

Computer Networks

Lecture 09

Wireless and Cellular Networks

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Lecture

09

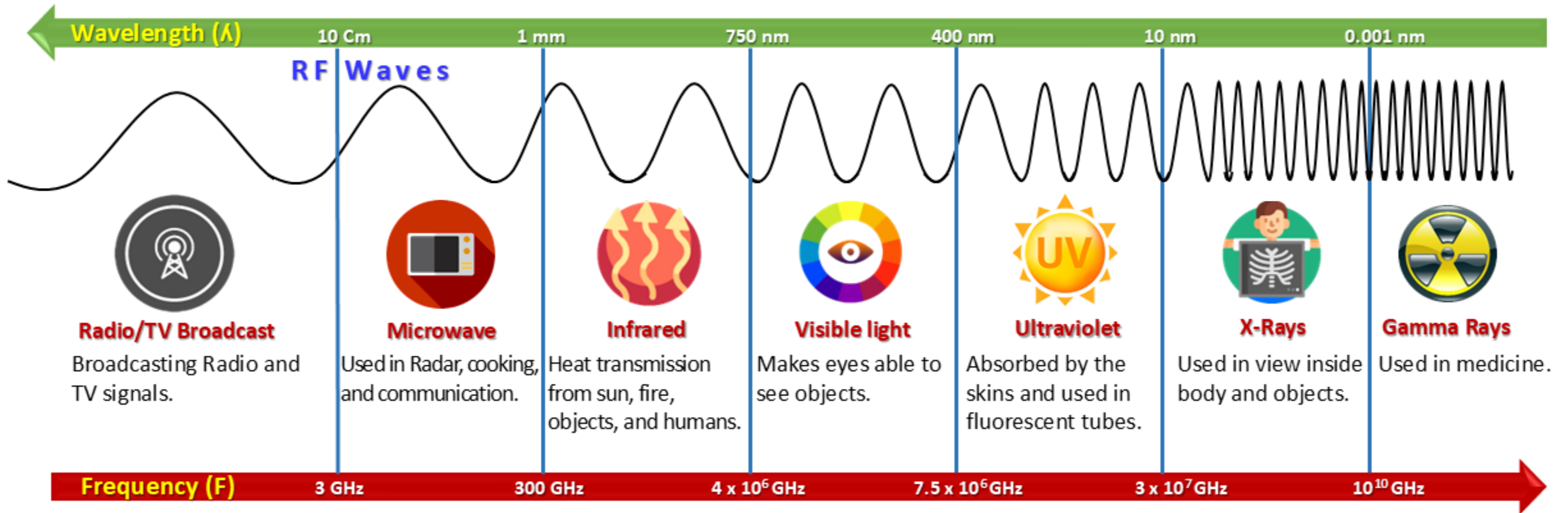
LEARNING OUTCOMES

- Understand the electromagnetic spectrum.
- Understand Radio Frequency ranges.
- Differentiate between 2.4 GHz and 5 GHz bands.
- Recognize the Elements of a wireless network.
- Understand Wireless modulation .
- Differentiate between active and passive scanning.
- Define Wi-Fi: 802.11 wireless LANs.
- Understand Wireless frame addressing.
- Understand Personal area networks.
- Understand cellular network components and technology .

What is a wireless network ?

- A wireless network refers to a computer network that makes use of **Radio Frequency (RF)** connections between nodes in the network.
- The number of wireless (mobile) phone subscribers now exceeds the number of wired phone subscribers (5-to-1).
- The number of wireless Internet-connected devices equals the number of wireline Internet-connected devices.
- Two important (but different) challenges:
 - **Wireless**: communication over wireless link.
 - **Mobility**: handling the mobile user who changes point of attachment to network.

Electromagnetic Waves



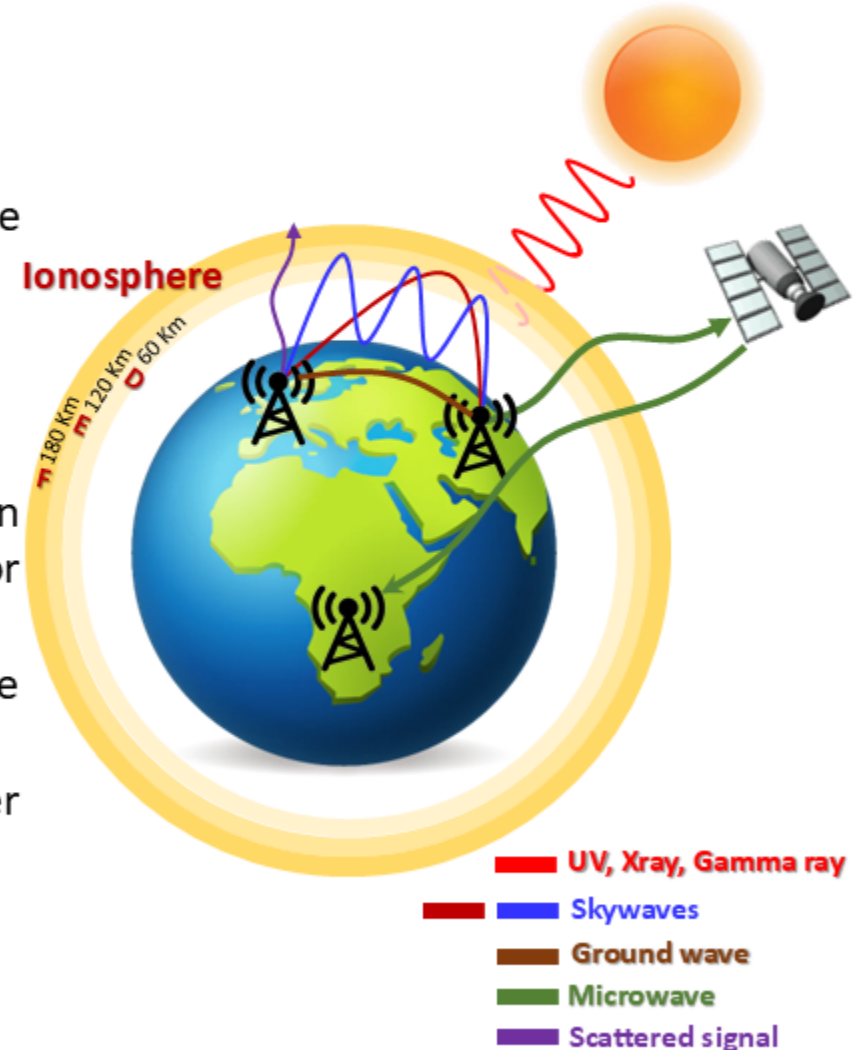
Why do we use RF Waves for communication?

➤ **The Ionosphere:**

- It is an electrified region within the upper atmosphere contains large concentrations of ions (charged particles) and free electrons.
- It prevents UV, X-Rays, and Gamma rays from passing to the earth.

➤ **RF waves :**

- RF waves are not harmful for humans.
- Since The ionosphere reflects RF waves (E and F layers) thus RF waves can bounce between the earth's surface and the ionosphere many times for many 1000's of Kilometers they called (**Skywaves**).
- **Microwaves** used to communicate with satellites, or anything else outside of Earth's atmosphere thus they called (**Space waves**).
- **Ground wave** is low and medium frequencies waves that propagate over the earth's surface (used for TV/AM/FM broadcast).



Types of RF Waves

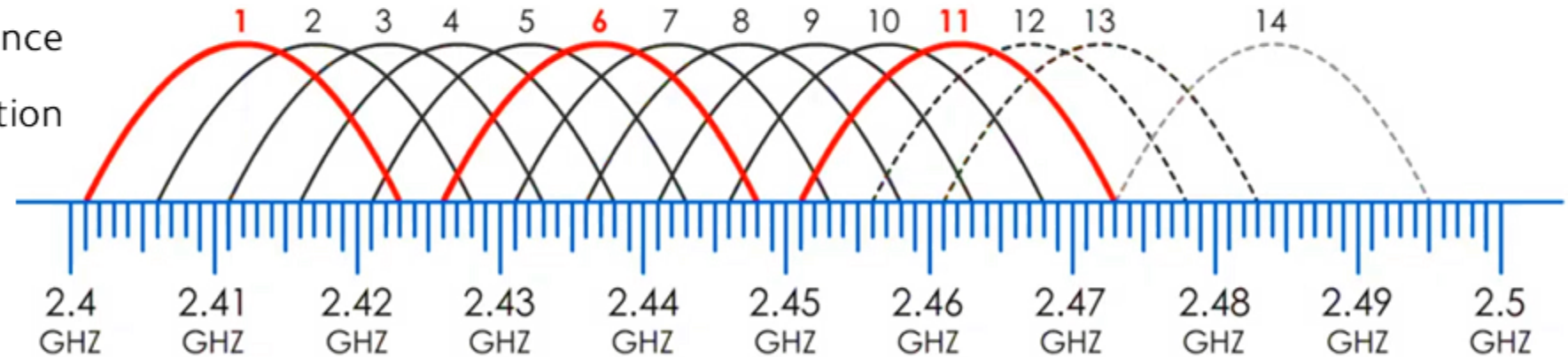
Frequency Band Name	Frequency Range	Wavelength range	Application
Extremely Low Frequency (ELF)	3-30 Hz	100000 to 10000 km	Underwater communication
Super Low Frequency (SLF)	30-300 Hz	10000 to 1000 km	AC power
Very Low Frequency (VLF)	3-30 kHz	100 to 10 km	For navigation alarms
Low Frequency (LF)	30-300 kHz	10 to 1 km	AM radio
Medium Frequency (MF)	300-3,000 kHz	1 km to 100 m	Aviation
High Frequency (HF)	3-30 MHz	100 to 10 m	Shortwave radio
Very High Frequency (VHF)	30-300 MHz	10 to 1 m	FM radio
Ultra-High Frequency (UHF)	300-3,000 MHz	1 m to 10 cm	Television, mobile phones, GPS
Super High Frequency (SHF)	3-30 GHz	10 cm to 1 cm	Satellite; wireless communication
Extremely High Frequency (EHF)	30-300 GHz	1 cm to 1 mm	Remote sensing; astronomy

➤ *Other Electromagnetic waves:*

- **Infrared** comes from the heat and thermal radiation, and it is not visible to the naked eyes, it used for medium and *short-range communications* such as TV remote control, robot control system, cordless microphone, headsets, modems, and other peripheral devices.
- **Visible light** is the light we can see. It is used in *fiber-optic communications*, where coded pulses of light travel through glass fibers from a source to a receiver.
- **Ultraviolet** have hazardous effects on the human body. It dose not used for communications, instead it used in other industrial fields.
- **X-rays and gamma rays** are very harmful to the human body causing the mutation of genes thus they do not used in communication, instead they are used widely in medical purposes.

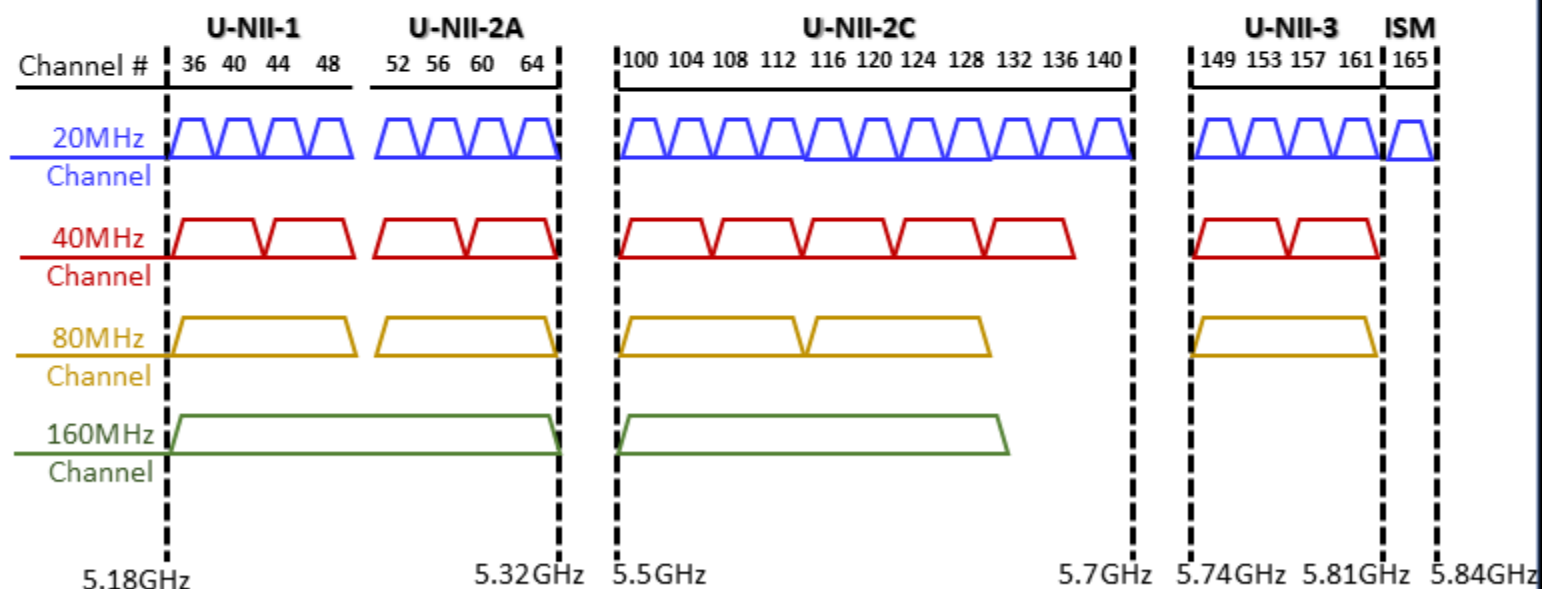
2.4 GHz band

- 2.4GHz frequency band divide into fixed frequency 14-channels, each channel is 20MHz wide, channels 12 and 13 are allowed to use in worldwide but in only USA are allowed with a “low power” mode. Channel 14 is banned in the USA and throughout most of the world but is allowed in Japan.
- 2.4 GHz Wi-Fi offers a better signal over long distances and through solid objects.
- **Cons:** Narrow band, interference other devices more congestion and noise.

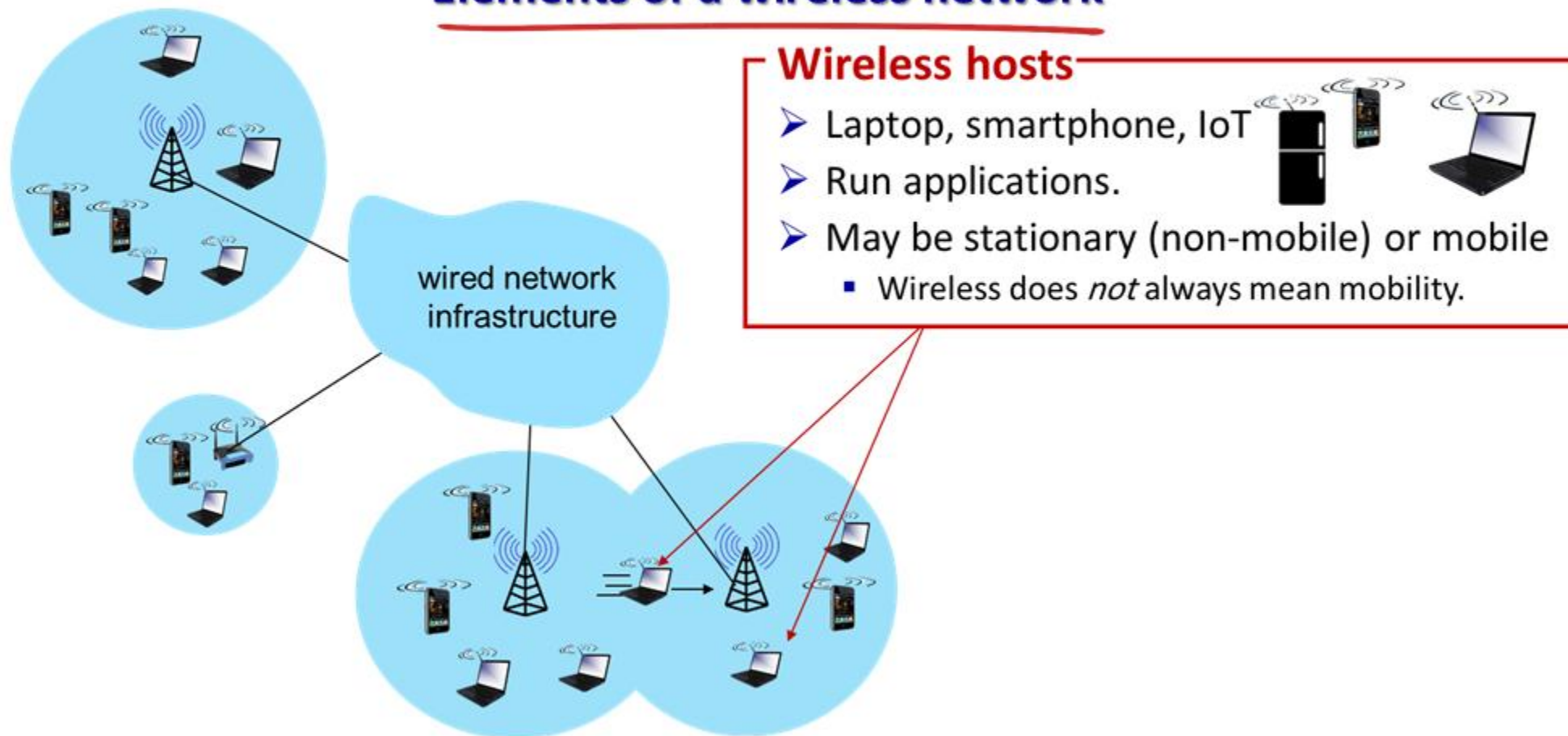


5 GHz band

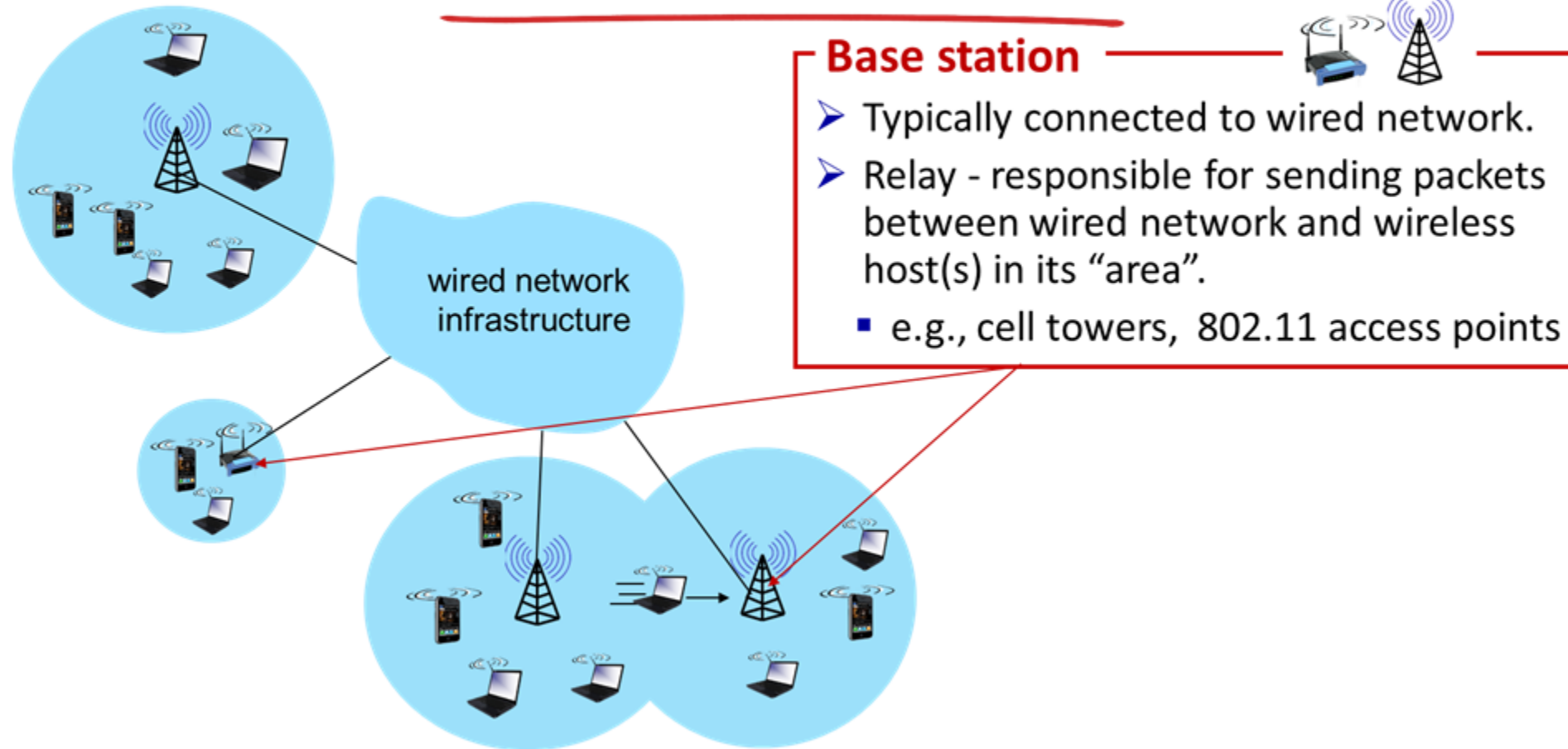
- 5GHz frequency band divide into non-overlapping 24-channels each 20MHz wide organized as U-NII-1 (Unlicensed National Information Infrastructure), U-NII-2A, U-NII-2C (U-NII-2 Extended), U-NII-3, and ISM (Industrial, Scientific, and Medical).
- 5GHz Wi-Fi cover less distance and isn't as good as penetrating through solid objects as 2.4 GHz Wi-Fi.



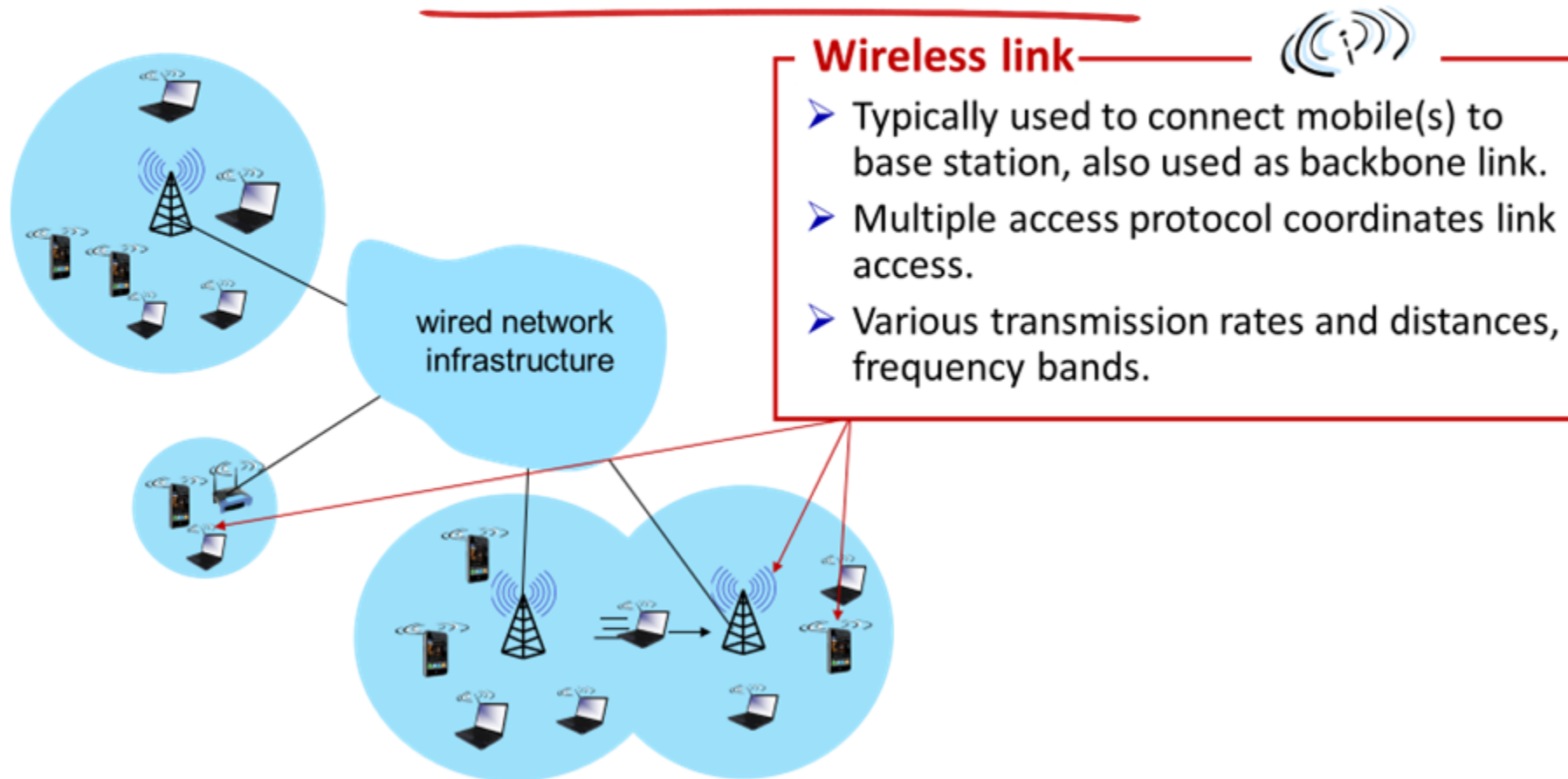
Elements of a wireless network



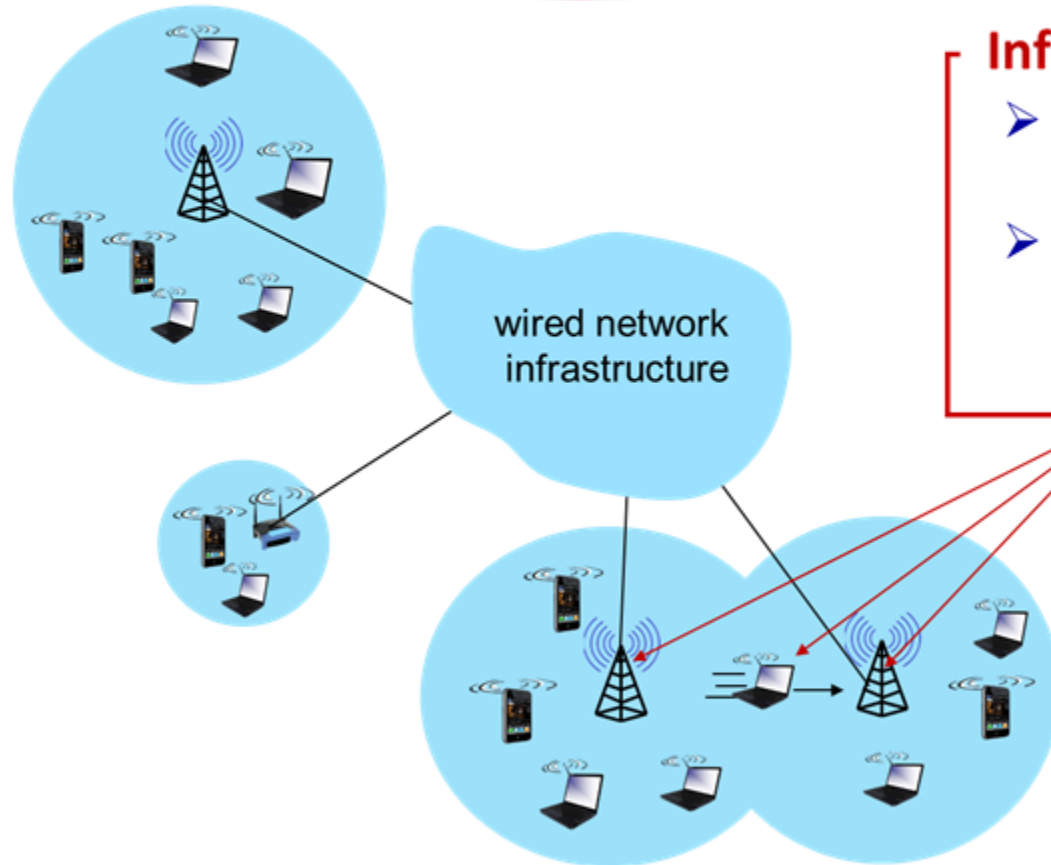
Elements of a wireless network



Elements of a wireless network



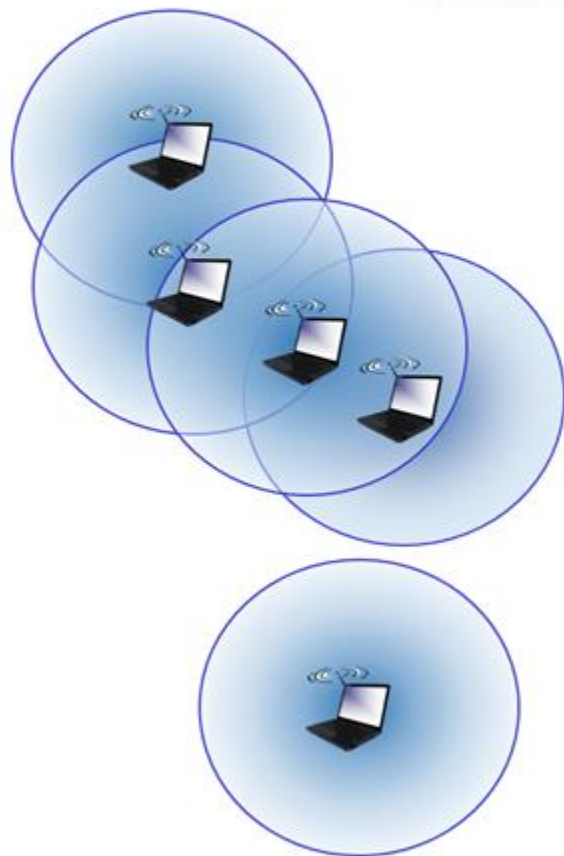
Elements of a wireless network



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

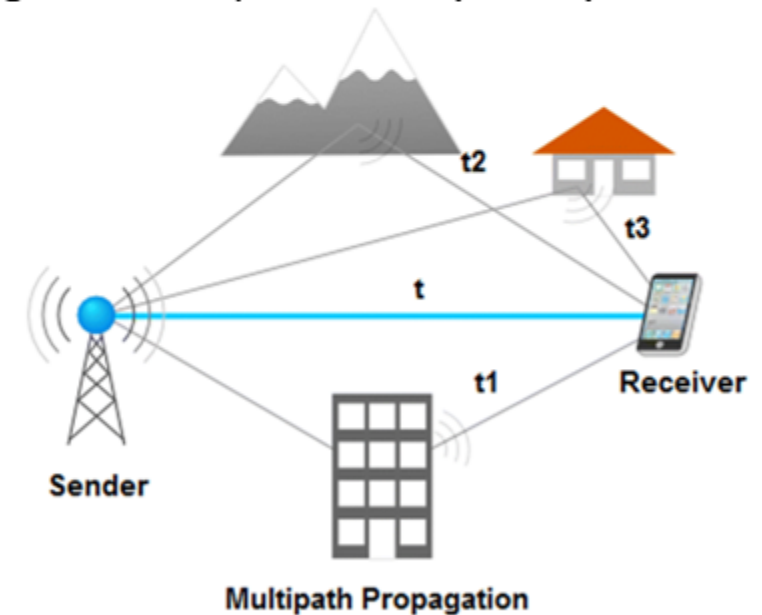
	Single hops	Multiple hops
Infrastructure (e.g., APs)	Host connects to base station (Wi-Fi, cellular) which connects to larger Internet.	Host may have to relay through several wireless nodes to connect to larger Internet: mesh net.
No Infrastructure	No base station, no connection to larger Internet (Bluetooth, ad hoc nets).	No base station, no connection to larger Internet. May have to relay to reach another a given wireless node MANET, VANET

Wireless links and network characteristics

Important differences from wired link

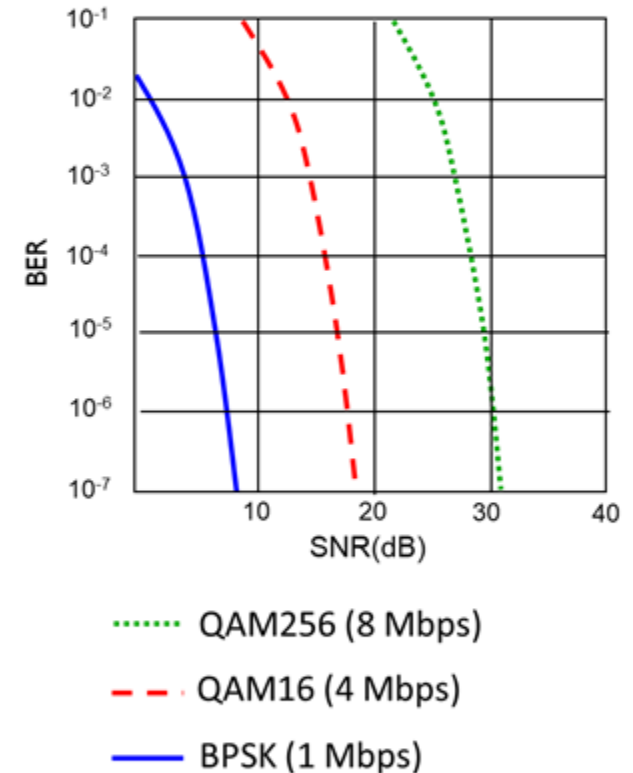
- **Decreased signal strength:** radio signal attenuates as it propagates through matter (path loss).
- **Interference from other sources:** wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., Wi-Fi, cellular, motors): interference
- **Multipath propagation:** radio signal reflects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

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



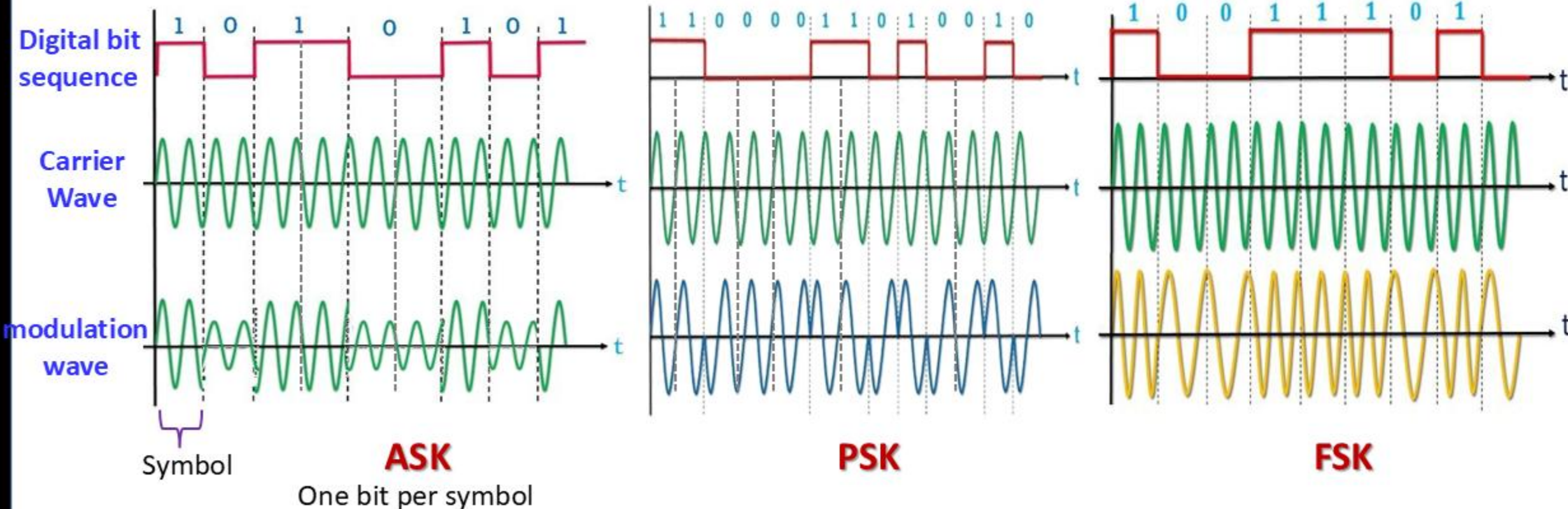
Wireless links and network characteristics

- 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 $\rightarrow$ increase SNR $\rightarrow$ 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 links and network characteristics

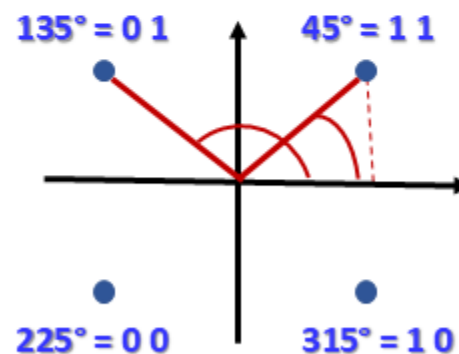
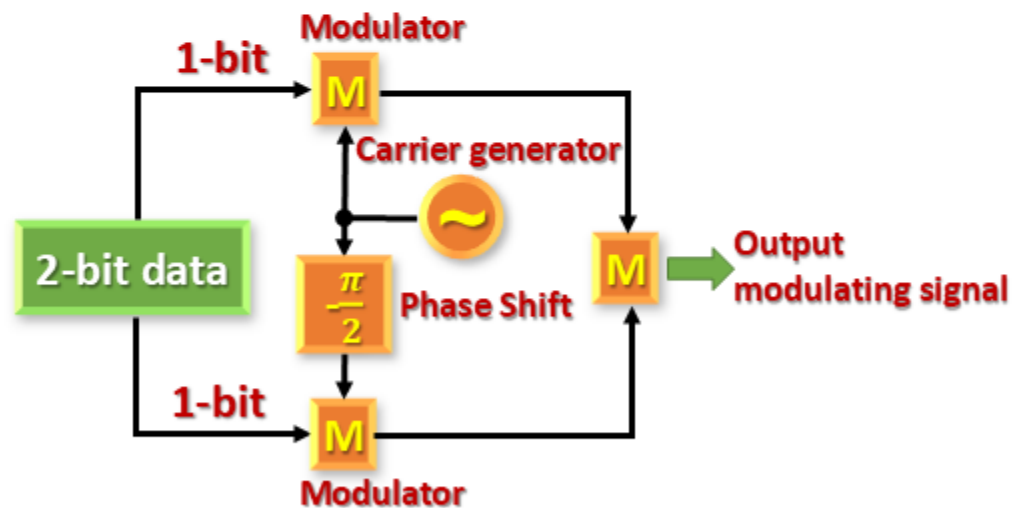
An overview of Wireless modulation



Wireless links and network characteristics

An overview of Wireless modulation

- Quadrature Phase Shift Keying (QPSK): allow twice as much data to be carried as PSK.
- Two bits per symbol
 - Data is encoded as one of four phases.

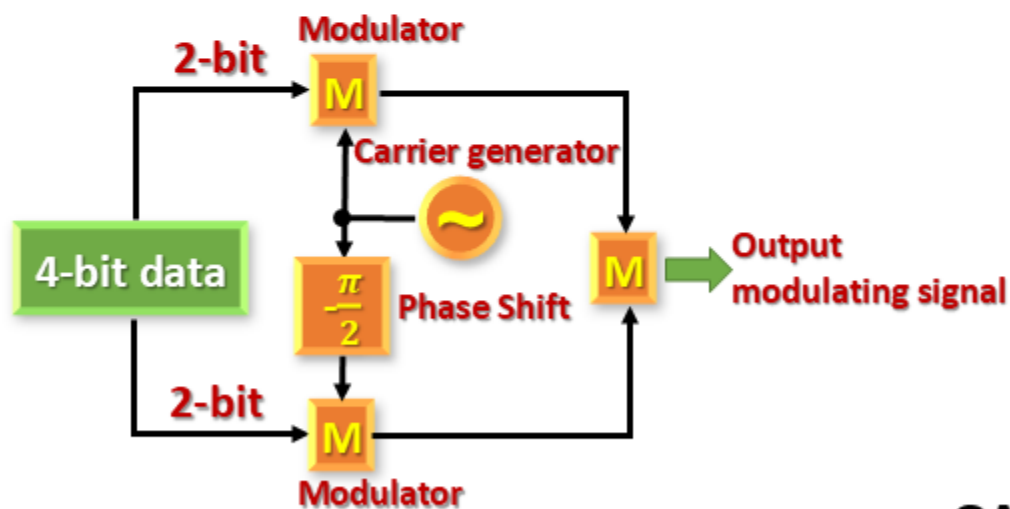


Symbol transmitted	Carrier Phase	Carrier amplitude
11	45°	1.0
01	135°	1.0
00	225°	1.0
10	315°	1.0

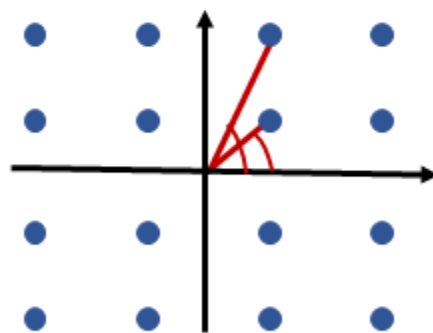
Wireless links and network characteristics

An overview of Wireless modulation

- Quadrature amplitude modulation (QAM) is an advanced modulation scheme widely used in Wi-Fi communication systems. *It combines phase modulation and amplitude modulation.*



QAM-16

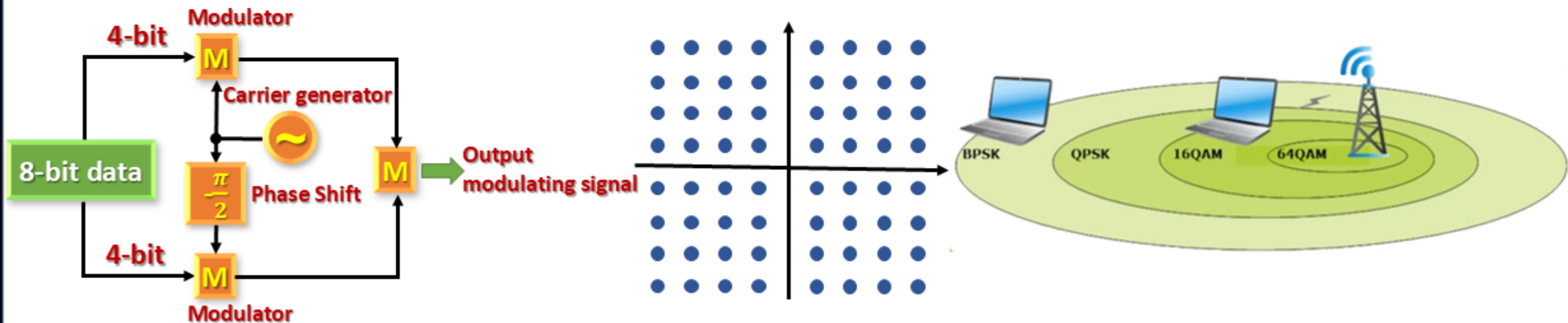


Symbol transmitted	Carrier Phase	Carrier amplitude
0000	225°	0.33
0001	225°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0

Wireless links and network characteristics

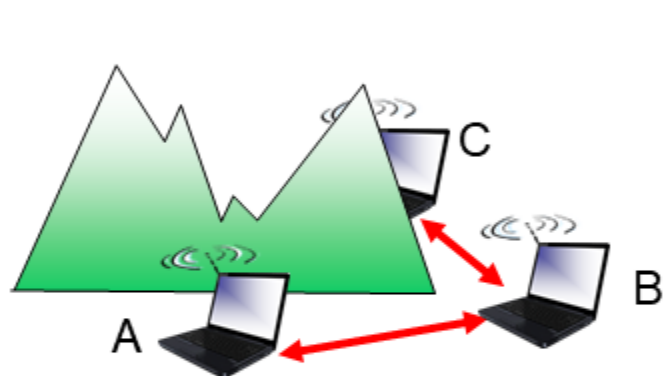
An overview of Wireless modulation

- The devices moves further away from the source with more difficult RF environment.
 - Modulation rate is reduced to preserve the desired BER.



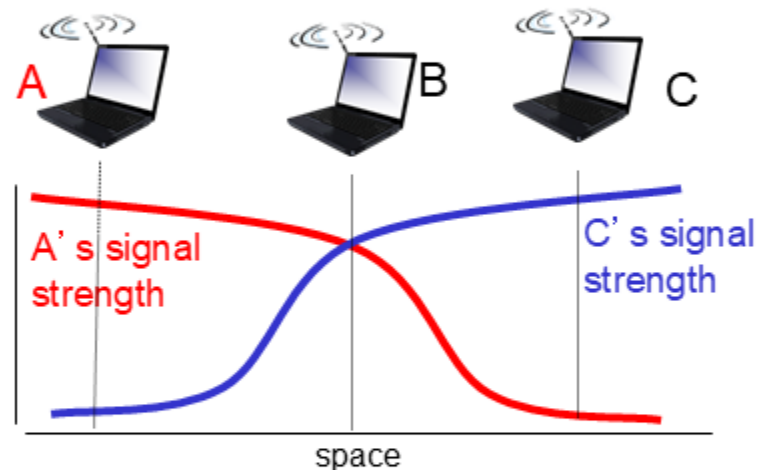
Wireless links and network characteristics

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 standard	Year	Max data rate	Range	Frequency
802.11a (Wi-Fi 2)	1999	54 Mbps	70m	5 GHz
802.11b (Wi-Fi 1)	1999	11 Mbps	30 m	2.4 GHz
802.11g (Wi-Fi 3)	2003	54 Mbps	30m	2.4 GHz
802.11n (Wi-Fi 4)	2009	600 Mbps	70m	2.4, 5 GHz
802.11ac (Wi-Fi 5)	2013	1.3 Gbps	70m	5 GHz
802.11ax (Wi-Fi 6)	2019	10 Gbps	70m	2.4, 5 GHz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347 Mbps	1 Km	900 Mhz

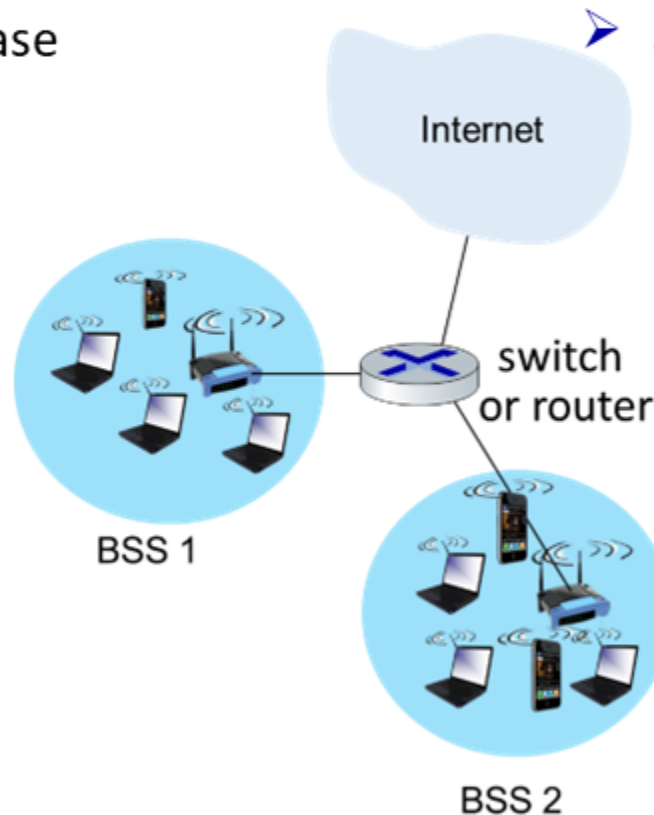
- All use CSMA/CA for multiple access and have base-station and ad-hoc network versions.

- Wireless host communicates with base station.

- base station = access point (AP).

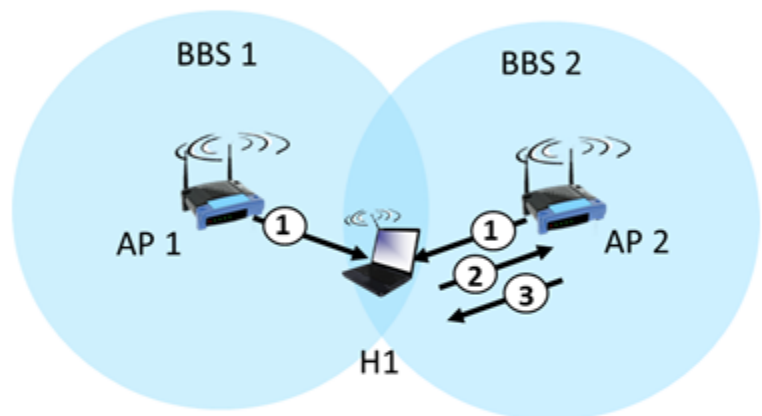
- Basic Service Set (BSS) (aka “cell”) in infrastructure mode contains:

- Wireless hosts.
 - Access point (AP): base station.
 - Ad hoc mode: hosts only.

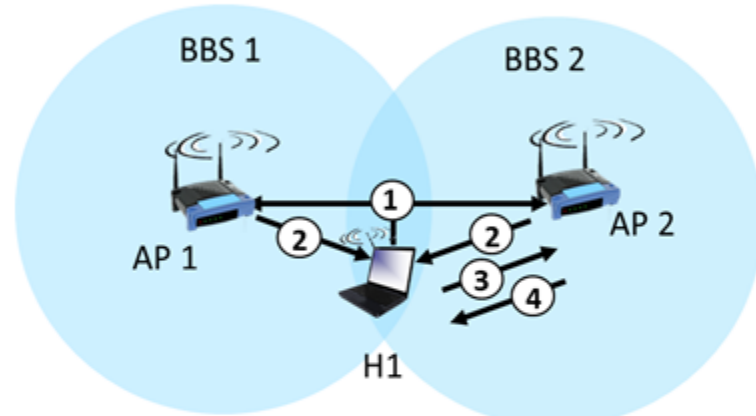


- Arriving host: must **associate** with an AP

- Scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address.
 - Selects AP to associate with.
 - Then may perform authentication then typically run DHCP to get IP address in AP's subnet.

802.11: passive/active scanning**Passive scanning:**

- (1) Beacon frames sent from Aps.
- (2) Association Request frame sent: H1 to selected AP.
- (3) Association Response frame sent from selected AP to H1.

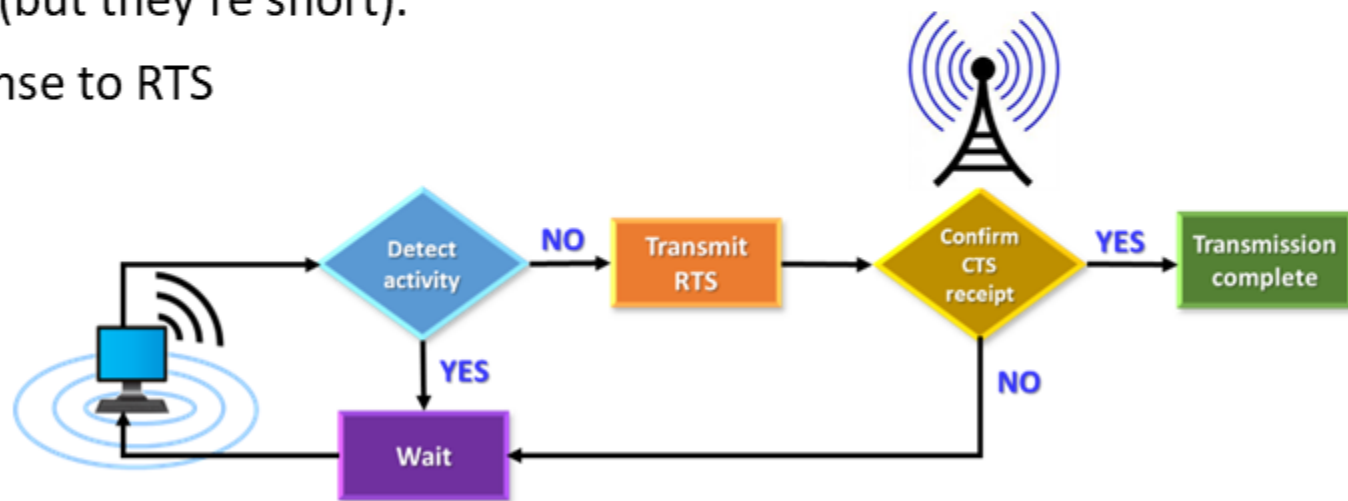
**Active scanning:**

- (1) Probe Request frame broadcast from H1.
- (2) Probe Response frames sent from Aps.
- (3) Association Request frame sent: H1 to selected AP .
- (4) Association Response frame sent from selected AP to H1.

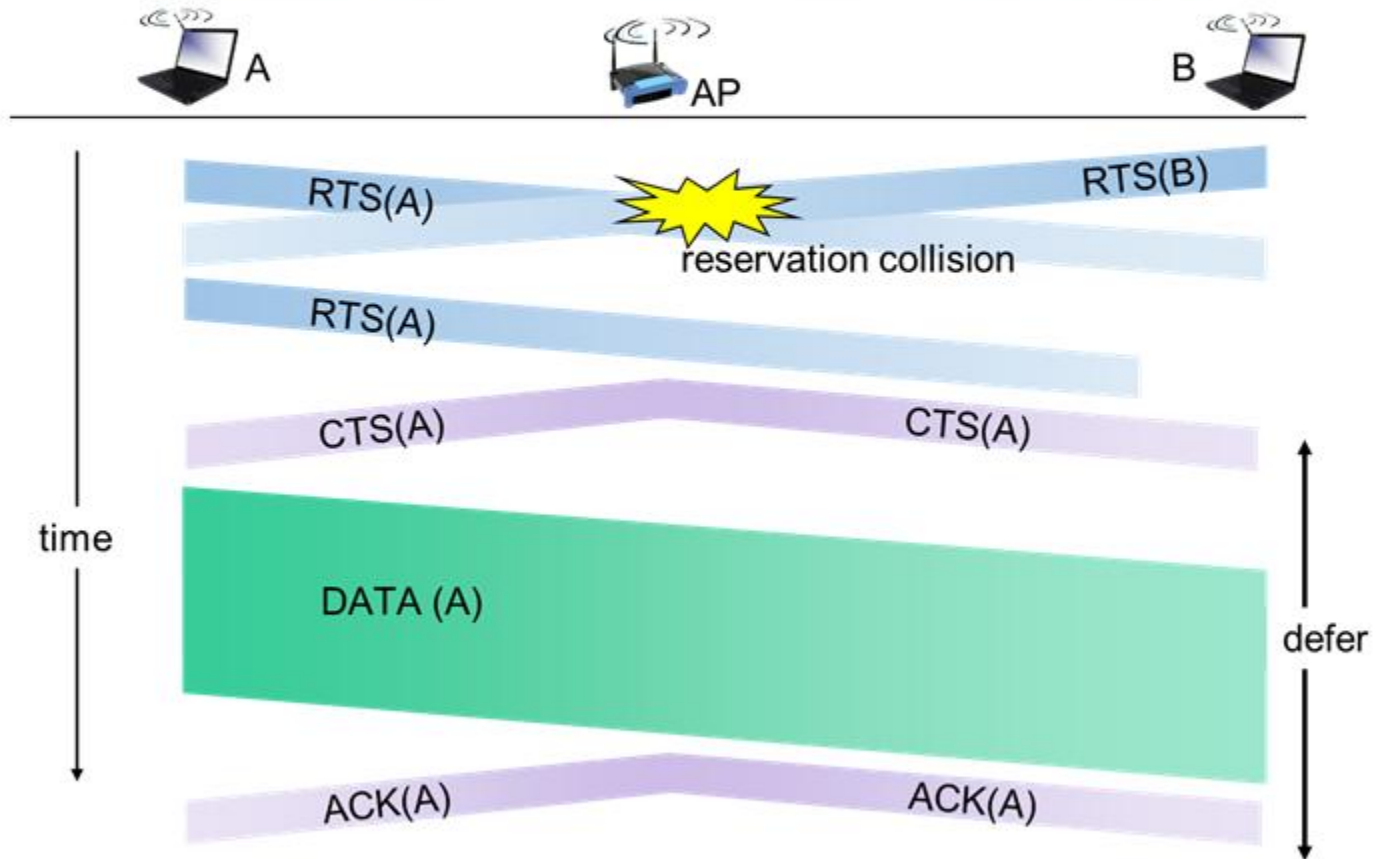
Avoiding collisions

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

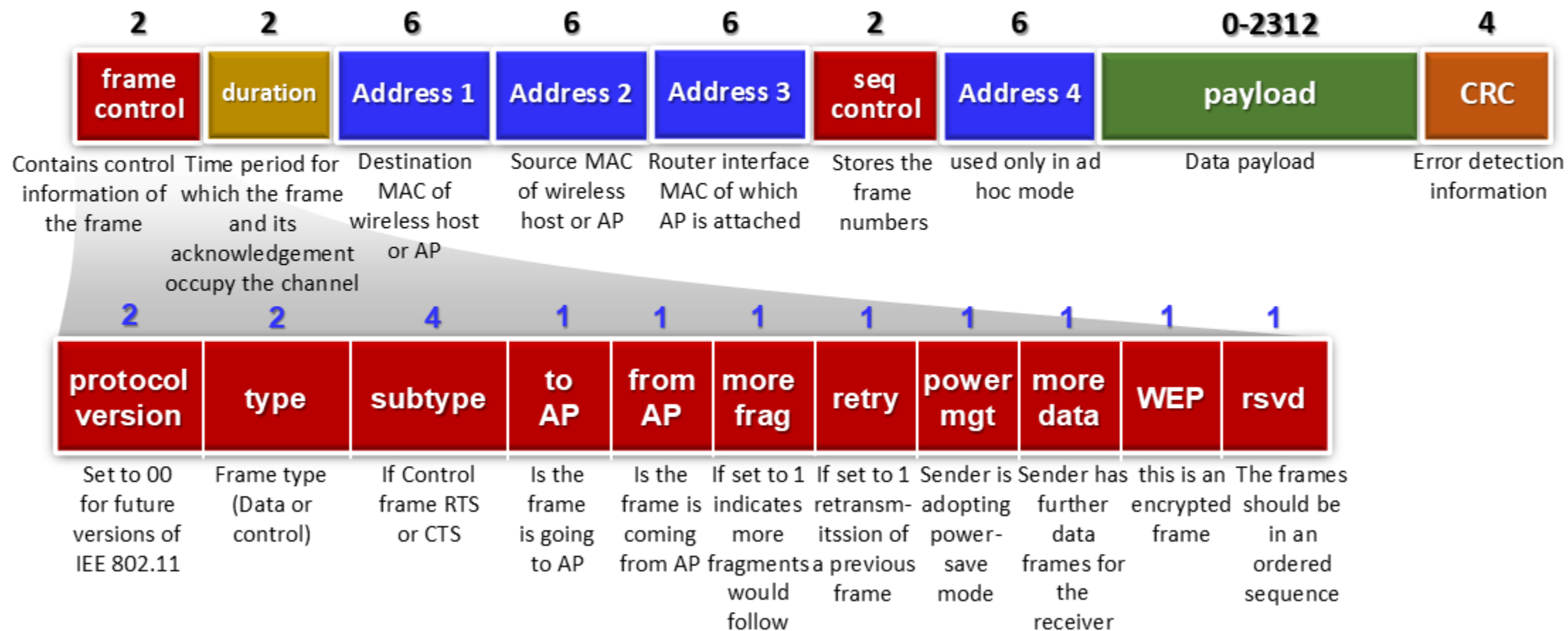
- Sender first transmits *small* request-to-send (RTS) packet to BS using CSMA
 - RTSs may still collide with each other (but they’re short).
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
 - Sender transmits data frame.
 - Other stations defer transmissions.



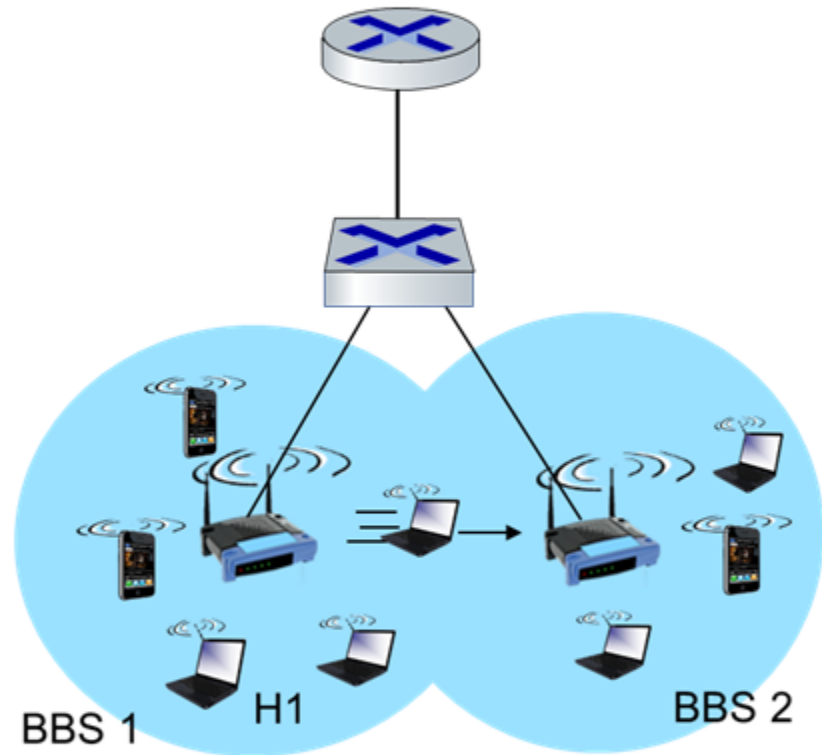
Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing

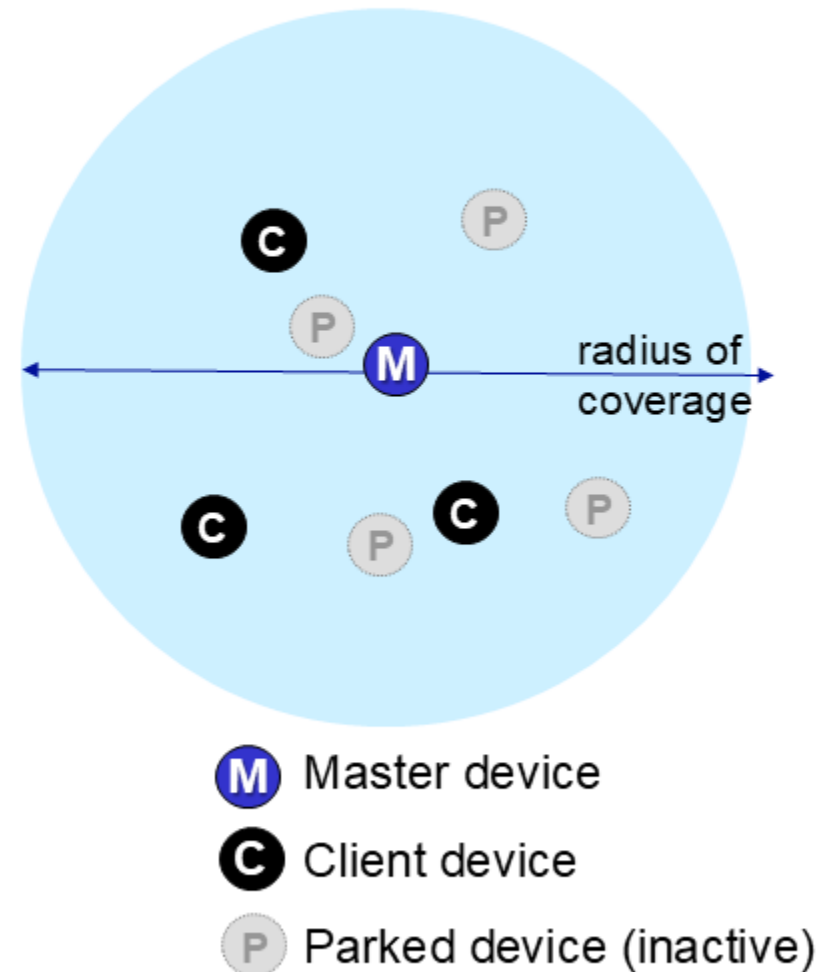


- H1 remains in same IP subnet: IP address can remain same.
- Switch: which AP is associated with H1?
 - Self-learning switch will see frame from H1 and “remember” which switch port can be used to reach H1.

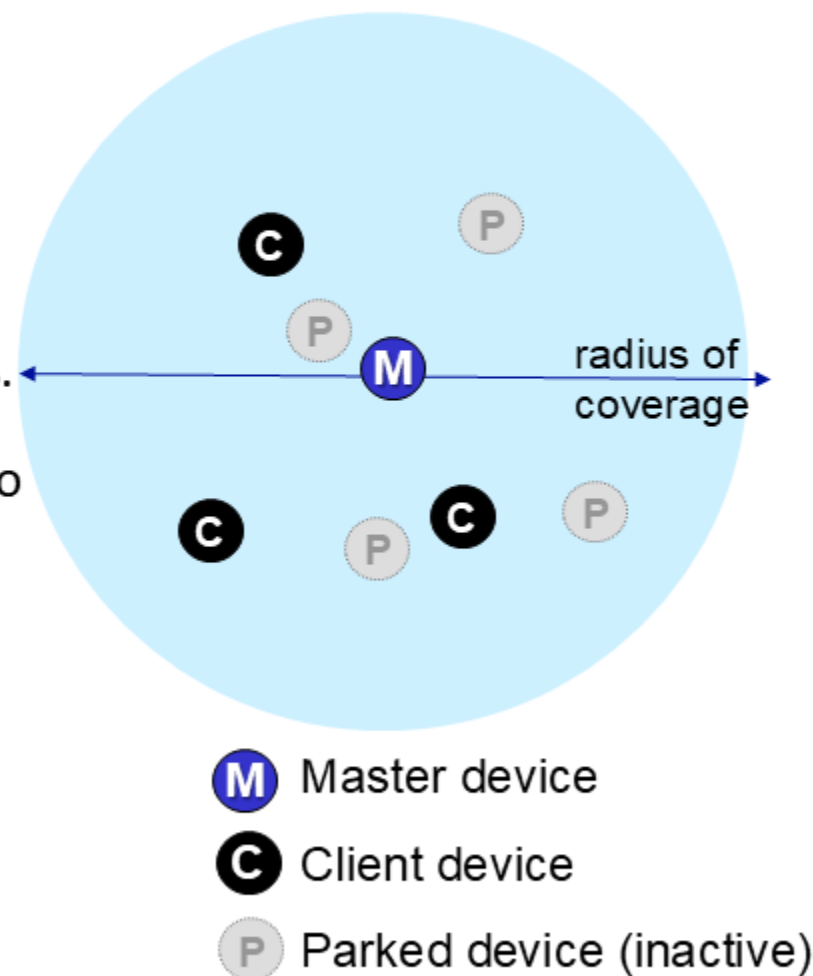


- **Node-to-AP:** “I am going to sleep until next beacon frame”
 - AP knows not to transmit frames to this node.
 - Node wakes up before next beacon frame.
- **Beacon frame:** contains list of mobiles with AP-to-mobile frames waiting to be sent
 - Node will stay awake if AP-to-mobile frames to be sent; otherwise sleep again until next beacon frame.

- Based on IEEE 802.15.
- Less than 10 m diameter.
- Replacement for cables (mouse, keyboard, headphones).
- Ad hoc: no infrastructure.
- 2.4-2.5 GHz ISM radio band, up to 3 Mbps.
- Master/slaves:
 - Slaves request permission to send (to master).
 - Master grants requests.



- **TDM**, 625 μ sec sec. slot.
- **FDM**: sender uses 79 frequency channels in known (FHSS).
 - Other devices/equipment not in piconet only interfere in some slots.
- **Parked mode**: clients can “go to sleep” (park) and later wakeup (to preserve battery).
- **Bootstrapping**: nodes self-assemble (plug and play) into piconet.



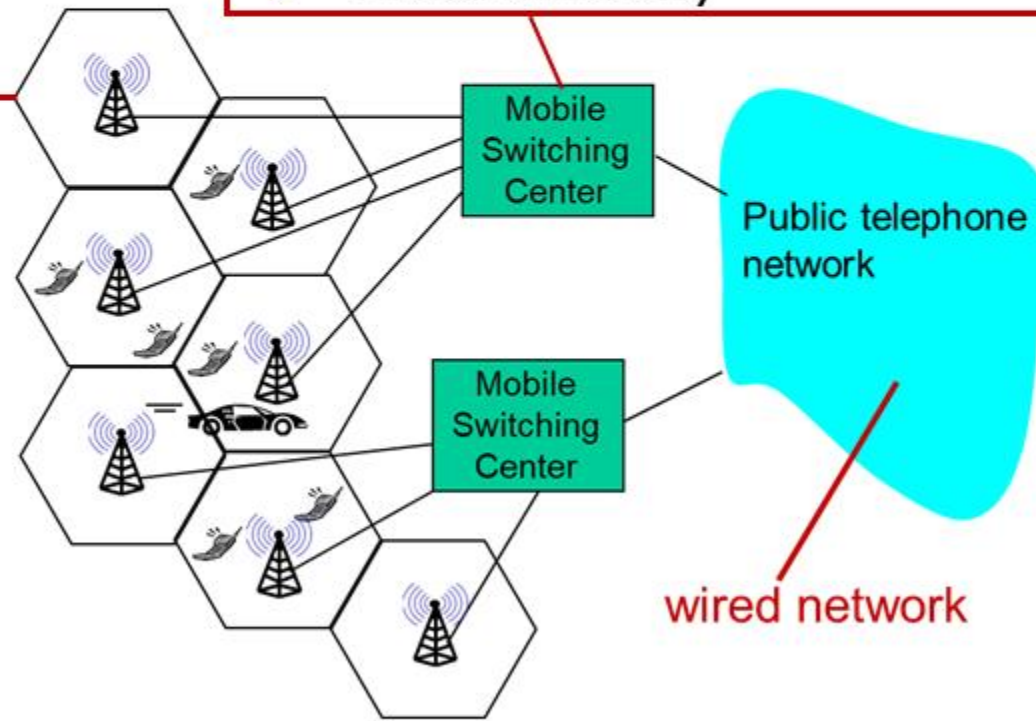
Components of cellular network architecture

Cell

- Covers geographical region
- *Base station* (BS) analogous to 802.11 AP
- *Mobile users* attach to network through BS
- *Air-interface*: physical and link layer protocol between mobile and BS

MSC

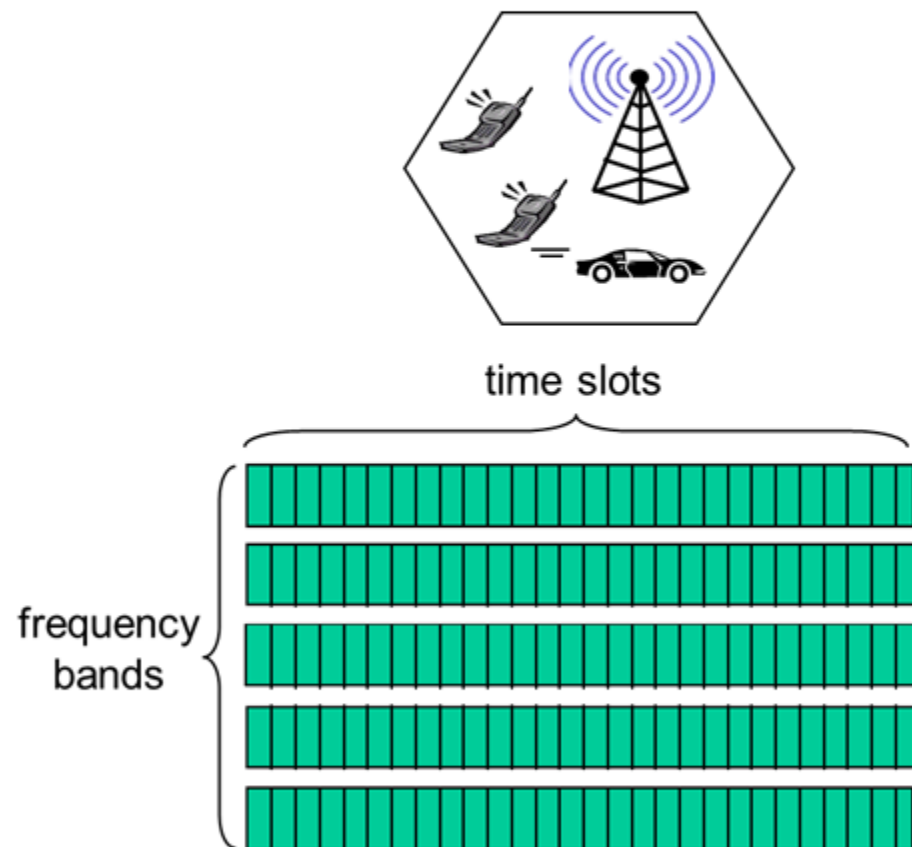
- Connects cells to wired tel. net.
- Manages call
- Handles mobility



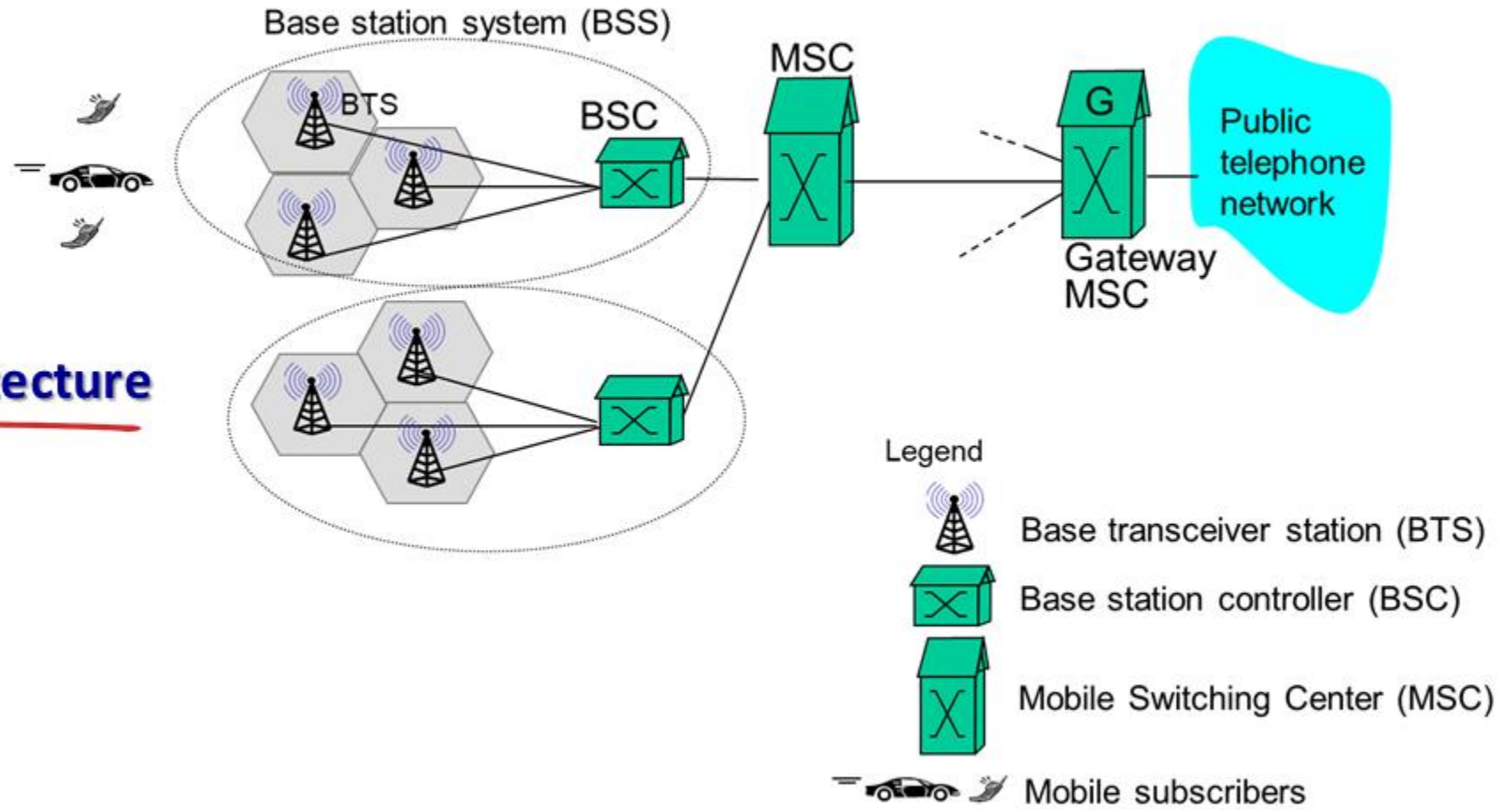
Cellular networks: the first hop

Two techniques for sharing mobile-to-BS
radio spectrum

- **Combined FDMA/TDMA:** divide spectrum in frequency channels, divide each channel into time slots
- **CDMA:** code division multiple access



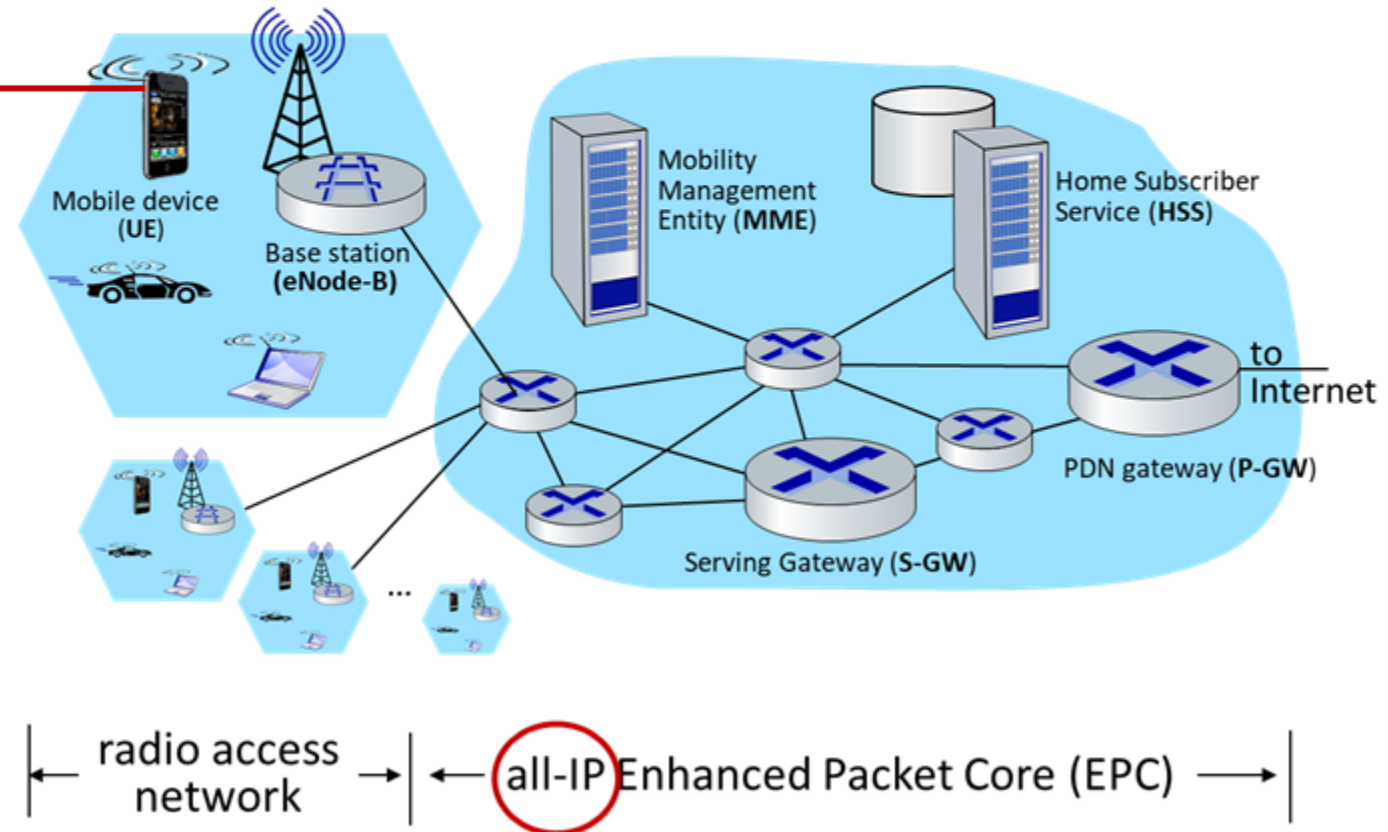
2G (voice) network architecture



Elements of 4G LTE architecture

Mobile device: ←

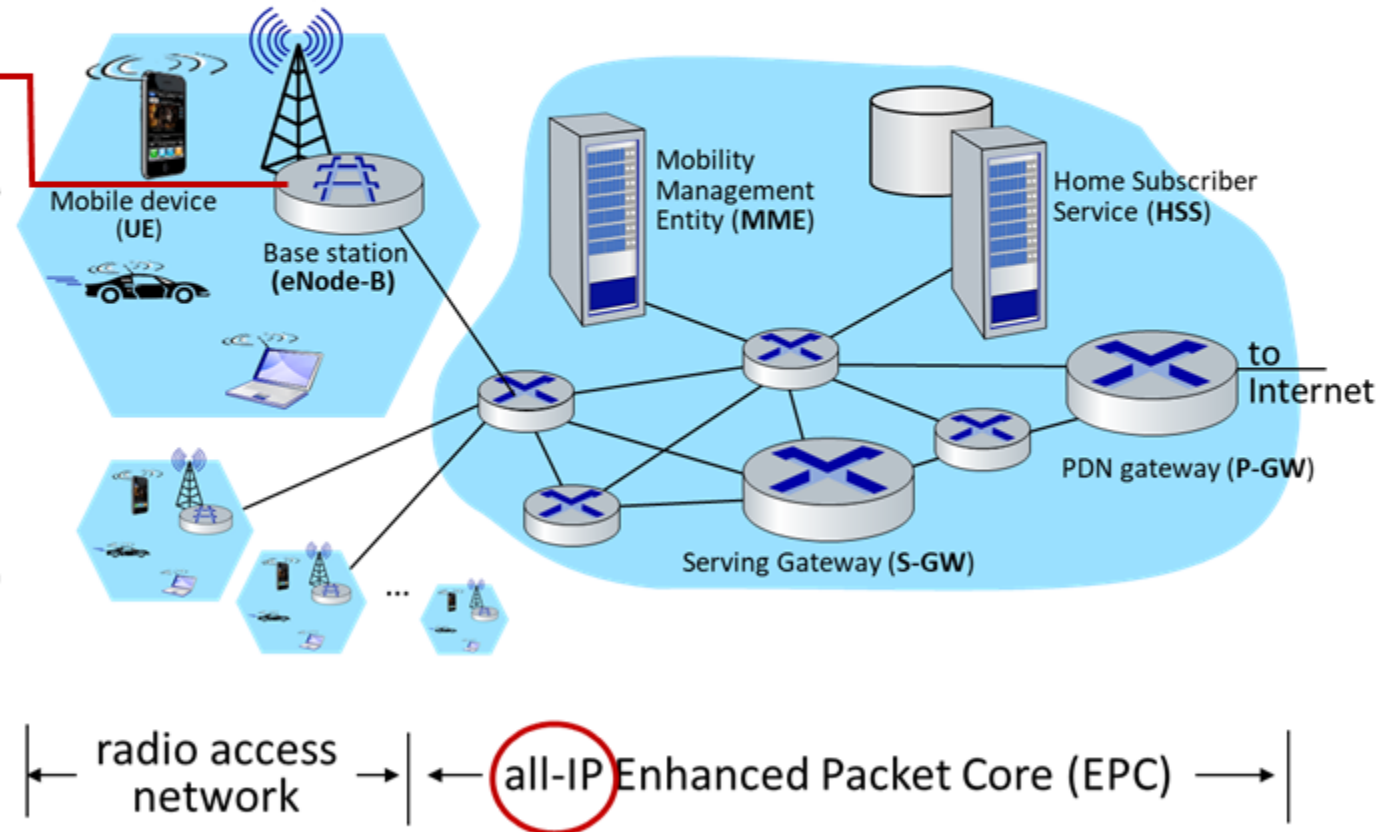
- Smartphone, tablet, laptop, IoT, ... with 4G LTE radio.
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card.
- LTE jargon: User Equipment (UE).



Elements of 4G LTE architecture

Base Station:

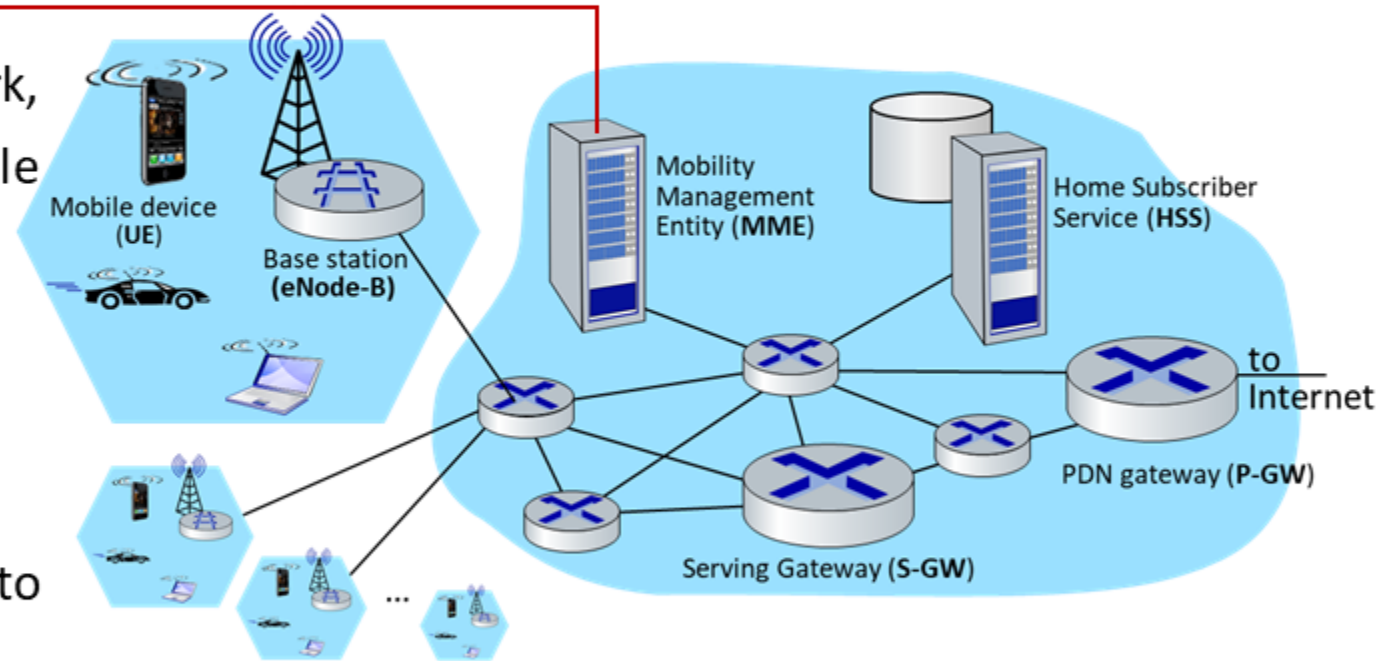
- At “edge” of carrier’s network
- Manages wireless radio resources, mobile devices in its coverage area (“cell”).
- Coordinates device authentication with other elements.
- Similar to Wi-Fi AP but:
 - Active role in user mobility.
 - Coordinates with nearby base stations to optimize radio use.
- LTE jargon: eNode-B



Elements of 4G LTE architecture

Mobility Management Entity:

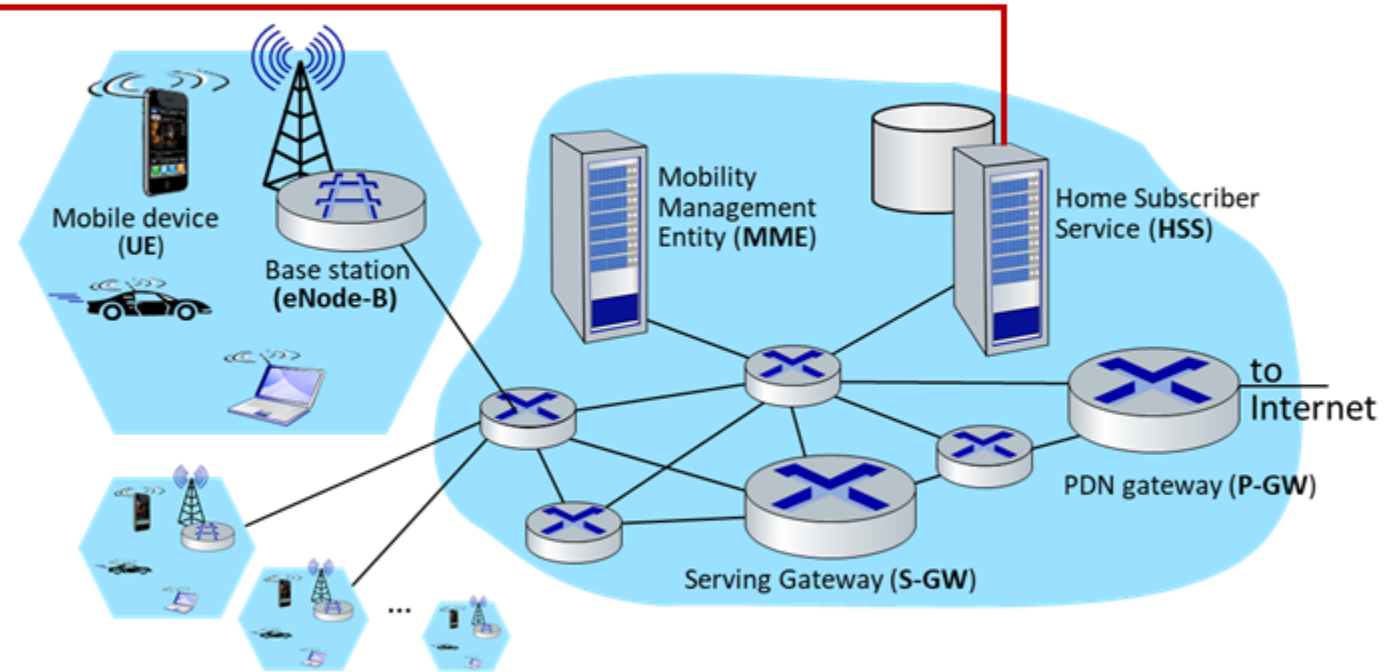
- Device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS.
- Mobile device management:
 - Device handover between cells.
 - Tracking/paging device location.
- Path (tunneling) setup from mobile device to P-GW.



Elements of 4G LTE architecture

Home Subscriber Service :

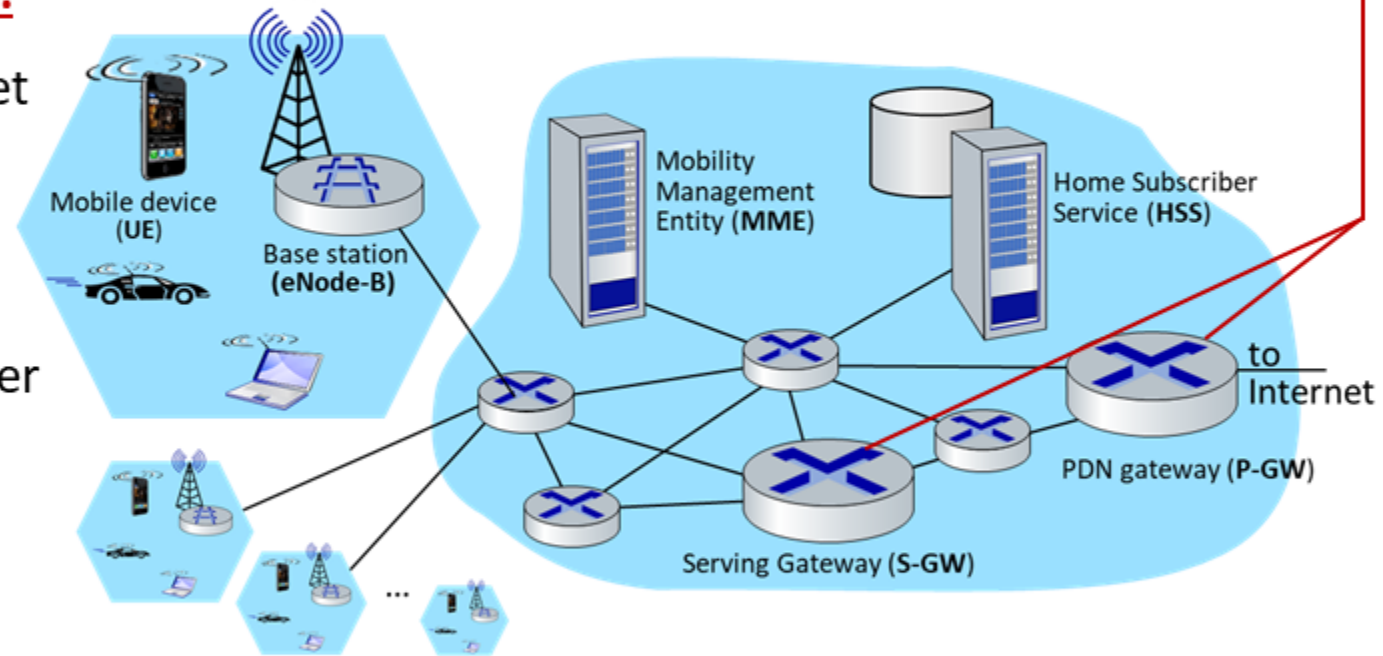
- Stores info about mobile devices for which the HSS's network is their "home network".
- Works with MME in device authentication.



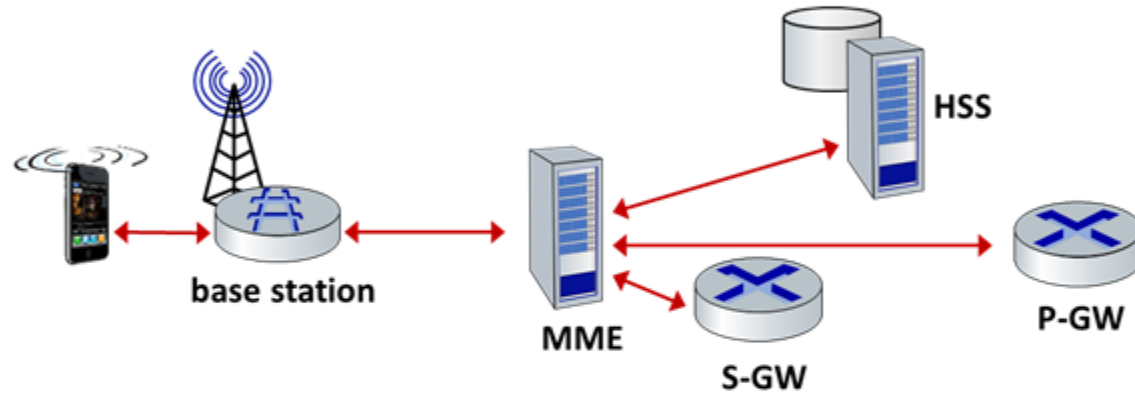
Elements of 4G LTE architecture

Serving Gateway (S-GW), PDN Gateway (P-GW):

- Lie on data path from mobile to/from Internet
- P-GW.
- Gateway to mobile cellular network.
- Looks like nay another internet gateway router
- provides NAT services.
- other routers:
 - Extensive use of tunneling.

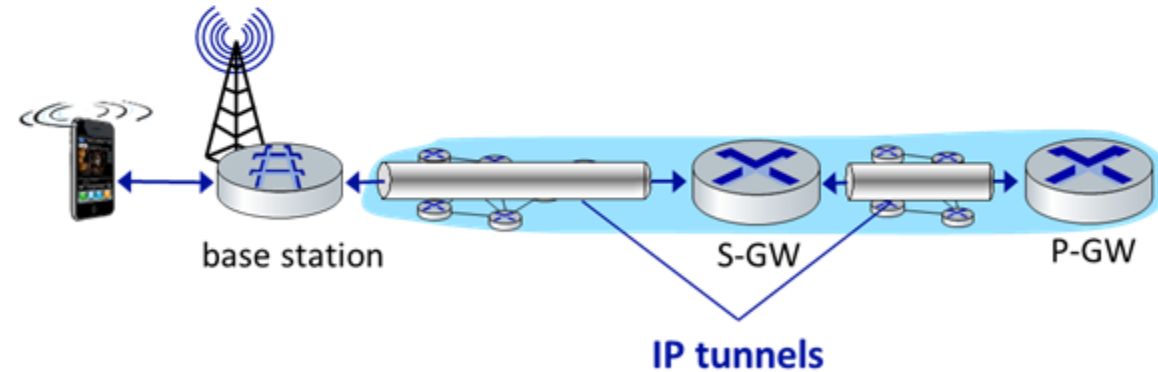


LTE: data plane control plane separation



Control plane

- New protocols for mobility management, security, authentication.



Data plane

- New protocols at link, physical layers.
- Extensive use of tunneling to facilitate mobility.

5G Cellular network overview

- **Goal:** 10x increase in peak bitrate, 10x decrease in latency, 100x increase in traffic capacity over 4G
- 5G NR (new radio):
 - Two frequency bands: FR1 (450 MHz–6 GHz) and FR2 (24 GHz–52 GHz): millimeter wave frequencies.
 - Compatible with 4G.
 - MIMO: multiple directional antenna (the higher frequency, the smaller the antenna).
 - Higher frequency waves carries more data than lower frequency waves.

