18-452/18-750
Wireless Networks and Applications
Lecture 9: Wireless LANs
802.11 Wireless

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Fall Semester 2018

http://www.cs.cmu.edu/~prs/wirelessF18/

Announcements

- Homework 1 should be out by tomorrow
- Project 1 by Friday
- Schedule:
  - » Thursday lecture from Silicon Valley campus
  - » Friday recitation from Pittsburgh campus
- Friday's lecture was not recorded
  - » Will schedule a makeup Q&A session

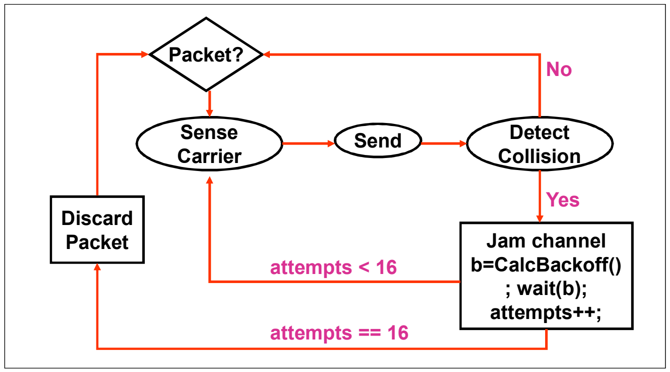
Outline

- Data link fundamentals
  - » And what changes in wireless
- Aloha
- Ethernet
- Wireless-specific challenges
  - » Ethernet review
  - » How wireless differs
- 802.11 and 802.15 wireless standards

"Regular" Ethernet CSMA/CD

- Multiple Access: multiple hosts are competing for access to the channel
- Carrier-Sense: make sure the channel is idle before sending – "listen before you send"
- Collision Detection: collisions are detected by listening on the medium and comparing the received and transmitted signals
- Collisions results in 1) aborting the colliding transmissions and 2) retransmission of the packets
- Exponential backoff is used to reduce the chance of repeat collisions
  - » Also effectively reduces congestion

Carrier Sense Multiple Access/ Collision Detection (CSMA/CD)



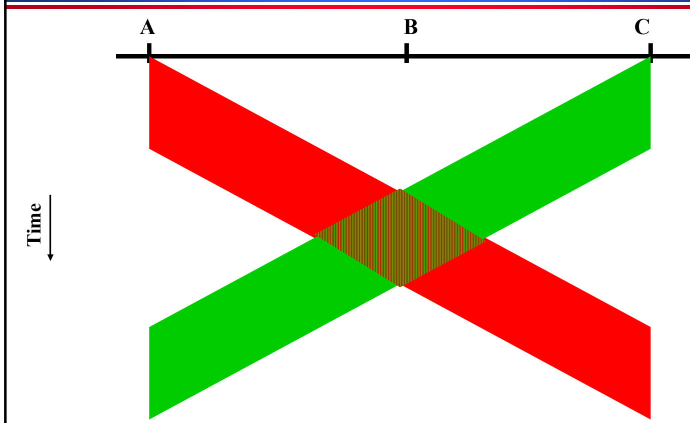
Ethernet Backoff Calculation

- Challenge: how do we avoid that two nodes retransmit at the same time collision
- Exponentially increasing random delay
  - » Infer "number" senders from # of collisions
  - » More senders → increase wait time
- First collision: choose K from {0,1}; delay is K x 512 bit transmission times
- After second collision: choose K from {0,1,2,3}
- After ten or more collisions, choose K from {0,1,2,3,4,…,1023}

How to Handle Transmission When Line is Sensed Busy

- ***p-persistent scheme***:
  - » Transmit with probability p once the channel goes idle
  - » Delay the transmission by t_{prop} with the probability (1-p)
- ***1-persistent scheme***: p = 1
  - » E.g. Ethernet
- ***nonpersistent scheme***:
  - » Reschedule transmission for a later time based on a retransmission delay distribution (e.g. exp backoff)
  - » Senses the channel at that time
  - » Repeat the process
- When is each solution most appropriate?

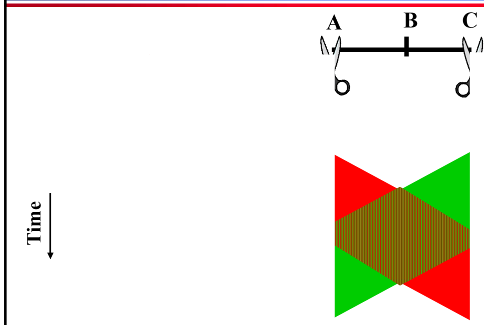
Collisions



Dealing with Collisions

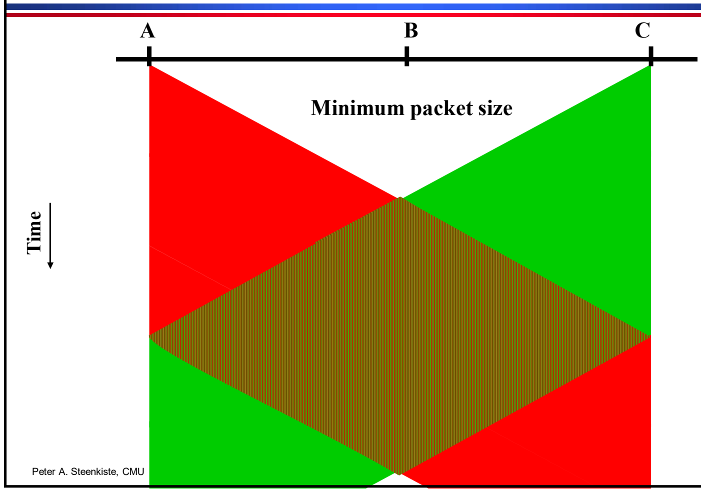
- Collisions will happen: nodes can start to transmit “simultaneously”
  - » Vulnerability window depends on length of wire
- Recovery requires that both transmitters can detect the collision reliably
  - » Clearly a problem as shown on previous slide
- How can we guarantee detection?

Detect Collisions



Limit length wire

Detect Collisions



So What about Wireless?

- Depends on many factors, but high level:
- Random access solutions are a good fit for data in the unlicensed spectrum
  - » Lower control complexity, especially for contention-based protocols (e.g., Ethernet)
  - » There may not always be a centralized controller
  - » May need to support multi-hop
  - » Also used in many unlicensed bands
- Cellular uses scheduled access
  - » Need to be able to guarantee performance
  - » Have control over spectrum – simplifies scheduled access
  - » More on this later in the course

Summary

- **Wireless uses the same types of protocols as wired networks**
  - » But it is inherently a multiple access technology
- **Some fundamental differences between wired and wireless may result in different design choices**
  - » Higher error rates
  - » Must support variable bit rate communication
  - » Signal propagation and radios are different

Outline

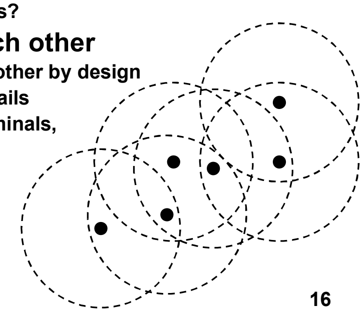
- **Data link fundamentals**
  - » And what changes in wireless
- **Aloha**
- **Ethernet**
- **Wireless-specific challenges**
- **802.11 and 802.15 wireless standards**

Wireless Ethernet is a Good Idea, but …

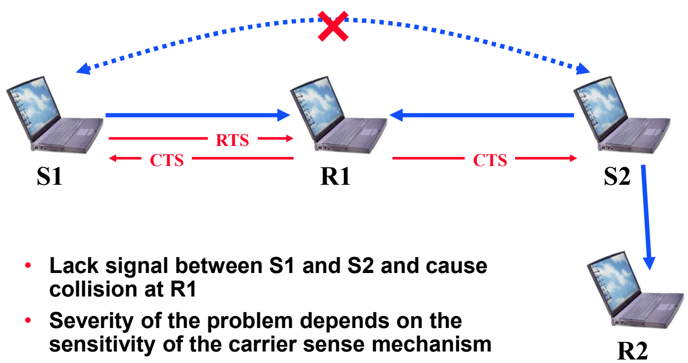
- **Attenuation varies with media**
  - » Also depends strongly on distance, frequency
- **Wired media have exponential dependence**
  - » Received power at d meters proportional to 10^{-kd}
  - » Attenuation in dB = *k d*, where *k* is dB/meter
- **Wireless media has logarithmic dependence**
  - » Received power at d meters proportional to d^{-n}
  - » Attenuation in dB = *n log d*, where *n* is path loss exponent; *n=2* in free space
  - » Signal level maintained for much longer distances?
- **But we are ignoring the constants!**
  - » Wireless attenuation at 2.4 GHz: 60-100 dB
  - » In practice numbers can be much lower for wired

Implications for Wireless Ethernet

- **Collision detection is not practical**
  - » Ratio of transmitted signal power to received power is too high at the transmitter
  - » Transmitter cannot detect competing transmitters (is deaf while transmitting)
  - » So how do you detect collisions?
- **Not all nodes can hear each other**
  - » Ethernet nodes can hear each other by design
  - » "Listen before you talk" often fails
  - » Hidden terminals, exposed terminals,
  - » Capture effects
- **Made worse by fading**
  - » Changes over time!

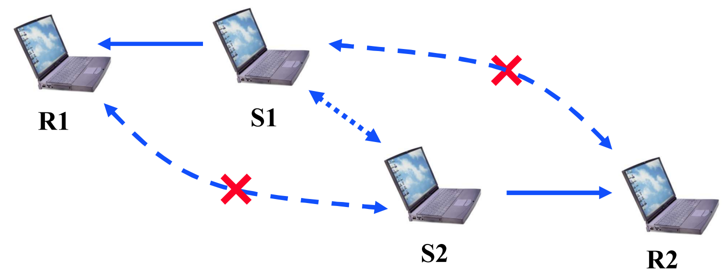


Hidden Terminal Problem



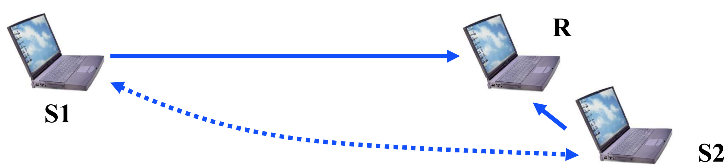
- Lack signal between S1 and S2 and cause collision at R1
- Severity of the problem depends on the sensitivity of the carrier sense mechanism
  - » Clear Channel Assessment (CCA) threshold

Exposed Terminal Problem



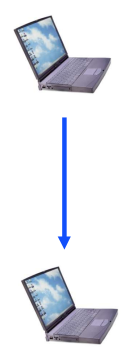
- Carrier sense prevents two senders from sending simultaneously although they do not reach each other's receiver
- Severity again depends on CCA threshold
  - » Higher CCA reduces occurrence of exposed terminals, but can create hidden terminal scenarios

Capture Effect



- Sender S2 will almost always "win" if there is a collision at receiver R.
- Can lead to extreme unfairness and even starvation.
- Solution is power control
  - » Very difficult to manage in a non-provisioned environment!

Wireless Packet Networking Problems



- Some nodes suffer from more interference than others
  - » Node density
  - » Traffic volume sent by neighboring nodes
- Leads to unequal throughput
- Similar to wired network: some flows traverse tight bottleneck while others do not

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- Wireless-specific challenges
- 802.11 and 802.15 wireless standards

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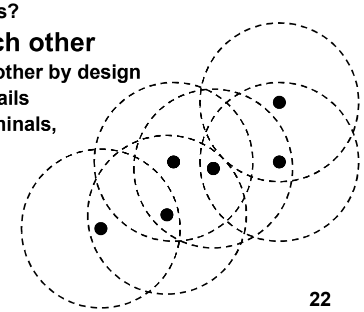

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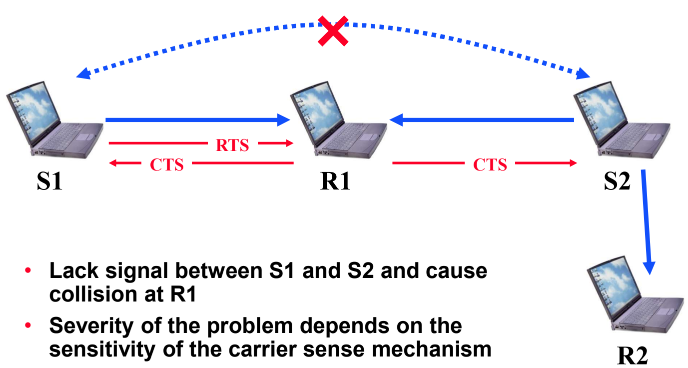

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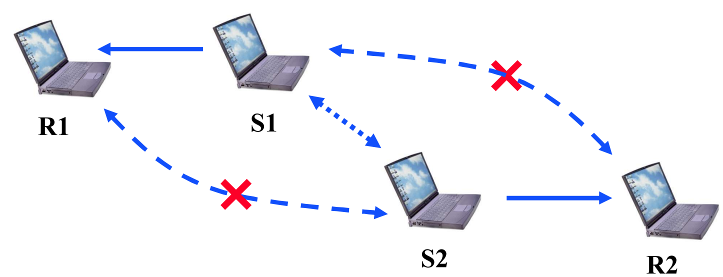

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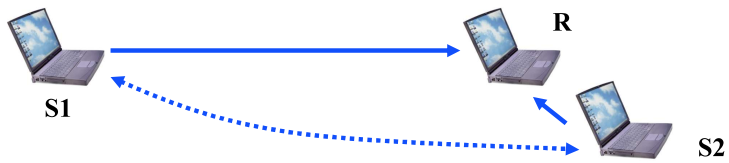

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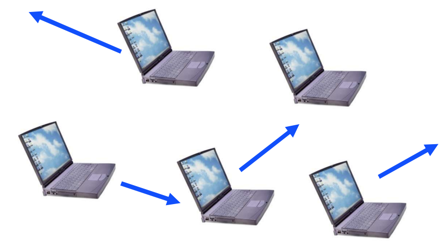
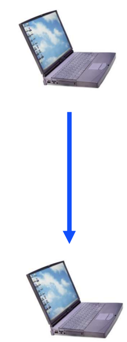

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Summary Wireless Challenges

- Wireless signal propagation creates problems for “wireless Ethernet”
  - » Collision Detection is not possible
  - » Hidden and exposed terminals
  - » Capture effect
- Aloha was the first wireless data communication protocol
  - » Simple: send whenever you want to
  - » Has low latency but low capacity

Outline

- Data link fundamentals
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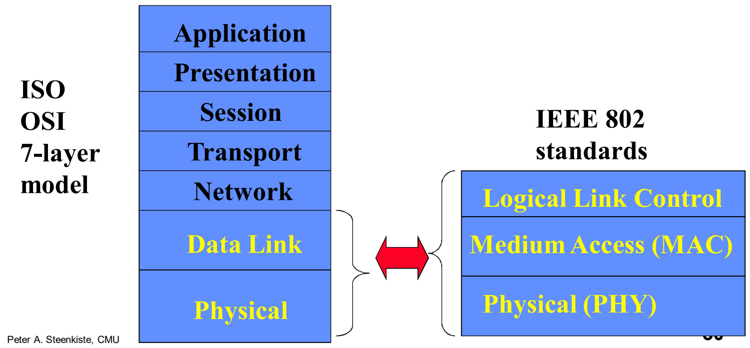
- Ethernet
- Aloha
- Wireless-specific challenges
- 802.11 and 802.15 wireless standards
  - » 802 protocol overview
  - » Wireless LANs – 802.11
  - » Personal Area Networks – 802.15

History

- Aloha wireless data network
- Car phones
  - » Big and heavy "portable" phones
  - » Limited battery life time
  - » But introduced people to "mobile networking"
  - » Later turned into truly portable cell phones
- Wireless LANs
  - » Originally in the 900 MHz band
  - » Later evolved into the 802.11 standard
  - » Later joined by the 802.15 and 802.16 standards
- Cellular data networking
  - » Data networking over the cell phone
  - » Many standards – throughput is the challenge

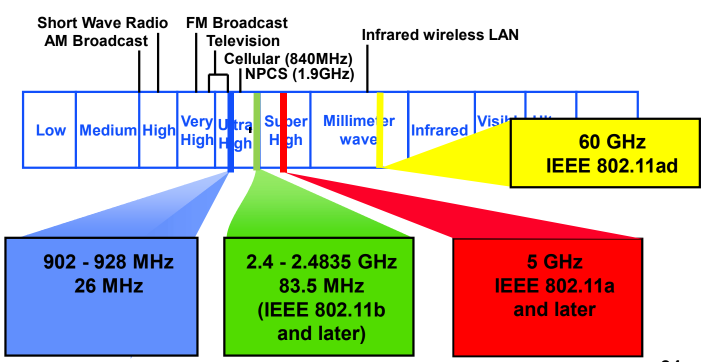
Standardization of Wireless Networks

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



Frequency Bands

- Industrial, Scientific, and Medical (ISM) bands
- Generally called "unlicensed" bands



The 802 Class of Standards

- List on next two slides
- Some standards apply to all 802 technologies
  - » E.g. 802.2 is LLC
  - » Important for inter operability
- Some standards are for technologies that are outdated
  - » Not actively deployed anymore
  - » Many of the early standards are obsolete

802 Standards – Part 1

Name	Description	Note
IEEE 802.1	Higher Layer LAN Protocols (Bridging)	active
IEEE 802.2	LLC	disbanded
IEEE 802.3	Ethernet	active
IEEE 802.4	Token bus	disbanded
IEEE 802.5	Token ring MAC layer	disbanded
IEEE 802.6	MANs (DQDB)	disbanded
IEEE 802.7	Broadband LAN using Coaxial Cable	disbanded
IEEE 802.8	Fiber Optic TAG	disbanded
IEEE 802.9	Integrated Services LAN (ISLAN or isoEthernet)	disbanded
IEEE 802.10	Interoperable LAN Security	disbanded
IEEE 802.11	Wireless LAN (WLAN) & Mesh (Wi-Fi certification)	active
IEEE 802.12	100BaseVG	disbanded
IEEE 802.13	Unused[2]	Reserved for Fast Ethernet development[3]
IEEE 802.14	Cable modems	disbanded
IEEE 802.15	Wireless PAN	active
IEEE 802.15.1	Bluetooth certification	active
IEEE 802.15.2	IEEE 802.15 and IEEE 802.11 coexistence	
IEEE 802.15.3	High-Rate wireless PAN (e.g., UWB, etc.)	
IEEE 802.15.4	Low-Rate wireless PAN (e.g., ZigBee, WirelessHART, MiWi, etc.)	active
IEEE 802.15.5	Mesh networking for WPAN	

802 Standards – Part 2

IEEE 802.15.6	Body area network	active
IEEE 802.15.7	Visible light communications	
IEEE 802.16	Broadband Wireless Access (WiMAX certification)	
IEEE 802.16.1	Local Multipoint Distribution Service	
IEEE 802.16.2	Coexistence wireless access	
IEEE 802.17	Resilient packet ring	hibernating
IEEE 802.18	Radio Regulatory TAG	
IEEE 802.19	Coexistence TAG	
IEEE 802.20	Mobile Broadband Wireless Access	hibernating
IEEE 802.21	Media Independent Handoff	
IEEE 802.22	Wireless Regional Area Network	
IEEE 802.23	Emergency Services Working Group	
IEEE 802.24	Smart Grid TAG	New (November, 2012)
IEEE 802.25	Omni-Range Area Network	

Outline

- 802 protocol overview
- Wireless LANs – 802.11
  - » Overview of 802.11
  - » 802.11 MAC, frame format, operations
  - » 802.11 management
  - » 802.11*
  - » Deployment example
- Personal Area Networks – 802.15

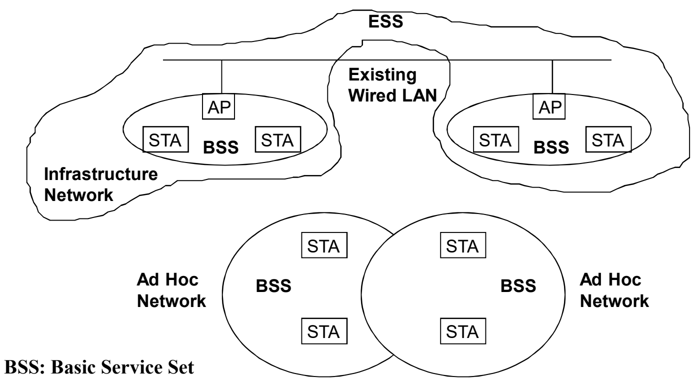
IEEE 802.11 Overview

- Adopted in 1997 with goal of providing
  - » Access to services in wired networks
  - » High throughput
  - » Highly reliable data delivery
  - » Continuous network connection, e.g. while mobile
- The protocol defines
  - » MAC sublayer
  - » MAC management protocols and services
  - » Several physical (PHY) layers: IR, FHSS, DSSS, OFDM
- Wi-Fi Alliance is industry group that certifies interoperability of 802.11 products

Infrastructure and Ad Hoc Mode

- Infrastructure mode: stations communicate with one or more access points which are connected to the wired infrastructure
  - » What is deployed in practice
- Two modes of operation:
  - » Distributed Control Functions - DCF ← **Our Focus**
  - » Point Control Functions – PCF
  - » PCF is rarely used - inefficient
- Alternative is “ad hoc” mode: multi-hop, assumes no infrastructure
  - » Rarely used, e.g. military
  - » Hot research topic!

802.11 Architecture



BSS: Basic Service Set
ESS: Extended Service Set

Terminology for DCF

- Stations and access points
- BSS - Basic Service Set
  - » One access point that provides access to wired infrastructure
  - » Infrastructure BSS
- ESS - Extended Service Set
  - » A set of infrastructure BSSs that work together
  - » APs are connected to the same infrastructure
  - » Tracking of mobility
- DS – Distribution System
  - » AP communicates with each other
  - » Thin layer between LLC and MAC sublayers