Spring ‘18 Course Preview: COS 463 Wireless Networks

COS 418: Distributed Systems
Lecture 22
Kyle Jamieson

[Selected content adapted from H. Hassanieh and P. Steenkiste]

Wireless is increasingly prevalent

- Health and Fitness
- Virtual Reality
- UAVs
- Internet of Things Sensors

Increasing wireless connectivity demand

Billions of wireless devices
Industrial Impact: Cisco Meraki

- Founders Biswas, Bicket, Aguayo PhD candidates who left program
  - Initial products: mesh networking technology from grad school

- Pivot three years later
  - Focus on cloud-managed Wi-Fi

  - Cisco acquisition, new Cisco Wi-Fi product line

  - **Takeaway:** Wireless technology → industry impact

Course Contents

- **Wireless From the Transport Layer Downwards**
  - Transport over wireless, Mesh, wireless routing etc.

- **Overcoming Bit Errors**
  - Error Detection and Correction, Convolutional Codes, “Rateless” codes

- **An Introduction to the Wireless Channel**
  - Noise, Multipath Propagation, spectrum, sampling, filter etc.

- **Practical wireless communication systems**
  - OFDM, channel estimation, MIMO etc.

- **Boutique topics**
  - Wireless interference, low power wireless communication system etc.

Prerequisites and Administrivia

- Assume basic familiarity with computer networking concepts and programming
  - **COS 217** required

  - Knowledge of C and one other programming language helpful, but not required

  - Not open to freshmen

- **COS 463** is a **COS systems-track** course

Target audiences

- **COS 463** is **cross-registered** with ELE (ELE 463)

  1. COS students who want to extend their networking background to wireless communications

  2. ELE students who want to extend their wireless communications knowledge to networks
Modes of delivery

- **Lectures**: Introduce concepts, gain background knowledge

- **Precepts & Lab**: hands-on training on wireless systems
  - **Learning by doing**: building wireless systems with a software defined radio platform
  - Precepts and labs **closely coupled**

Lab sessions

- **Build real wireless networks** on software defined radio
  - C and/or Python knowledge helpful, but not required

Goals of the Class

1. **Understand wireless networks’** design and architecture
   - From **signals** to **bits** to **datagrams**
   - **Understand** design choices and tradeoffs

2. Understand how the design of **wireless networks** interacts with the rest of the **wired Internet**

3. Gain proficiency in **building real** wireless networks

Readings

- **Text book**: Cory Beard and William Stallings, *Wireless Communication Networks and Systems*
- **Reference material**: Eldad Perahia, Robert Stacey, *Next Generation Wireless LANs*
Class Grading

• Mid-term exam: 20%
• Final exam: 30%
• Lab programming assignments: 40%
• Class participation: 10%
  – Precept attendance and participation
  – Activity on Piazza

Today

1. How do wireless and wired networks differ?
2. What makes wireless interesting?
3. What new services does wireless enable?

Wireless is less reliable

• In wired networks, link bit error rate is $10^{-12}$ and less
• Wireless networks are far from that target
  – Bit error rates of $10^{-6}$ and above are common!
• Why?

Today

1. How do wireless and wired networks differ?
   – A shared wireless medium
   – Multipath propagation
   – Mobility
2. What makes wireless interesting?
3. What new services does wireless enable?
Wireless is a shared medium

- Transmitters broadcast
- Devices can operate either in transmit or receive mode
- How do you coordinate access to the medium?

Why is a point-to-point link the wrong abstraction for building wireless networks?

Reason #1: Interference

- **Noise** is naturally present in the environment from many sources
- **Interference** can be from other users of the same technology, other technologies altogether
- Impacts the throughput users can achieve

Traditional wireless network design

- Mimics wired network design
  - Assumes wireless links are point-to-point
- **But** most wireless links have a broadcast nature
**Reason #2: Can leverage broadcast**

- Want to exchange packets, but out of direct range

**Solution using wired abstraction**

- Requires four transmissions in total

**Idea: Router combines the packets**

- Requires just three transmissions in total

**Router broadcasts the combination**

- Requires just three transmissions in total
**Summary: Shared medium is very different**

- Wireless' shared medium is **very different** than point-to-point wired links
- So need to **think about wireless networks differently**
- **Interference** is a **major problem**
- But also can leverage **broadcast nature** of wireless
  - **Four to three** transmissions **increases throughput**
  - Serve **more users** or **increase app performance**
    - **Better Skype calls**

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**Today**

1. **How do wireless and wired networks differ?**
   - A **shared** wireless medium
   - **Multipath propagation**
   - **Mobility**

2. What makes wireless interesting?

3. What new services does wireless enable?

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**Multipath propagation**

- Signal **bounces off surface** and **interferes with itself**
- **Can be constructive** or **destructive**, depending on the respective path lengths
- Can be **more than two paths**

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**Today**

1. **How do wireless and wired networks differ?**
   - A **shared** wireless medium
   - **Multipath propagation**
   - **Mobility**

2. What makes wireless interesting?

3. What new services does wireless enable?
Mobility affects link throughput

- Quality of transmission depends on distance, other factors
- Affects the throughput mobile users achieve
- Worst case: Outages, periods with no connectivity!

And it gets worse...

- Impact of mobility on transmission is complex
  - Multipath effects
- Mobility also affects addressing and routing

Today

1. How do wireless and wired networks differ?
2. What makes wireless interesting?
   - Deep Intellectual challenges
   - Cross-layer design
3. What new services does wireless enable?
Some things are well understood…

Q: What’s the capacity of a point-to-point link?
   – Bits/second can "reliably" communicate

• Before Shannon:
  – Only way to make probability of bit error arbitrarily small is to reduce the rate of communication.

• After Shannon (with some assumptions):
  – Up to some rate C (Shannon Capacity), coding can make chance of bit error arbitrary small!

…others aren’t understood well at all!

Q: What’s the capacity of a wireless network?

A [Information theory]: “ ”
A [Computer networks]: “Let’s build a better medium access control protocol!”

Today

1. How do wireless and wired networks differ?

2. What makes wireless interesting?
   – Deep Intellectual challenges
   – Cross-layer design

3. What new services does wireless enable?

The argument for cross-layer design

• Traditional approach: Optimize within layers
• New Approach: Design and optimize across layers

Applications
Transport Layer
Network Layer
Physical Layer
End-to-End (including Transport)
Communications and Coding
Radio Hardware, Antennas
Why is layer separation sub-optimal?

Scenario: Laptop in a “dead spot”

With layer separation:
A few bit errors → persistent loss
But two access points unlikely to have same bit error

Solution: A cross-layer Approach

Physical layer delivers partially-correct packets
Link/network layers combine correct bits across different access points to correct errors

A challenge for bit combining

“First bit is 1”
“First bit is 0”

Which access point should we believe?
Idea: Network cooperates with PHY layer

- Physical layer already estimates **probability of correctness (confidence)** in each 0/1 bit decision
- **Idea:** Expose **confidence** to the higher layers

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<thead>
<tr>
<th>Confidence</th>
<th>Physical Layer</th>
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Solution: Use confidences across layers

- **Idea:** Network cooperates with PHY layer
- **Idea:** Expose confidence to the higher layers
- **Solution:** Use confidences across layers

- **Scenario:** Laptop in a Dead Spot
- **High-speed Ethernet**
- **First bit is 0 with 0.5 confidence**
- **First bit is 0 with 0.8 confidence**

Believe the access point with higher confidence

Experiment: Packet delivery v. poor coverage

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<thead>
<tr>
<th>Fraction of Packets Delivered</th>
<th>Average Bit Error Rate</th>
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<tbody>
<tr>
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<td>0.001</td>
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**Layer Separation**
Experiment: Packet delivery v. poor coverage

Fraction of Packets Delivered

- Cross-layer Approach
- Layer separation

Average Bit Error Rate

Fundamental change in network architecture

- Traditional approach: Optimize within layers
- New Approach: Design and optimize across layers

Applications
Transport Layer
Network Layer
Physical Layer

Today
1. How do wireless and wired networks differ?
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New Services: Wireless localization

- GPS does not work indoors → use Wi-Fi to localize

Indoor Navigation
Business Analytics
WiFi Geofencing
Indoor Robotic Navigation
Localization and RFID tags

Localize Everything and Anything!

Battery-free stickers to tag any and every object

Smart homes

RFID motion tracking in the air
For further information:
Class Website

[www.cs.princeton.edu/courses/archive/spring18/cos463](http://www.cs.princeton.edu/courses/archive/spring18/cos463)

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<th>Monday topic:</th>
<th>Cluster Scheduling and Fairness</th>
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**COS-463 Wireless Networks (Spr)**

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<tr>
<th>Week</th>
<th>Topic</th>
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**Monday topic:**
Cluster Scheduling and Fairness