CSCI-1680 Wireless

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Based partly on lecture notes by Scott Shenker and John Jannotti

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
 - 4B cellphone subscribers vs. 1B computers
- What's behind the scenes?



Wireless is different

- Signals sent by the sender don't always 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
- 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
- Most 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 ~r² factor for omni-directional antennas in free-space
- Exponent depends on type and placement of antennas



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.

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 user
- Should be efficient and fair if more users
- 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?



- 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















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
- 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 (e.g., pipelines) monitoring
- Multihop networking to share Internet access
 - E.g. NYC Mesh





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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-toany (dissemination)
- DV too brittle: inconsistencies can cause loops
- DSDV
 - Destination Sequenced Distance Vector



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



Backscatter

- Transmit without generating signals!
 Don't transmit, reflect!
- Flashlight and mirror analogy





Backscatter





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

