Introduction to Networking and the Wireless Edge

AI-Edge summer REU program

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Overview of today's REU seminar

- Networking 101 - in 10 minutes
- Wireless networks: motivation, applications
- Architectural components of a wireless network
- 5G: architectural overview
- 5G: selected topics for REU

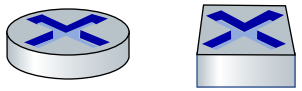
For more information:

- Networking: http://gaia.cs.umass.edu/kurose_ross
- Wireless Networking: https://gaia.cs.umass.edu/wireless_and_mobile_networking

The Internet: a "nuts and bolts" view

Billions of connected computing devices:

- running Internet applications
- *clients, servers*
- 5.3 B Internet users (2024)



Packet switches: forward packets (chunks of data)

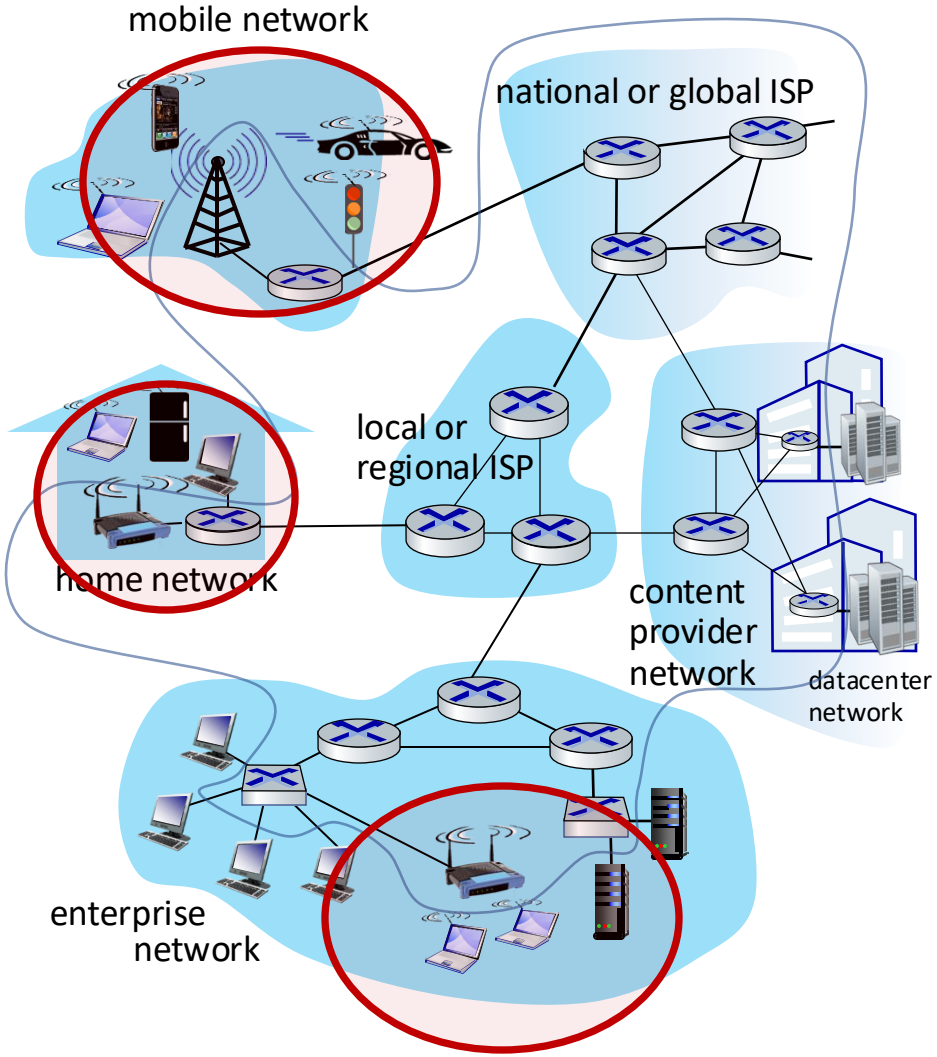
- *routers, switches*

Communication links

- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

Networks

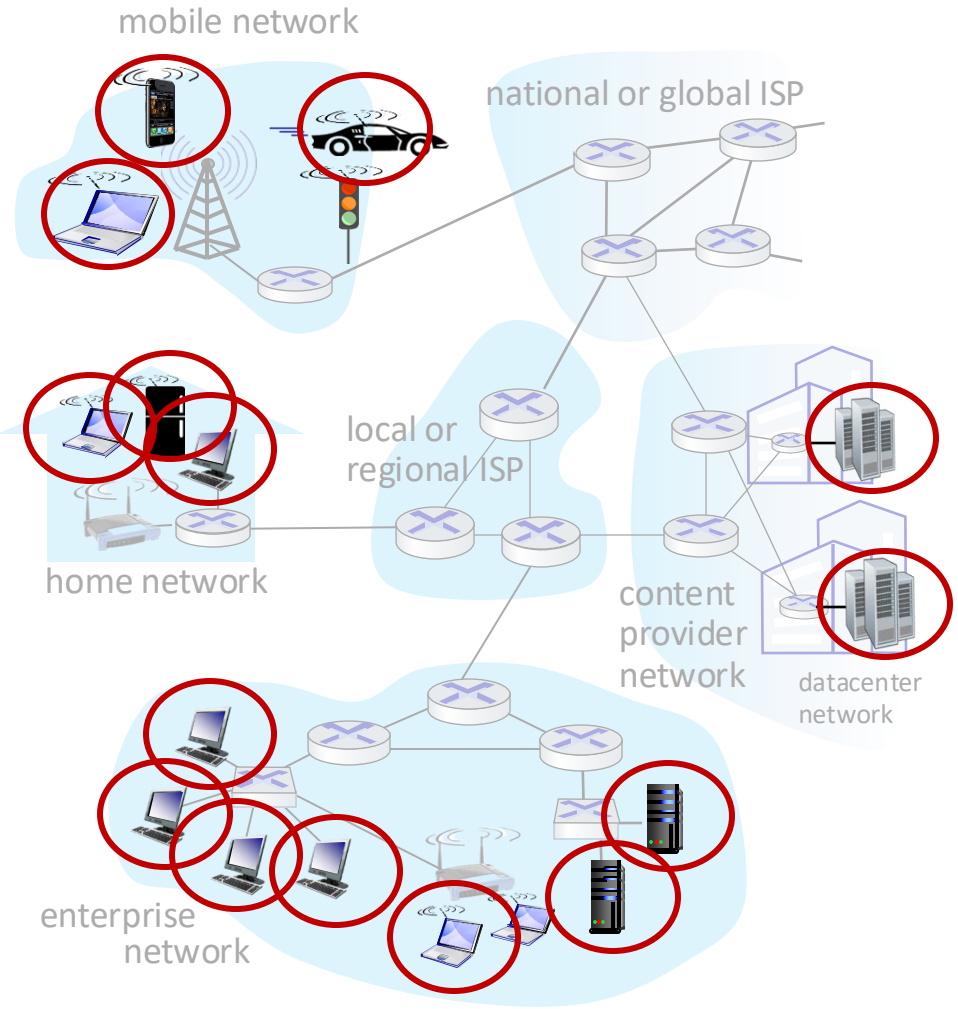
- collection of devices, routers, links: managed by an organization



What is the Internet: a “nuts and bolts” view

Network edge:

- user devices at network edge: clients
- servers often in data centers



Internet-connected devices (not just computers)

Amazon Echo

Internet refrigerator

IP picture frame

Tweet-a-watt: monitor energy use

laptop

bikes

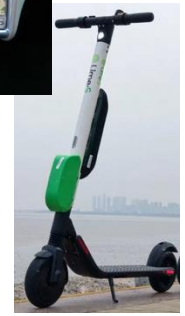
Web-enabled toaster + weather forecaster

wireless and mobile devices

cars

Security Camera

Slingbox: remote control cable TV



scooters

sensor

Fitbit

AR devices

Internet phones

Gaming devices

diapers

Pacemaker & Monitor

What is the Internet: a “nuts and bolts” view

Network devices:

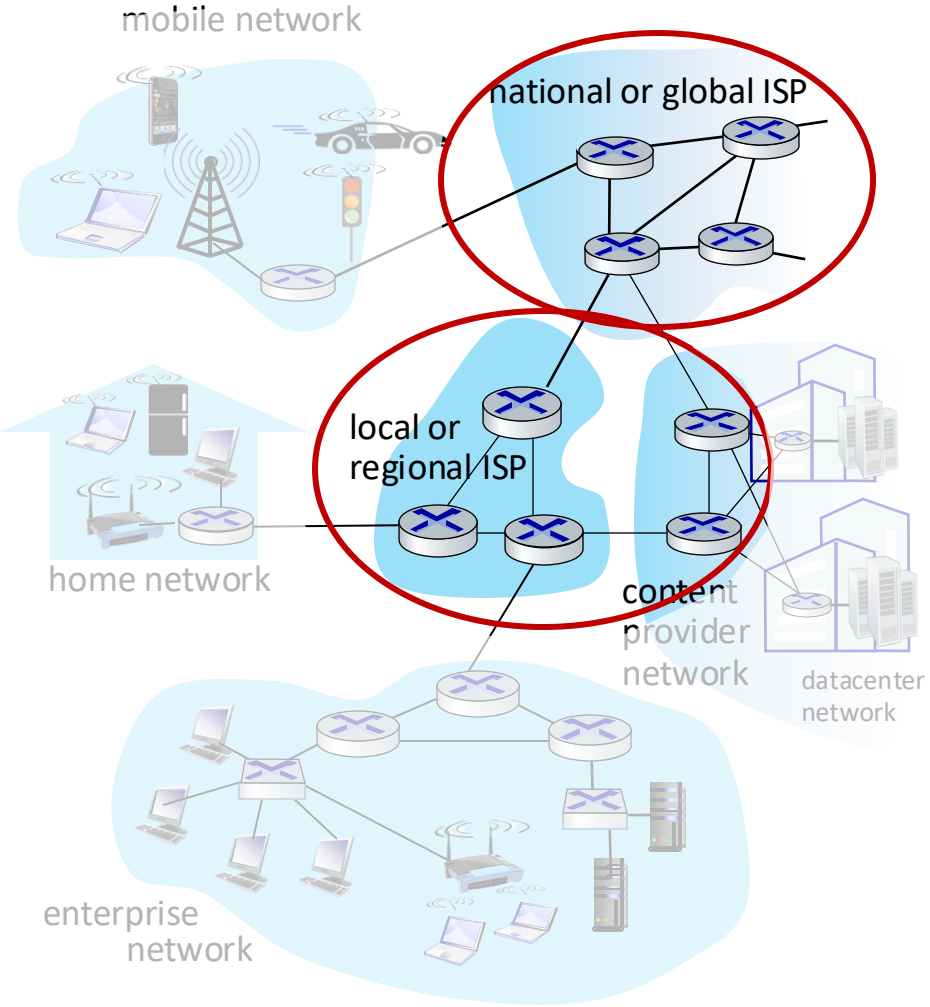
- user devices: aka “clients”
- servers often in data centers

Network edge:

- devices, servers connect directly to access networks: (Comcast, Verizon, UMass, company networks)

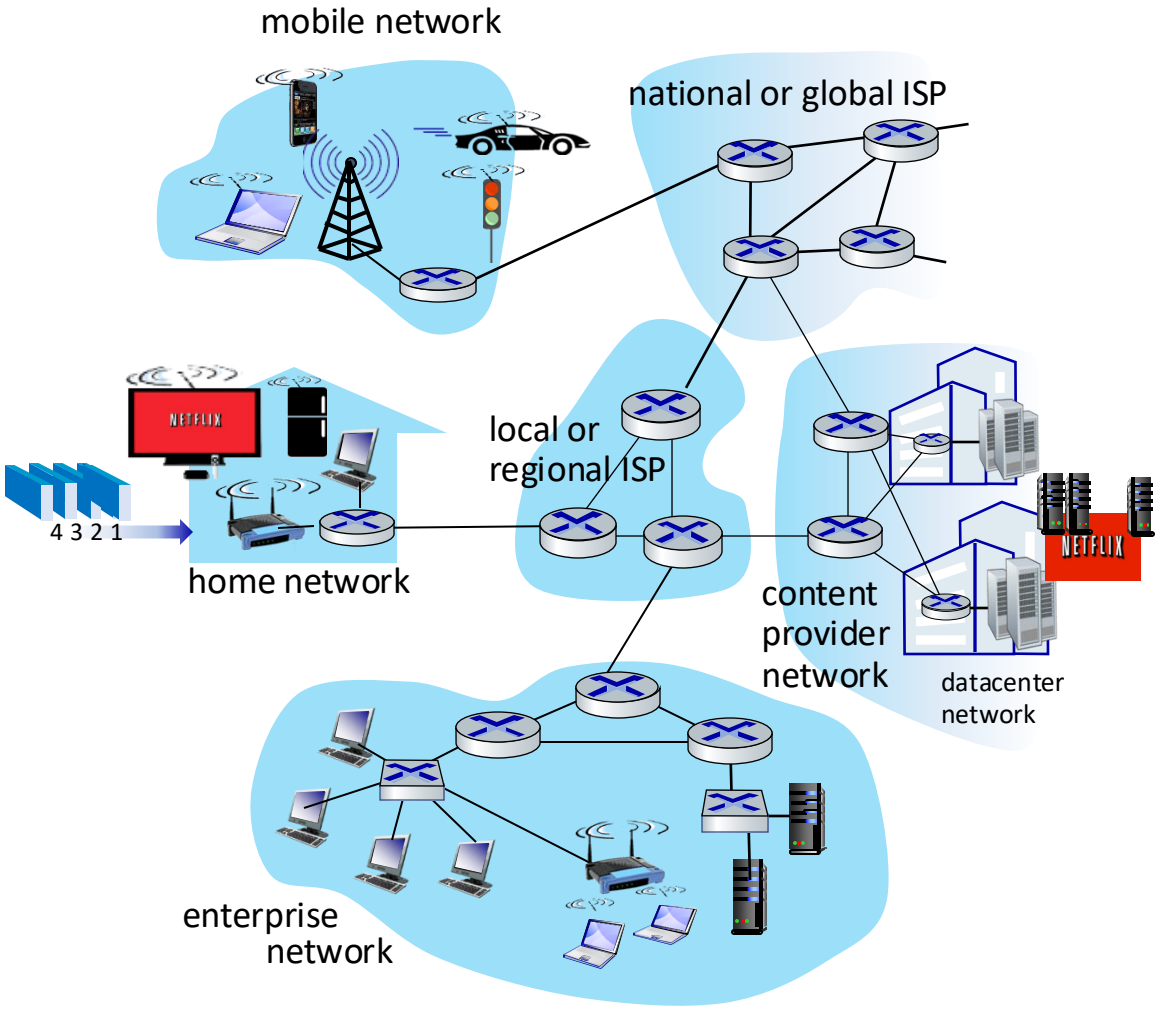
Network core:

- interconnected regional, national, global Internet Service Providers (ISPs): AT&T, Sprint, Level-3, NTT
- interconnected global company networks (e.g., Google, Facebook)



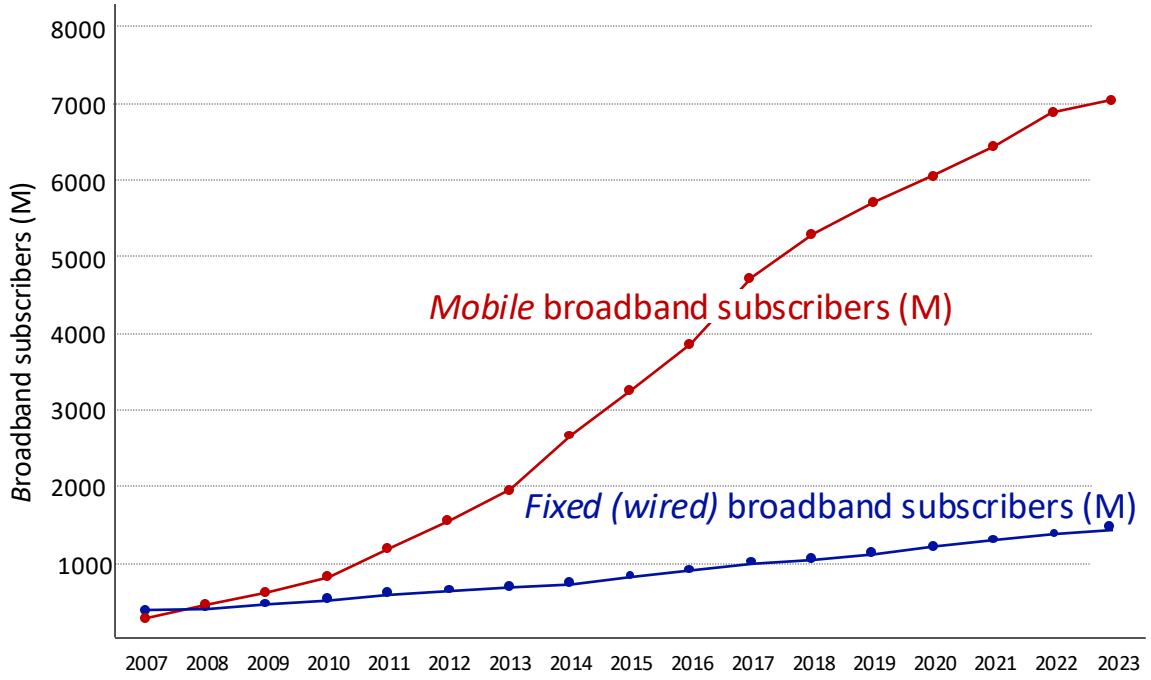
Packet switching

- hosts break application-layer messages into *packets*
- network forwards packets from one router to the next, across links on path from source to destination
- destination re-assembles packets into application message



Wireless and Mobile Networks: context

- more mobile-broadband-connected (cellular) devices than fixed-broadband-connected devices devices (5-1 in 2025)!
  - wireless connectivity even great when WiFi users considered (80% of broadband homes use WiFi)



Data source: www.statista.com (1/25)

Wireless and Mobile Networks: context

Majority of Internet web site traffic directed to mobile (rather than fixed) devices

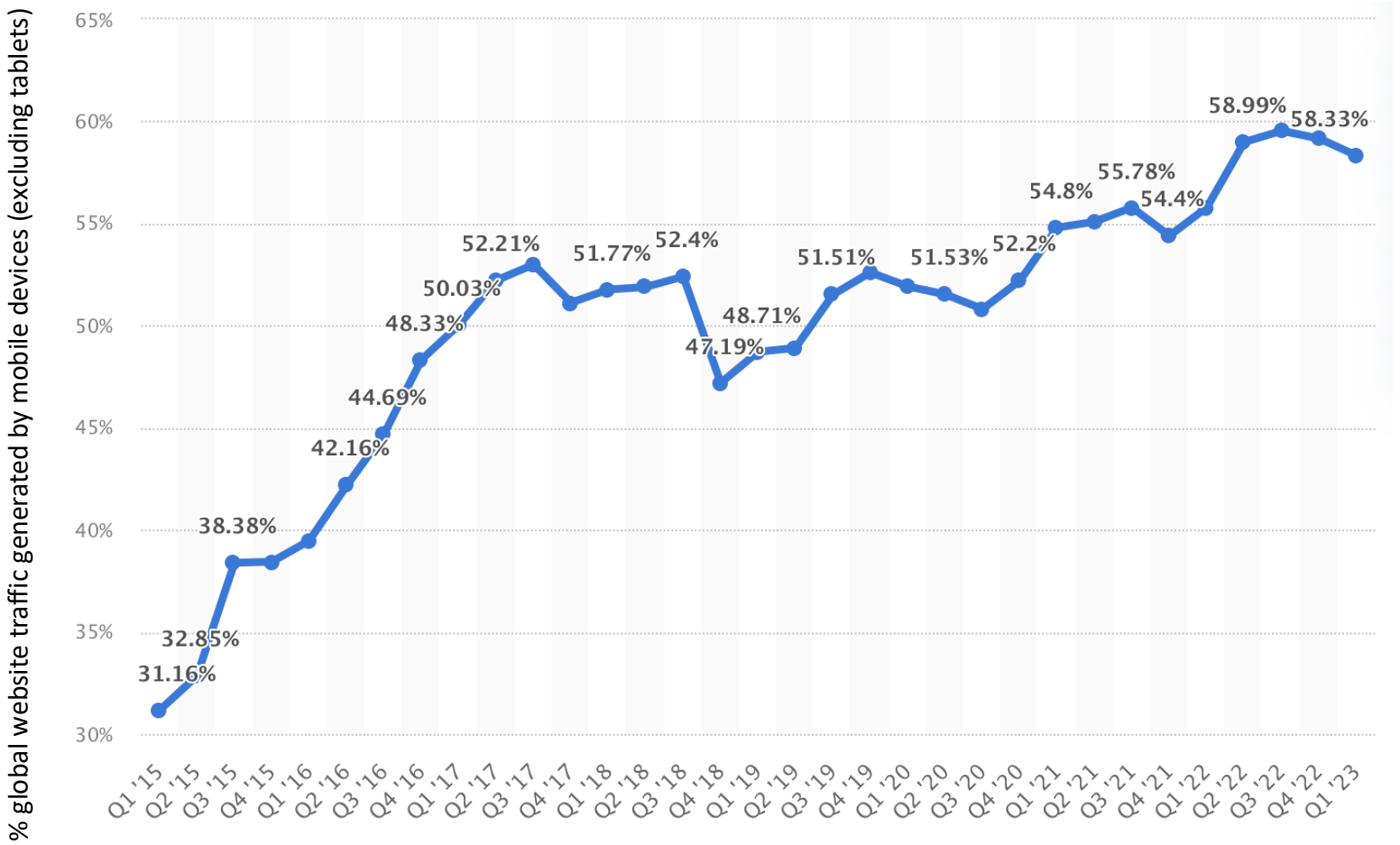


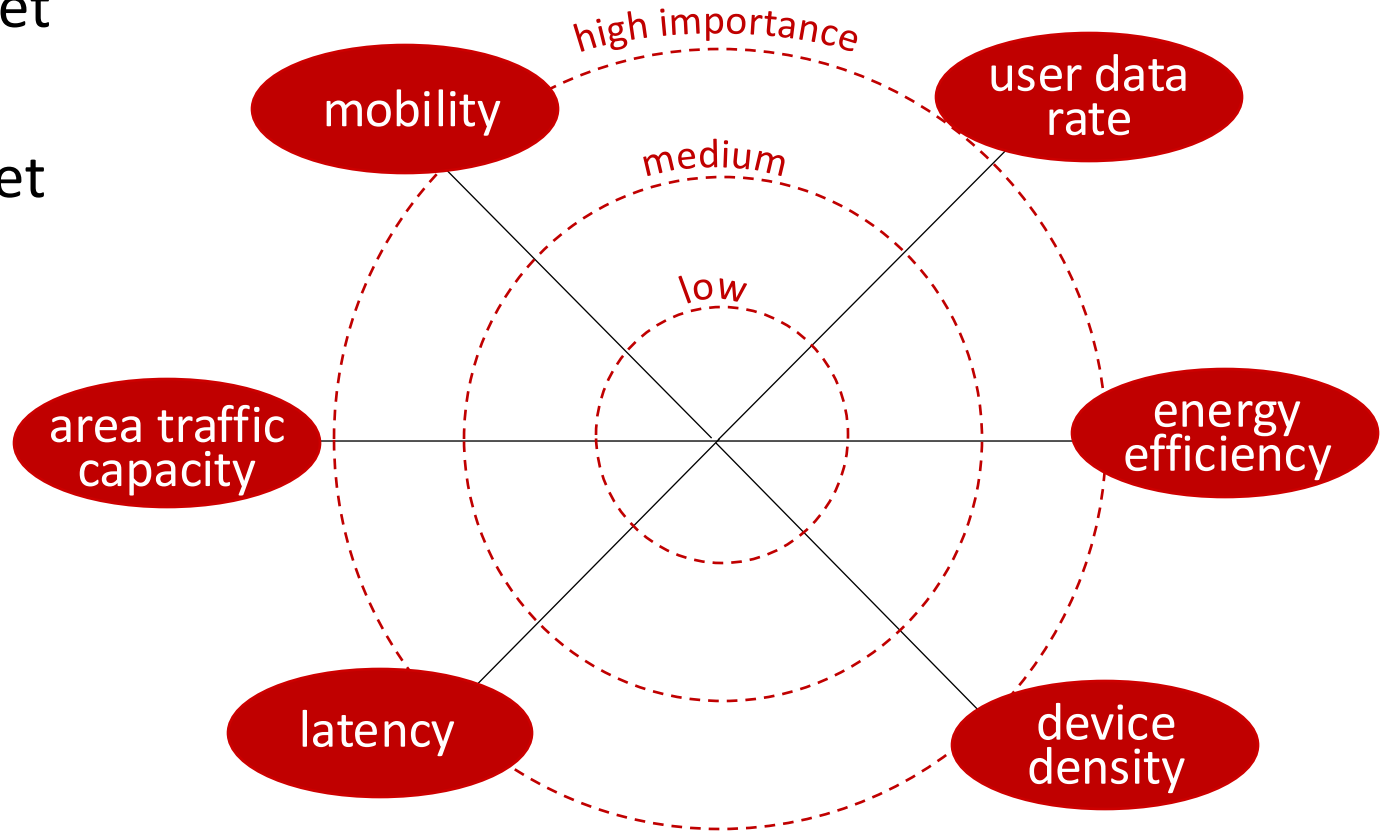
Image source: www.statista.com (11/23)

Wireless applications their needs

Six application areas :

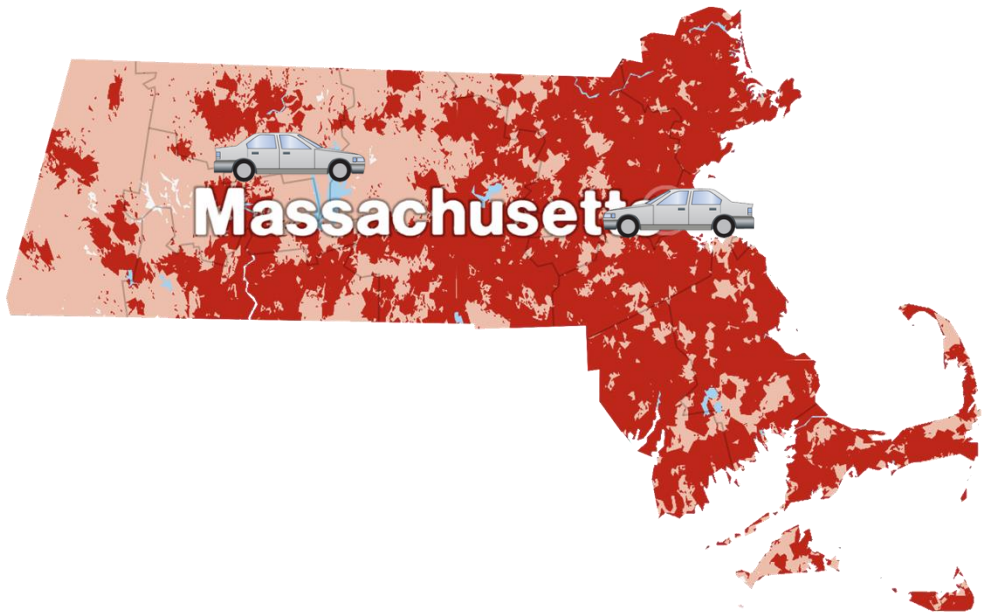
- Wide-area Mobile Wireless Internet Access
- Local-area Mobile Wireless Internet Access
- Fixed Wireless Internet Access
- Satellite Networks for Internet Access and Sensing
- Cable replacement
- Internet of Things (IoT)

Application needs:

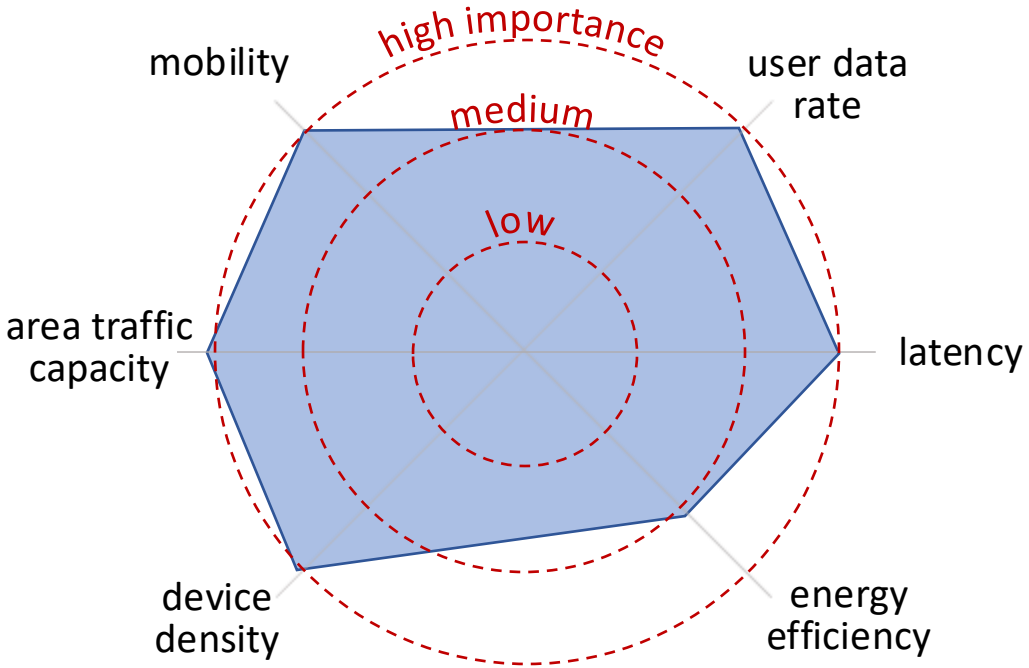


Wide-area Mobile Wireless Internet Access

- device ranges over tens or hundreds of miles while maintaining *continuous* Internet connectivity (e.g., VoIP, streaming, ongoing TCP connection)
- *only* provided by cellular networks



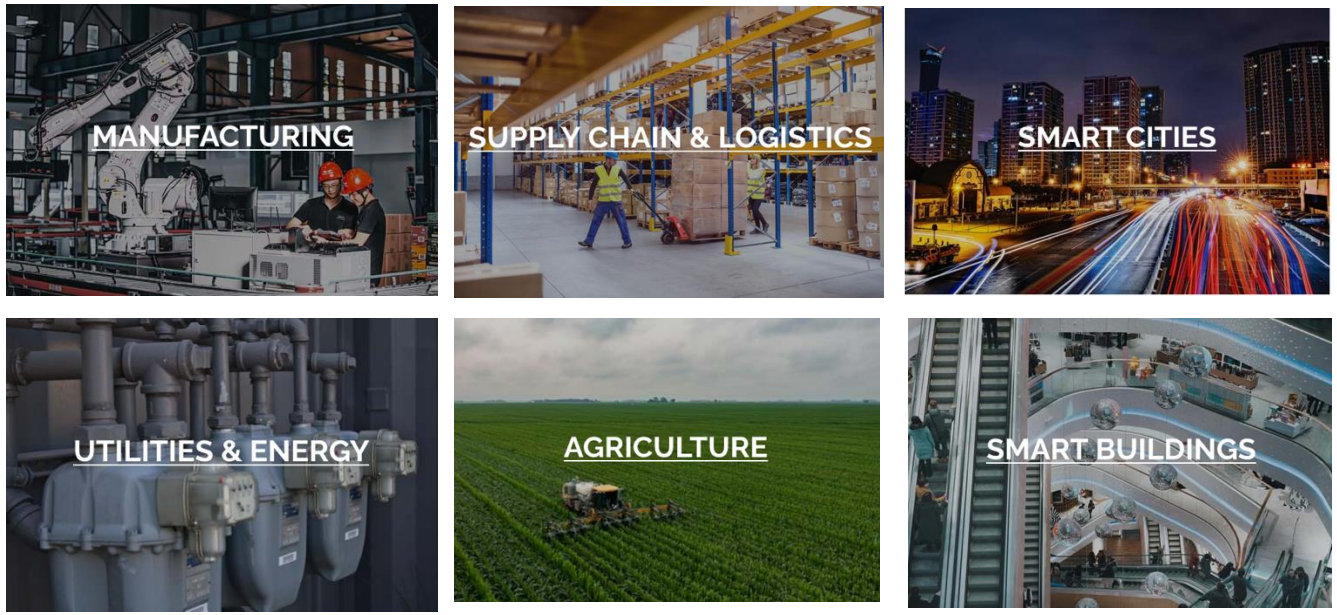
Q: two high importance, 1 medium/low importance



wide-area mobile Internet access

Internet-of-Things

- connecting devices (often small, energy-constrained) to computation that senses, monitors, reports, and controls phenomena in the physical world
- Bluetooth, WiFi, cellular, LoRaWAN



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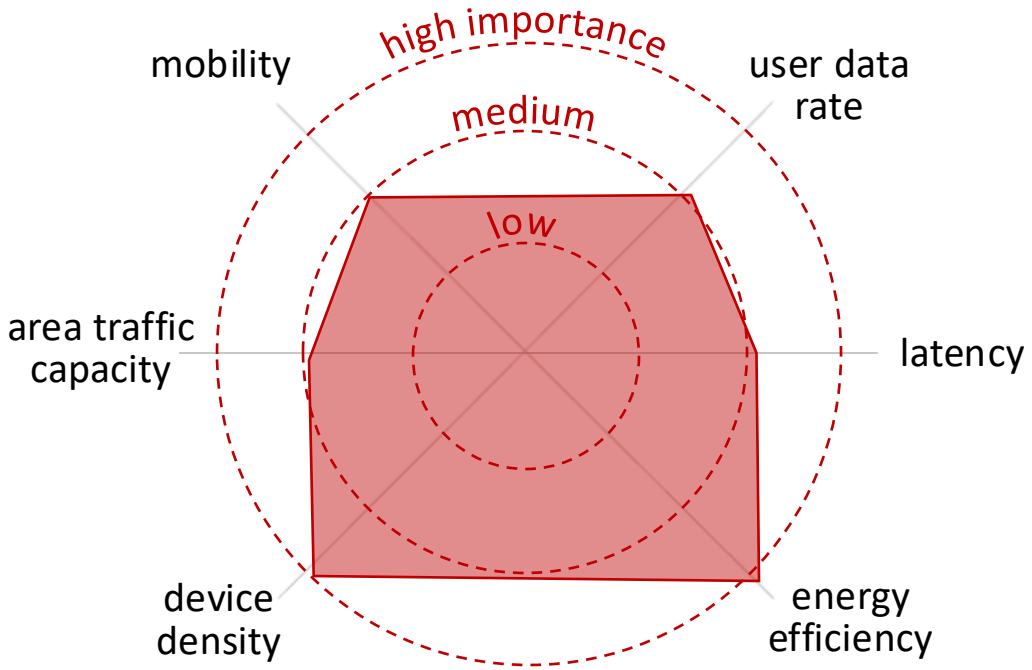

Internet of Things

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- Networking 101 - in 10 minutes
- Wireless networks: motivation, applications
- Elements of a wireless network
- 5G: architectural overview
- 5G: selected topics for REU

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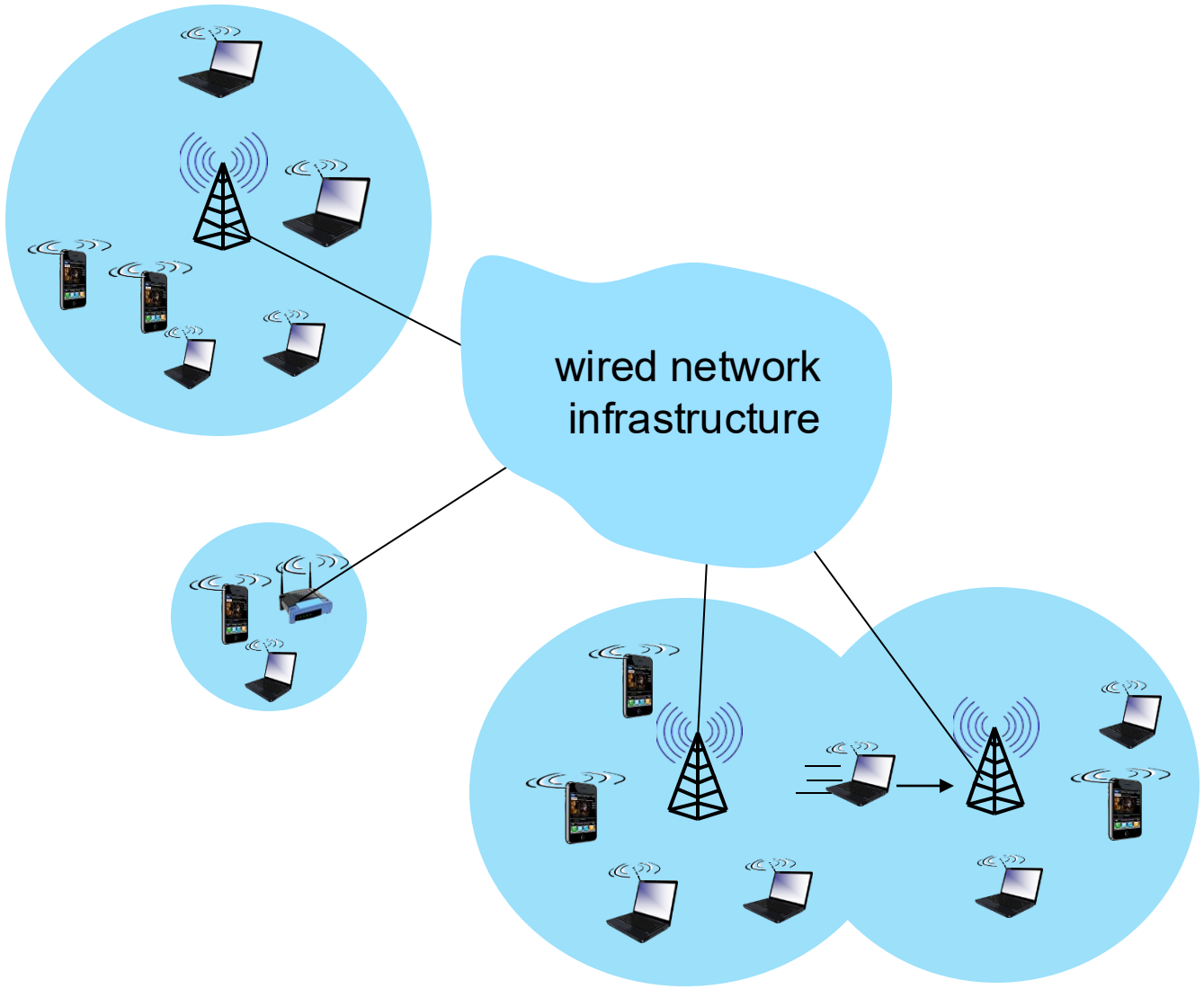
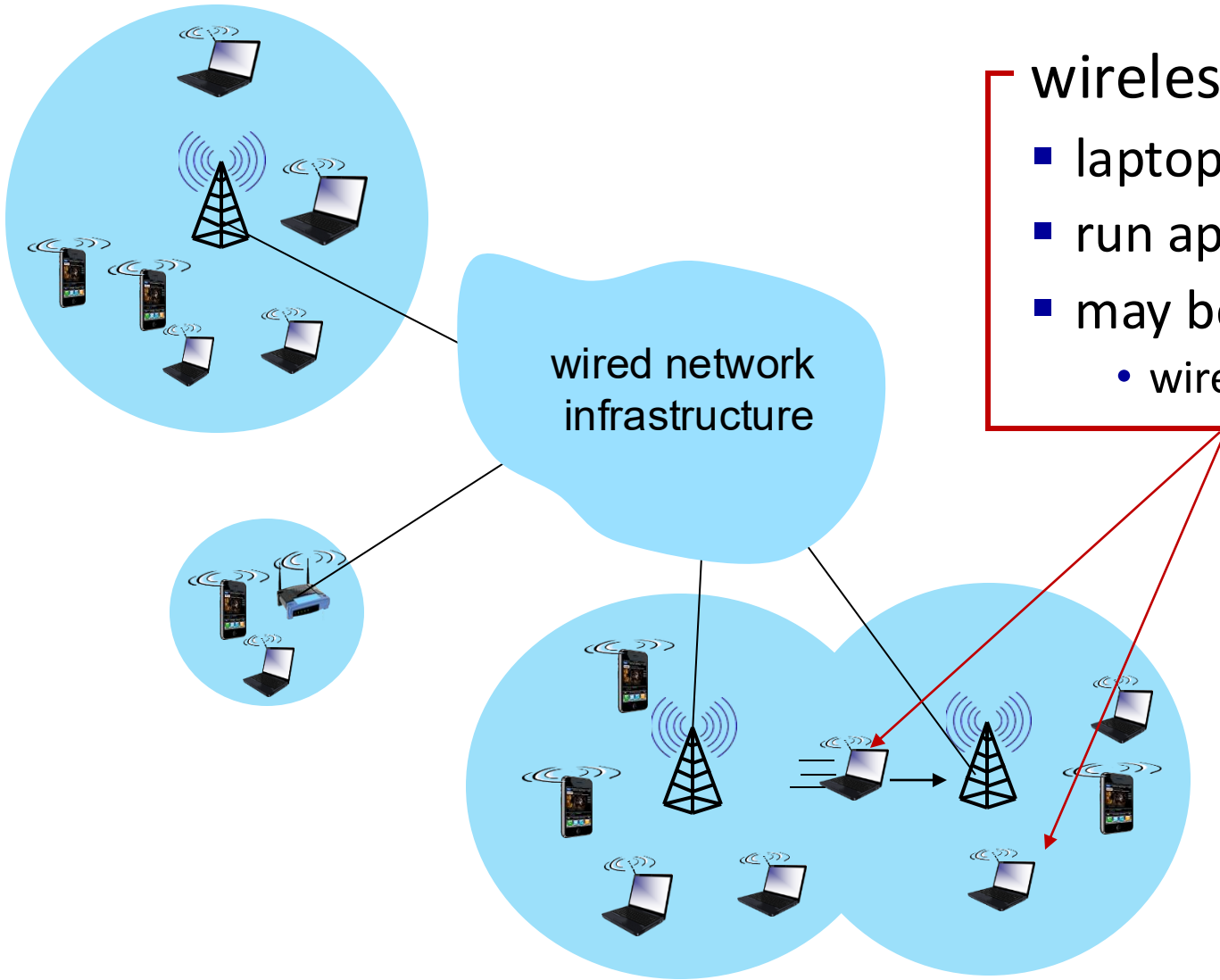
Elements of a wireless network



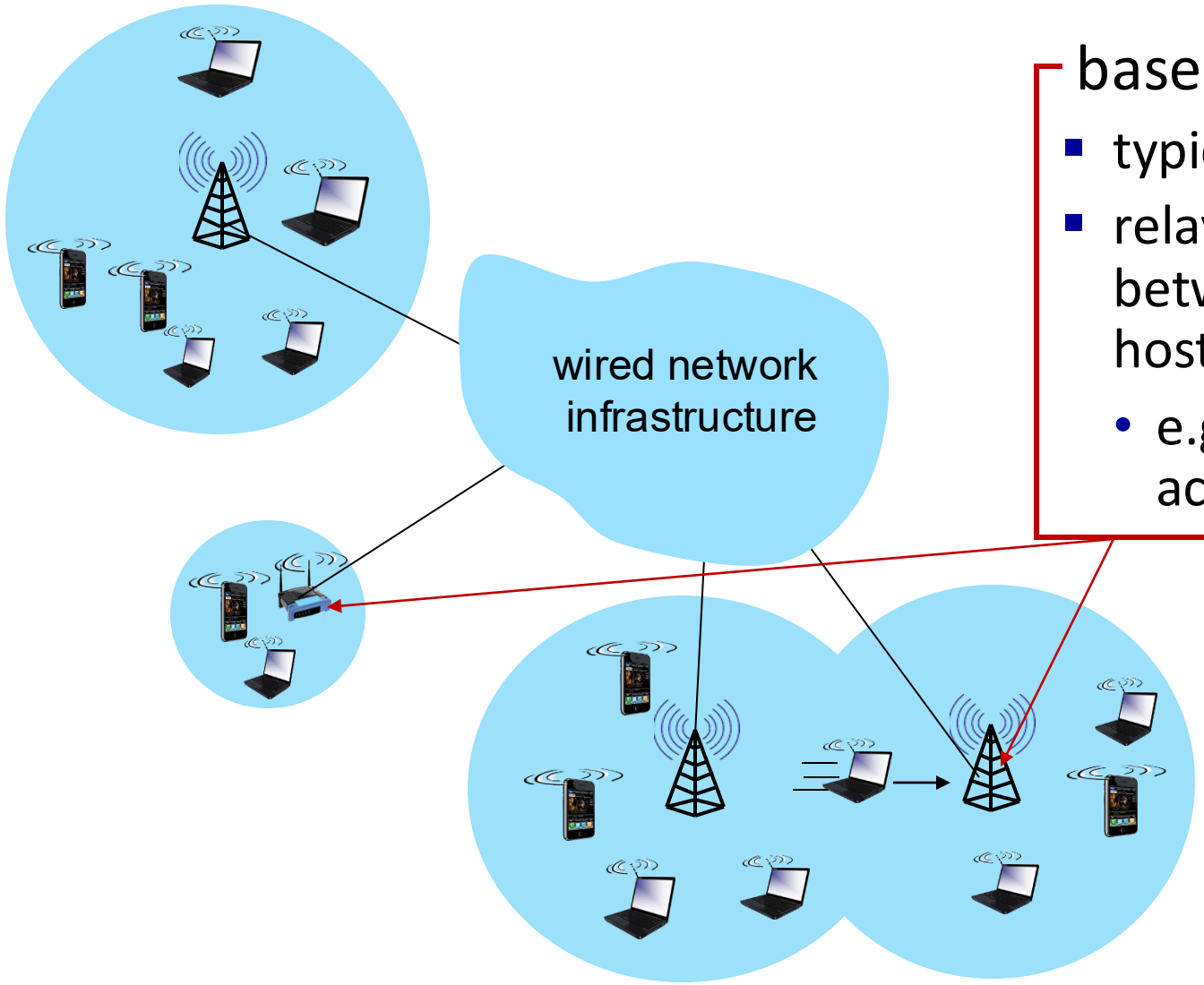
Elements of a wireless network



wireless hosts

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

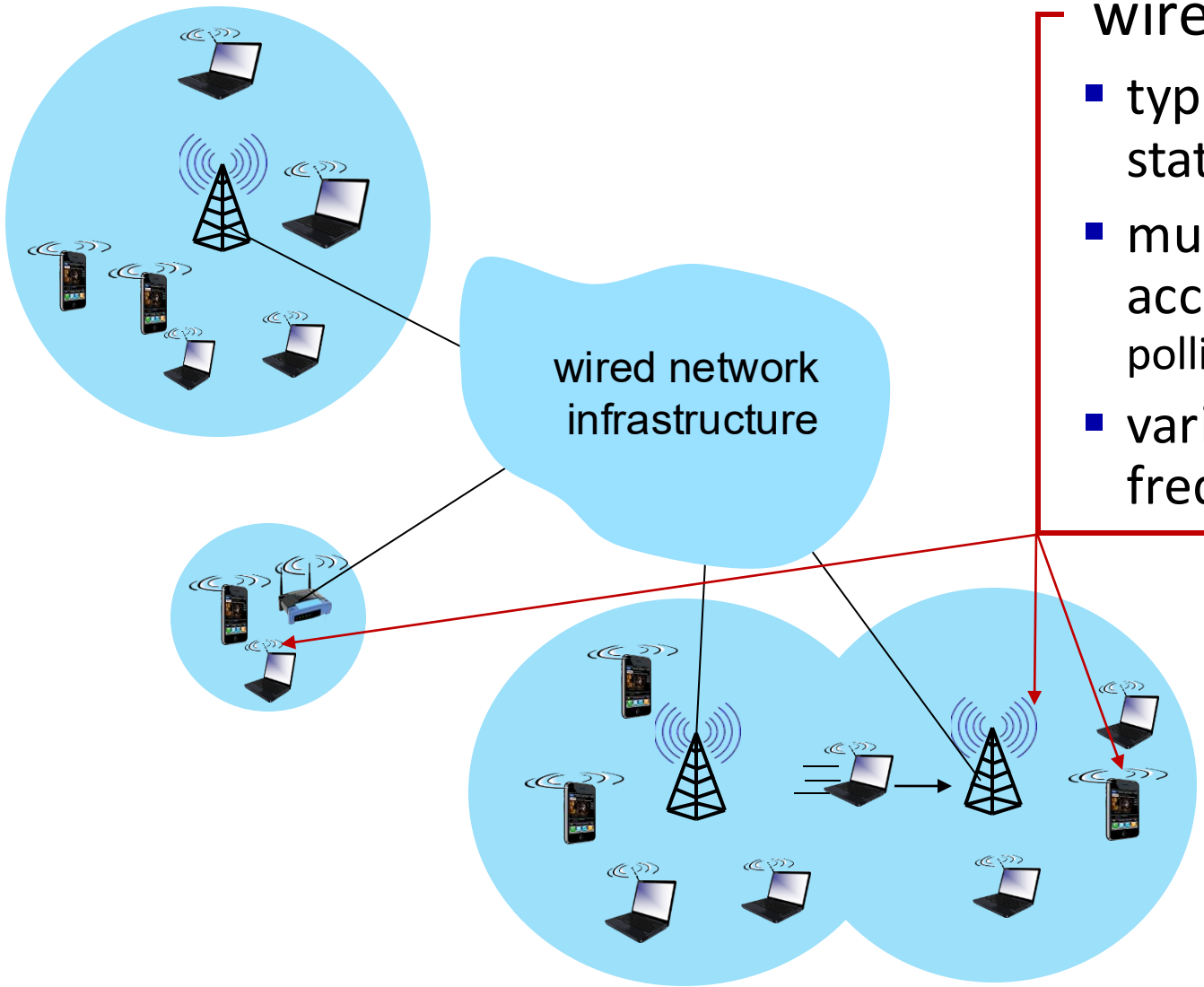
Elements of a wireless network



base station

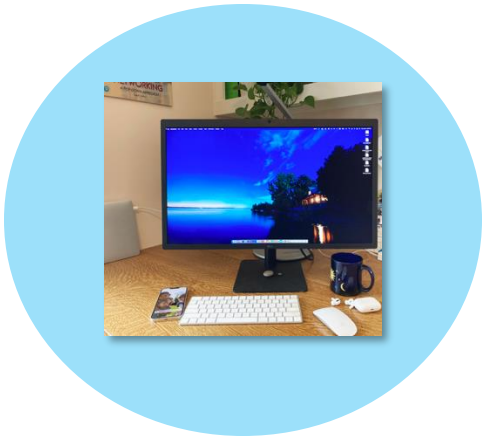
- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., 4G/5G cell towers, 802.11 (WiFi) access points (APs)

Elements of a wireless network



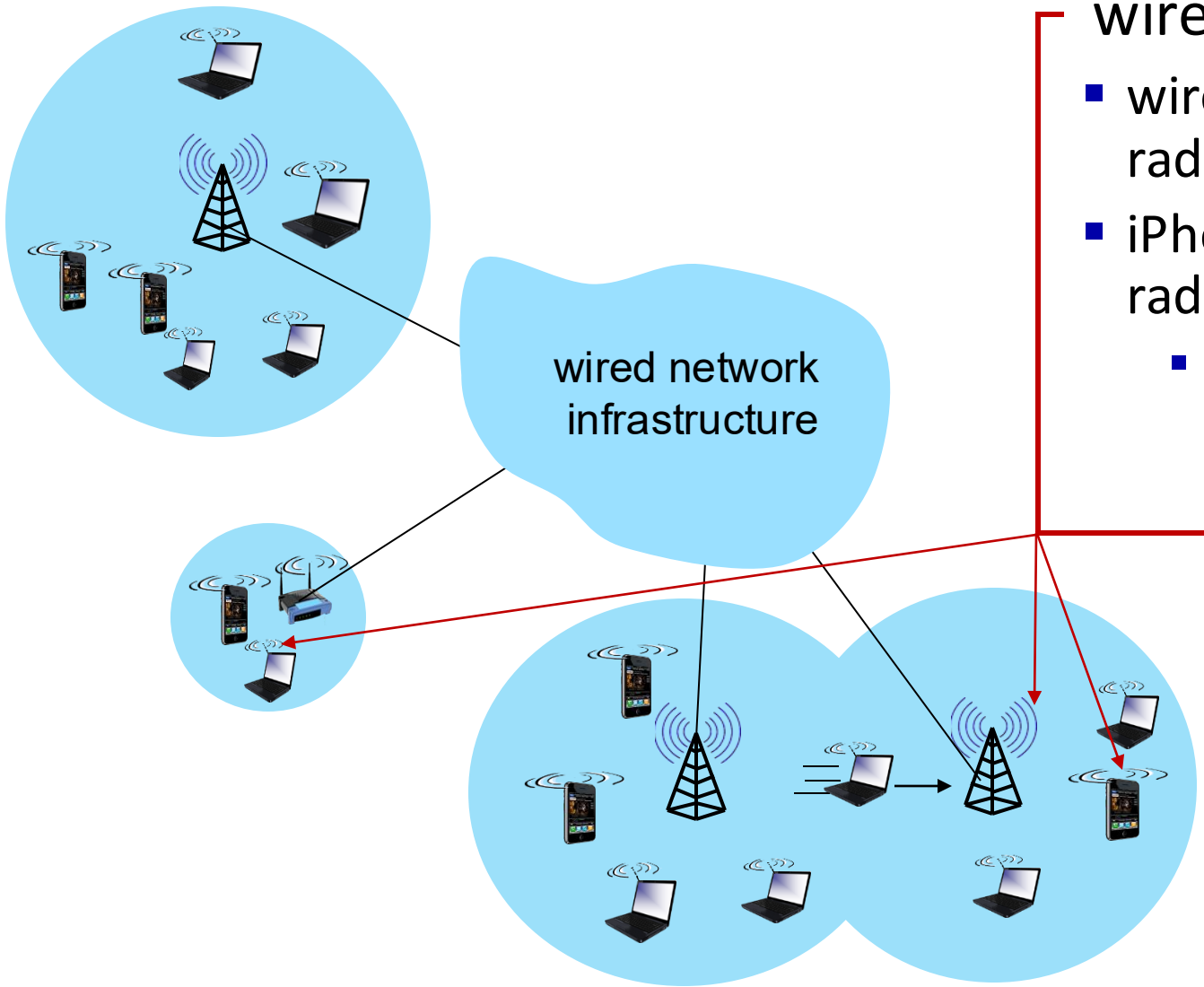
wireless link

- 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

Wireless networks: radio

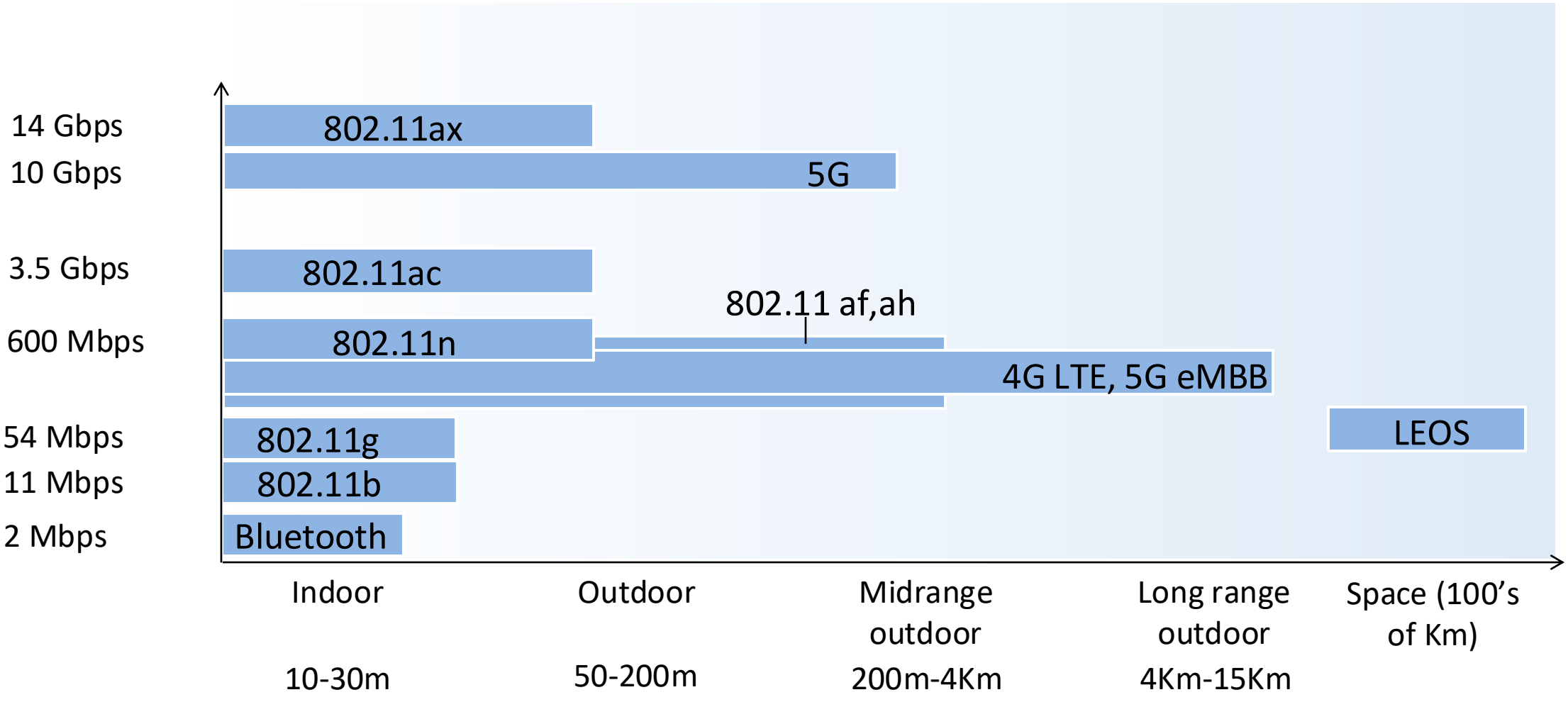
Wireless radio

- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
- propagation environment effects
  - reflection
  - obstruction by objects
  - interference/noise

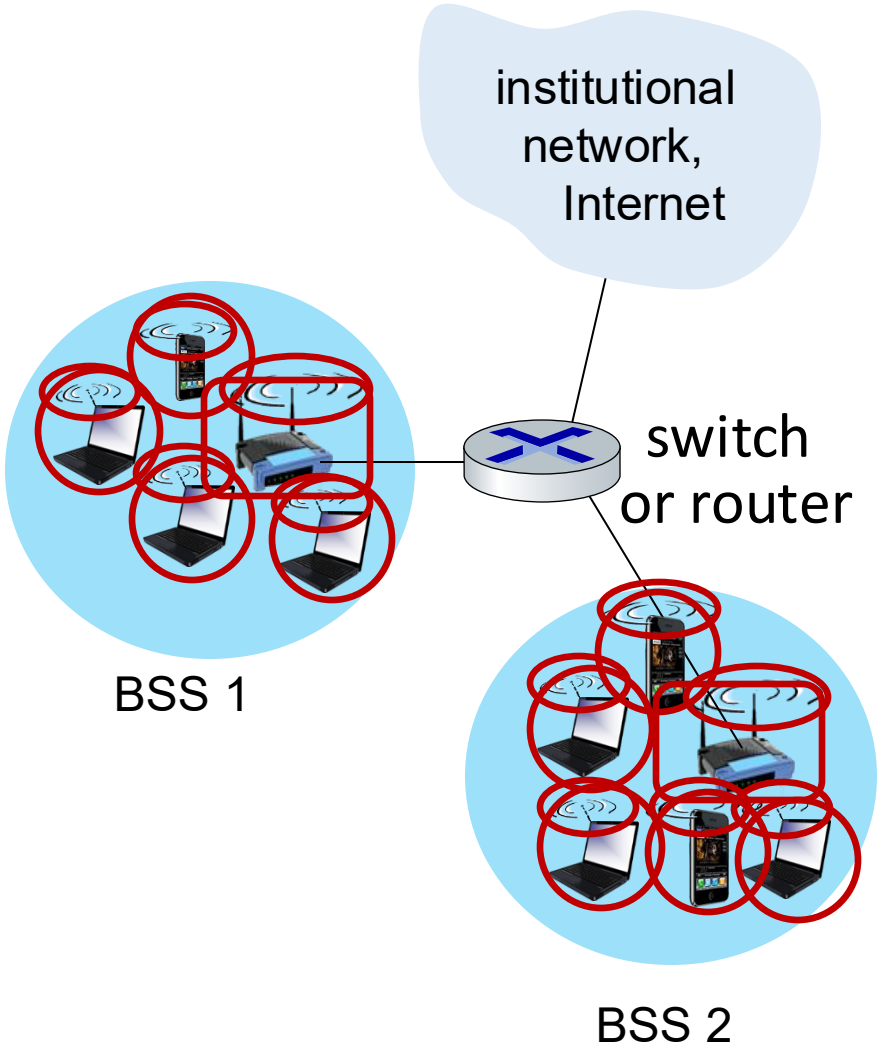
Radio link types:

- Wireless LAN (WiFi)
  - 10-1000's Mbps; 10'-100s of meters
- wide-area (e.g., 4G/5G cellular)
  - 10's Mbps over ~10 Km
  - Gbps over short distances (mmwave)
- Bluetooth: cable replacement
  - short distances, limited rates
- satellite
  - geostationary: < 45 Mbps per channel, 270 msec e-e delay
  - LEOS: 50-100 Mbps downlink (Starlink), 46 msec LEOS

Characteristics of selected wireless links



802.11 (WiFi) LAN architecture (overview)



- wireless host communicates with base station
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - wireless channel
  - access point (AP): base station
- other network services (identity management, IP addressing and routing, DHCP) handled by institutional IP infrastructure: WiFi is a layer-2 (only) network!

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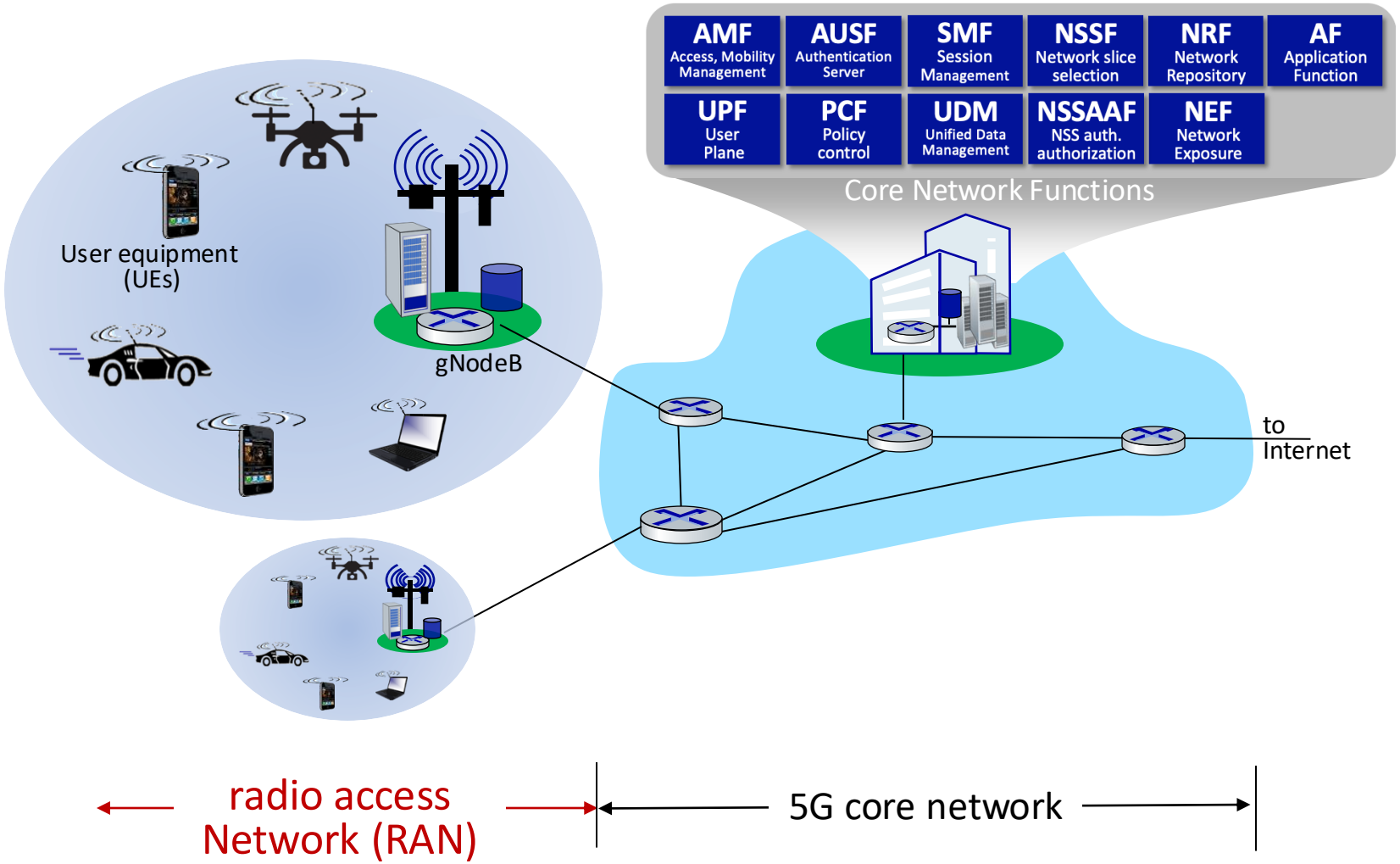
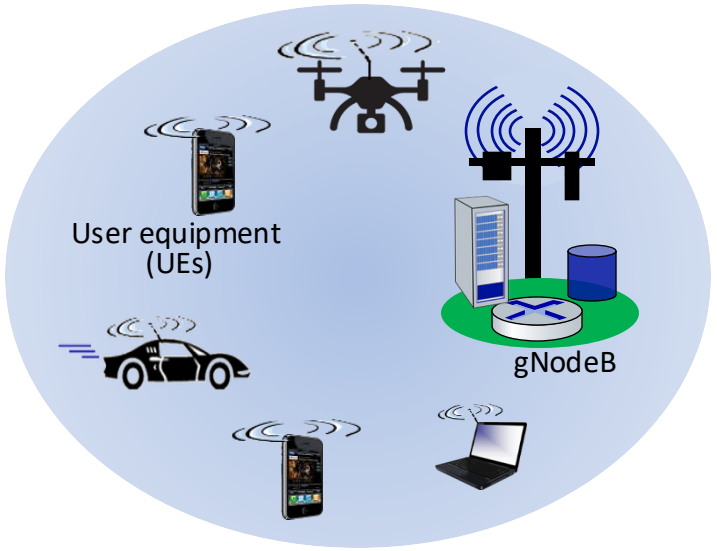
Architectural Elements of 5G



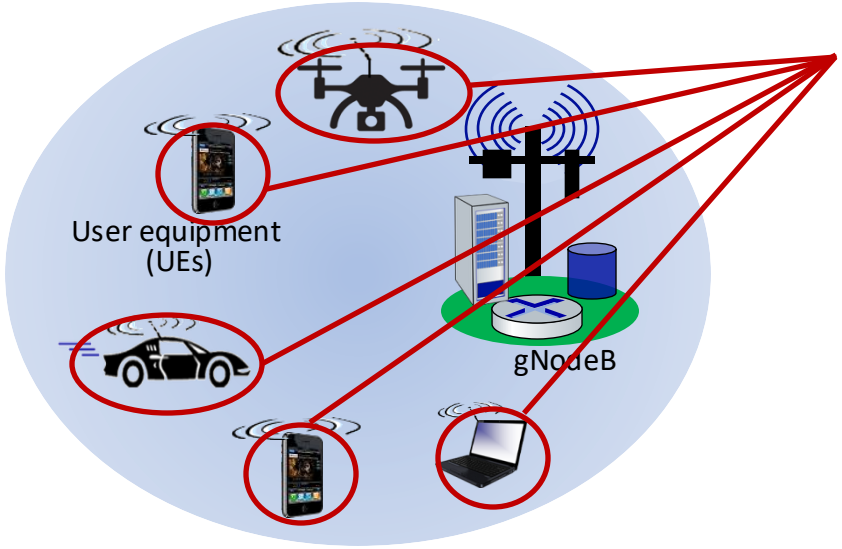
5G Radio Access Network (RAN)



5G RAN: edge network connecting devices (UEs) to base station (gNodeB)

- 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)

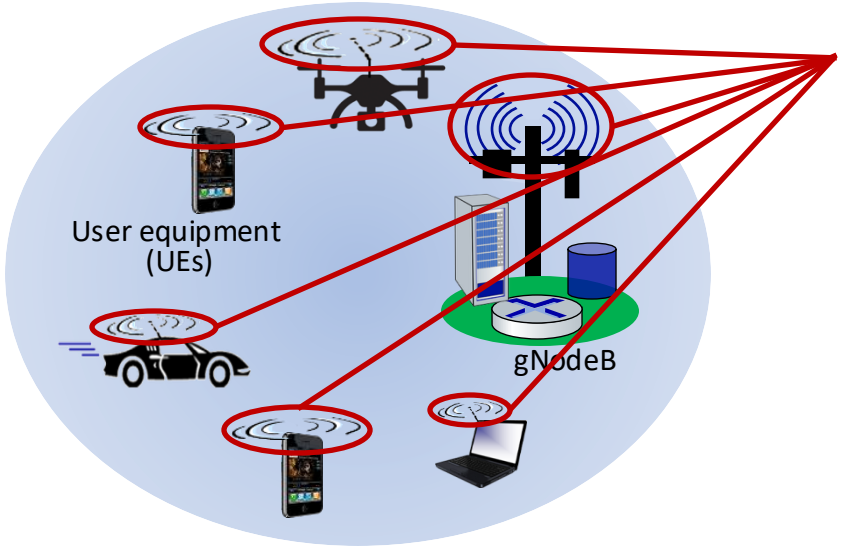
5G RAN components



5G User Equipment (UE):

- smartphone, tablet, laptop, IoT device
- UEs host, run applications
- devices attached in RAN
- may or may not be mobile

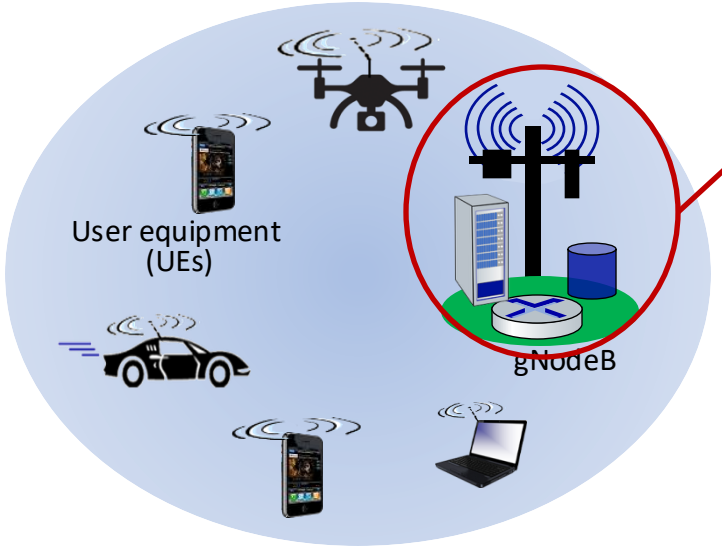
5G RAN components



Radio Channel (aka New Radio, NR, in 5G)

- Physical (PHY) layer: OFDMA
- UEs only communicate with base station
  - via uplink, downlink channels
  - UEs do not communicate directly with each other
- various uplink/downlink physical and logical channel defined

5G RAN components

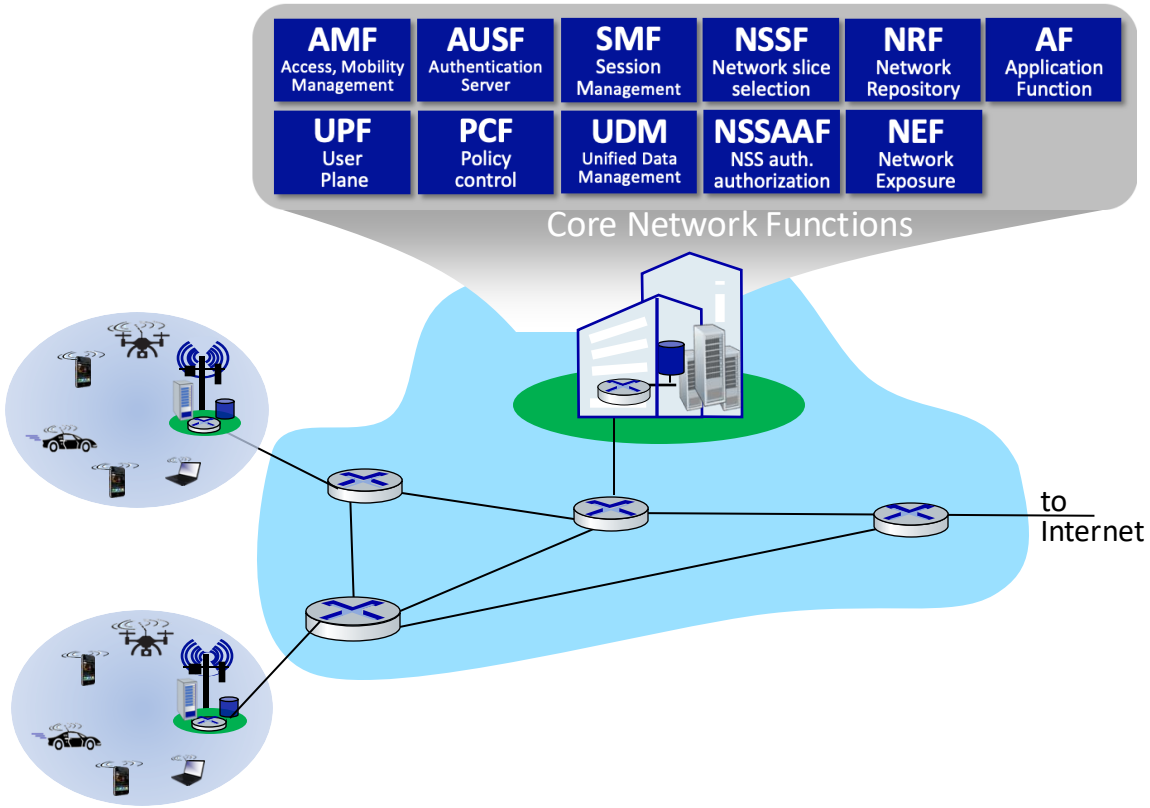


Base station (aka Next Generation Node B (gNodeB or gNB in 5G):

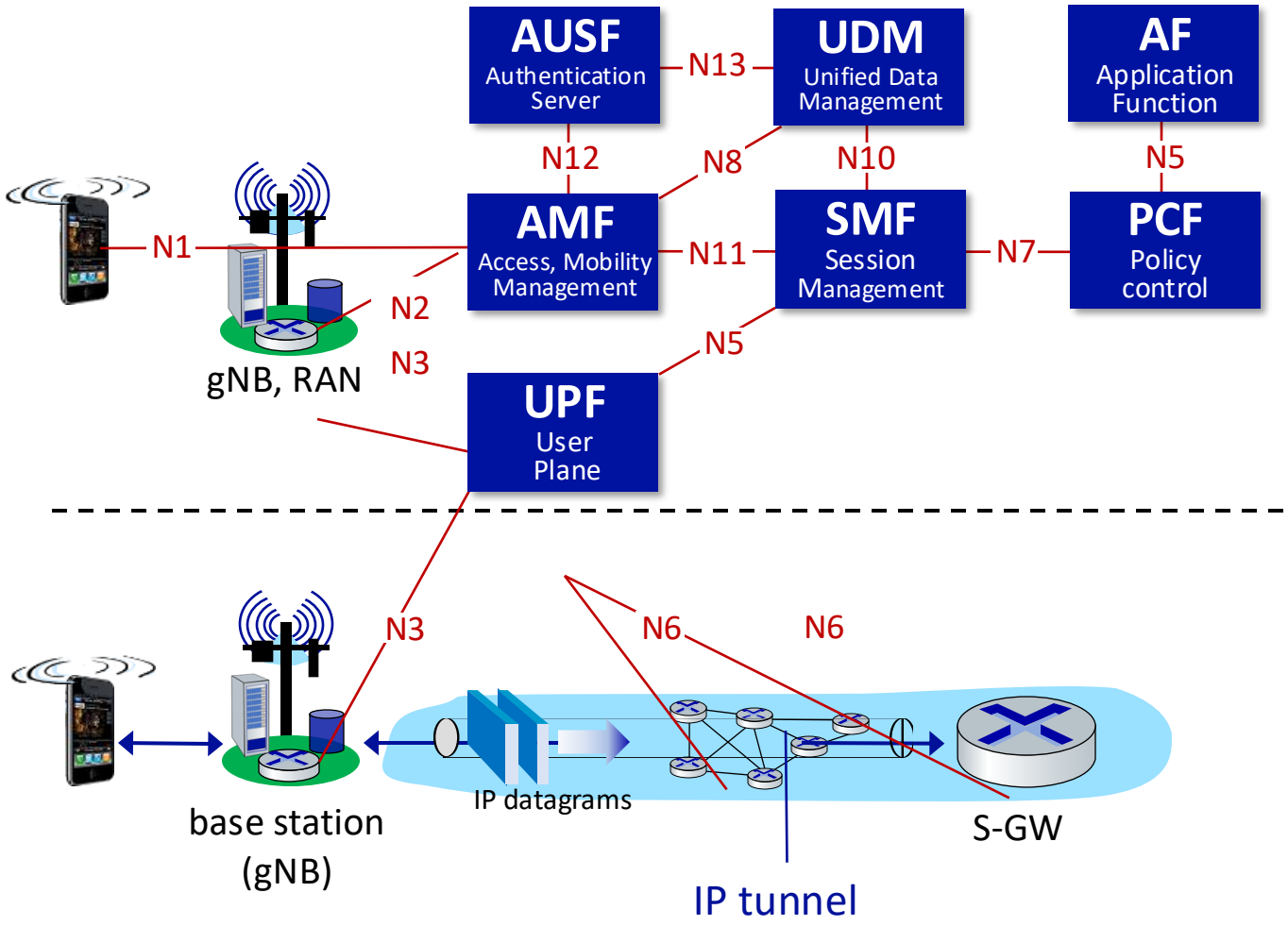
- central control point for RAN, role somewhat analogous to that of WiFi AP
- computing, storage may be located at gNB
- all communication between UEs and other endpoints (other UEs, 5G Core, Internet) go through gNB
- aka Extended Node B (eNB) in 4G

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 UEs and gNBs
  - "all Internet" 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 control- and user- plane separation (CUPS)



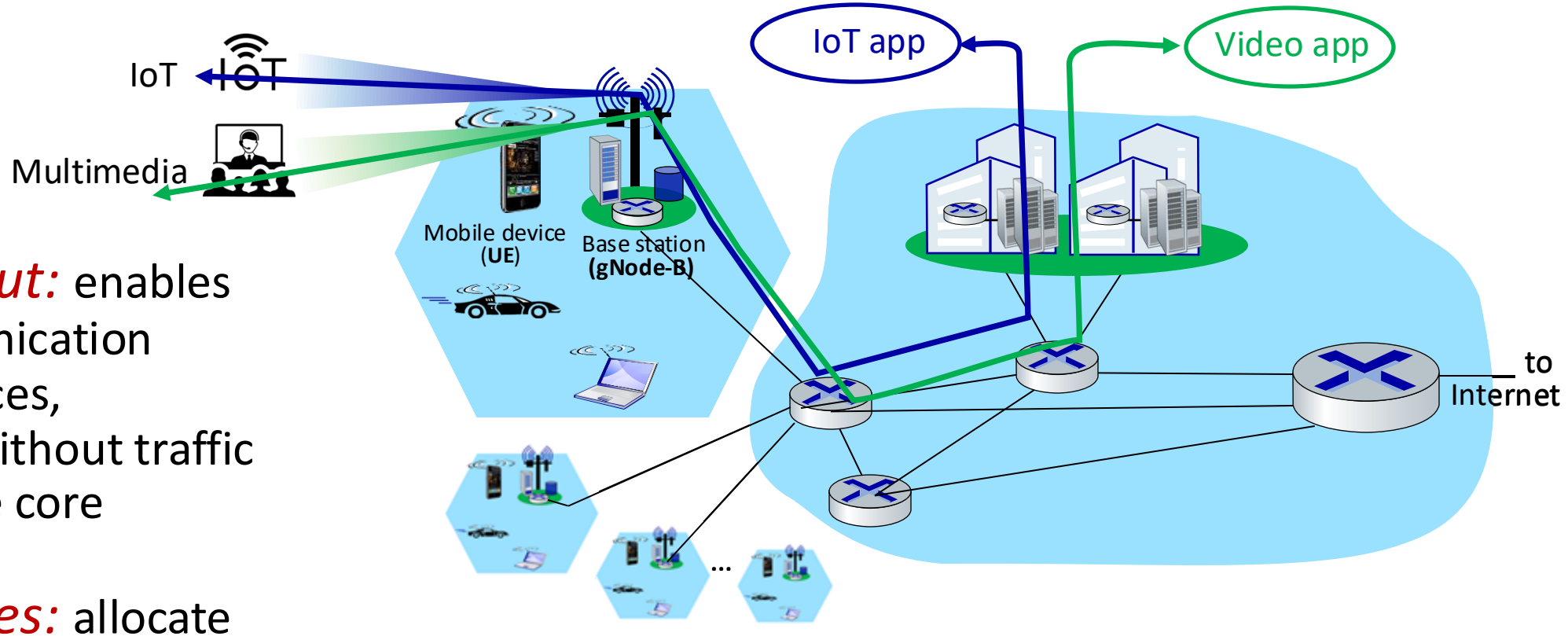
control plane

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

data plane

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

5G: Local application breakout, slicing

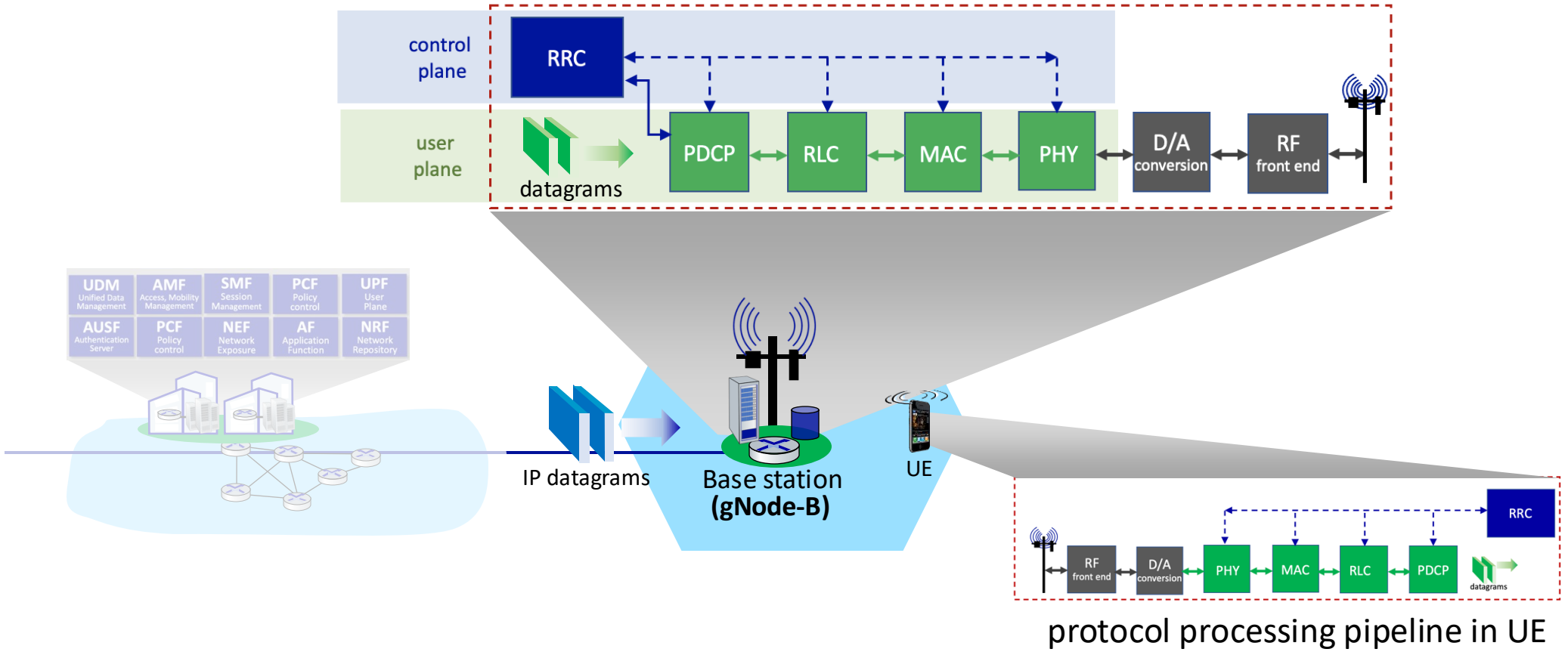


local breakout: enables direct communication between devices, applications without traffic leaving mobile core

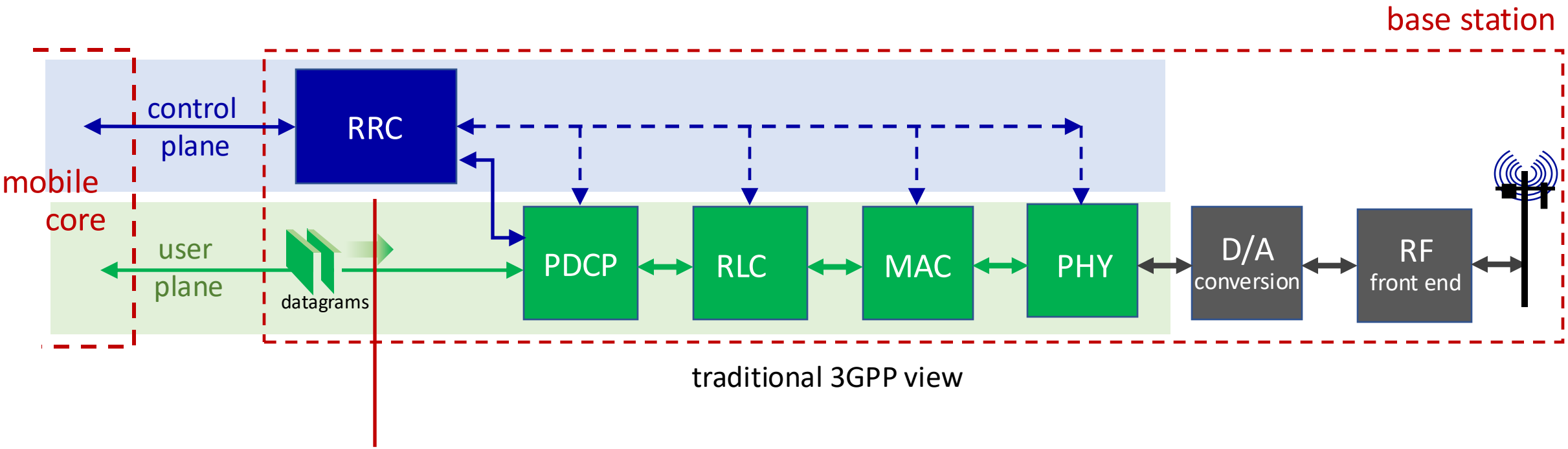
network slices: allocate resources end-end, segregate traffic to deliver different QoS to a collection of devices, apps

RAN packet processing pipeline: context

RAN: transfers datagrams between mobile core and UEs



RAN packet processing pipeline



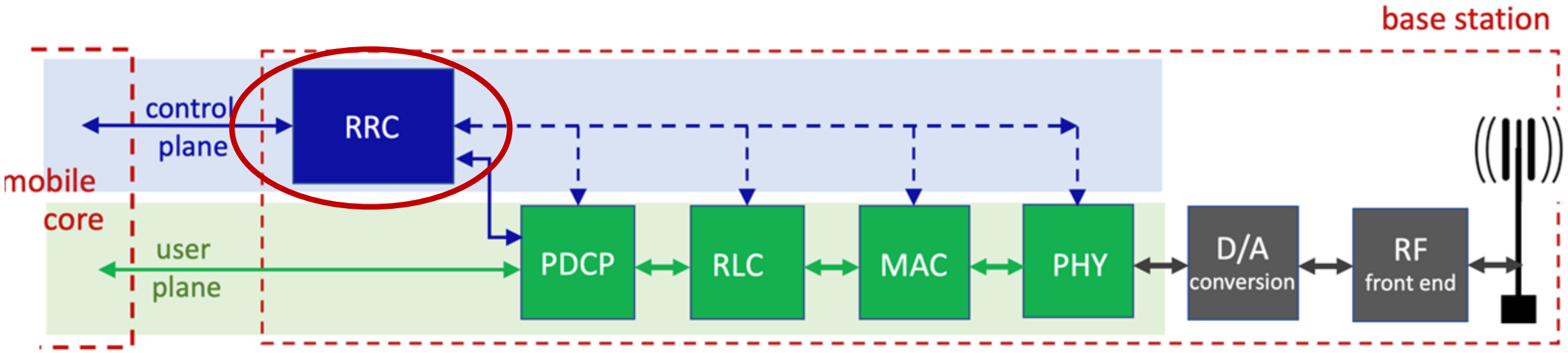
RRC (Radio Resource Control)

- configures coarse-grained, policy-related aspects of pipeline (e.g., scheduling prioritization, security)
- this implements the RAN's control plane
- does not process user plane packets

Software-defined RAN

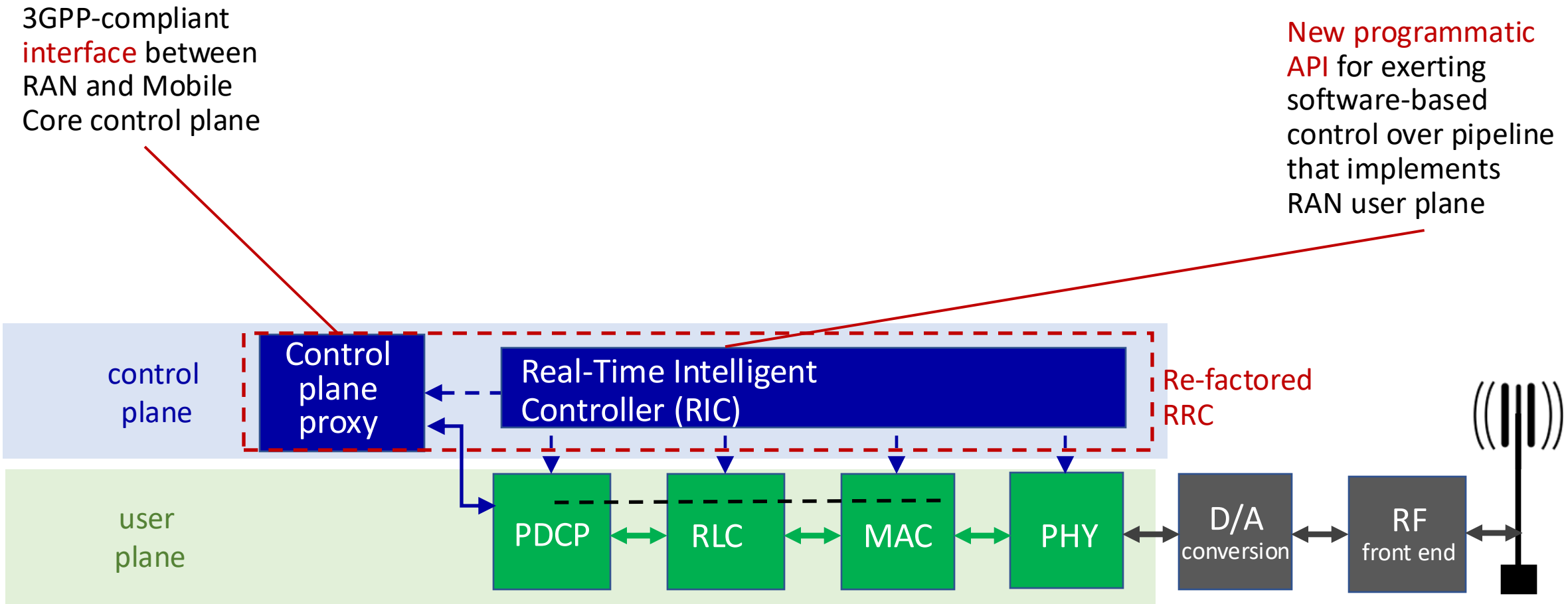
Recall our earlier description of traditional RAN base station (below)

- tightly coupled control and data planes
- let's focus on control / management: RRC *implementation*



Software-defined RAN

- *SD-RAN:* implementing RAN using SDN approach



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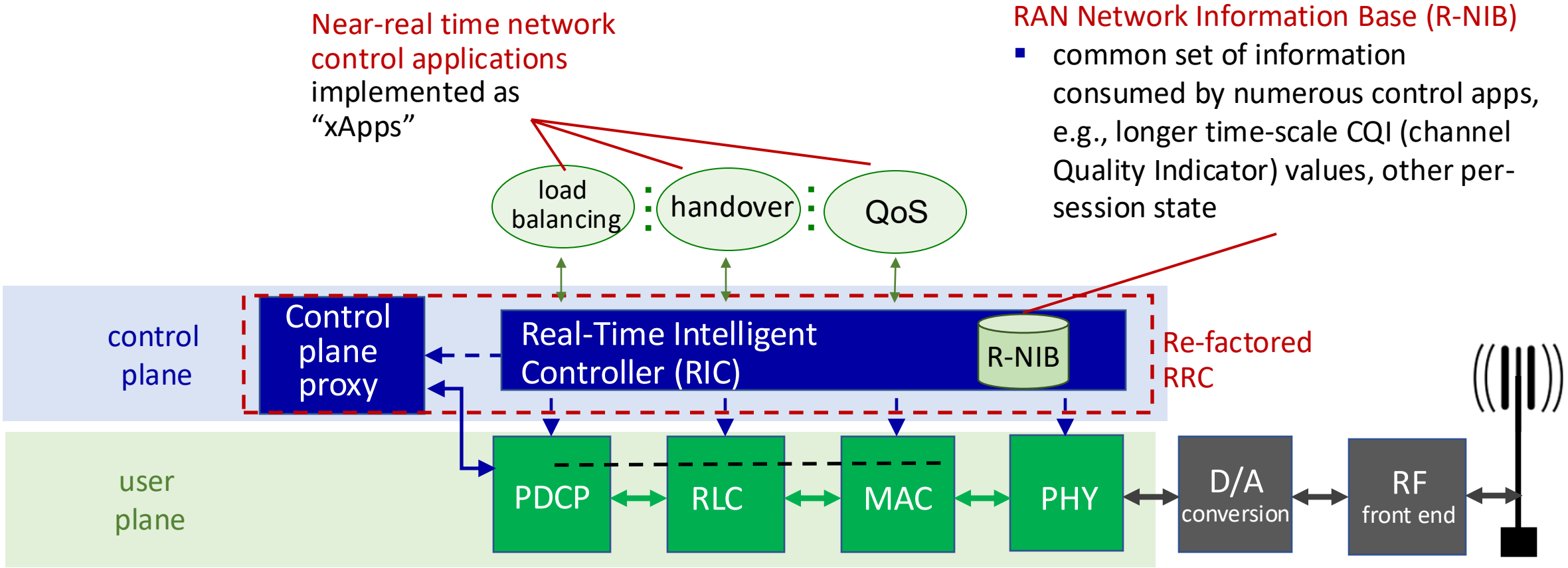
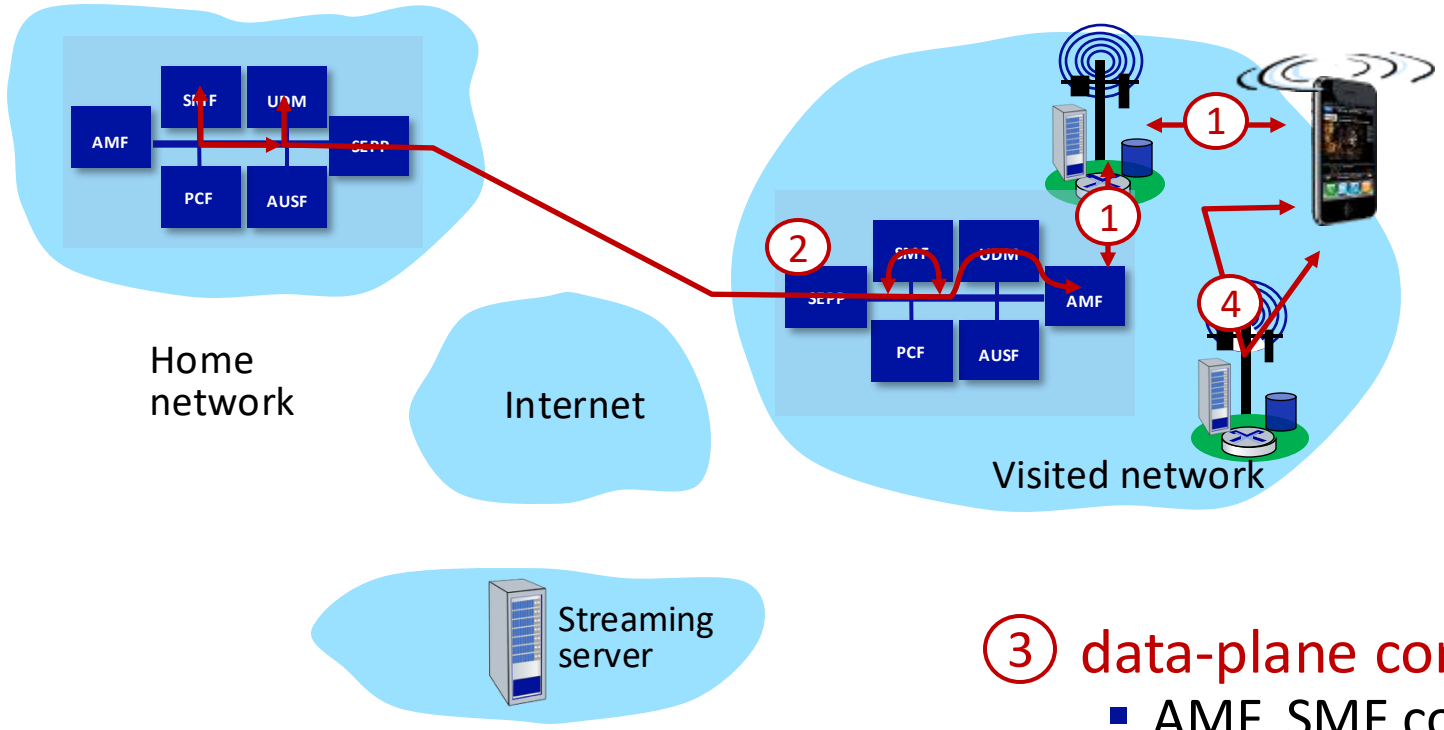


Mobility in 5G networks: major mobility tasks



① association:
- covered earlier
- mobile provides IMSI – identifying itself, home network

② control-plane configuration:
- AMF, visited UDM, home UDM establish control-plane state: mobile in visited network

③ data-plane configuration:
- AMF, SMF configures forwarding tunnels
- visited, home network establish tunnels from home to mobile, *only if home-routed*

④ mobile handover:
- mobile device changes its point of attachment to visited network


THANKS!