Link Layer: Wireless and WiFi

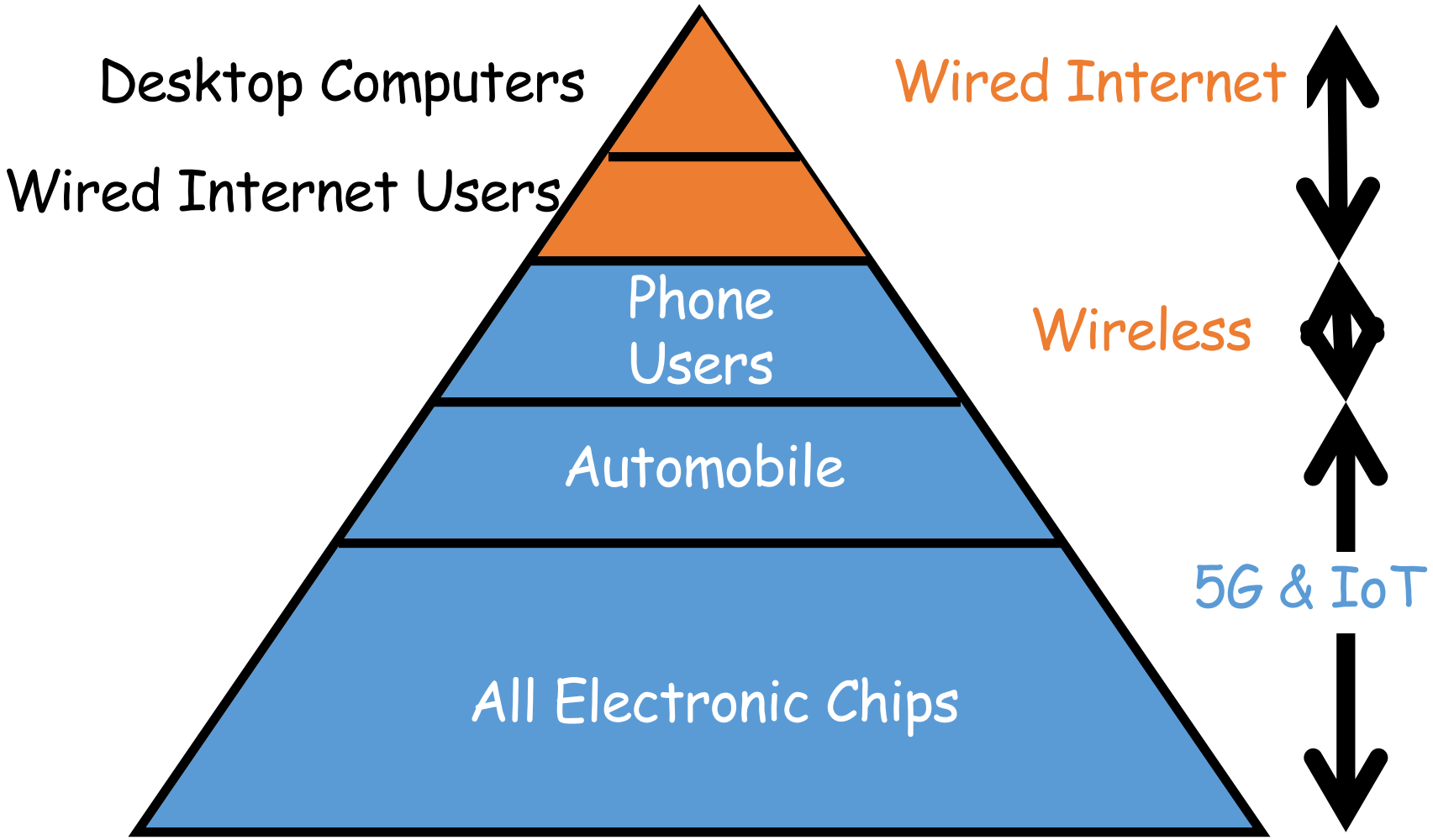
CS204: Advanced Computer Networks

Nov 6, 2023

Agenda

- Introduction to wireless
  - Architecture Options
  - Wireless Link Characteristics
- WiFi
  - Challenges to design wireless link layers
  - WiFi's Approach

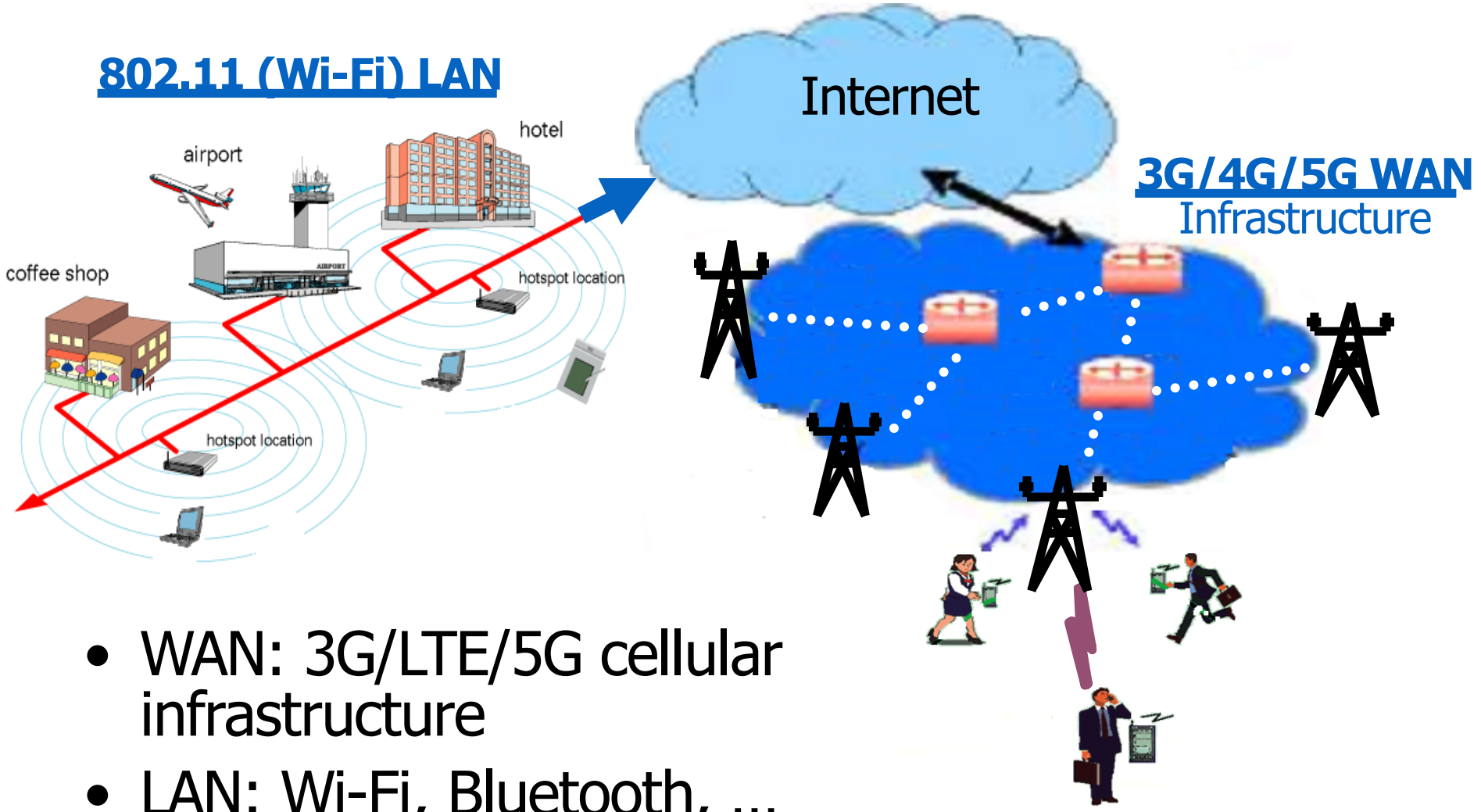
“Internet” Beyond the Wired World



Why Wireless?

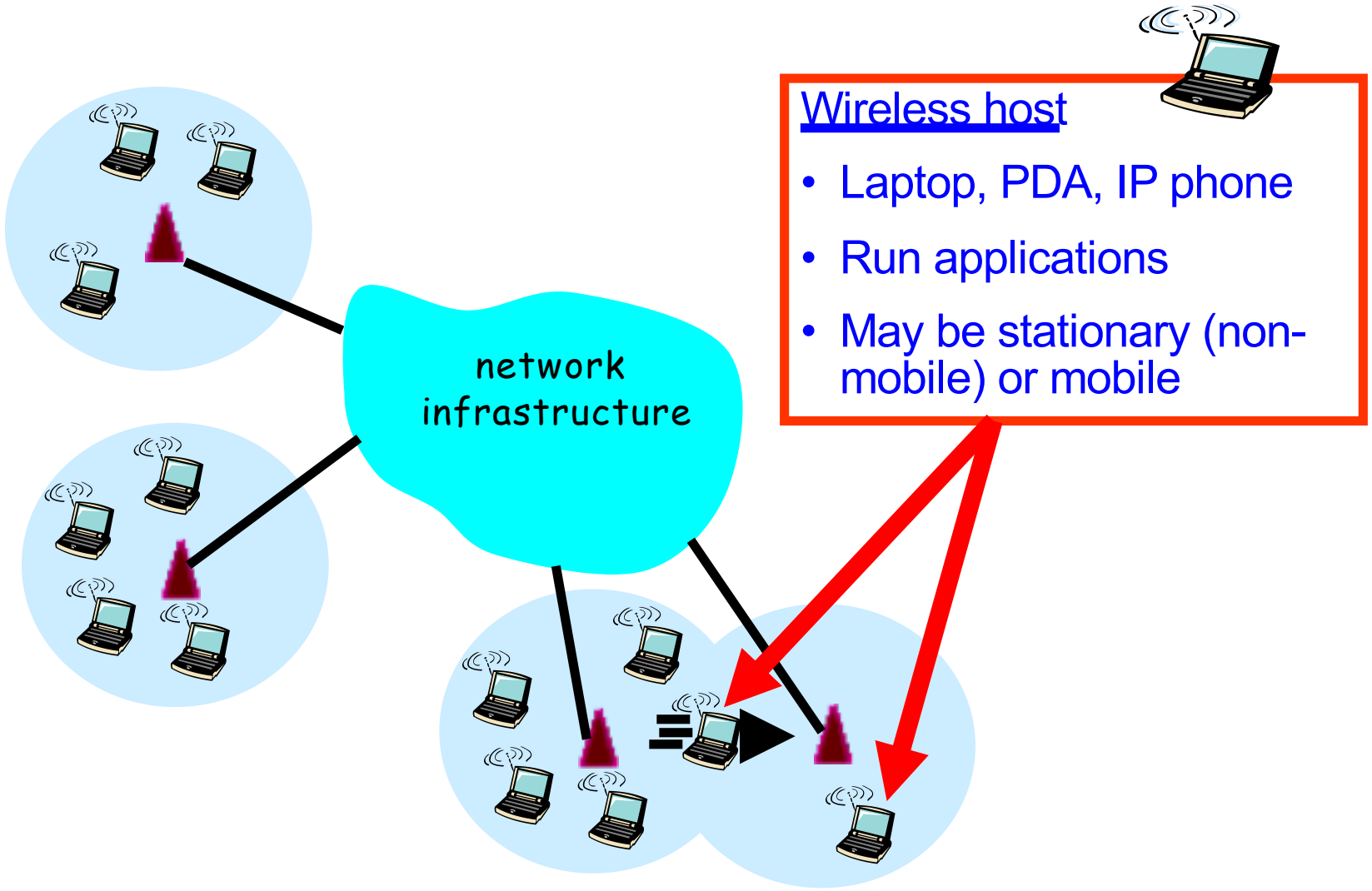
- Short-range communication: convenience
  - Free of cables/wires
  - Freedom to move
- Long-range: potentially lower latency
  - Wired: 0.42~0.72 (of speed of light in vacuum)
    - Reflection makes the signal travel much longer distance
  - Wireless (RF over the air): ~1.0 (of speed of light in vacuum)

Current Wireless Internet

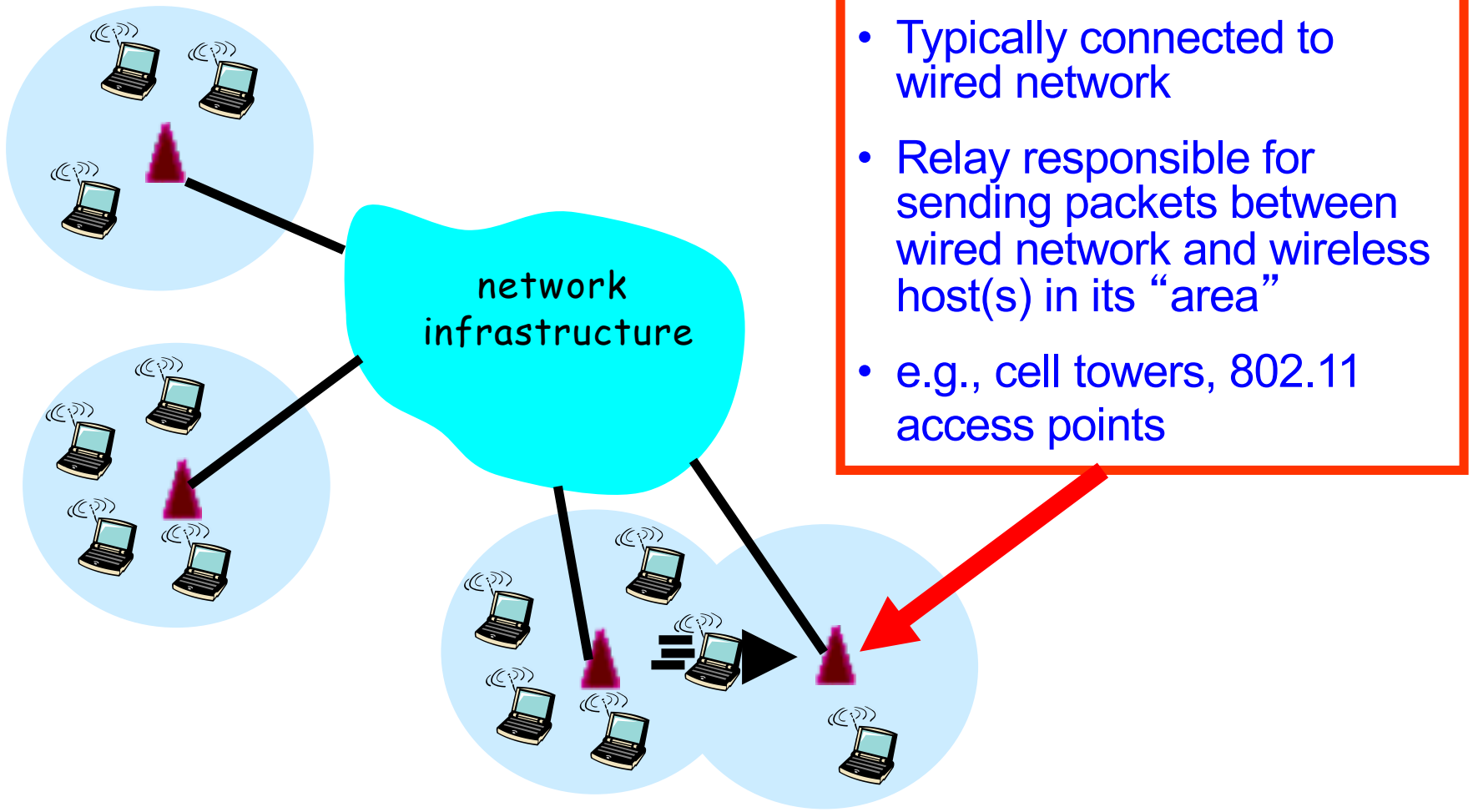


- WAN: 3G/LTE/5G cellular infrastructure
- LAN: Wi-Fi, Bluetooth, …

Wireless Network: Wireless Hosts



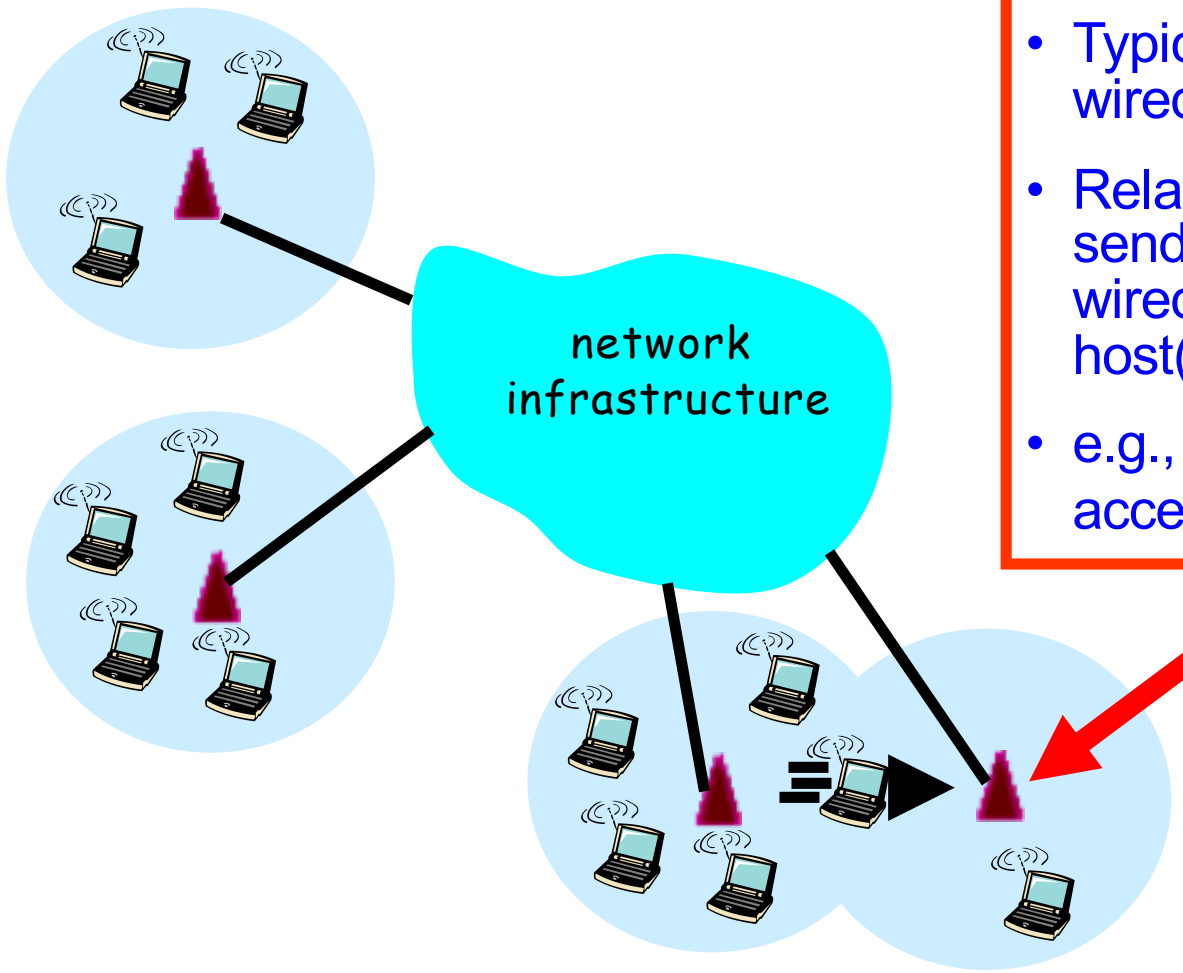
Wireless Network: Base Station



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

Wireless Network: Base Station



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Comparisons of 4G and 802.11

- Coverage
  - 4G: bigger coverage (100s ~ 5km)
  - 802.11a/g/n/ac: smaller (100s feet)
- Throughput
  - 802.11a/g/n/ac: up to 54M/600M/6.93G bps
  - 4G: 5~100 Mbps downlink; 2~50Mbps uplink (5G -> Gbps)
- Applications supported:
  - 802.11: mainly data, but also Internet VoIP
  - 4G: data plus carrier-grade voice

Introduction to Wireless Network Problems

- Fundamental issues
  - wireless
  - mobility
- They affect the design & operation of each layer in the protocol stack

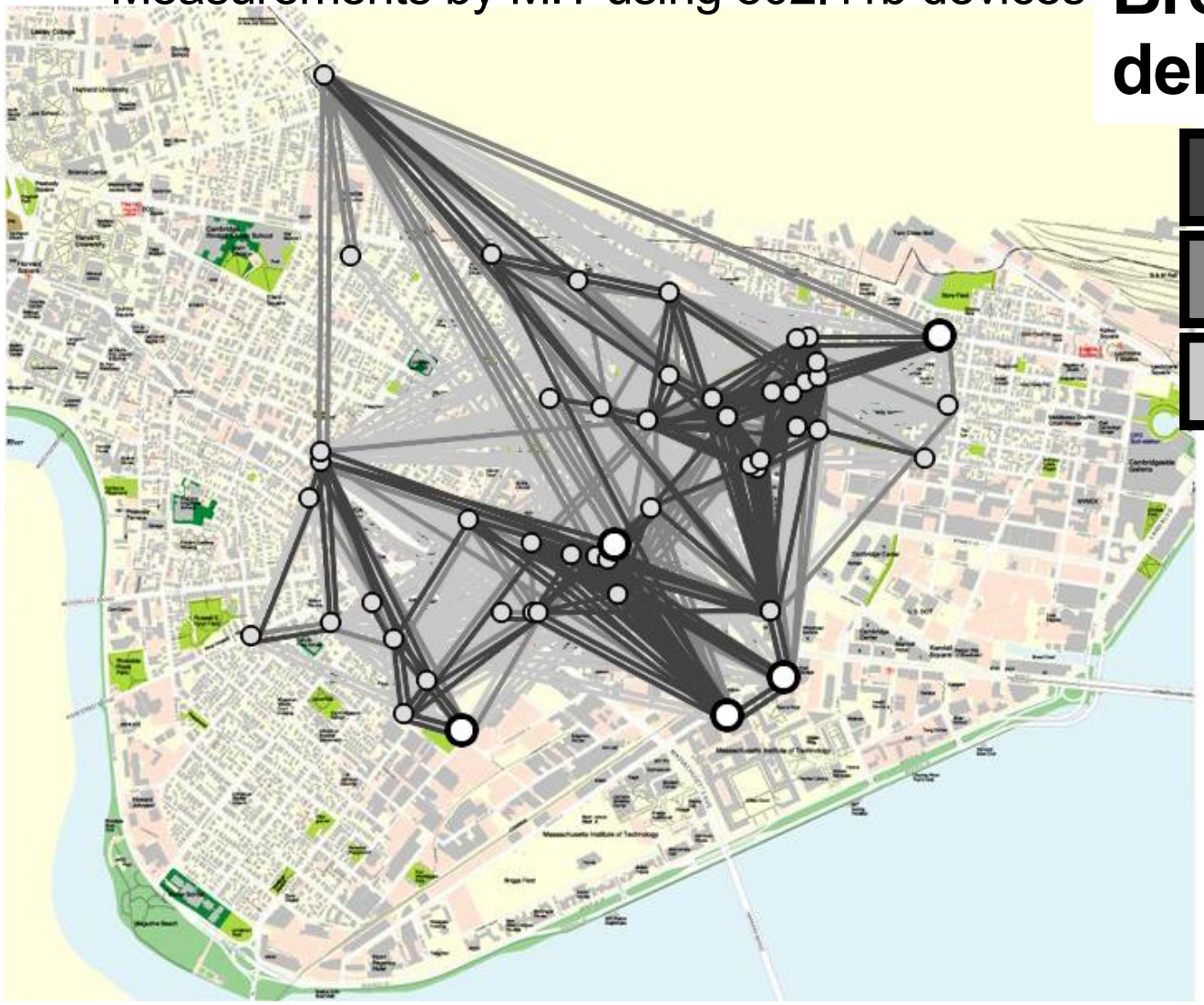
1st Point for Wireless Networks: The network is the Channel!

- Experiences show that a key difference from the wired network is the *wireless channel*

- Wireless channel has very different characteristics from the wired channel!

Example Case: High Loss

Measurements by MIT using 802.11b devices

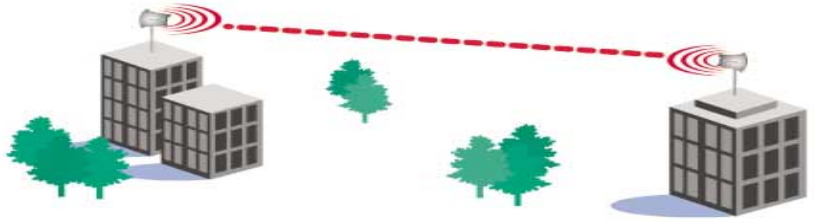


Broadcast packet delivery probability

- **70-100%**
- **30-70%**
- **1-30%**

Root cause for high data loss rate in wireless links: Wireless transmission characteristics

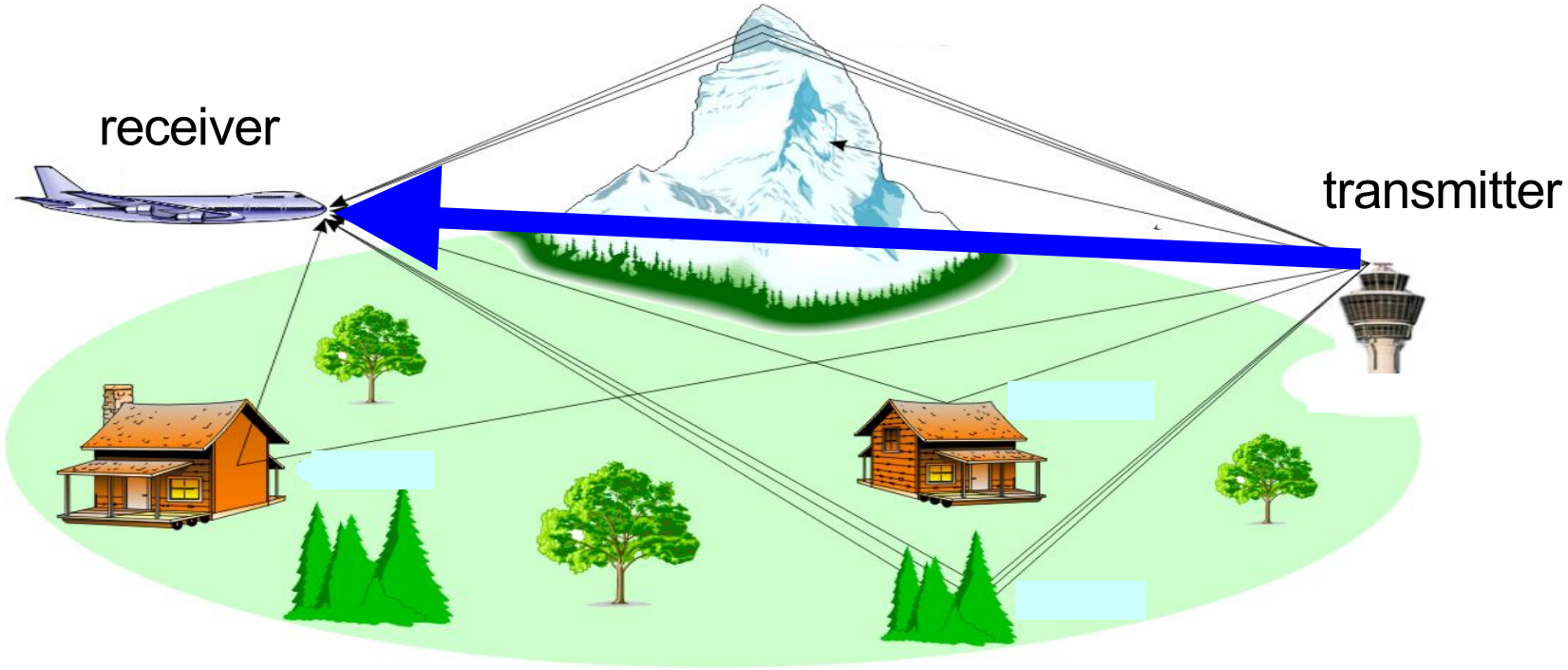
- Decreasing signal strength over distance
  - Disperses as it travels greater distance
  - Attenuates as it passes through object
  - Received power is inversely proportional to the distance: distance-power gradient
    - Free space: factor 2; 2~3 for residential areas, offices and manufacturing floors; 4 for urban radio communications



Wireless reception is location dependent

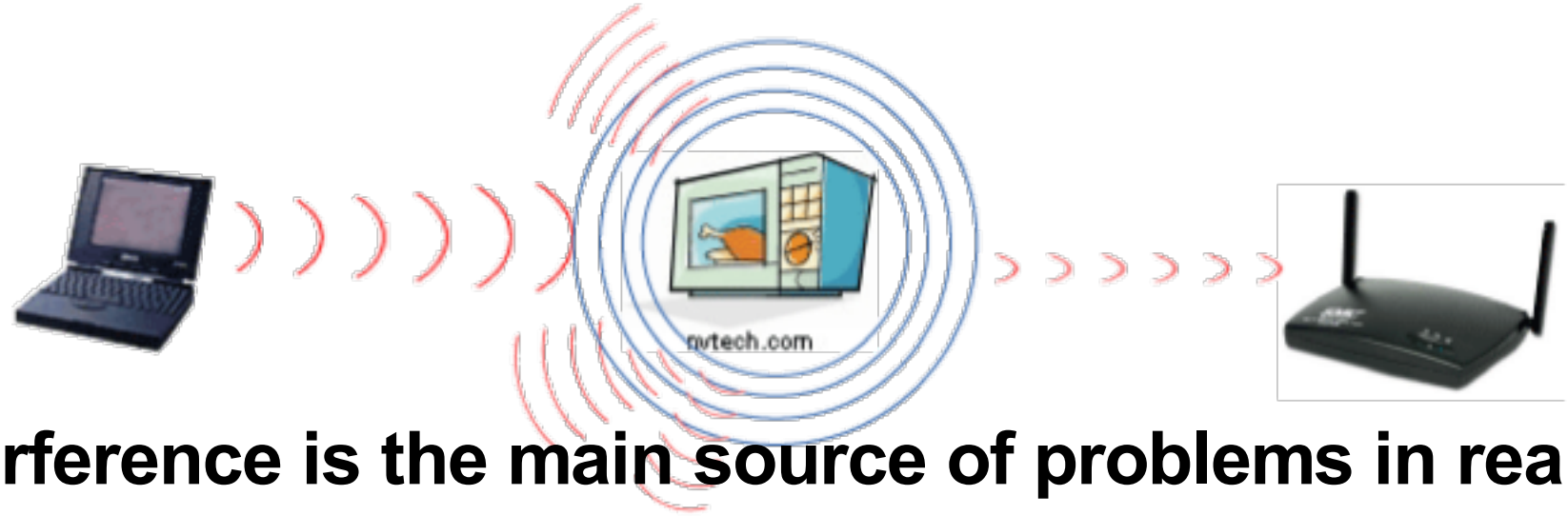
Wireless transmission characteristics

- Multi-path fading
  - Radio signals reflect off objects
  - Taking many paths of different lengths
  - Blurring of signal at the receiver



Wireless transmission characteristics

- Interference from other sources
  - Radio sources over same frequency band
    - e.g., 2.4 GHz wireless phone interferes with 802.11 wireless LAN
    - Electromagnetic noise (e.g., microwave oven)

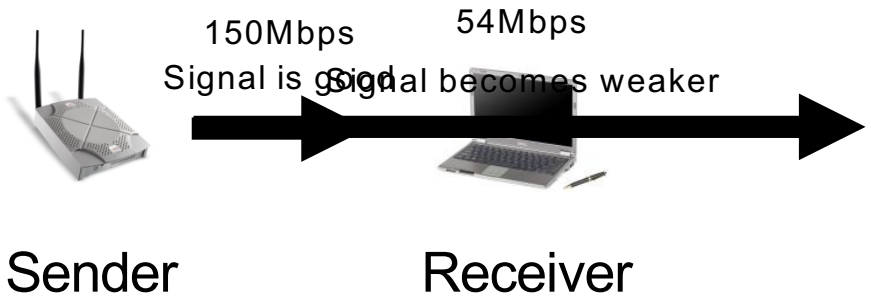


Interference is the main source of problems in reality

Wireless transmission characteristics

Wireless link capacity is location dependent

- Channel capacity ~ S/N (signal to noise ratio) or SINR (signal to interference noise ratio) more precisely



2nd Point: Mobility incurs dynamics in space!

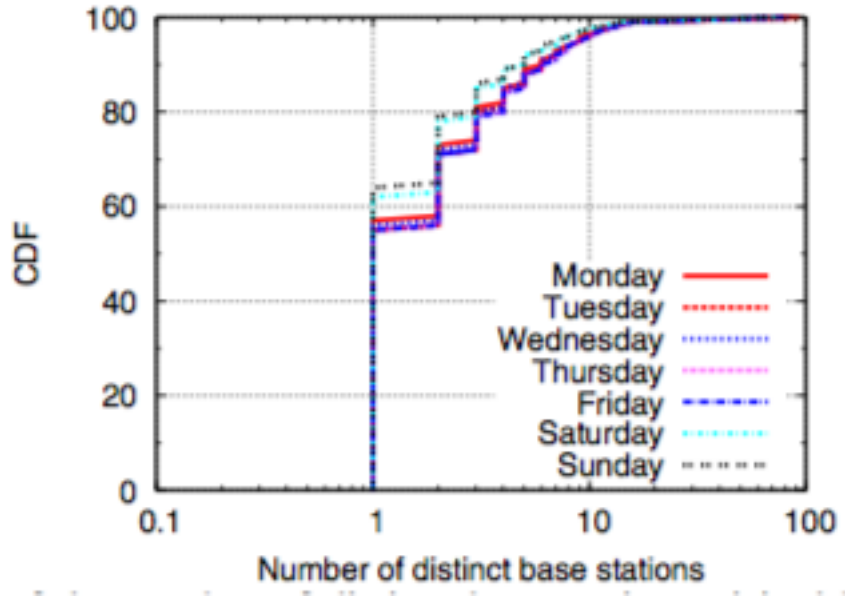
- Mobile networks will use wireless channels
- Temporal-spatial dynamics!!!

Issues:

- Mobile Internet services
- How users move? → mobility models
- Impact of mobility on networks?

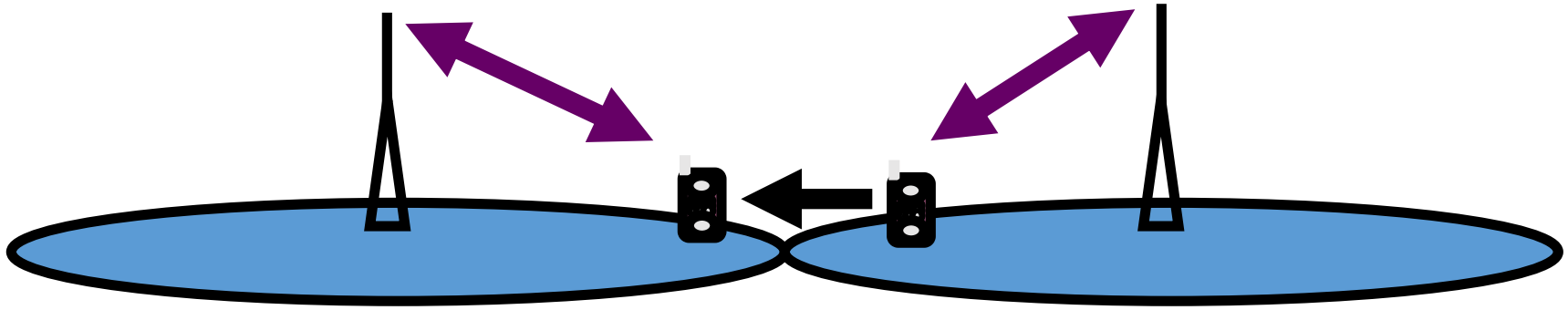
Measured User Mobility in Reality

- Use # of 3G Base Stations visited as the metric
  - 60% users are mostly “static”
  - >95% users travel <10 BSes each day
  - <0.01% users visit >50 BSes daily



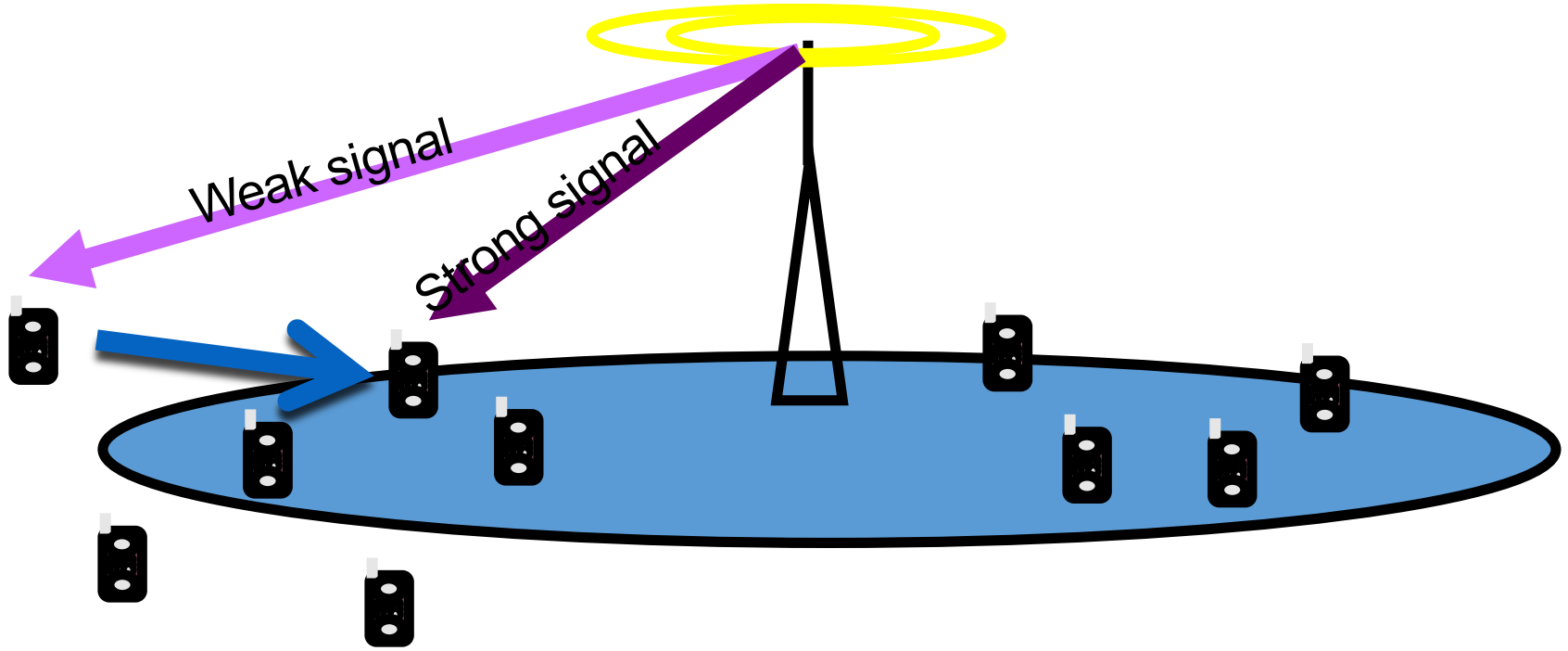
Mobility Impact

- Incur resource availability changes as the user roams
  - Old location has more resource (released by the mobile user)
  - New location has less resource (after serving the mobile user)
  - Spatially changing with user mobility pattern



Mobility Impact

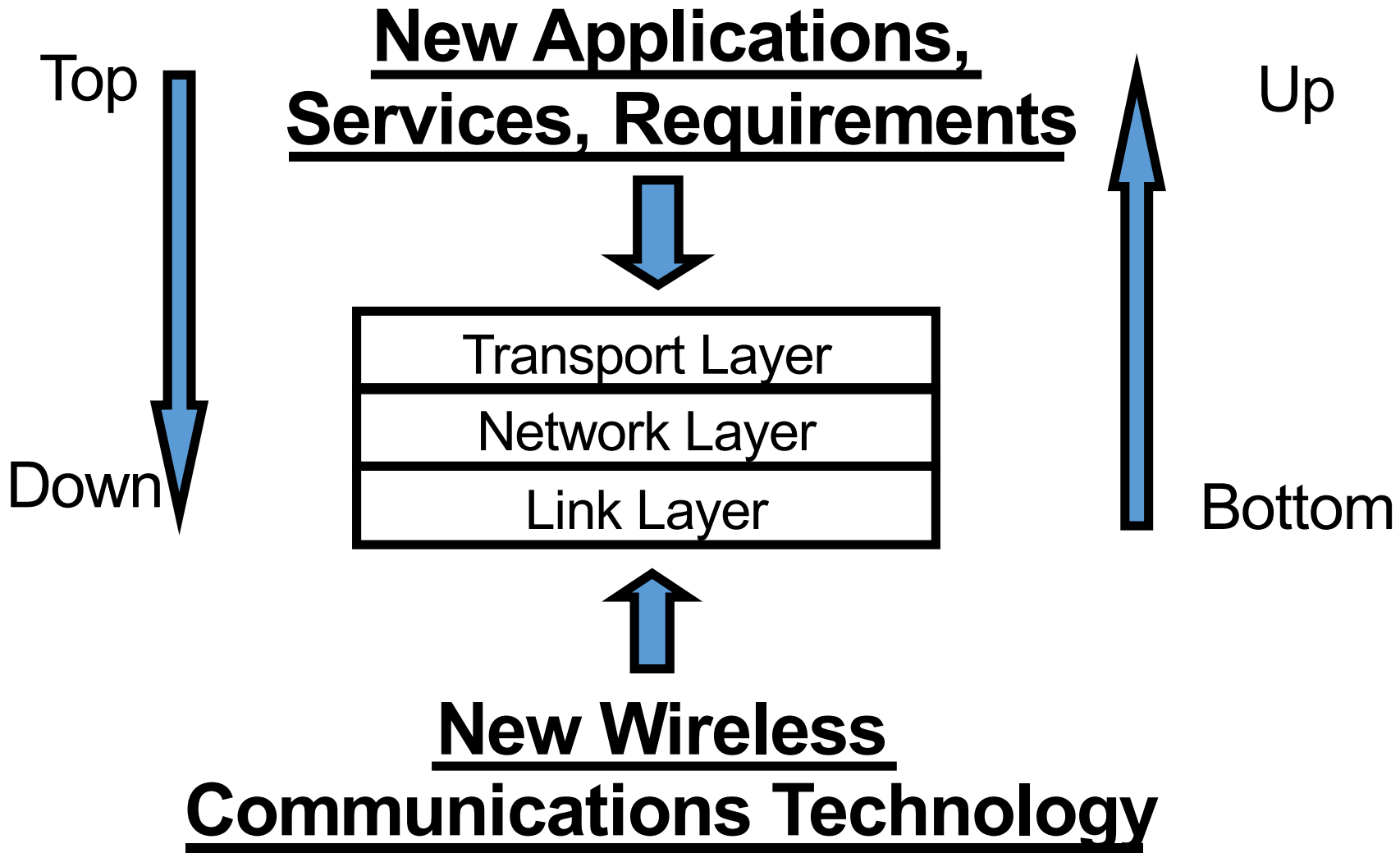
- Mobility causes dynamic wireless reception
- Mobility can be good for wireless:
  - Move to a “better” location



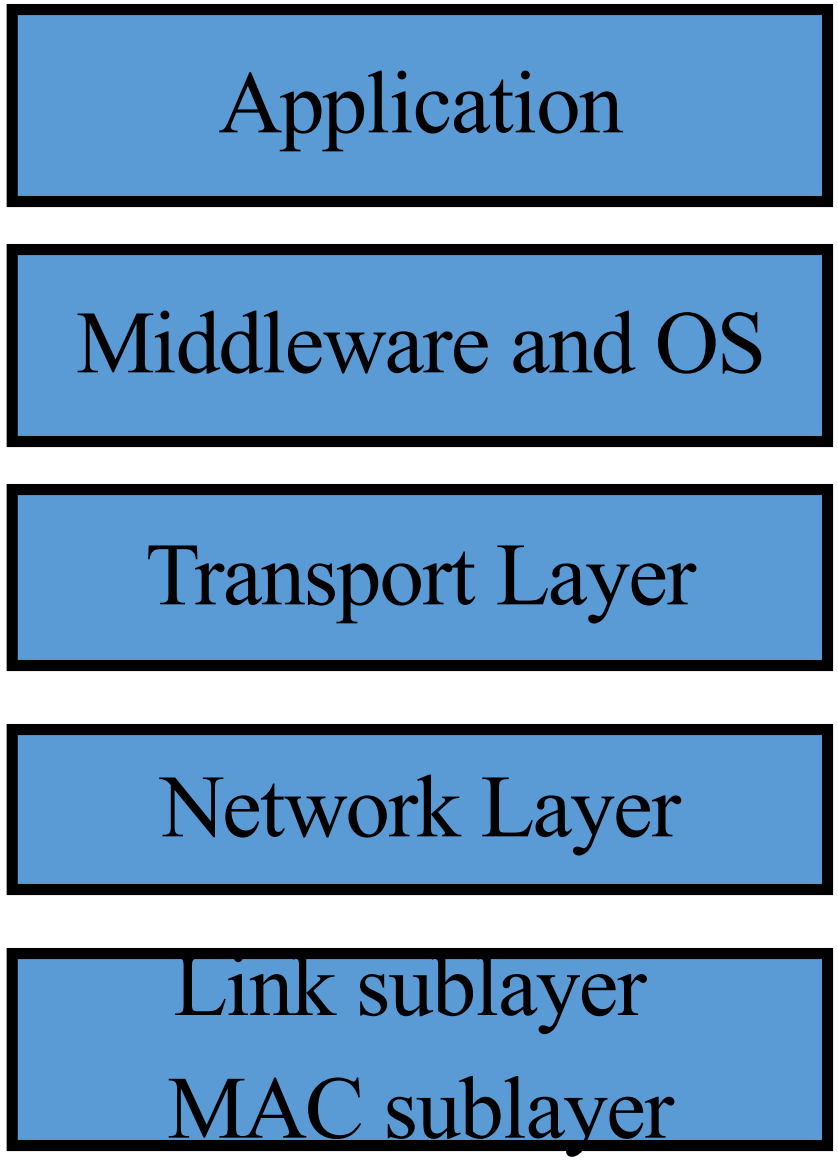
Mobility

- The key differentiator from Internet service
  - “Any time, any where” service
- The TCP/IP based legacy Internet design offers no mobility solution
  - Service disruption on the move
- Key factor next
  - Industrial Internet, Internet of Things. …

Drivers for Wireless Technology To Date

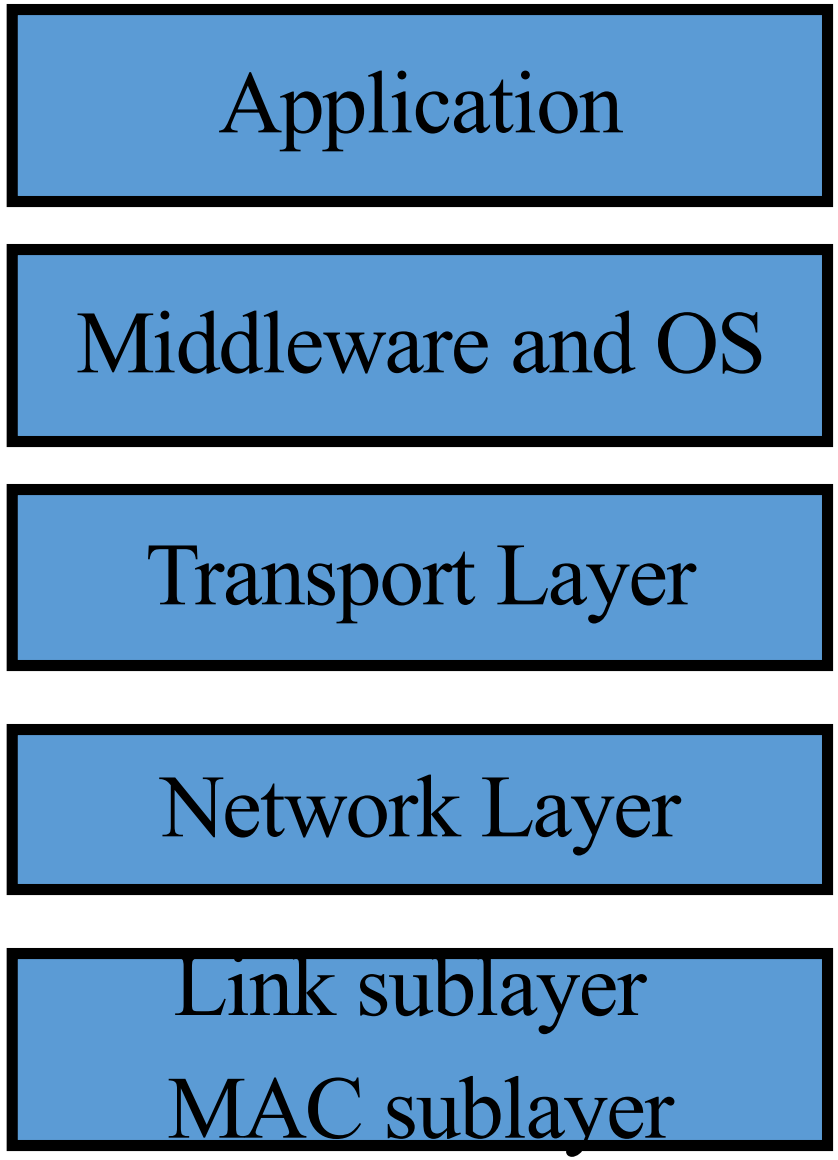


Wireless Impact on Protocol Stack



- ➢ Partial network connectivity
- ➢ Changing network quality: delay, throughput
- ✓ Diverse data losses
- ❖ Opportunistic connectivity
- ❖ Time-varying link bandwidth
- o Location-dependent error
- o Hidden terminals

Mobility Impact on Protocol Stack



- ➢ Connection, disconnection
- ➢ Disconnection, reconnection
- ✓ Mobility-induced data losses
- ❖ Topology change
- ❖ Time-varying capacity
- o Link-layer handoff
- o Varying link quality

Link/MAC Sublayer Design

- The protocol design focuses on Link/MAC
  - Hide nasty impact of wireless
    - SAME QUALITY AS WIRED LINK !!
  - Offer seamless services while mobile
  - Overall, “Anytime, anywhere” services
- Meanwhile, the higher layer still stays the same

Cross-Layer Design?

- What for cross-layer:
  - Information to be shared among layers
  - Informed decision/action for other layers
- PHY info to higher layers
  - Link/MAC layer
    - Control transmit power, modulations to reduce error rate or rexmit
  - Network layer
    - Bit-error rate information in order to switch another network interface with lower bit-error-rate
  - Application layer
    - Channel condition information
    - Various standard coding techniques for multi-media applications

Bad Effect for Cross-Layer Design

Cautionary perspective:

- Undesirable consequences on overall system performance
- The importance of architecture
  - Stability
  - Robustness
  - Spaghetti design – hard to upkeep
  - …

Agenda

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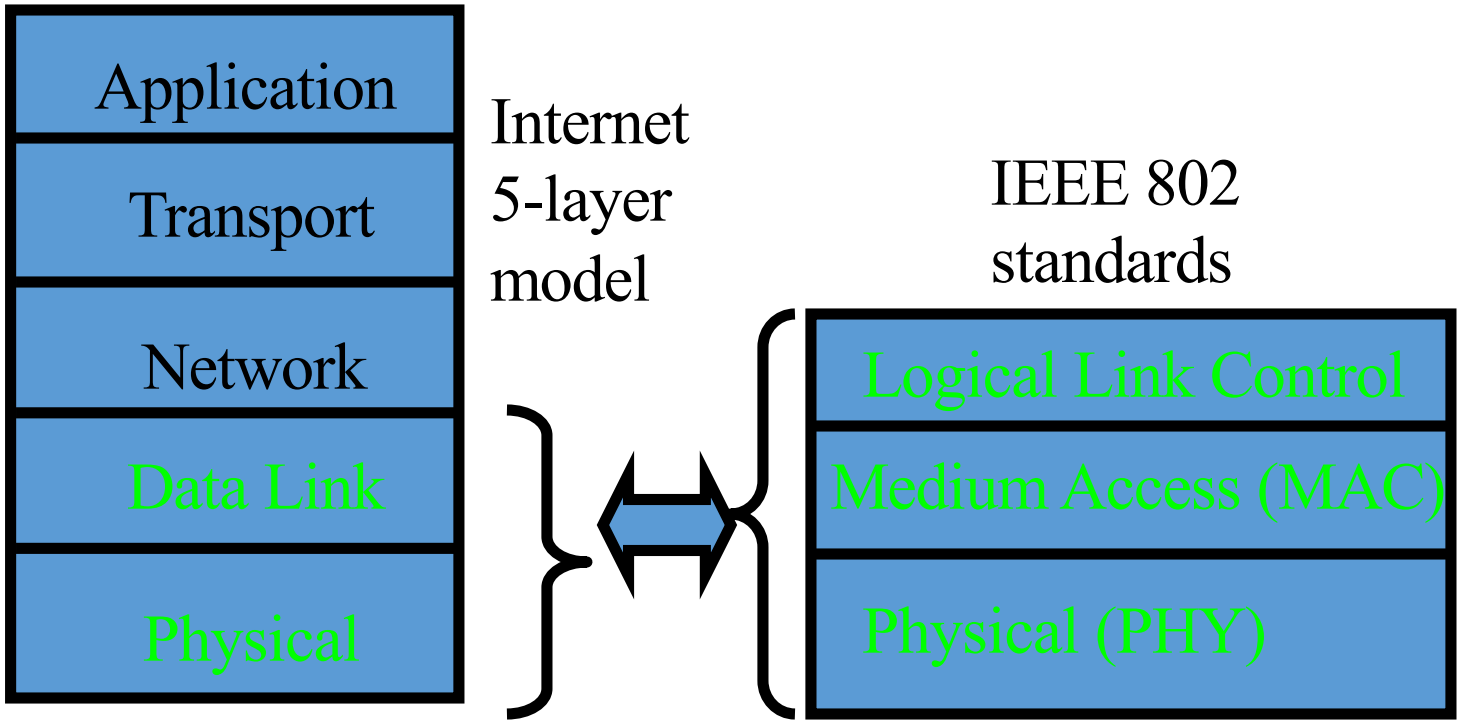
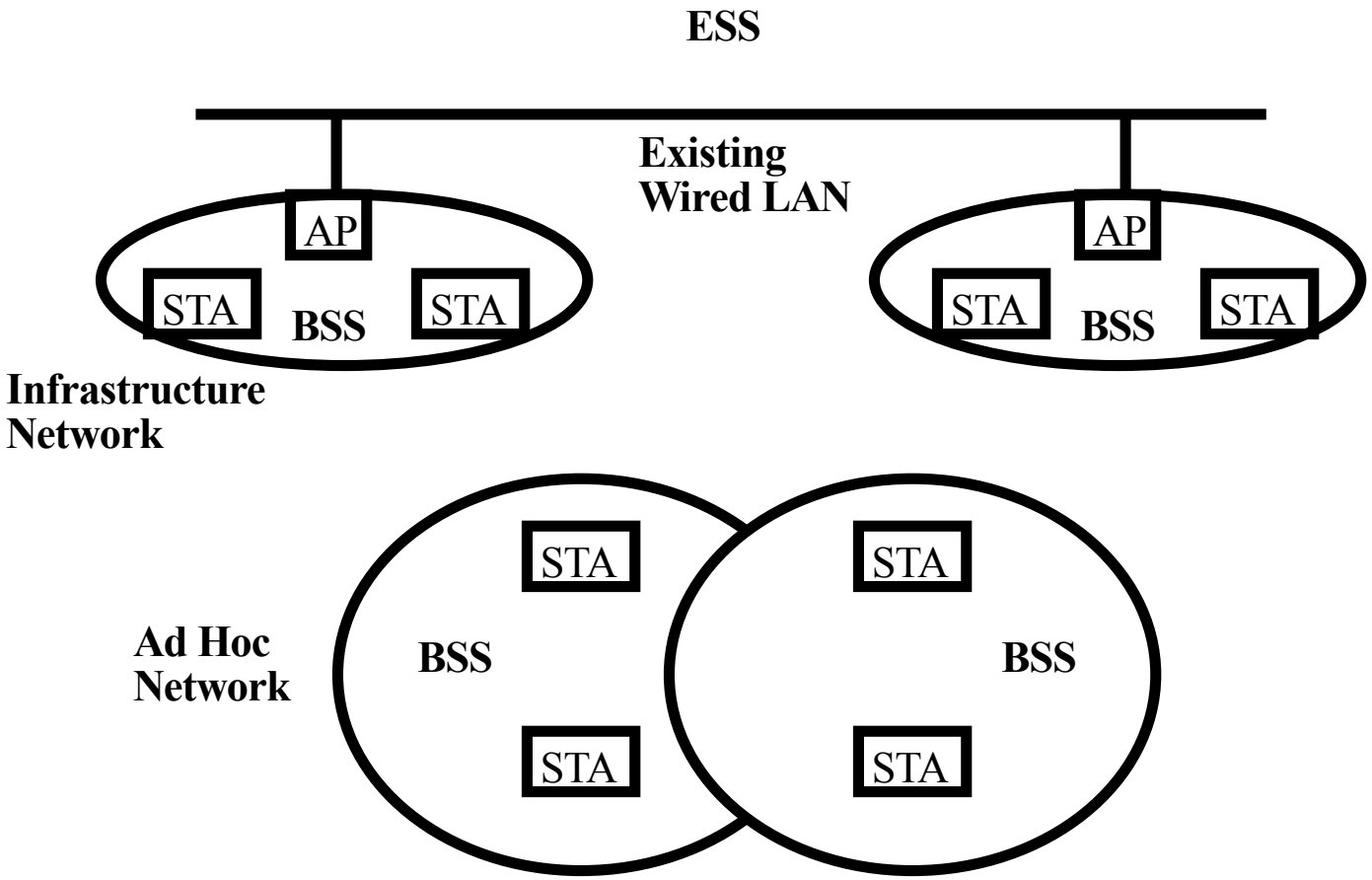
Standardization of Wireless Networks

- WiFi networks are standardized by IEEE
- Under 802 LAN/MAN standards committee



802.11 Architecture

- Two Modes: Infrastructure & Ad hoc



Wireless Channel is the Network

- Direct Sequence Spread Spectrum (DSSS) PHY
  - 2.4 GHz : RF : 1 ~ 2 Mbps
- The Frequency Hopping Spread Spectrum (FHSS) PH
  - 110KHz deviation : RF : PMD controls channel hopping : 2 Mbps
- Infrared (IR) PHY
  - Indoor : IR : 1 and 2 Mbps
- High Rate DSSS PHY – IEEE 802.11b
  - 2.4 GHz : 5.5 ~ 11Mbps

- The OFDM PHY – IEEE 802.11a/g
  - 5.0 GHz : 6~54Mbps
- MIMO: 802.11n/ac: 450Mbps/1.3Gbps
- 60GHz: 802.11ad: 7Gbps

Rich PHY features drive 802.11 standard evolution

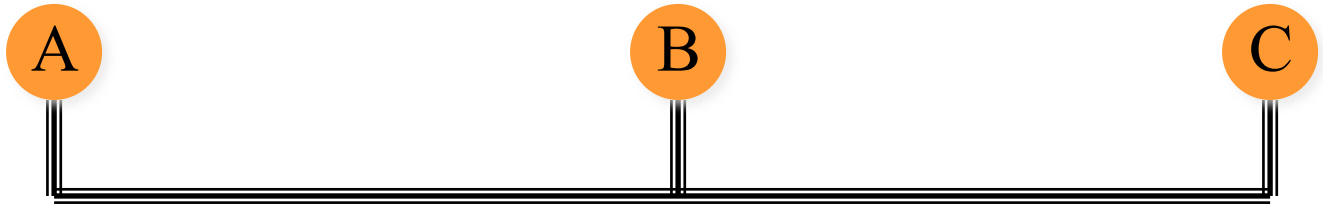
802.11 MAC

- Design Challenges for wireless MAC
  - Hidden/exposed terminals
  - fair share of the channel access
- Basic Access Mechanism for Data Traffic
  - CSMA/CA
  - Binary exponential back-off
  - Deferring via NAV – Network Allocation Vector

Review on CSMA/CD (starting point)

- MAC used by Ethernet
  - Random multiple access
  - Successful in wired network setting
  - Bursty data as the main traffic source

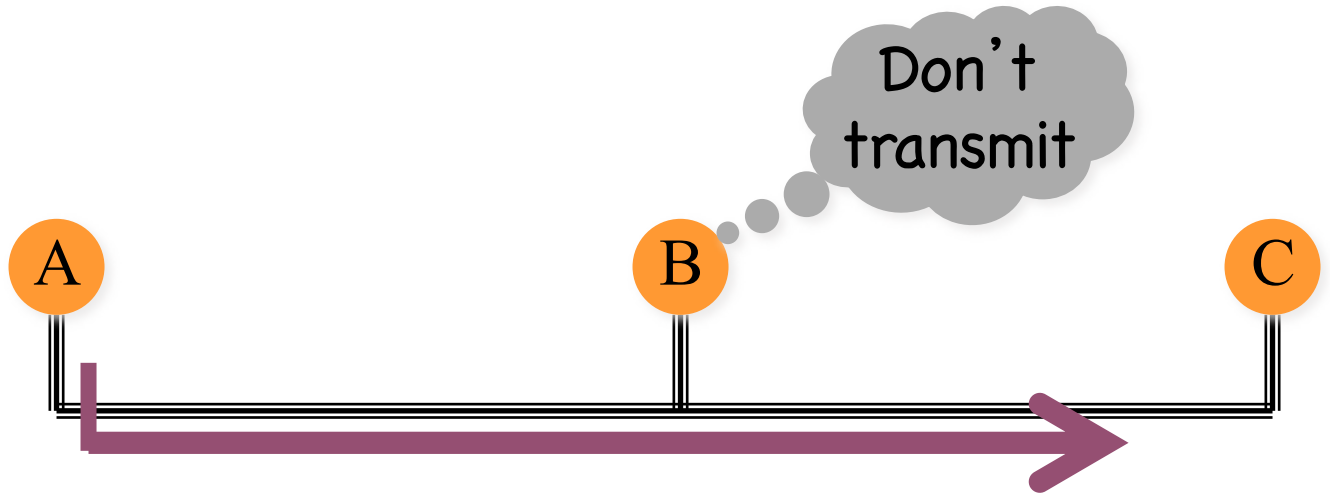
- Multiple nodes share the wired channel



Idea of CSMA

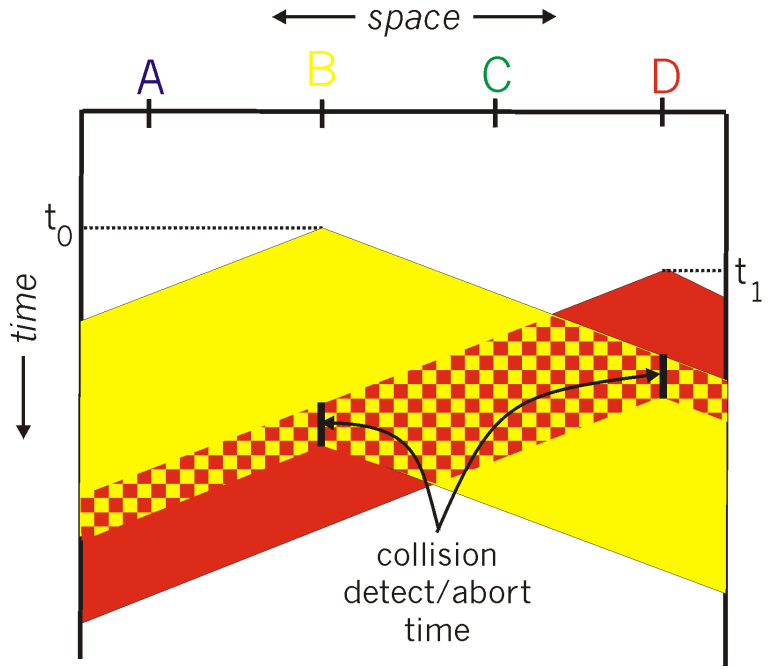
- Transmit and pray
  - Plenty of collisions --> poor throughput at high load
- Listen before you talk (Carrier Sense)
  - Defer transmission when signal on channel

Can collisions still occur?



CSMA/CD (Collision Detection)

- Collisions can still occur
- Keep listening to channel
  - While transmitting



- If (Transmitted_Signal != Sensed_Signal)
  - → Sender knows it's a Collision
  - → ABORT

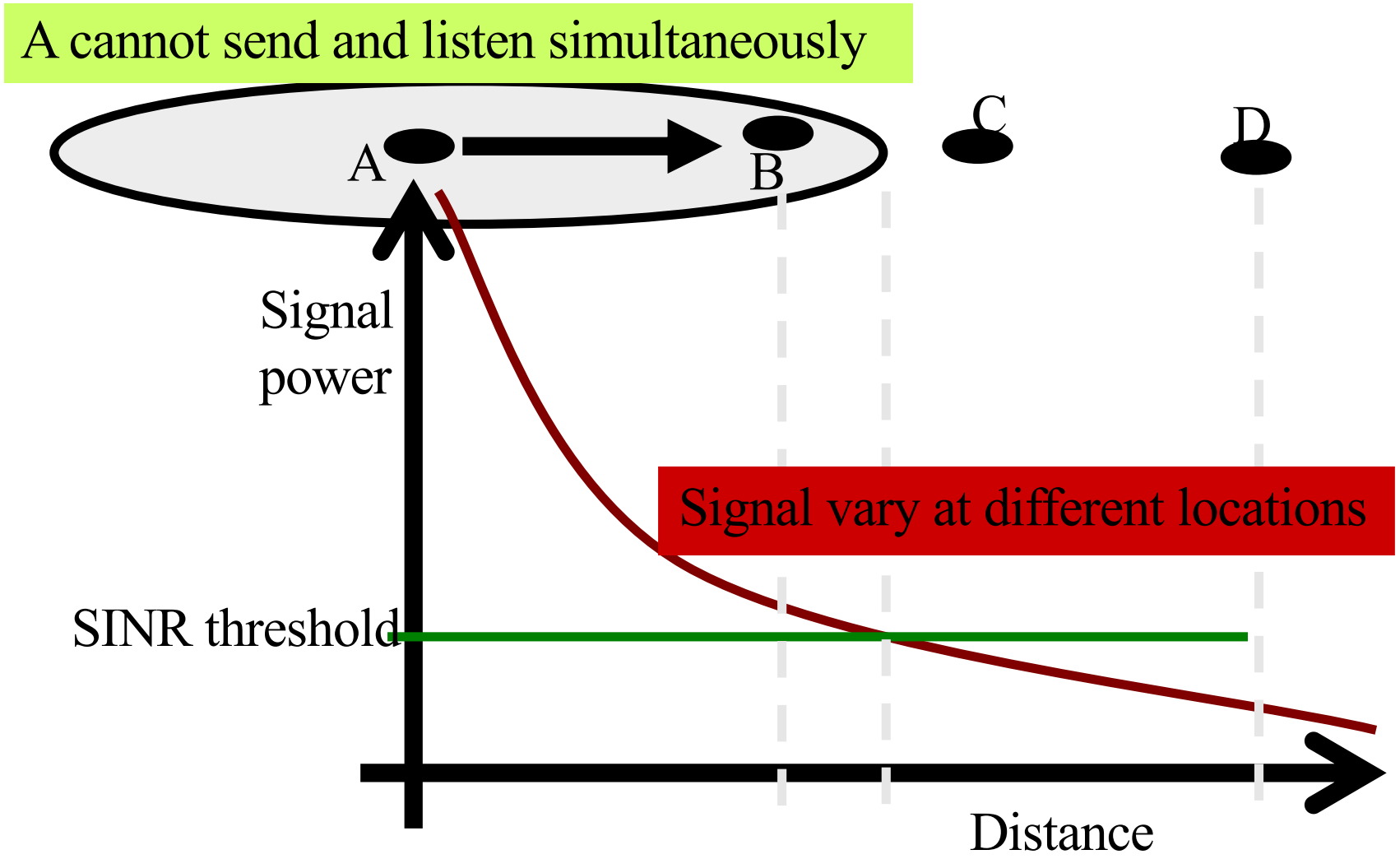
Ethernet CSMA/CD MAC Summary

- **CSMA/CD**: Carrier sensing, deferral as in CSMA
  - collisions detected within short time
  - colliding transmissions aborted, reducing channel wastage
- **Collision Detection**:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - Two key assumptions
    - Transmitter send/listen concurrently: If (Sensed - received = null)? Then success
    - The signal is identical at Tx and Rx

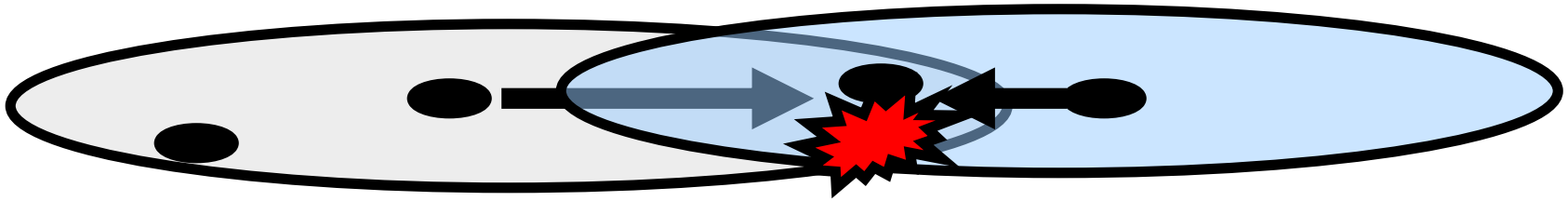
Unfortunately…

- **Neither assumption holds over wireless!!**

Wireless Signal Attenuation



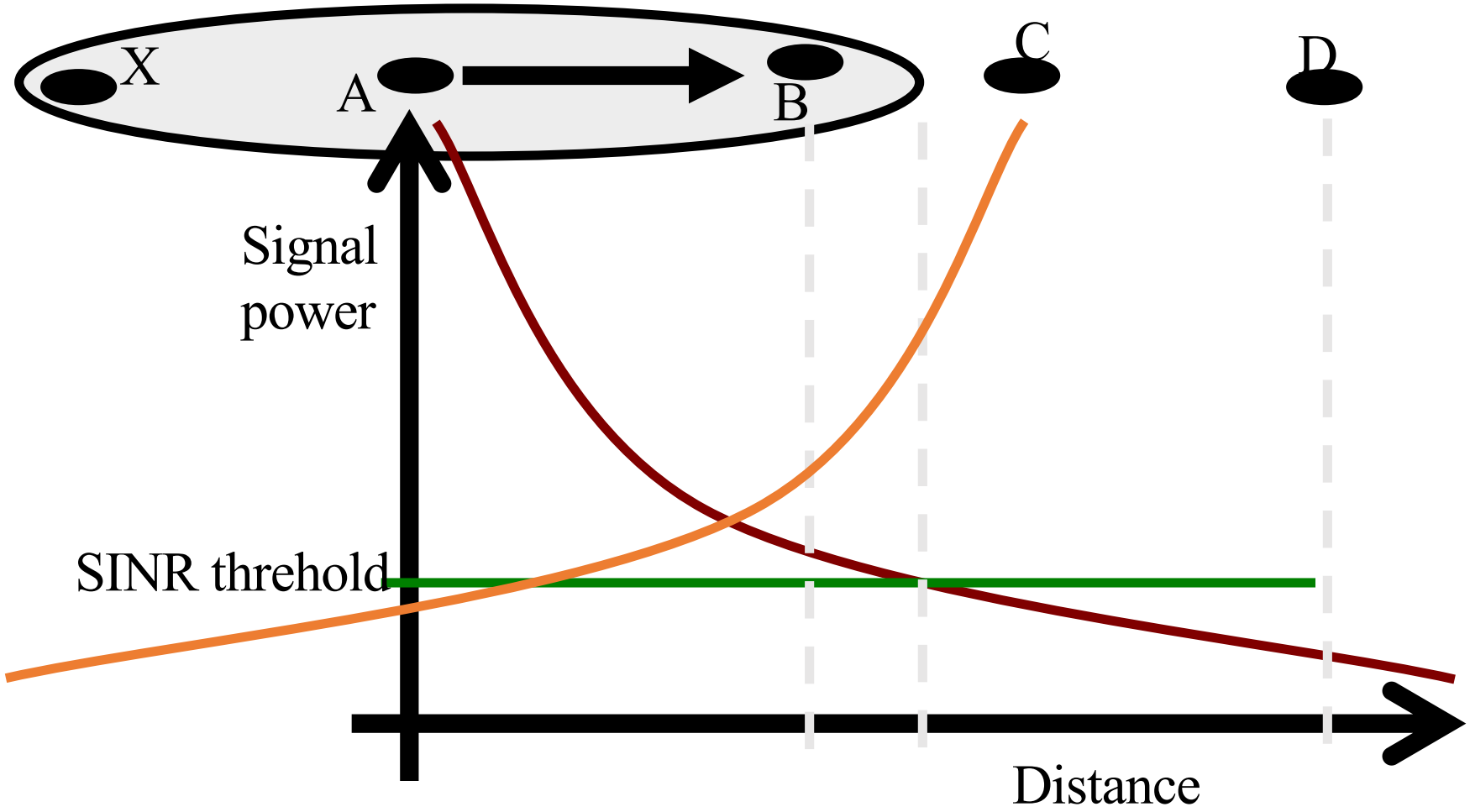
Collision Detection @sender



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

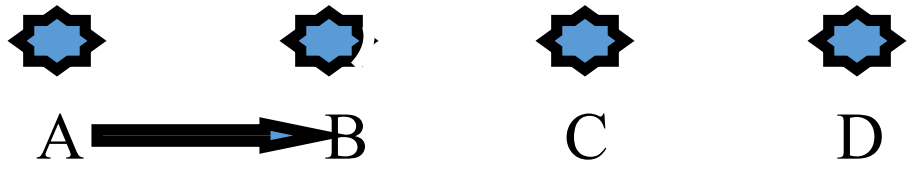
Collision Detection @sender

C is the hidden terminal to A



Hidden Terminal Problem

- HiddenTerminals: within the range of the intended receiver, but outside transmitter
  - **hidden sender C**



Problem: A transmits to B, if C transmits (to D), collision at B
Solution: hidden sender C needs to defer (Question: who tells C, A or B?)

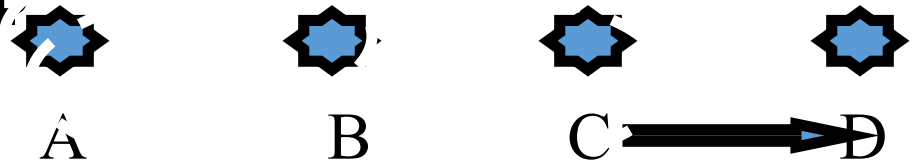
  - **hidden receiver C**

1. C is deferring
2. C cannot hear D
3. C moves away
4. C replies but D cannot hear

Problem: A transmits to B, if D xmits to C, C cannot reply. D confuses (4 cases)
Solution: D needs to be notified that its receiver C is hidden

Exposed Terminal Problem

- Exposed Terminals: within the range of the intended sender, but outside the receiver
  - **Exposed sender B**



Problem: C transmits to D, if B transmits (to A), B cannot hear from A
Solution: exposed sender B needs to defer

  - **Exposed receiver B**

1. B cannot hear A
2. B hears but defers
3. B moves away
4. B replies but A cannot hear

Problem: C transmits to D, if A xmits to B, B cannot hear. A confuses (4 cases)
Solution: A needs to be notified that its receiver B is exposed (how can B hear A?)

Summary of hidden/exposed terminals

- Receiver's perception of a clean/collided packet is critical

- Hidden/exposed senders need to defer their transmissions
- Hidden/exposed receivers need to notify their senders about their status