CS/ECE 438: Communication Networks
Fall 2019

6. Wireless & Mobile Networks

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

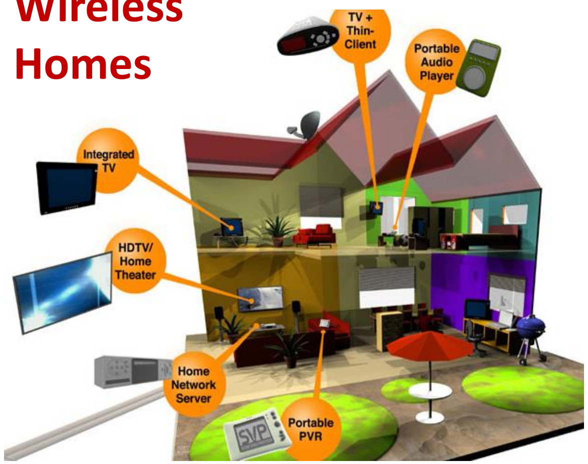
Chapter 6 : Wireless and Mobile Networks

Background:

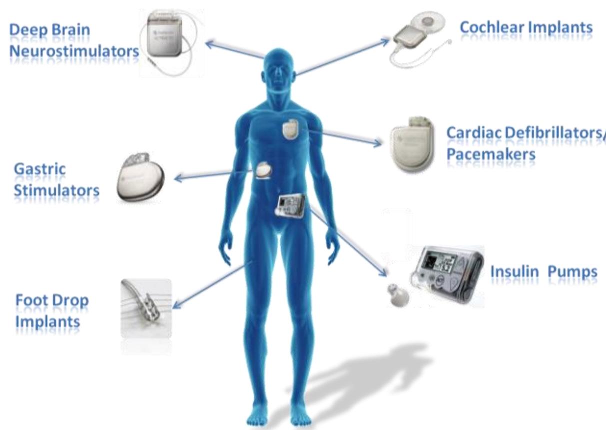
- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wireline Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access
- two important (but different) challenges
  - *wireless:* communication over wireless link
  - *mobility:* handling the mobile user who changes point of attachment to network

Wireless Networks Increasingly Prevalent

Wireless Homes



Wireless Biomedical Implants



Wireless Wearables

Cellular Networks

Wireless Sensors

UAVs

Wireless Data Centers

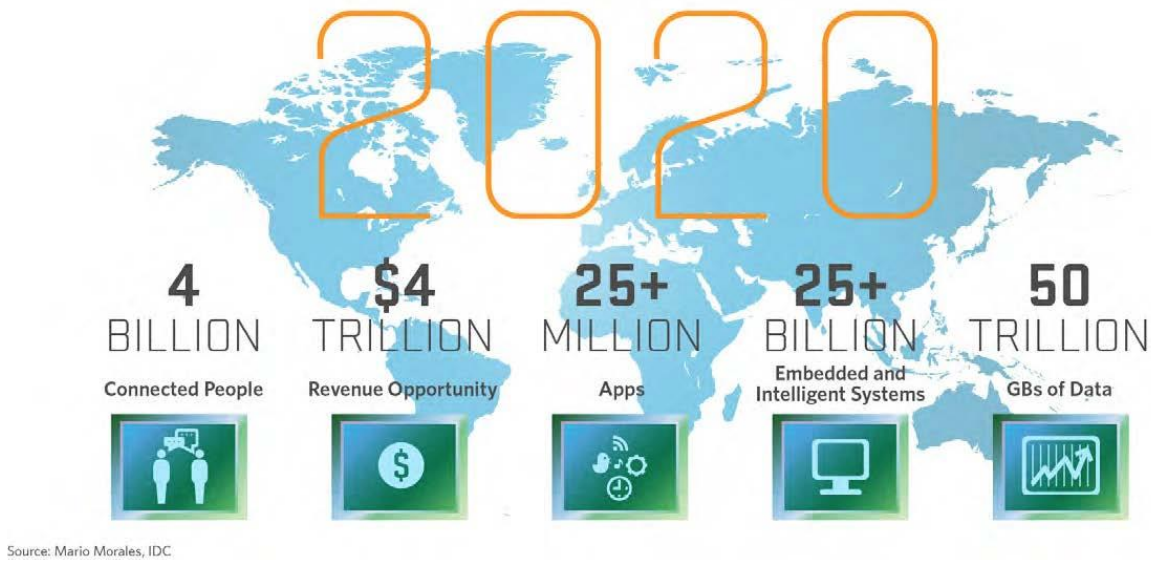
Wireless VR

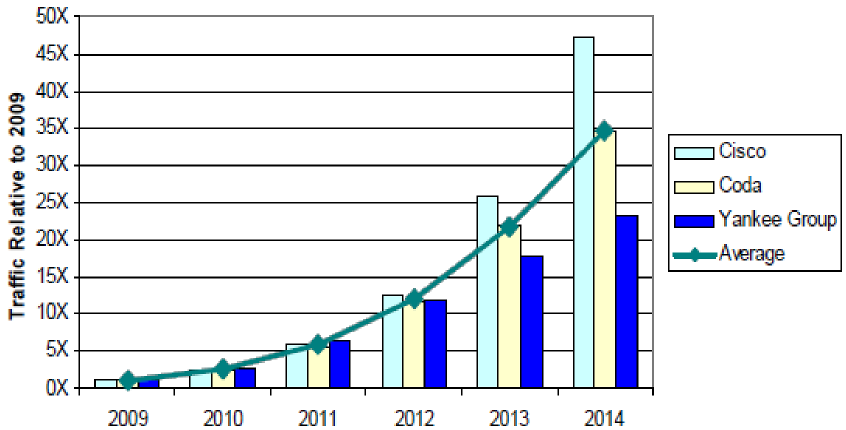
Wireless Vehicles

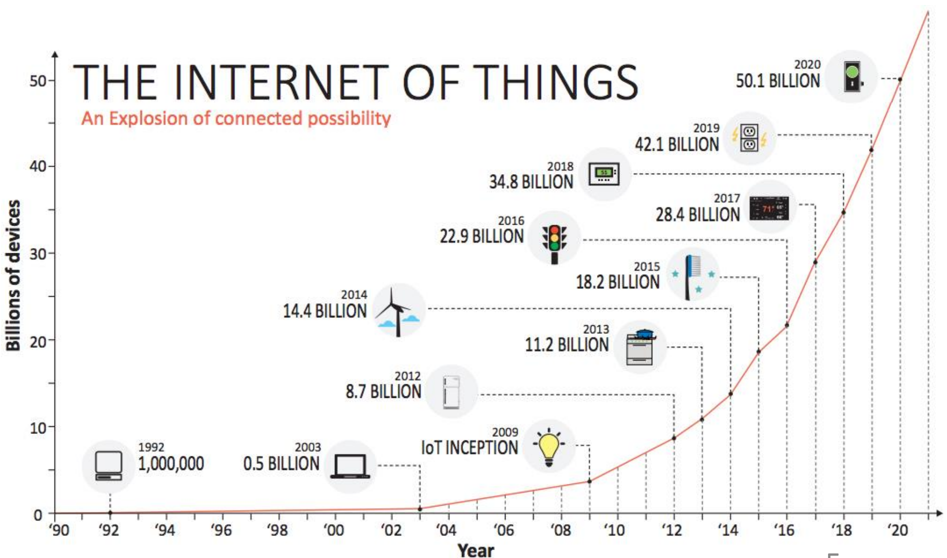
Increasing Demand for Wireless Connectivity

NBC/Instagram

Increasing Demand for Wireless Connectivity







Many Motivations for Wireless

- Unrestricted mobility / deployability
  - Unplugged from power outlet
- Significantly lower cost
  - No cable layout, service provision
  - Low maintenance
- Ease
  - Direct communication with minimum infrastructure

No Free Lunch

- Numerous challenges
  - Channel fluctuation
  - Lower bandwidth
  - Limited Battery power
  - Disconnection due to mobility
  - Security
  - …

Question Is …

Can’t we use the rich “wireline” knowledge ?

In solving the wireless challenges

The Answer

Wireless channel: A dispersive medium

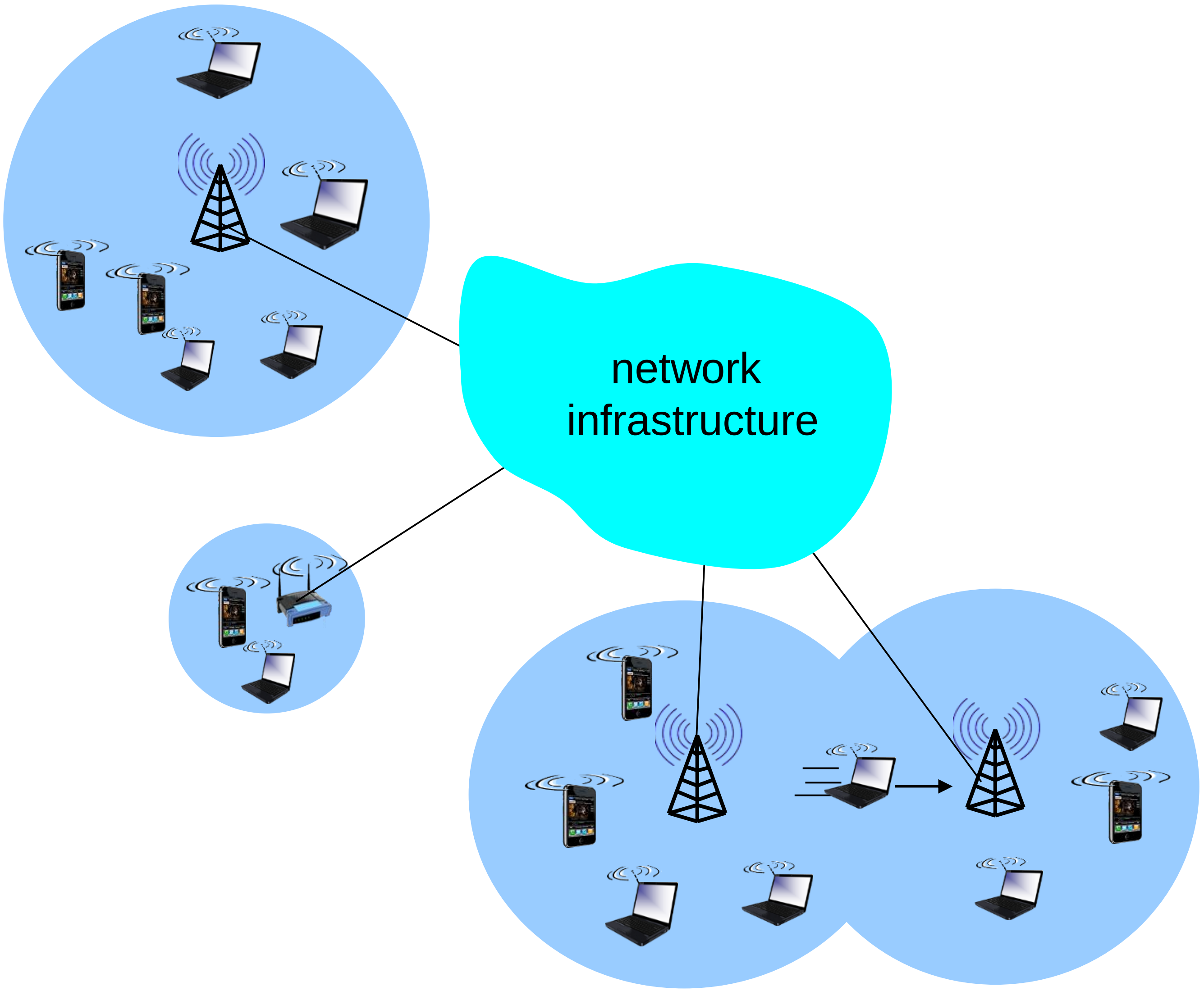
The PHY and MAC layer completely dissimilar

The whole game changes

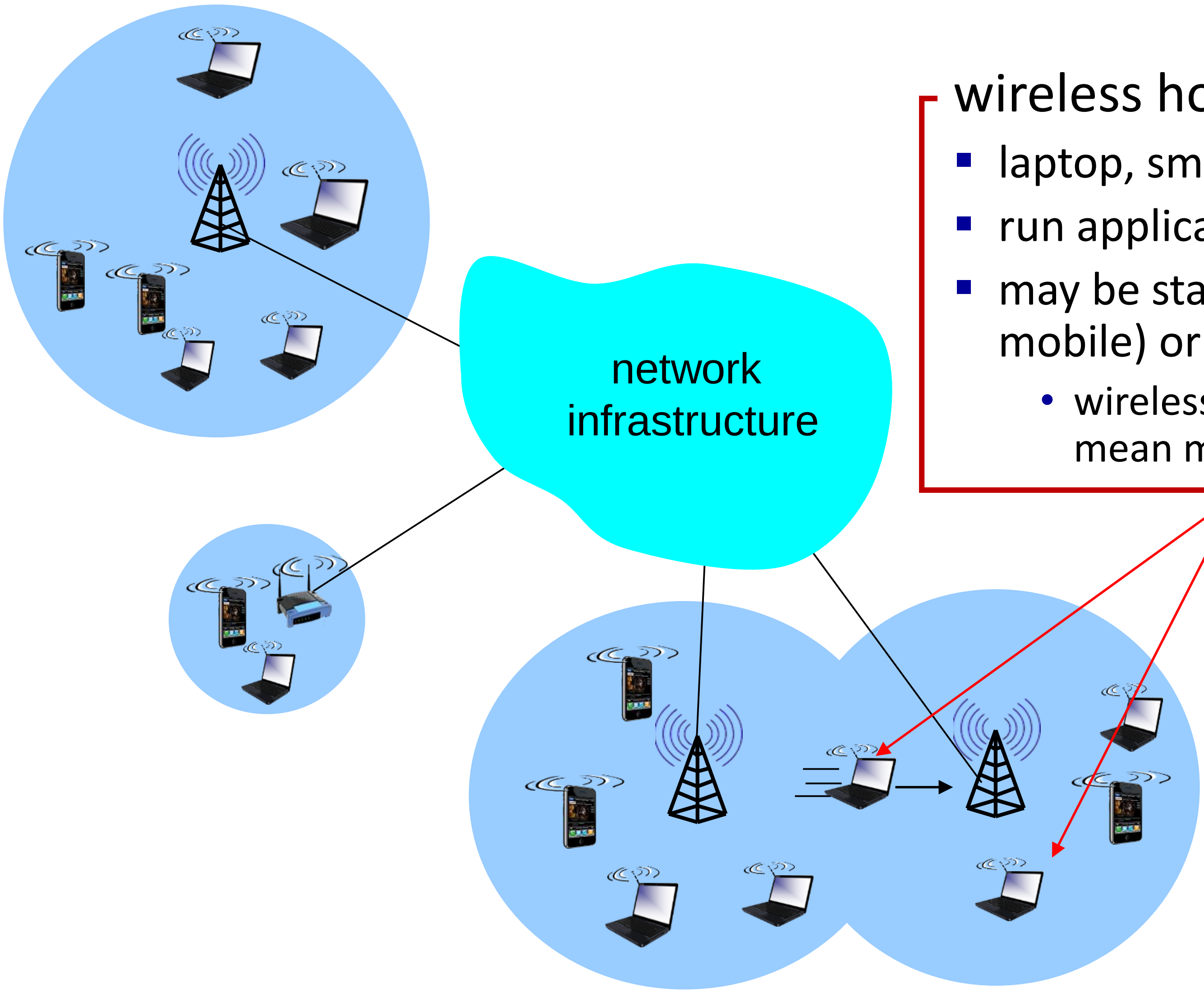
Chapter 6: Outline

- Introduction
- Wireless Links
- Wireless MAC
- WiFi: 802.11 Wireless LANs
- Cellular Networks: 3G, LTE
- Mobility

Elements of a wireless network



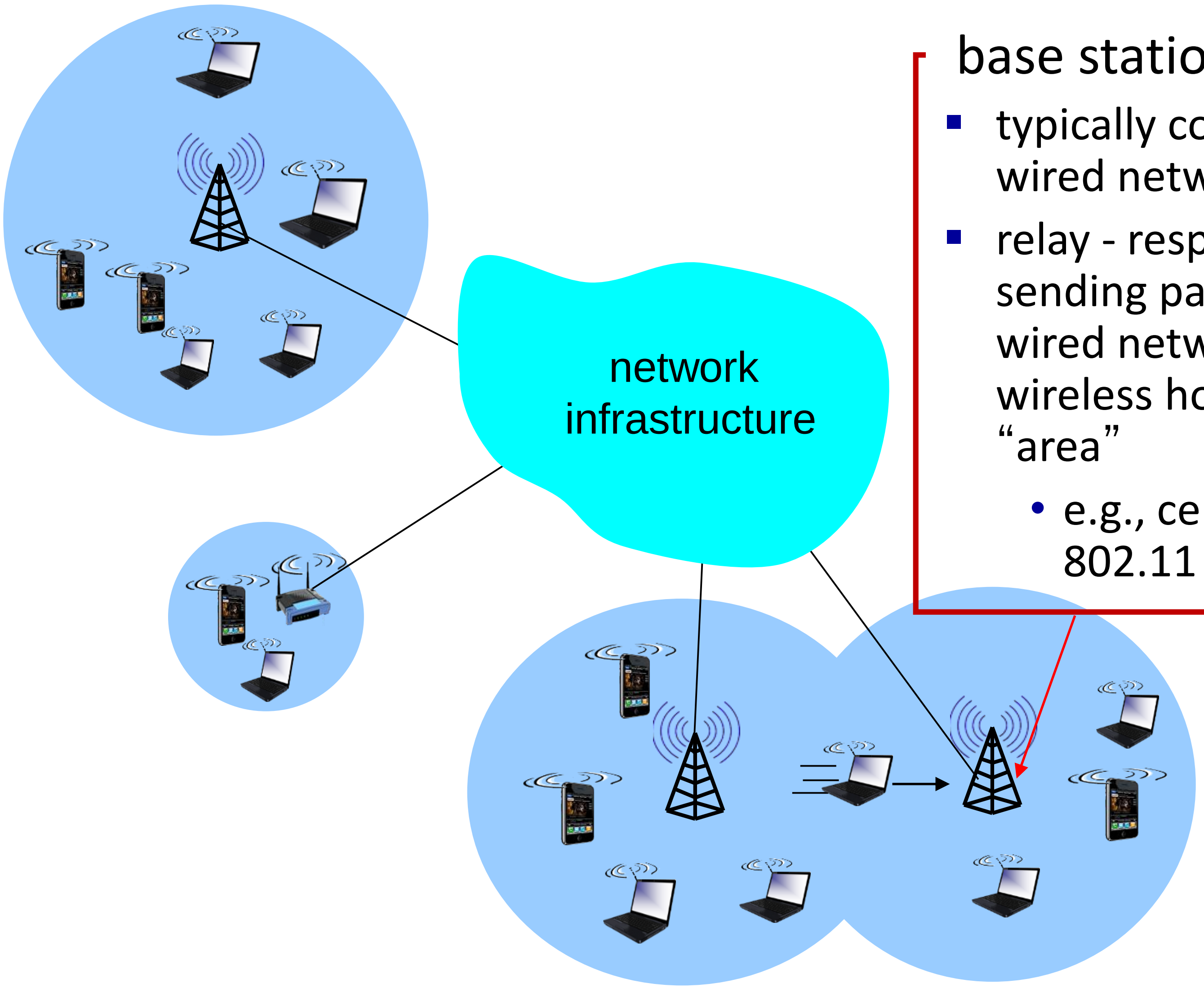
Elements of a wireless network



wireless hosts

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

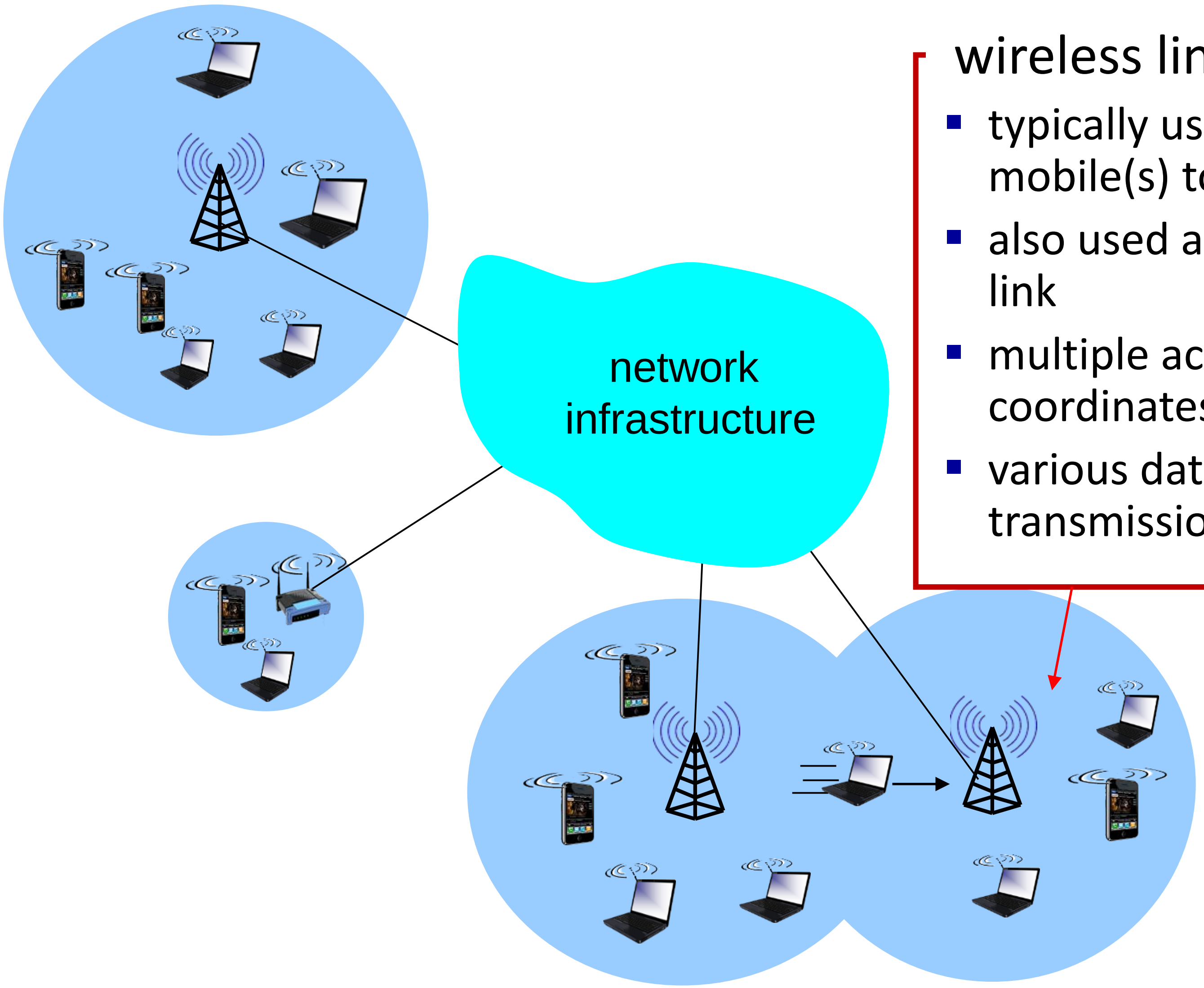
Elements of a wireless network



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

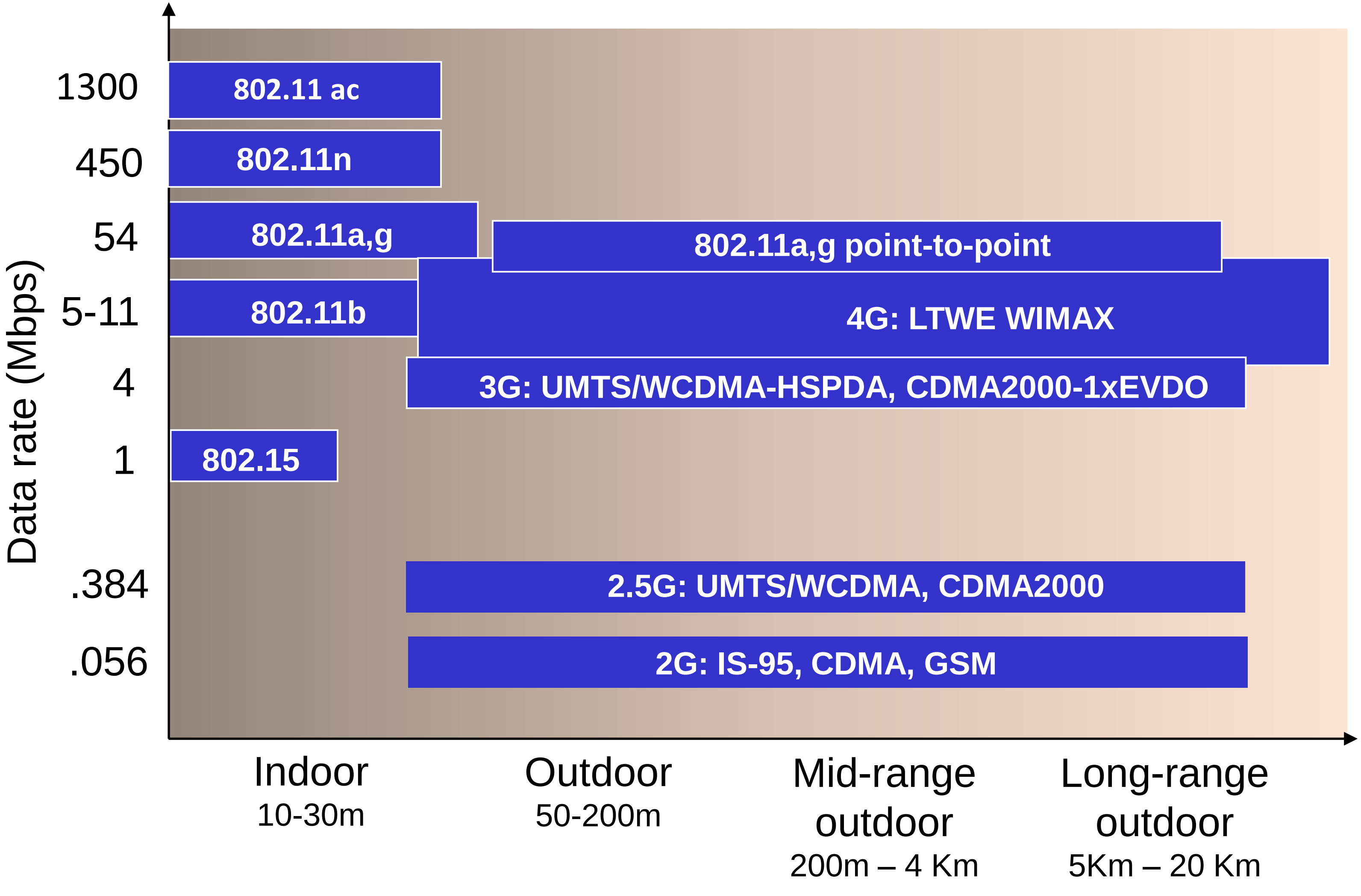
Elements of a wireless network



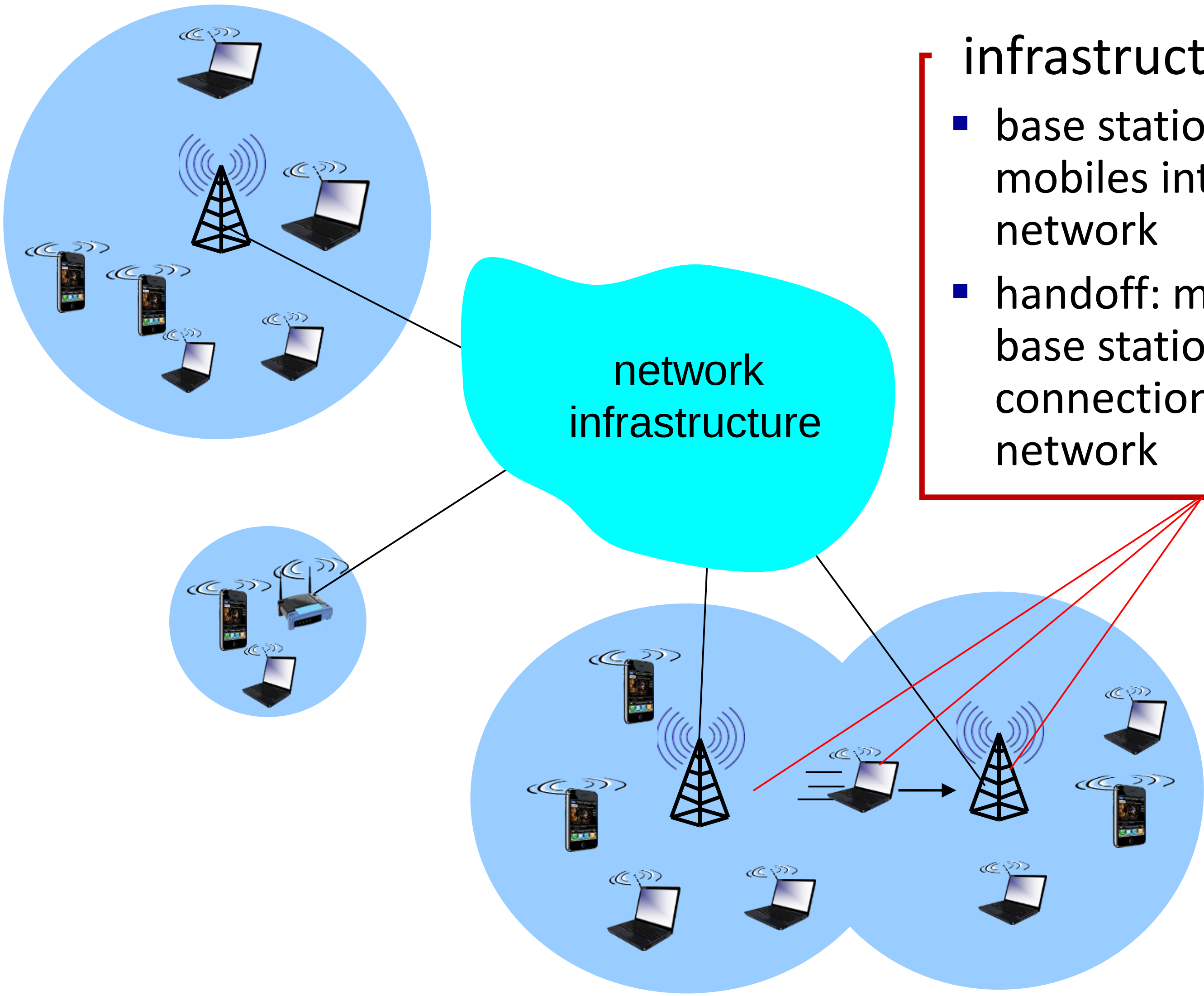
wireless link

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

Characteristics of selected wireless links



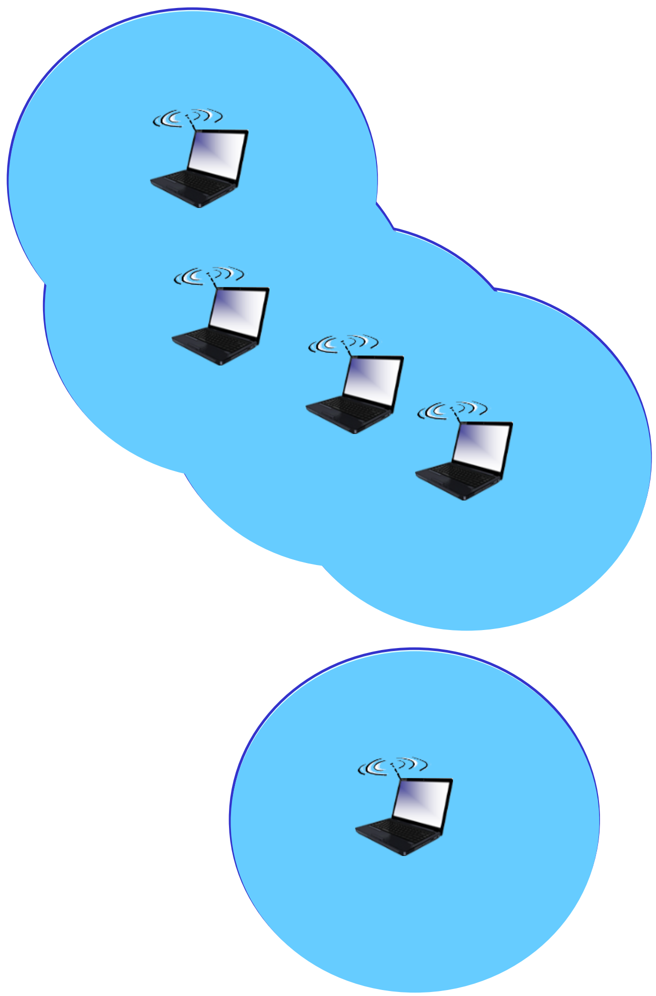
Elements of a wireless network



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, WiMAX, 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 other a given wireless node MANET, VANET

Chapter 6: Outline

- ✓ Introduction
- ❑ Wireless Links
- ❑ Wireless MAC
- ❑ WiFi: 802.11 Wireless LANs
- ❑ Cellular Networks: 3G, LTE
- ❑ Mobility

Wireless Link Characteristics

important differences from wired link ….

- *decreased signal strength:* radio signal attenuates as it propagates through matter (path loss)

$$P_{Rx} = \frac{G_{Tx}\, G_{Rx}\, \lambda^2}{(4\pi d)^2}\, P_{Tx}$$

$$Path\ Loss\ (dB) = 10 \log_{10} P_{Tx}/P_{Rx}$$

Wireless Link Characteristics

important differences from wired link ….

- *decreased signal strength:* radio signal attenuates as it propagates through matter (path loss)

$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$

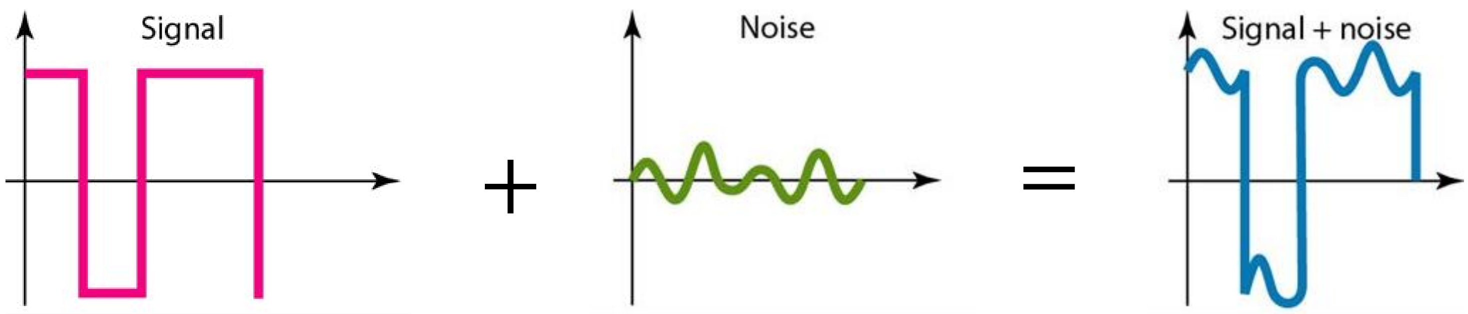
$$x(t) \longrightarrow y(t) = h\, x(t) + n(t)$$

$Signal - to - Noise\ Ratio$:

$$SNR = \frac{|h|^2 \times |x(t)|^2}{|n(t)|^2} = \frac{|h|^2 P_{Tx}}{N}$$

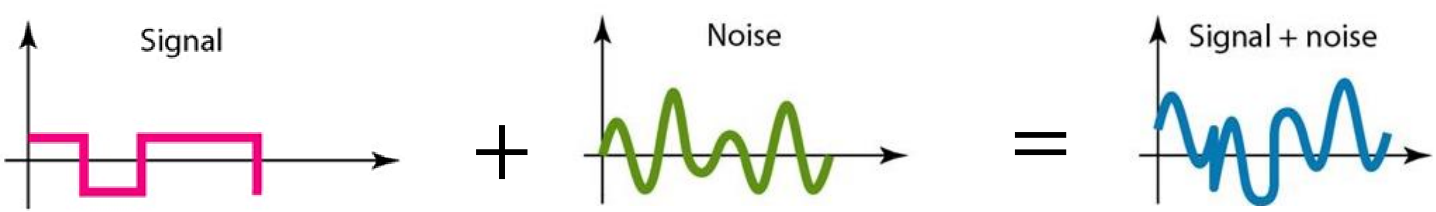
Wireless Link Characteristics

- SNR: signal-to-noise ratio
  - High SNR – easier to extract signal from noise (a "good thing")



Bits: 0 1 0 0

  - Low SNR – hard to extract signal from noise (a "bad thing")



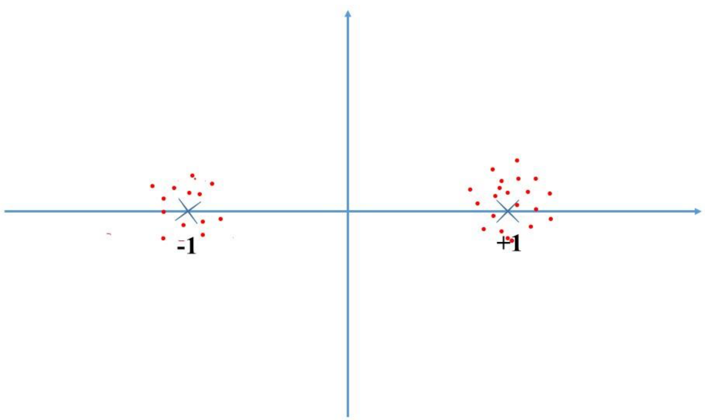
Bits: 0 1 0 0

HIGH SNR → Low Bit Error Rate
LOW SNR → High Bit Error Rate

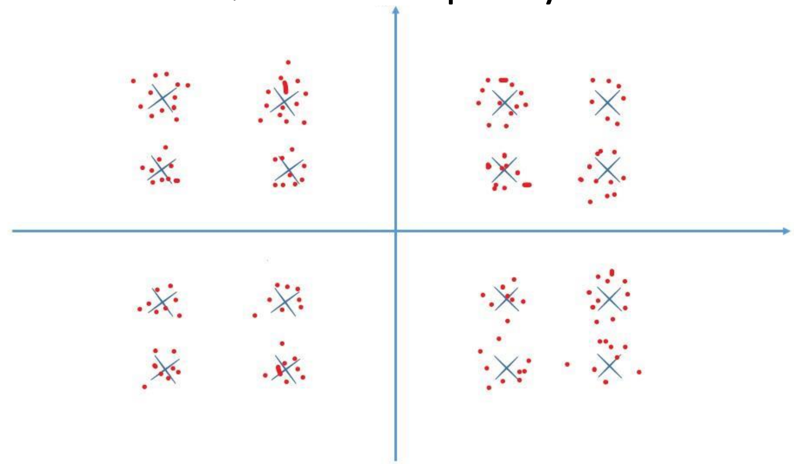
Wireless Link Characteristics

- SNR: signal-to-noise ratio
  - High SNR ➔ Lower Bit Error ➔ Use higher order modulation i.e. pack more bits per symbol

BPSK: 1 bit per symbol



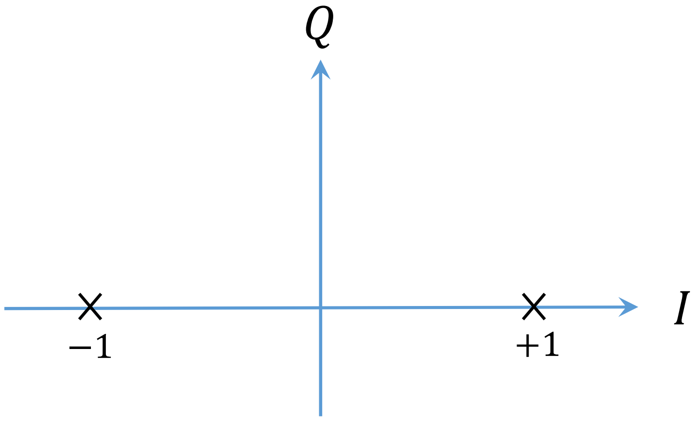
16 QAM: 4 bits per symbol



$$Bit\ Rate = Bandwidth \times bits/symbol$$

Wireless Link Characteristics

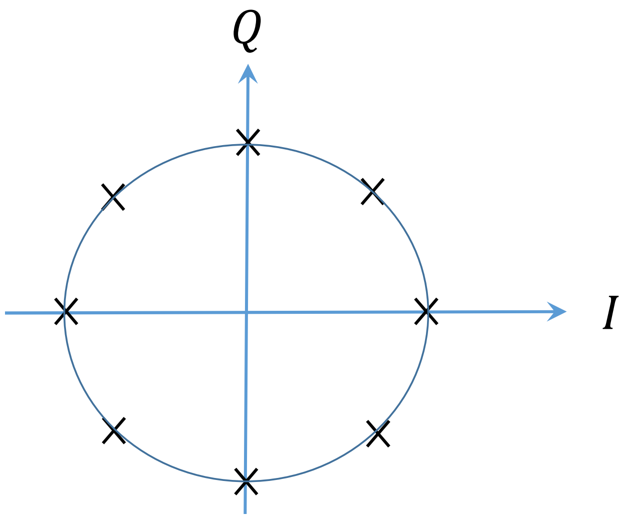
- SNR: signal-to-noise ratio
  - High SNR ➔ Lower Bit Error ➔ Use higher order modulation i.e. pack more bits per symbol
  - Some types of modulations:
    - BPSK: Binary Phase Shift Keying



Wireless Link Characteristics

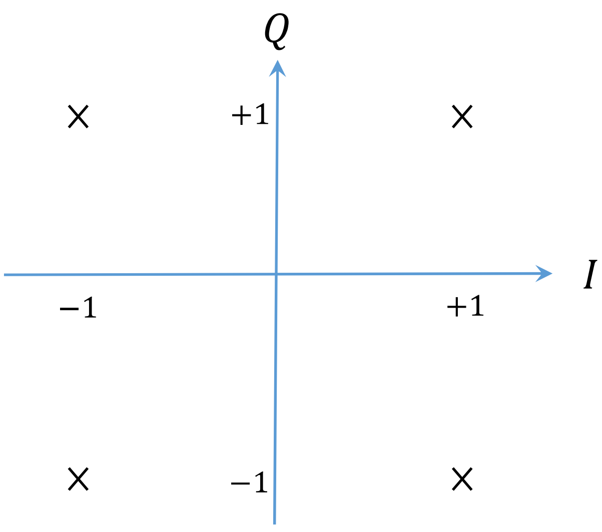
- SNR: signal-to-noise ratio
  - High SNR ➔ Lower Bit Error ➔ Use higher order modulation i.e. pack more bits per symbol

  - Some types of modulations:
    - BPSK: Binary Phase Shift Keying
    - QPSK: Phase Shift Keying



Wireless Link Characteristics

- SNR: signal-to-noise ratio
  - High SNR ➔ Lower Bit Error ➔ Use higher order modulation i.e. pack more bits per symbol
  - Some types of modulations:
    - BPSK: Binary Phase Shift Keying
    - QPSK: Quadrature Phase Shift Keying
    - QAM: Quadrature Amplitude Modulation



Wireless Link Characteristics

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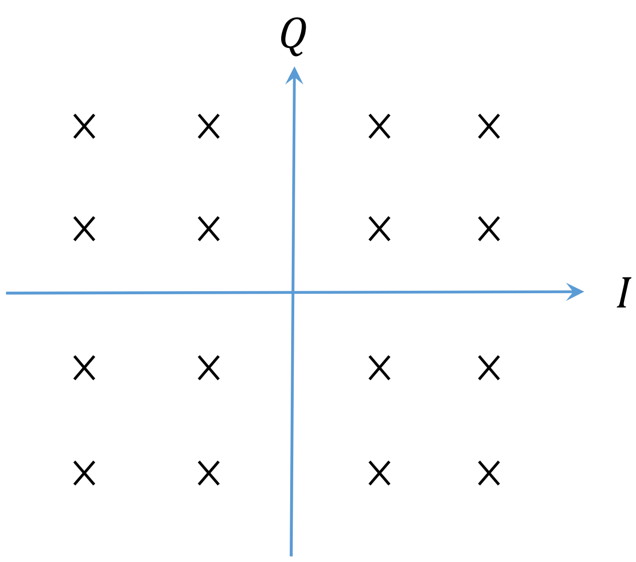
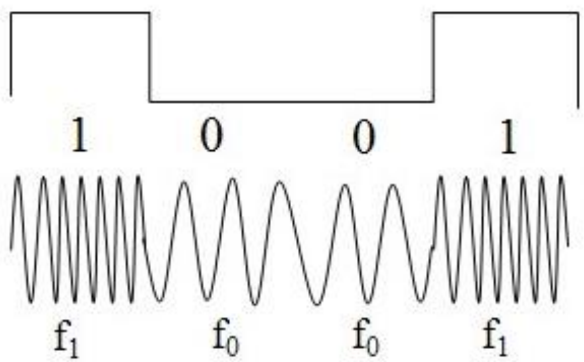


Wireless Link Characteristics

- SNR: signal-to-noise ratio
  - High SNR ➔ Lower Bit Error ➔ Use higher order modulation i.e. pack more bits per symbol

  - Some types of modulations:
    - BPSK: Binary Phase Shift Keying
    - QPSK: Quadrature Phase Shift Keying
    - QAM: Quadrature Amplitude Modulation
    - FSK: Frequency Shift Keying



Wireless Link Characteristics

- SNR: signal-to-noise ratio
  - High SNR ➔ Lower Bit Error ➔ Use higher order modulation i.e. pack more bits per symbol

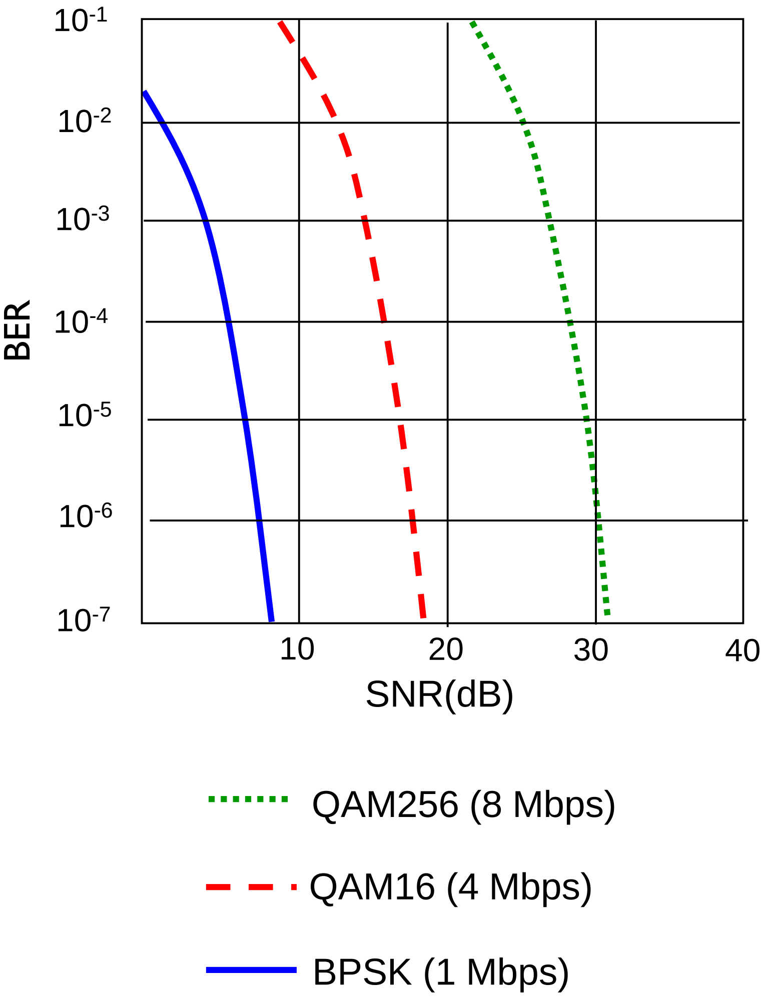
  - Some types of modulations:
    - BPSK: Binary Phase Shift Keying
    - QPSK: Quadrature Phase Shift Keying
    - QAM: Quadrature Amplitude Modulation
    - FSK: Frequency Shift Keying
    - PAM: Pulse Amplitude Modulation
    - On-OFF Keying

Wireless Link Characteristics

- *SNR versus BER tradeoffs*
  - *given physical layer modulation:*

    Higher SNR → Low BER

  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, coding)→ rate adaptation



Wireless Link Characteristics

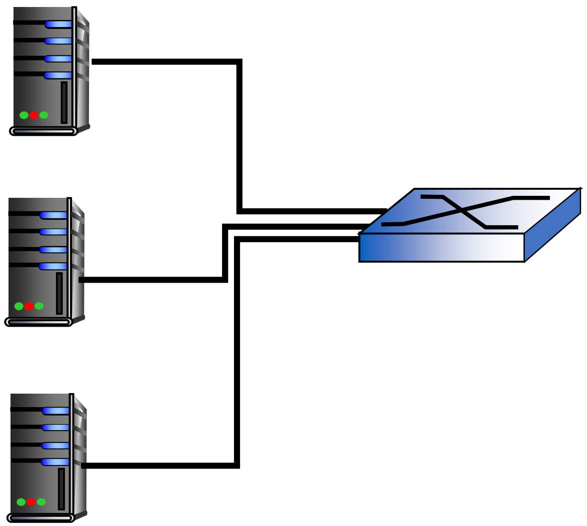
- *Given SNR, what is maximum rate that we can achieve?*
  - *Shannon Capacity Theorem:*

$$Capacity = Bandwidth \times \log_2(1 + SNR)$$

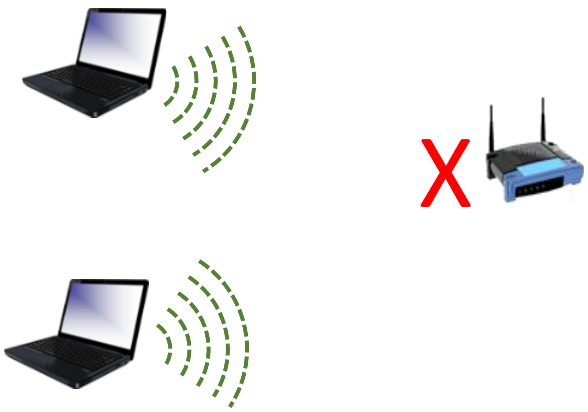
Wireless Link Characteristics

important differences from wired link ….

- *interference from other sources:* standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well



Multiple Wired Links → No Interference



Multiple Wireless Links → Interference

Wireless Link Characteristics

important differences from wired link ….

- *interference from other sources:* standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well

$Signal - to - Interference \; \& \; Noise \; Ratio$:

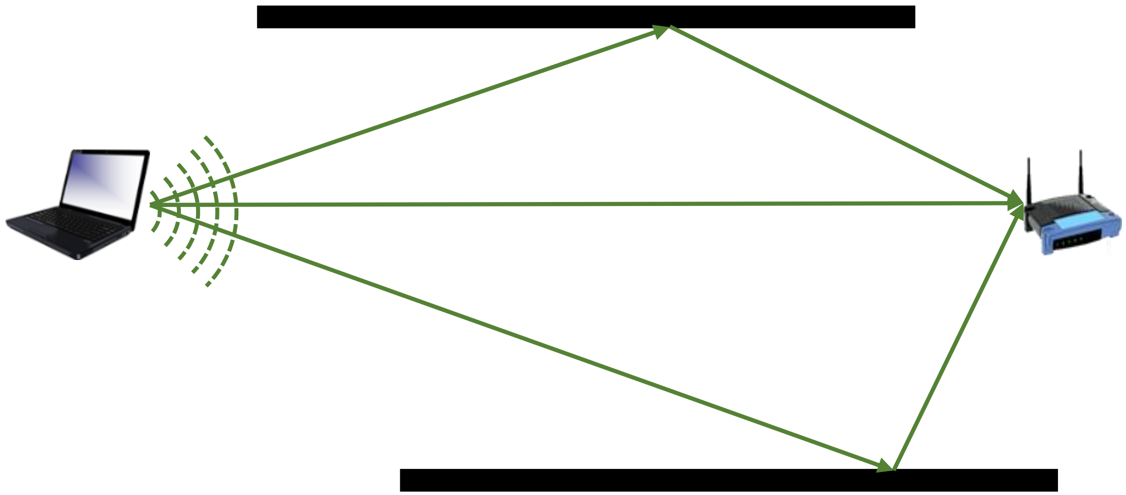
$$SINR = \frac{Received\ Signal\ Power\ (P_{Rx})}{Interference\ (I) + Noise\ (N)}$$

MAC Protocols necessary to avoid interference!

Wireless Link Characteristics

important differences from wired link ….

- *multipath propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times

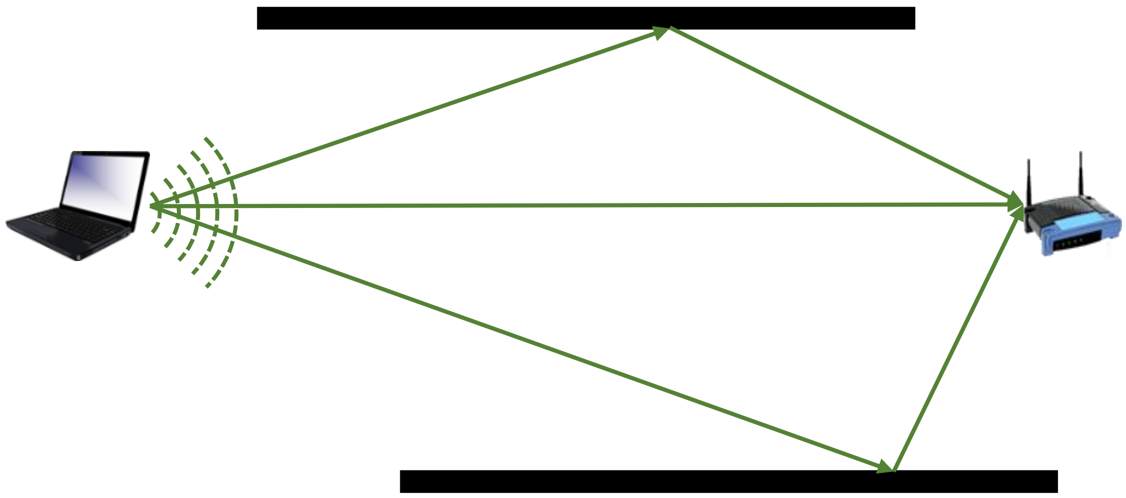


$$y(t) = h_1\, x(t-\tau_1) + h_2\, x(t-\tau_2) + h_3\, x(t-\tau_3)$$

Wireless Link Characteristics

important differences from wired link ….

- *multipath propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times



$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t)$$

Wireless Link Characteristics

important differences from wired link ....

- *multipath propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times

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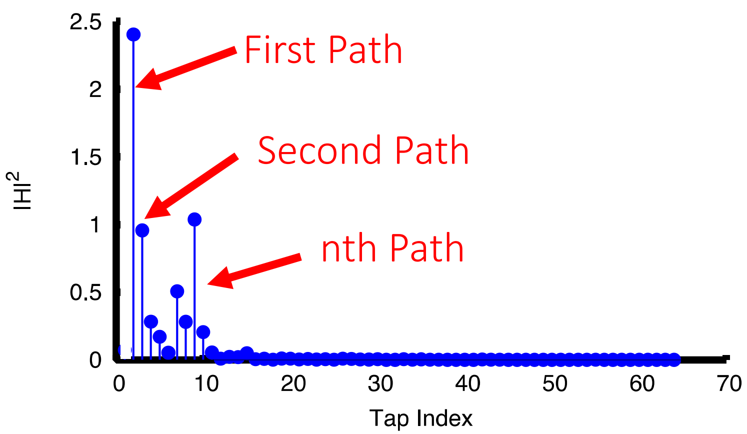
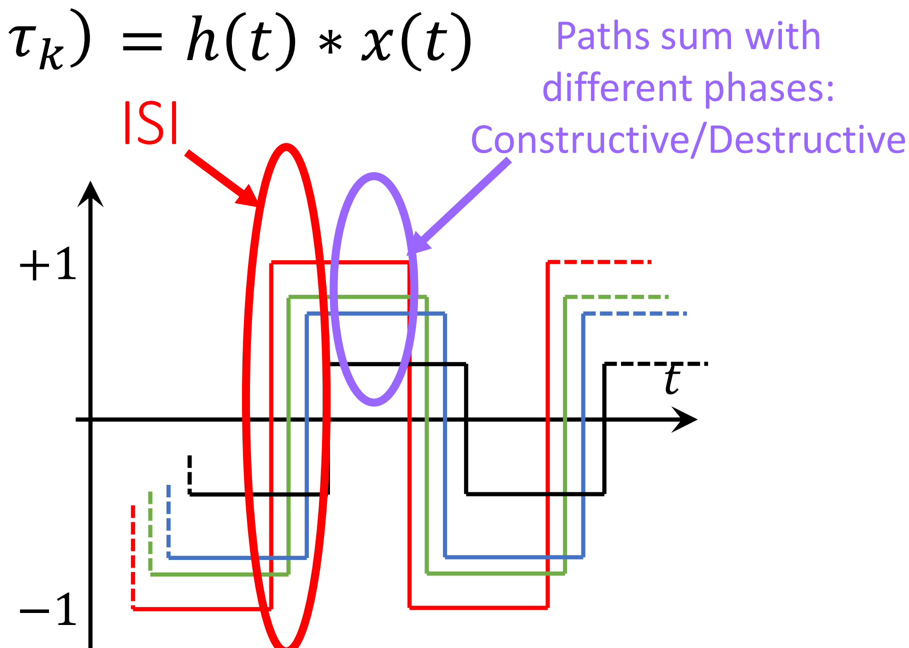


Multi-tap Channel ➡



ISI: Inter-Symbol-Interference

Symbols arriving along late paths interfere with following symbols.

Wireless Link Characteristics

Frequency Selective Fading:

Example 2 paths with distance $d_1 = 1m, d_2 = 1.06m$*:*

$$h = h_1 + h_2 = \frac{\lambda}{d_1}\, e^{j2\pi d_1/\lambda} + \frac{\lambda}{d_2}\, e^{j2\pi d_2/\lambda}$$

$@f_1 = 2.5GHz\ (\lambda = 12\ cm)$*:*

$$h = 0.12\, e^{j\frac{2\pi}{3}} + 0.113\, e^{j\frac{5\pi}{3}} \approx 0.006$$

$@f_2 = 5GHz\ (\lambda = 6\ cm)$*:*

$$h = 0.06\, e^{j\frac{5\pi}{3}} + 0.05\ e^{j\frac{5\pi}{3}} \approx 0.116$$

$17 \times$

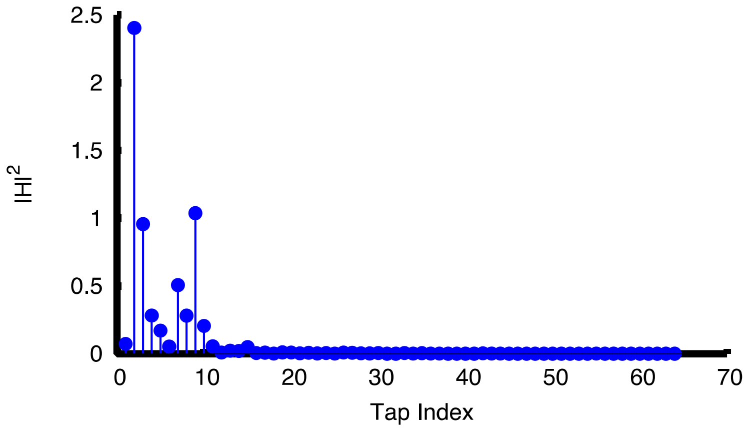
➔ 24dB

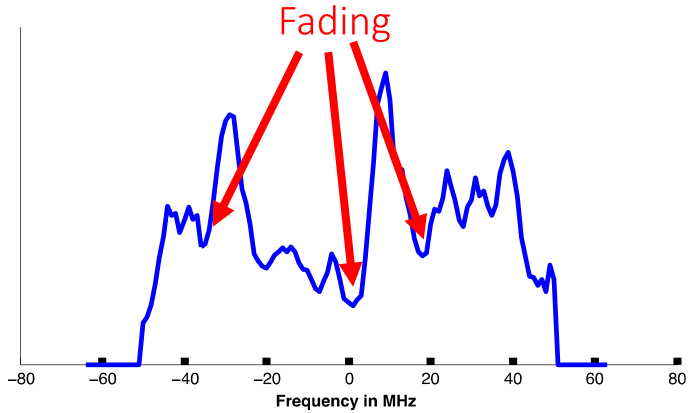
Wireless Link Characteristics

important differences from wired link ….

- *multipath propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times

$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$





Wireless Link Characteristics

important differences from wired link ….

- *multipath propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times
  - Inter-Symbol-Interference
  - Frequency Selective Fading

Wireless Link Characteristics

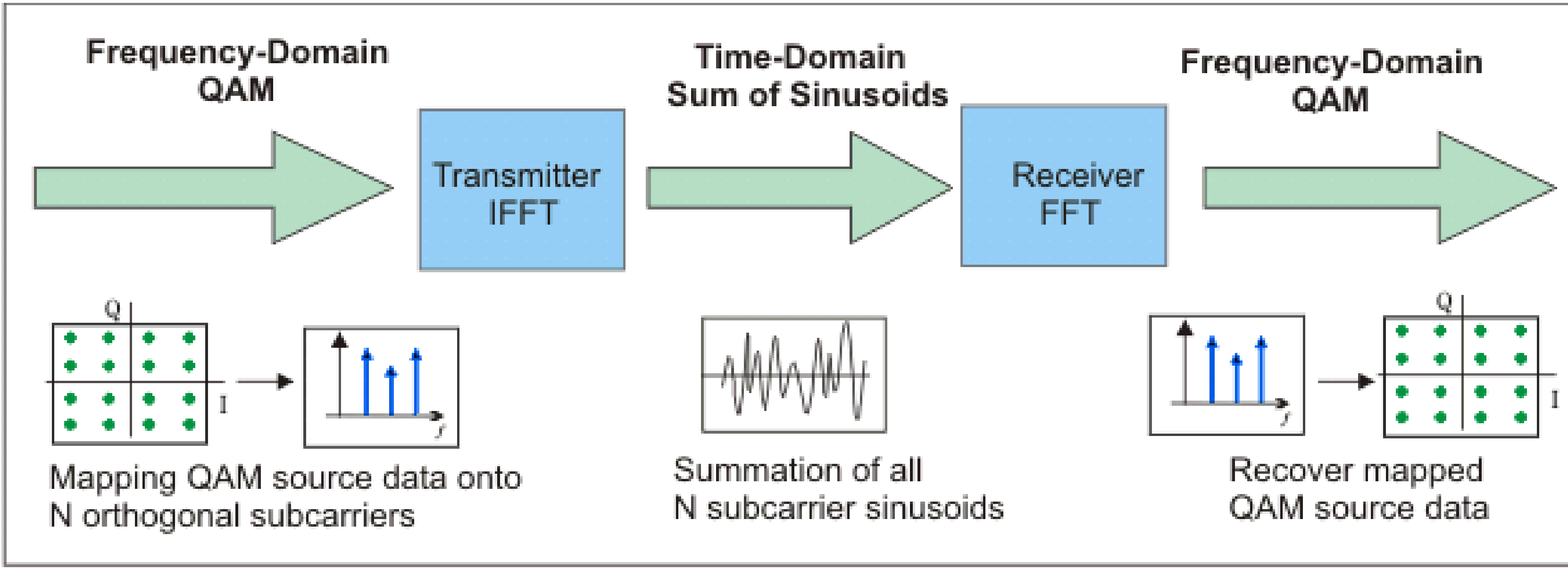
important differences from wired link ....

- *multipath propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times
- Solution:

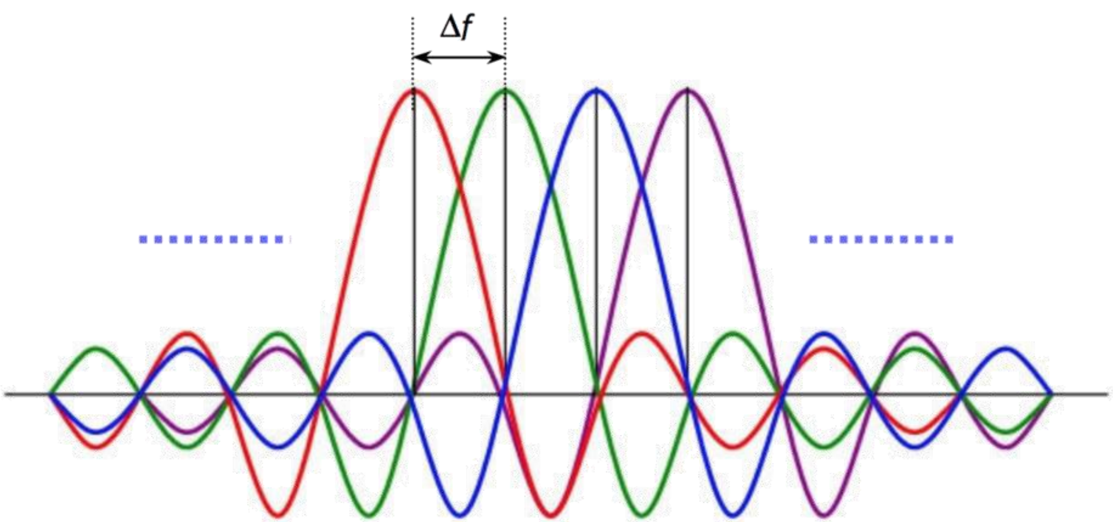
OFDM: Orthogonal Frequency Division Multiplexing

- Idea: transmit symbols in frequency not time.

Orthogonal Frequency Division Multiplexing



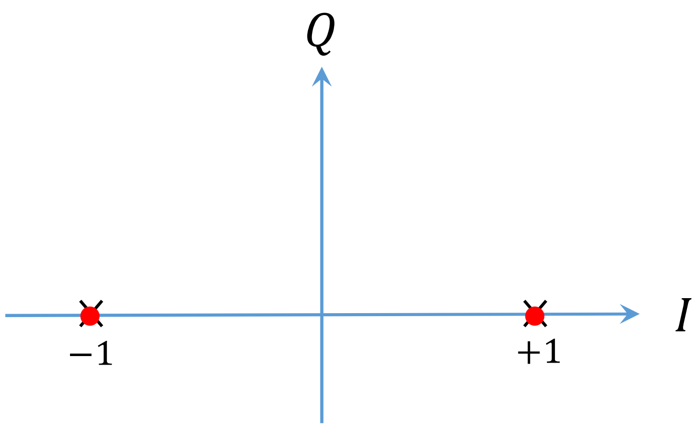
Simplified OFDM System Block Diagram

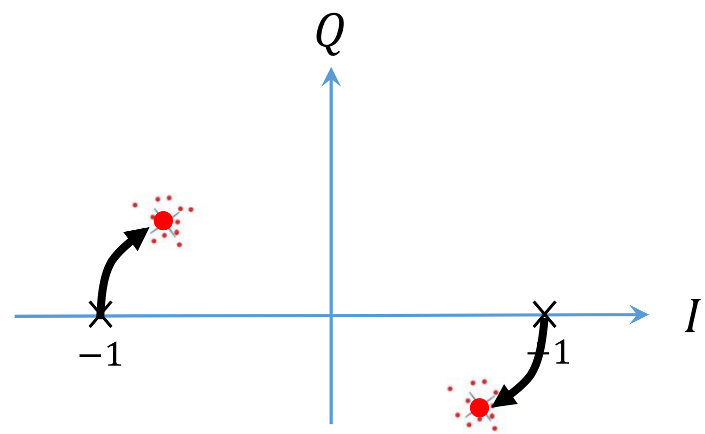


Channel Estimation and Correction

$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$

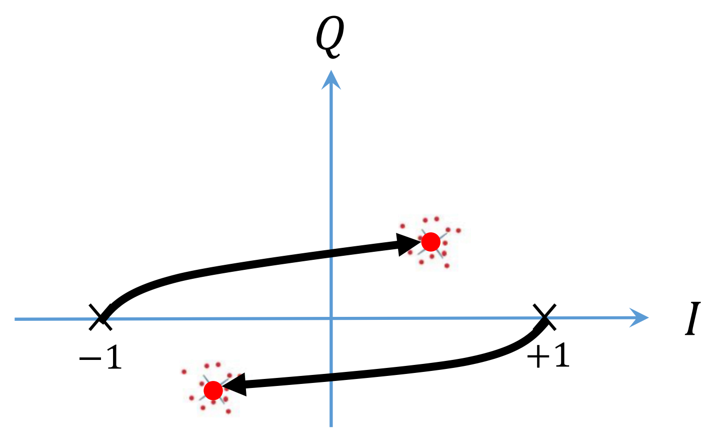
$$x(t) \longrightarrow y(t) = h\,x(t) + n(t)$$





How to estimate and correct for channel?

Send Preamble Bits



Channel Estimation and Correction

$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$

$x(t)$

$$y(t) = h\, x(t) + n(t)$$

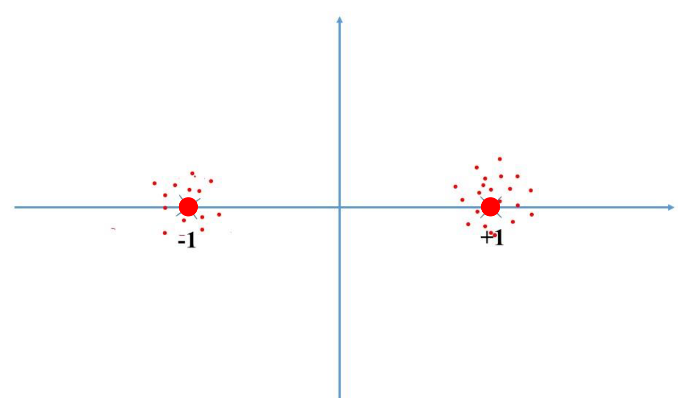
Preamble Bits: Known bits

$x(0) = 1 \longrightarrow y(0) = h + n(0)$

$x(1) = 1 \longrightarrow y(1) = h + n(1)$

$x(2) = -1 \longrightarrow y(2) = -h + n(2)$

Estimate channel: $\tilde{h} = \sum_k \frac{y(k)}{x(k)}$



Correct channel: $\tilde{x}(t) = \frac{y(t)}{\tilde{h}}$

Channel Estimation and Correction

$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$

$x(t)$

$$y(t) = h(t) * x(t) + n(t)$$

What about multi-tap channel?

OFDM: Send bits in frequency domain

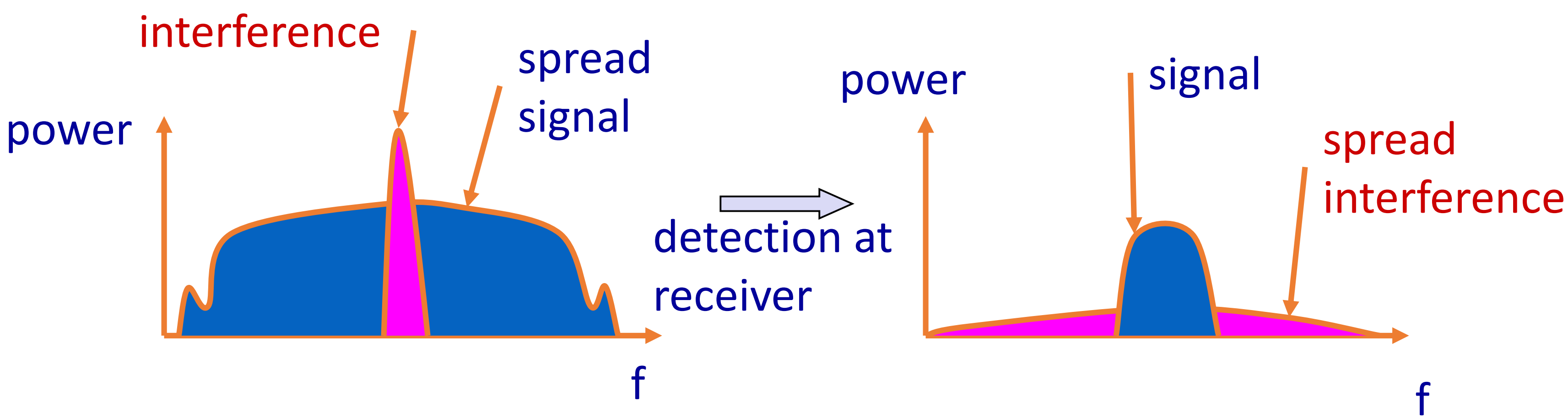
$$h(t) * x(t) \Leftrightarrow H(f)X(f)$$

Channel estimation and correction can be done in frequency domain.

$$\widetilde{H}(f) = \frac{Y(f)}{X(f)}$$

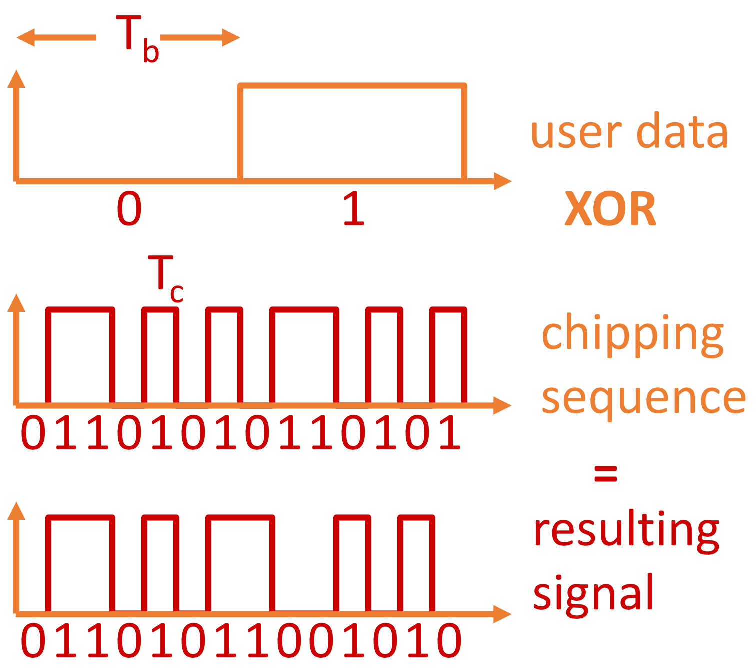
Spread Spectrum

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code



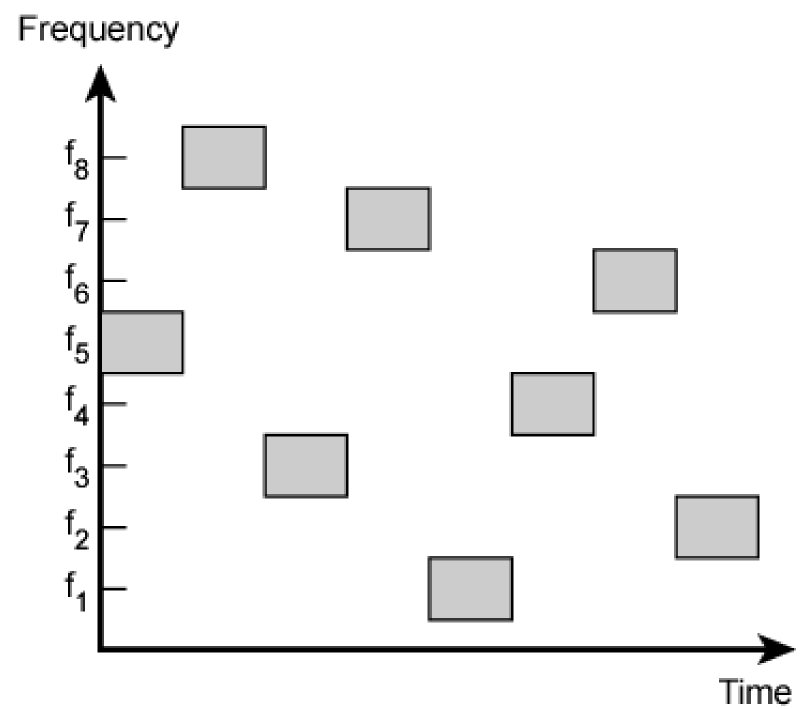
DSSS (Direct Sequence Spread Spectrum)

- XOR the signal with pseudonoise (PN) sequence (chipping sequence)
- Advantages
  - reduces frequency selective fading
  - Robust to interference
  - Multi-user
- Used in 3G & 802.11b



FHSS (Frequency Hopping Spread Spectrum)

- Discrete changes of carrier frequency
  - sequence of frequency changes determined via PN sequence
- Advantages
  - frequency selective fading and interference limited to short period
  - uses only small portion of spectrum at any time
  - Secure
- Used in bluetooth & military applicaitons



(b) Channel use

Wireless Link Characteristics

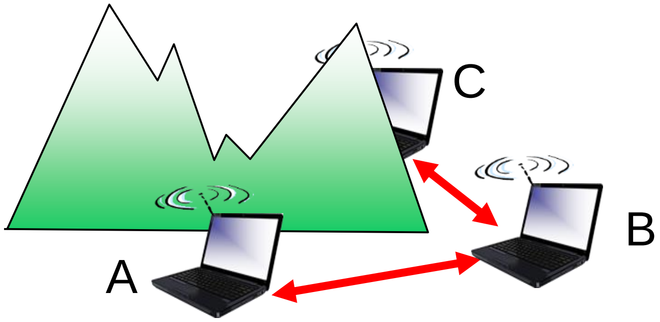
important differences from wired link ….

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

…. make communication across (even a point to point) wireless link much more "difficult"

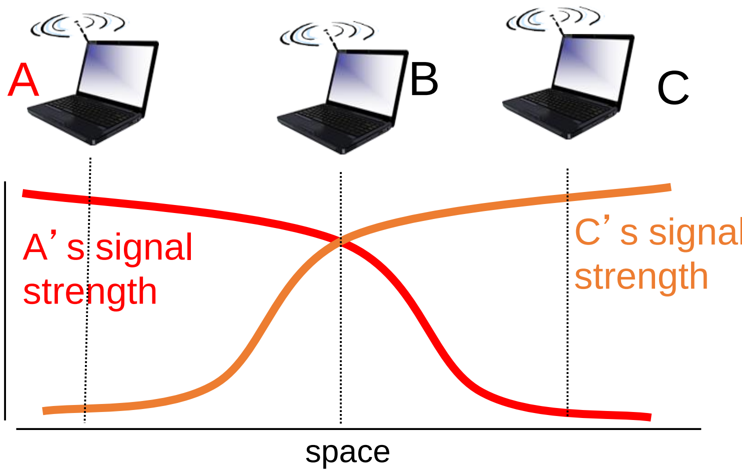
Wireless network characteristics

Multiple wireless senders and 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

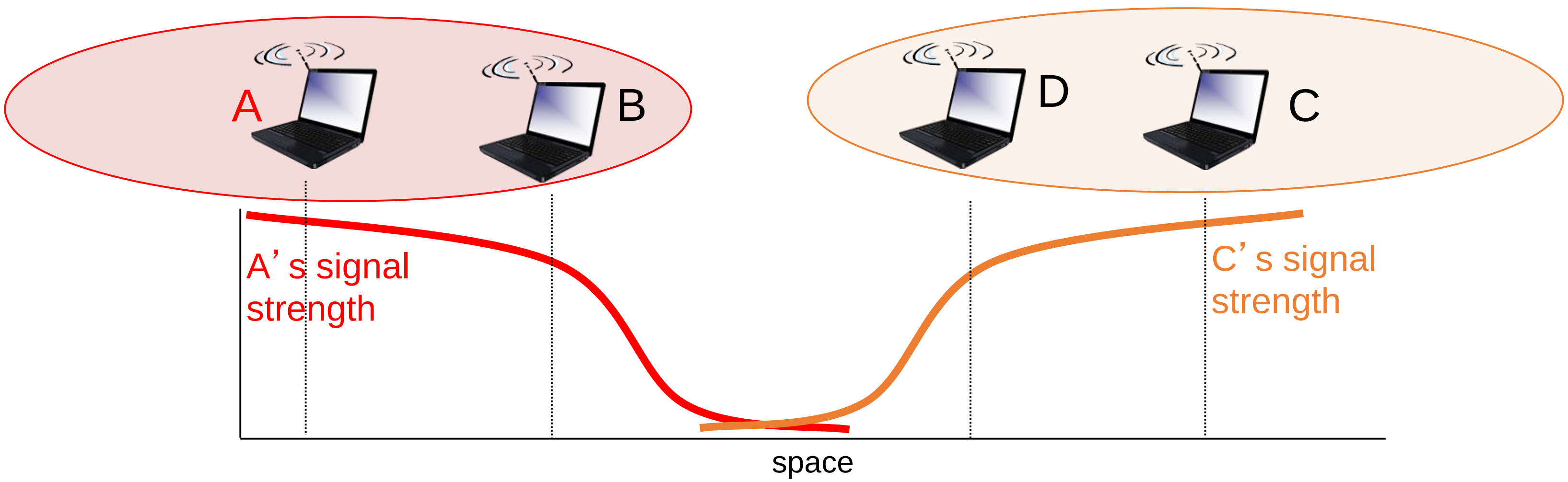


Signal attenuation:

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

Wireless network characteristics

Advantage of signal attenuation: Spatial Reuse

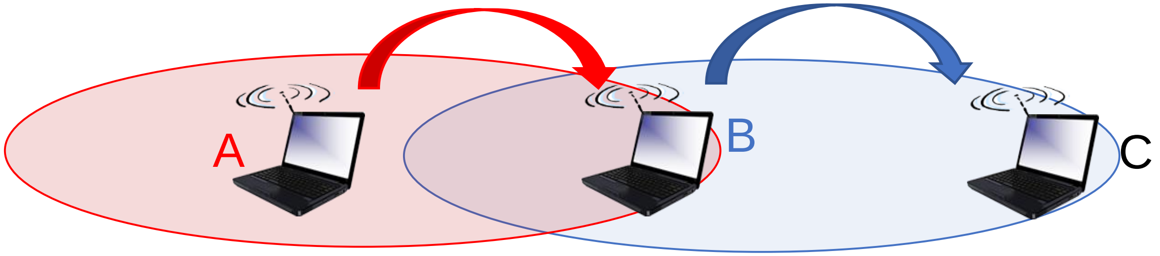


Wireless network characteristics

Problem: A wants to transmit a packet to C

Option 1: A increases its power such that its packet reaches C

Option 2: A sends that packet to B which intern send it to C

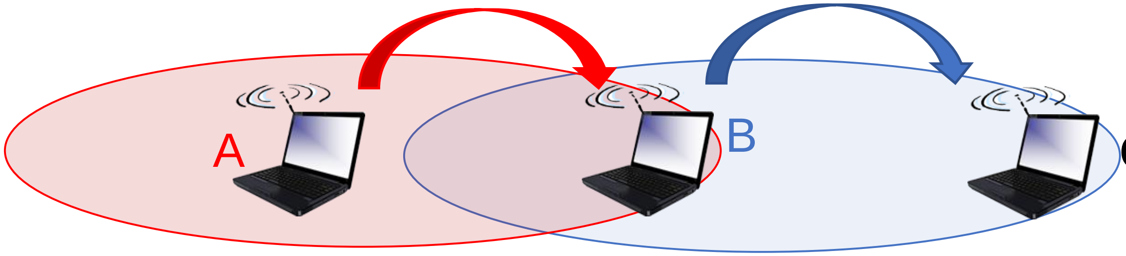


Wireless network characteristics

Problem: A wants to transmit a packet to C

To double transmission range, we need: 4x more overall power!

To transmit over two hops, we need: 2x more overall power!



Wireless network characteristics

Multi-hop wireless networks:

- Increase TX power: increase transmission range by N times, need $N^2 \times$ more power
- Multi-hop links: increase transmission range by N times, need $N \times$ more power

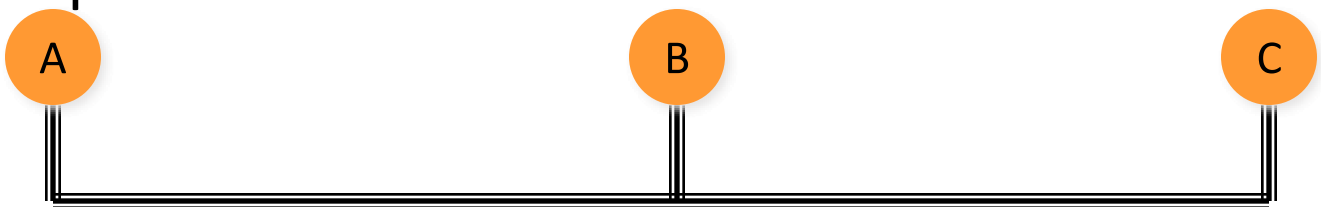
Ad hoc multi-hop wireless networks!

Chapter 6: Outline

- ✓ Introduction
- ✓ Wireless Links
- ❑ Wireless MAC
- ❑ WiFi: 802.11 Wireless LANs
- ❑ Cellular Networks: 3G, LTE
- ❑ Mobility

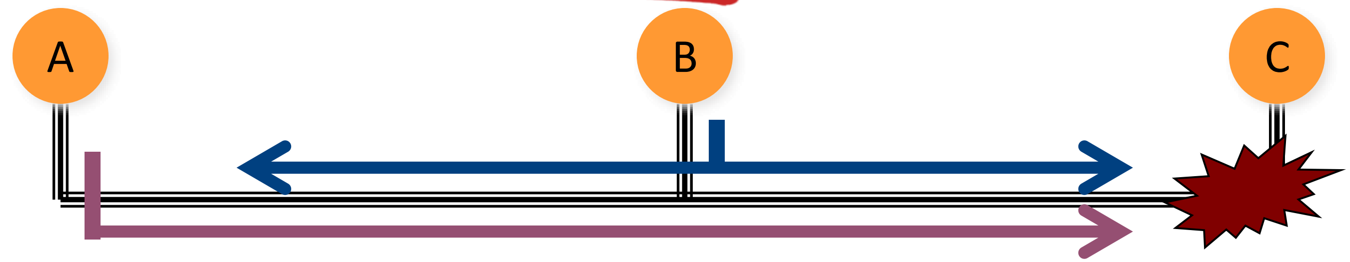
The Channel Access Problem

- Multiple nodes share a channel



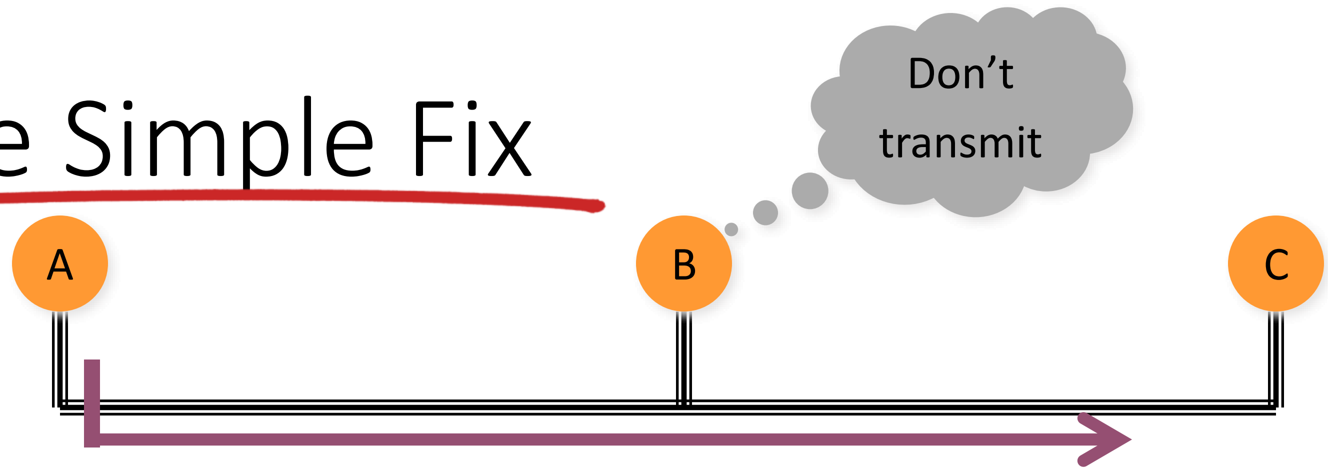
- Pairwise communication desired
  - Simultaneous communication not possible
- MAC Protocols
  - Suggests a scheme to schedule communication
    - Maximize number of communications
    - Ensure fairness among all transmitters

The Trivial Solution



- Transmit and pray
  - Plenty of collisions → poor throughput at high load

The Simple Fix



- Transmit and pray
  - Plenty of collisions → poor throughput at high load
- Listen before you talk
  - Carrier sense multiple access (CSMA)
  - Defer transmission when signal on channel

Can collisions still occur?

CSMA collisions

Collisions can still occur:

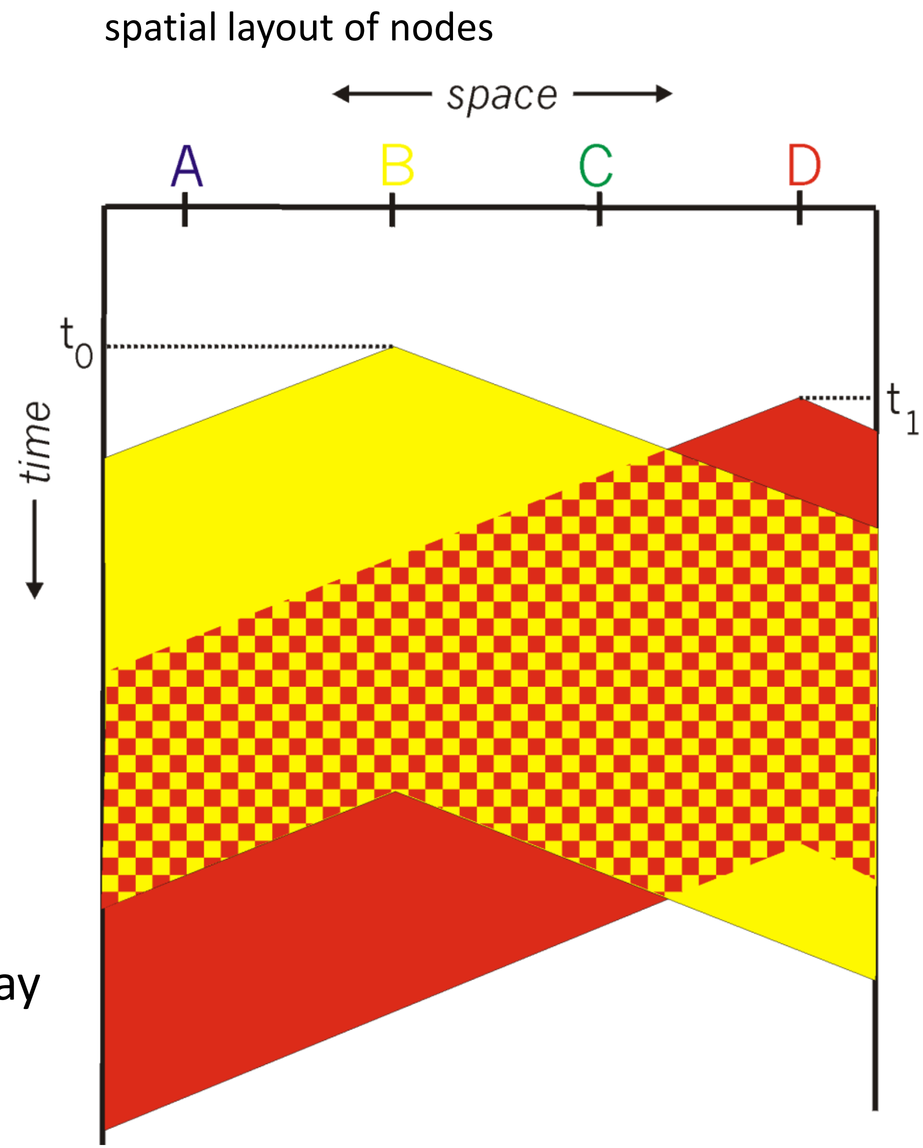
Propagation delay non-zero between transmitters

When collision:

Entire packet transmission time wasted

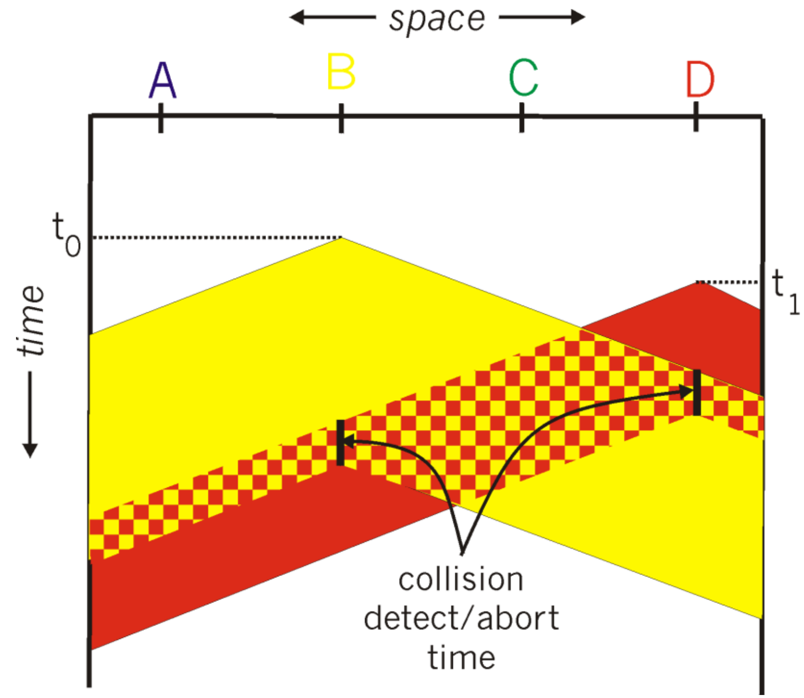
note:

Role of distance & propagation delay in determining collision probability



CSMA/CD (Collision Detection)

- Keep listening to channel
  - While transmitting



- If (Transmitted_Signal != Sensed_Signal)

→ Sender knows it's a **Collision**

→ **ABORT**

2 Observations on CSMA/CD

- Transmitter can send/listen concurrently
  - If (Sensed - received = null)? Then success

- The signal is identical at Tx and Rx
  - Non-dispersive

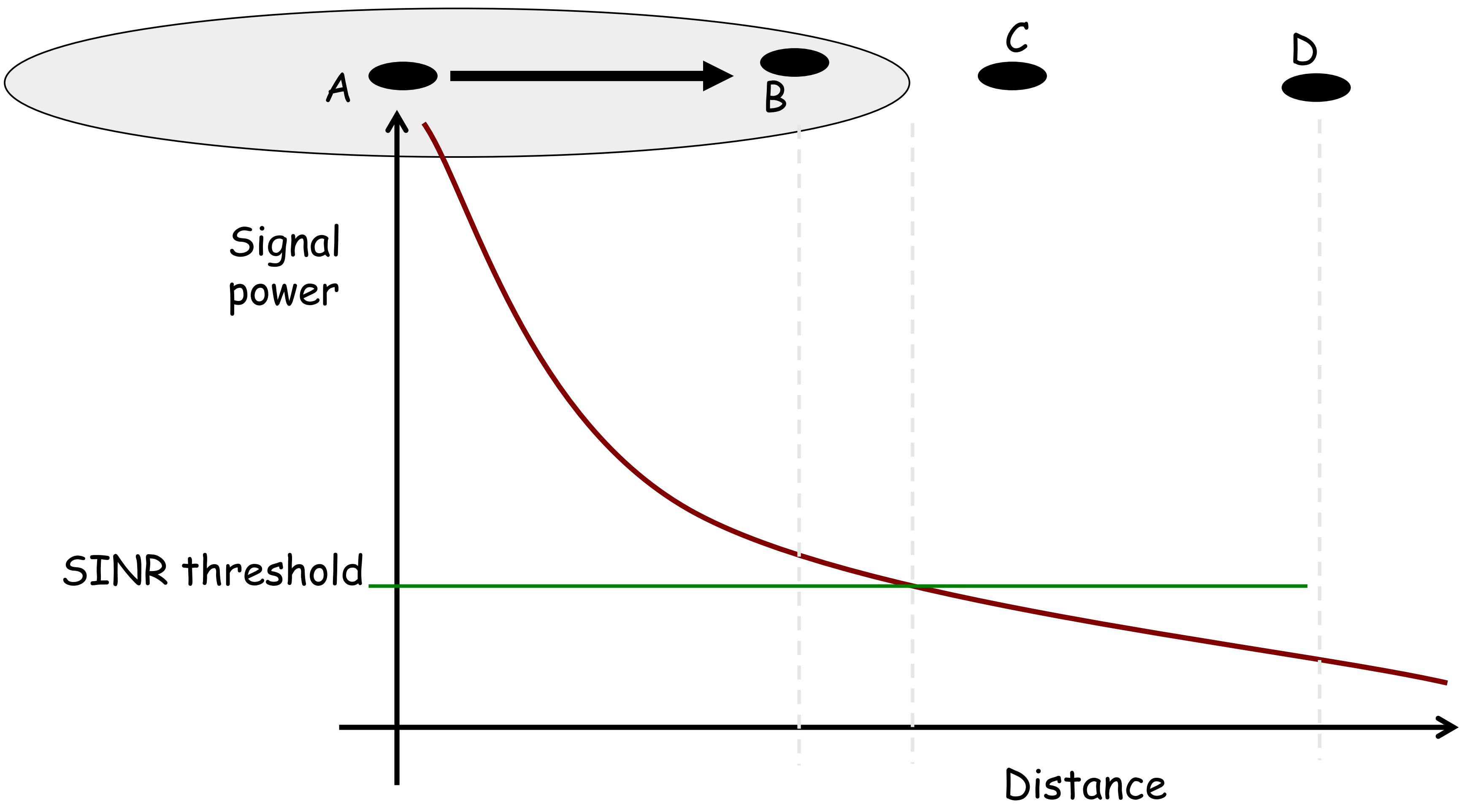
The transmitter can DETECT if and when collision occurs

Unfortunately …

Both observations do not hold for wireless

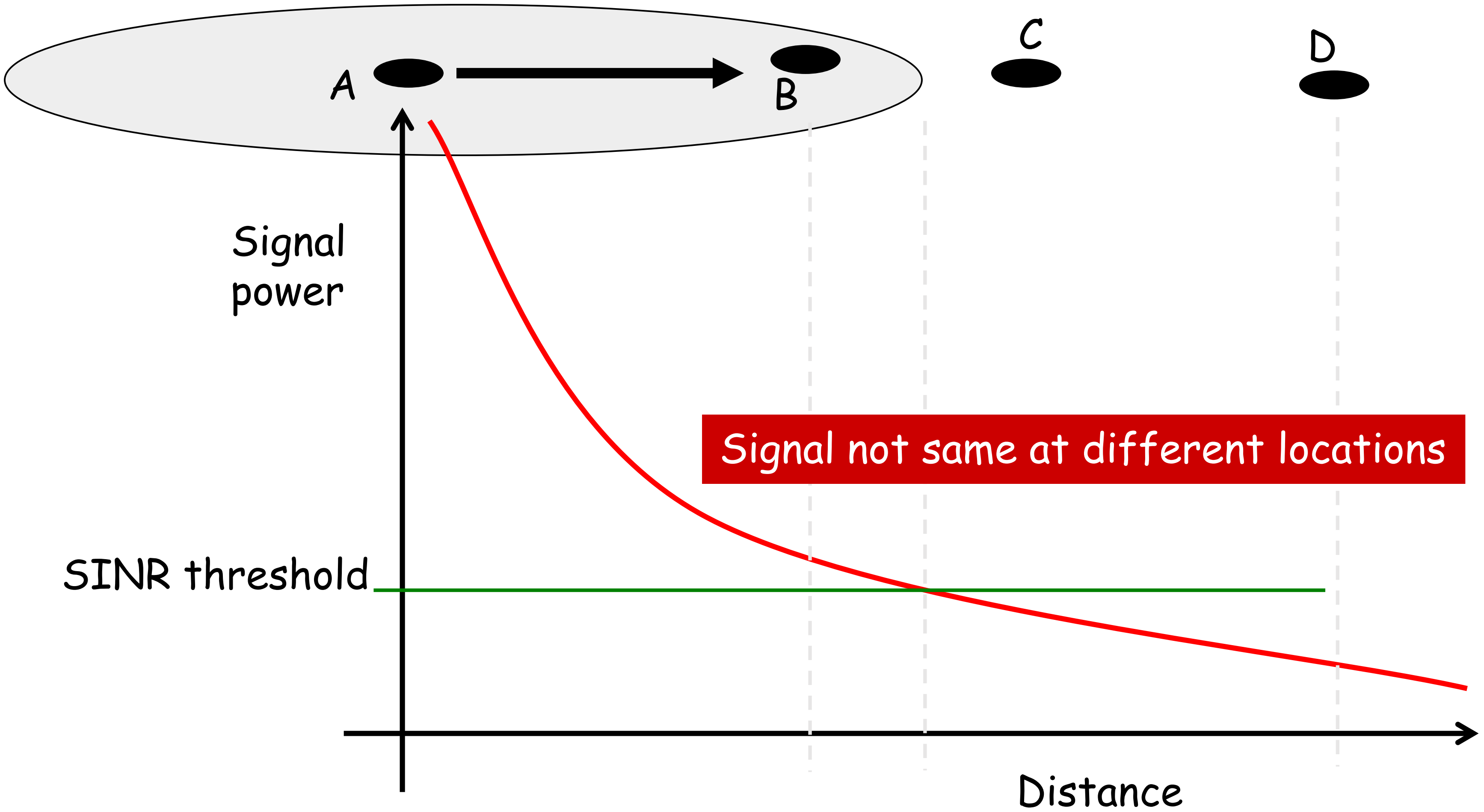
Leading to …

Wireless Medium Access Control



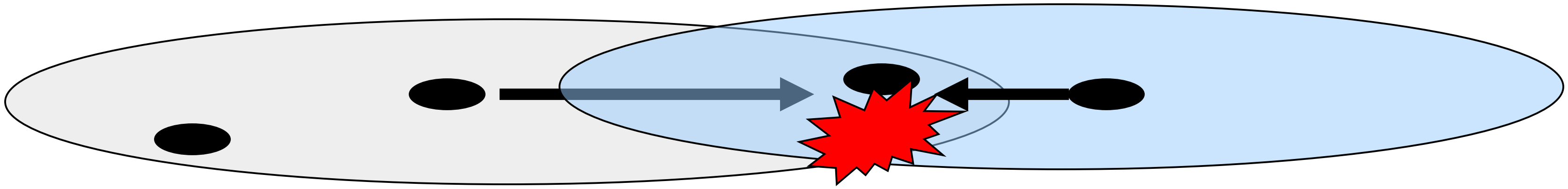
Wireless Media Disperse Energy

A cannot send and listen in parallel

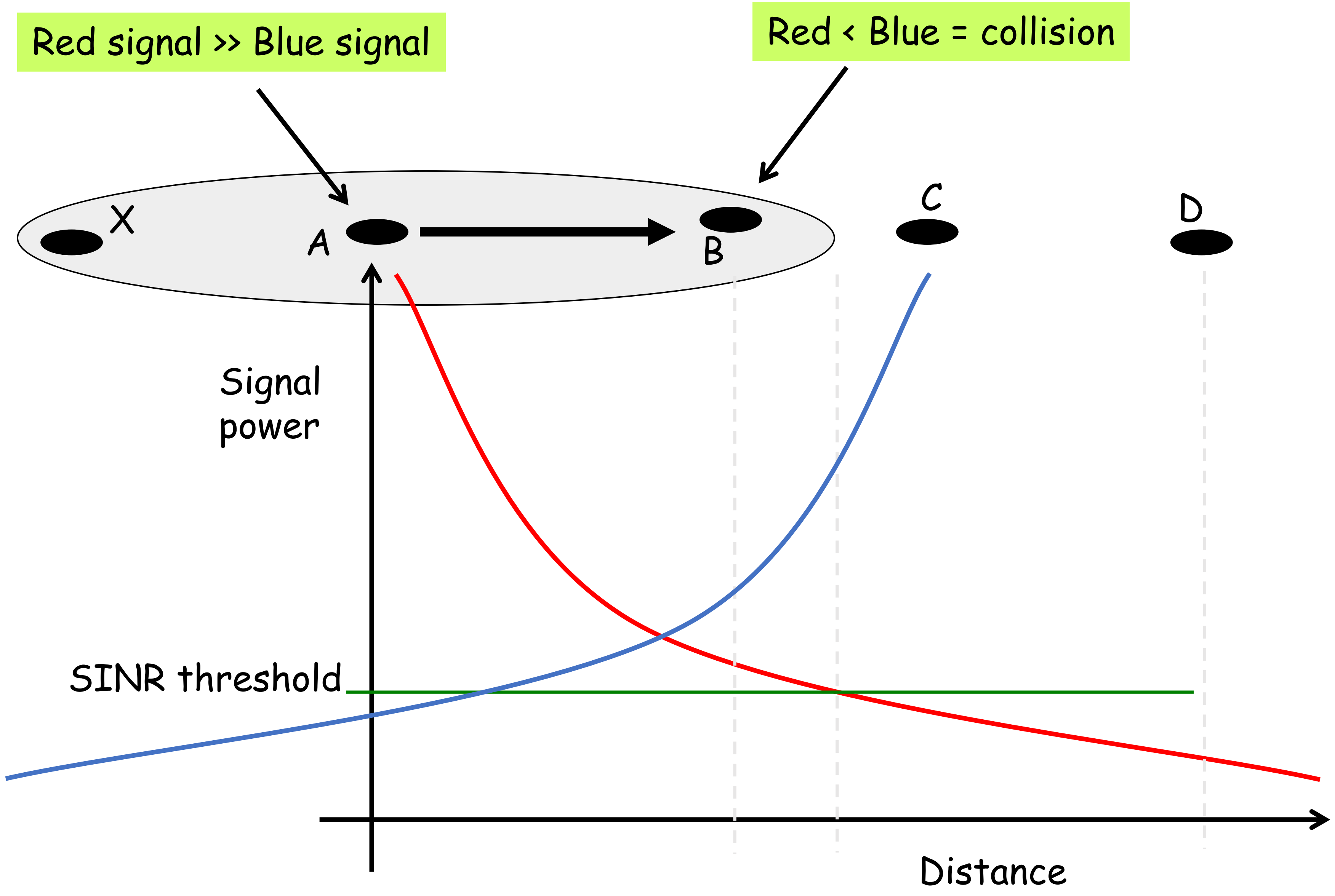


Signal not same at different locations

Collision Detection Difficult

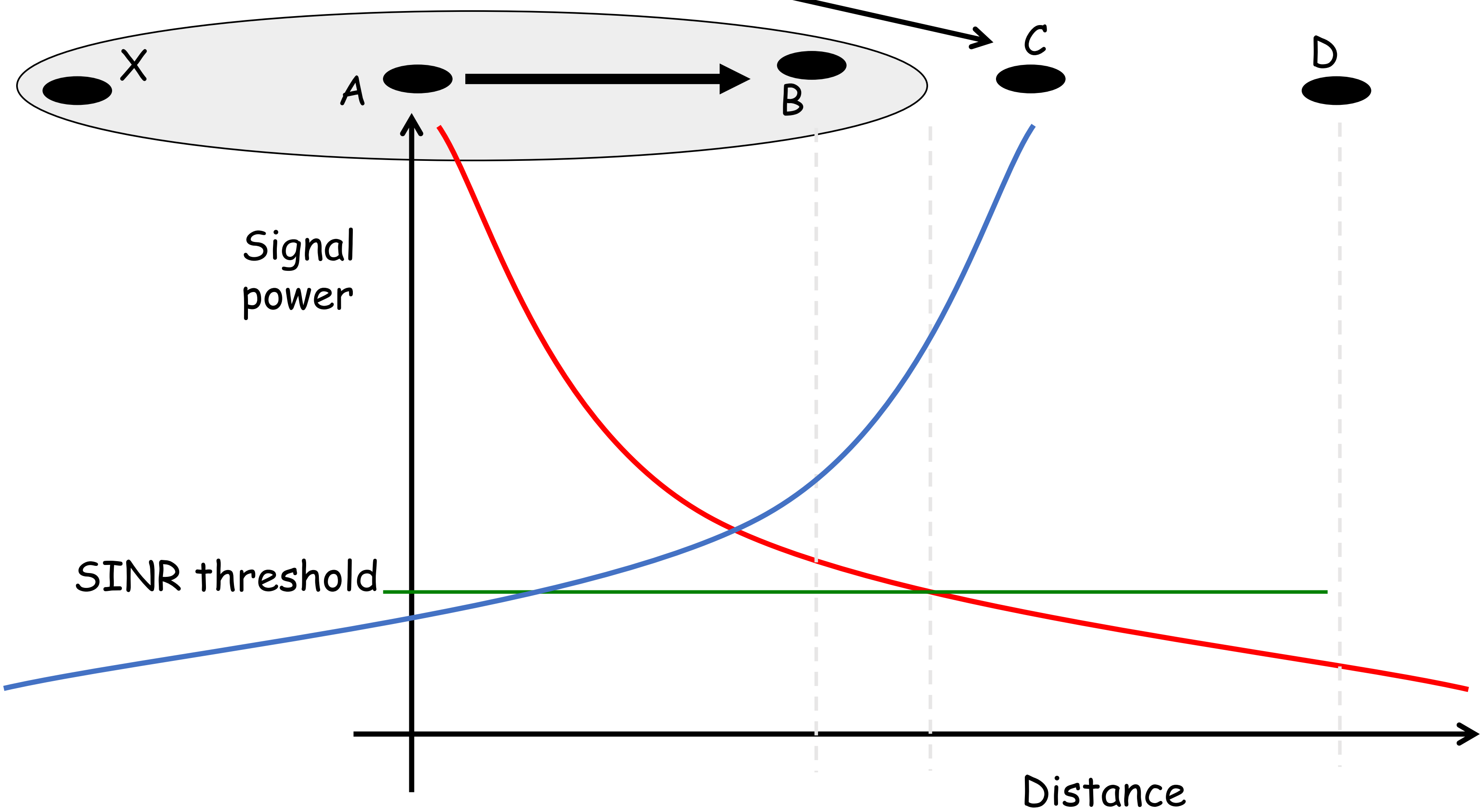


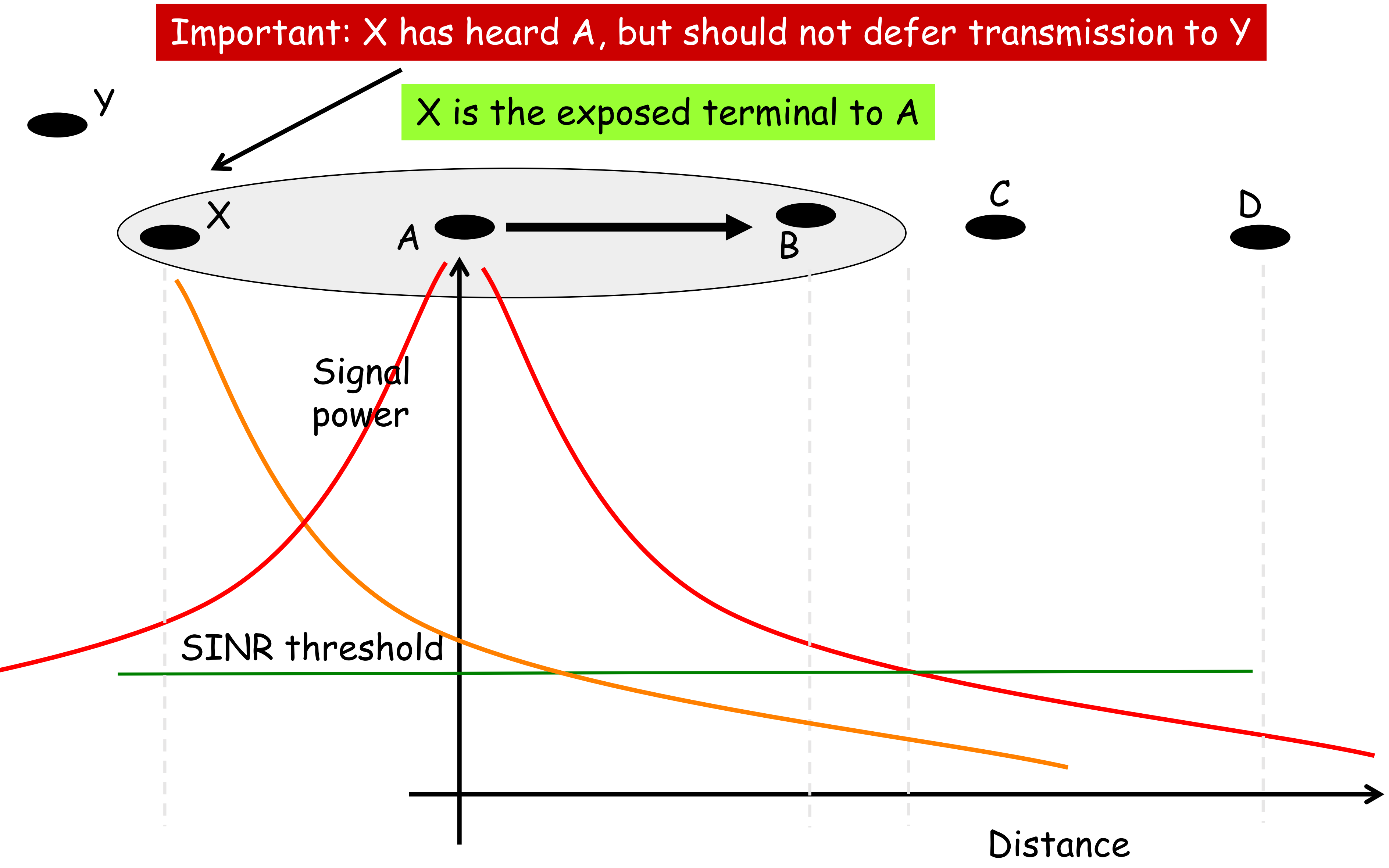
- Signal reception based on SINR
  - Transmitter can only hear itself
  - Cannot determine signal quality at receiver


Red signal >> Blue signal
Red < Blue = collision
X
A
B
C
D
Signal
power
SINR threshold
Distance

Important: C has not heard A, but can interfere at receiver B

C is the hidden terminal to A





Important: X has heard A, but should not defer transmission to Y
X is the exposed terminal to A
Y
X
A
B
C
D
Signal power
SINR threshold
Distance

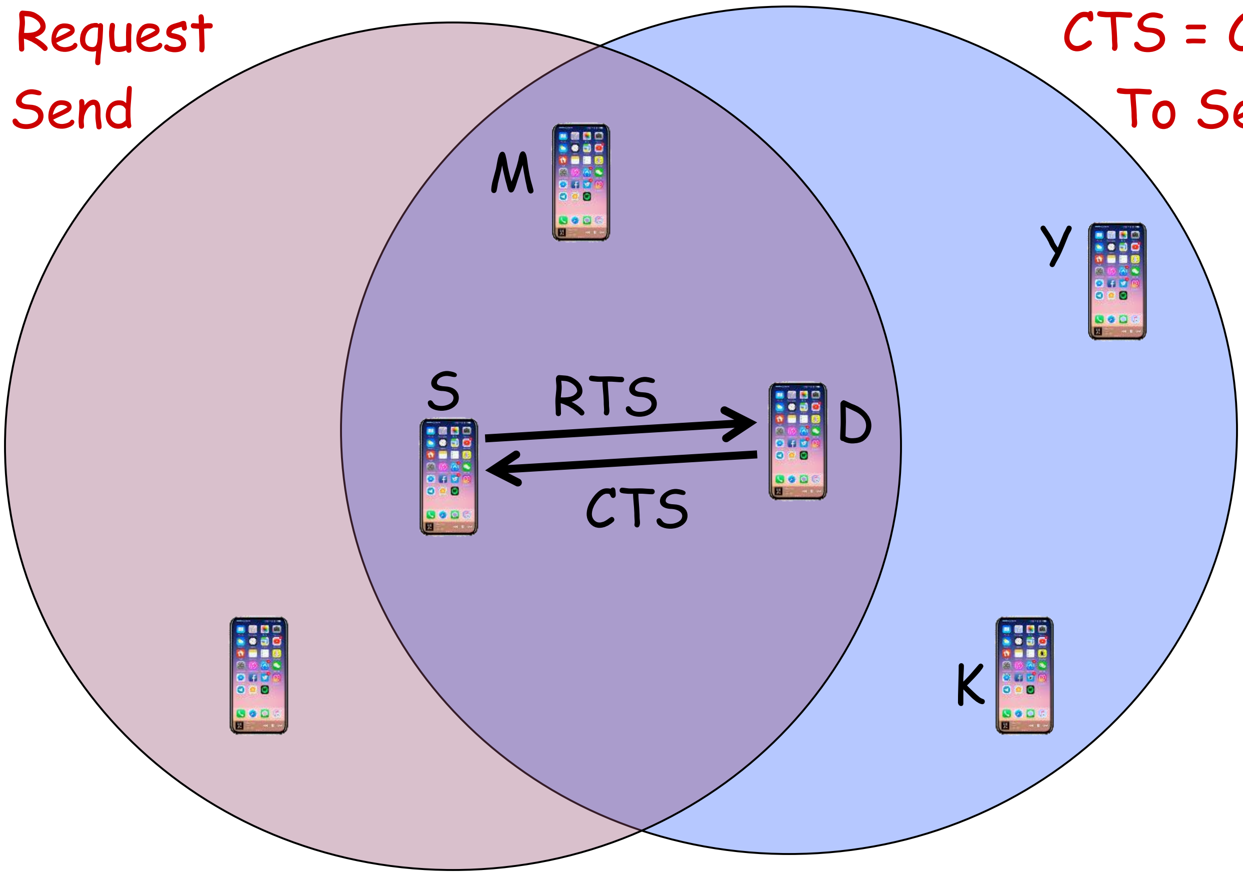
Hidden and Exposed Terminal Problems

Critical to wireless networks even today

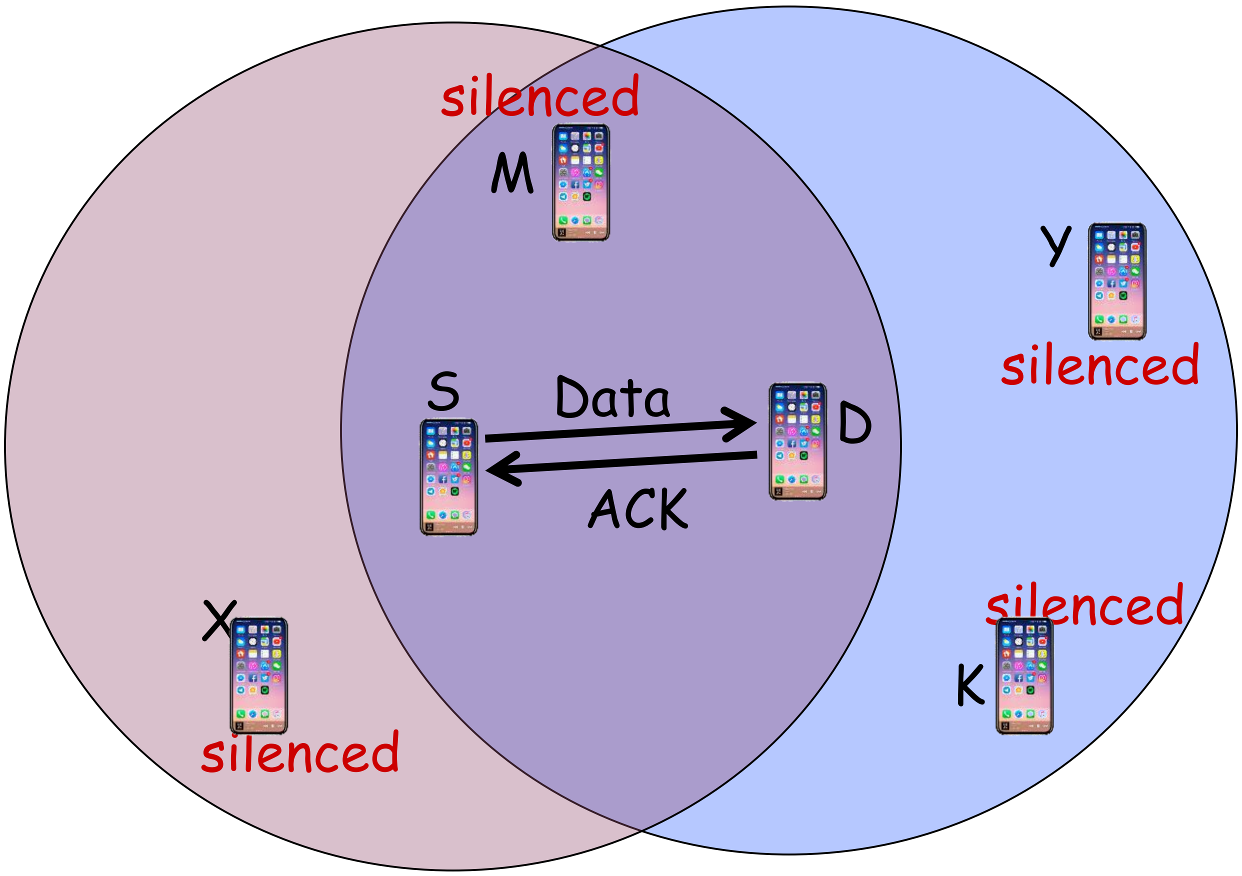
IEEE 802.11

RTS = Request To Send

CTS = Clear To Send



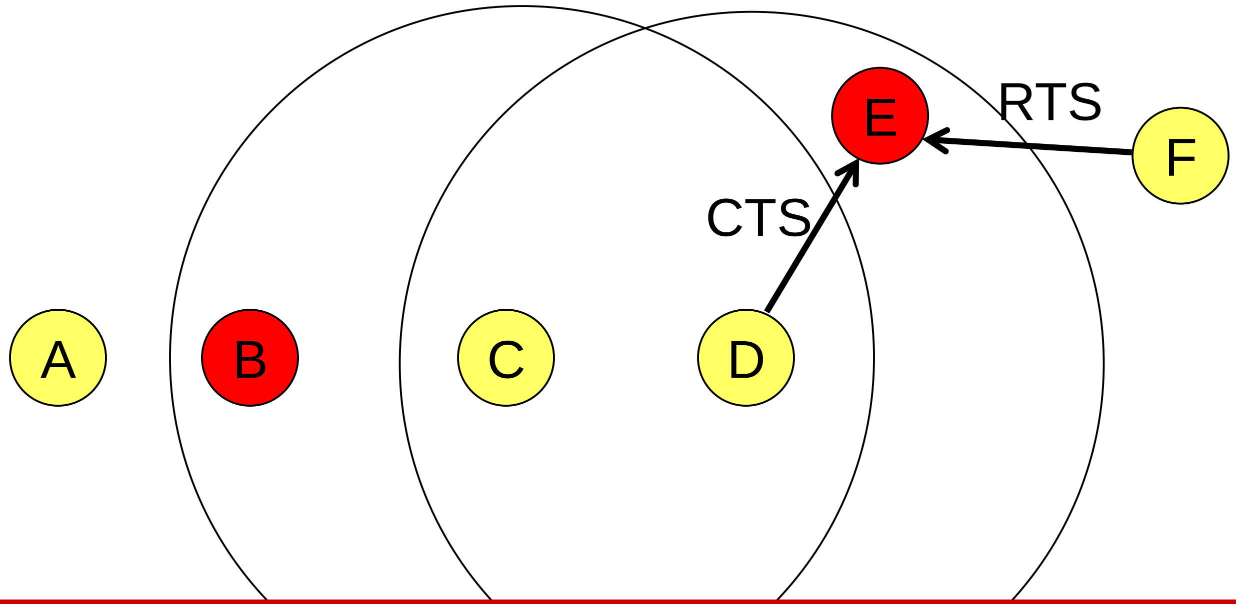
IEEE 802.11



But is that enough?

RTS/CTS

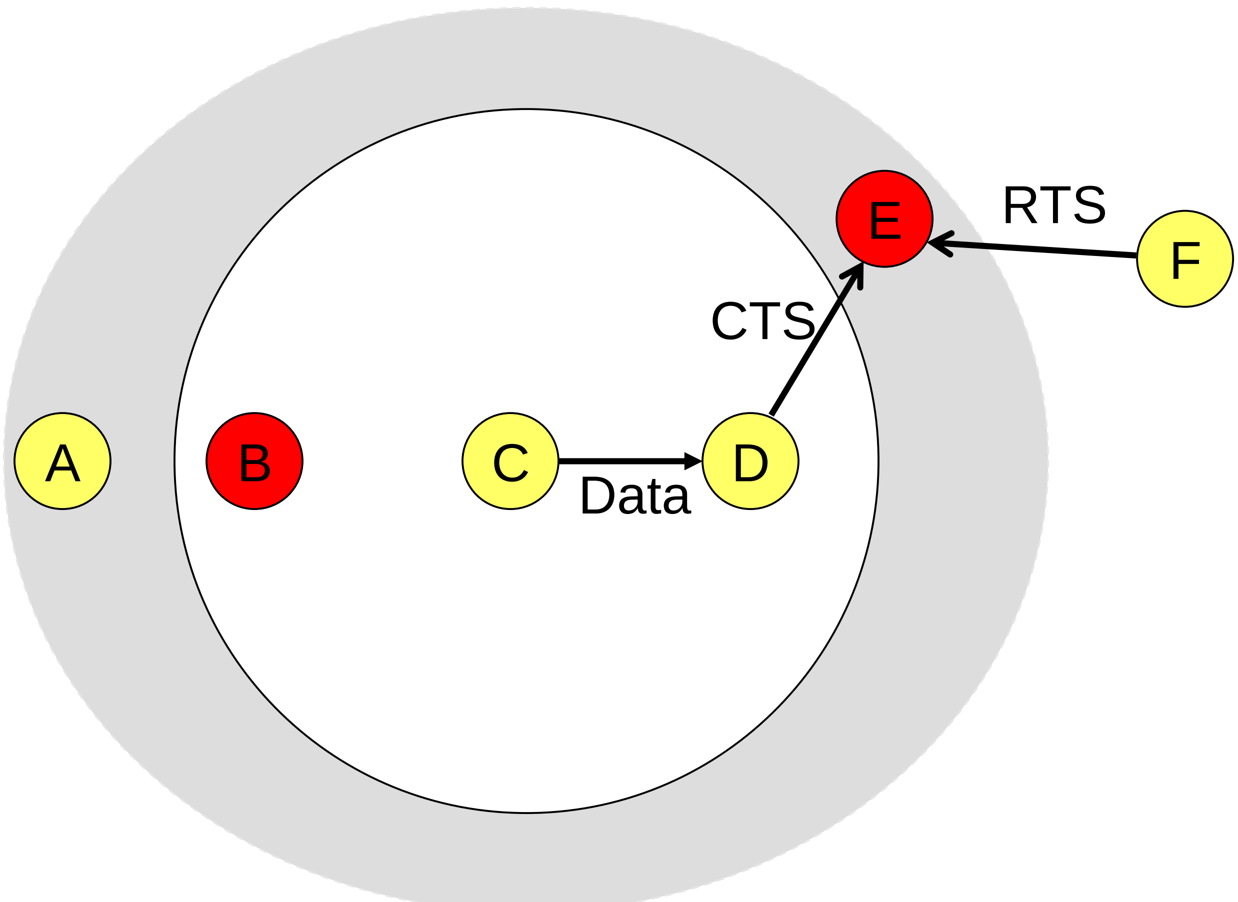
- Does it solve hidden terminals ?
  - Assuming carrier sensing zone = communication zone



E does not receive CTS successfully → Can later initiate transmission to D.
Hidden terminal problem remains.

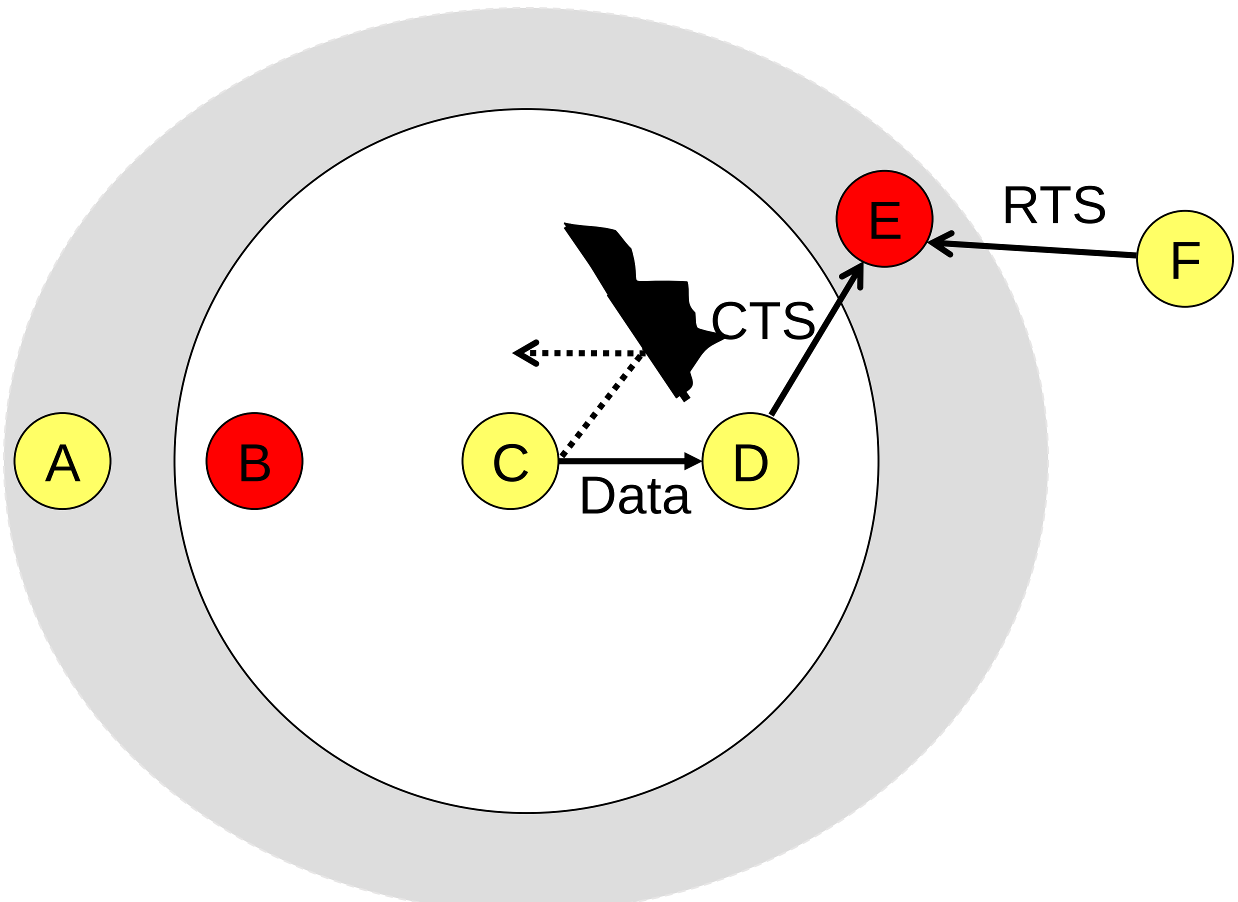
Hidden Terminal Problem

- How about increasing carrier sense range ??
  - E will defer on sensing carrier → no collision !!!



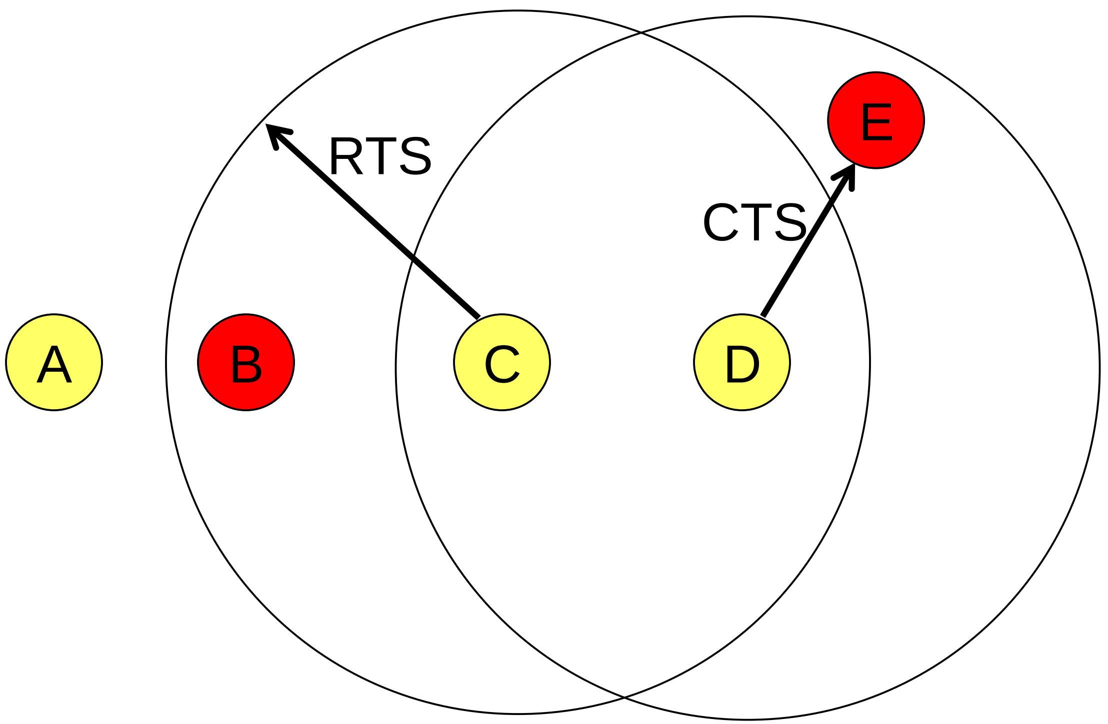
Hidden Terminal Problem

- But what if barriers/obstructions ??
  - E doesn't hear C → Carrier sensing does not help



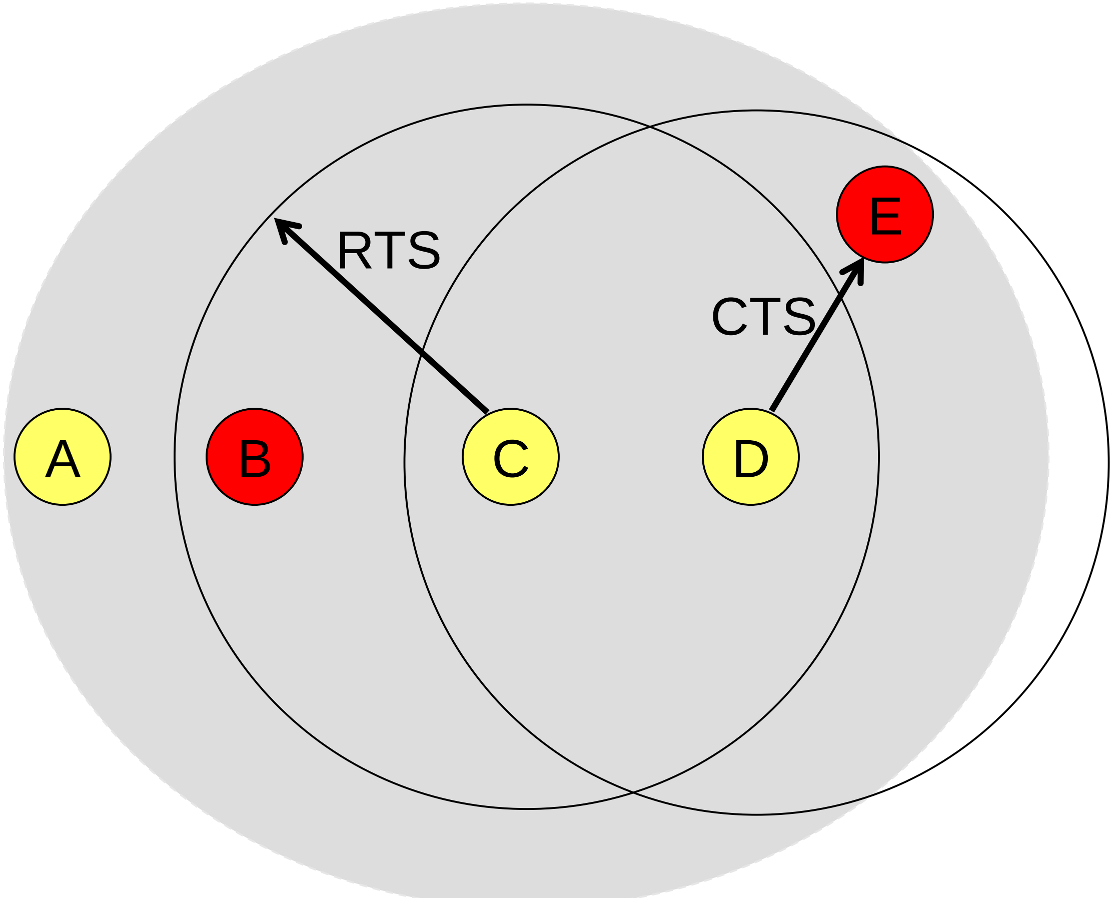
Exposed Terminal

- B should be able to transmit to A
  - RTS prevents this



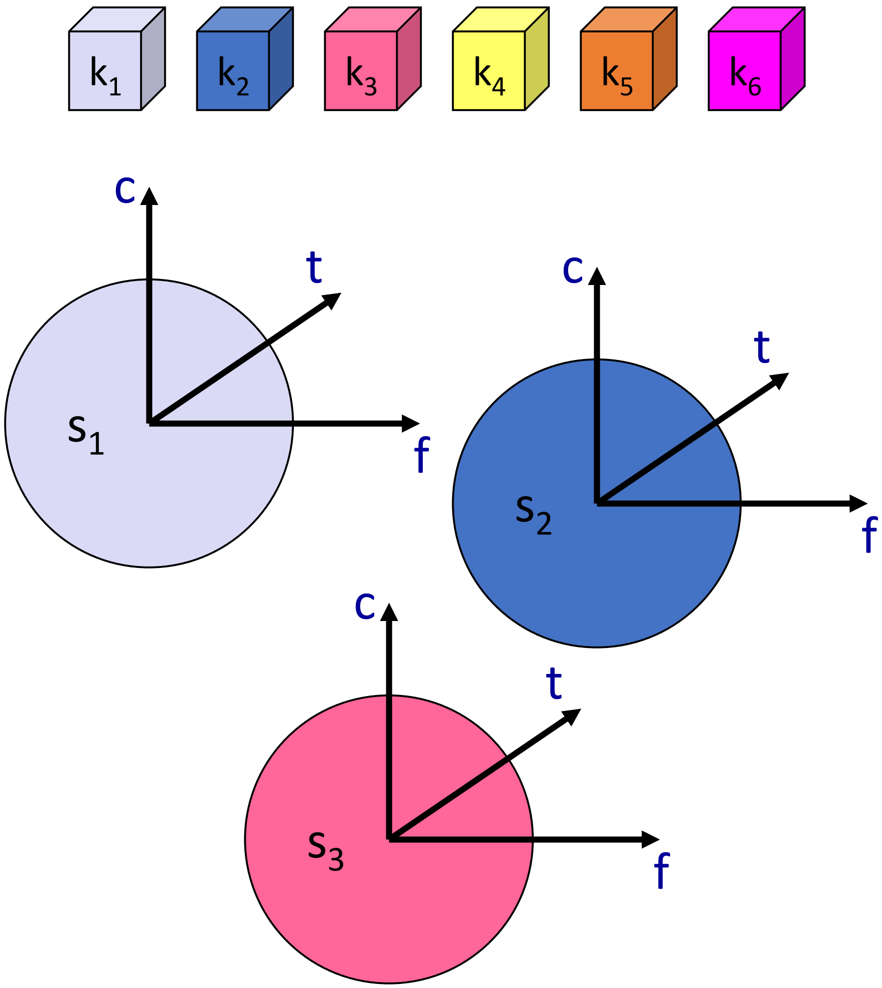
Exposed Terminal

- B should be able to transmit to A
  - Carrier sensing makes the situation worse



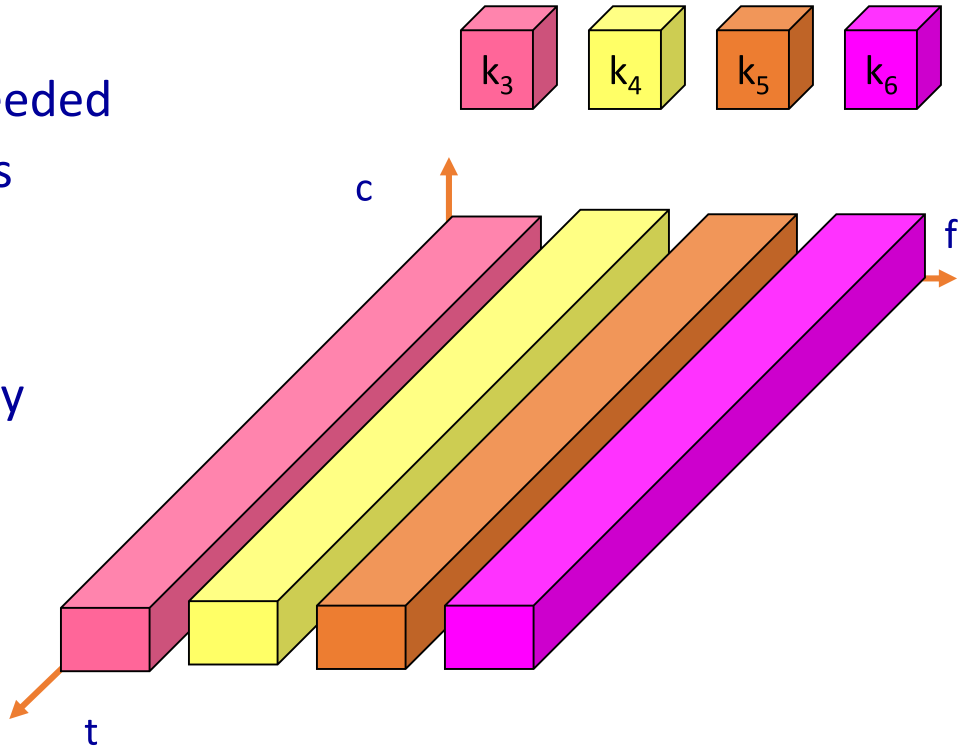
Multiplexing

- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)



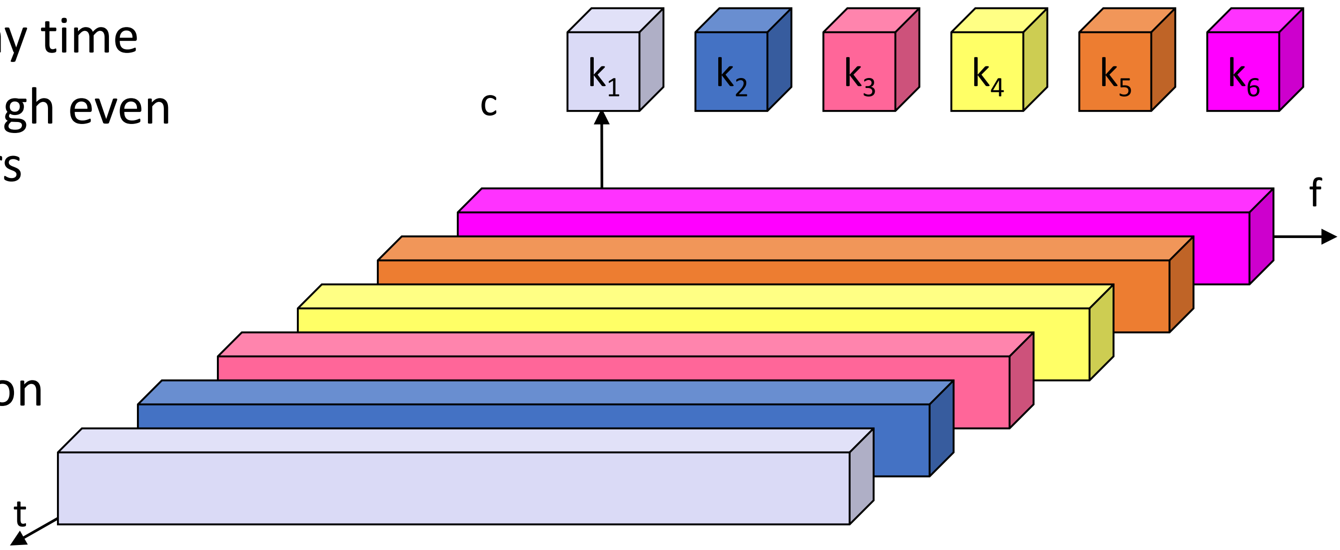
Frequency multiplex

- Separation of spectrum into smaller frequency bands
- Channel gets band of the spectrum for the whole time
- Advantages:
  - no dynamic coordination needed
  - works also for analog signals
- Disadvantages:
  - waste of bandwidth
    if traffic distributed unevenly
  - inflexible
  - guard spaces



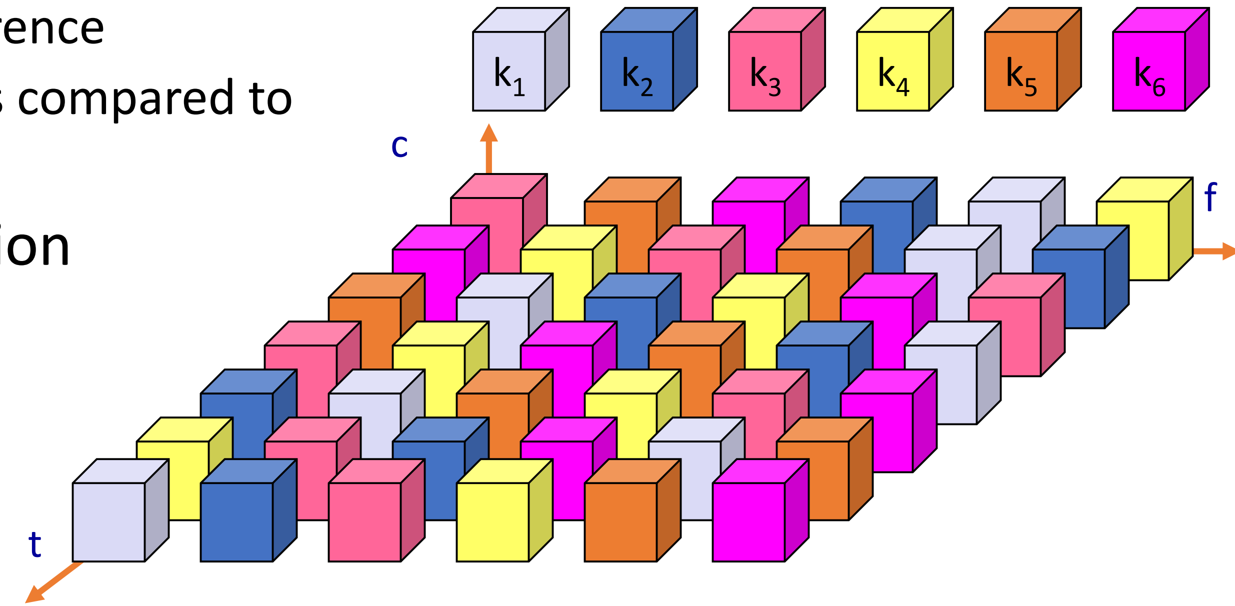
Time multiplex

- Channel gets the whole spectrum for a certain amount of time
- Advantages:
  - only one carrier in the medium at any time
  - throughput high even for many users
- Disadvantages:
  - precise synchronization necessary



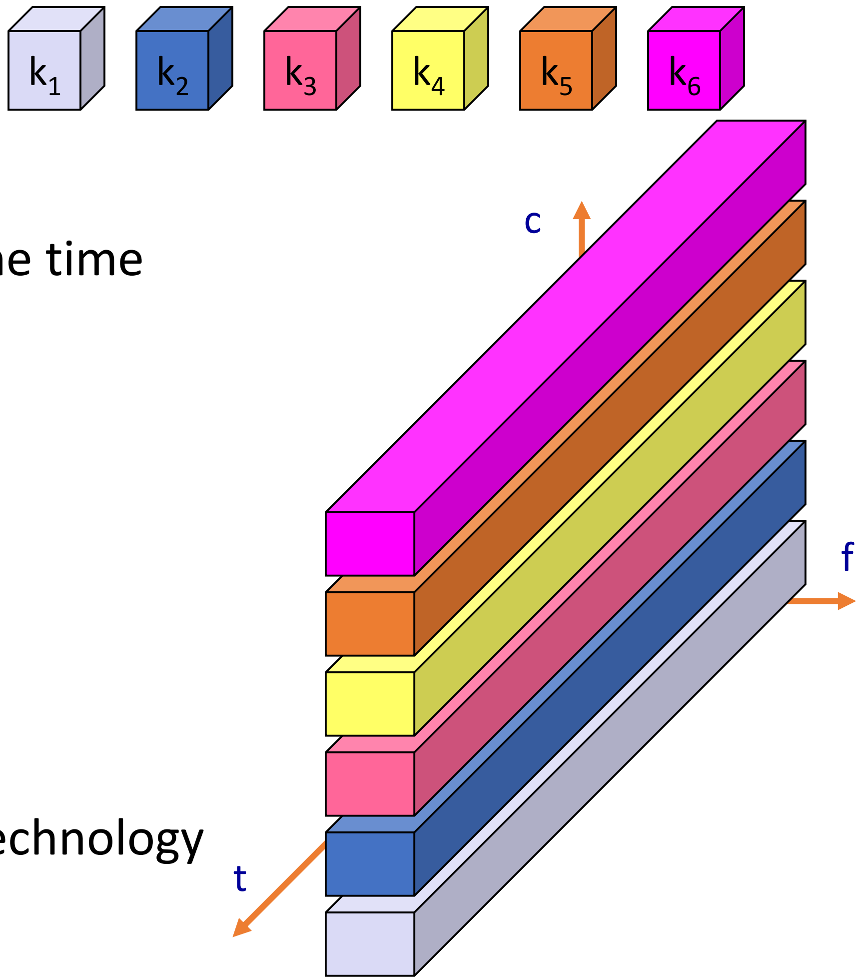
Time and frequency multiplex

- A channel gets a certain frequency band for a certain amount of time (e.g. GSM)
- Advantages:
  - better protection against tapping
  - protection against frequency selective interference
  - higher data rates compared to code multiplex
- Precise coordination required



Code multiplex

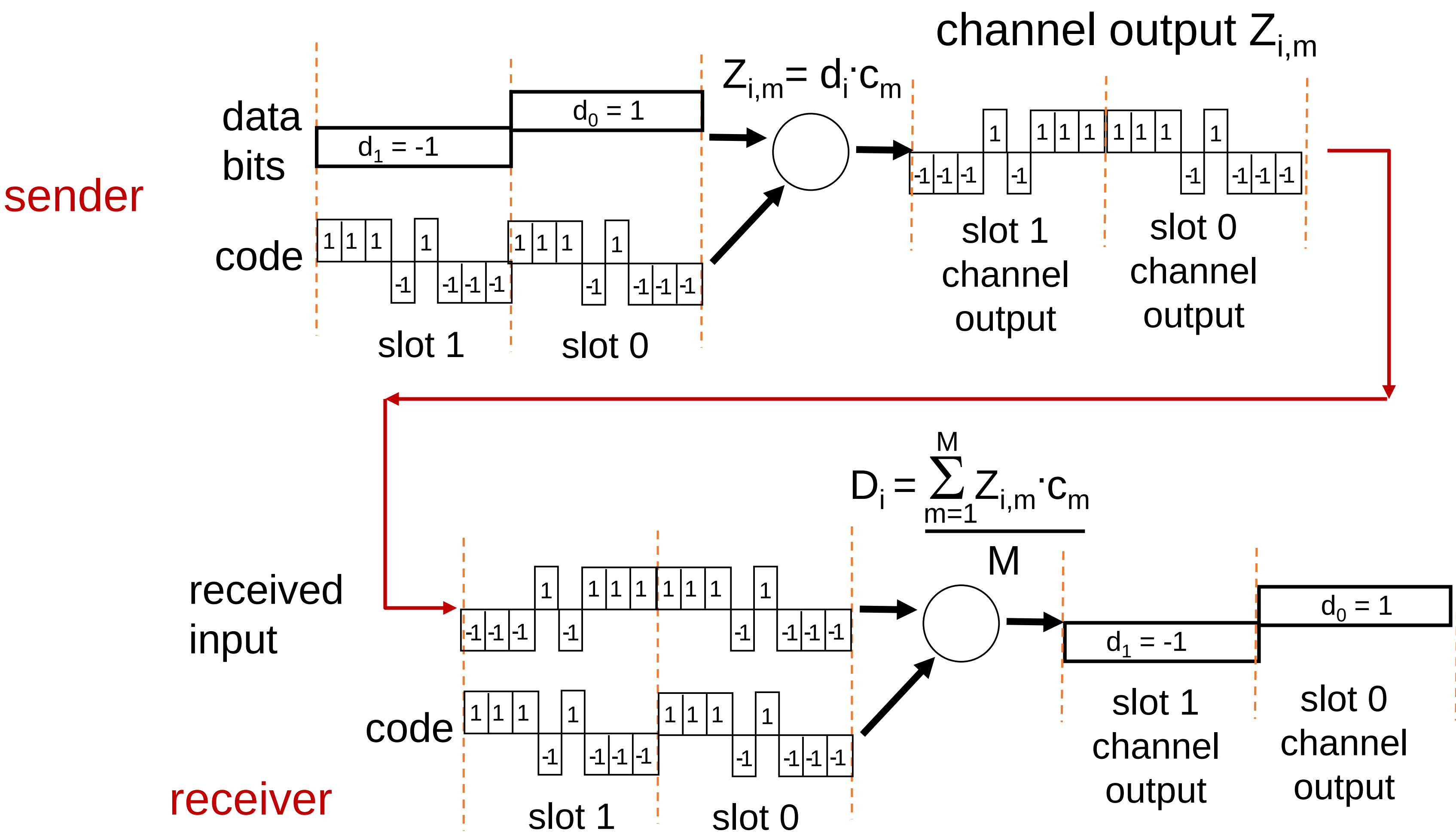
- Each channel has unique code
- All channels use same spectrum at same time
- Advantages:
  - bandwidth efficient
  - no coordination and synchronization
  - good protection against interference
- Disadvantages:
  - lower user data rates
  - more complex signal regeneration
- Implemented using spread spectrum technology



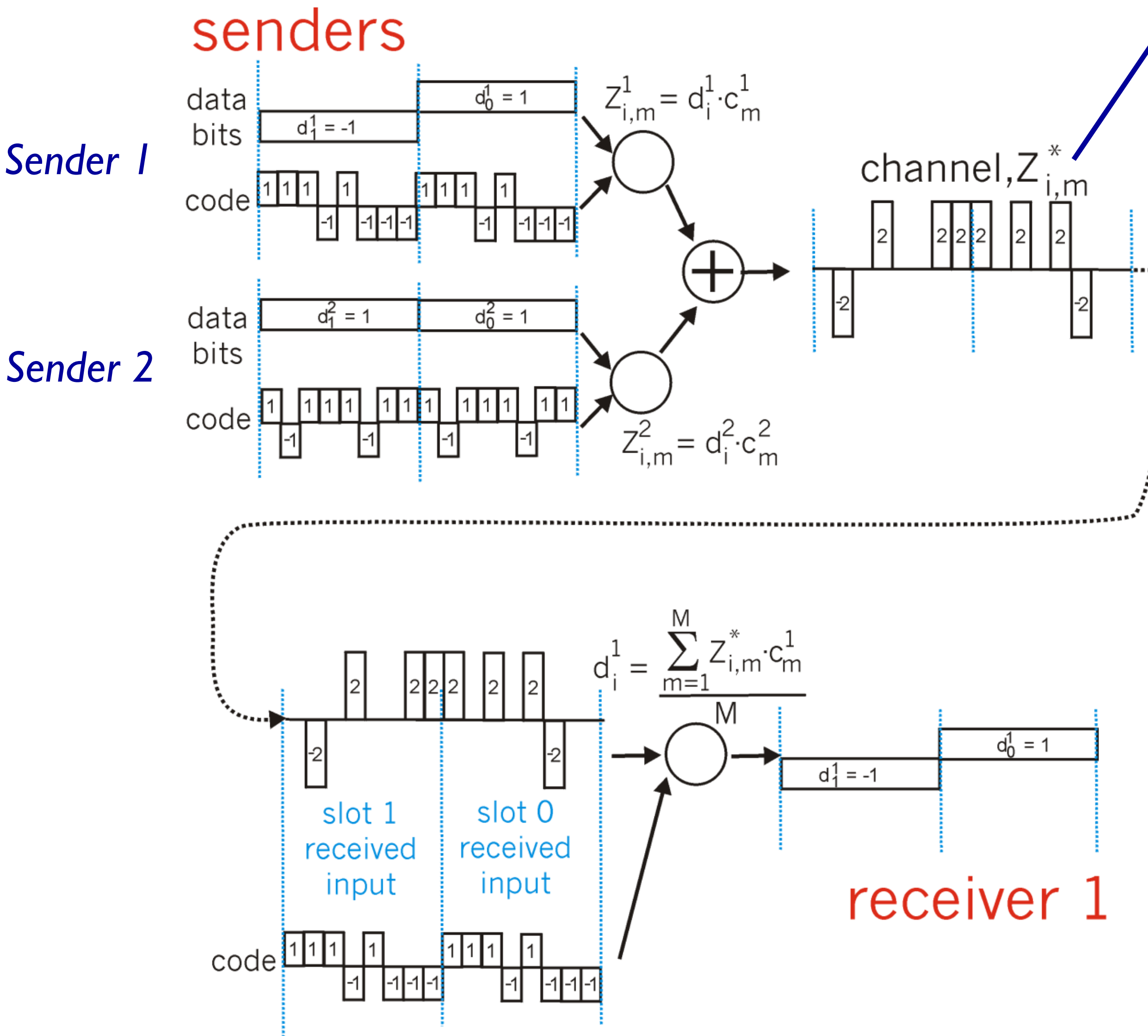
Code Division Multiple Access (CDMA)

- unique "code" assigned to each user; i.e., code set partitioning
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- Example codes: Gold Codes, Walsh Codes

CDMA encode/decode



CDMA: two-sender interference



channel sums together transmissions by sender 1 and 2

using same code as sender 1, receiver recovers sender 1's original data from summed channel data!

Code Division Multiple Access (CDMA)

- Ideally, need codes to have good:

Auto-correlation properties: $c_i(t) \cdot c_i(t) = 1$

Cross-correlation properties: $c_i(t) \cdot c_j(t) = 0 \text{ for } j \neq i$

$$\left(\sum_i h_i d_i(t)\, c_i(t) \right) \cdot c_i(t) = h_i d_i(t)$$

- Need orthogonal codes:

For N users, length of code is exponential in N → 2^{N-1}

- Near Far Effect Problem→ need power management

Chapter 6: Outline

- ✓ Introduction
- ✓ Wireless Links
- ✓ Wireless MAC
- ❑ WiFi: 802.11 Wireless LANs
- ❑ Cellular Networks: 3G, LTE
- ❑ Mobility

IEEE 802.11 Wireless LAN

802.11b

- 2.4-5 GHz unlicensed spectrum
- up to 11 Mbps
- direct sequence spread spectrum (DSSS) in physical layer
  - all hosts use same chipping code

802.11ad/ay: Millimeter wave

- 2.4, 5, 60 GHz range
- Up to 7 Gbps

802.11a

- 5-6 GHz range
- up to 54 Mbps

802.11g

- 2.4-5 GHz range
- up to 54 Mbps

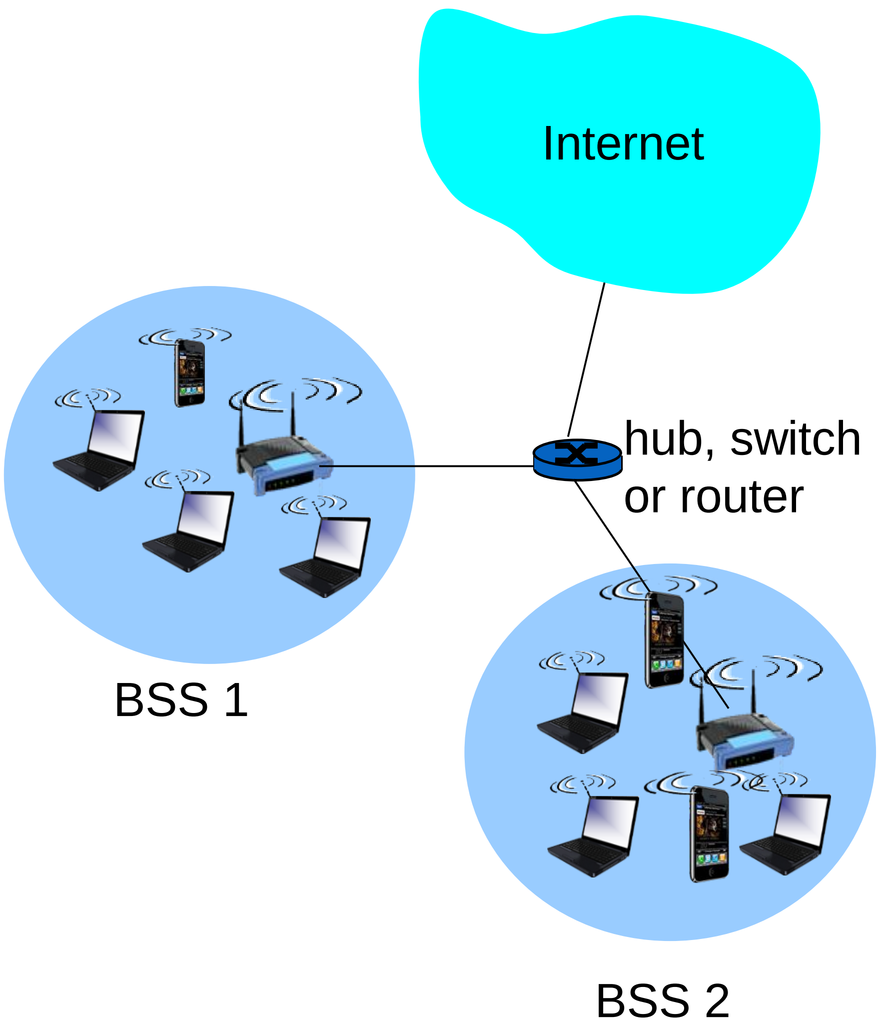
802.11n: multiple antenna

- 2.4-5 GHz range
- up to 200 Mbps

802.11ac: multiple antenna

- 2.4-5 GHz range
- Up to 1.69 Gbps

802.11 LAN architecture

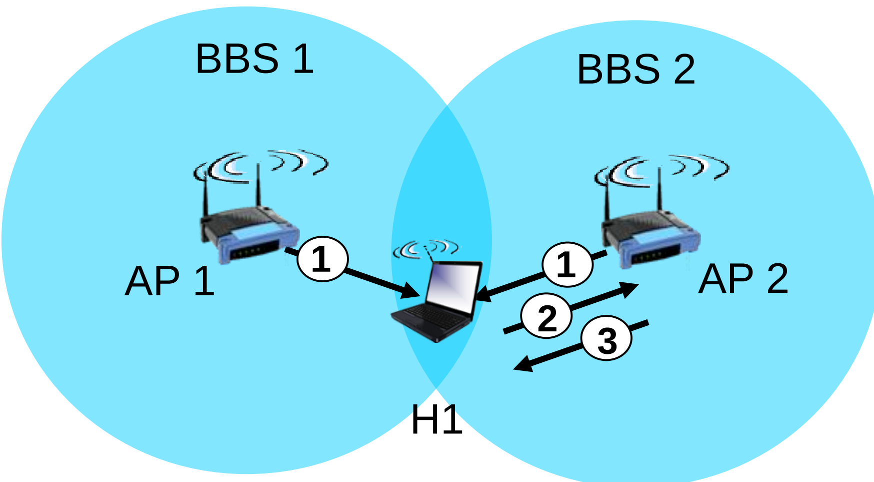


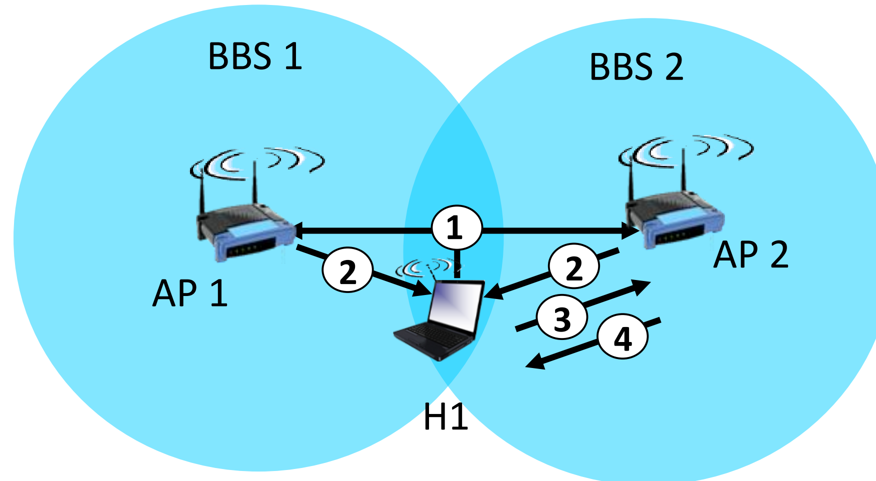
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels, association

- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- 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
  - may perform authentication
  - will typically run DHCP to get IP address in AP's subnet

802.11: passive/active scanning





passive scanning:

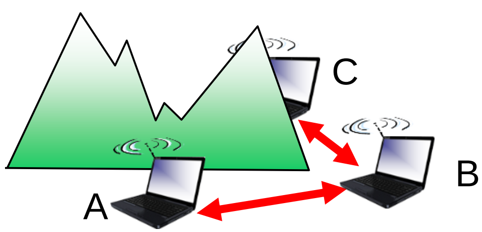
(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent from selected AP to H1

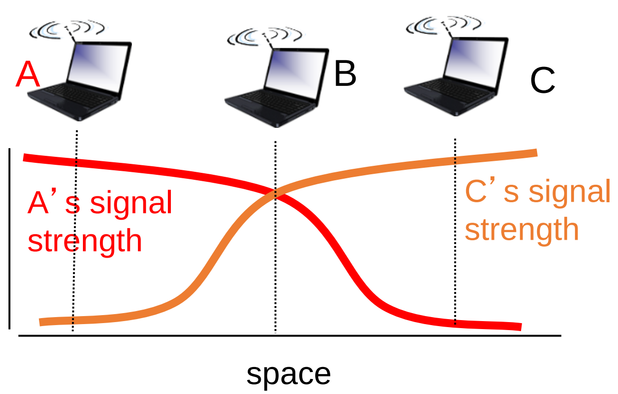
***active scanning*:**

(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

IEEE 802.11: multiple access

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by other node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





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

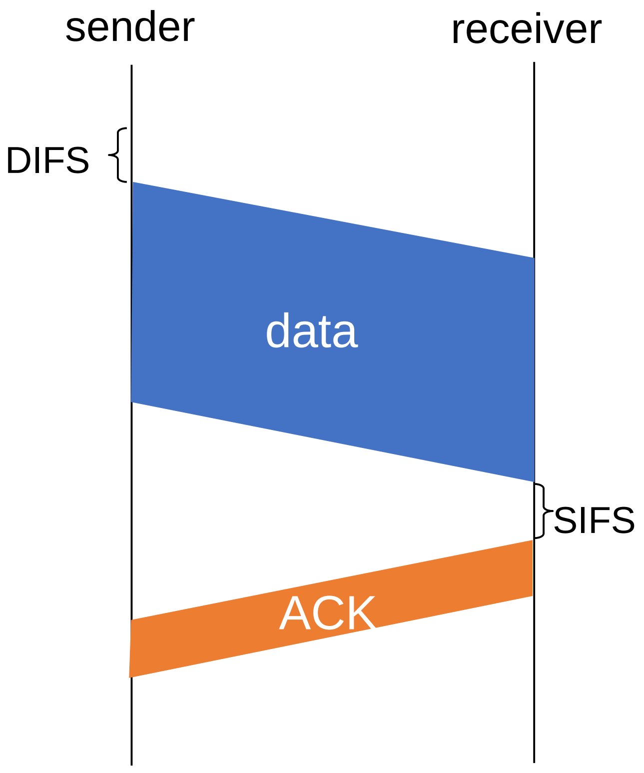
transmit when timer expires

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)



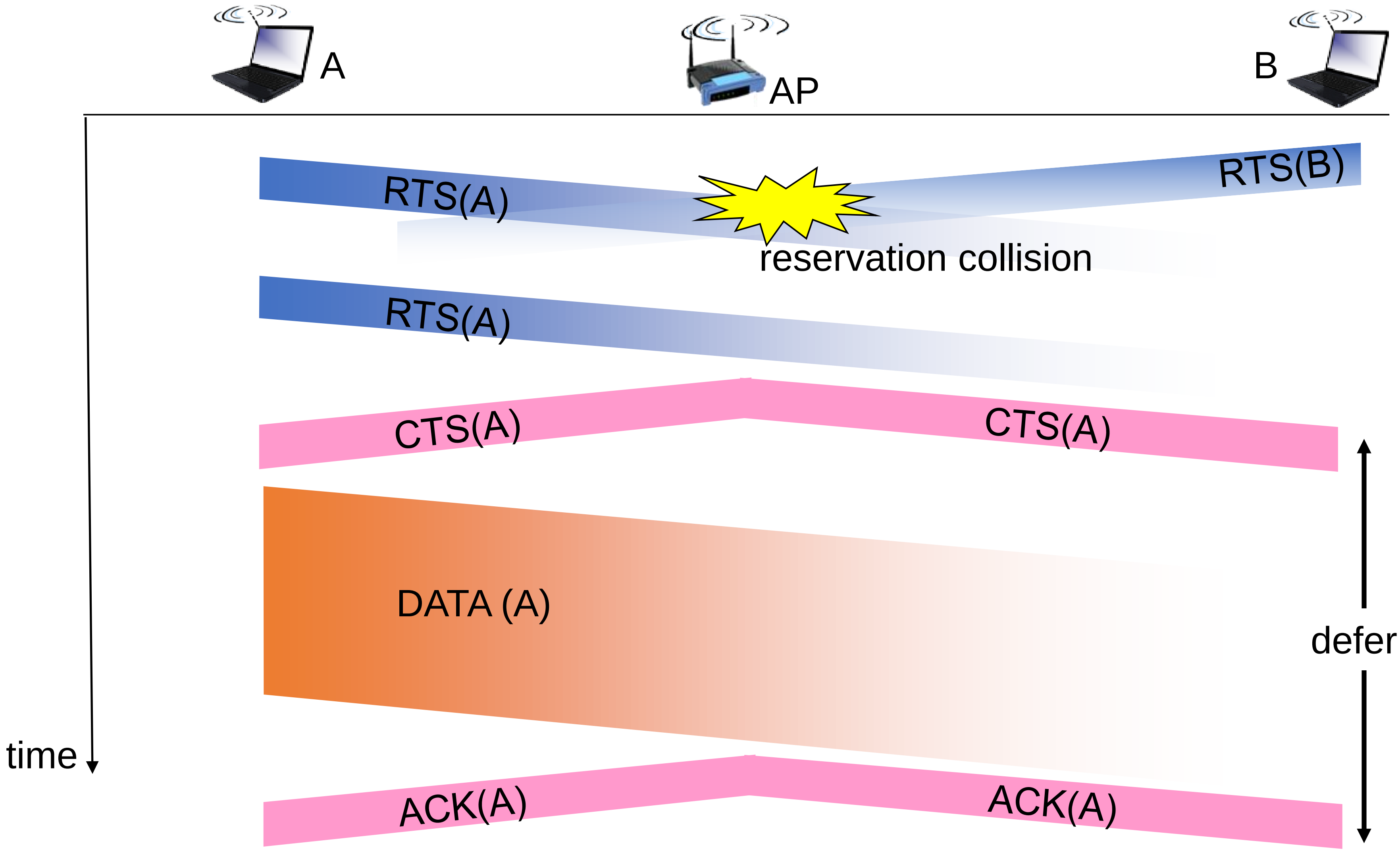
Avoiding collisions (more)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

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

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing

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

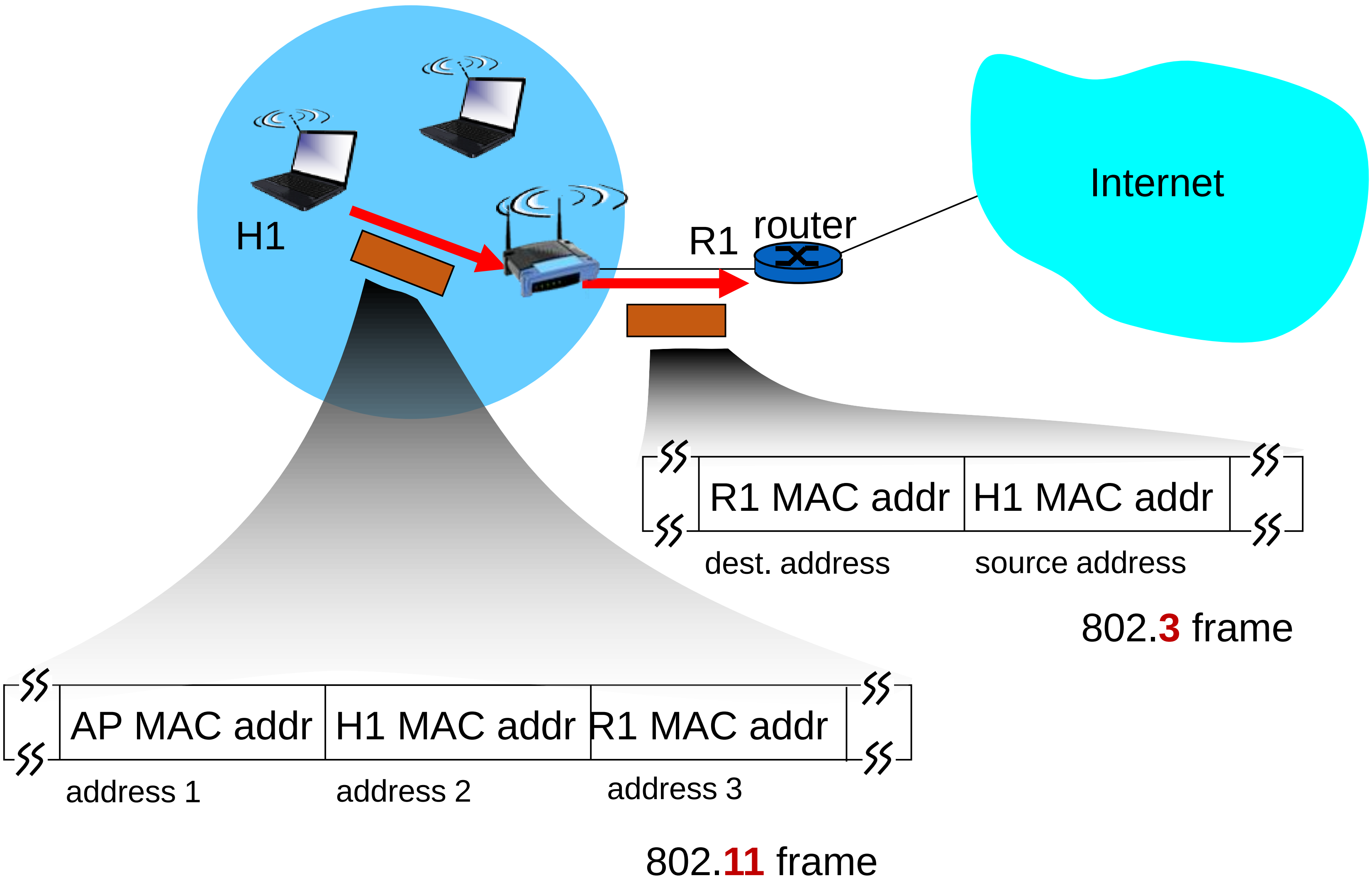
Address 1: MAC address of wireless host or AP to receive this frame

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

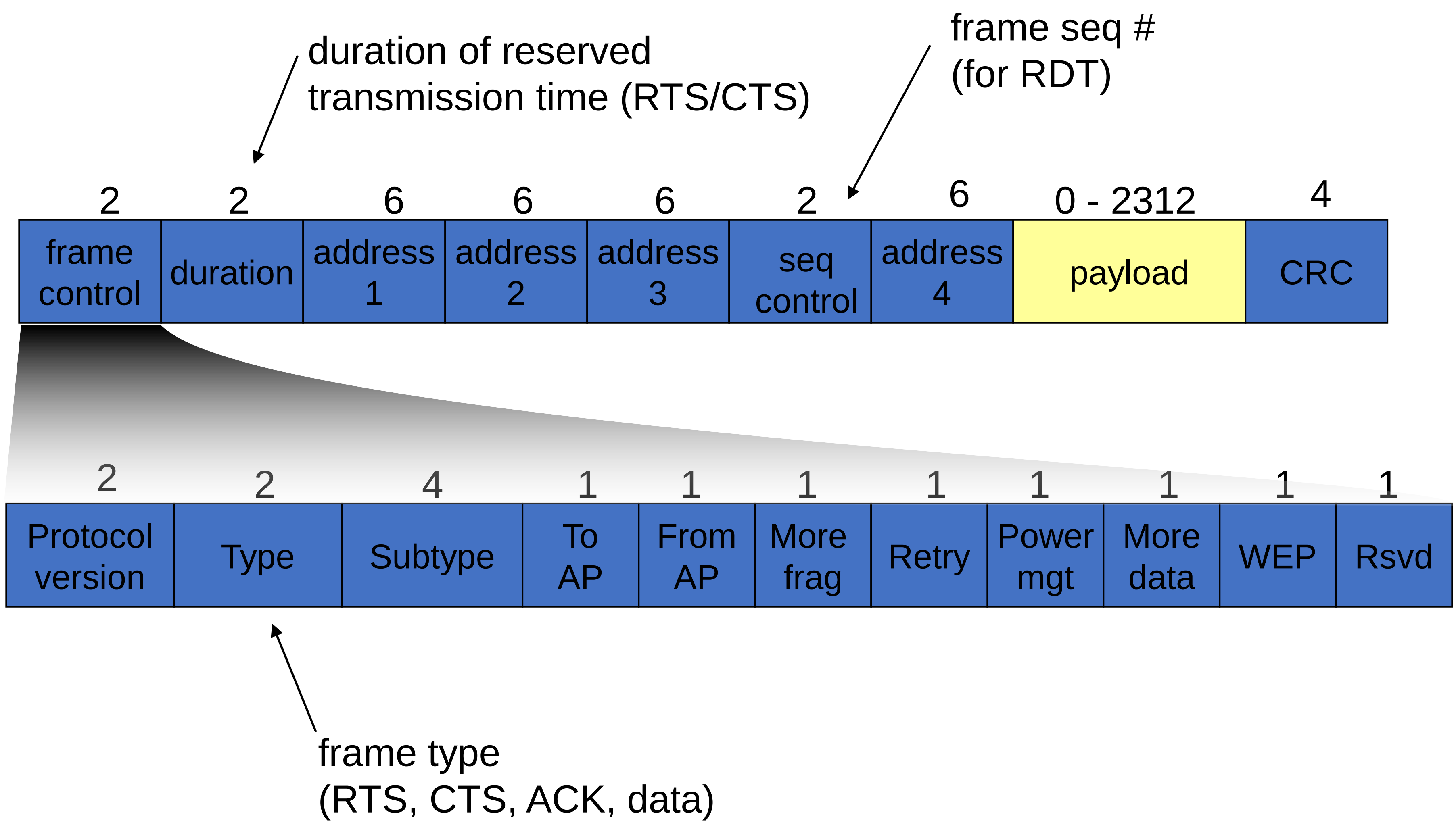
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

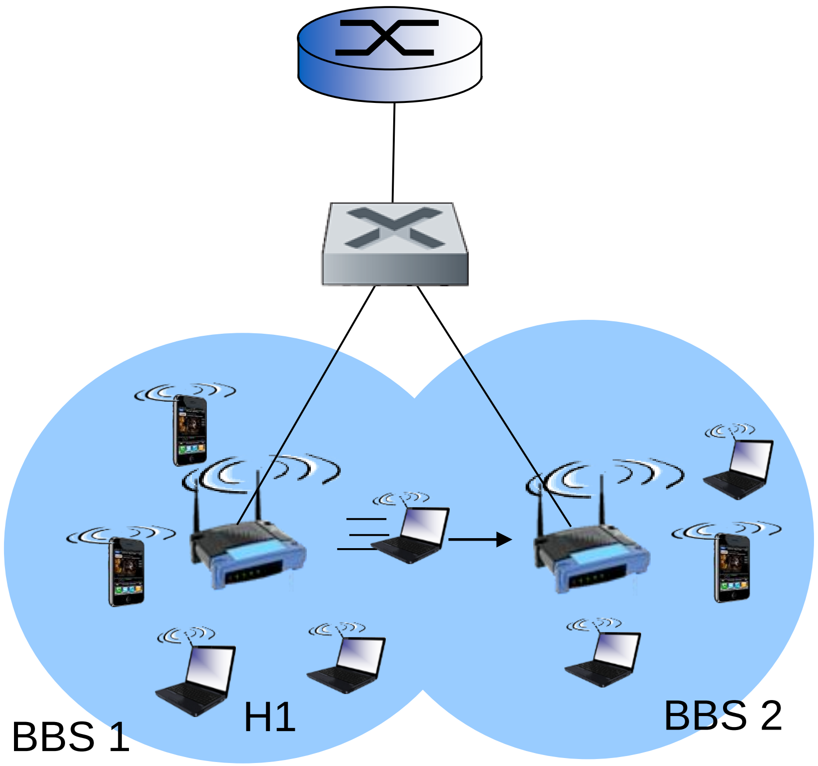


802.11 frame: more



802.11: mobility within same subnet

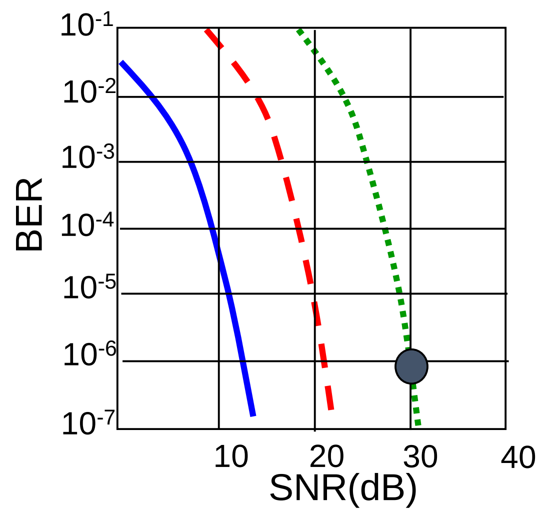
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and “remember” which switch port can be used to reach H1

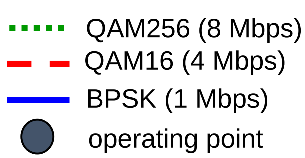


802.11: advanced capabilities

Rate adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies





1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER

Chapter 6: Outline

- ✓ Introduction
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- ❑ Mobility

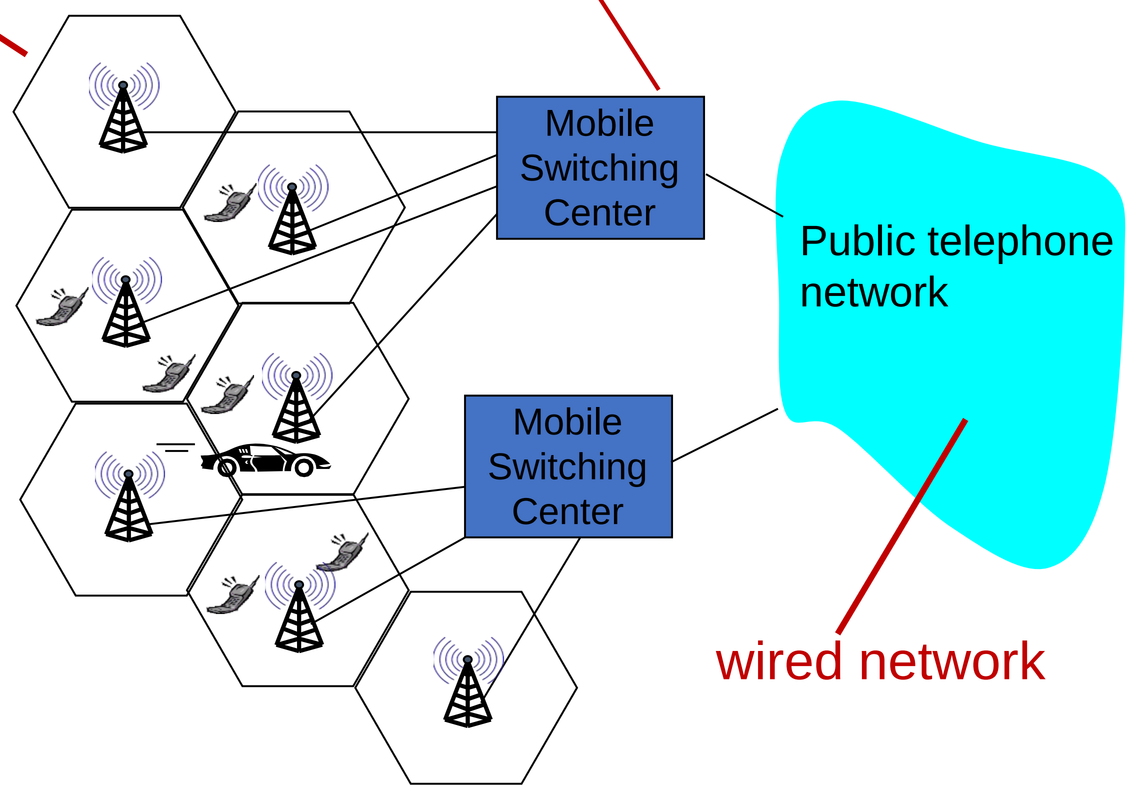
Components of cellular network architecture

MSC

- connects cells to wired tel. net.
- manages call setup (more later!)
- handles mobility (more later!)

cell

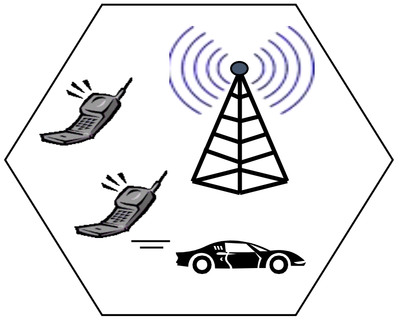
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

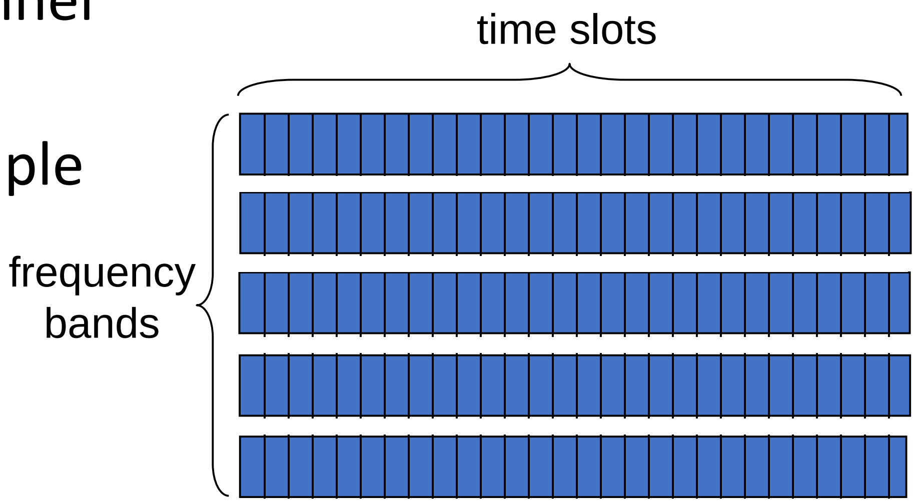


Cellular networks: the first hop

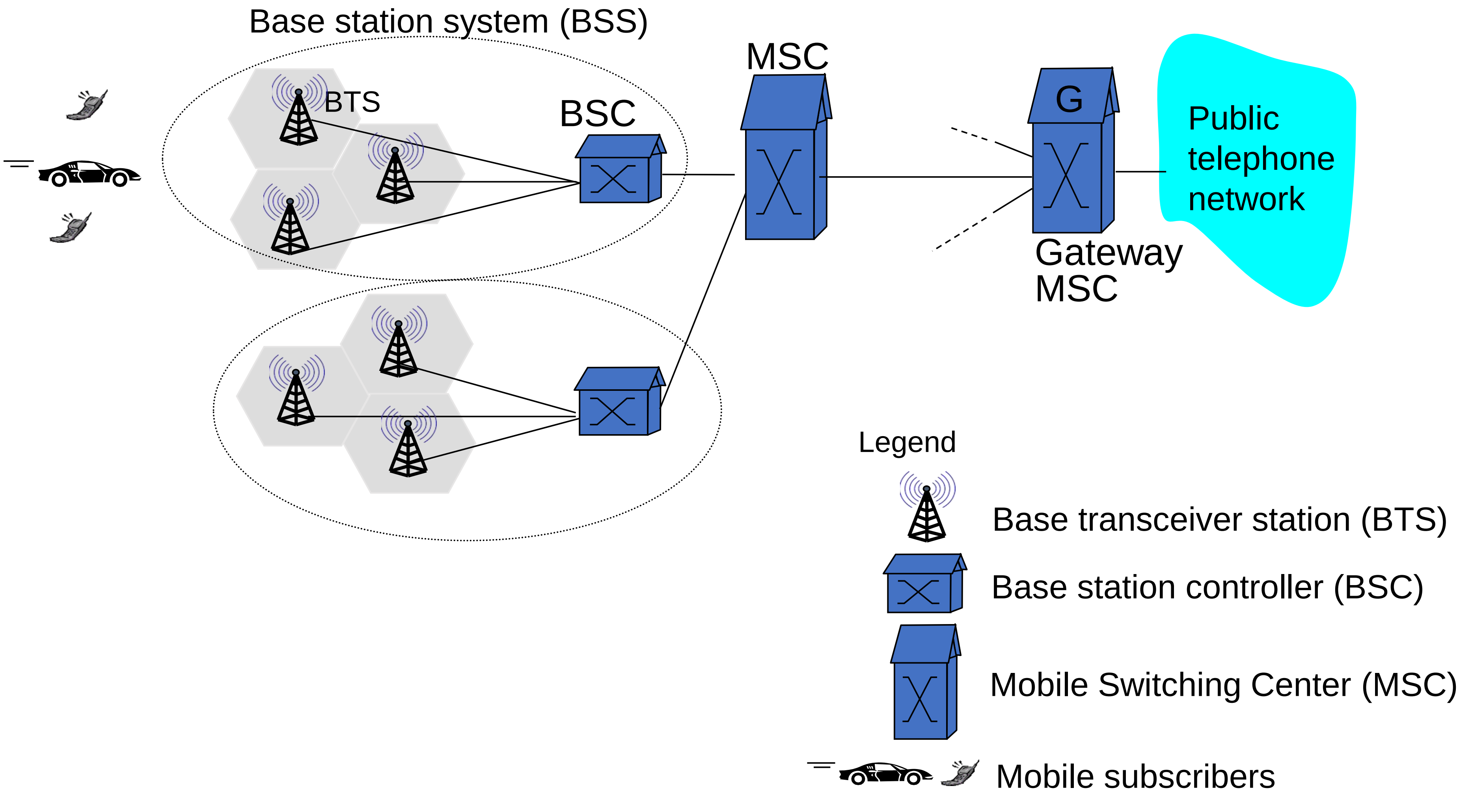
Two techniques for sharing mobile-to-BS radio spectrum

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

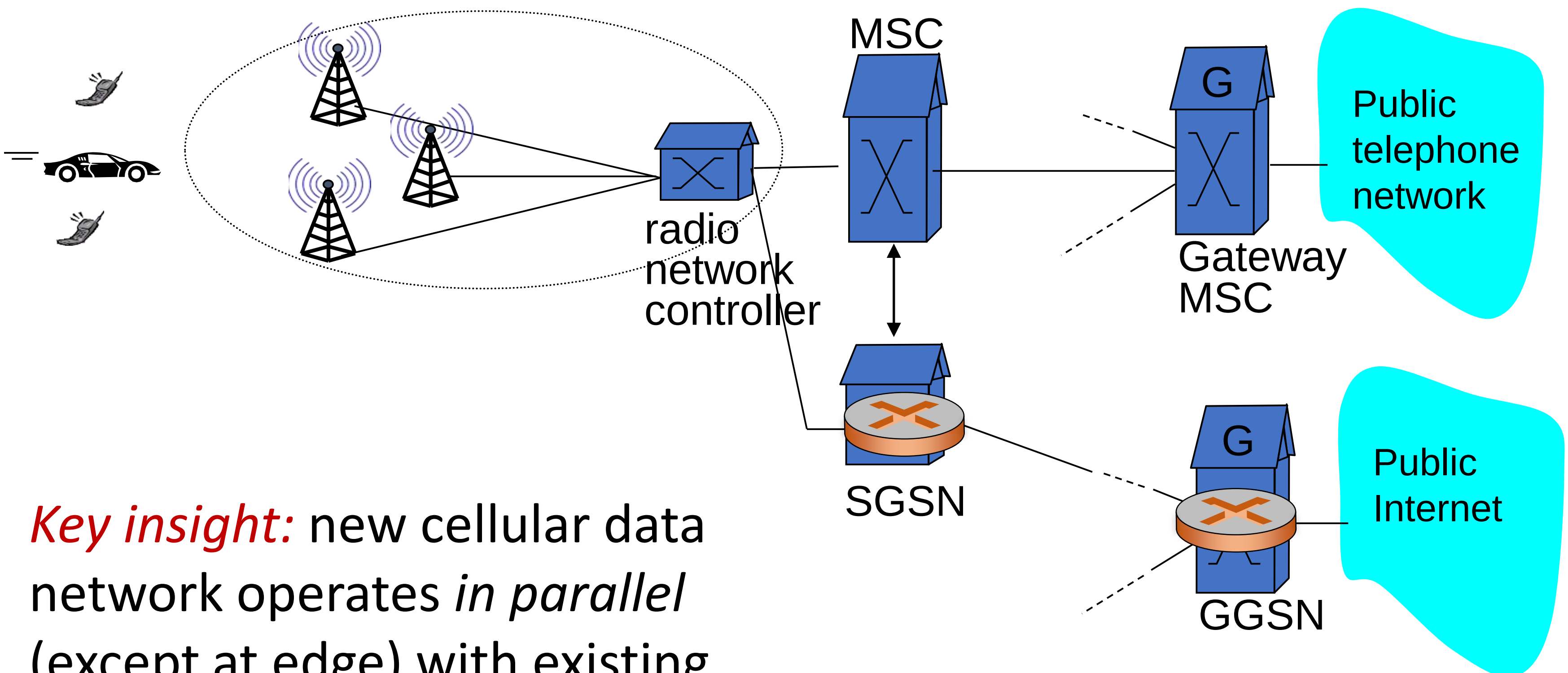




2G (voice) network architecture

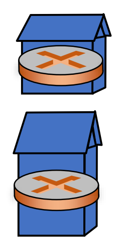


3G (voice+data) network architecture

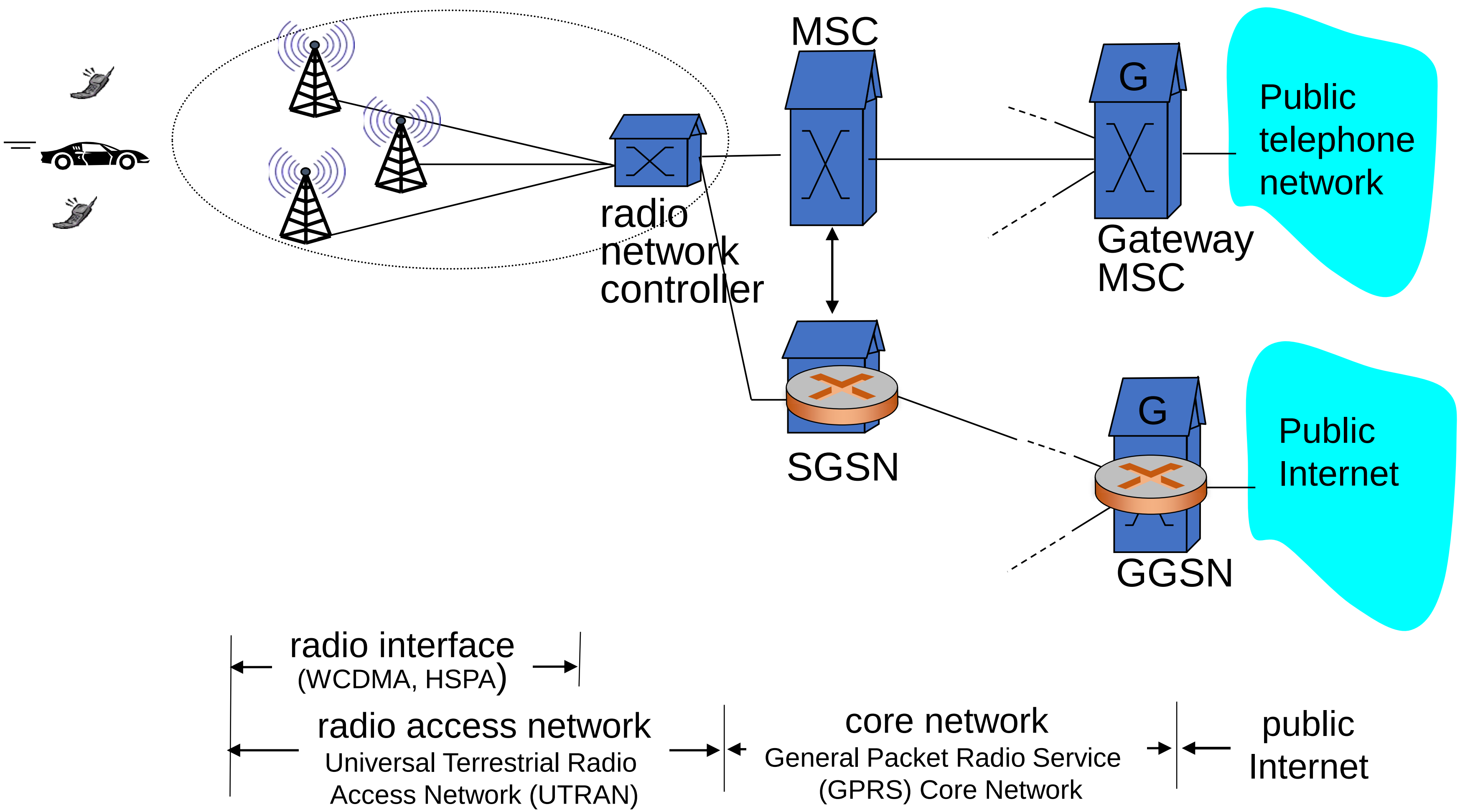


Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

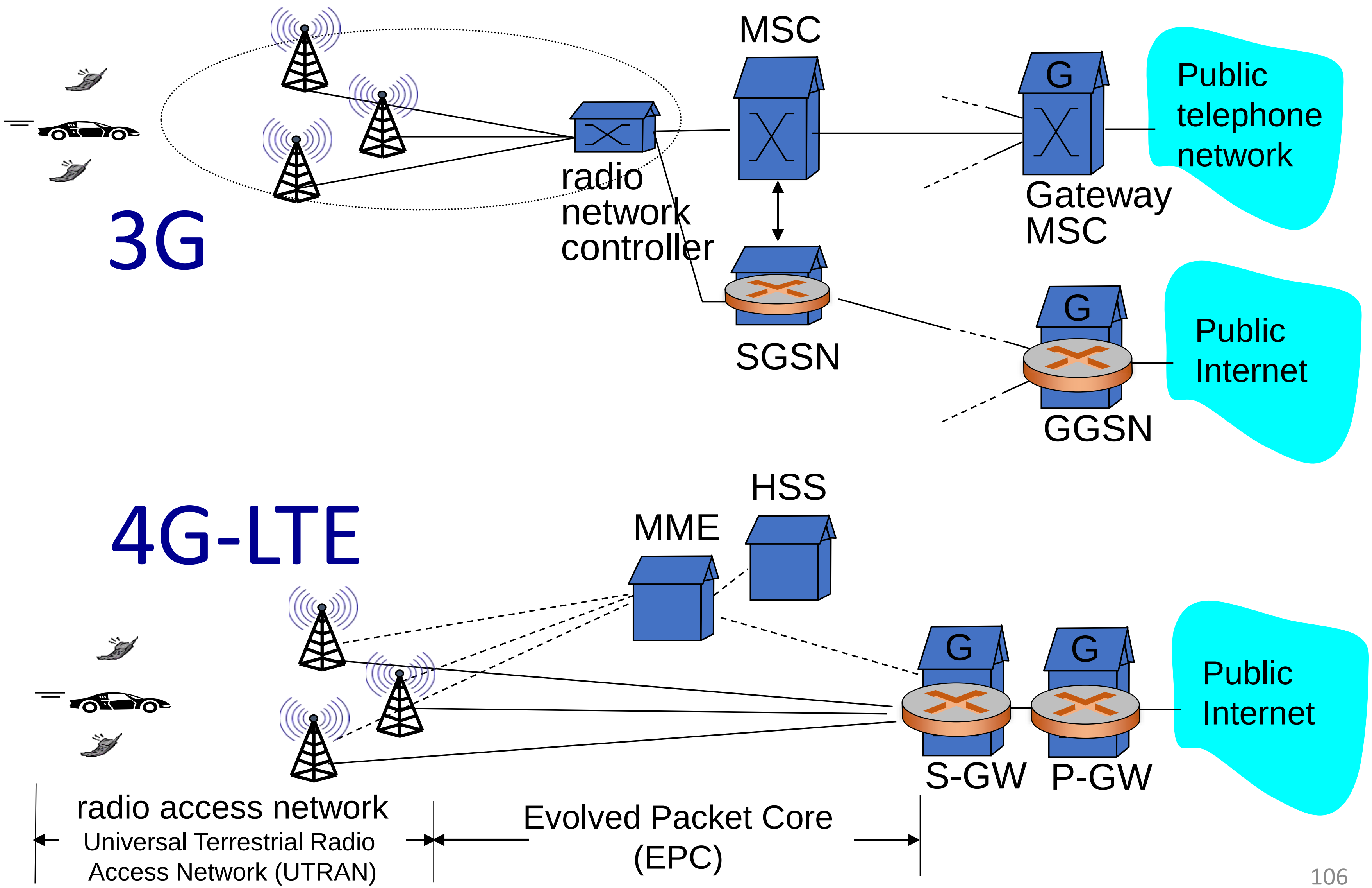
- voice network *unchanged* in core
- data network operates in parallel



3G (voice+data) network architecture

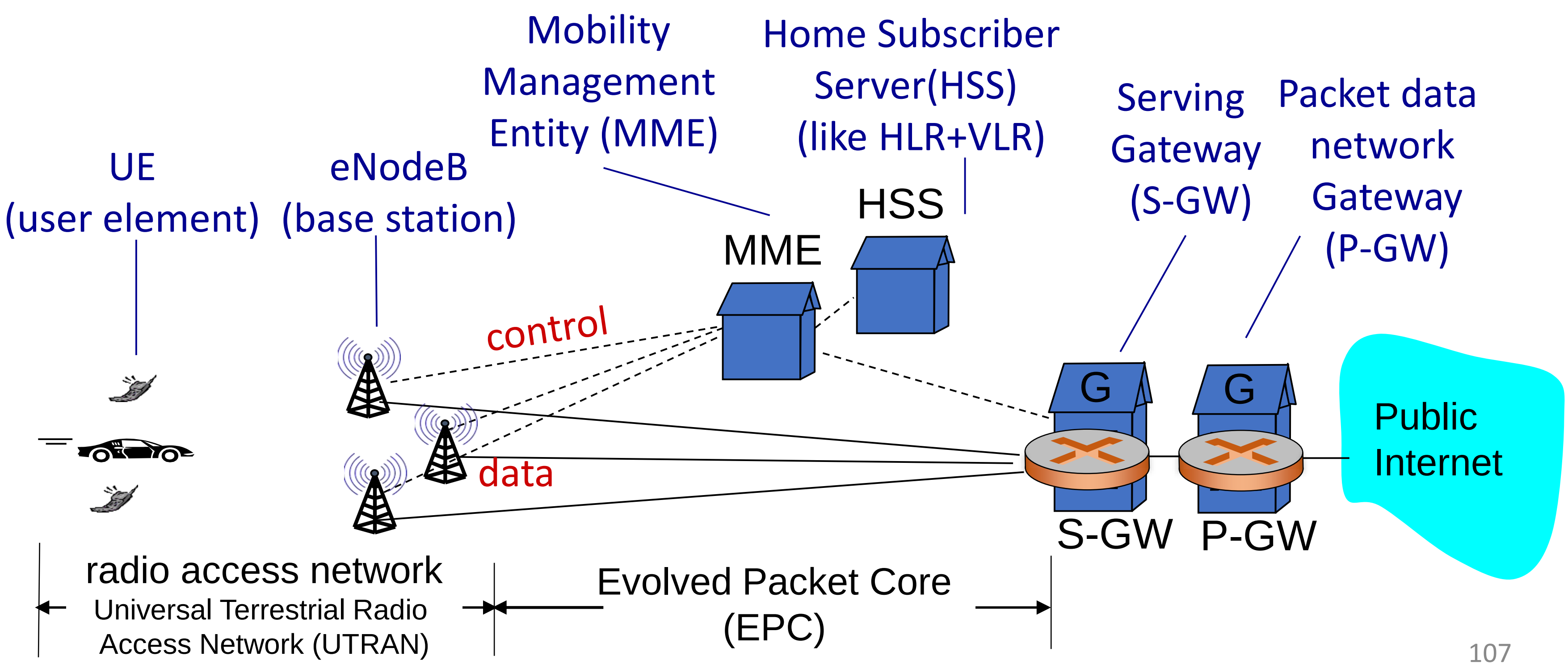


3G versus 4G LTE network architecture

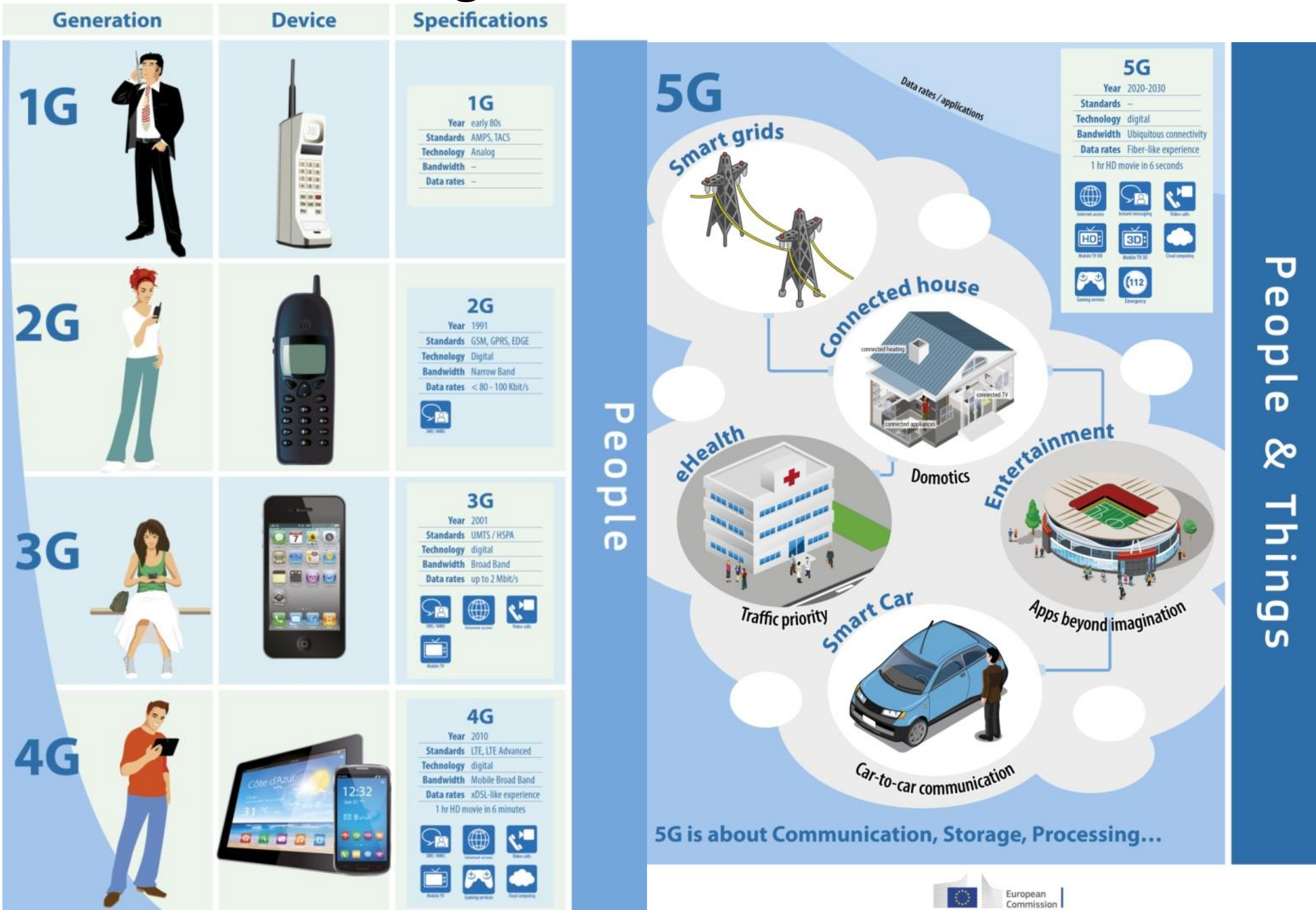


4G: differences from 3G

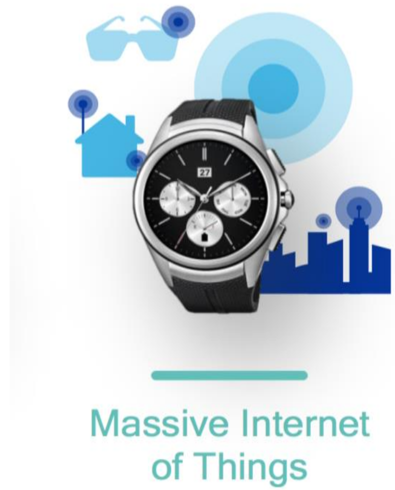
- all IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway

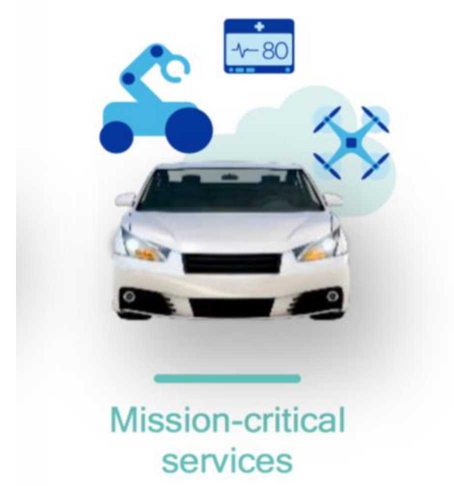


Mobile Technologies from 1G – 5G



5G: Unified Air Interface





Enhanced Mobile Broadband (eMBB)

- 100+ Mbps avg. throughput
- 10+ Gbps peak throughput

Massive Machine Type Communications (mMTC)

- $10^6/km^2$ connection density
- Low cost/energy connectivity

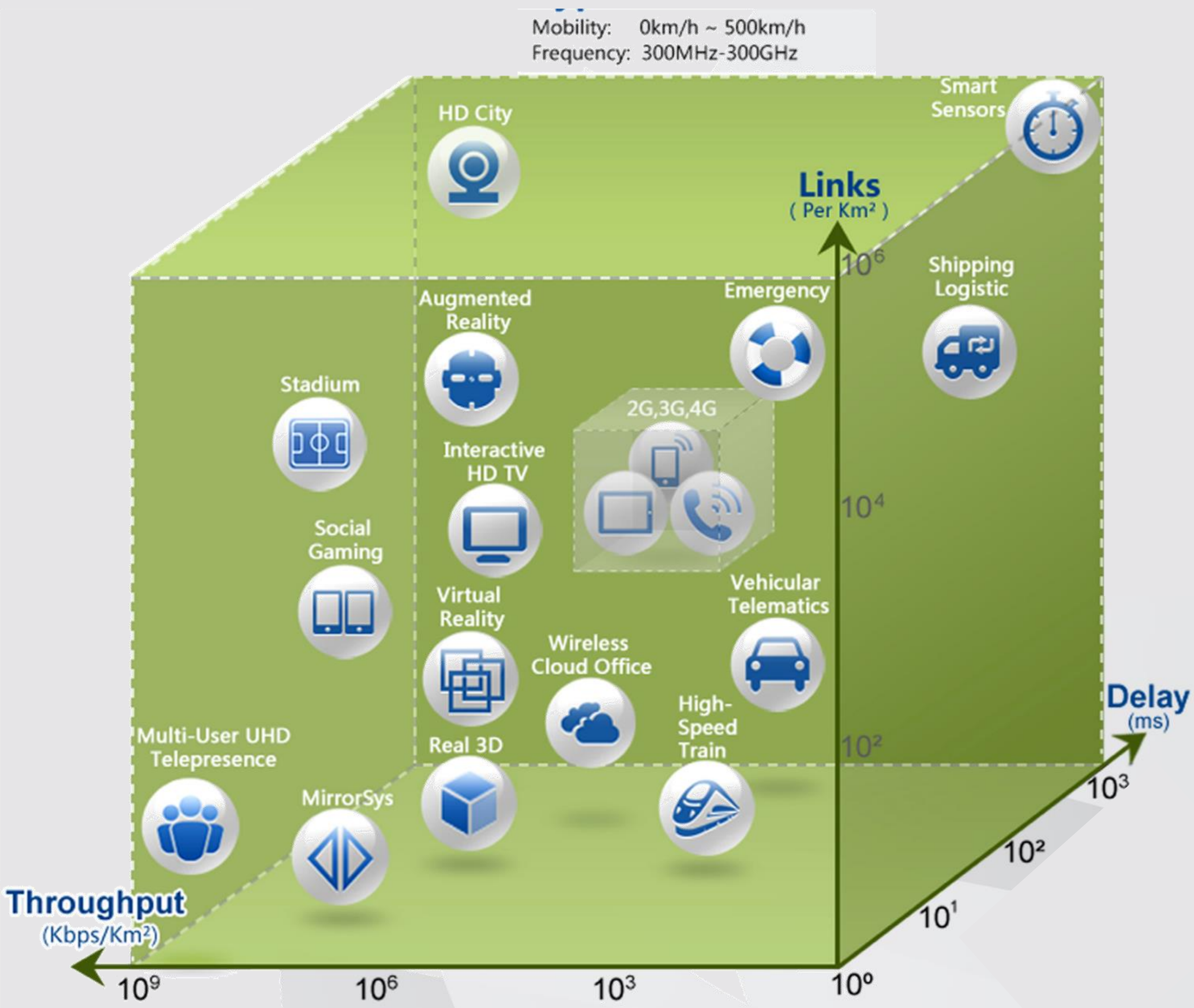
Ultra-Reliable, Low-Latency Communications (uMTC)

- 99.999% service availability
- 1 – 10 ms latency

- Mobile video and gaming
- Cloud computing and storage
- High speed connectivity

- Billions of connected devices
- Sensor networks
- IoT / M2M / D2D

- Tactile Internet
- Natural disaster relief
- E-Medicine and Health care



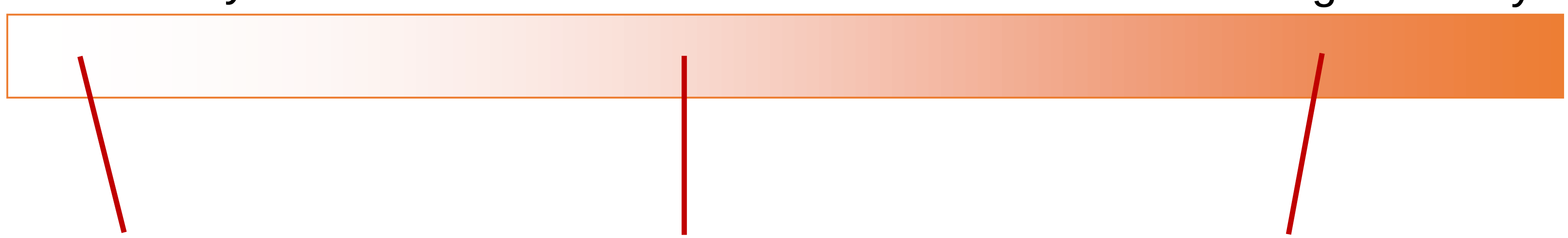
Mobility: 0km/h ~ 500km/h
Frequency: 300MHz-300GHz
HD City
Smart Sensors
Links
(Per Km²)
10^6
Shipping Logistic
Emergency
Augmented Reality
Stadium
2G,3G,4G
Interactive HD TV
10^4
Social Gaming
Virtual Reality
Vehicular Telematics
Wireless Cloud Office
High-Speed Train
Delay
(ms)
Multi-User UHD Telepresence
Real 3D
10^2
MirrorSys
10^3
10^2
10^1
Throughput
(Kbps/Km²)
10^9
10^6
10^3
10^0

Chapter 6: Outline

- ✓ Introduction
- ✓ Wireless Links
- ✓ Wireless MAC
- ✓ WiFi: 802.11 Wireless LANs
- ✓ Cellular Networks: 3G, LTE
- ❑ Mobility

What is mobility?

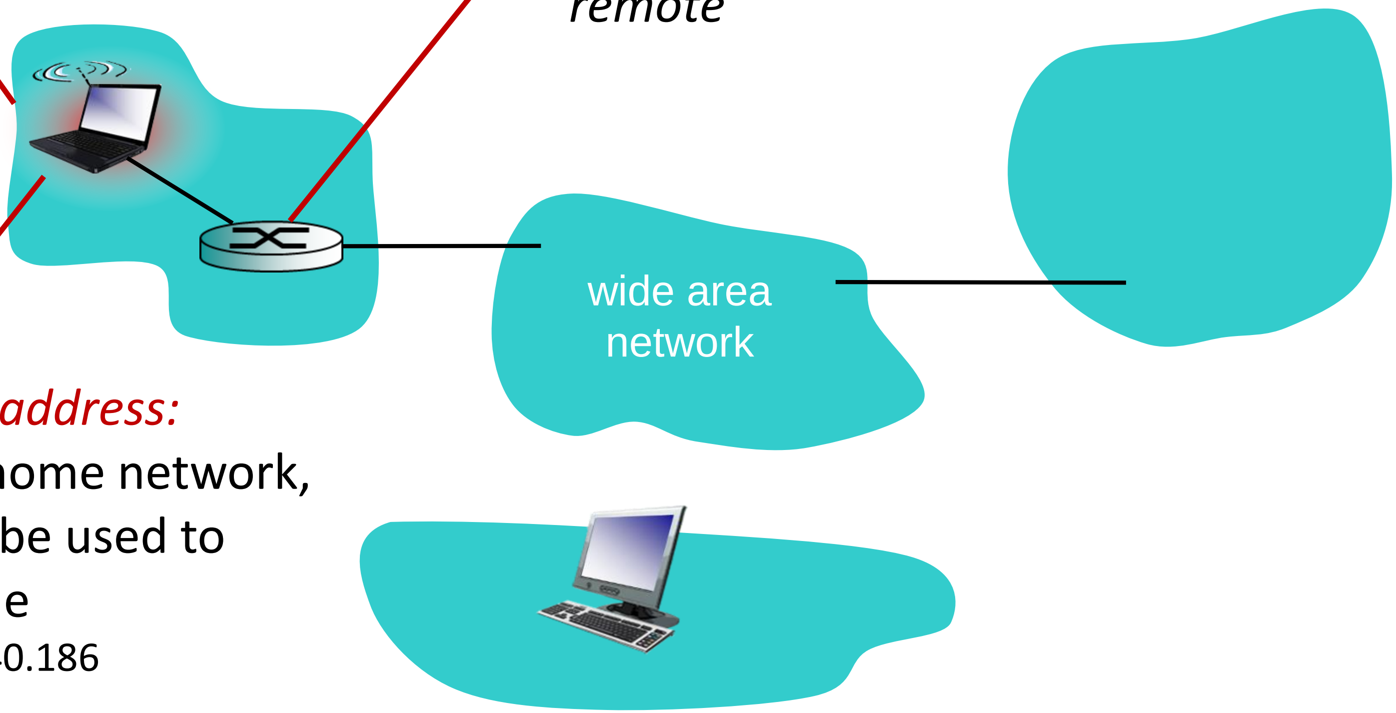
- spectrum of mobility, from the *network* perspective:



Mobility: vocabulary

home network: permanent "home" of mobile
(e.g., 128.119.40/24)

home agent: entity that will perform mobility functions on behalf of mobile, when mobile is remote



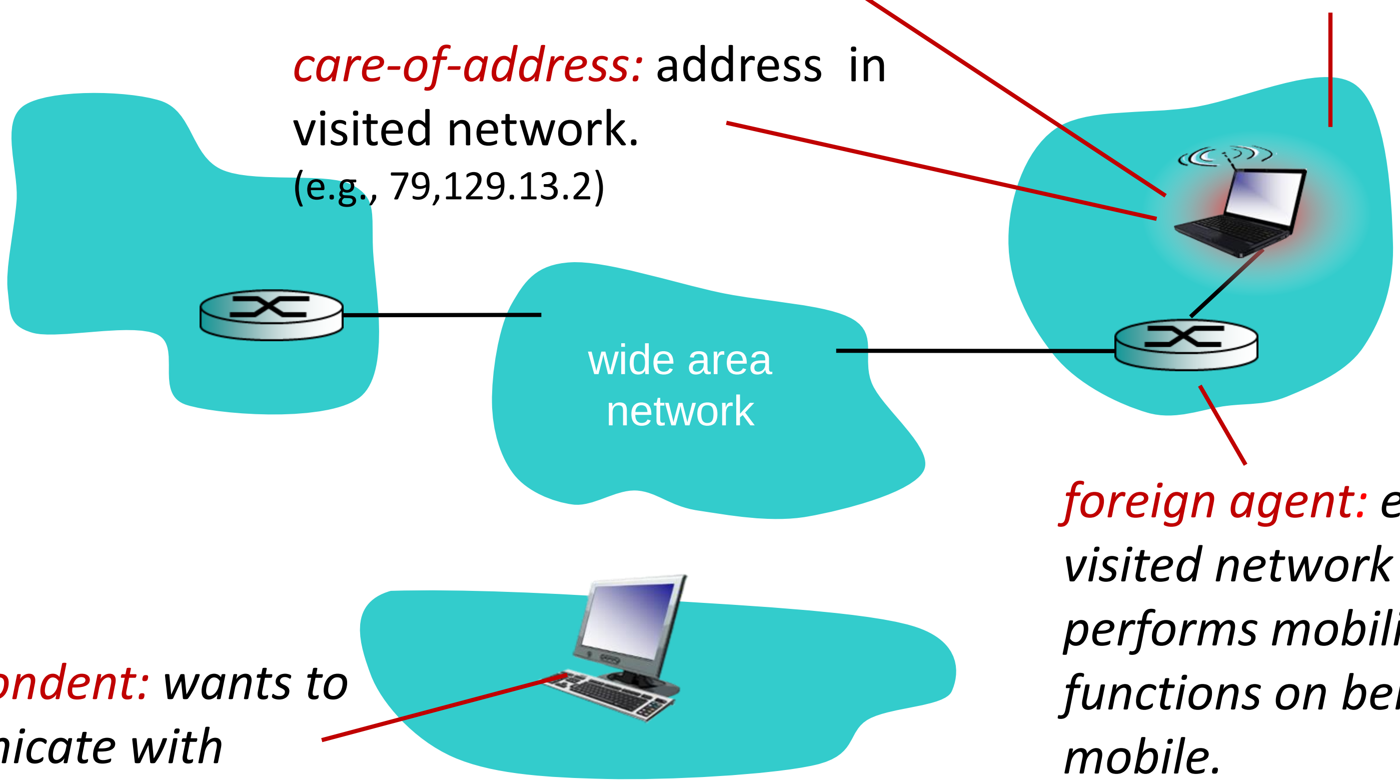
permanent address:
address in home network, *can always* be used to reach mobile
e.g., 128.119.40.186

Mobility: more vocabulary

permanent address: remains constant (e.g., 128.119.40.186)

visited network: network in which mobile currently resides (e.g., 79.129.13/24)

care-of-address: address in visited network. (e.g., 79,129.13.2)



foreign agent: entity in visited network that performs mobility functions on behalf of mobile.

correspondent: wants to communicate with mobile

Mobility: approaches

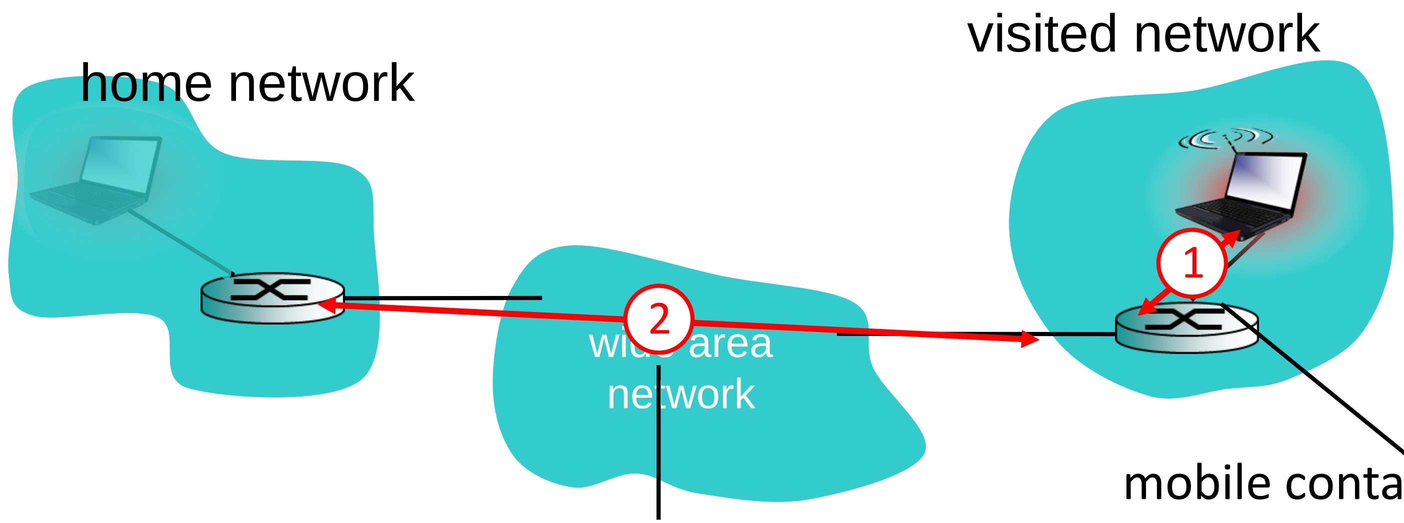
- *let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - routing tables indicate where each mobile located
  - no changes to end-systems
- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

Mobility: approaches

- *let routing handle it:* routers advertise permanent address of mobile … residence via usual routing table exc…
  - routing table … ere each mobile located
  - no changes to … ns

- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

Mobility: registration



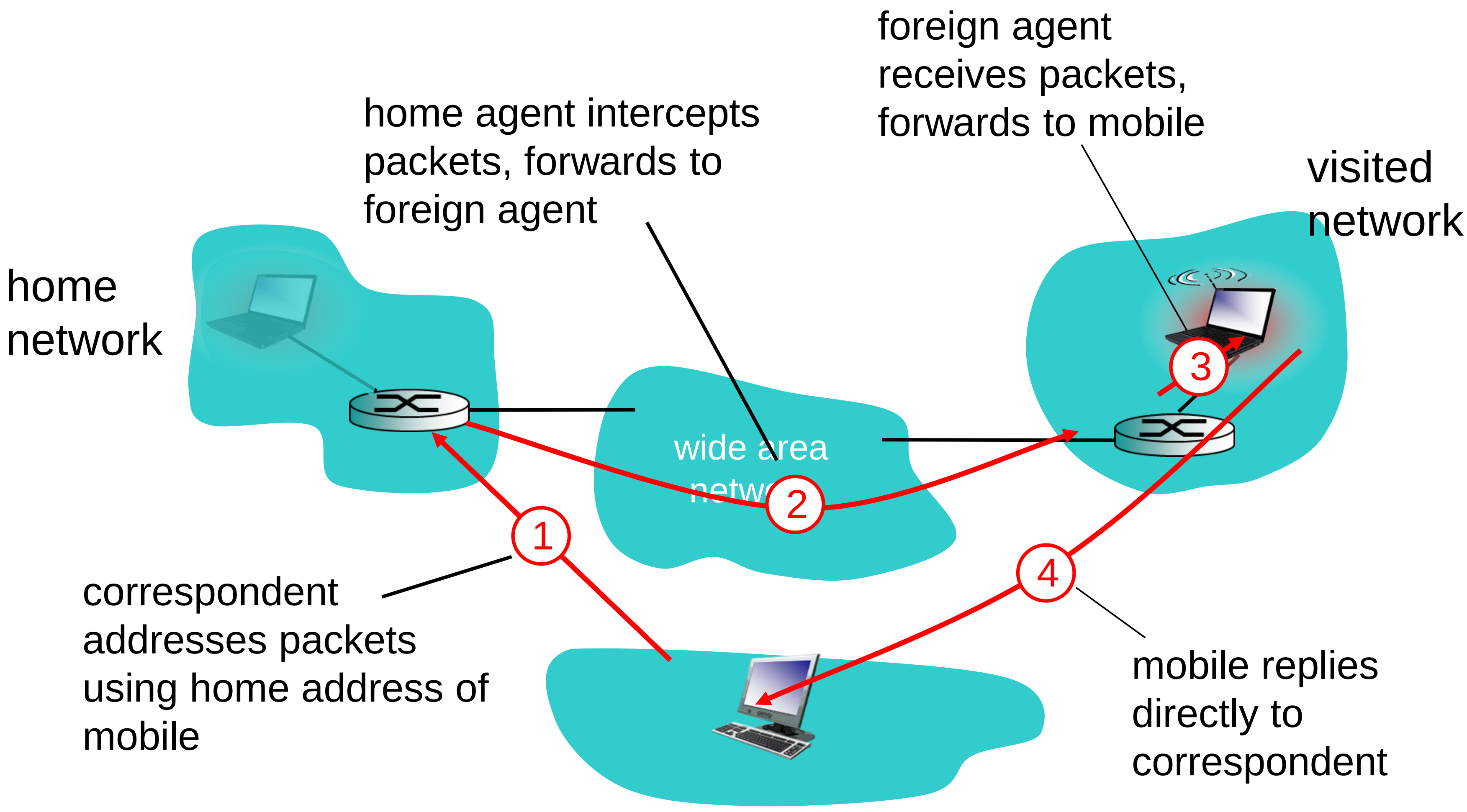
foreign agent contacts home agent home: "this mobile is resident in my network"

mobile contacts foreign agent on entering visited network

end result:

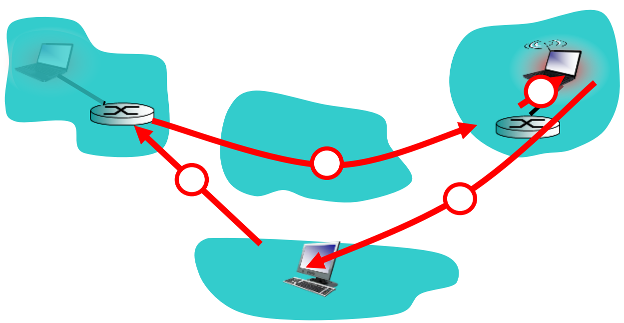
- foreign agent knows about mobile
- home agent knows location of mobile

Mobility via indirect routing

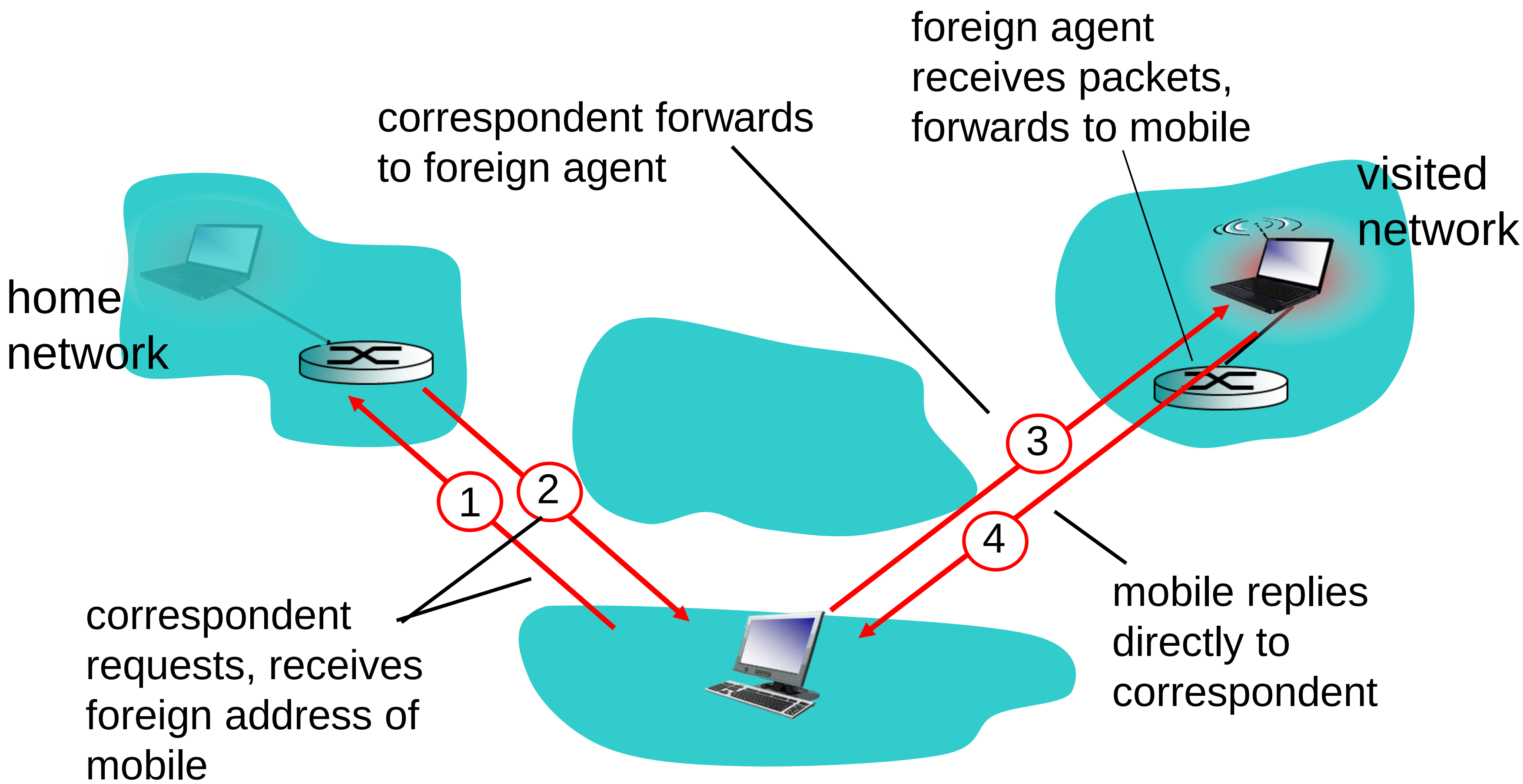


Indirect Routing: comments

- mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile
  - inefficient when correspondent, mobile are in same network

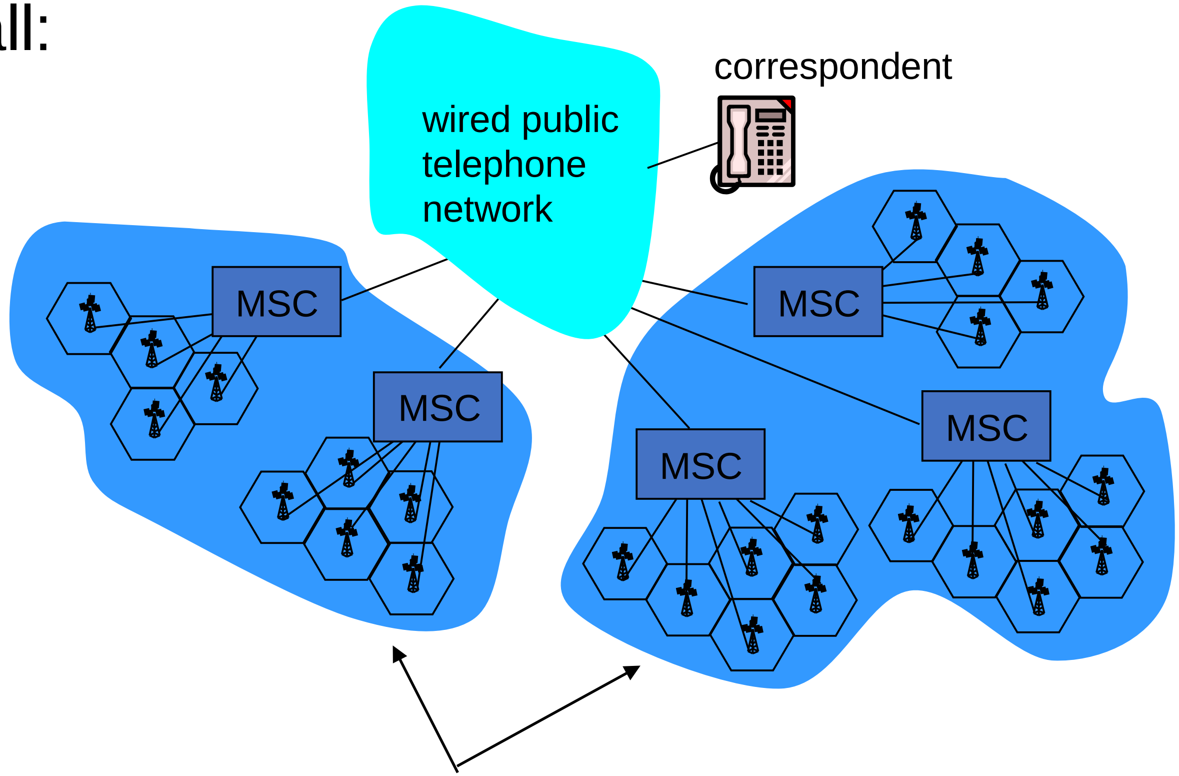


Mobility via direct routing



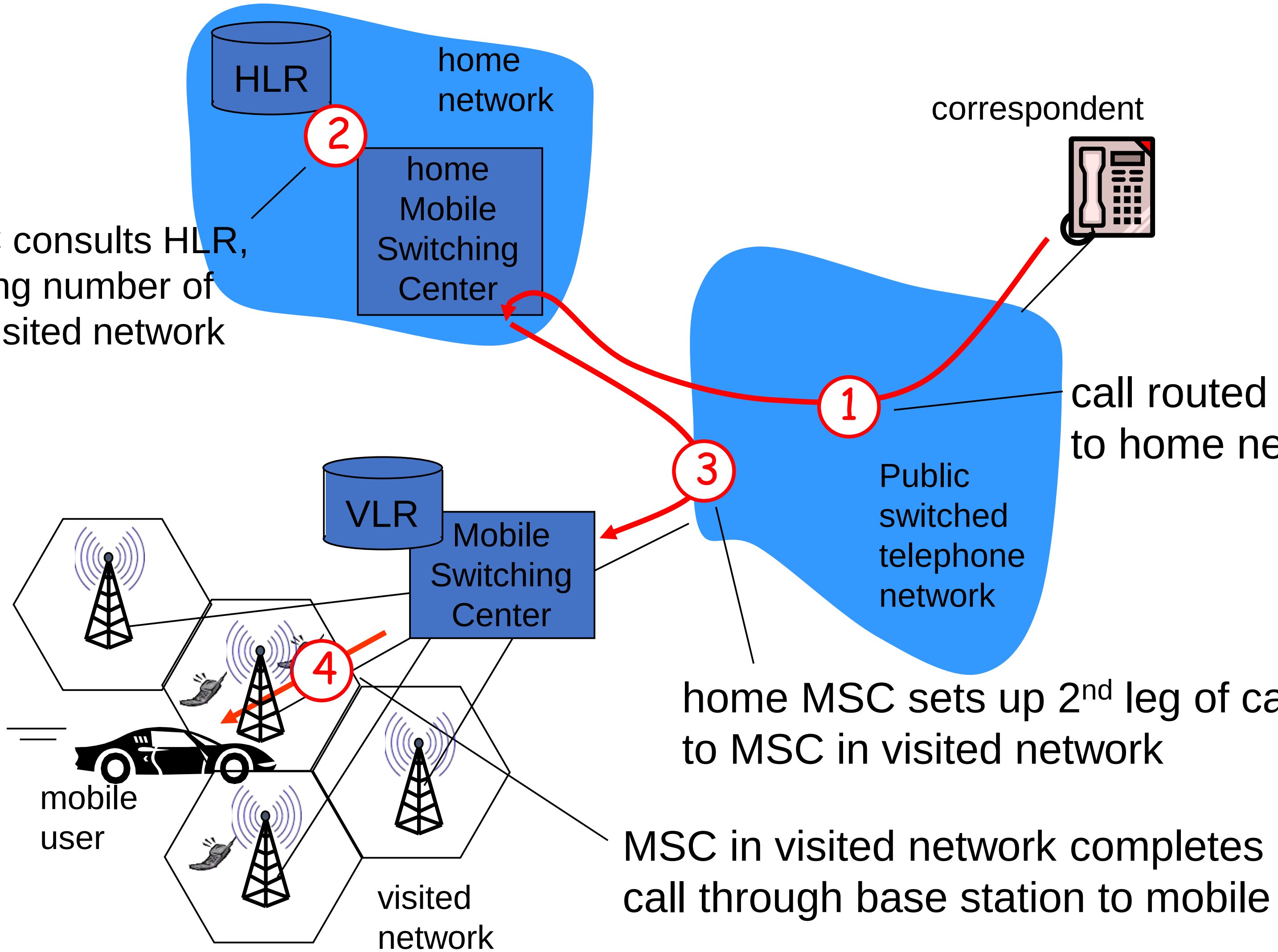
Components of cellular network architecture

recall:



different cellular networks,
operated by different providers

GSM: indirect routing to mobile



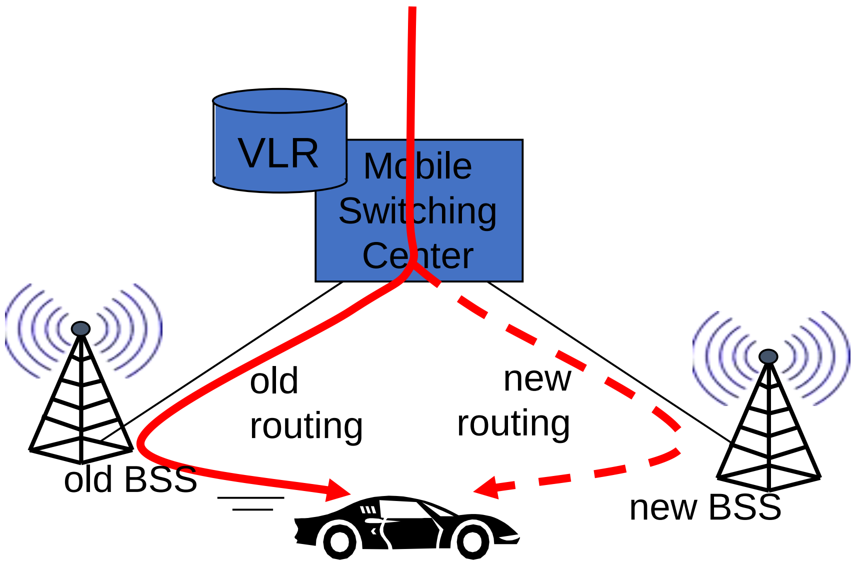
home MSC consults HLR, gets roaming number of mobile in visited network

call routed to home network

home MSC sets up 2nd leg of call to MSC in visited network

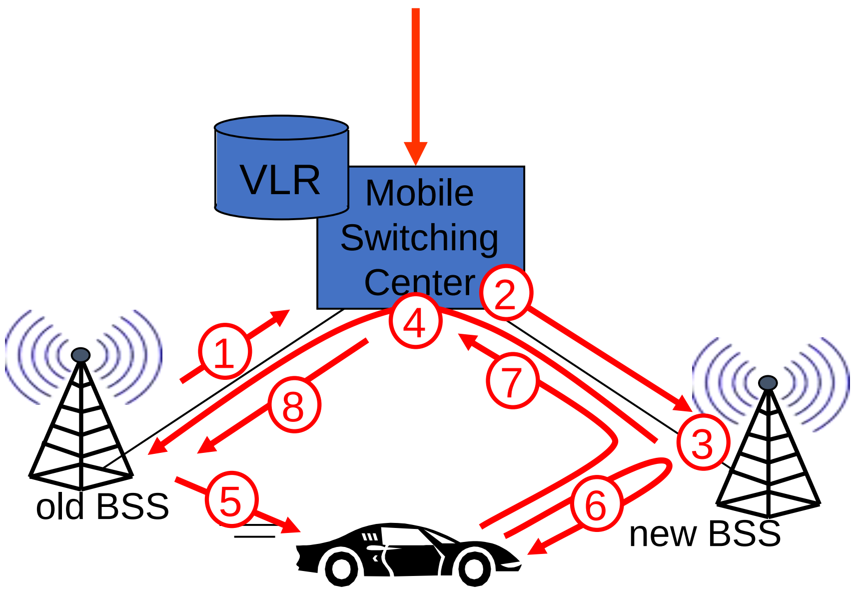
MSC in visited network completes call through base station to mobile

GSM: handoff with common MSC



- *handoff goal:* route call via new base station (without interruption)
- reasons for handoff:
  - stronger signal to/from new BSS (continuing connectivity, less battery drain)
  - load balance: free up channel in current BSS
  - GSM doesn't mandate why to perform handoff (policy), only how (mechanism)
- handoff initiated by old BSS

GSM: handoff with common MSC



1. old BSS informs MSC of impending handoff, provides list of 1^+ new BSSs
2. MSC sets up path (allocates resources) to new BSS
3. new BSS allocates radio channel for use by mobile
4. new BSS signals MSC, old BSS: ready
5. old BSS tells mobile: perform handoff to new BSS
6. mobile, new BSS signal to activate new channel
7. mobile signals via new BSS to MSC: handoff complete. MSC reroutes call

8 MSC-old-BSS resources released

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Wireless, mobility: impact on higher layer protocols

- logically, impact *should* be minimal …
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile
- … but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily
  - delay impairments for real-time traffic
  - limited bandwidth of wireless links