Class Introduction

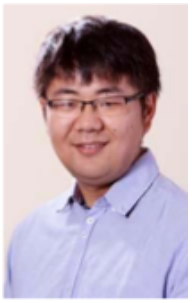
COS 463: Wireless Networks
Lecture 1
Kyle Jamieson

[Parts adapted from H. Hassanieh, P. Steenkiste]

Course staff and office hours

Kyle Jamieson

CS room 305



Longfei Shangguan

CS room 418C

Allen Welkie

CS room 418C

- **Office hours:** By appointment, synchronized with Lab programming exercise deadlines on Piazza

Wireless is increasingly prevalent

Smart Home

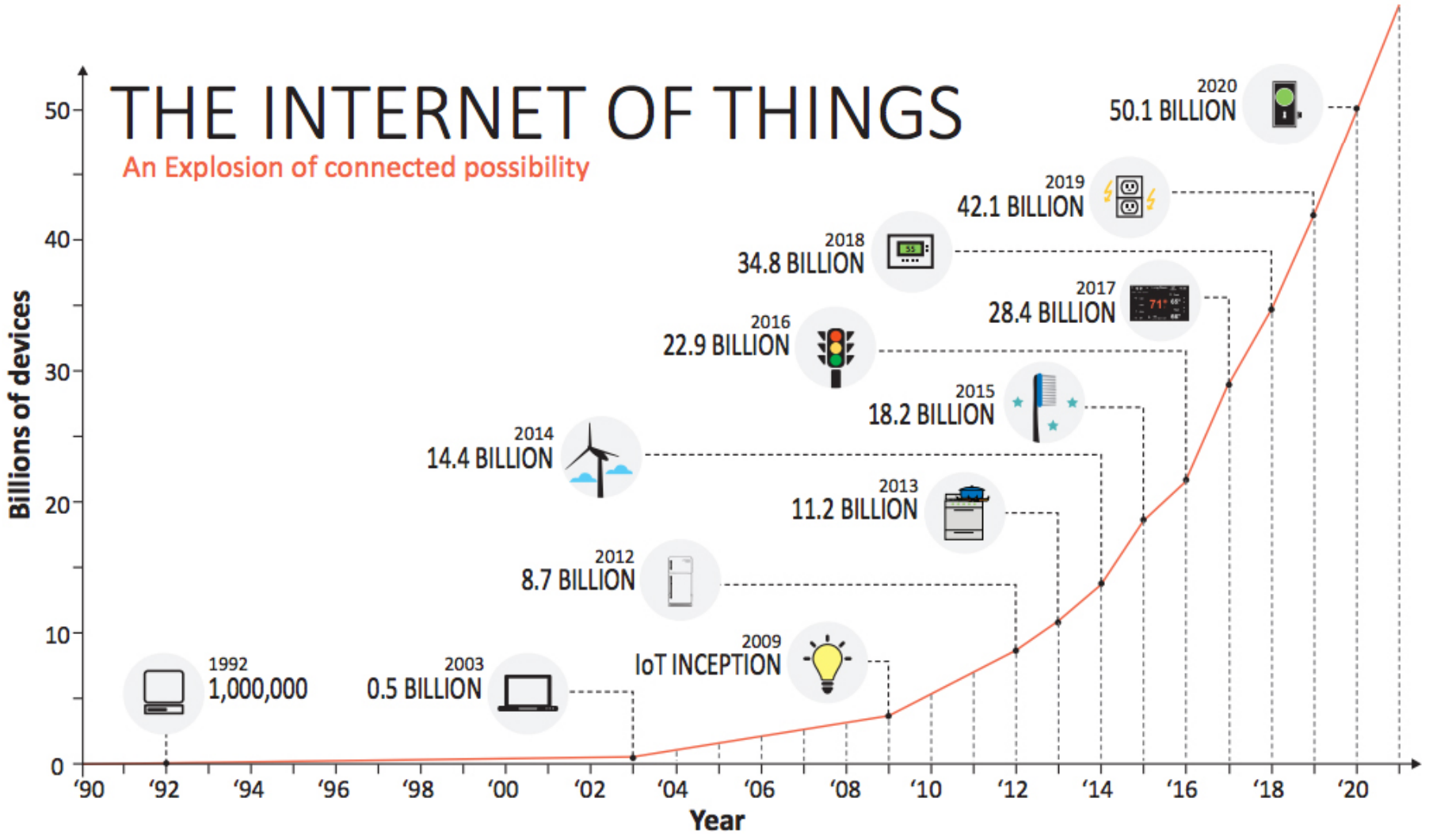
- Health and Fitness
- Virtual Reality
- UAVs
- Internet of Things Sensors

Vehicular Networks

Cellular Networks

Mobile connectivity for people: Increased wireless demand

Next demand driver: 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**

Roofnet Mesh Network

- Cisco acquisition, new Cisco Wi-Fi product line

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

COS 463: Course Approach

- Gain **deep knowledge** of wireless networks by learning **across all layers** of the stack
  - Some "ELE" content, some "COS" content

- **Taught from first principles:** build up **Computer Systems, Signal Processing** knowledge

- Test that knowledge and **cement understanding** by hands-on programming lab assignments
  - **Build** something **>> "Know"** something
  - Labs on real software-defined radio hardware
    - Real-world **"surprises"**

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

Course Contents

1. **Wireless From the Transport Layer Downwards**
   - Transport over wireless, link layer, medium access

2. **Overcoming Bit Errors**
   - Error Detection/correction, convolutional & "Rateless" codes

3. **An Introduction to the Wireless Channel**
   - Noise, Multipath Propagation, radio spectrum

4. **Wireless Physical Layer concepts**
   - OFDM, channel estimation, MIMO etc.

5. **Boutique topics**
   - Visible light communication, low power, Wi-Fi localization

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**

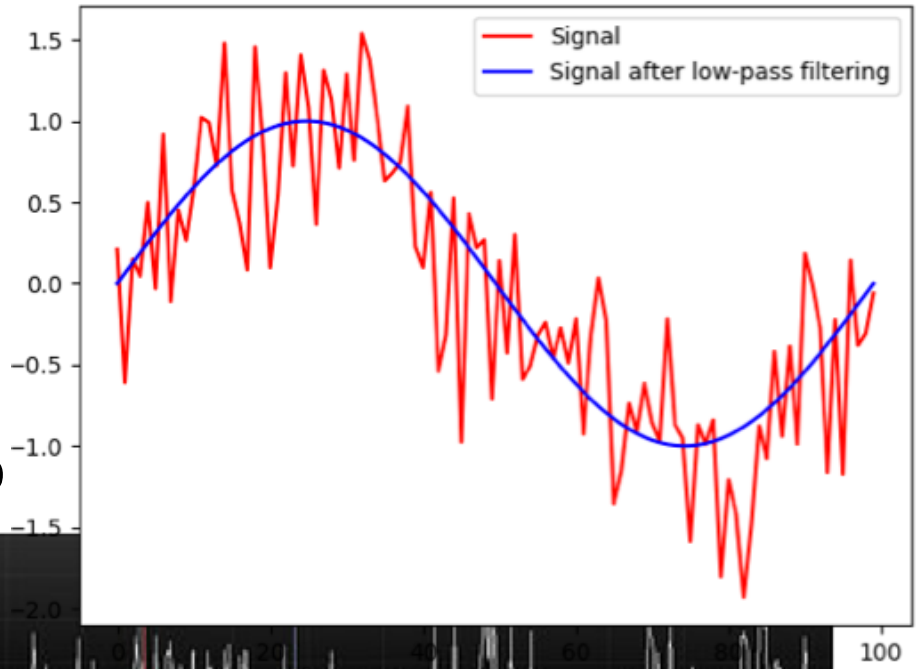
Lab logistics

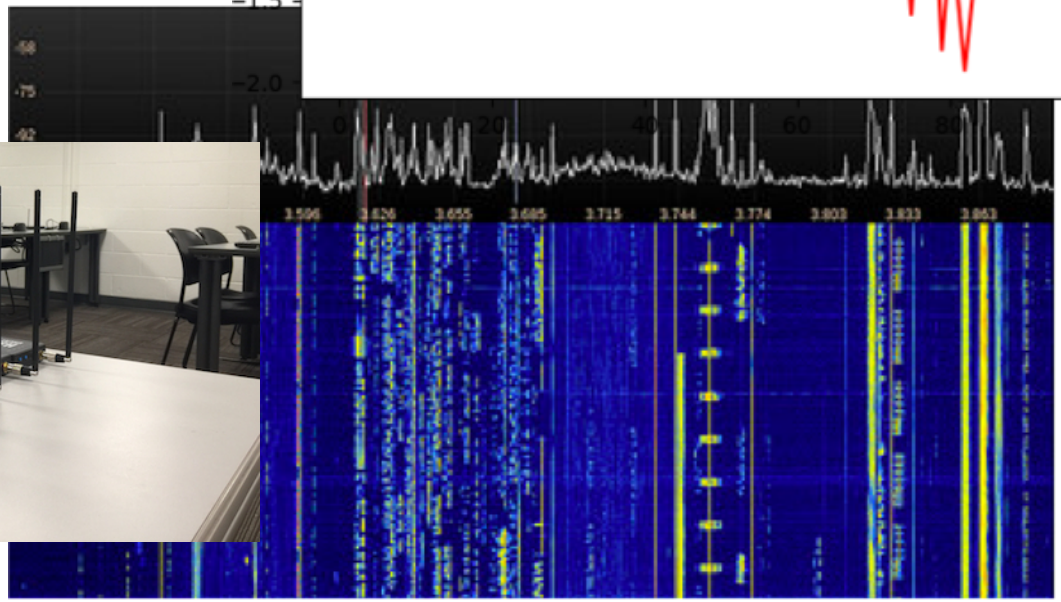
- **Lab location:** 87 Prospect, Garden Level, Room 065


- Enrolled students as of Feb 1 are added to Salto room and building access control list
  - **Visit a hotspot** and tap your TigerCard to update
  - If you weren't enrolled Feb 1, send instructors a private Piazza message requesting access

Lab: Building a spectrum analyzer

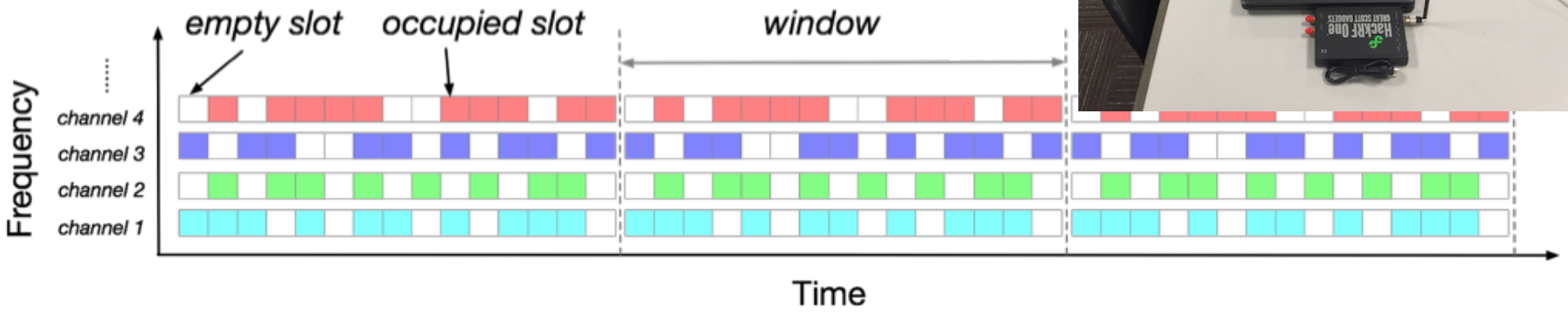
- Introduce you to basic signal processing concepts
  - Fast Fourier Transform (FFT)
  - Low-pass filtering
- Learning how to use the HackRF software-defined radio





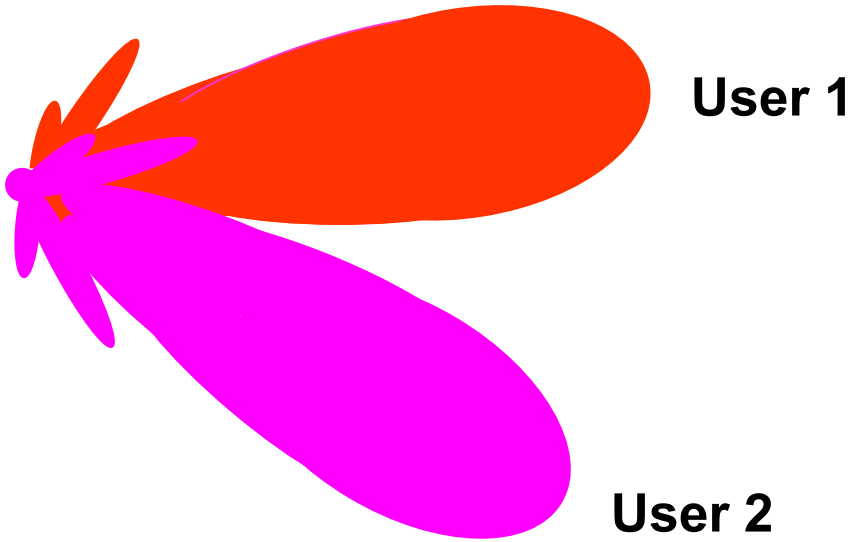
Lab: Sharing the Wireless Medium

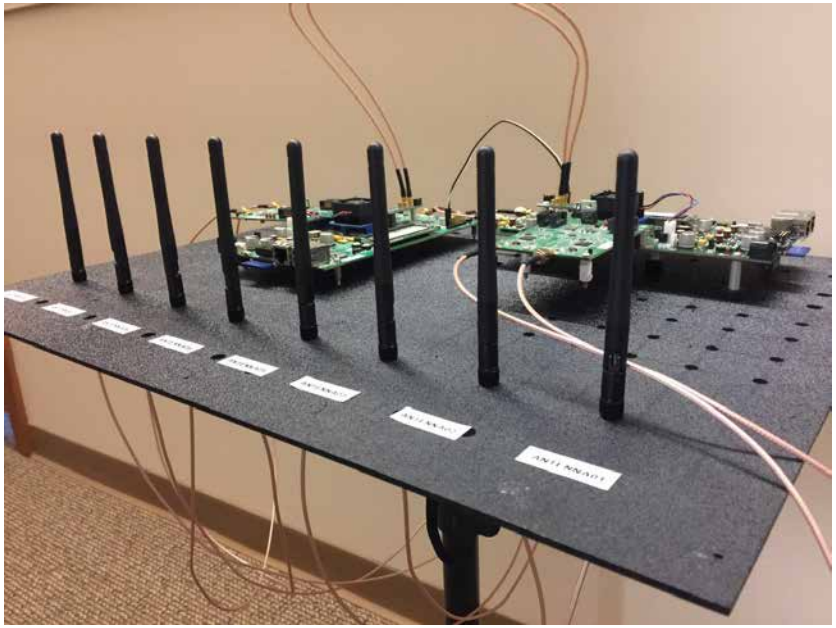
- We set up a **transmitter** in the room
- You **listen** for an empty time or frequency slot and **send** in that slot
- We show the result in a live "scoreboard"



Lab: Array Signal Processing

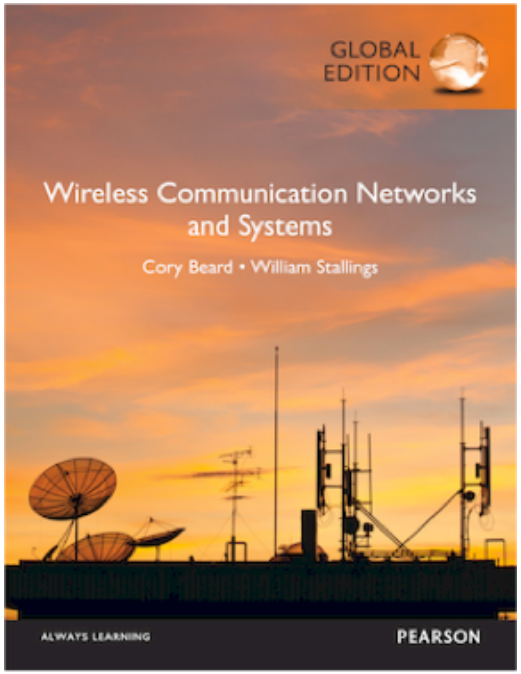
- **Angle-of-arrival estimation** using multiple antennas
- **Transmit beamforming** using multiple antennas

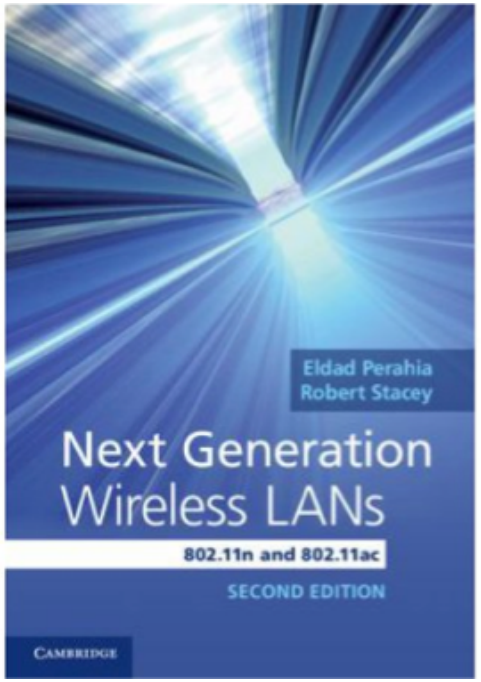




Readings

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





Class Grading

- Midterm exam: **20%**
- Final exam: **30%**
- Five lab programming assignments: **40%**
- Class participation: **10%**
  - Precept attendance and participation
  - Activity on Piazza

- **Midterm and final exam coverage:** Everything mentioned in lecture and precept, all readings, all labs
  - **Emphasis** on the concepts discussed in lecture & precepts, and lab content

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**
   - Less reliable links
   - Mobility

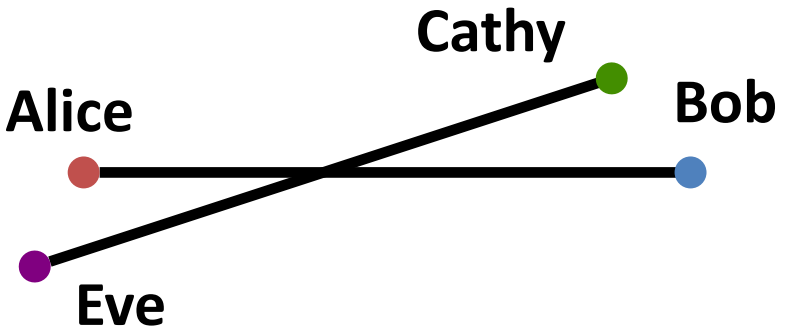
2. What makes wireless interesting?

3. What new services does wireless enable?

Wireless is a shared medium

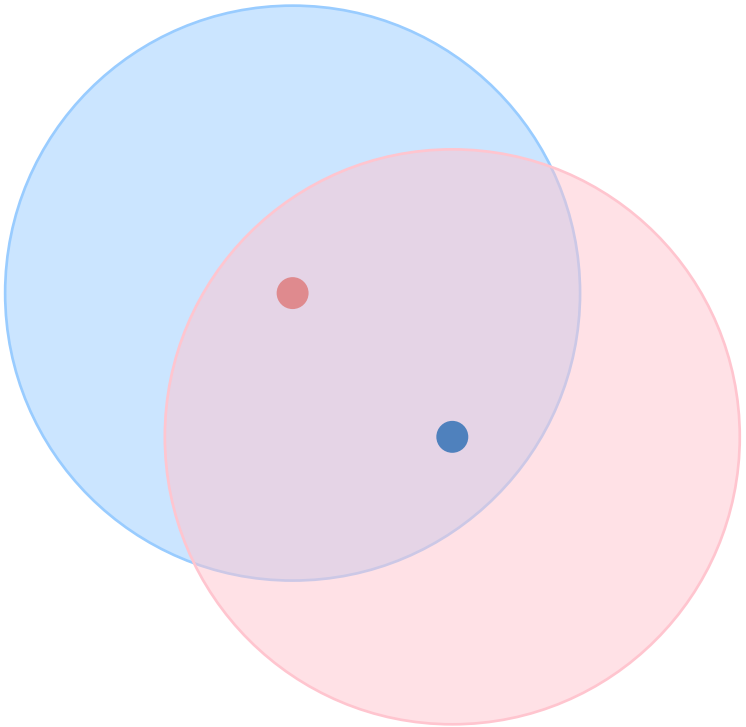
- **Wired networks:**

Alice and Bob's conversation is **independent of** Cathy and Eve's conversation



- **Wireless networks:**

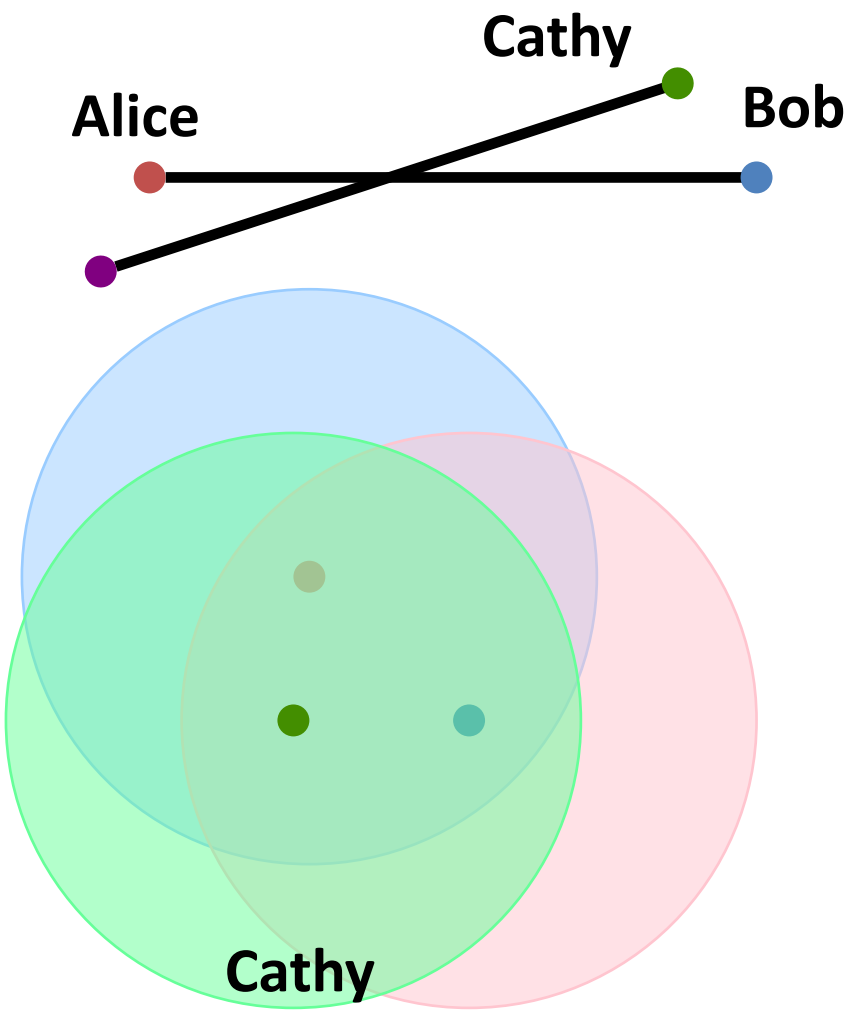
Close by **wireless** conversations **share the same wireless medium**



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



Reason #2: Can leverage broadcast

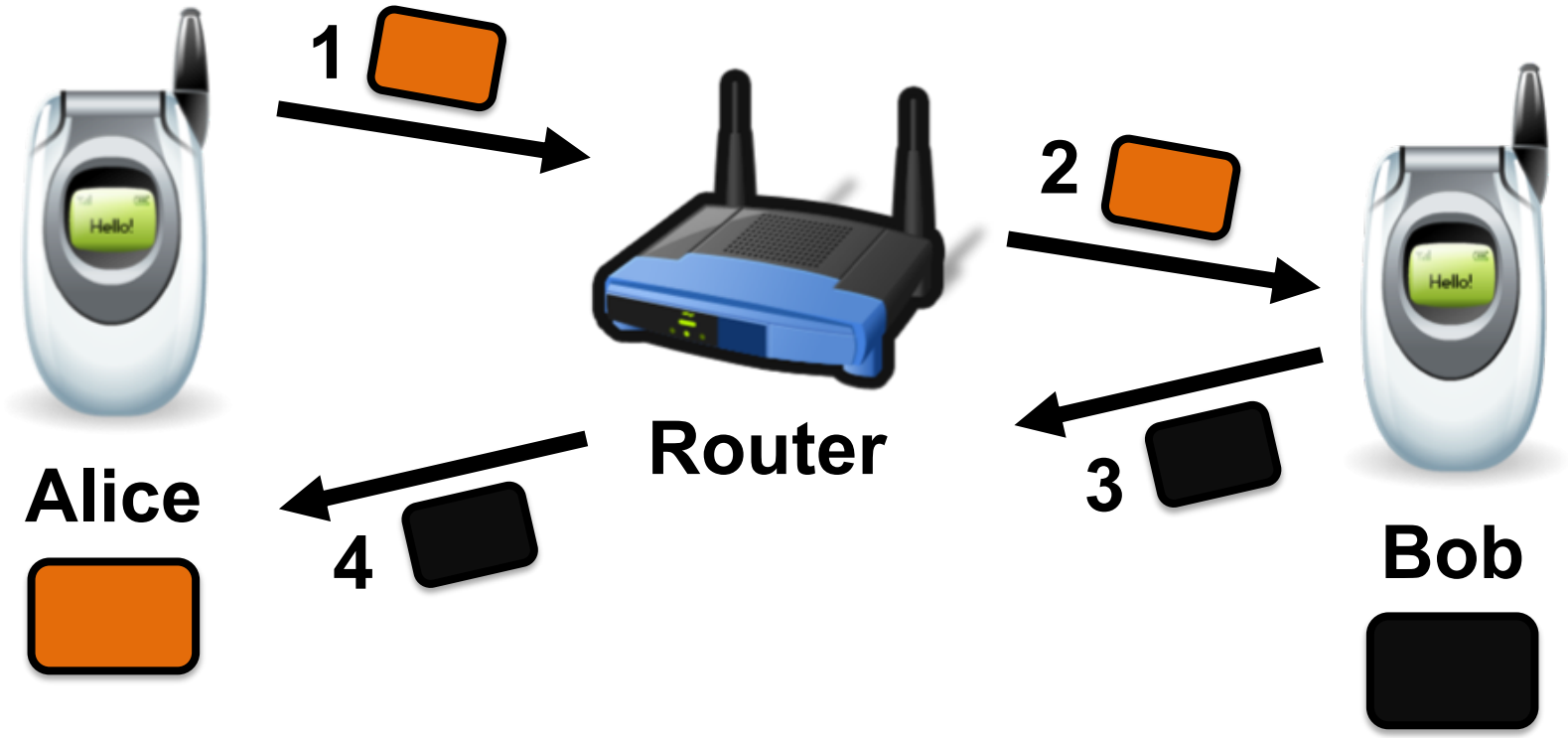
Alice

Router

Bob

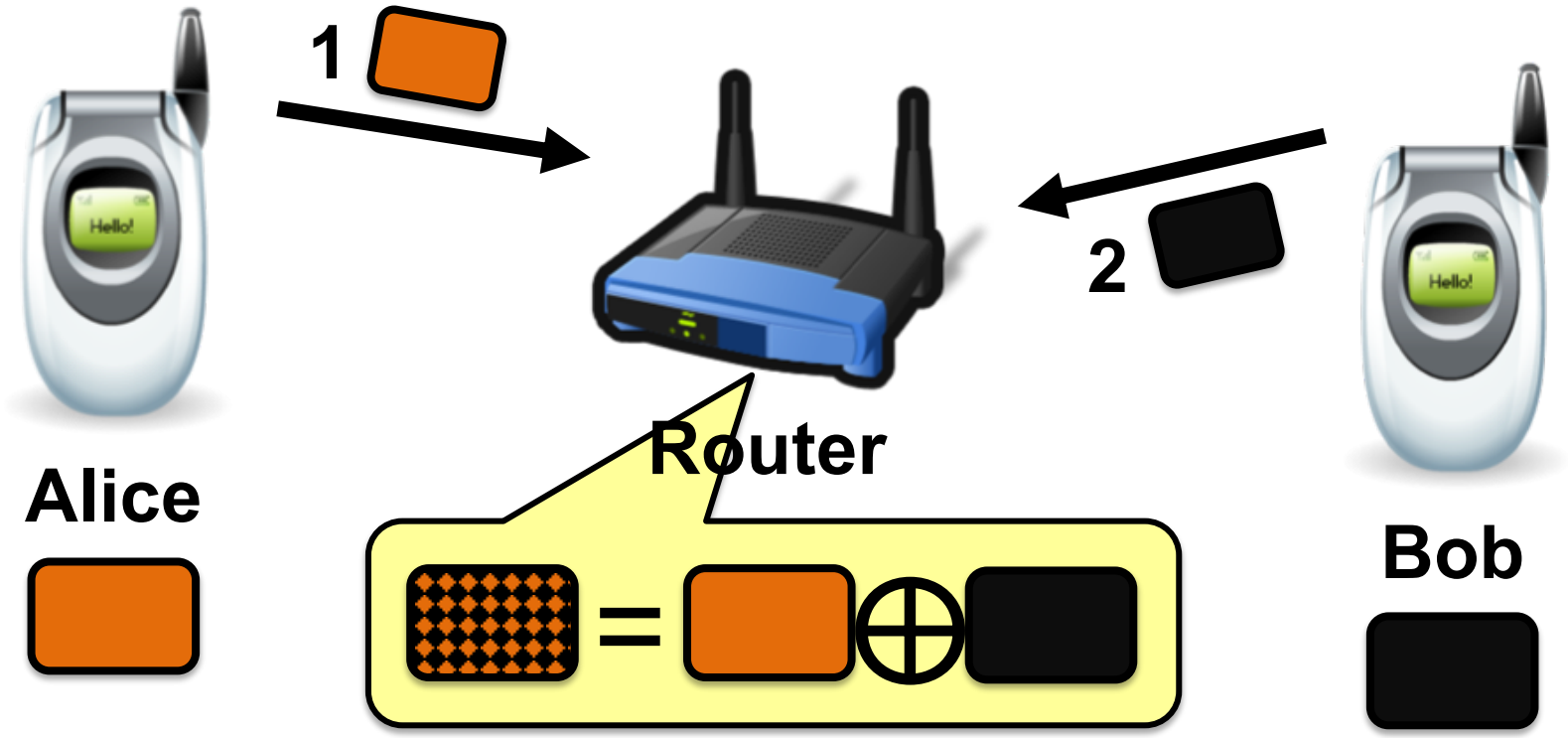
- Want to **exchange packets,** but **out of direct range**

Solution using wired abstraction

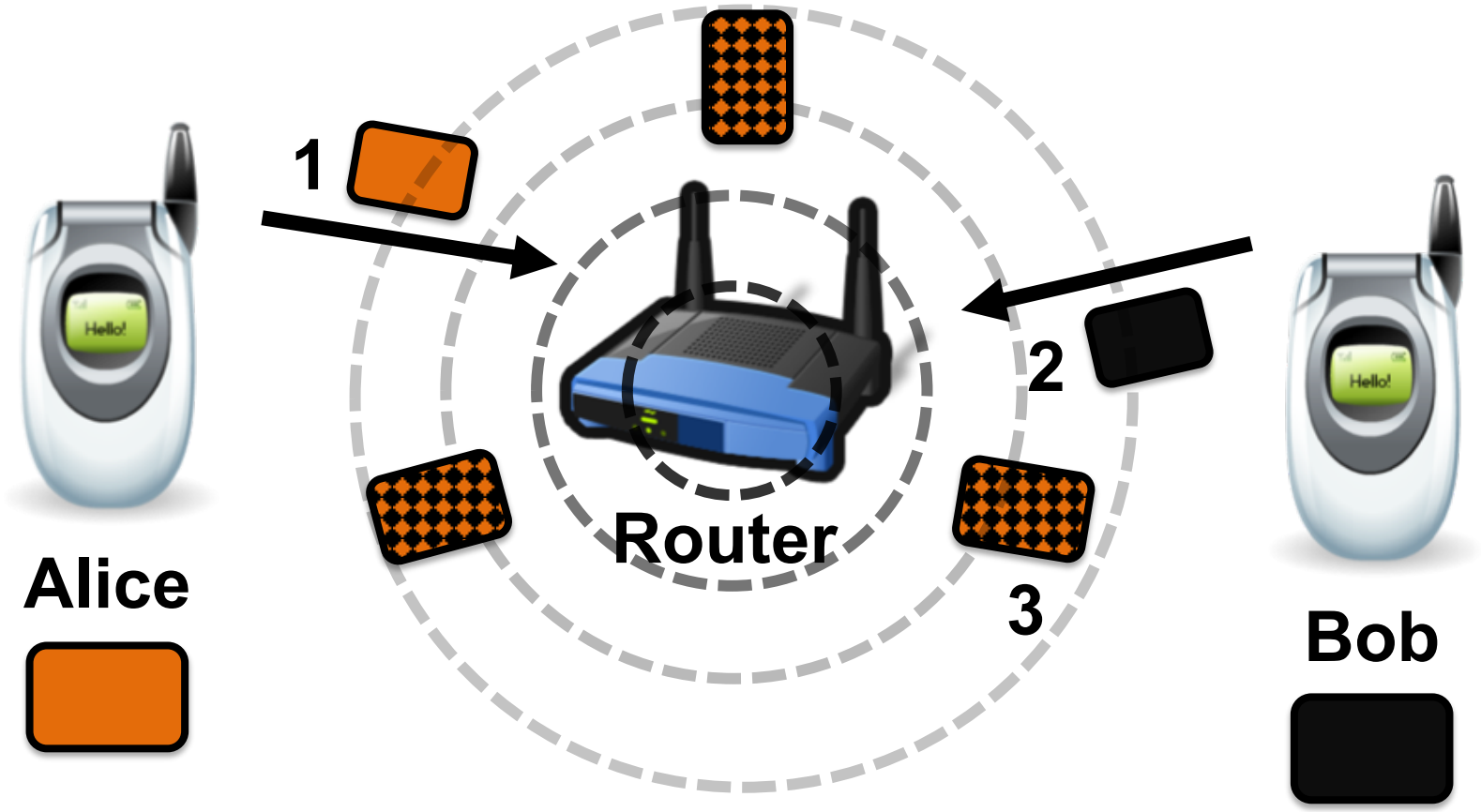


- Requires **four transmissions** in total

Idea: Router combines the packets



Router broadcasts the combination



- Requires just **three transmissions** in total

Sumary: 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**

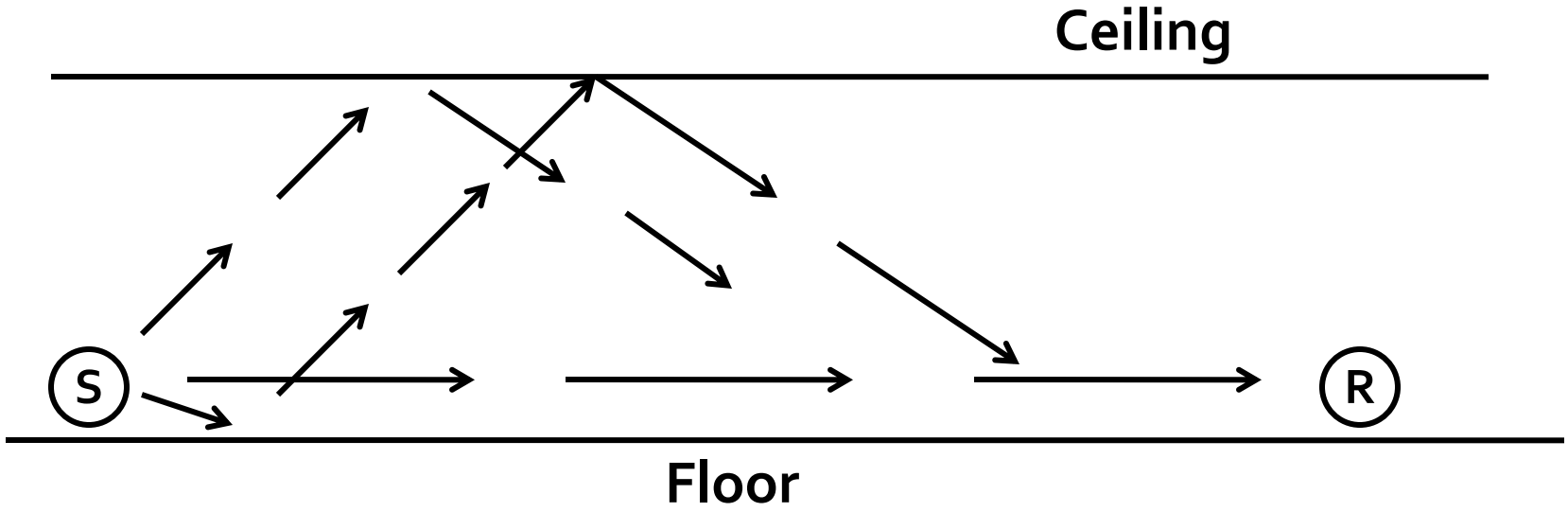
Today

1. **How do wireless and wired networks differ?**
   - A *shared* wireless medium
   - **Less reliable links**
   - Mobility

2. What makes wireless interesting?

3. What new services does wireless enable?

Less reliable links: 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**

Today

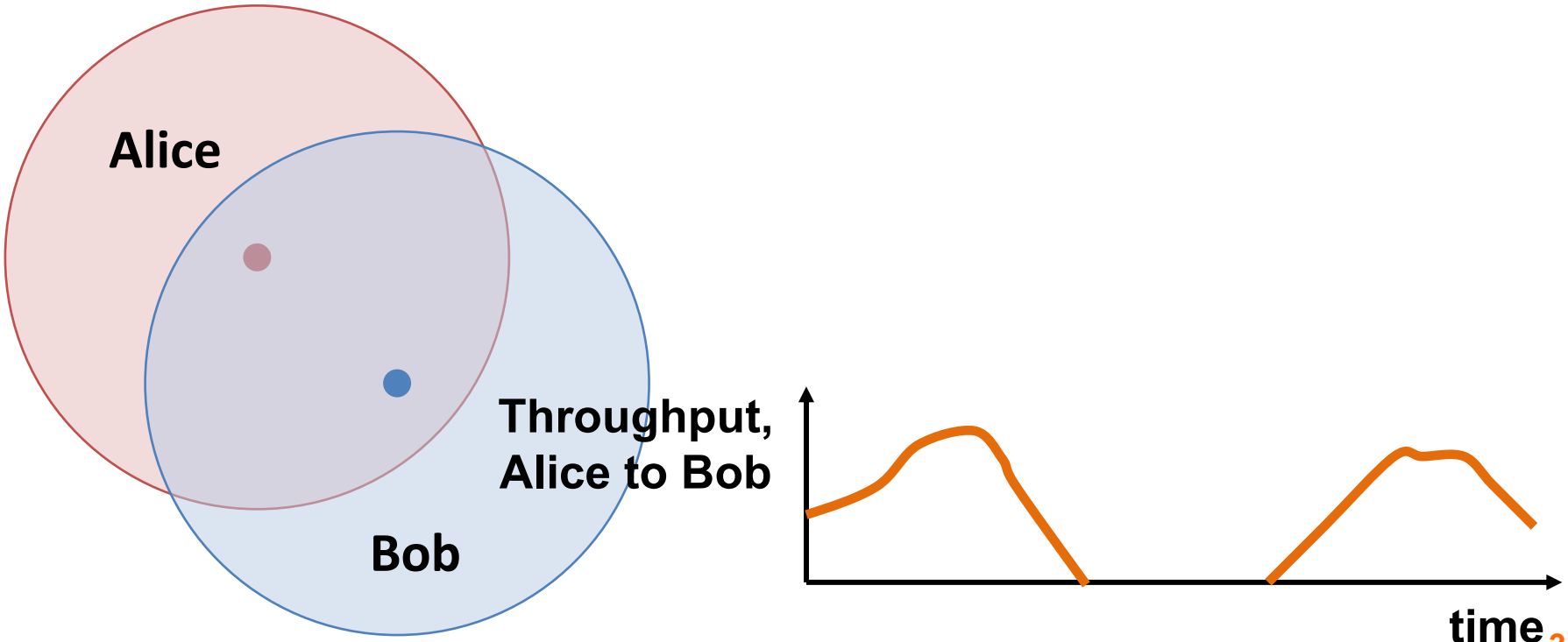
1. **How do wireless and wired networks differ?**
   - A *shared* wireless medium
   - Less reliable links
   - **Mobility**

2. What makes wireless interesting?

3. What new services does wireless enable?

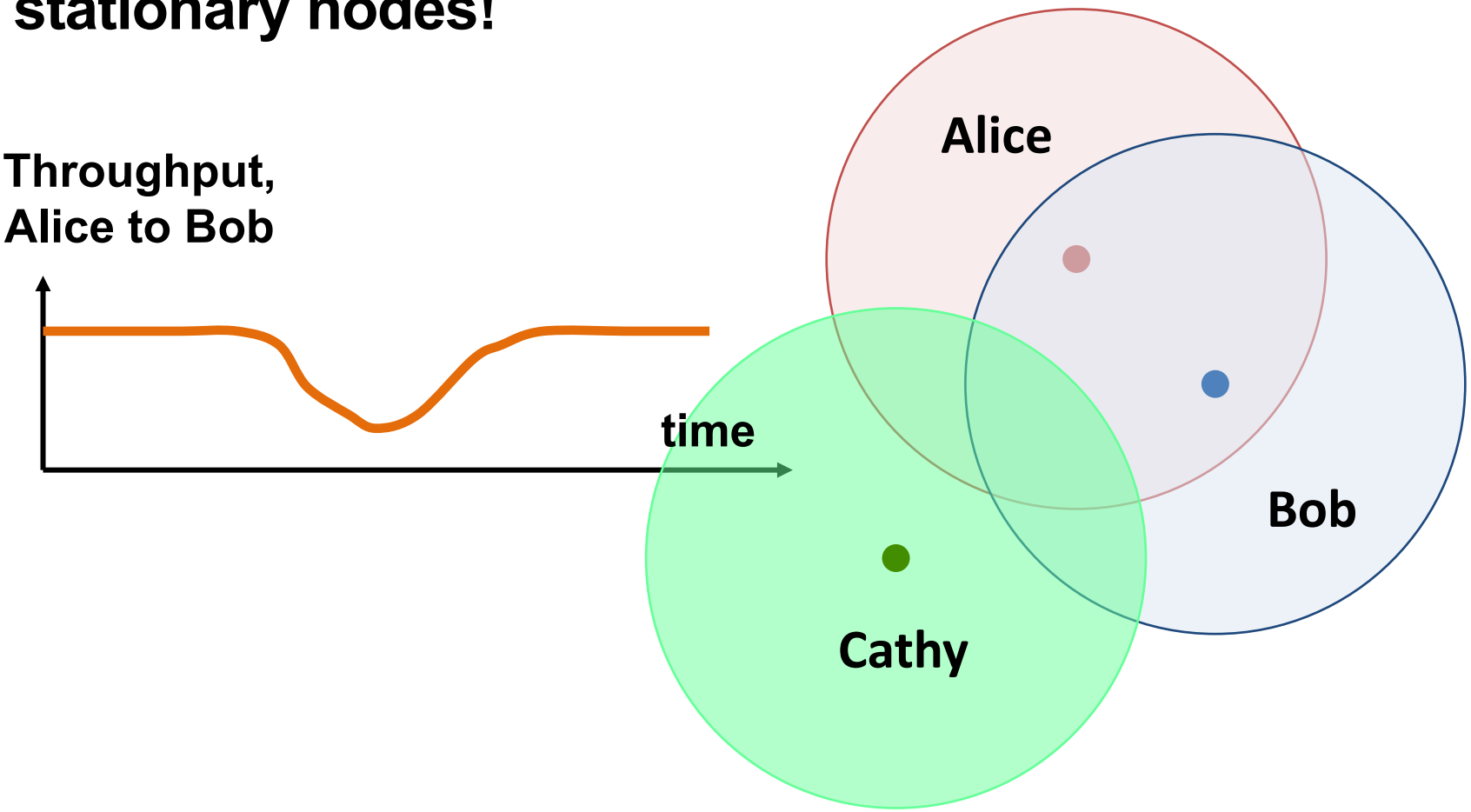
Mobility affects link throughput

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



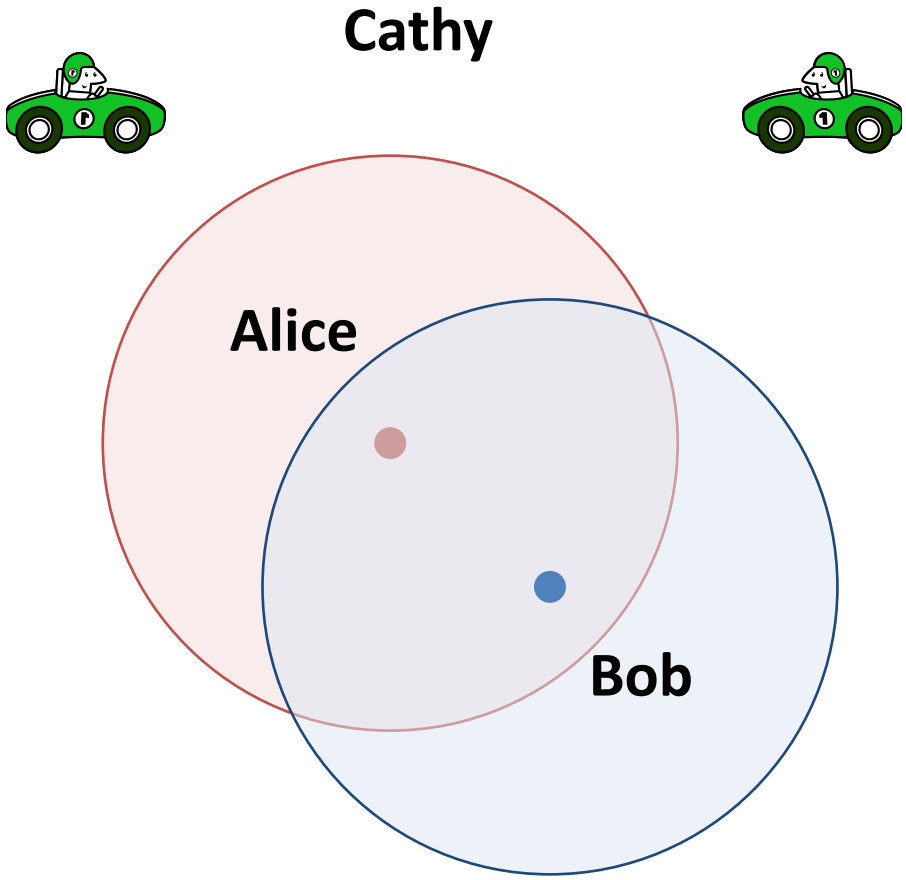
Mobility matters, even if stationary!

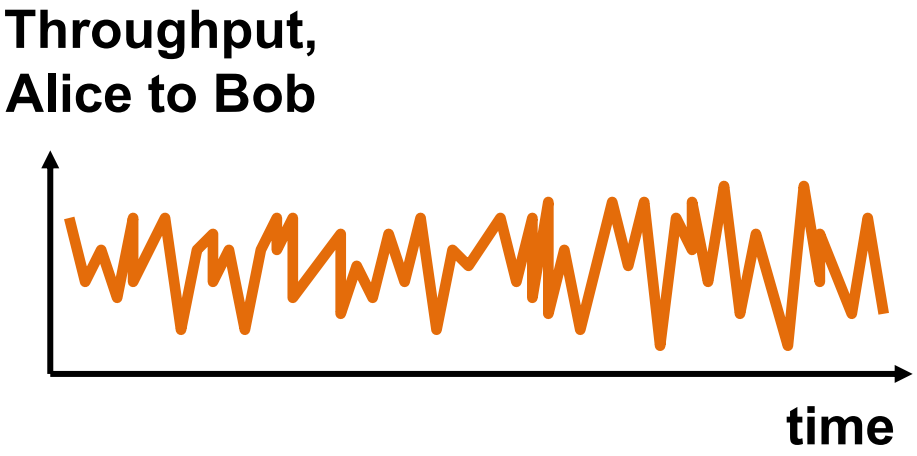
- **Mobile people, devices** affect wireless channel of **stationary nodes!**



Mobility matters, still!

- Impact of mobility on transmission is **complex:**
  - **Multipath effects**





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

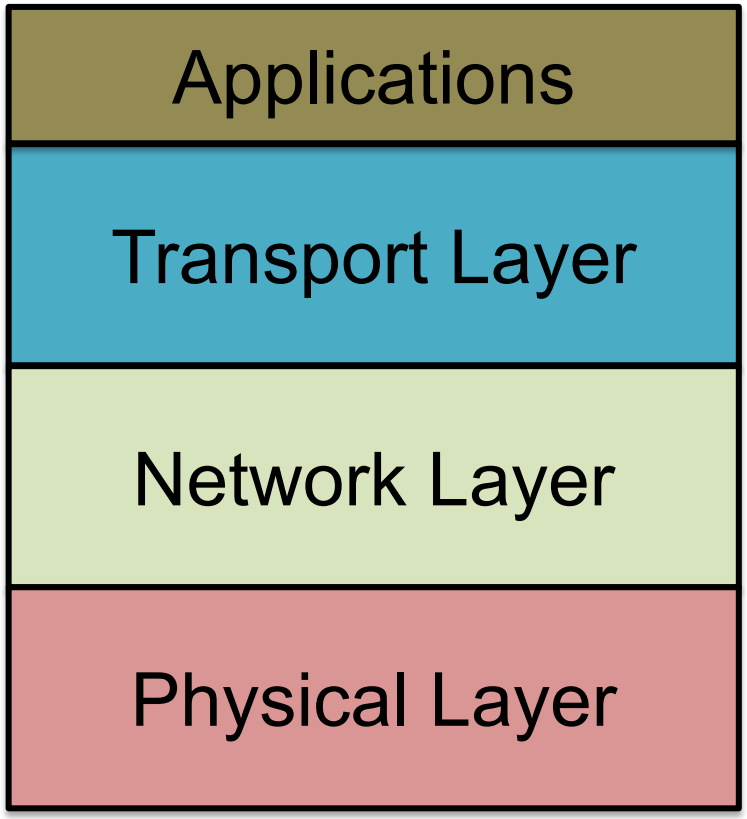
1. How do wireless and wired networks differ?

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

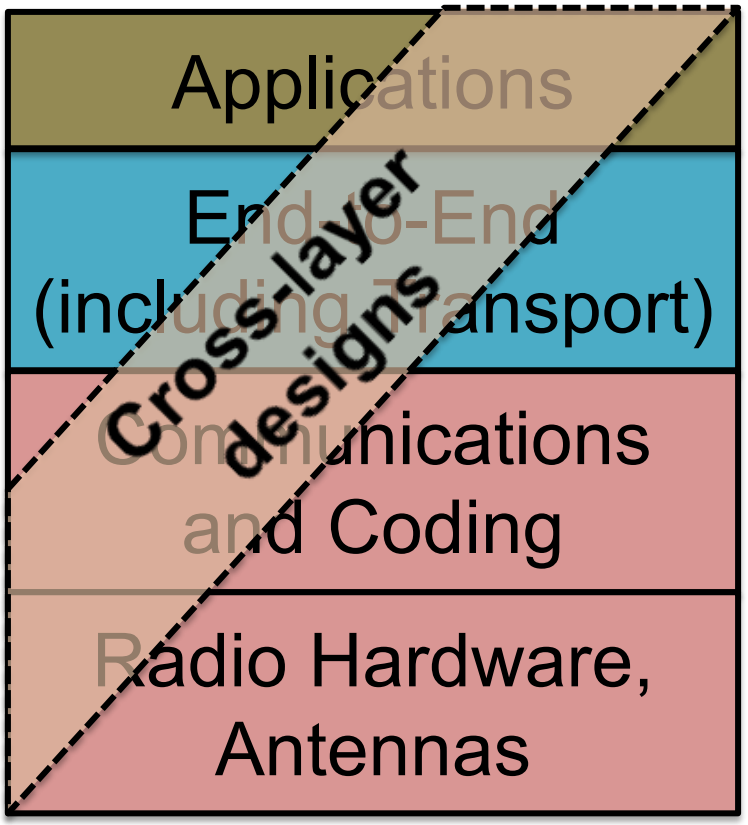
3. What new services does wireless enable?

The argument for cross-layer design

- **Traditional approach:** Optimize **within** layers

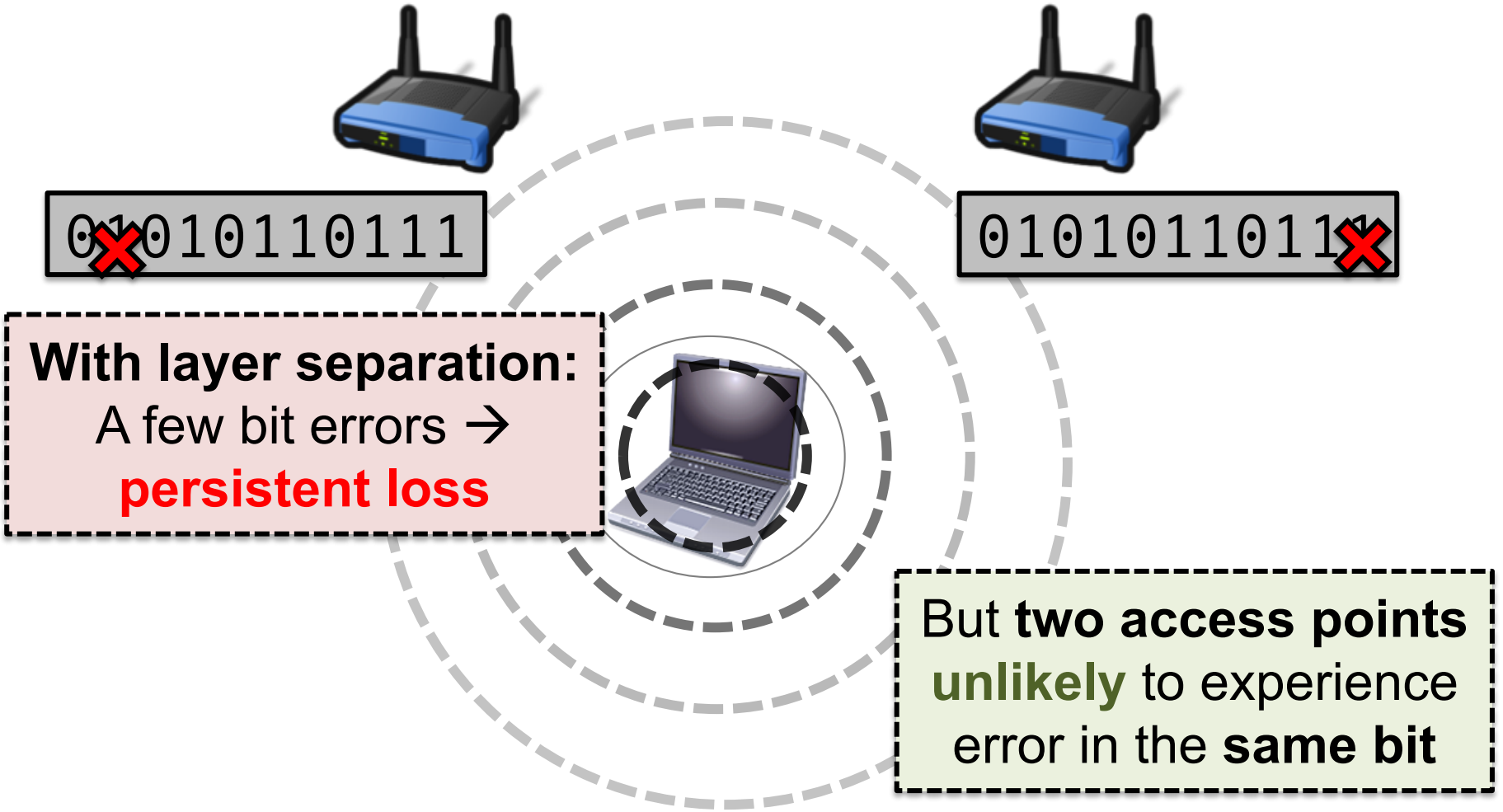


- **New Approach:** Design and optimize **across** layers

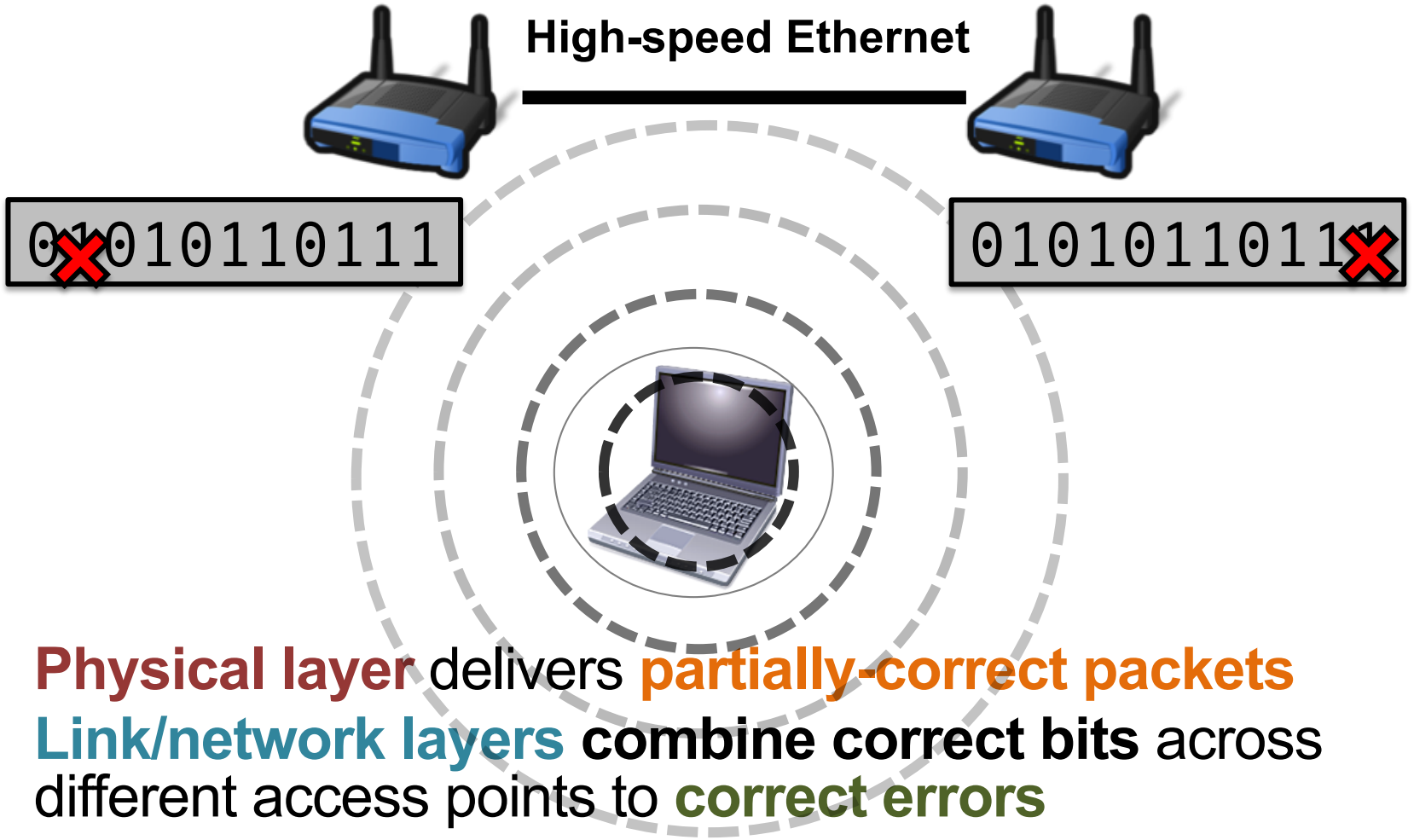


Why is layer separation **sub-optimal?**

Scenario: Laptop in a “dead spot”

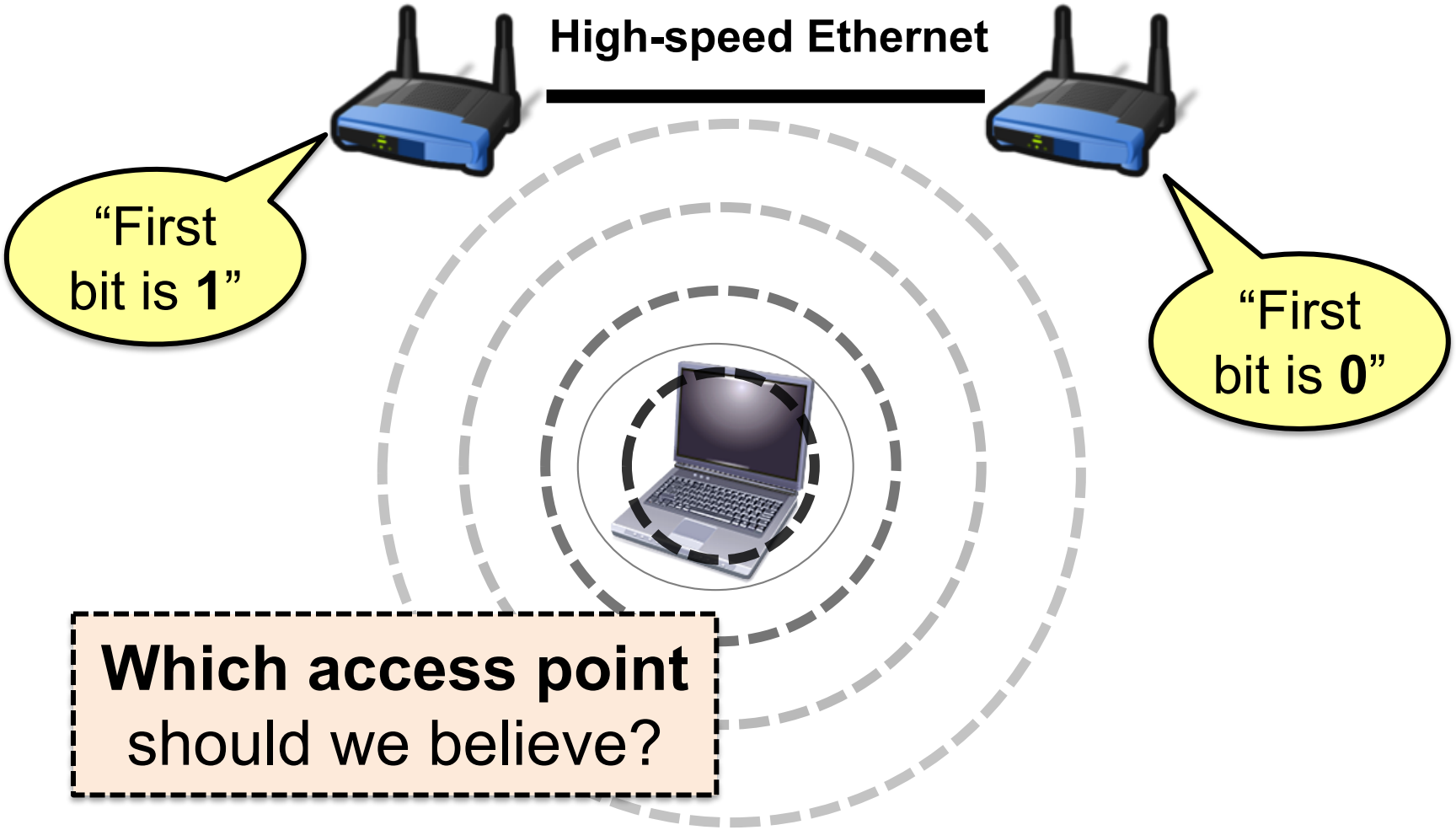


Solution: A cross-layer Approach



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

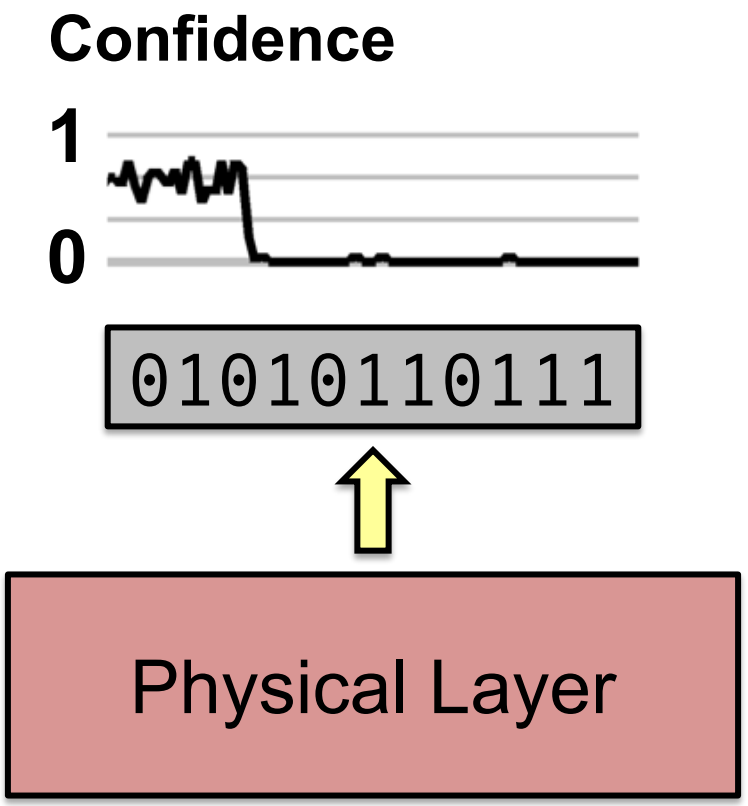
A challenge for bit combining



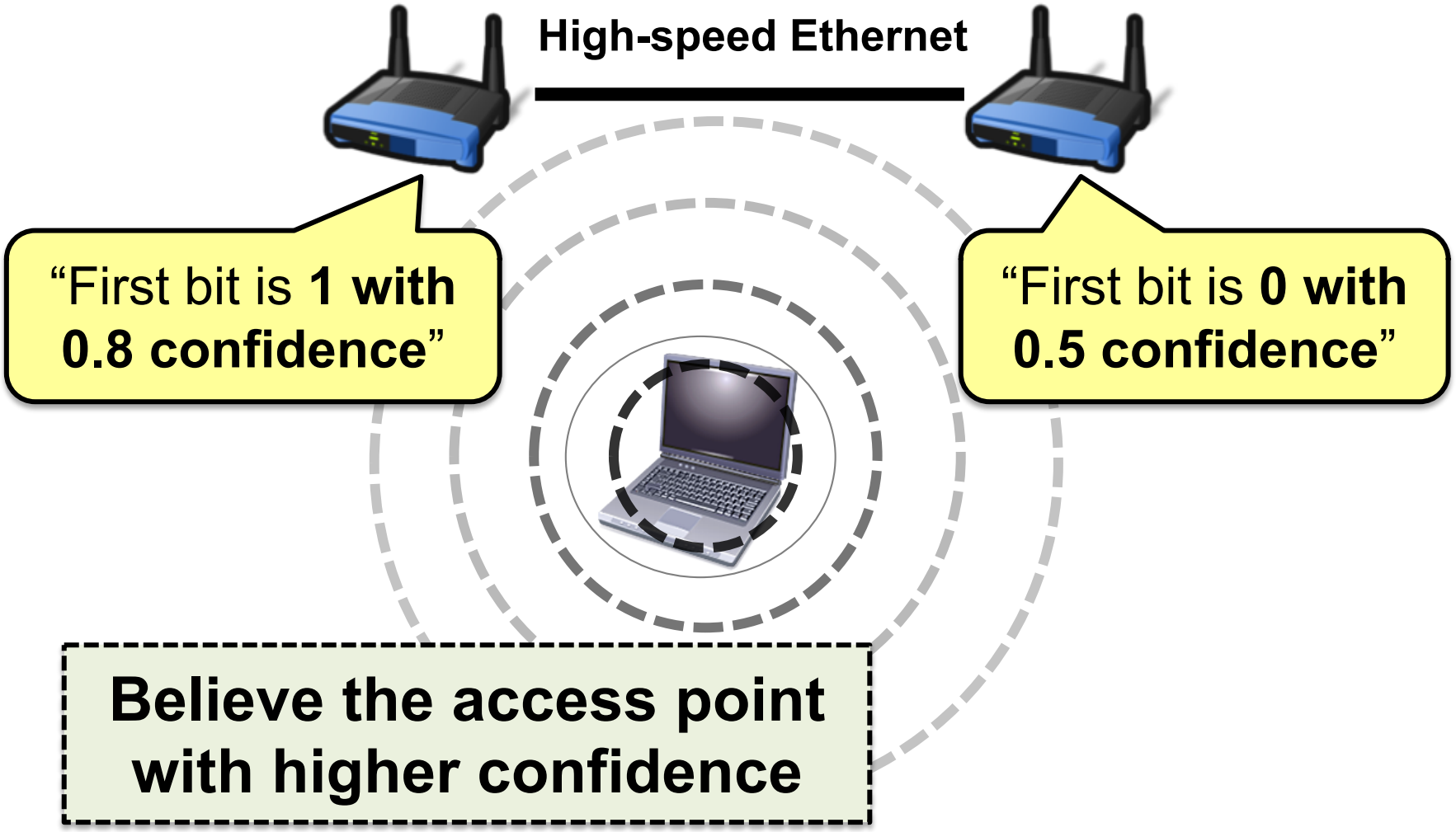
Idea: Network cooperates with PHY layer

- Physical layer **already estimates probability of correctness (*confidence*)** in each 0/1 bit decision

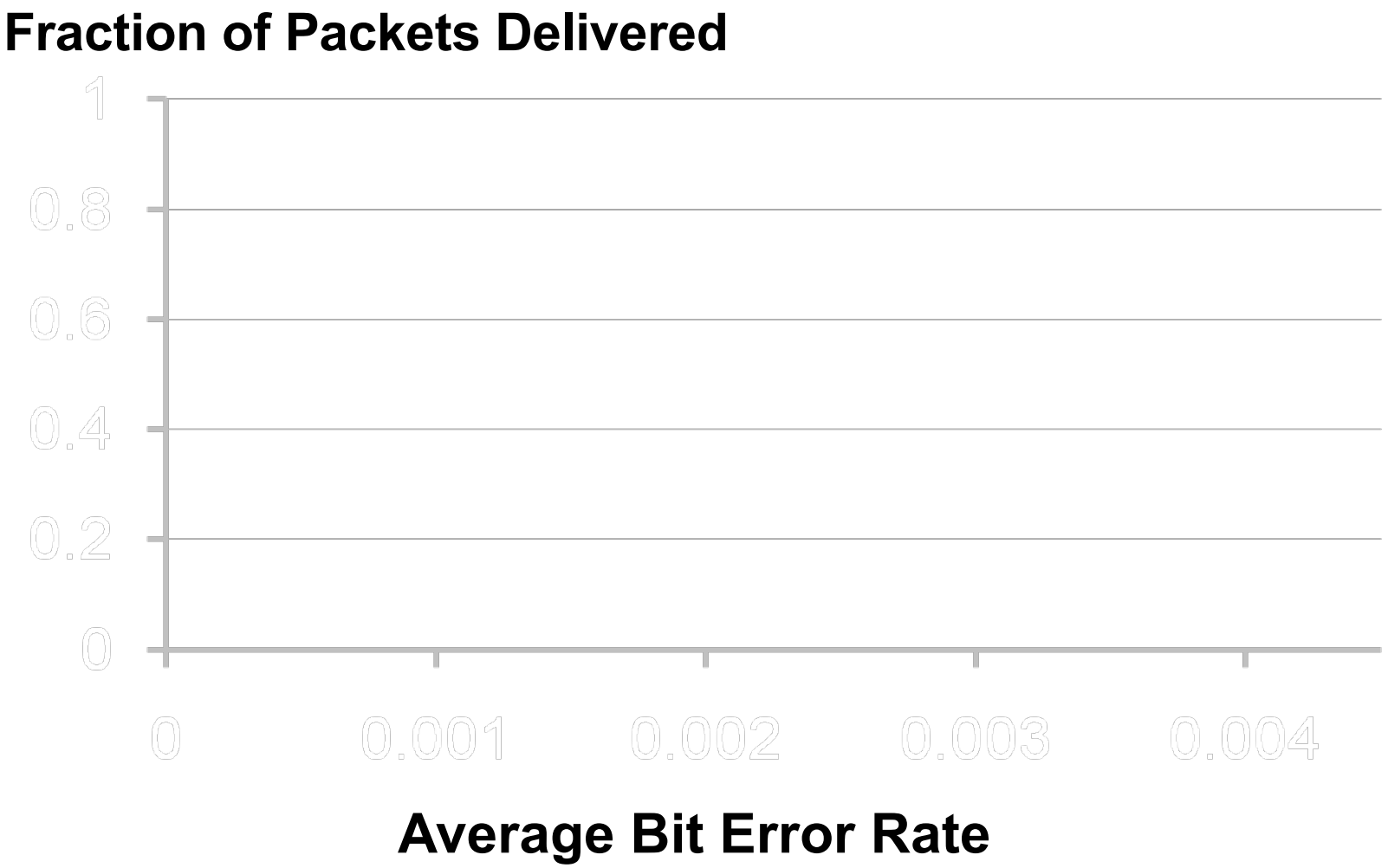
- **Idea: Expose confidence** to the higher layers



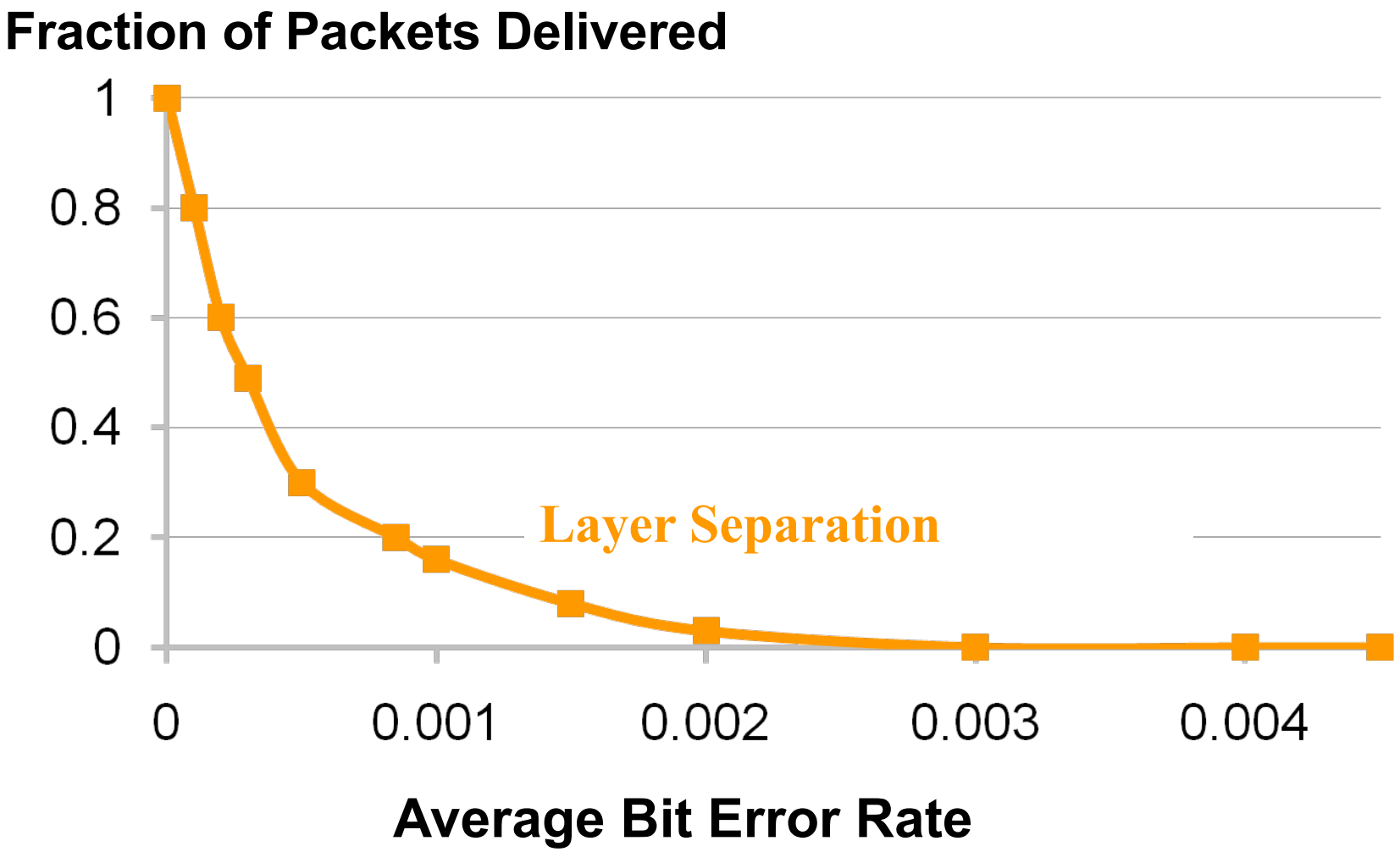
Solution: Use confidences across layers



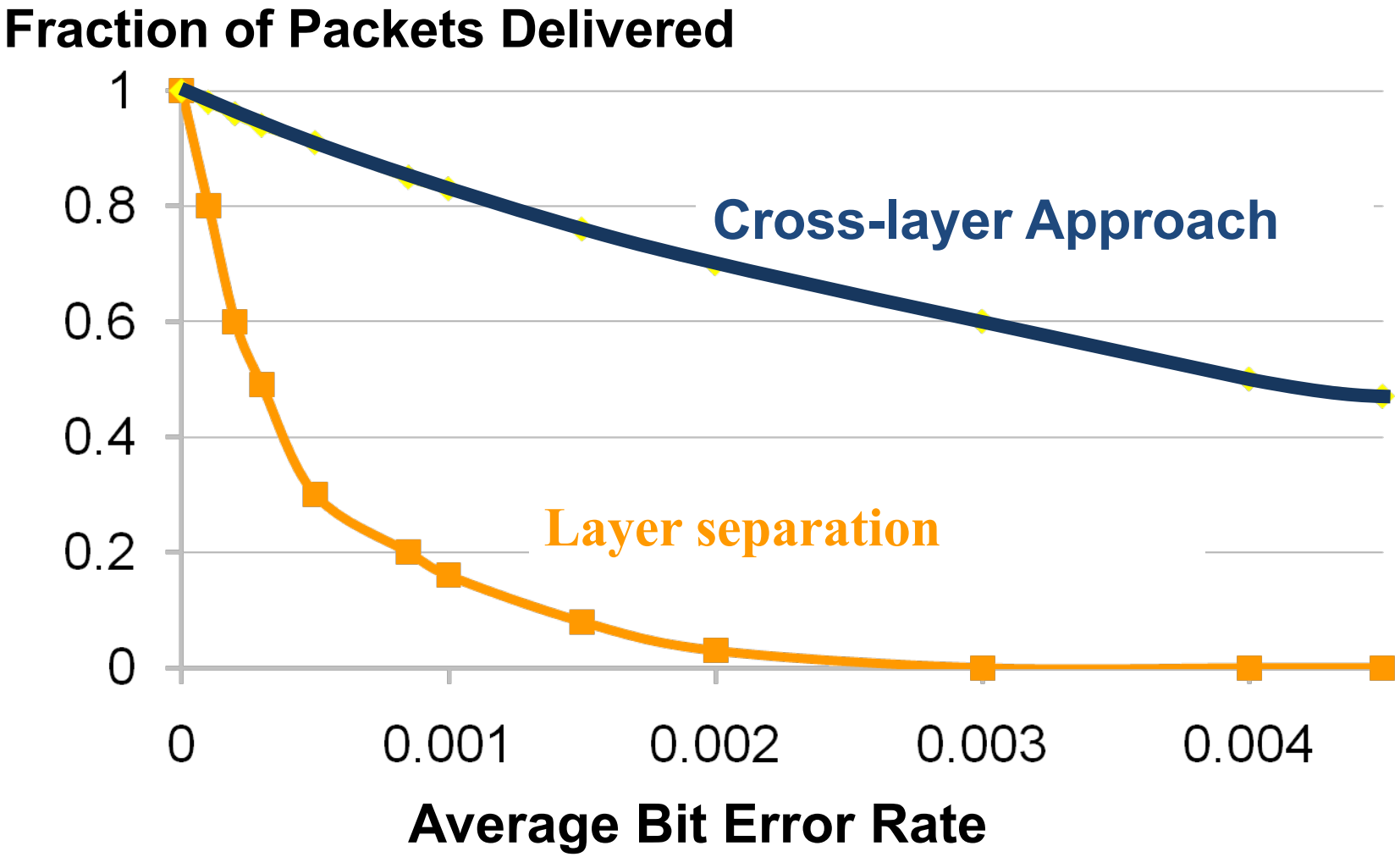
Experiment: Packet delivery v. poor coverage



Experiment: Packet delivery v. poor coverage

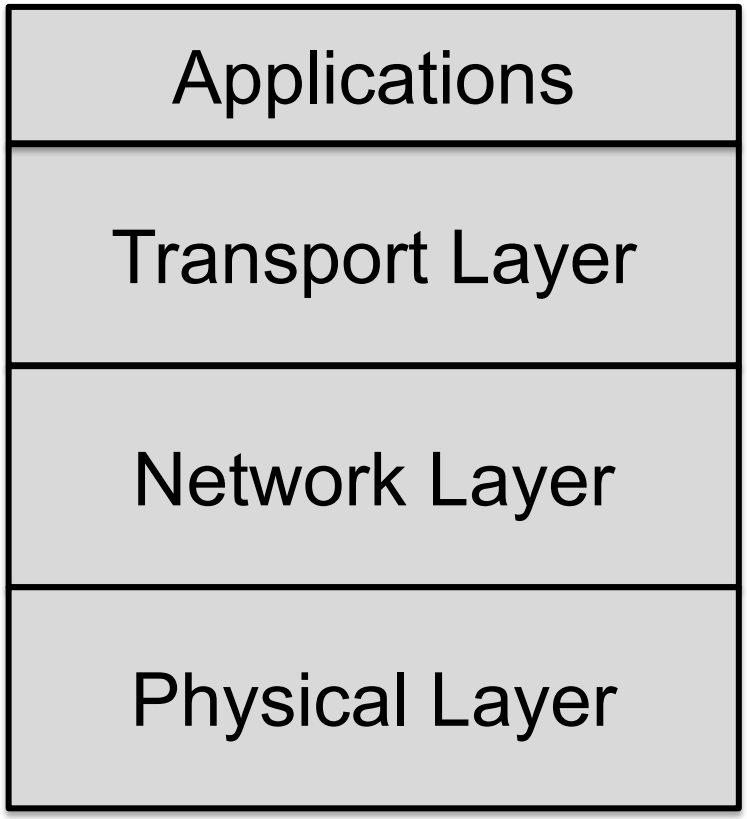


Experiment: Packet delivery v. poor coverage

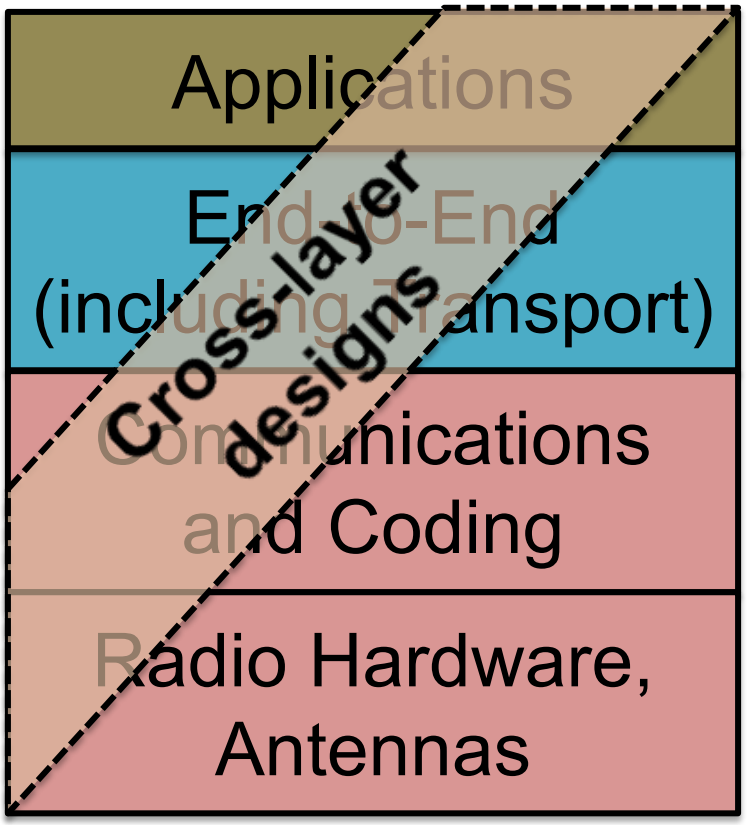


Fundamental change in network architecture

- **Traditional approach:** Optimize **within** layers



- **New Approach:** Design and optimize **across** layers



Today

1. How do wireless and wired networks differ?

2. What makes wireless interesting?

3. **What new services does wireless enable?**

New Services: Wireless localization

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

Indoor Navigation

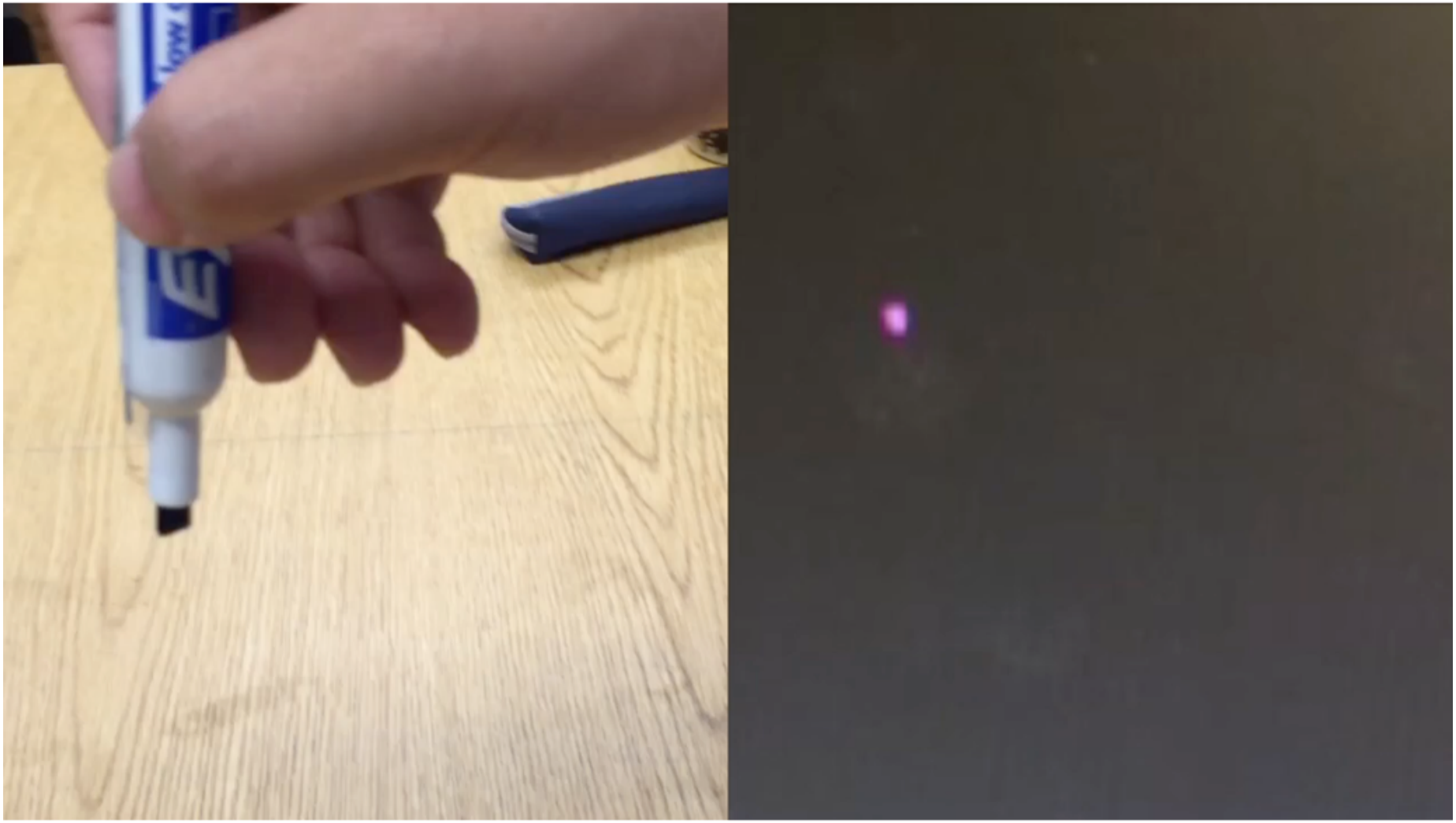
Business Analytics

WiFi Geofencing

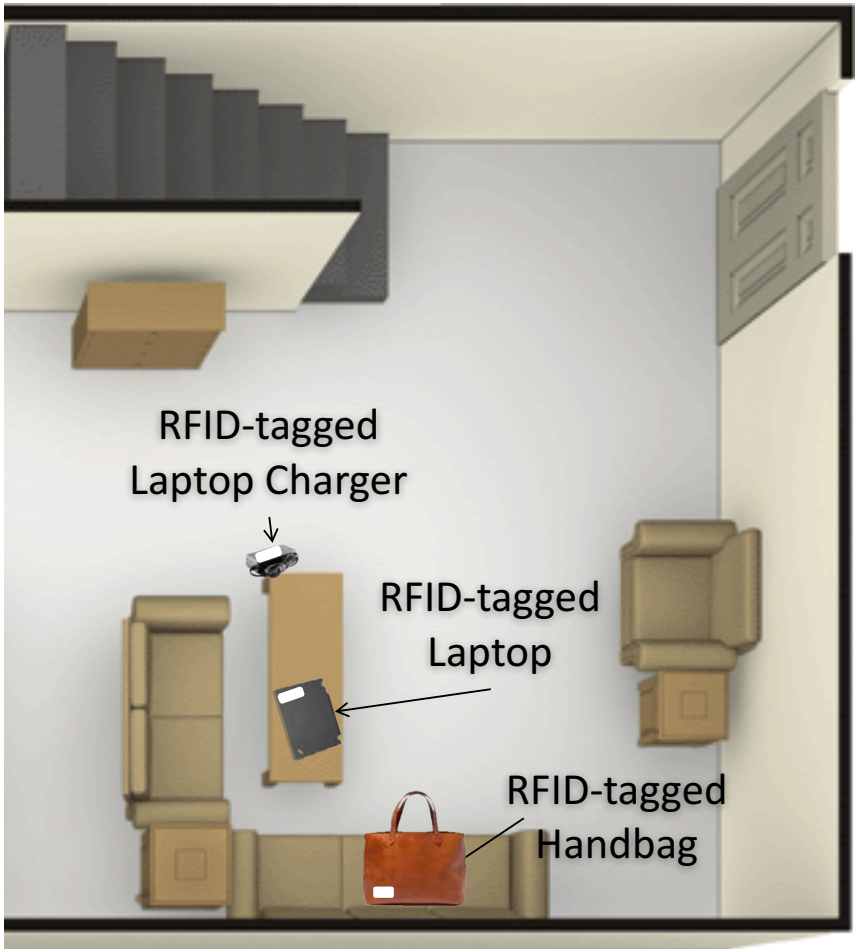
Indoor Robotic Navigation

How do we get virtual touch screens?

RFID motion tracking in the air



RFID technology: Smart homes



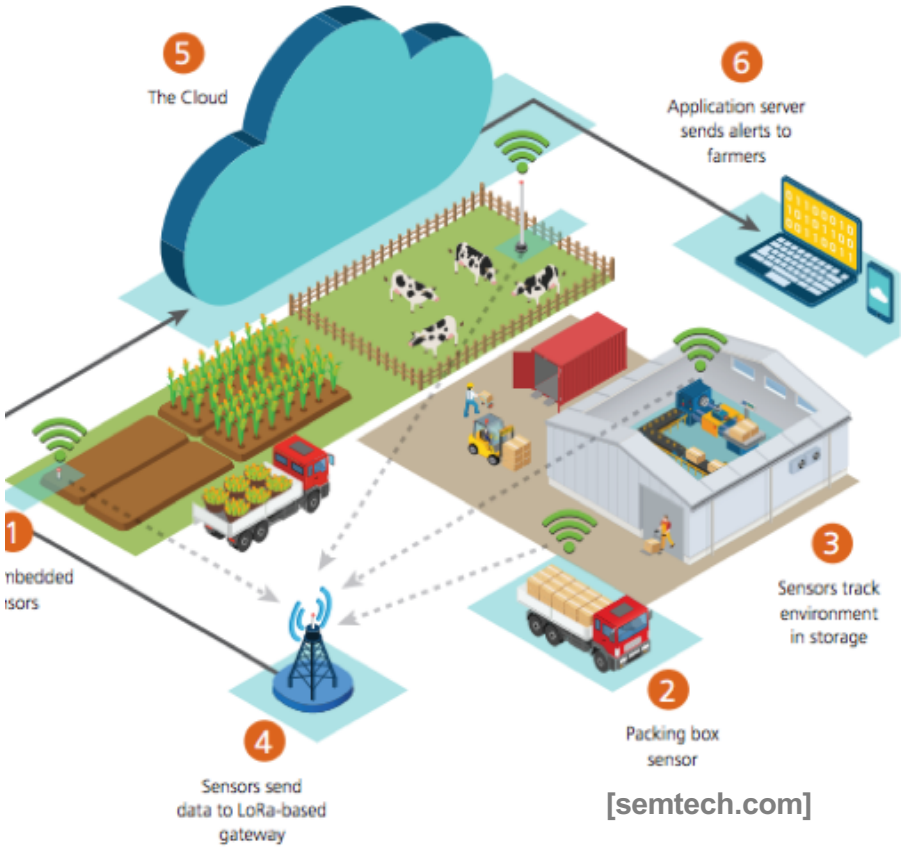
- Localize everything and anything in the home
- **RFID:** Battery-free stickers to tag any and every object

Low Power, Wide Area Networks

- Wireless, battery operated sensors and devices

- **Long Range:** Kilometers
- **Long lifetime:** 10-20 years
- **Low cost**

- **Applications:**
  - Smart electricity, water, utility meters
  - Asset tracking: e.g. Vehicle fleet monitoring
  - **Agriculture monitoring**



Class Website

www.cs.princeton.edu/courses/archive/spring18/cos463

COS-463 Wireless Networks (Spring 2018)

Home Syllabus Reading List Announcements Piazza

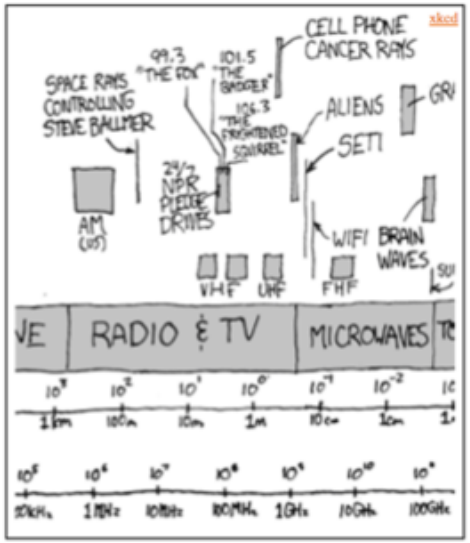
Overview

Over the past one and a half decades, we have seen a polar shift in the way we access the Internet, our usage patterns moving from tethered workstations, to laptops, then to a variety of smaller mobile devices. Furthermore, in the next decade, we are headed on a trajectory to bring the internet to many millions of sensors and embedded computational devices. A wireless first or last hop figures prominently into the needs of each such device.

But in contrast with wired networks, wireless networks must cope with several challenges stemming from several fundamental differences between radio links and wired links:

1. Over a certain link, portions of a packet may be received correctly, while the remaining portions may contain bit errors. Background noise, reflections, and obstructions in the physical space between sender and receiver impact the delivery of individual bits proabilistically.
2. Concurrent transmissions from different nearby senders result in interference between nearby wireless links that is difficult to model or predict.
3. At certain wireless frequencies, transmissions are inherently omnidirectional (broadcast), and may reach or affect unintended receivers.

COS-463 is an undergraduate-level class that provides an



Latest Announcements

2/5: Start of Spring Semester
Spring classes begin

See all announcements RSS feed

Thursday

Systems & Networking Concepts: Layering, End-to-End Arguments
Transport over Wireless I: TCP Split Connection

Friday Precept

Python Intro and Signal Processing Primer
Location: 87 Prospect Street, Room 065