Chapter 7
Wireless and Mobile Networks

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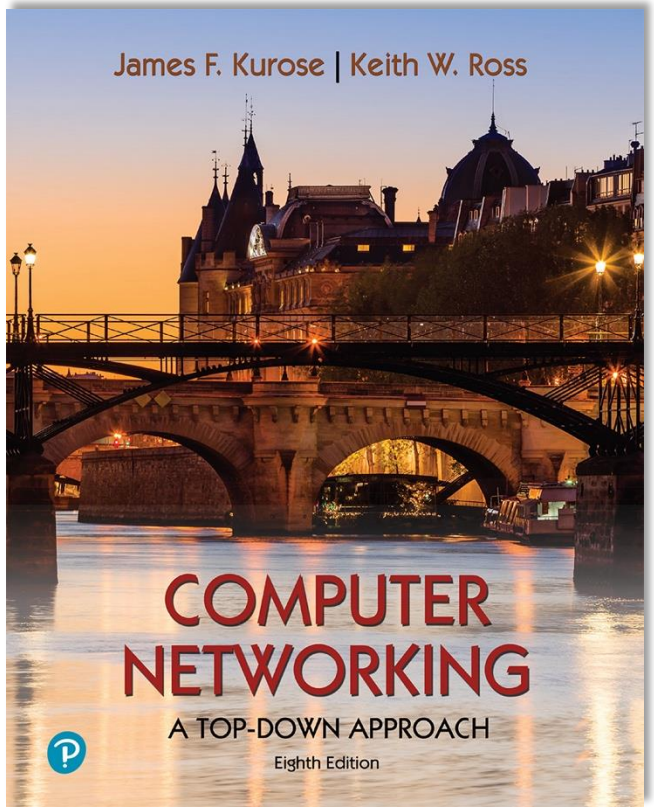


Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Adapted from the slides of the book's authors

Wireless and Mobile Networks: context

- more wireless (mobile) phone subscribers than fixed (wired) phone subscribers (10-to-1 in 2019)!
- more mobile-broadband-connected devices than fixed-broadband-connected devices devices (5-1 in 2019)!
  - 4G/5G cellular networks now embracing Internet protocol stack, including SDN
- two important (but different) challenges
  - wireless: communication over wireless link
  - mobility: handling the mobile user who changes point of attachment to network

Chapter 7 outline

- Introduction

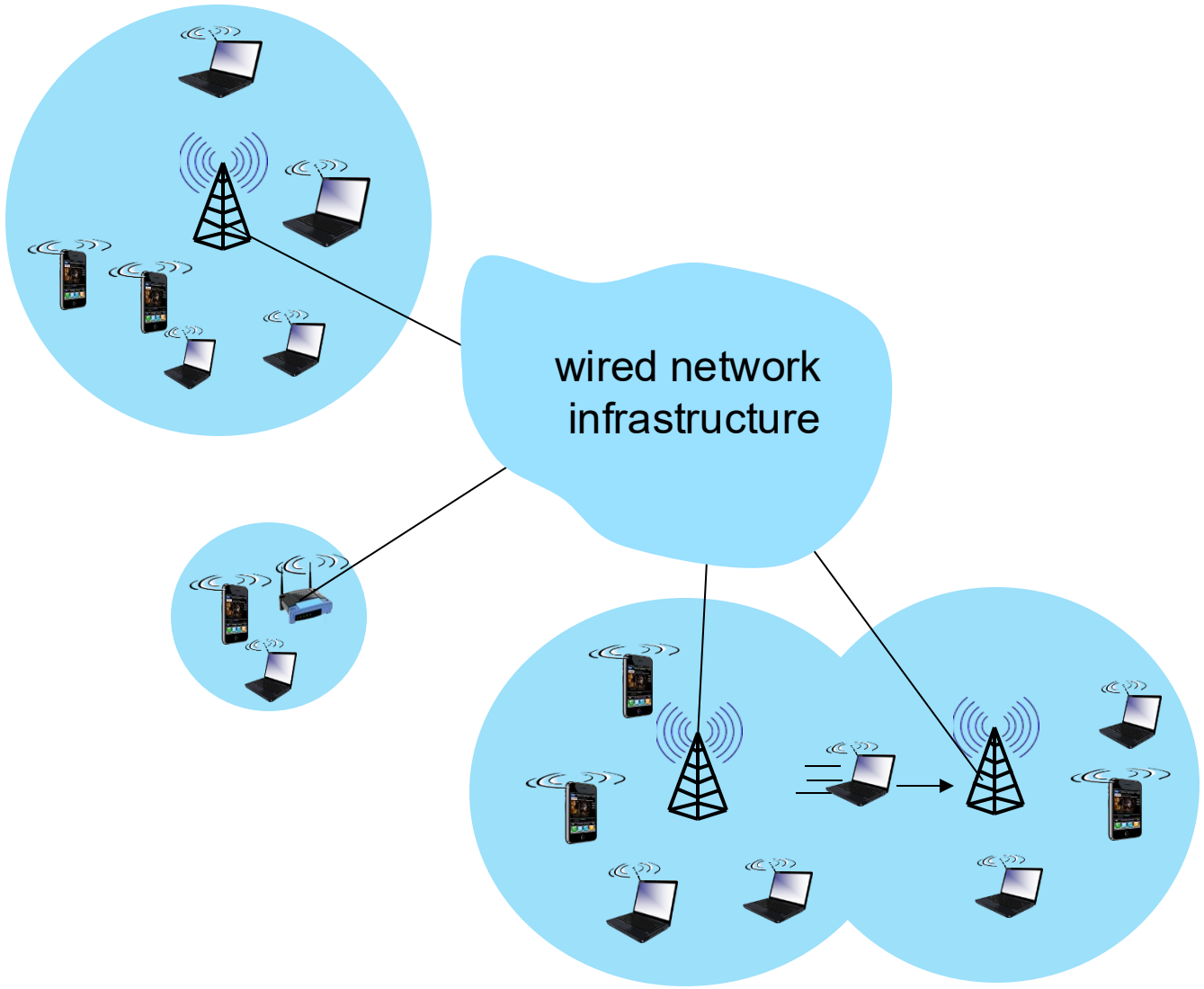
Wireless

- Wireless Links and network characteristics
- WiFi: 802.11 wireless LANs

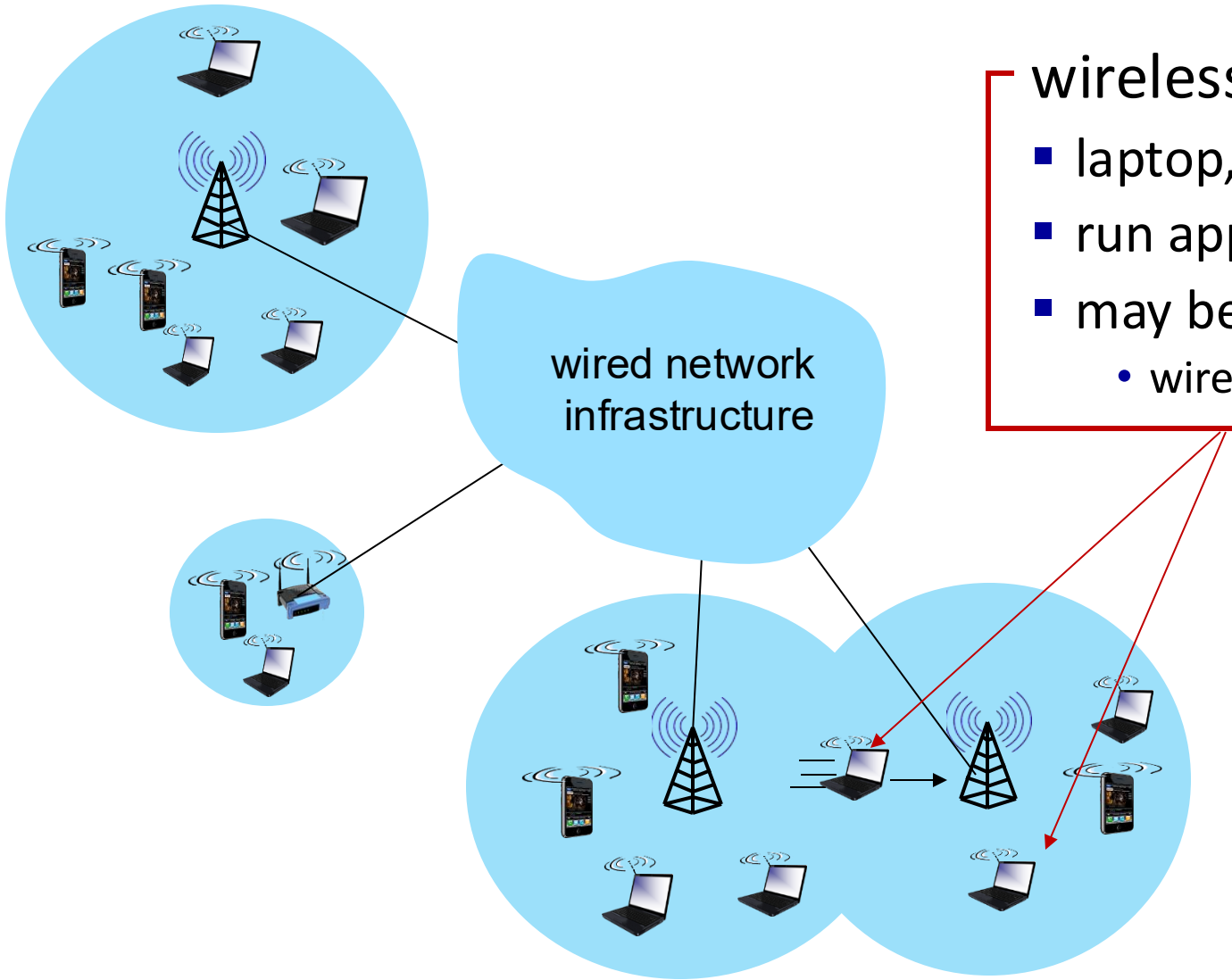
My research

- 5G and cellular networks

Elements of a wireless network



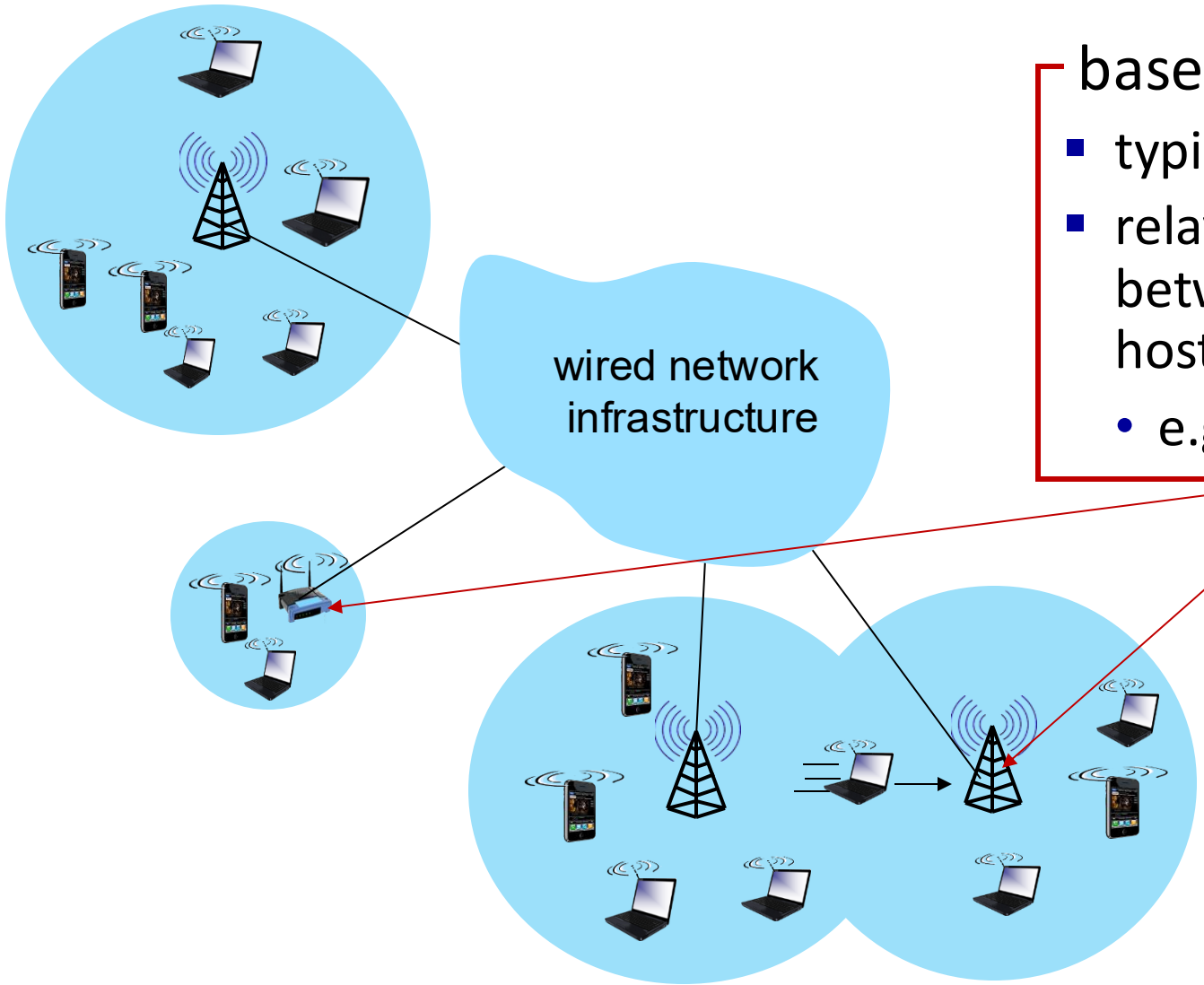
Elements of a wireless network



wireless hosts

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

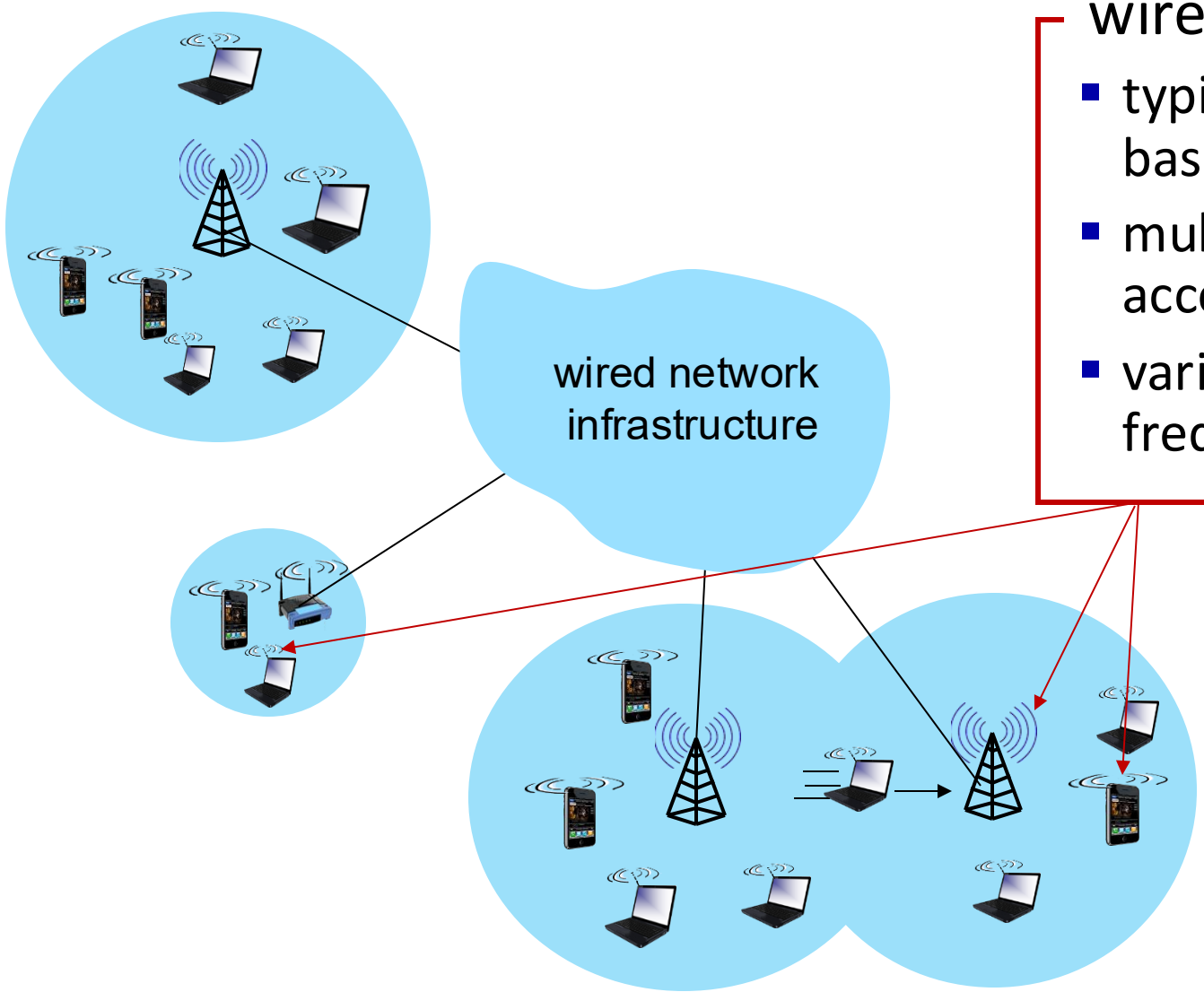
Elements of a wireless network



base station

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

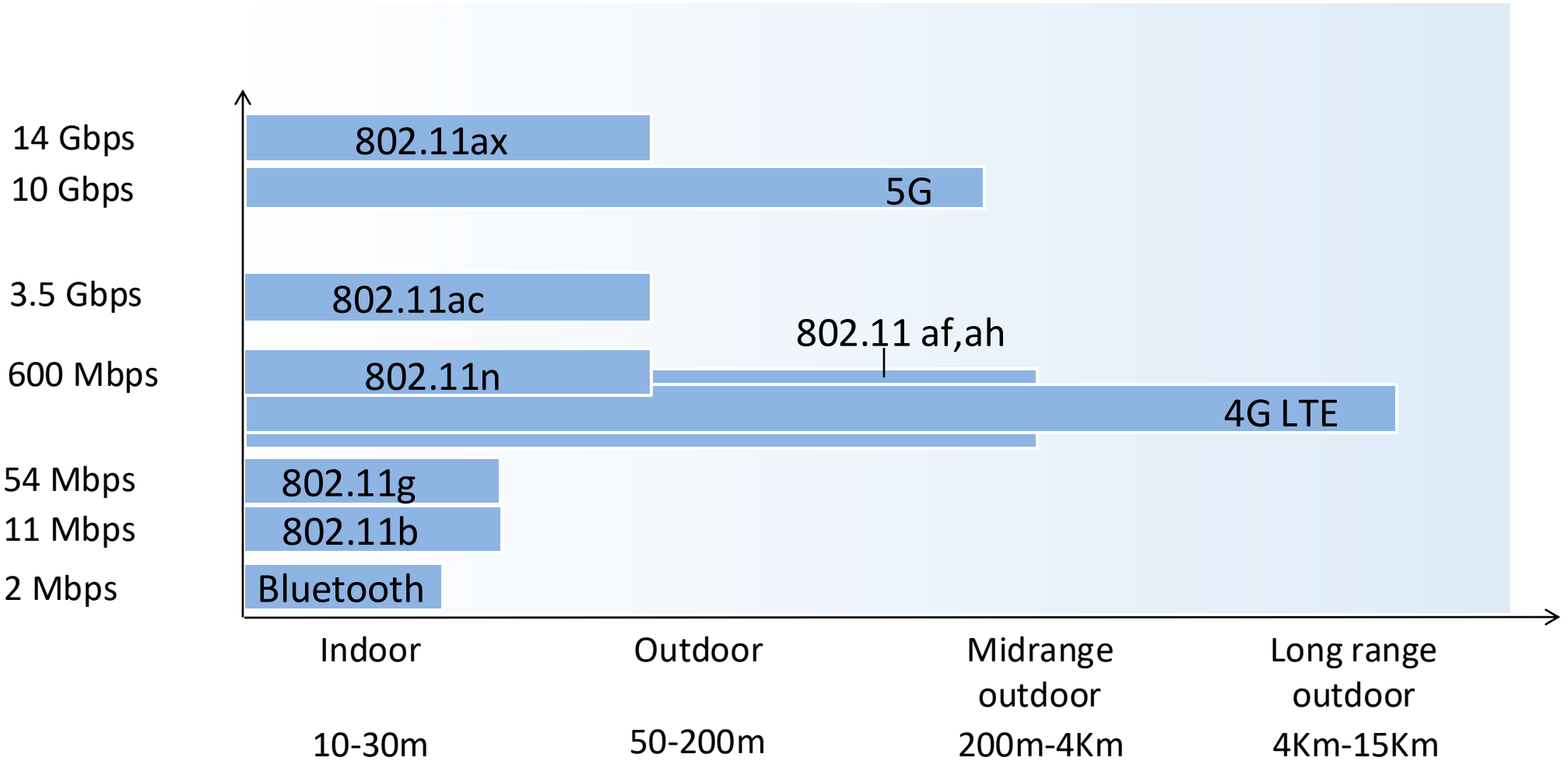
Elements of a wireless network



wireless link

- typically used to connect mobile(s) to base station, also used as backbone link
- multiple access protocol coordinates link access
- various transmission rates and distances, frequency bands

Characteristics of selected wireless links



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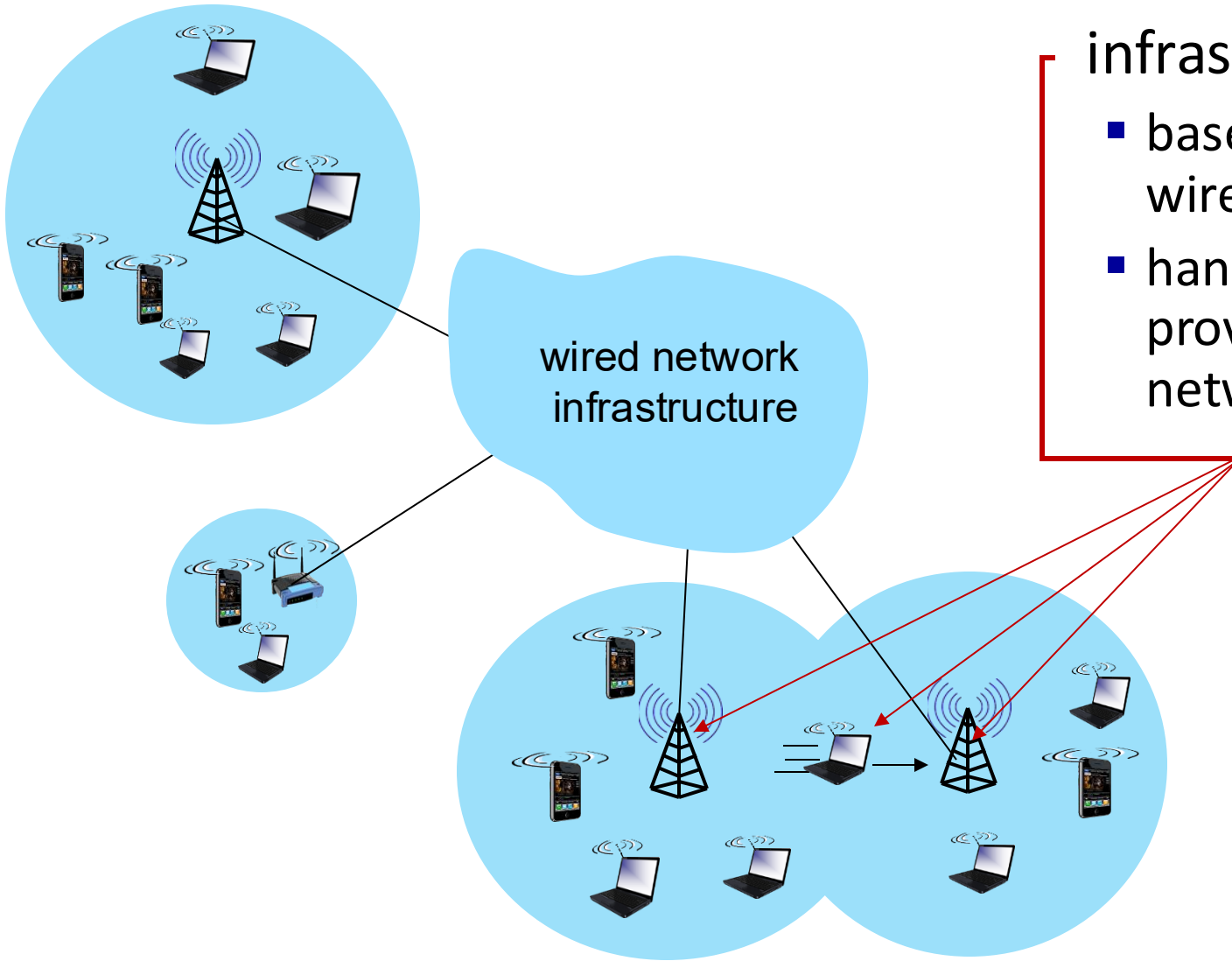

infrastructure mode

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

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Wireless link characteristics (1)

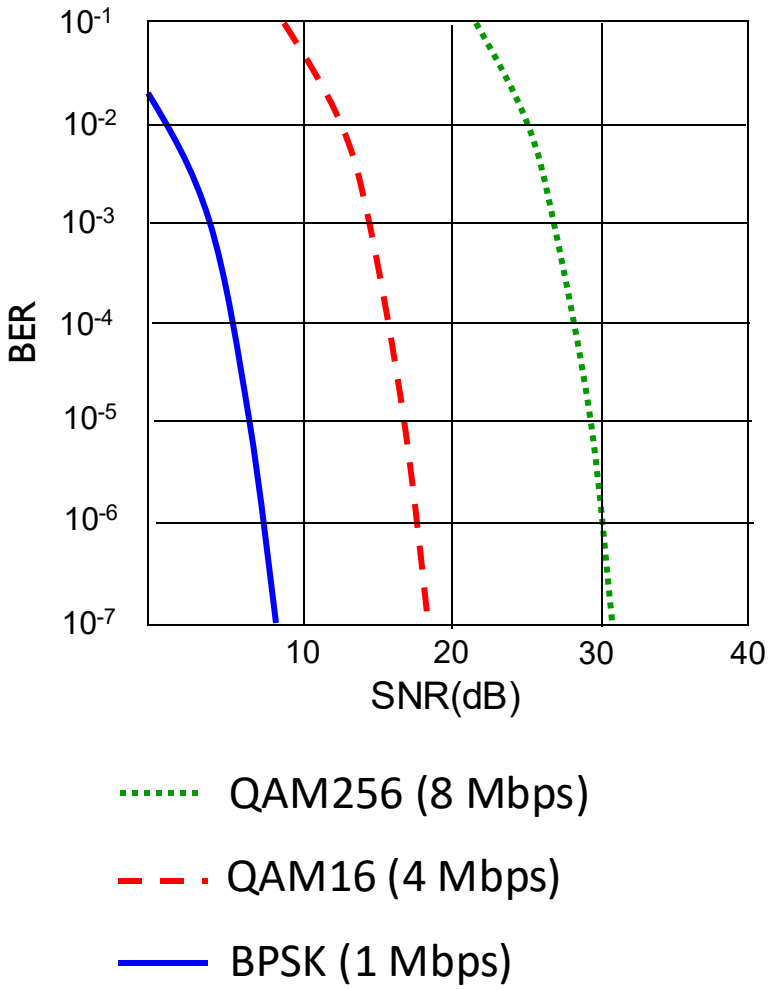
important differences from wired link ….

- 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”

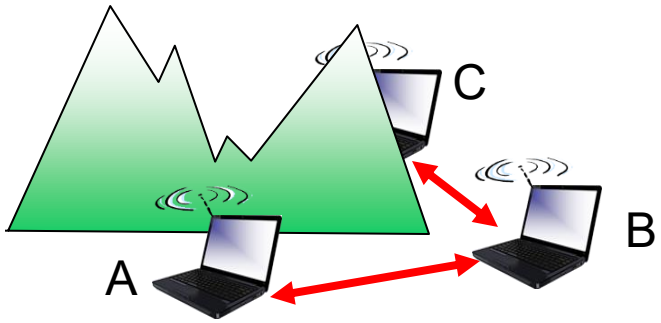
Wireless link characteristics (2)

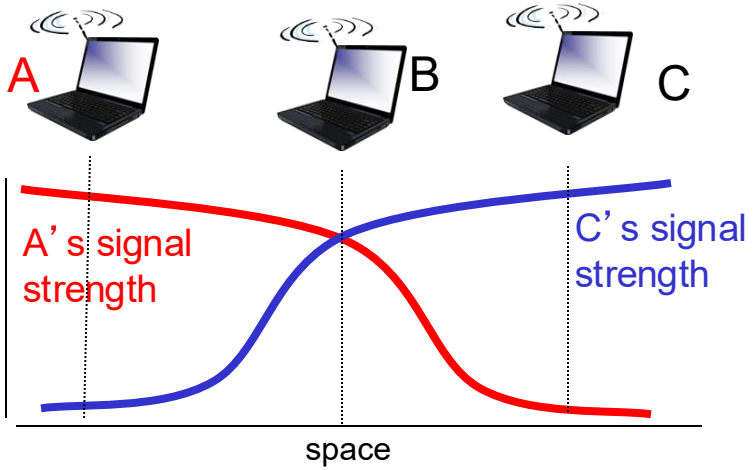
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- SNR versus BER (Bit Error Rate) tradeoffs
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - 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

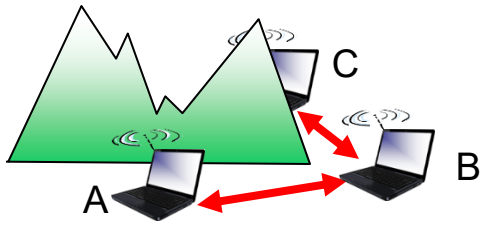
- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

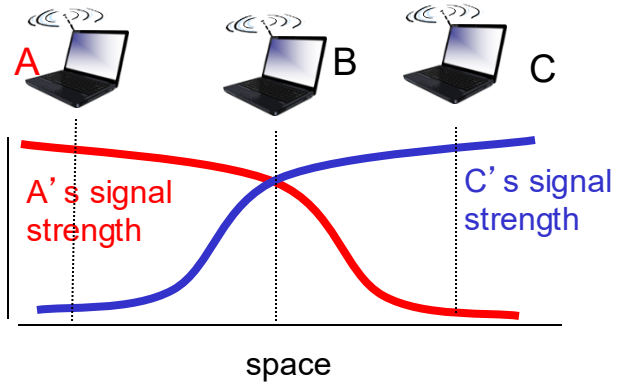
Signal attenuation:

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

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/CollisionAvoidance





IEEE 802.11 MAC Protocol: CSMA/CA

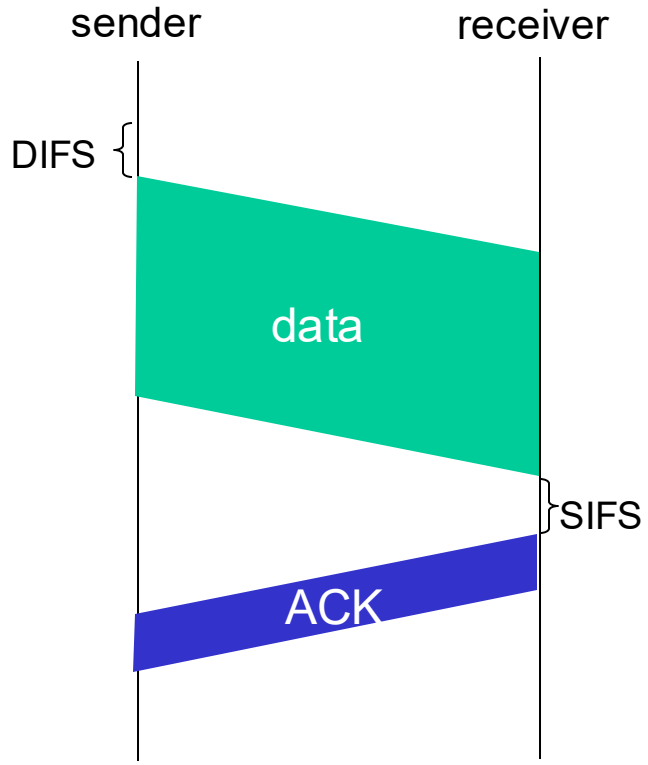
802.11 sender

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)

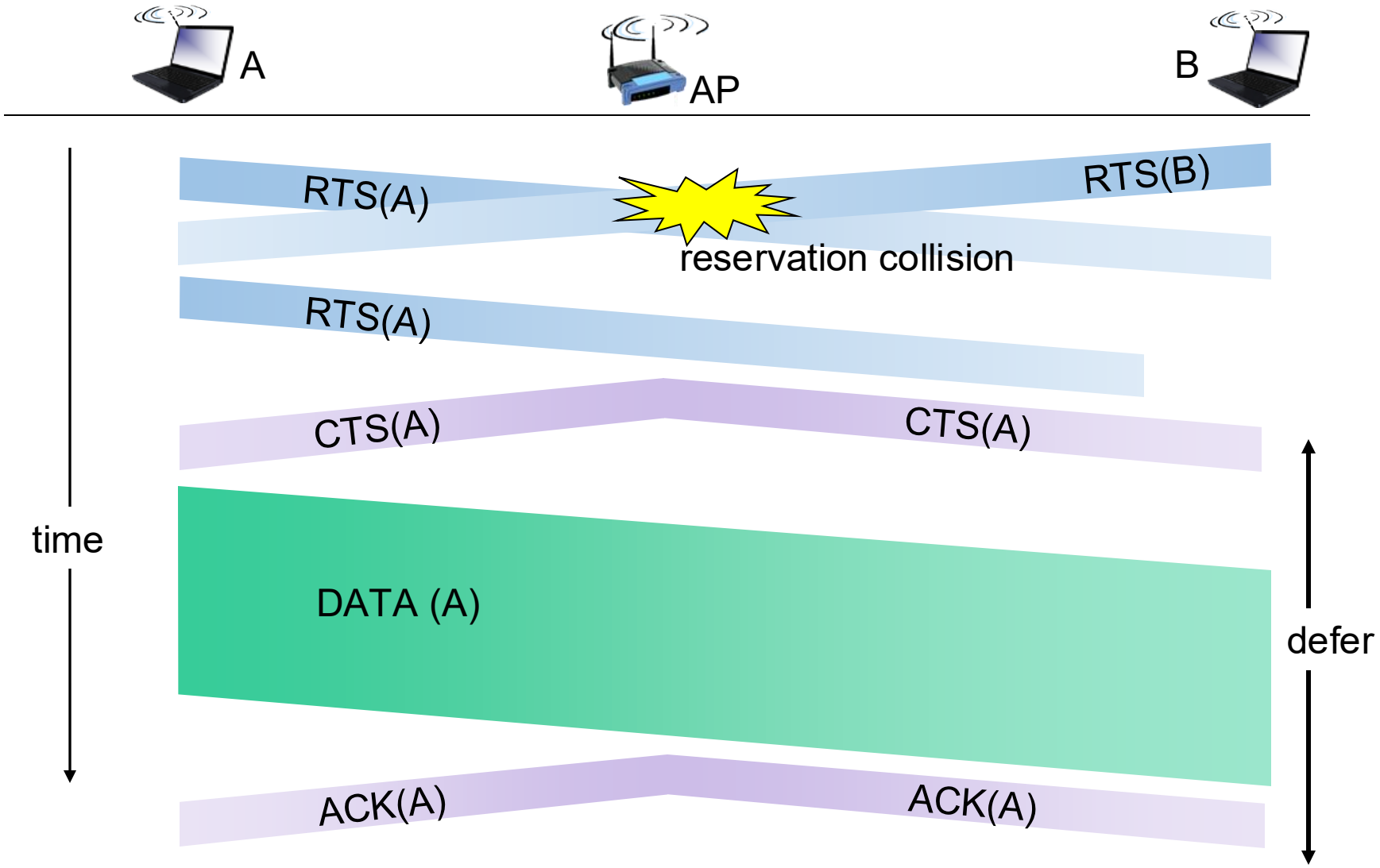


Avoiding collisions (more)

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



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- Cellular networks: 4G and 5G

Mobility

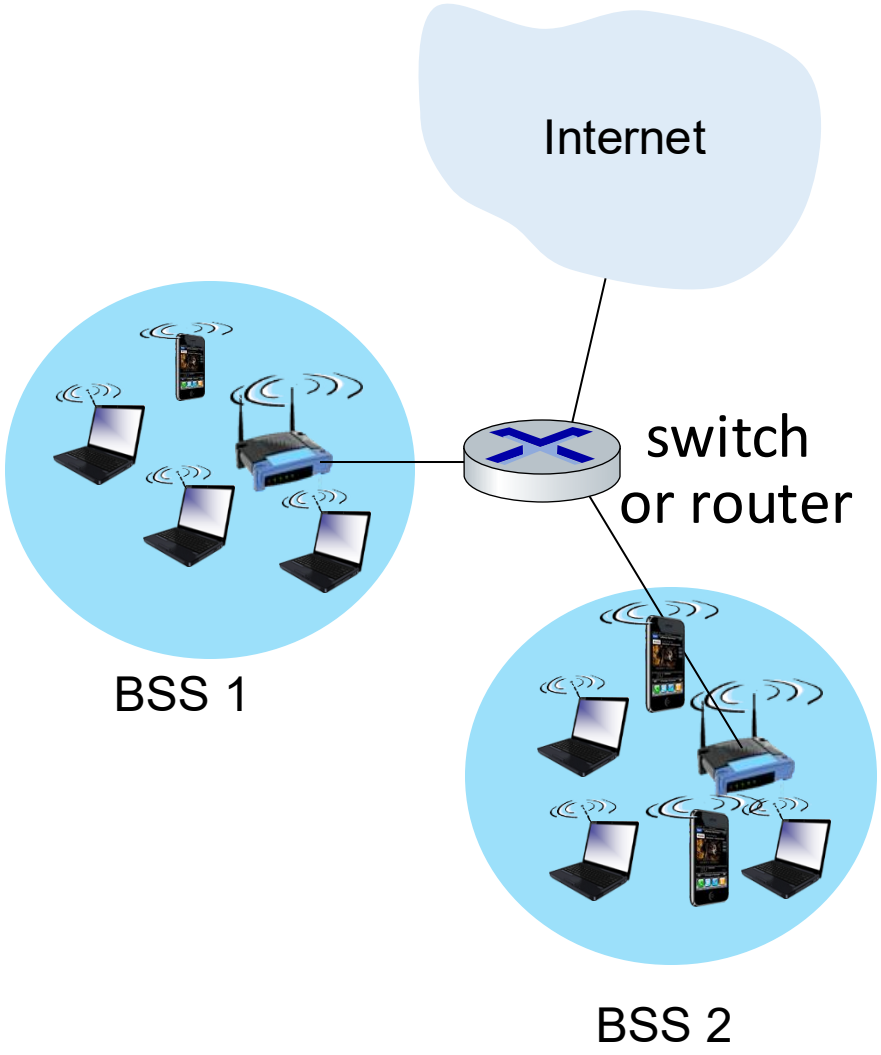
- Mobility management: principles
- Mobility management: practice
  - 4G/5G networks
  - Mobile IP
- Mobility: impact on higher-layer protocols

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 (exp.)	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

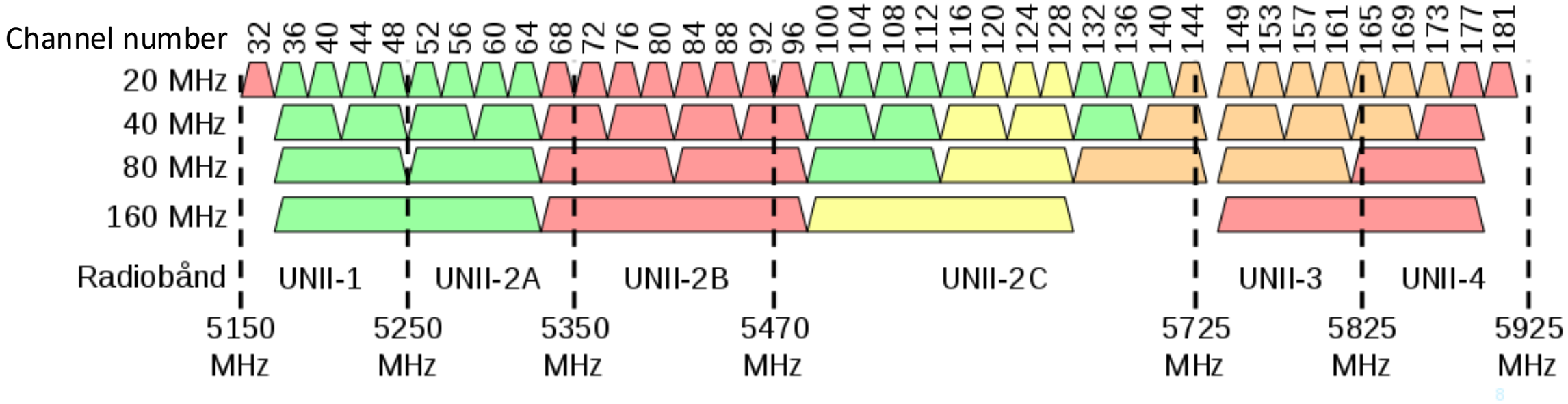
802.11 LAN architecture



- 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!



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

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Cellular Networks – The Dominant Choice for Connectivity

📌 Massive Adoption

5.75 billion mobile users (70.3% of the global population)

96% of internet users access the web via mobile devices

Mobile networks provide connectivity in urban & rural areas where fixed broadband is limited

📌 Explosive Growth in Mobile Data

60% of global internet traffic comes from mobile networks

Mobile data traffic expected to triple by 2030

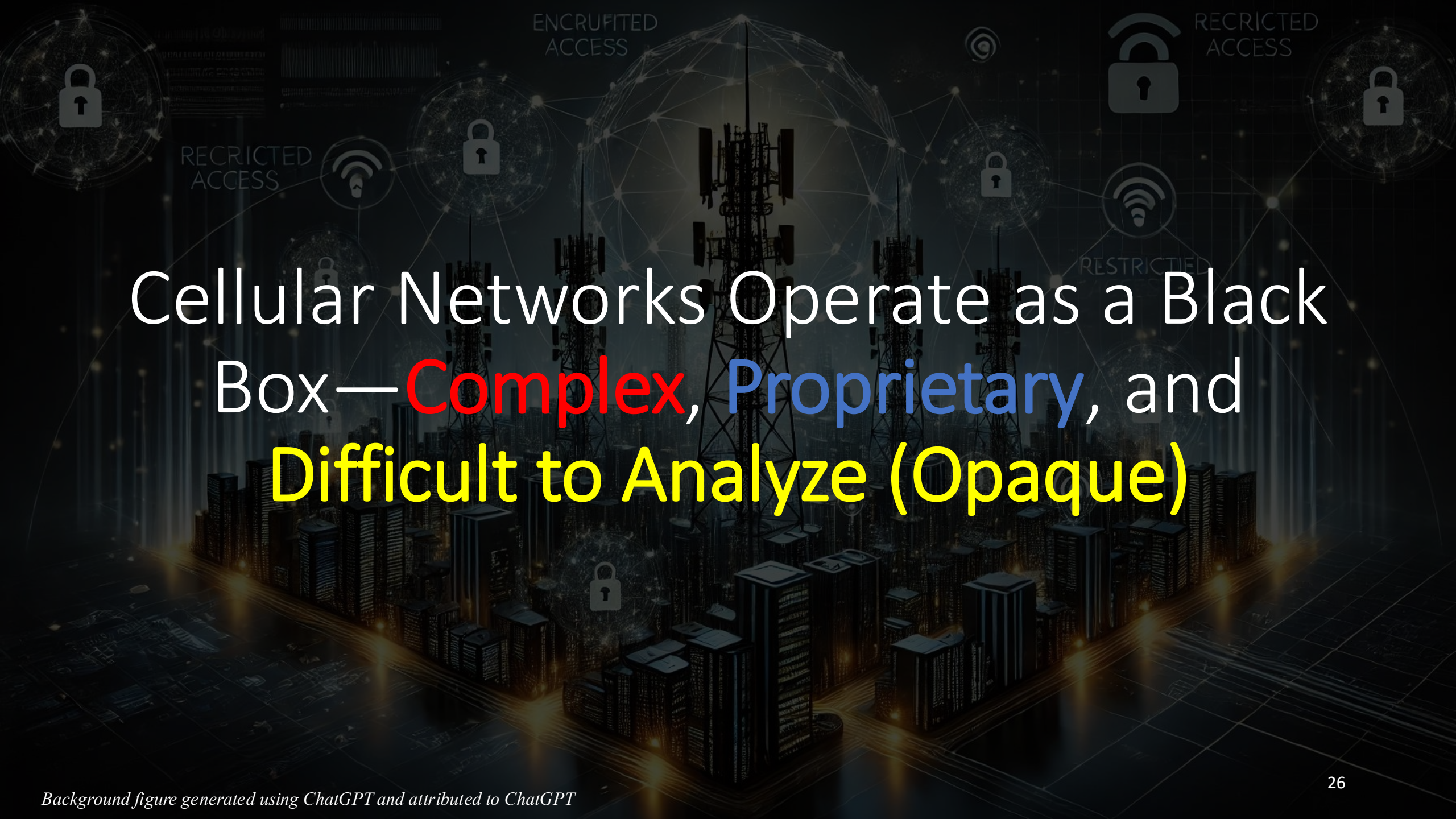
Demand driven by video streaming, IoT, and cloud applications

Cellular Network is Expected to be a Critical Infrastructure for Powering Diverse Applications

High Bandwidth | **Ultra-Low Latency** | **Guaranteed Reliability**


Can cellular network deliver the performance these application required? If not, why?

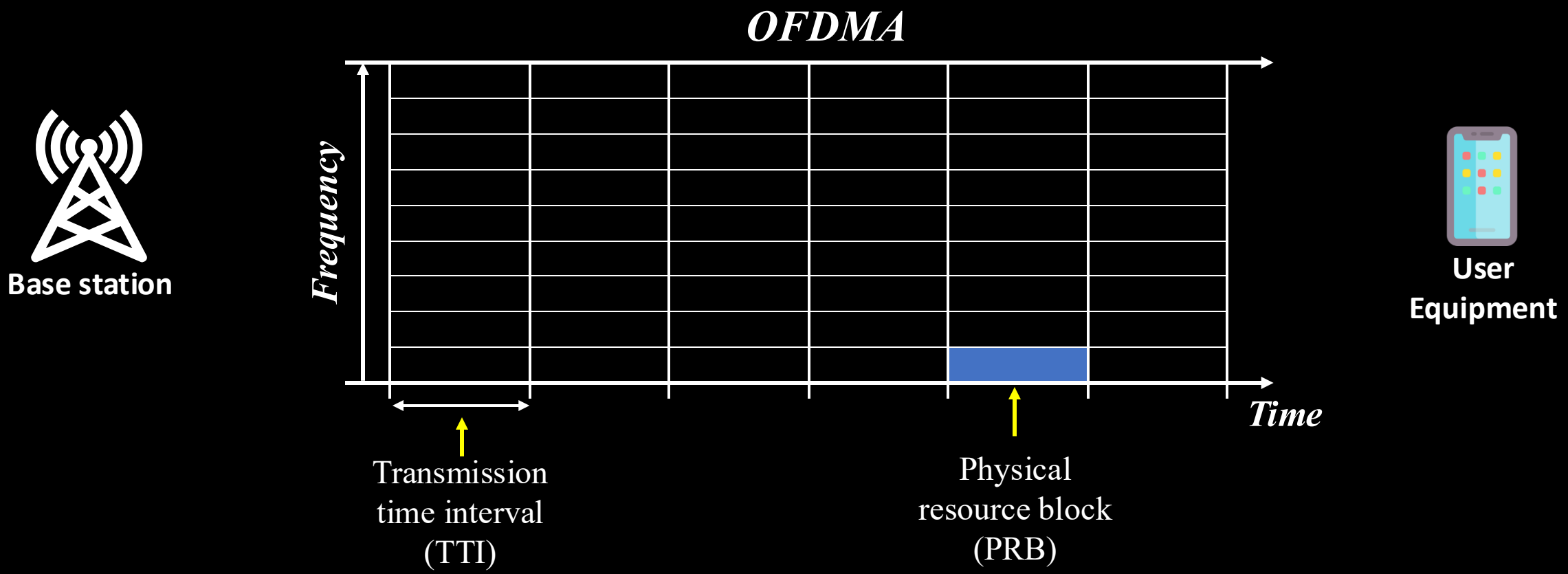
Figures generated using ChatGPT and attributed to ChatGPT



Cellular Networks Operate as a Black Box—Complex, Proprietary, and Difficult to Analyze (Opaque)

Background figure generated using ChatGPT and attributed to ChatGPT

Cellular Network is Complex and Proprietary: Resource Management in OFDMA



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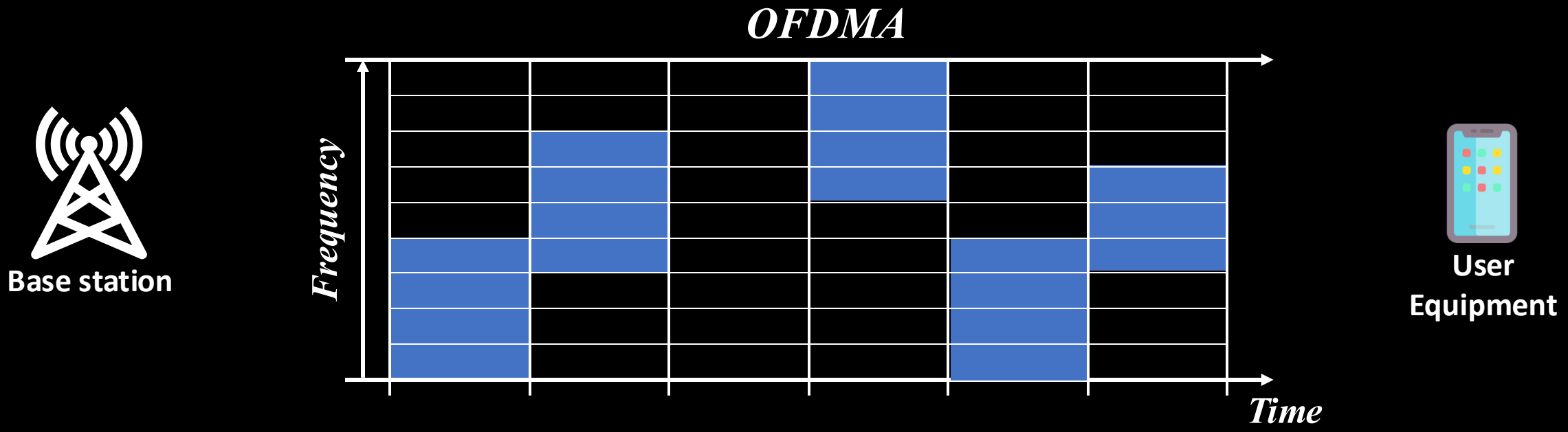

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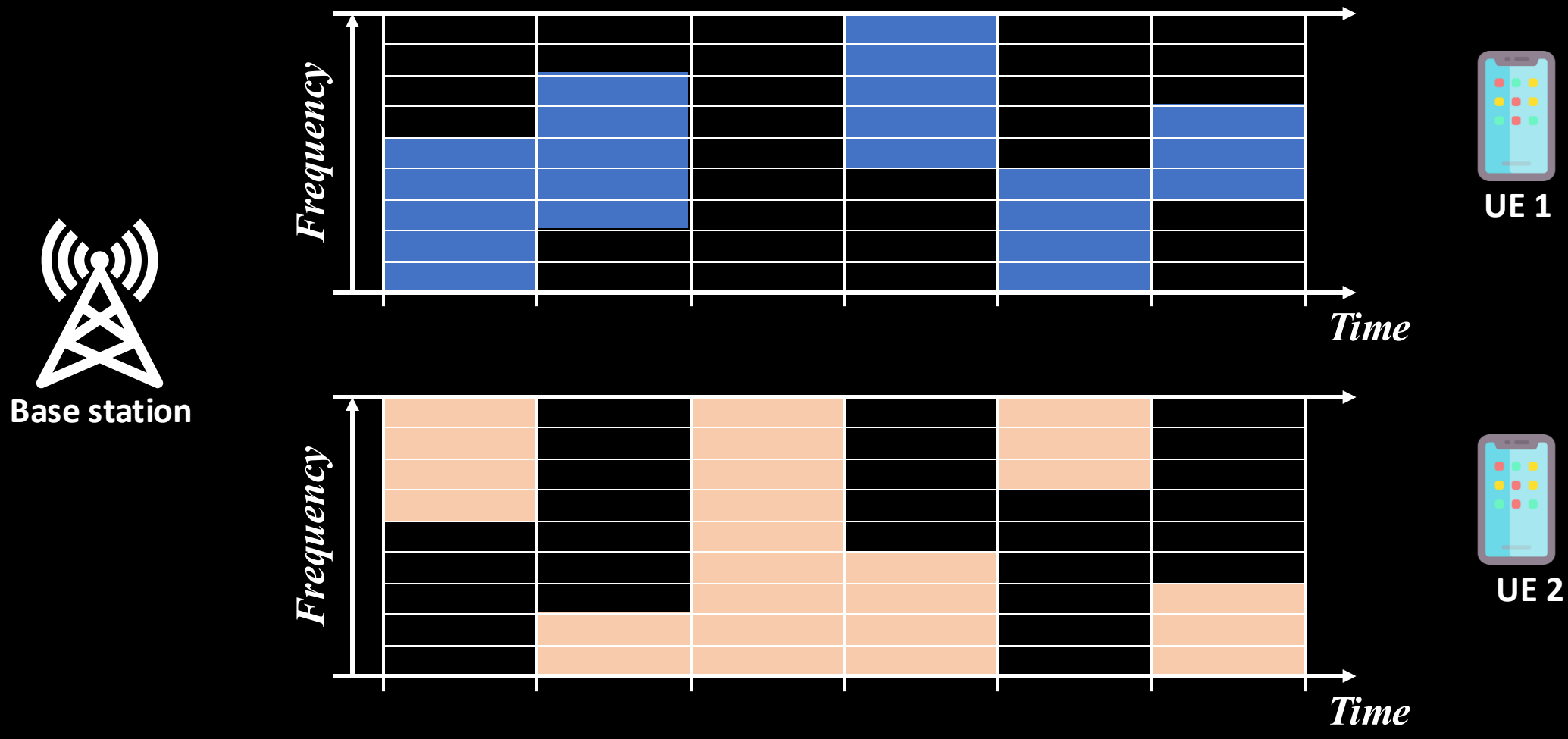

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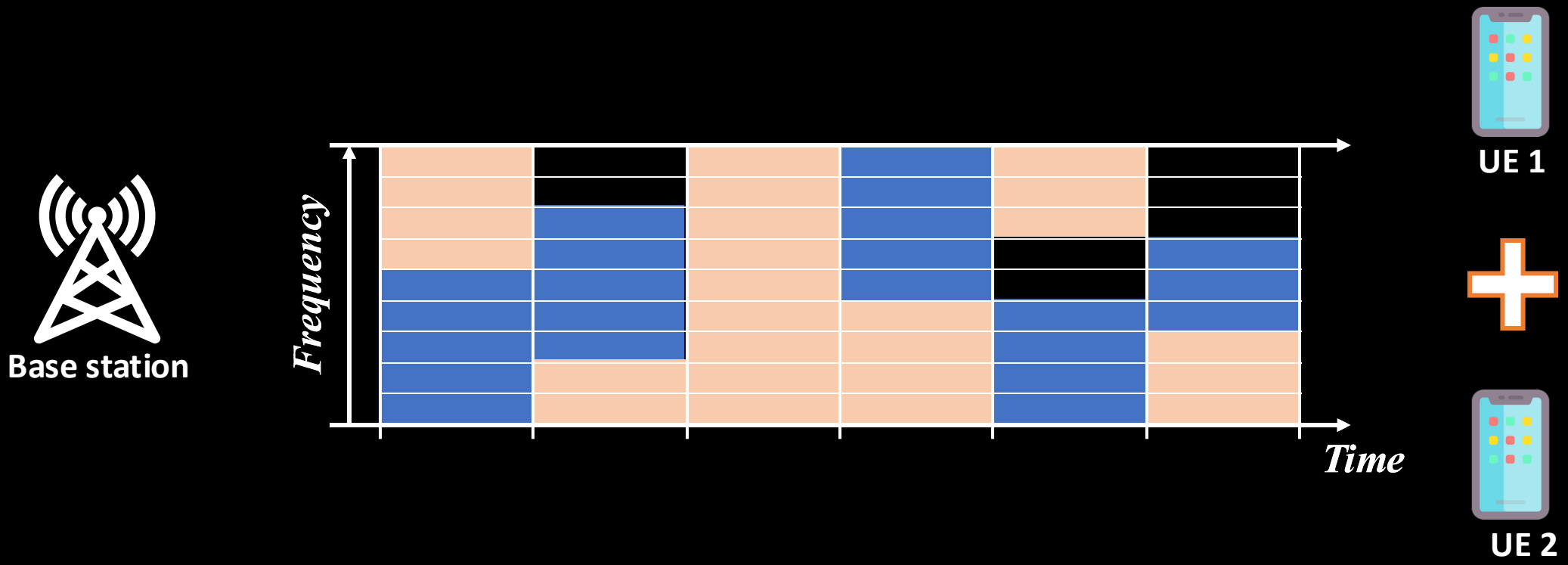

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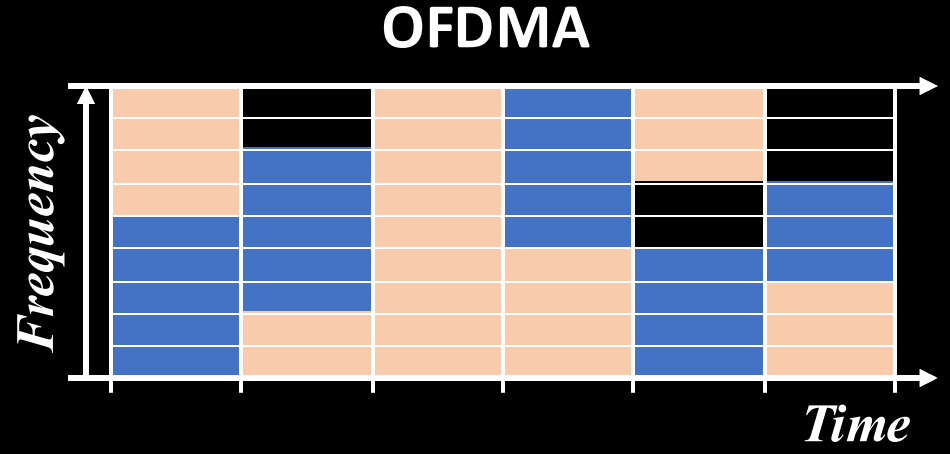
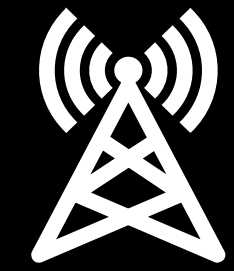




The OFDMA architecture is defined by the 3GPP standard

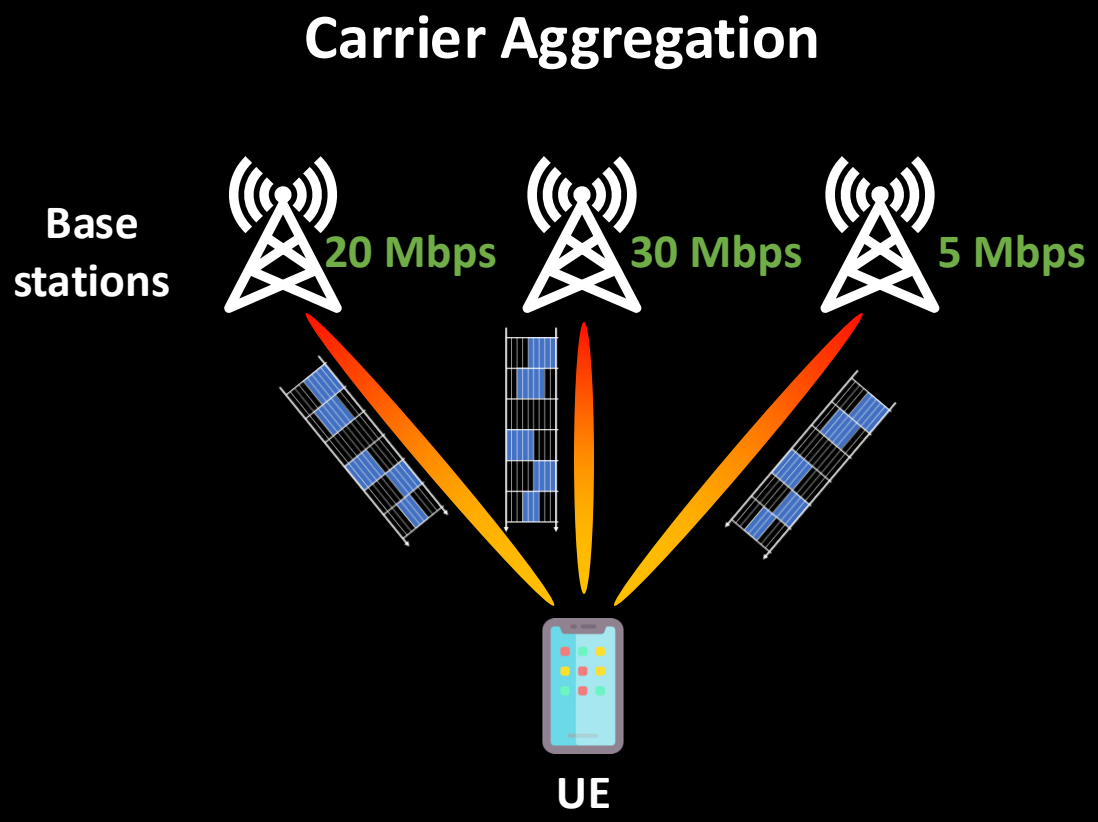
Leave the flexibility for implementing the resource management algorithm

The resource management algorithm is designed and implemented by network device vendor (Erison, Nokia, Qualcomm, Huawei)

The resource management algorithm is proprietary (core IP)

Even AT&T and Verizon doesn't know the details

Cellular Network is Complex and Proprietary: Carrier Aggregation and Load Balancing



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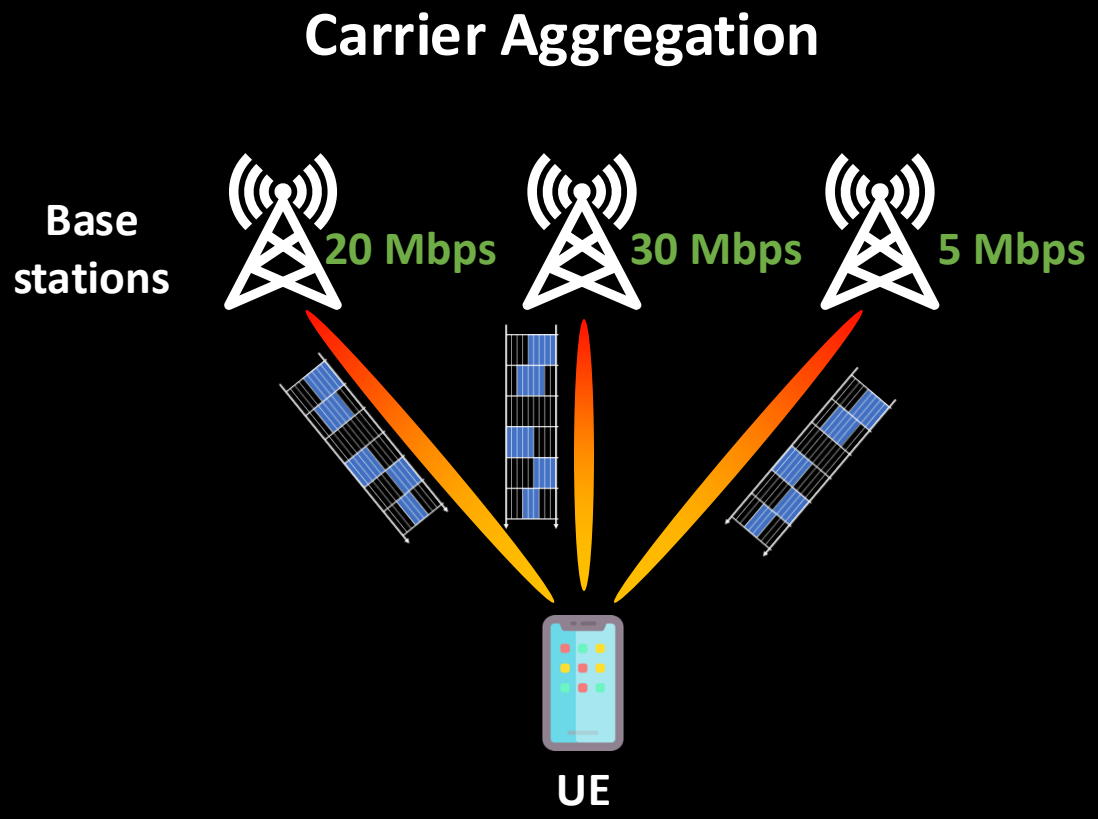

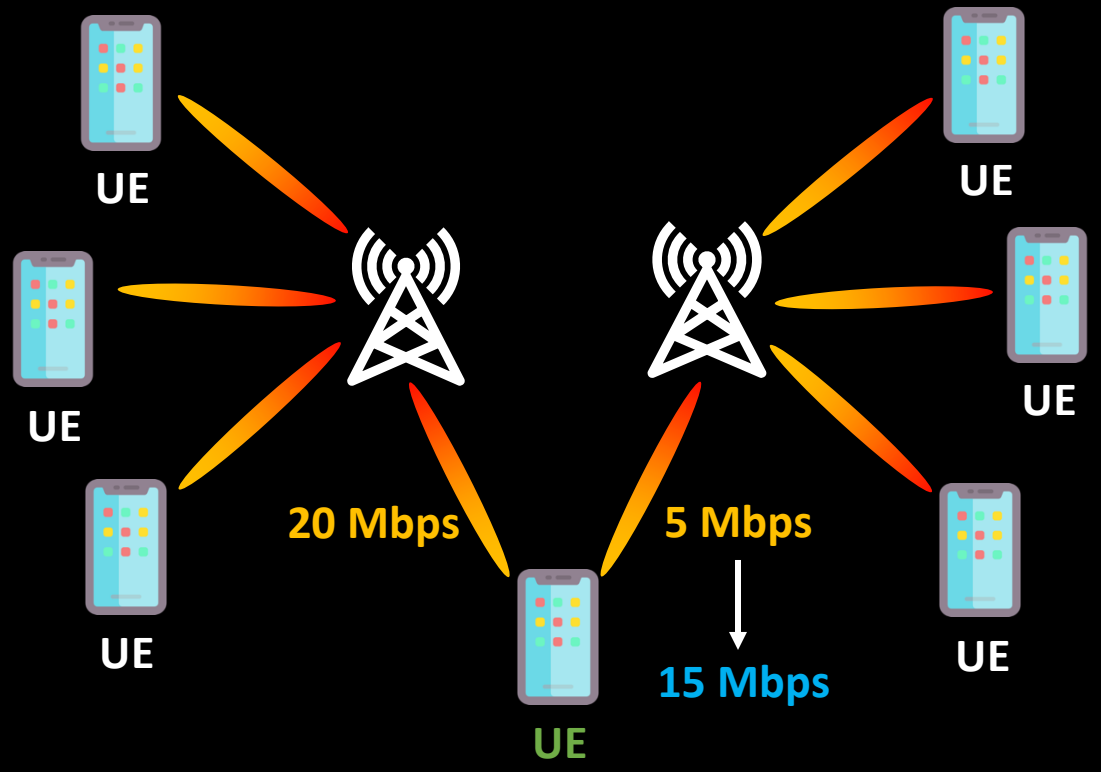

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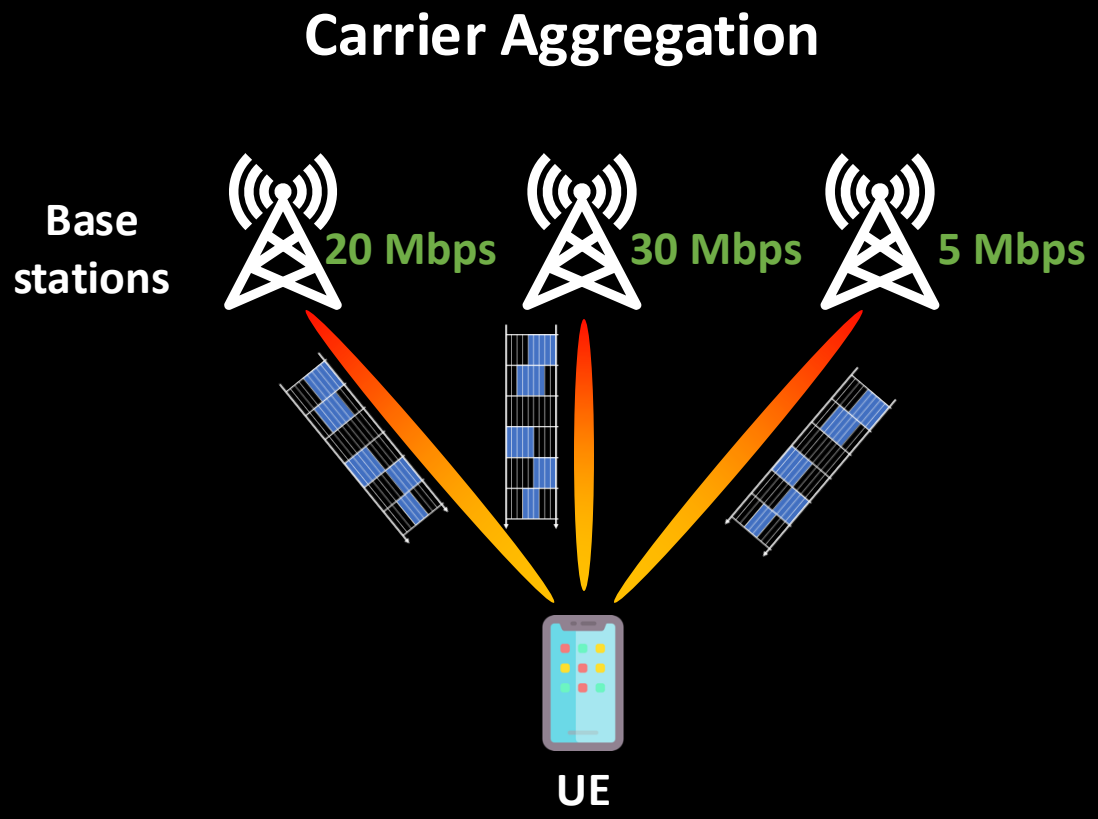

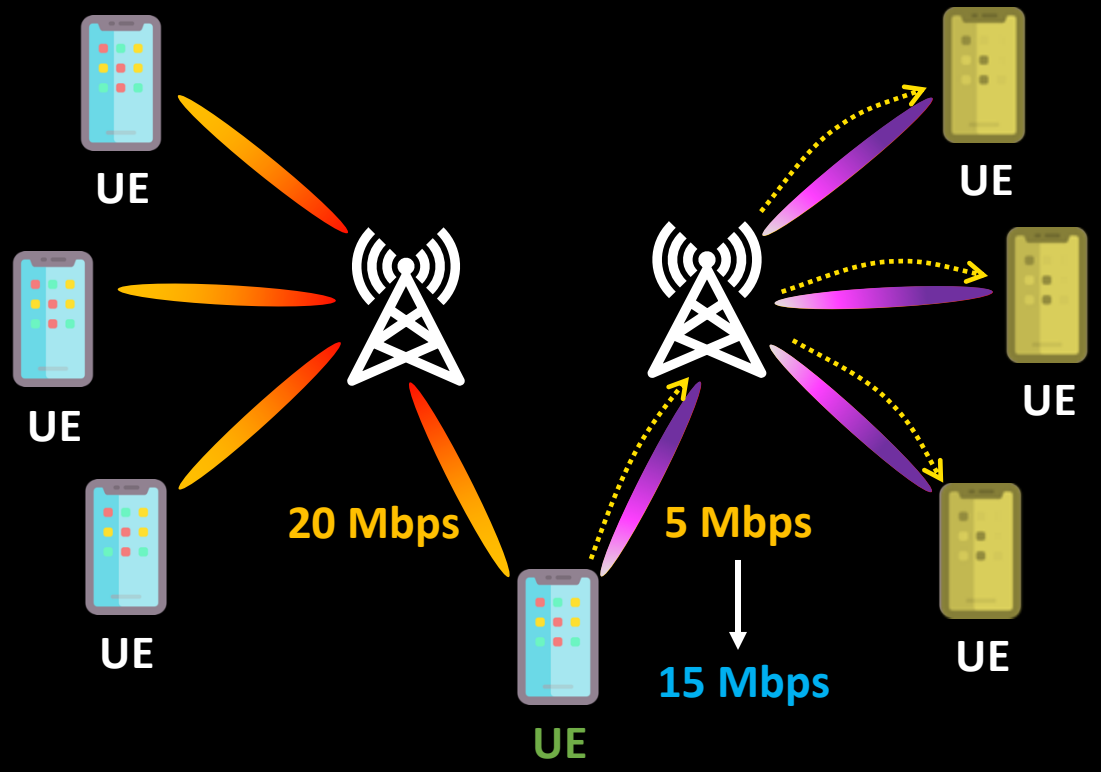

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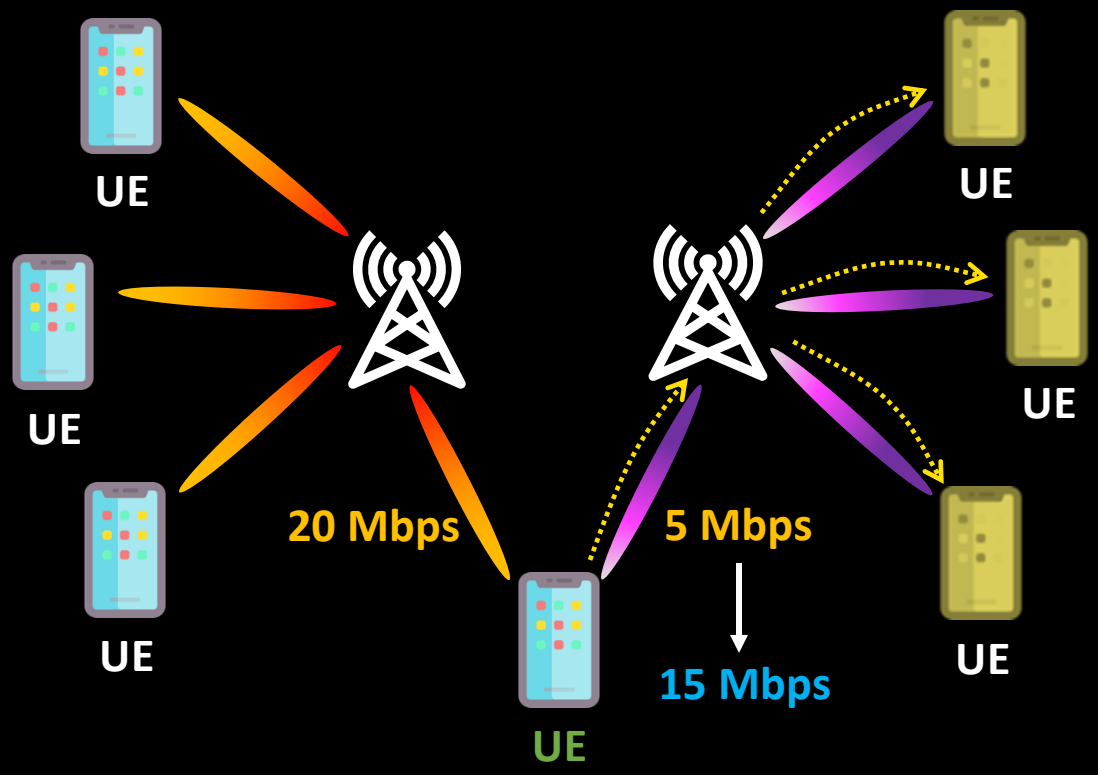

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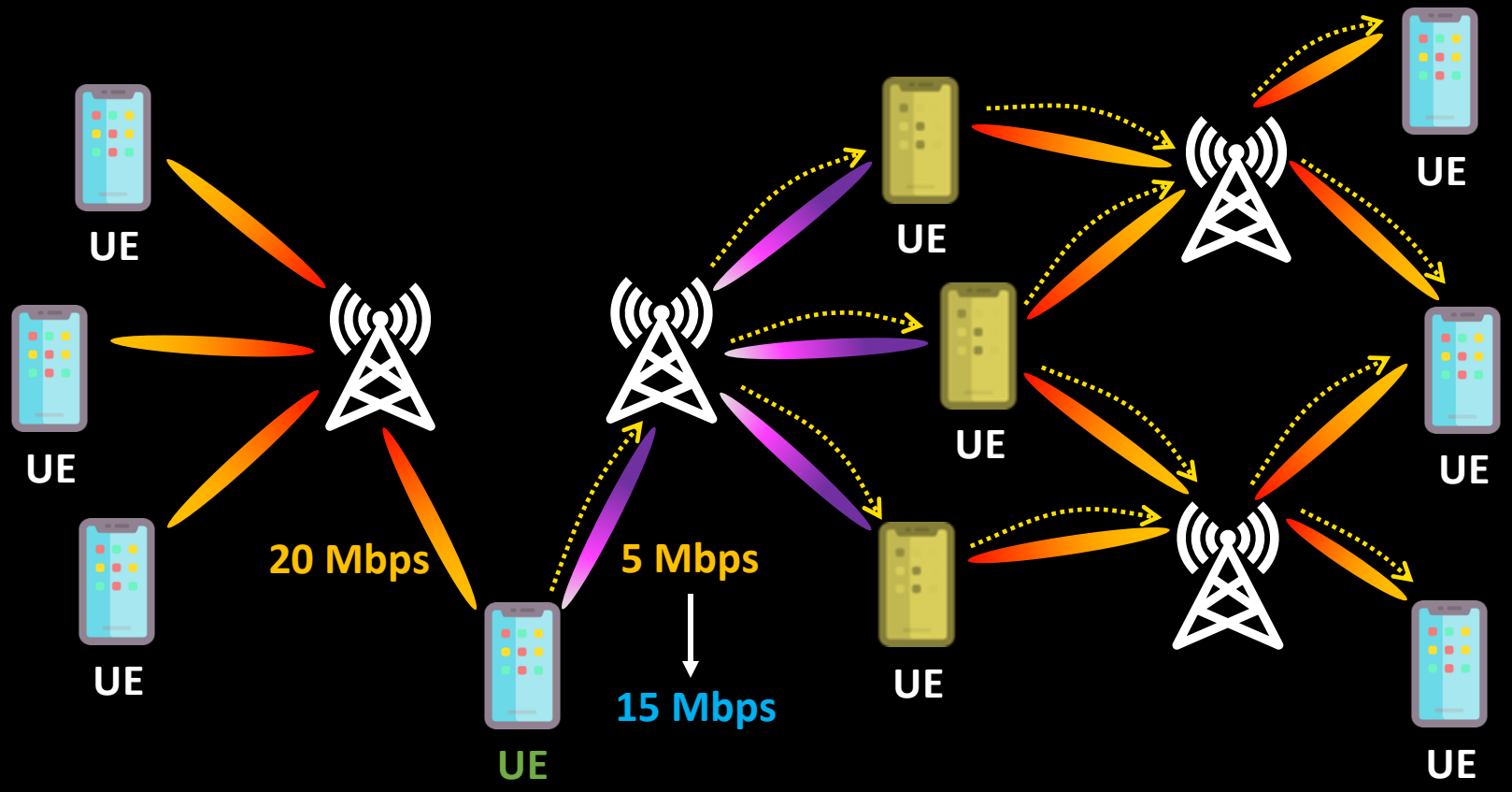

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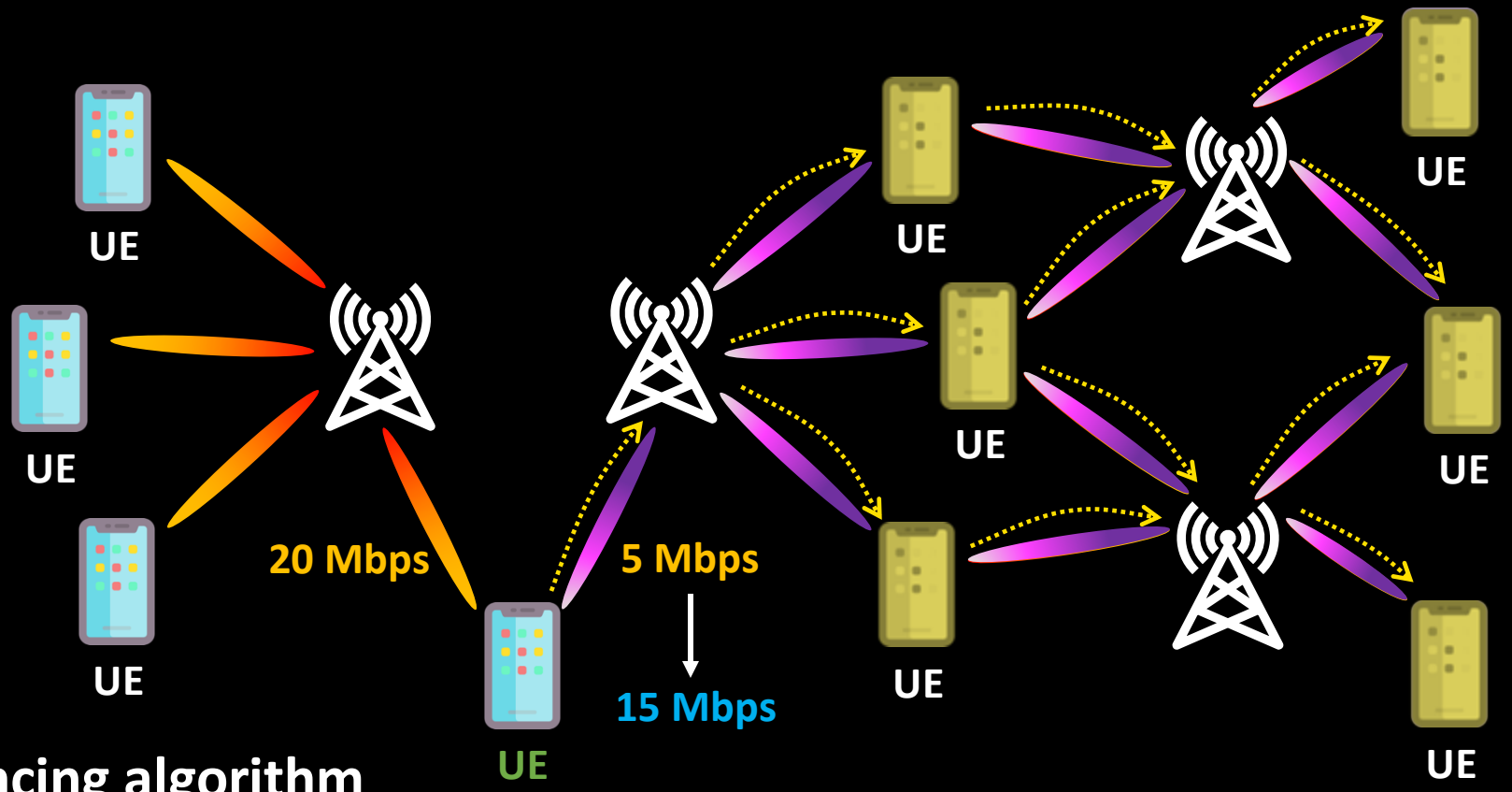
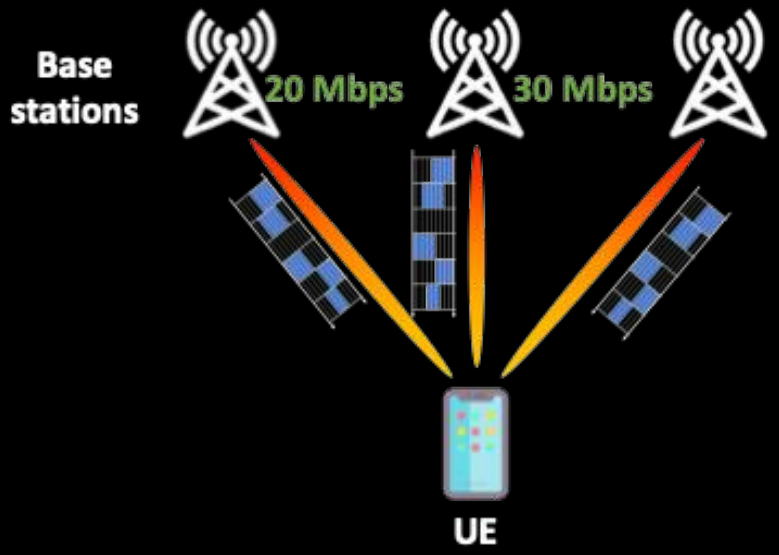


Network-wide load balancing algorithm

- **balance the traffic load** of base station
- **maximize the experience** of each UE

Cellular Network is Complex and Proprietary: Carrier Aggregation and Load Balancing



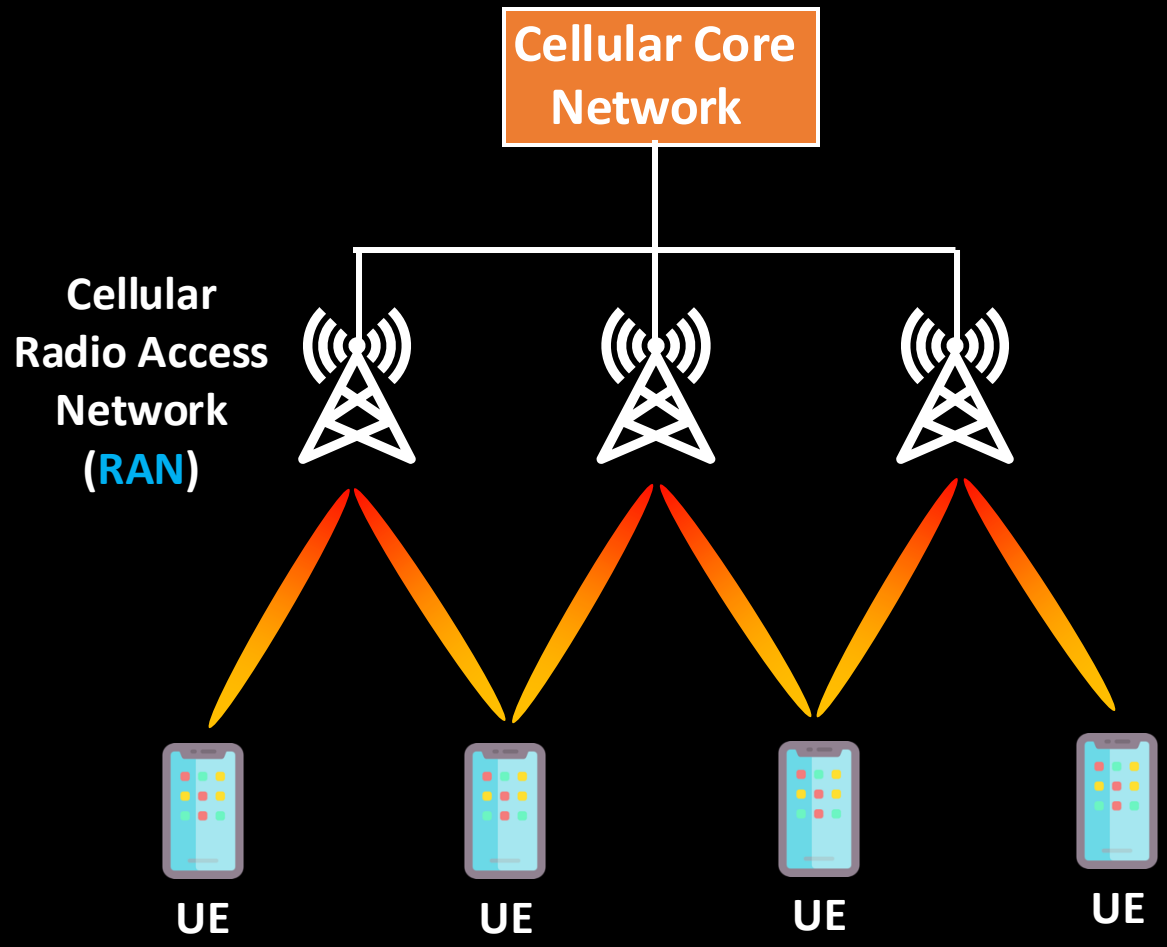
Carrier Aggregation technique details are regulated by 3GPP standard

The load-balancing algorithm is implemented by the network operator (such as AT&T, Verizon and T-Mobile)

The load-balancing algorithm is proprietary (core IP)

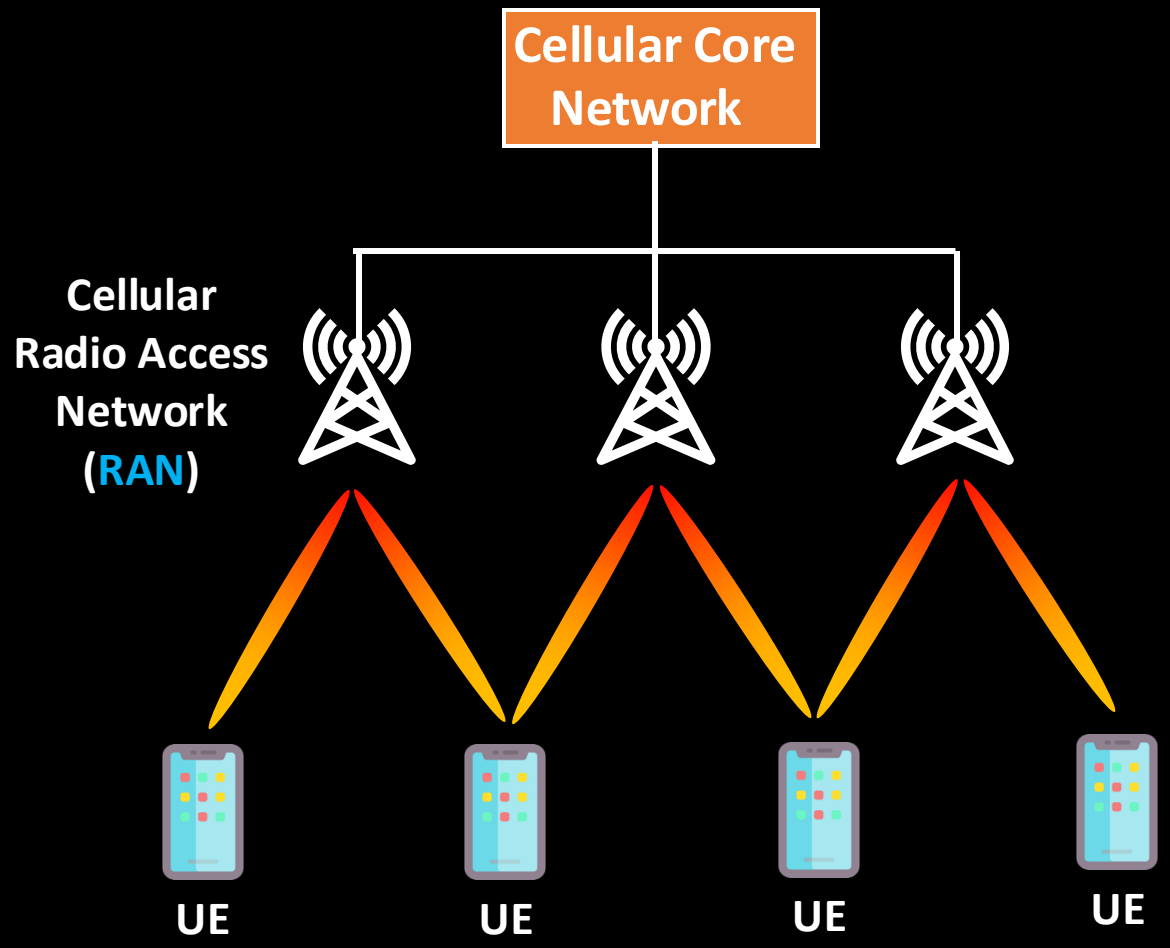
Figure generated using ChatGPT and attributed to ChatGPT

Cellular Network is Complex and Proprietary



- **Massive MIMO** – Multiple Current Data Stream
- **Dynamic Spectrum Sharing (DSS)** – Coexistence of 5G/4G for Maximum Spectrum Efficiency
- **Multi-user Beamforming (MU-MIMO)** – Smart Antenna Techniques
- **Hand-Over** – Seamless Transition Between Cells for Continuous Connectivity
- **Network Slicing** – Customizing Network Resources for Different Applications

Cellular Network is Complex and Proprietary and thus Difficult to Analyze



Multiple Stakeholders

3GPP (Standard Setter) – Complex Standards & Flexibility in Implementation

Network Device Vendors (Hardware Manufacturer) – Proprietary Implementations & Vendor-Specific Optimizations

Network Operator (Service Provider) – Carrier-Specific Network Management Policy and Optimization

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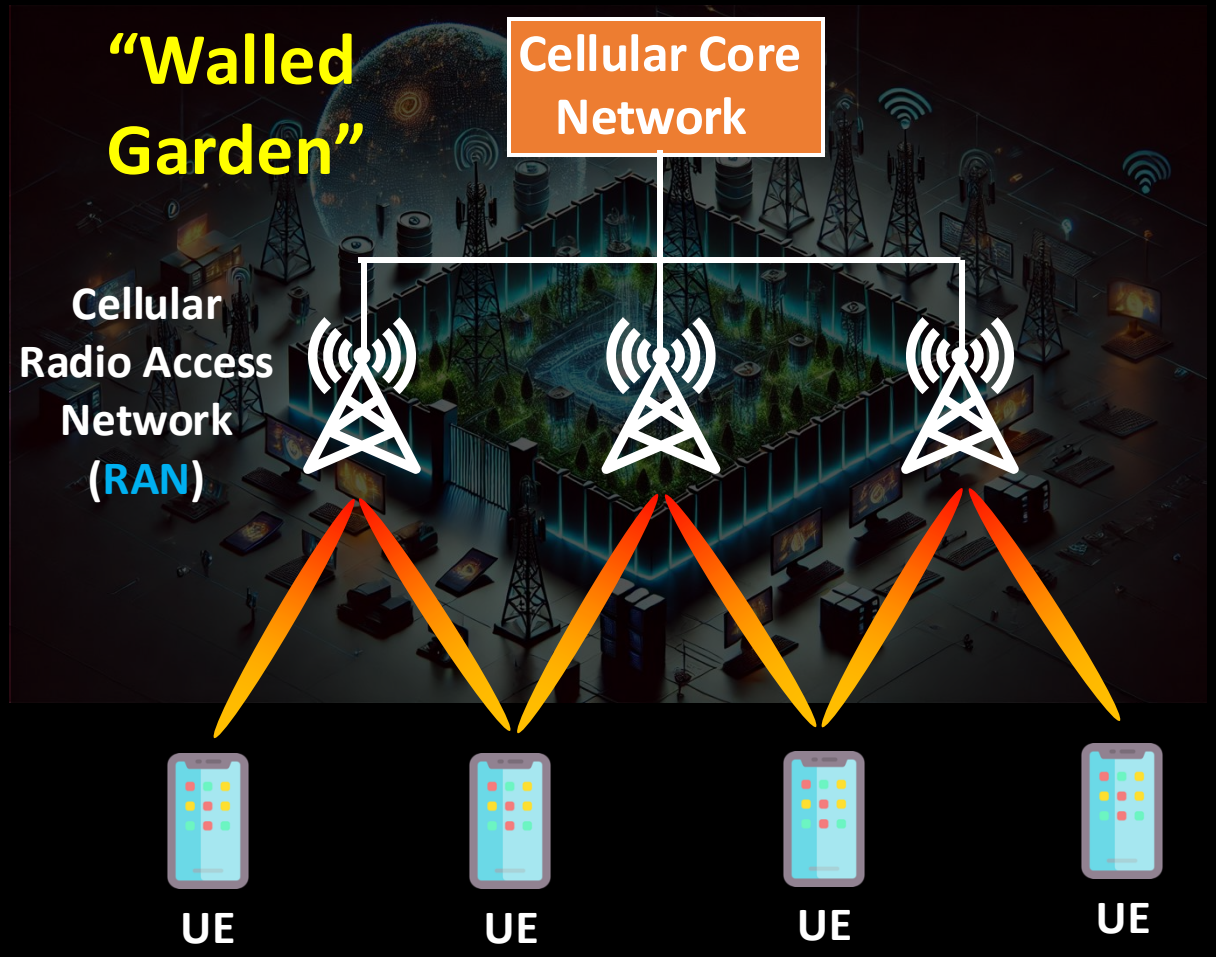

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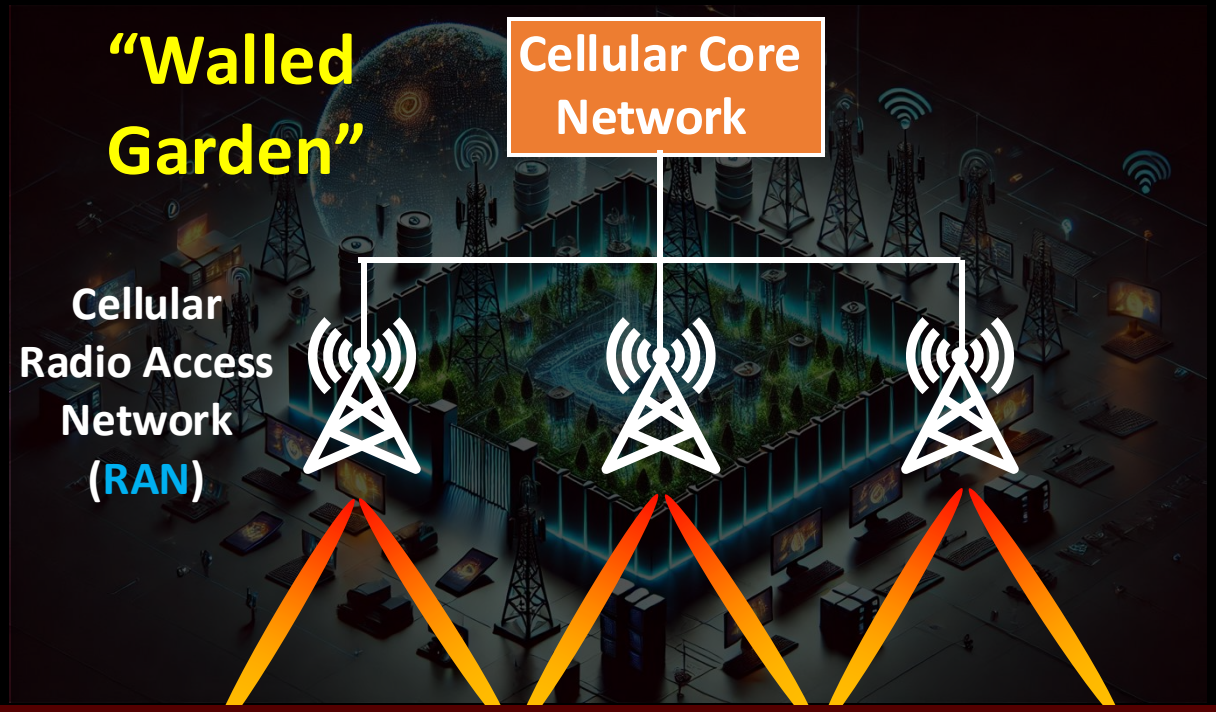


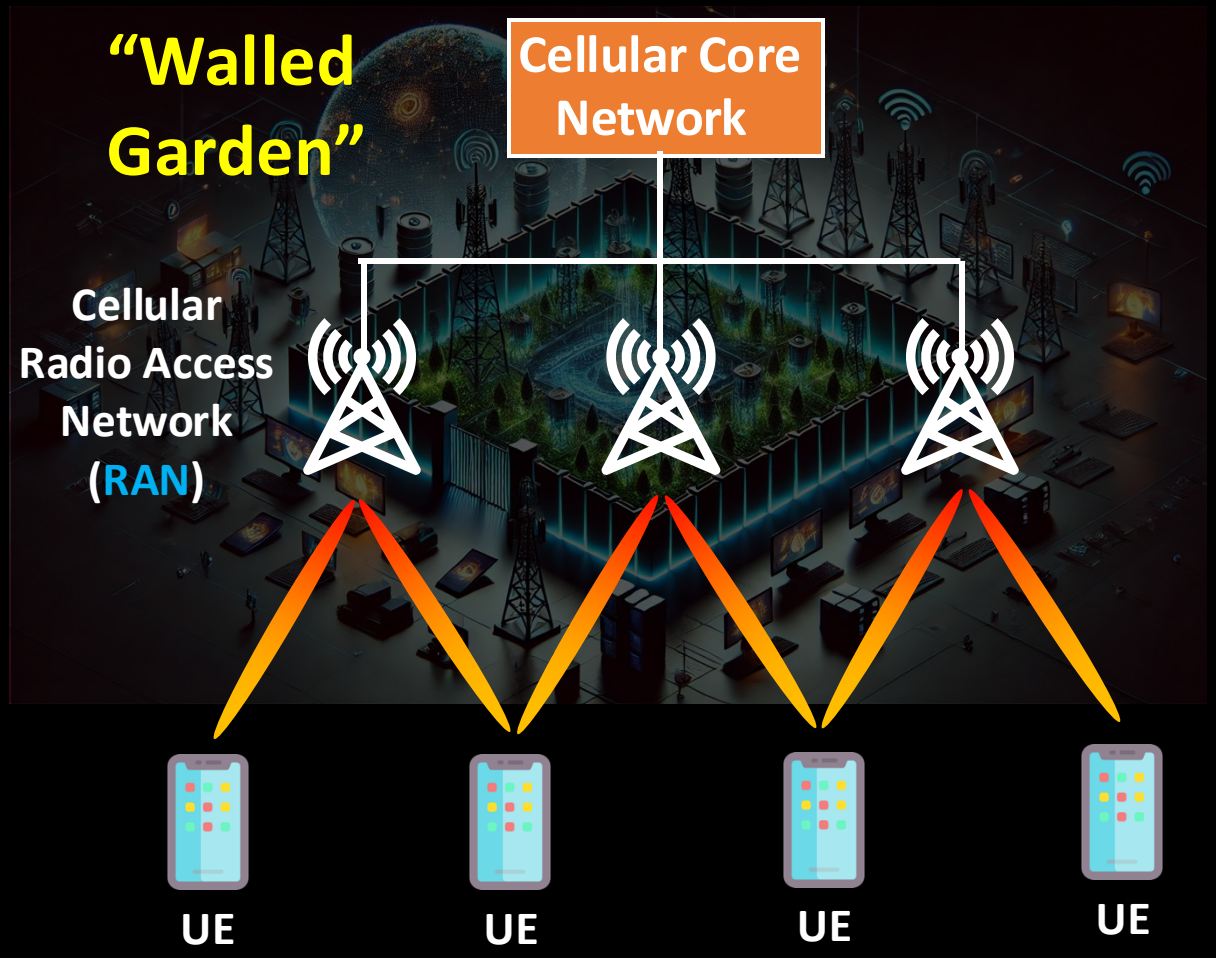
Multiple Stakeholders

3GPP (Standard Setter) – Complex Standards & Flexibility in Implementation

Network Device Vendors (Hardware Manufacturer) – Proprietary Implementations & Vendor-Specific Optimizations

Each network operator tightly controls its deployed network as a *"walled garden"*, restricting access and limiting transparency

GAP: High-Demand Applications *vs.* Walled Garden of Cellular Networks



Next-Generation High-Demand Applications

VR/AR

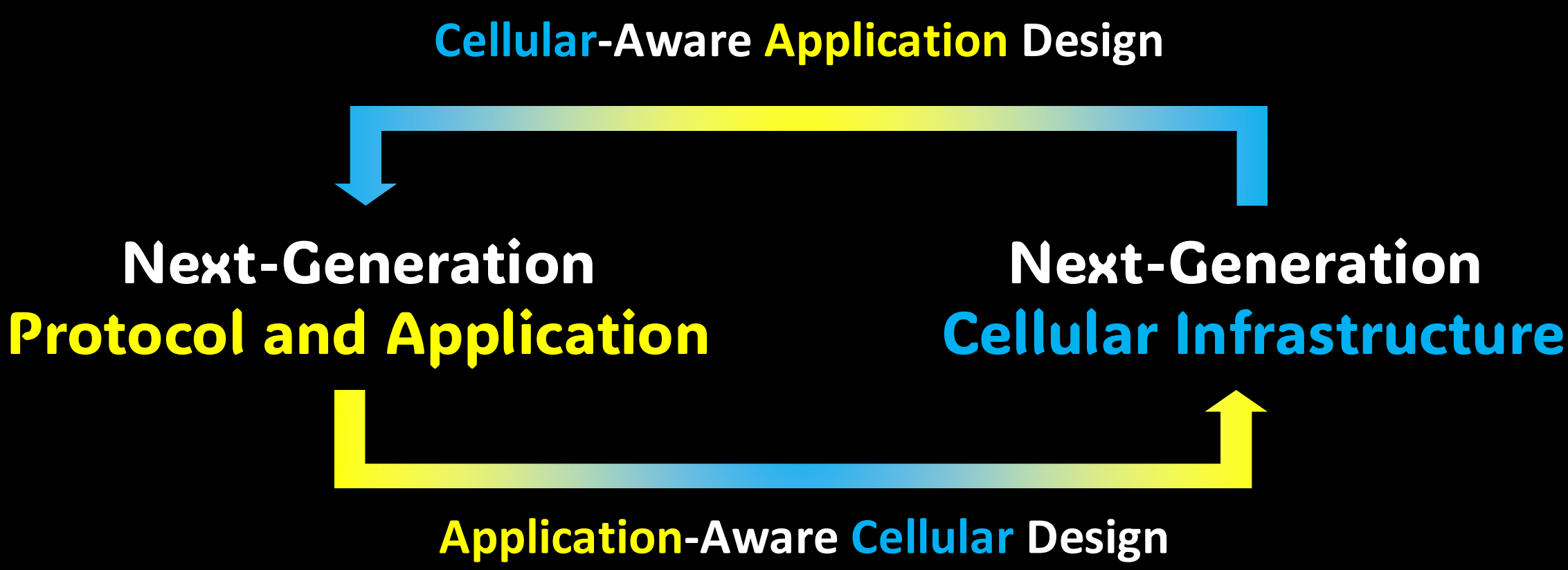
Autonomous Vehicles

Healthcare

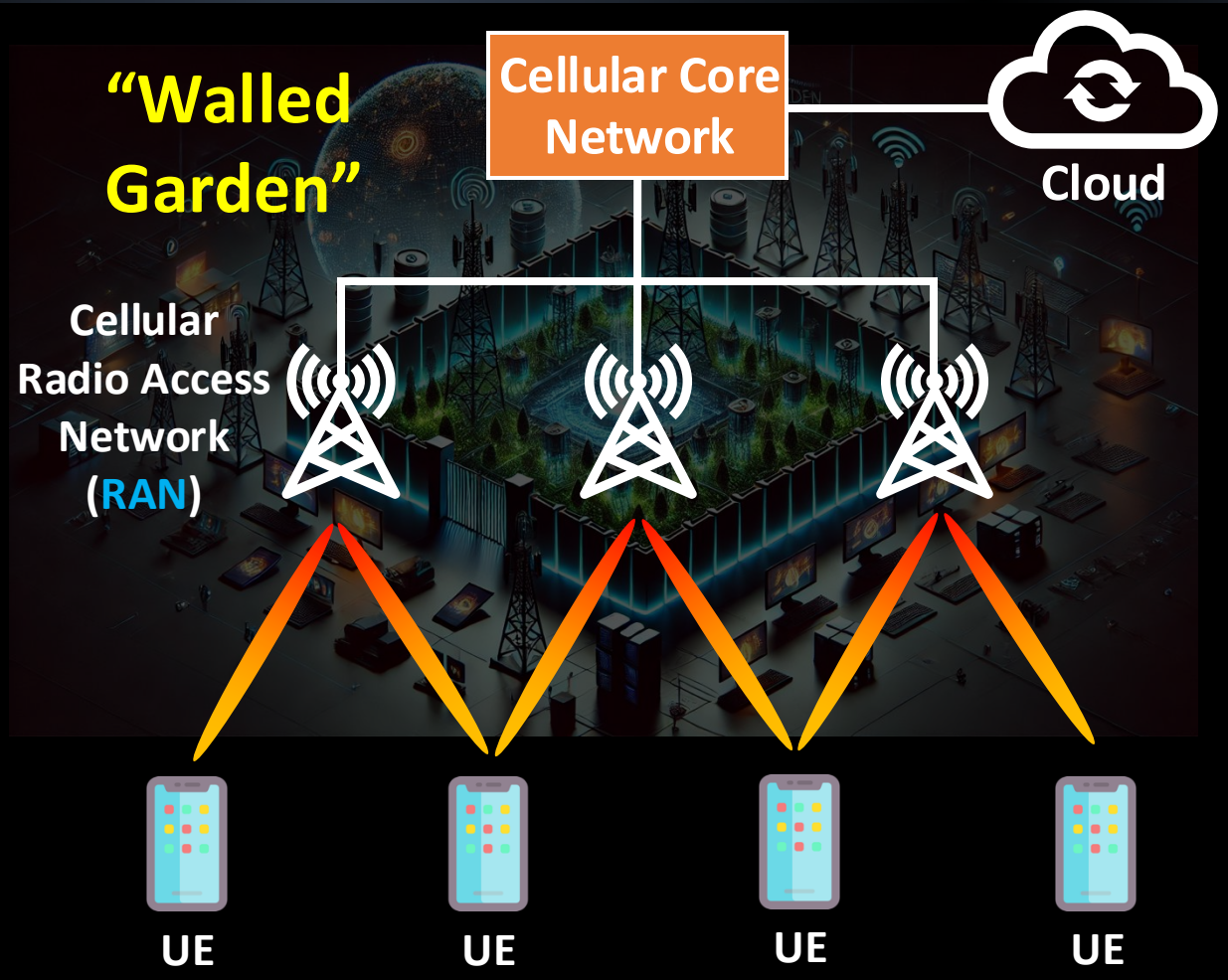
Industrial Automation

High Bandwidth | Ultra-Low Latency | Guaranteed Reliability

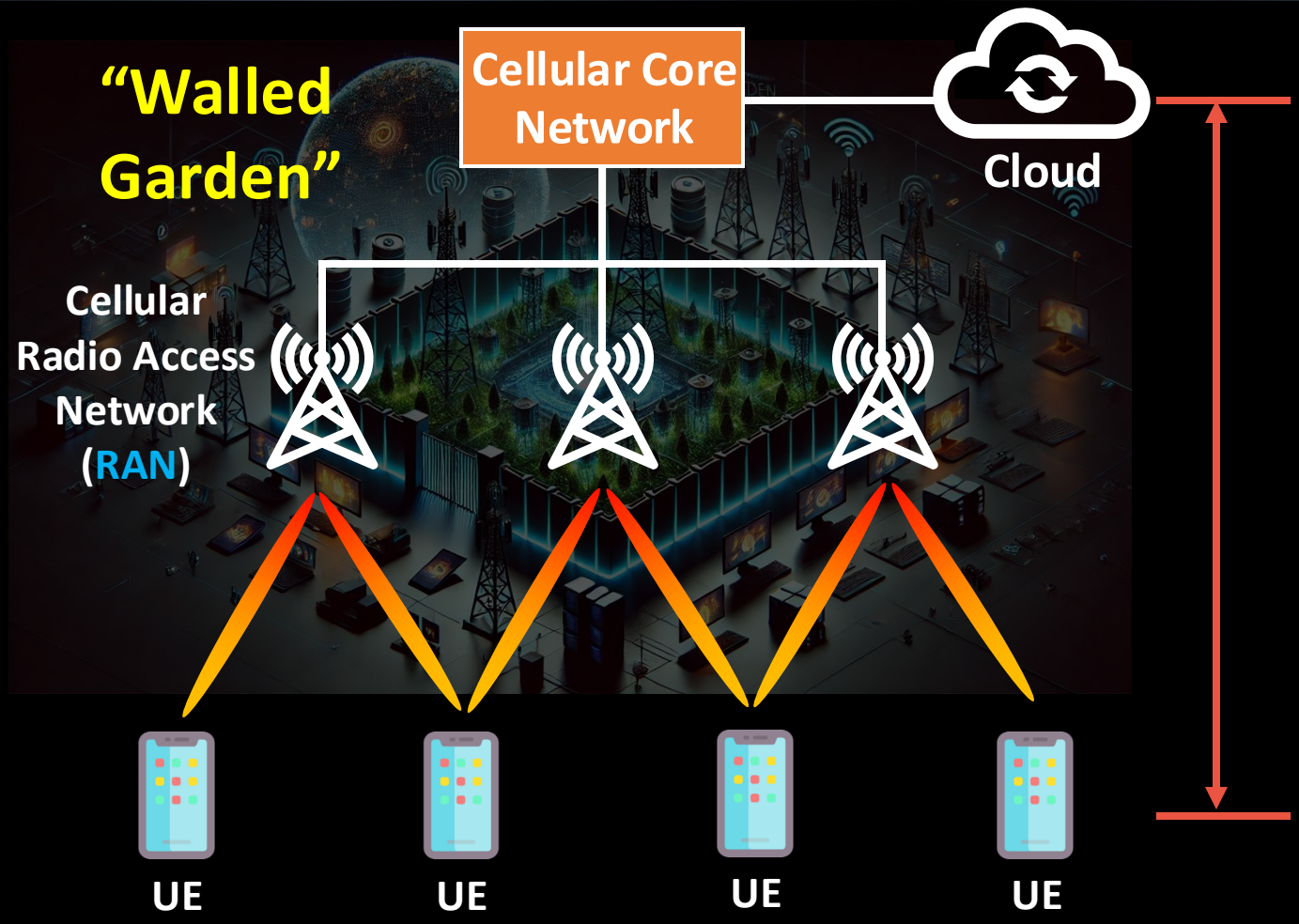
Opportunity:
Application-Infrastructure Co-Design



Challenge:
Visibility into the Walled-Garden of Cellular Network



Research: Break the Barrier and Providing Cross-Layer Visibility into Cellular Network



End-to-end Connection

- TCP UDP

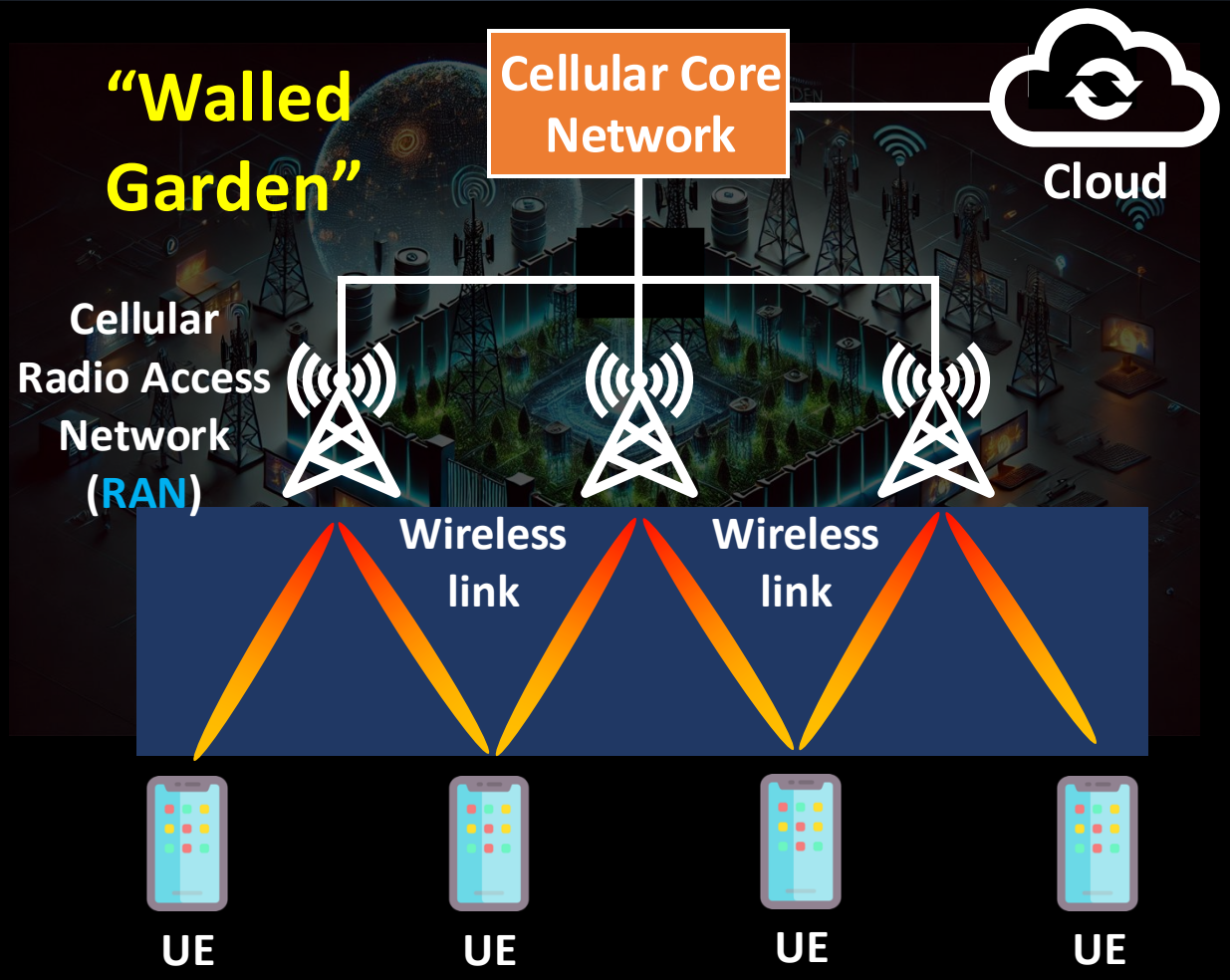
End-to-end Applications

End-to-end Metrics

- Packet delay
- Packet loss
- Application-level metrics

Lack of insights from cellular networks

Research: Break the Barrier and Providing Cross-Layer Visibility into Cellular Network



Wireless link between base station and UE

- Wireless is a broadcast medium in its nature
- No cooperation from the service provider

Capable of monitoring the traffic between base station and all the UE it serves

Data maybe encrypted

- Only the unencrypted data can be decoded

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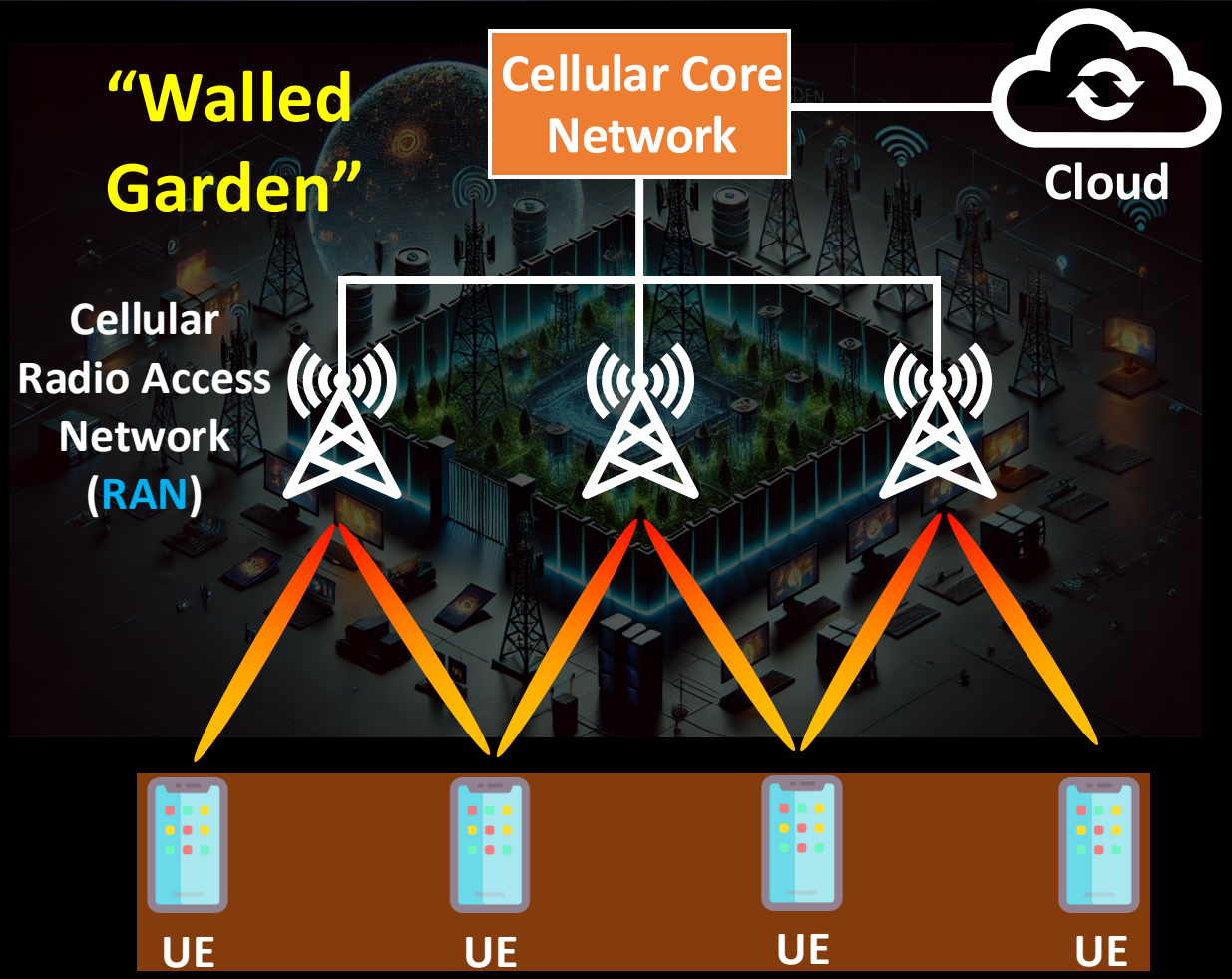


Commercial Mobile Phones (UE)

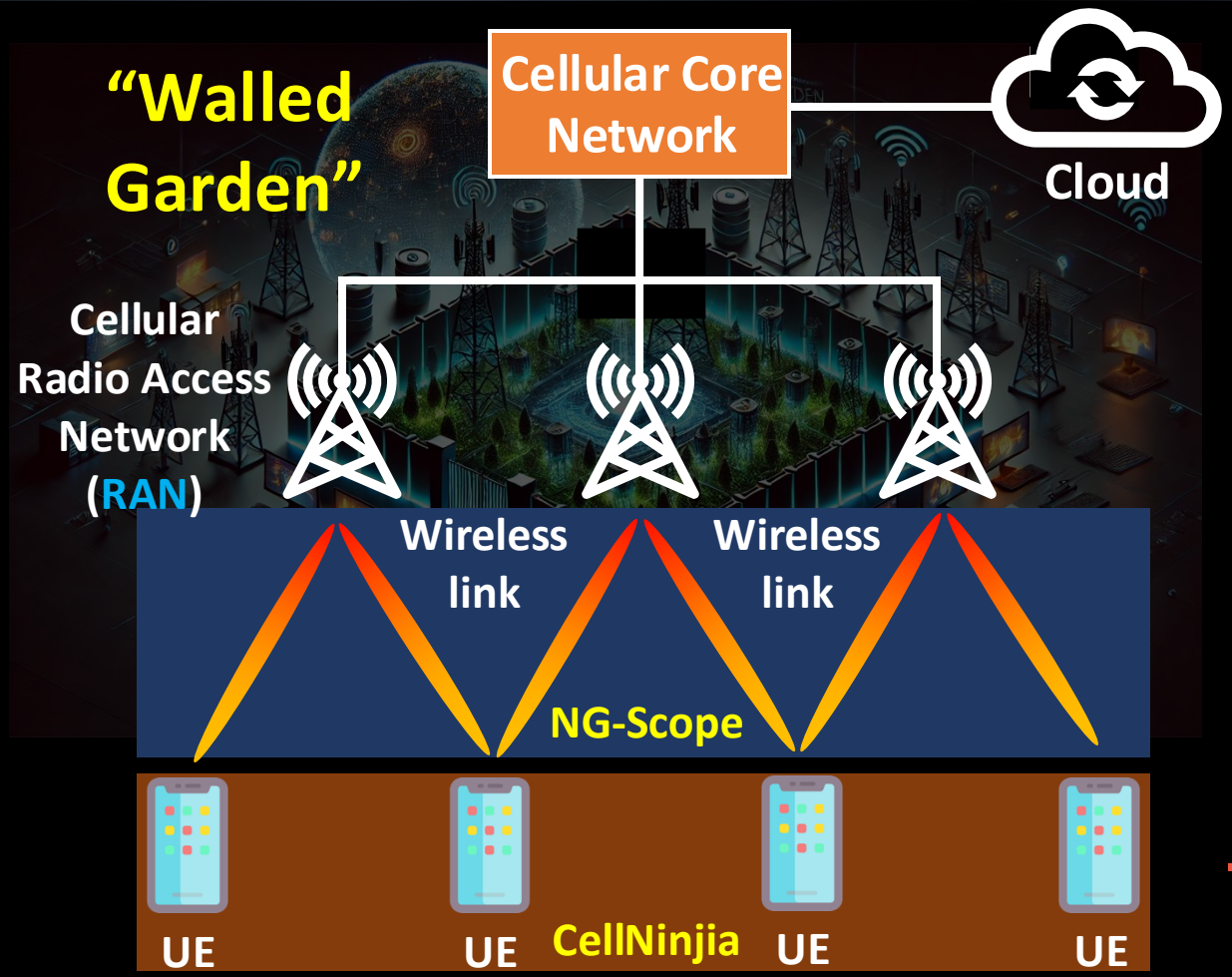
- Capable of decoding all the messages
- Possible of exposing all the interactions between UE and base stations

Cellular Modem is Proprietary

- Modem vendors like Qualcomm only exposes limited information about the internal status

Can only monitoring one device

Research: Break the Barrier and Providing Cross-Layer Visibility into Cellular Network



End-to-end Connection and Applications

Monitoring Wireless link between base station and UE (NG-Scope)

Monitoring all Interactions between base stations and UE at the UE (CellNinjia)