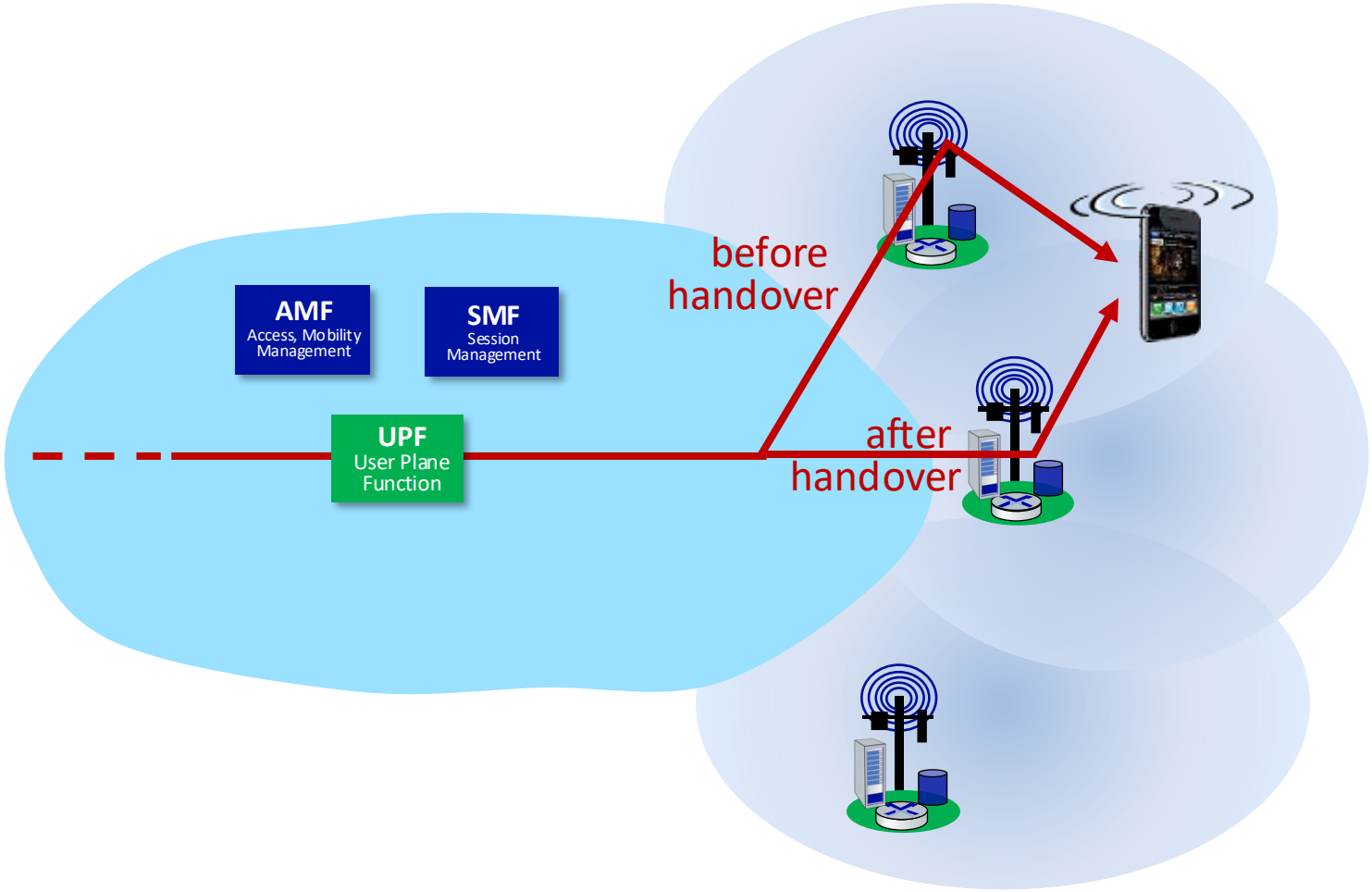
- 5-layer Internet data plane
- extensive use of tunneling

Mobility in a WiFi network

- 802.11: a link-layer standard, takes a link-layer approach towards mobility
- Extended Service Set (ESS): multiple BSS's, in same layer-3 subnet, each with same SSID
- mobility between BSSs in same ESS
  - Fast re-authentication
  - AP can suggest new APs to device
- proprietary (vendor) solutions for enhanced mobility



Mobility in 5G networks: handover



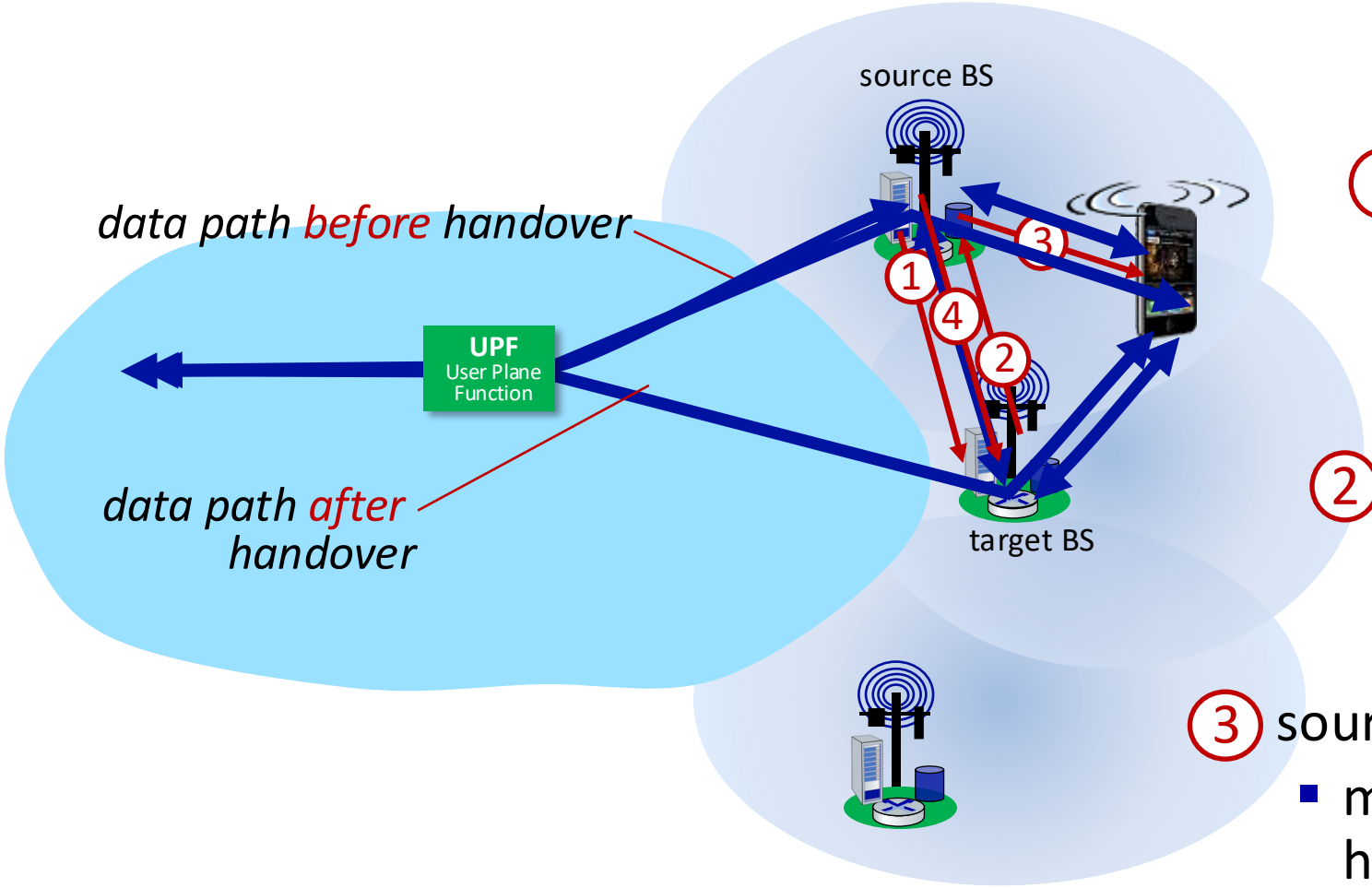
Handover:

- mobile device changes is point of attachment to the network
- data flow to device changes from *source* base station to *target* base station

Why perform handover?

- stronger signal from target base station
- target base station has less devices, less traffic

Mobility in 5G networks: handover



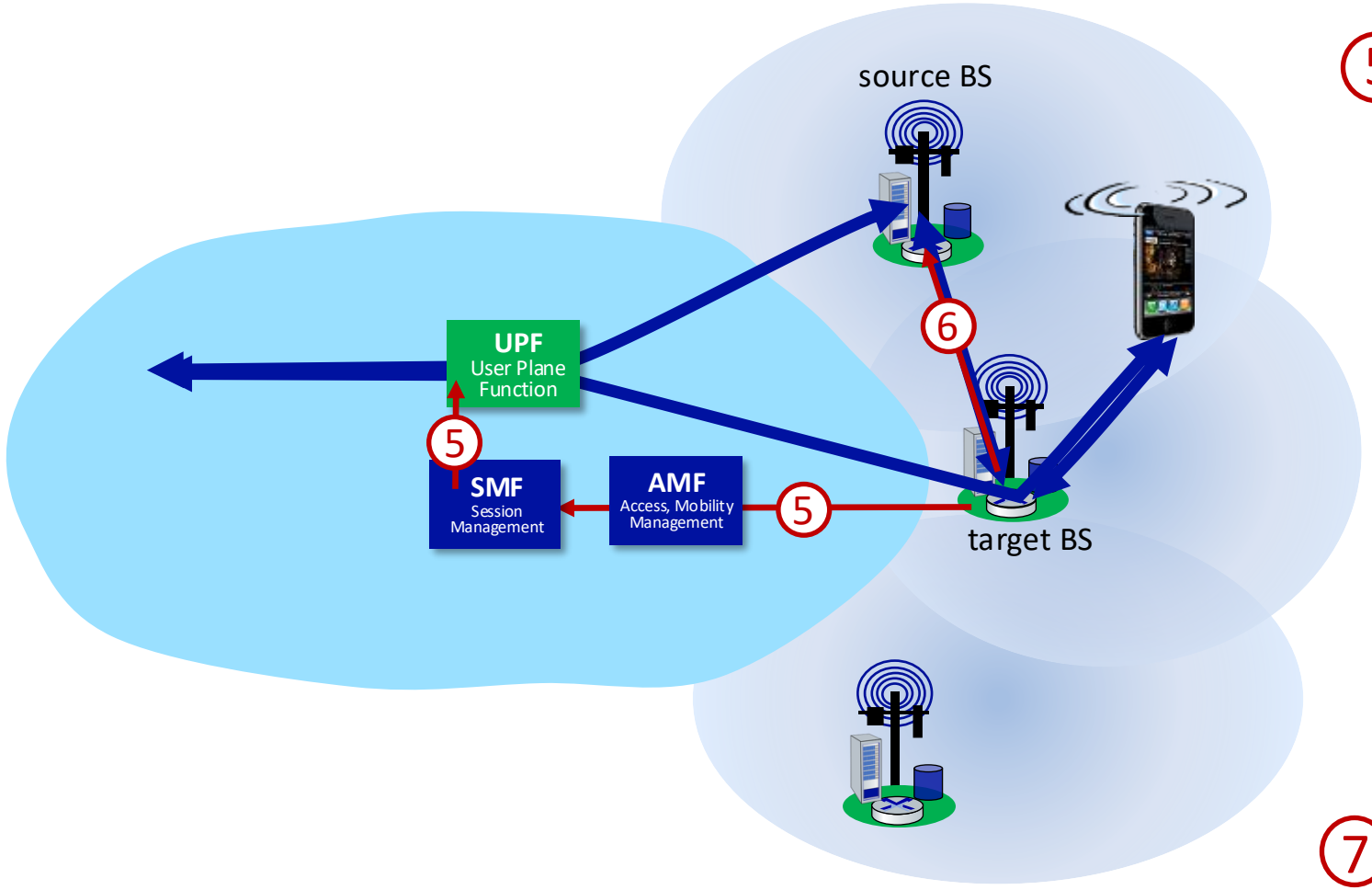
1. current (source) BS selects target BS, sends *Handover Request message* to target BS

2. target BS pre-allocates radio time slots, responds with HR ACK with info for mobile

3. source BS informs mobile of new BS
   - mobile can now send via new BS - handover *looks* complete to mobile

4. source BS stops sending datagrams to mobile, instead forwards to new BS (who forwards to mobile over radio channel)

Mobility in 5G networks: handover



5 target BS informs AMF, SMF that it is new BS for mobile
- SMF instructs UPF to change tunnel endpoint to be (new) target BS

6 target BS ACKs back to source BS: handover complete, source BS can release resources

7 mobile's datagrams now flow through new tunnel from target BS to UPF

Wireless and mobile networks: Summary

- The physical layer: radio
- The wireless *access* network
  - principles, WiFi, 5G
- The wireless core network
  - principles, 5G
- Mobility
- Bluetooth, satellite, IoT wireless networks



For a more extensive treatment of wireless and mobile networks visit: https://gaia.cs.umass.edu/wireless_and_mobile_networks