CSCI-1680
Wireless

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Based partly on lecture notes by Scott Shenker and Rodrigo Fonseca

Wireless

- **Today: wireless networking truly ubiquitous**
  - 802.11, 3G, (4G), WiMAX, Bluetooth, RFID, …
  - Sensor networks, Internet of Things
  - Some new computers have *no* wired networking (mine is about 3 years old, in fact)
  - 4B cellphone subscribers vs. 1B computers
- **What's behind the scenes?**

Wireless is different

- **Signals sent by the sender *often* don't reach the receiver intact**
  - Varies with space: *attenuation*, *multipath*
  - Varies with time: conditions change, *interference*, *mobility*
- ***Distributed*: sender doesn't know what happens at receiver (contrast with wired Ethernet)**
- **Wireless medium is inherently *shared***
  - No easy way out with switches

Implications

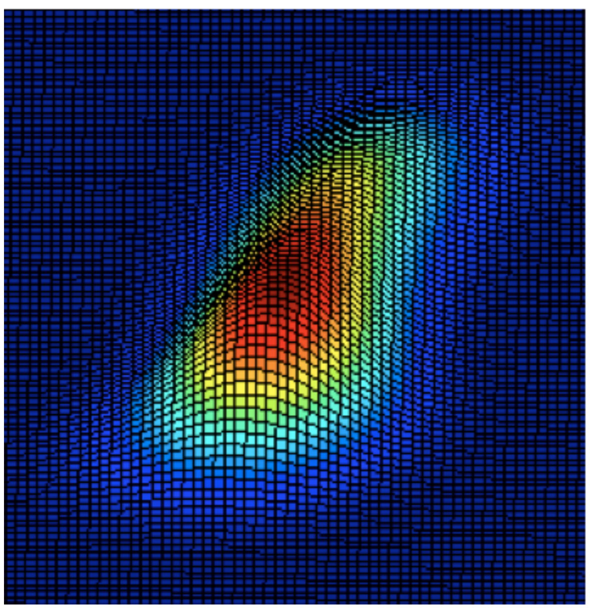
- **Different mechanisms needed**
- **Physical layer**
  - Different knobs: antennas, transmission power, encodings
- **Link Layer**
  - Distributed medium access protocols
  - Topology awareness
- **Network, Transport Layers**
  - Routing, forwarding
- **Interesting advances *do not* abstract away the physical and link layers**

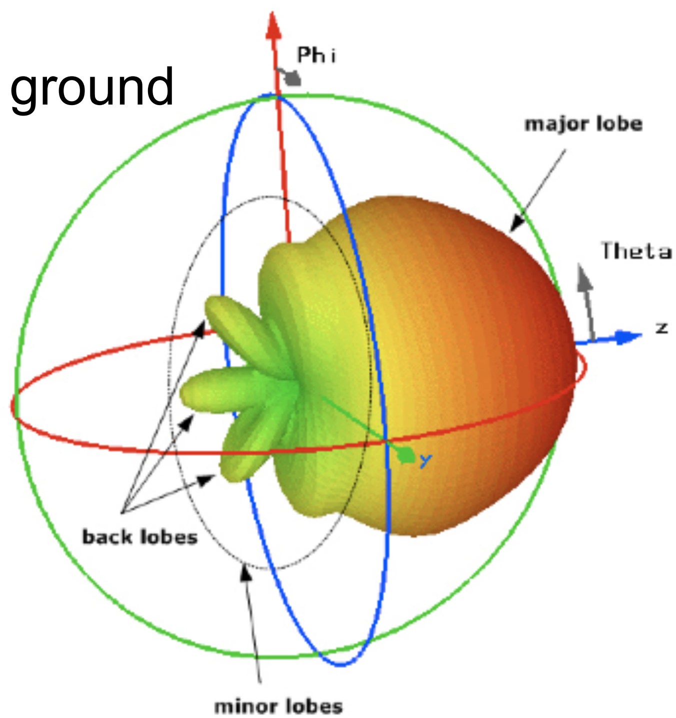
Physical Layer

- **Specifies physical medium**
  - Ethernet: Category 5 cable, 8 wires, twisted pair, R45 jack
  - WiFi wireless: 2.4GHz
- **Specifies the signal**
  - 100BASE-TX: NRZI + MLT-3 encoding
  - 802.11b: binary and quadrature phase shift keying (BPSK/QPSK)
- **Specifies the bits**
  - 100BASE-TX: 4B5B encoding
  - 802.11b @ 1-2Mbps: Barker code (1bit -> 11chips)

What can happen to signals?

- **Attenuation**
  - Signal power attenuates by $\sim r^2$ factor for omni-directional antennas in free-space
  - Exponent depends on type and placement of antennas
    - < 2 for directional antennas
    - > 2 if antennas are close to the ground

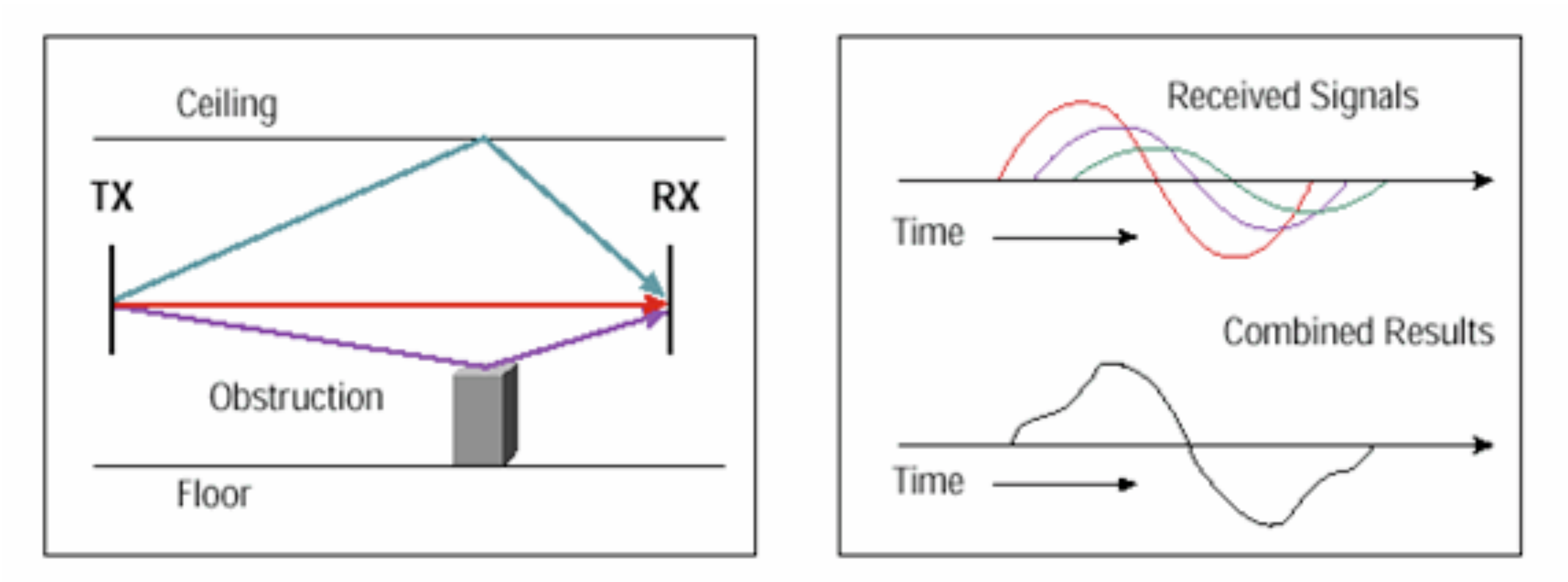




Interference

- **External sources**
  - *E.g.*, 2.4GHz unlicensed ISM band
  - 802.11
  - 802.15.4 (ZigBee), 802.15.1 (Bluetooth)
  - 2.4GHz phones
  - Microwave ovens
- **Internal sources**
  - Nodes in the same network/protocol can (and do) interfere
- **Multipath**
  - Self-interference (destructive)

Multipath



- **May cause attenuation, destructive interference**

Picture from Cisco, Inc.

Signal (+ Interference) to Noise Ratio

- **Remember Shannon?**
- **Shannon-Hartley**

C – Capacity
B – maximum frequency of signal
M – number of discrete “levels” per symbol

$$C = 2B \log_2(M) \text{ bits/sec} \quad (1)$$

- **But noise ruins your party**

$$C = B \log_2(1 + S/N) \text{ bits/sec} \quad (2)$$

$$(1) \leq (2) \Rightarrow M \leq \sqrt{1 + S/N}$$

- **Noise limits your ability to distinguish levels**
  - For a fixed modulation, increases Bit Error Rate (BER)
- **Could make signal stronger**
  - Uses more energy
  - Increases interference to other nodes

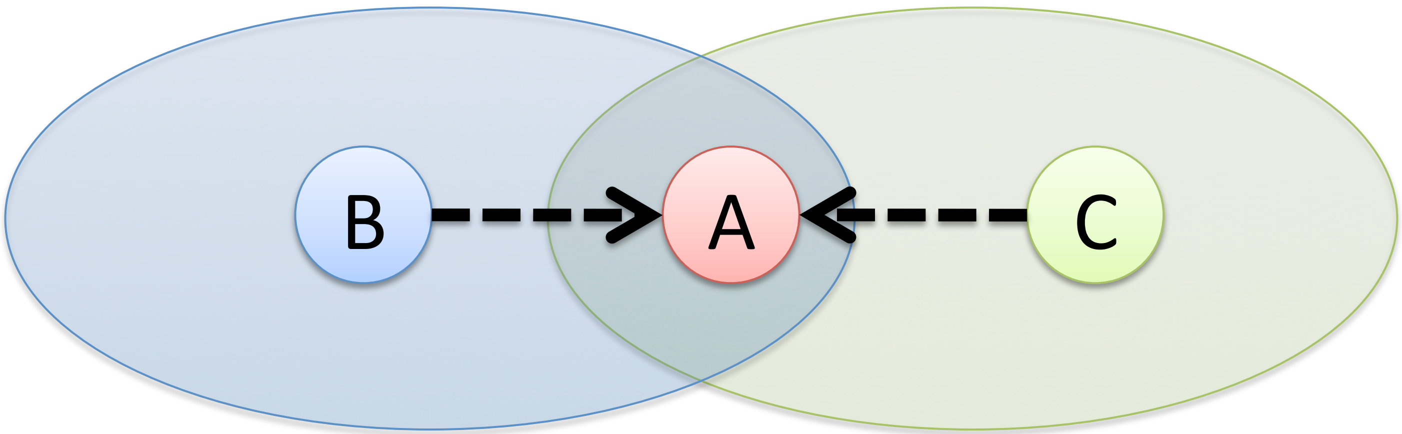
Wireless Modulation/Encoding

- **More complex than wired**
- **Modulation, Encoding, Frequency**
  - Frequency: number of symbols per second
  - Modulation: number of chips per symbol
    - E.g., different phase, frequency, amplitude
  - Encoding: number of chips per bit (to counter errors)
- **Example**
  - 802.11b, 1Msps: 11Mcps, DBPSK, Barker Code
    - 1 chip per symbol, 11 chips/bit
  - 802.11b, 2Msps: 22Mcps, DQPSK, Barker Code
    - 2 chips per symbol, 11 chips/bit

Link Layer

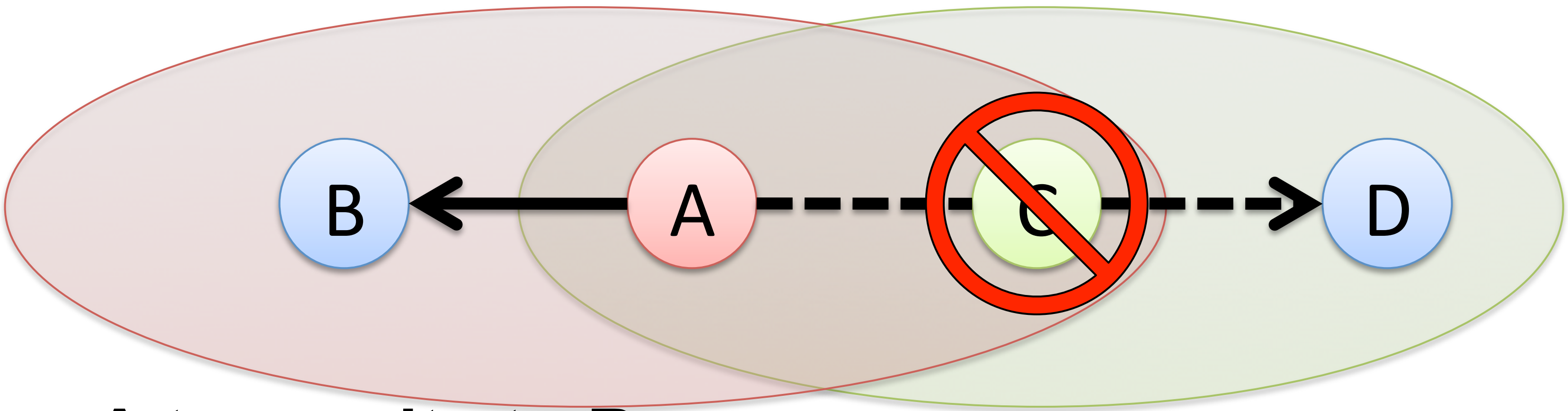
- **Medium Access Control**
  - Should give 100% if one transmitter
  - Should be efficient and fair if more
- **Ethernet uses CSMA/CD**
  - Can we use CD here?
- **No! Collision happens at the receiver**
- **Protocols try to *avoid* collision in the first place**

Hidden Terminals



- **A can hear B and C**
- **B and C can't hear each other**
- **They both interfere at A**
- **B is a *hidden terminal* to C, and vice-versa**
- **Carrier sense at sender is useless**

Exposed Terminals



- **A transmits to B**
- **C hears the transmission, backs off, even though D would hear C**
- **C is an *exposed* terminal to A's transmission**
- **Why is it still useful for C to do CS?**

Key points

- **No global view of collision**
  - Different receivers hear different senders
  - Different senders reach different receivers
- **Collisions happen at the *receiver***
- **Goals of a MAC protocol**
  - Detect if receiver can hear sender
  - Tell senders who might interfere with receiver to shut up

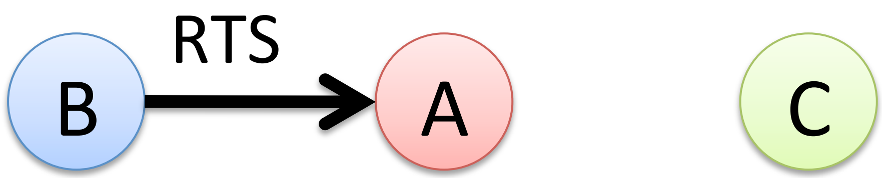
Simple MAC: CSMA/CA

- **Maintain a waiting counter c**
- **For each time channel is free, c--**
- **Transmit when c = 0**
- **When a collision is inferred, retransmit with exponential backoff**
  - Use lack of ACK from receiver to infer collision
  - Collisions are expensive: only full packet transmissions
- **How would we get ACKs if we didn't do carrier sense?**

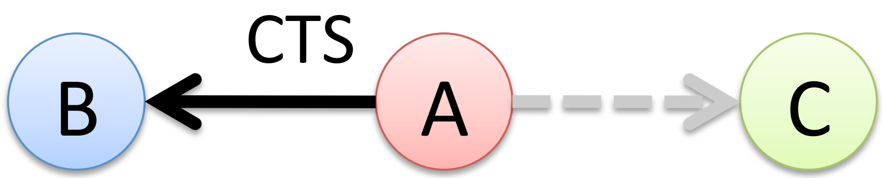
RTS/CTS

- **Idea: transmitter can check availability of channel at receiver**
- **Before every transmission**
  - Sender sends an RTS (Request-to-Send)
  - Contains length of data (in *time* units)
  - Receiver sends a CTS (Clear-to-Send)
  - Sender sends data
  - Receiver sends ACK after transmission
- **If you don't hear a CTS, assume collision**
- **If you hear a CTS for someone else, shut up**

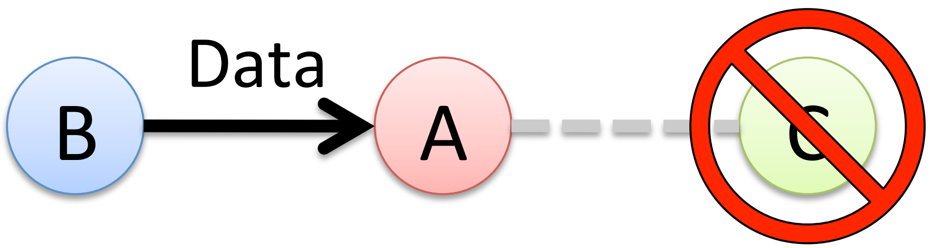
RTS/CTS



RTS/CTS



RTS/CTS



Benefits of RTS/CTS

- **Solves hidden terminal problem**
- **Does it?**
  - Control frames can still collide
  - E.g., can cause CTS to be lost
  - In practice: reduces hidden terminal problem on data packets

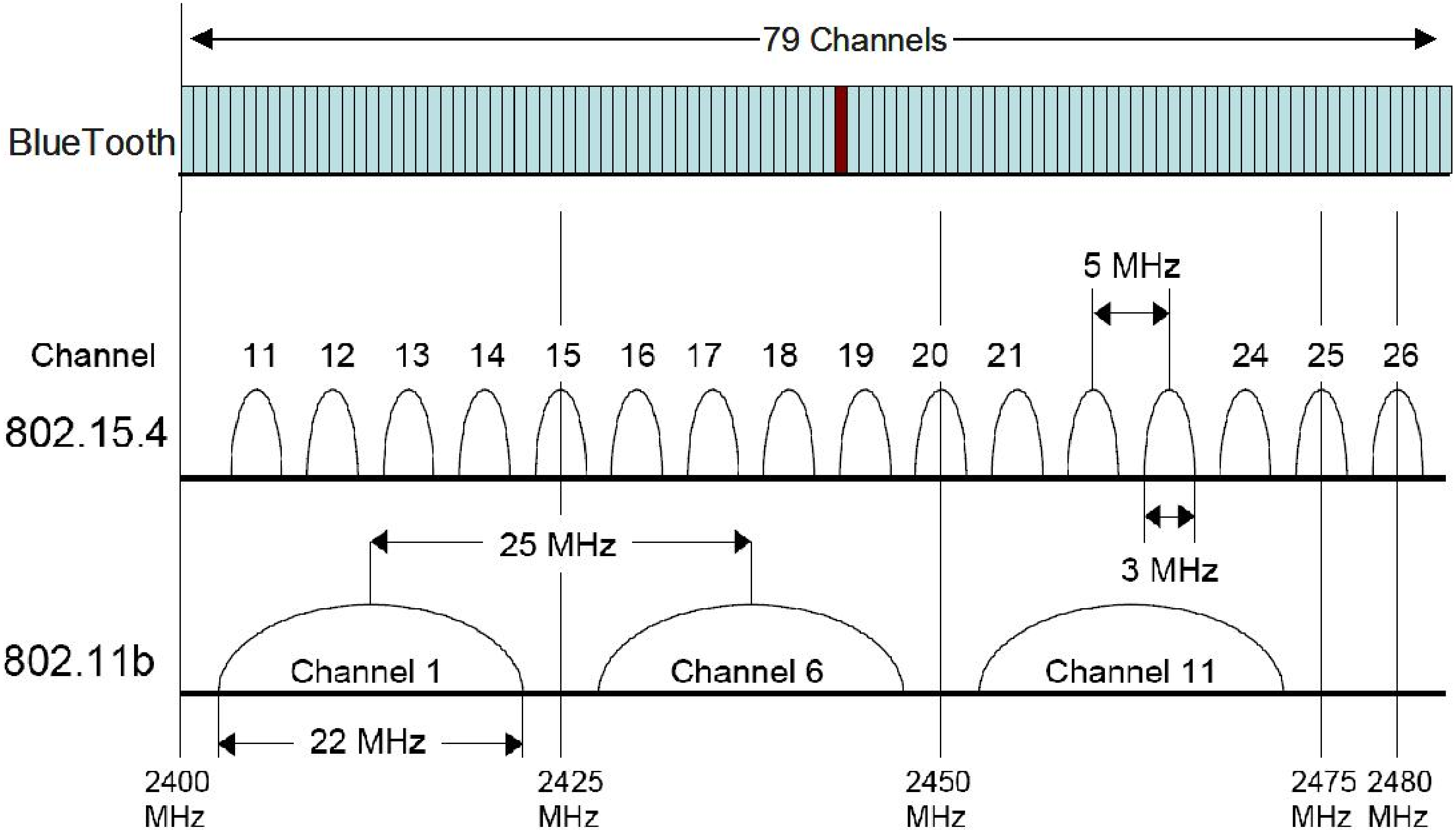
Drawbacks of RTS/CTS

- **Overhead is too large for small packets**
  - 3 packets per packet: RTS/CTS/Data (4-22% for 802.11b)
- **RTS still goes through CSMA: can be lost**
- **CTS loss causes lengthy retries**
- **33% of IP packets are TCP ACKs (small!)**
- **In practice, WiFi doesn't use RTS/CTS**

Other MAC Strategies

- **Time Division Multiplexing (TDMA)**
  - Central controller allocates a time slot for each sender
  - May be inefficient when not everyone sending
- **Frequency Division**
  - Multiplexing two networks on same space
  - Nodes with two radios (think graph coloring)
  - Different frequency for upload and download

ISM Band Channels



Network Layer

- **What about the network topology?**
- **Almost everything you use is *single hop*!**
  - 802.11 in infrastructure mode
  - Bluetooth
  - Cellular networks
  - WiMax (Some 4G networks)
- **Why?**
  - Really hard to make multihop wireless efficient

WiFi Distribution System

- **802.11 typically works in *infrastructure mode***
  - Access points – fixed nodes on wired network
- **Distribution system connects APs**
  - Typically connect to the same Ethernet, use learning bridge to route to nodes' MAC addresses
- **Association**
  - Node negotiates with AP to get access
  - Security negotiated as well (WEP, WPA, etc)
  - Passive or active

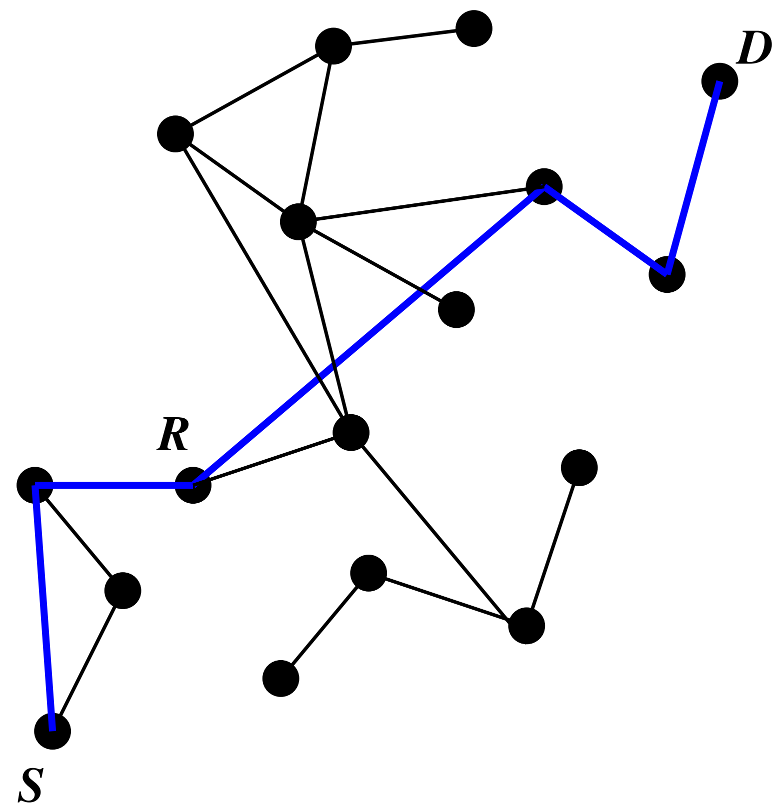
Wireless Multi-Hop Networks

- **Some networks are multihop, though!**
  - Ad-hoc networks for emergency areas
  - Vehicular Networks
  - Sensor Networks
    - E.g., infrastructure monitoring
  - Multihop networking to share Internet access
    - E.g. Meraki

Many Challenges

- **Routing**
  - Link estimation
- **Multihop throughput dropoff**

The Routing Problem



- Find a route from S to D
- Topology can be very dynamic

Routing

- **Routing in ad-hoc networks has had a lot of research**
  – General problem: any-to-any routing
  – Simplified versions: any-to-one (base station), one-to-any (dissemination)
- **DV too brittle: inconsistencies can cause loops**
- **DSDV**
  – Destination Sequenced Distance Vector

DSDV

- **Charles Perkins (1994)**
- **Avoid loops by using sequence numbers**
  - Each destination increments own sequence number
    - Only use EVEN numbers
  - A node selects a new parent if
    - Newer sequence number or
    - Same sequence number and *better* route
  - If disconnected, a node increments destination sequence number to next ODD number!
  - No loops (only transient loops)
  - Slow: on some changes, need to wait for root

Many Others

- DSR, AODV: on-demand
- Geographic routing: use nodes' physical location and do greedy routing
- Virtual coordinates: derive coordinates from topology, use greedy routing
- Tree-based routing with on-demand shortcuts
- …

Routing Metrics

- **How to choose between routes?**
- **Hopcount is a poor metric!**
  - Paths with few hops may use long, marginal links
  - Must find a balance
- **All links do *local retransmissions***
- **Idea: use expected transmissions over a link as its cost!**
  - ETX = 1/(PRR) (Packet Reception Rate)
  - Variation: ETT, takes data rate into account

Multihop Throughput

- **Only every third node can transmit!**
  - Assuming a node can talk to its immediate neighbors
  - (1) Nodes can't send and receive at the same time
  - (2) Third hop transmission prevents second hop from receiving
  - (3) Worse if you are doing link-local ACKs
- **In TCP, problem is worse as data and ACK packets contend for the channel!**
- **Not to mention multiple crossing flows!**

Sometimes you can't (or shouldn't) hide that you are on wireless!

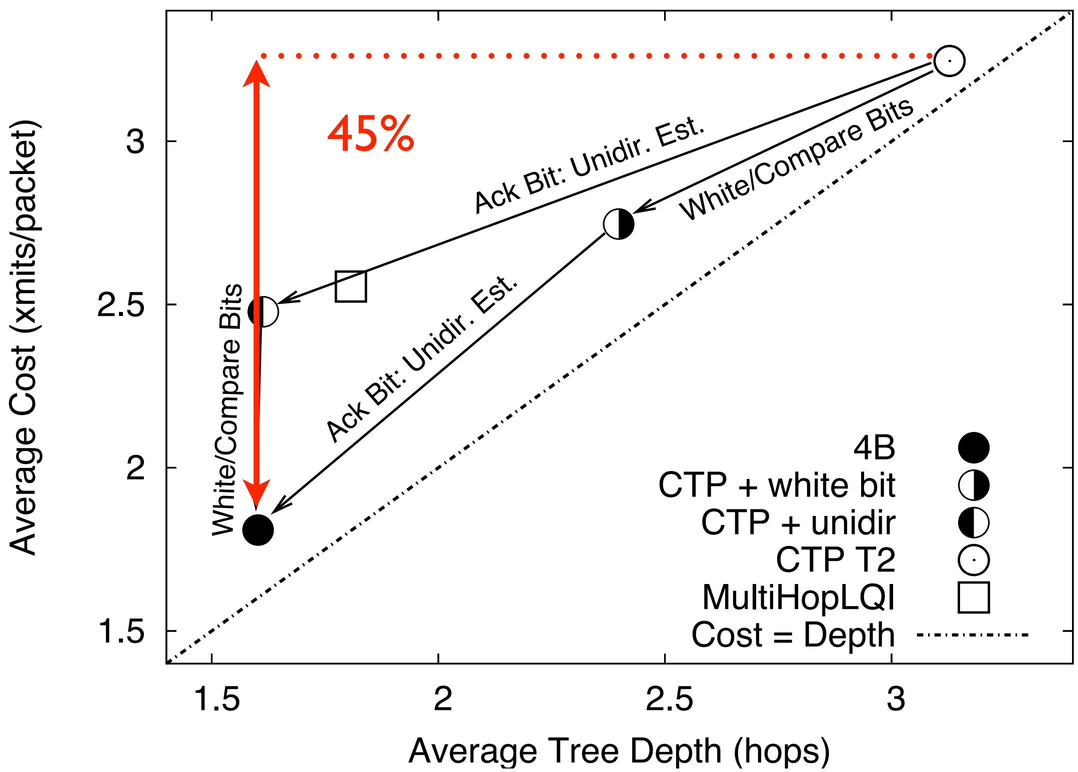
- Three examples of relaxing the layering abstraction

Examples of Breaking Abstractions

- **TCP over wireless**
  - Packet losses have a strong impact on TCP performance
  - Snoop TCP: hide retransmissions from TCP end-points
  - Distinguish congestion from wireless losses

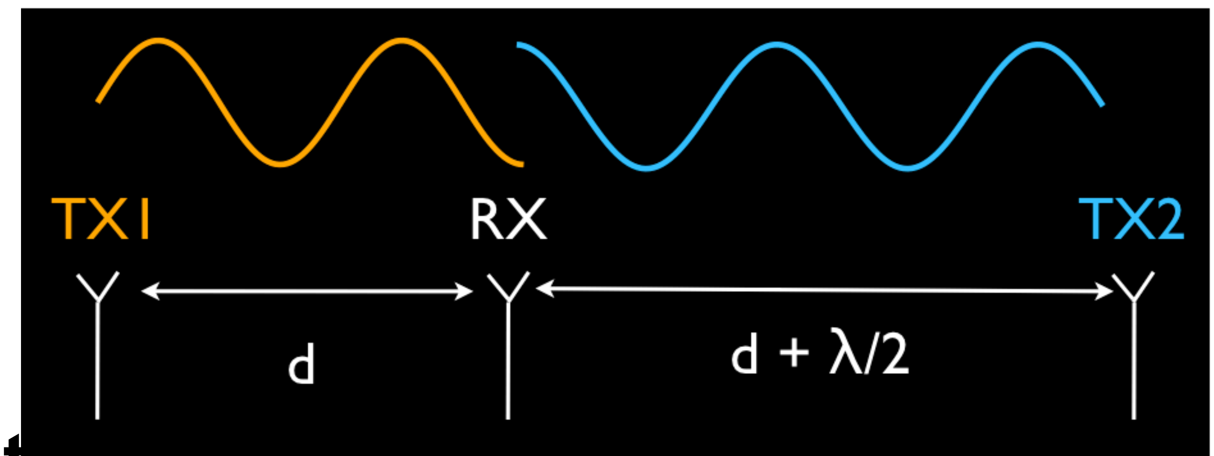
4B Link Estimator

- **Uses information from Physical, Routing, and Forwarding layers to help estimate link quality**



Stanford's Full Duplex Wireless

- **Status quo: nodes can't transmit and receive at the same time**
  - Why? TX energy much stronger than RX energy
- **Key insight:**



- **With other tricks, 92% of optimal bandwidth**

Summary

- **Wireless presents many challenges**
  - Across all layers
  - Encoding/Modulation (we're doing pretty well here)
  - Distributed multiple access problem
  - Multihop
- **Most current protocols sufficient, given over provisioning (*good enough syndrome*)**
- **Other challenges**
  - Smooth handoff between technologies (3G, Wifi, 4G…)
  - Low-cost, long range wireless for developing regions
  - Energy usage

Coming Up

- Next time: security