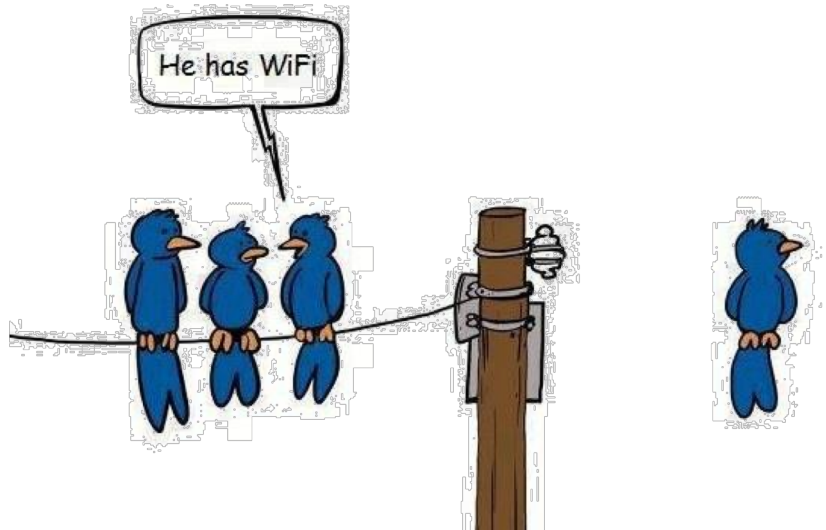
ECE 257B: Principles of Wireless Networks

Lecture 1: Introduction to Wireless Research

Dinesh Bharadia



Source: Slides borrowed from Haitham, Swarun, Fadel, Dina and Sachin

Why take this class?

How to conduct research and read research papers?

Learn Fundamentals of Wireless communication, sensing, localization and low power communication

Advanced topics: Cross-layer network optimization, full duplex radios, wireless power transfer, Phy layer security, GPS and Drones

Join Piazza

Where:

https://piazza.com/ucsd/winter2019/ece257b/

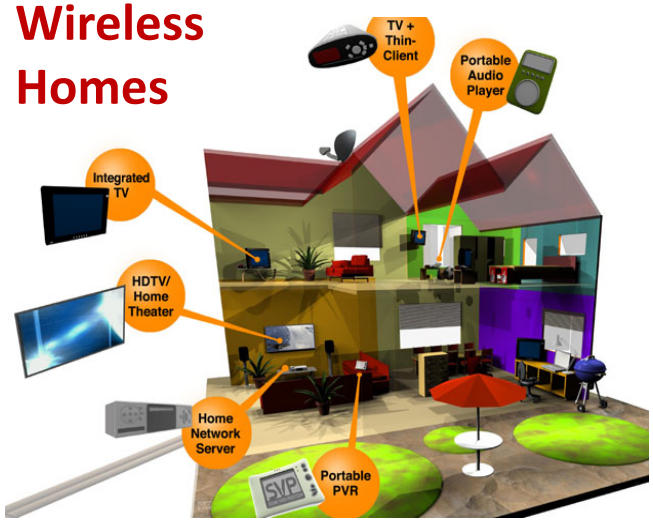
Who:

Anyone who is auditing the course should join piazza, all lecture notes here on would be posted on Piazza

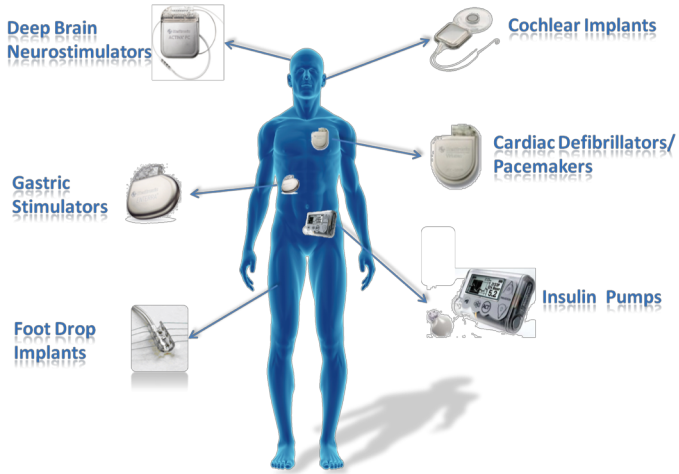
Increasing Demand for Wireless Connectivity

Wireless Networks Increasingly Prevalent

Wireless Homes



Wireless Biomedical Implants



Wireless Wearables

Cellular Networks

Wireless Sensors

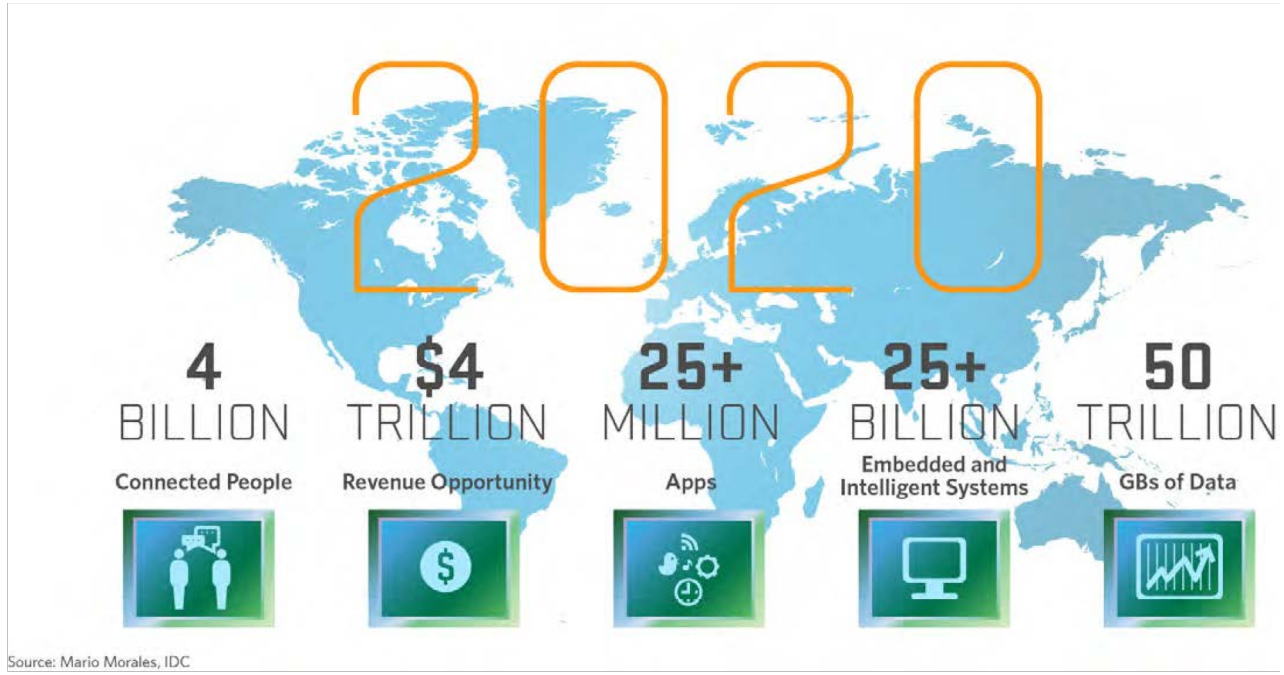
UAVs

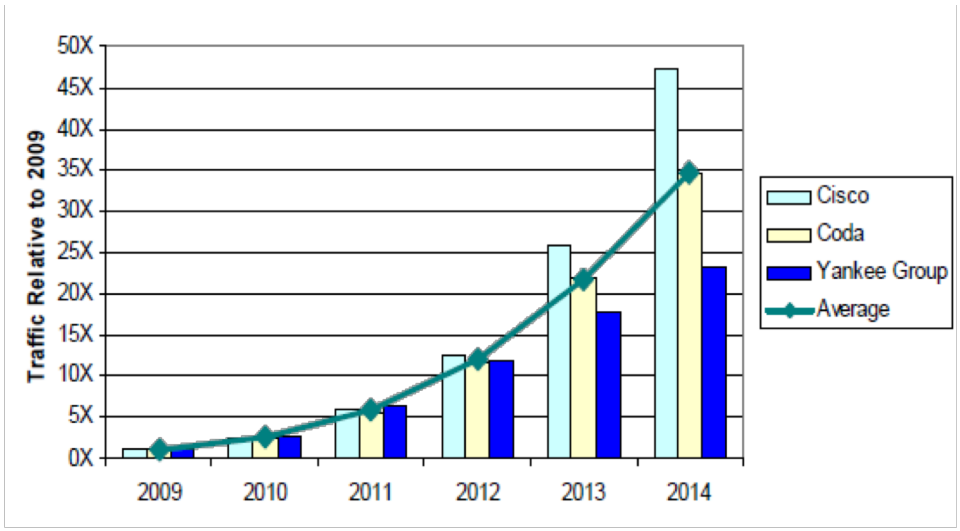
Wireless Data Centers

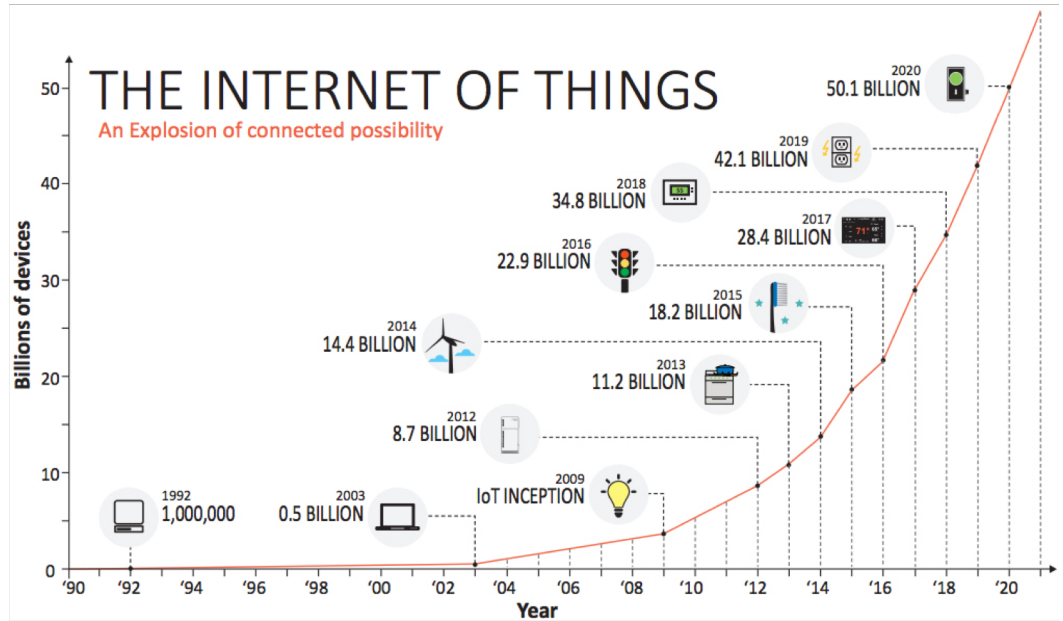
Wireless VR

Wireless Vehicles

Increasing Demand for Wireless Connectivity

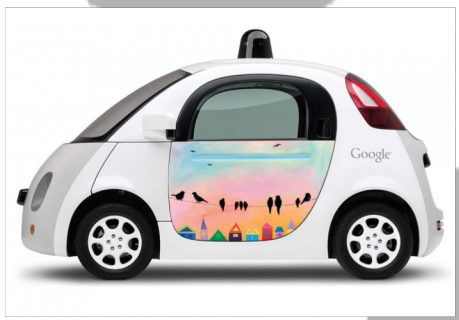






Wireless Networks for Control not just communication

All interaction from objects, machines and humans



Self-driving cars

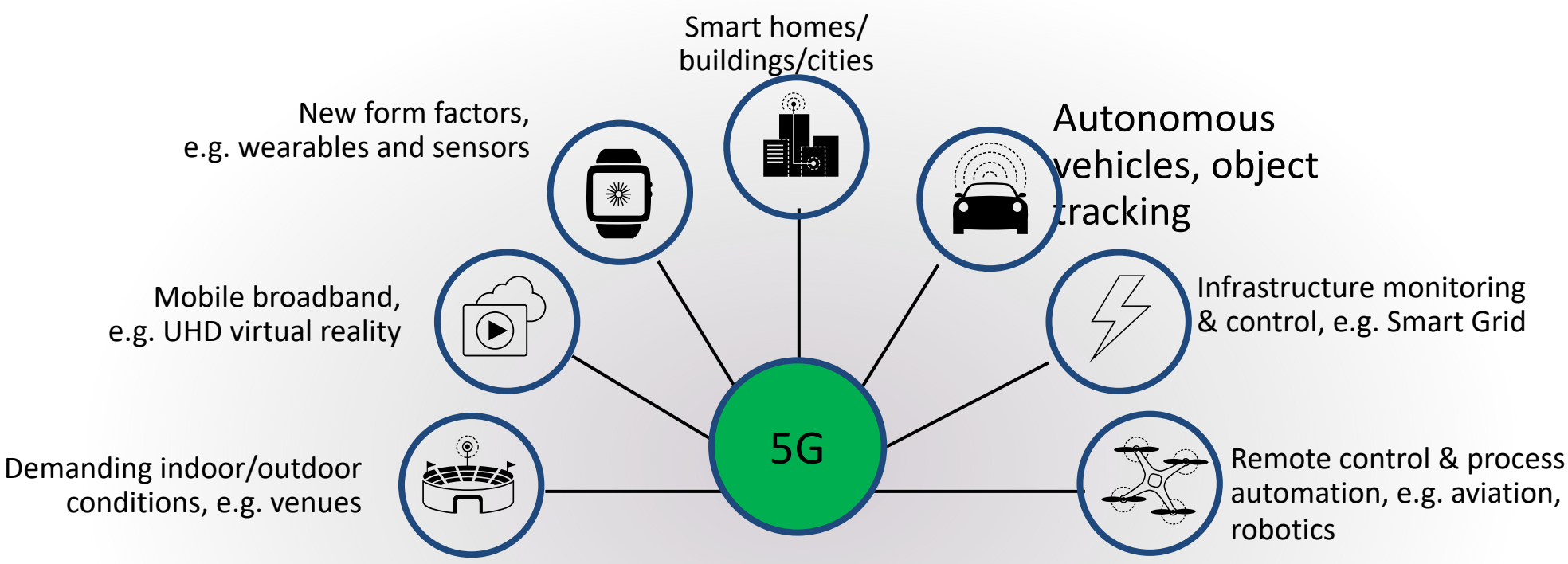
Robots

AR, VR

IoT sensors

…a network to accommodate these devices

Pillars of 5G



Enhanced Mobile Broadband

Faster, more uniform user experiences

Wide Area Internet of Things

More efficient, lower cost communications with deeper coverage

Higher-Reliability Control

Lower latency and higher reliability

Source: Qualcomm

The course would cover the fundamentals of the pillars

General Information

- Staff
  - Lecturer: Dinesh Bharadia, dineshb+ECE257B@ucsd.edu (Subject: ECE257B:….)
- Material (new class)
  - Mainly research papers
  - Lecture Notes (each student will be a scribe for one lecture)
- Prerequisites
  - Any undergraduate networking, wireless, communications or RF class
  - Basic math and signal processing: probability, Fourier, Dijkstra's shortest path alg., …
  - Matlab or C programming (Important for the project).
- Grading
  - 45% Research Project: Proposal (5%), Mid-quarter Progress report(15%), presentation and final report (25%)
    - Research project: propose and test new ideas. (Negative results are OK, Idea can be related to your own research)
    - Systems project: Need to empirically experiment and test your proposed ideas.
  - 30% Paper reviews and class participation and assignments
    - Read 0,1 papers before each class and write short review.
    - Mini-class Quiz on the paper read before hand.
    - Discussion includes: Short summary (3-4 lines), 2-3 points describing paper strength, 2-3 points describing paper weakness.
  - 25% Final exam

Outline Part 1

http://web.eng.ucsd.edu/~dineshb/ECE257B

Exploiting Time and Frequency

- Physical Layer (OFDM): How can we talk to any other radio?

Exploiting Space Diversity (Space Fourier Transform for communication and localization)

- MIMO, Virtual MIMO
- Wireless Localization (AoA and ToF)

Wireless Sensing (Radars and Wireless Sensing)

- Localization & Tracking, Wireless Gesture Recognition, Wireless Imaging, Contactless Bio-Sensing

Internet of Things:

- Backscatter Communications: How can we make long distance, low power, high data rate communications?
- LoRa Networks, Ultra-low Power Networking, Ambient Backscatter, Smart Cities and Environments

Outline Part 2

http://web.eng.ucsd.edu/~dineshb/ECE257B

Cross-Layer Network Optimizations:

- Medium Access Control combined with PHY layer inputs to optimize network performance
- Interference cancellation for Network Efficiency

Full-Duplex Radios

- Traditionally, networks have been half-duplex, self-interference cancellation enabling full-duplex radios.

Mmwave Systems

- 14 Ghz of bandwidth at frequencies where wavelength is order of 1mm, challenges with these frequencies

Flexible set of topics depending on class interest.

Pre-requisite

- Strong DSP background with Matlab experience
- Undergraduate class on communication
- Homework 0 is posted
  - OFDM receiver implementation
  - Provided with Transmitter code, which can be used to test your receiver implementation
  - Test: Dataset captured on software defined radio is provided for QPSK and 16 QAM, you need to decode those!

Introduction to Wireless Networks

Wireless networks provide advantages

- Mobility
- Eliminates piles of wires at home and office

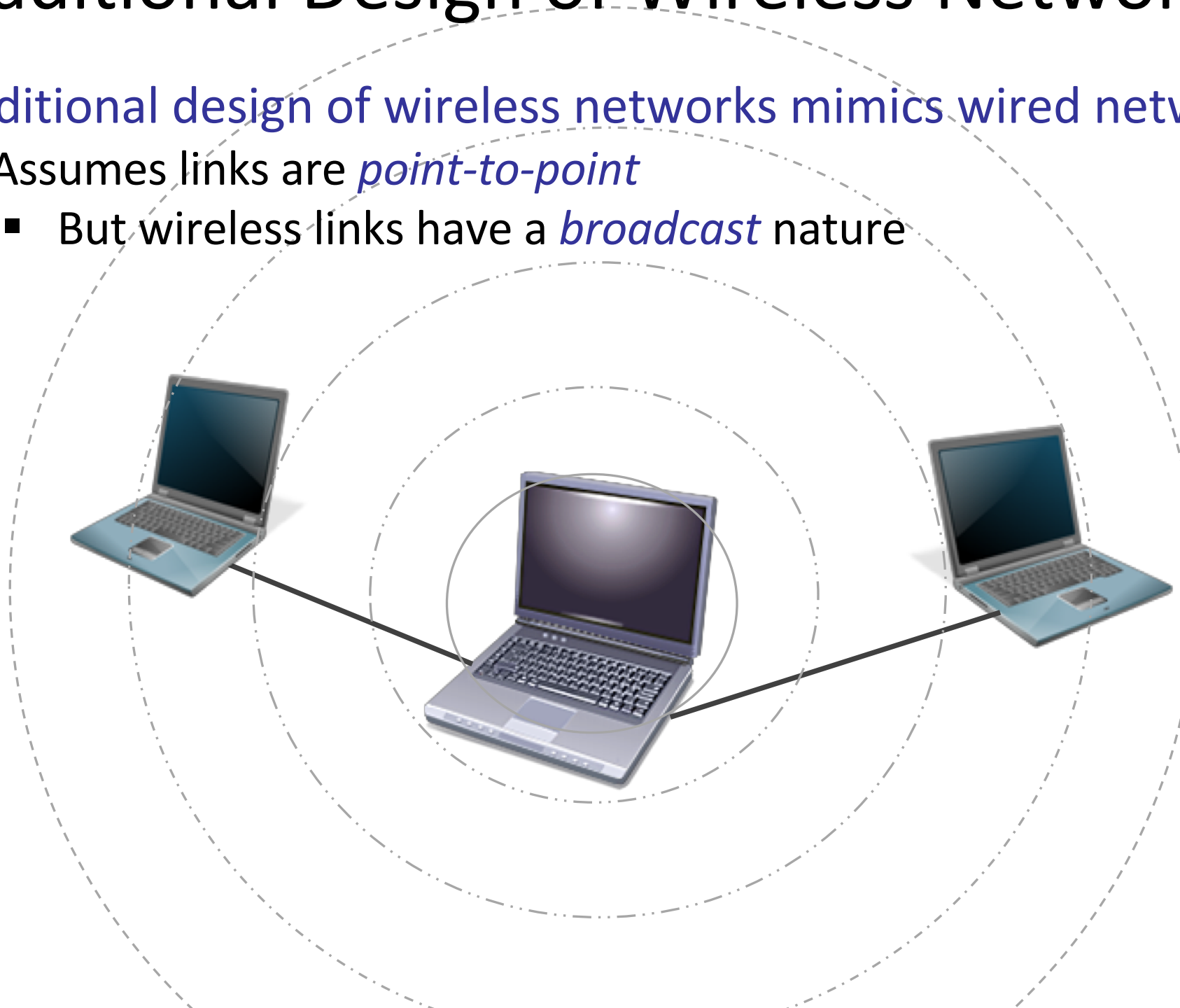
But wireless networks present different challenges

- The medium is shared → Nearby transmitters can interfere
  → Need medium access protocols
- The medium is shared → throughput is relatively low particularly when there are many devices
- Channel quality could be bad and/or unpredictable → high bit errors which could result in dead spots

Traditional Design of Wireless Networks

Traditional design of wireless networks mimics wired networks

- Assumes links are *point-to-point*
  - But wireless links have a *broadcast* nature



Why point-to-point is a suboptimal abstraction for wireless links?

Scenario: Alice and Bob want to exchange two packets; their radio range doesn't allow them to reach each other→ they need a router to relay the packets between them

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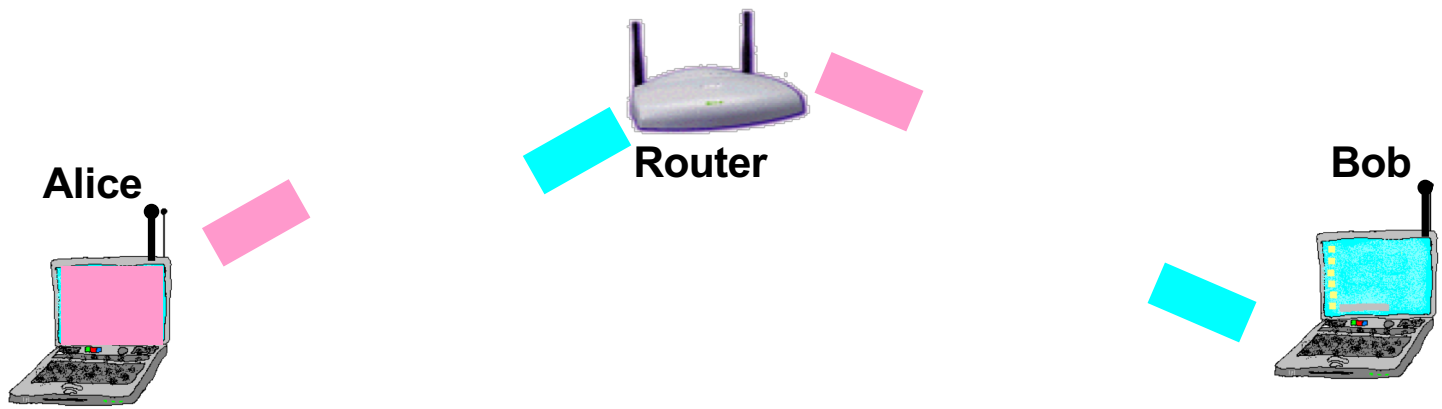
Traditional Approach



Requires 4 transmissions

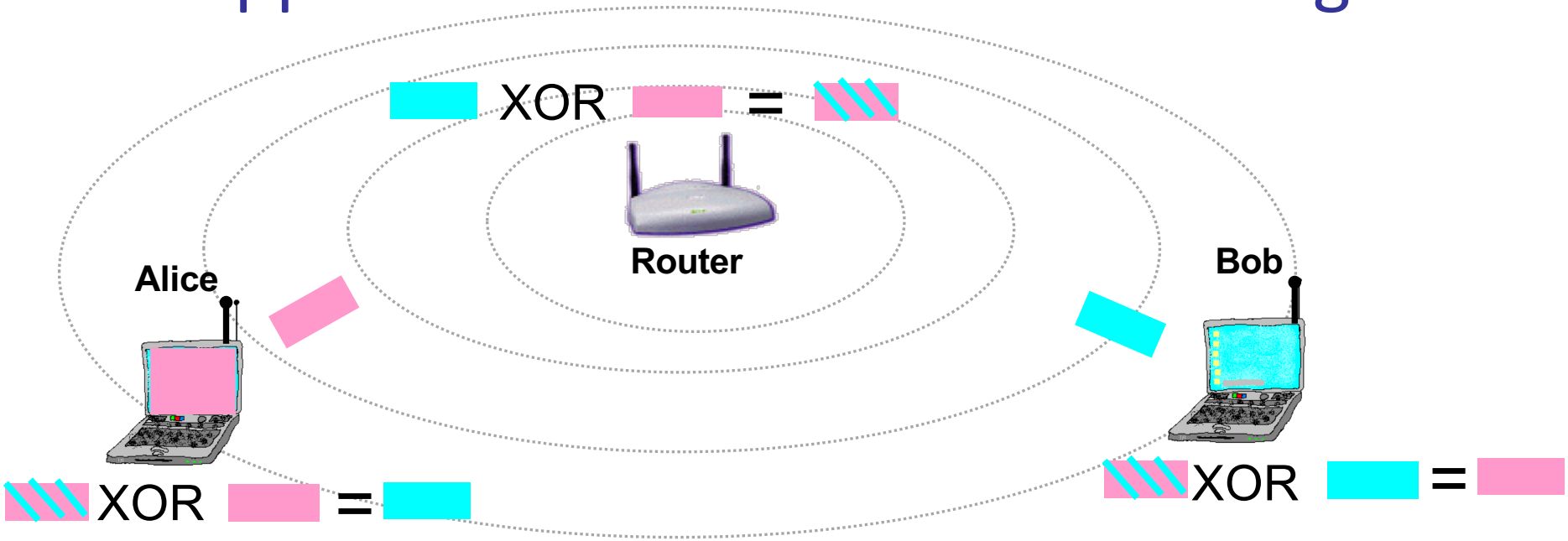
- Alice to router; Router to Bob; Bob to router; Router to Alice

But wireless links are *broadcast* not *point-to-point!*

- Can we exploit broadcast to do better?

Scenario: Alice and Bob want to exchange two packets; their radio range doesn't allow them to reach each other→ they need a router to relay the packets between them

New Approach Based on Network Coding



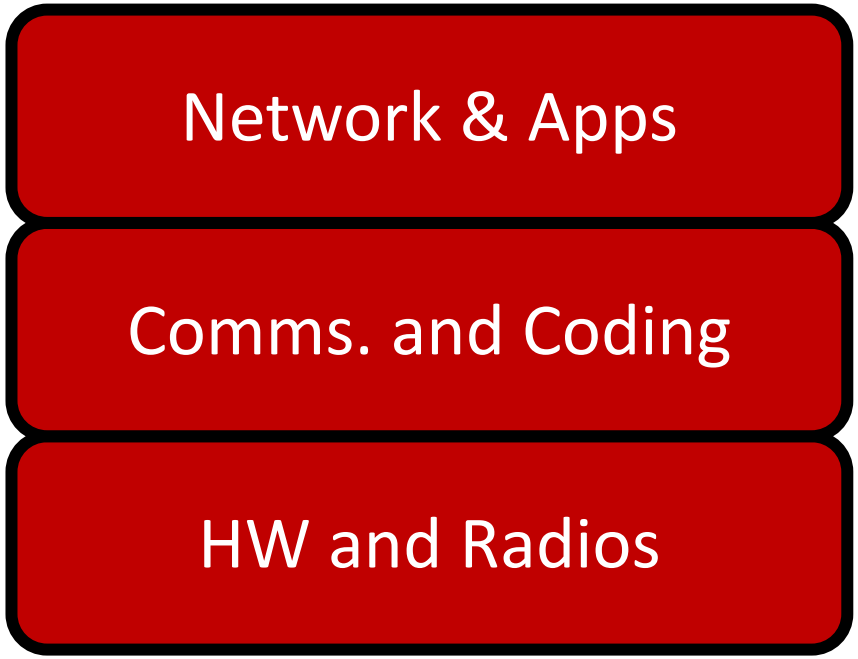
Requires 3 transmissions instead of 4

- Alice to router; Bob to router; and router to both Alice and Bob

Harnessing the broadcast nature of wireless via network coding increases throughout

Traditional Approach

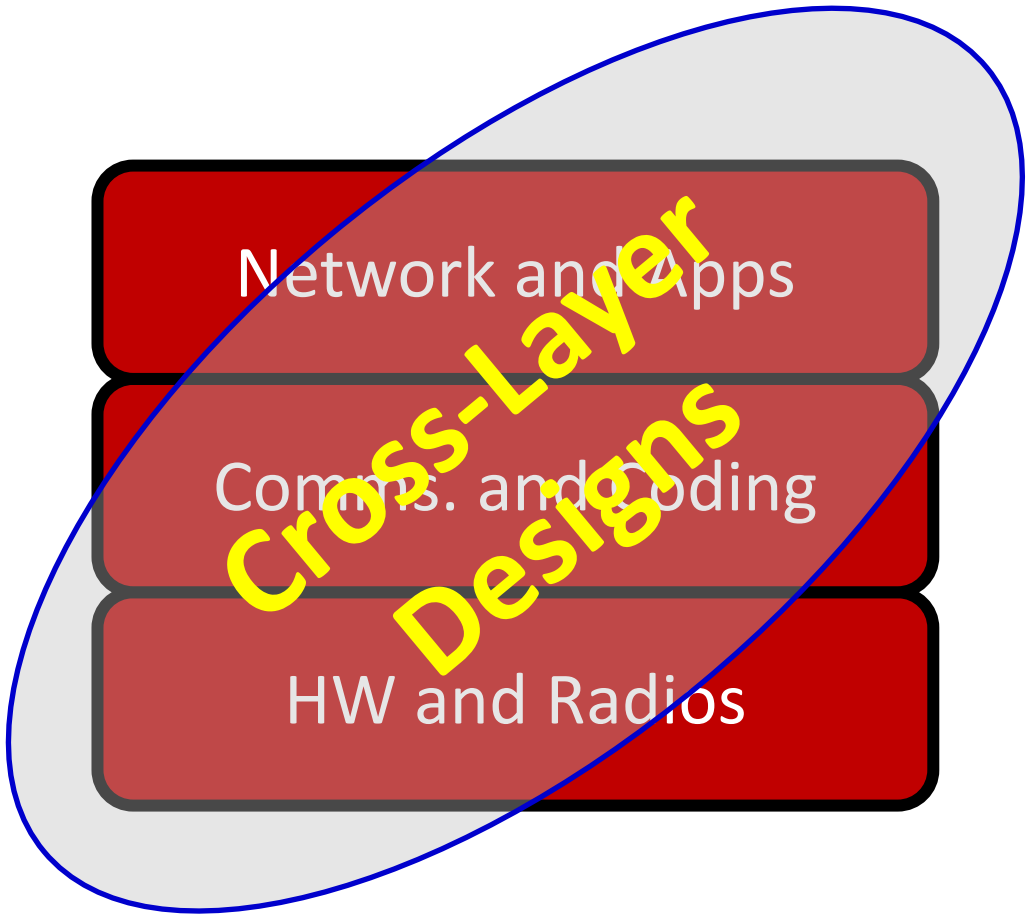
Optimize within isolated layers



Disruptive gains are unlikely

New Approach

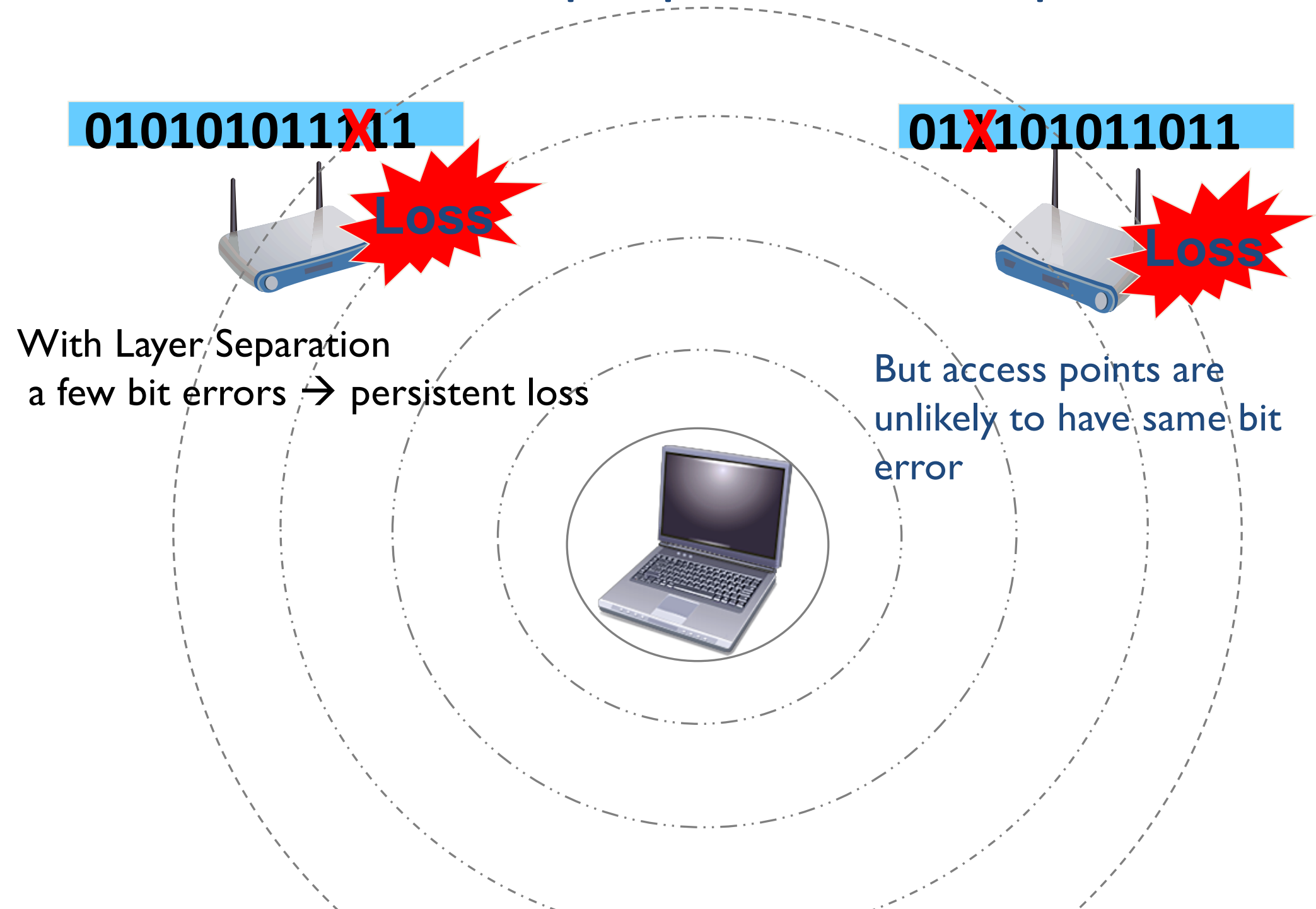
Optimize across the layers



Major opportunities!

Why layer separation is suboptimal?

Scenario: Laptop in a Dead Spot



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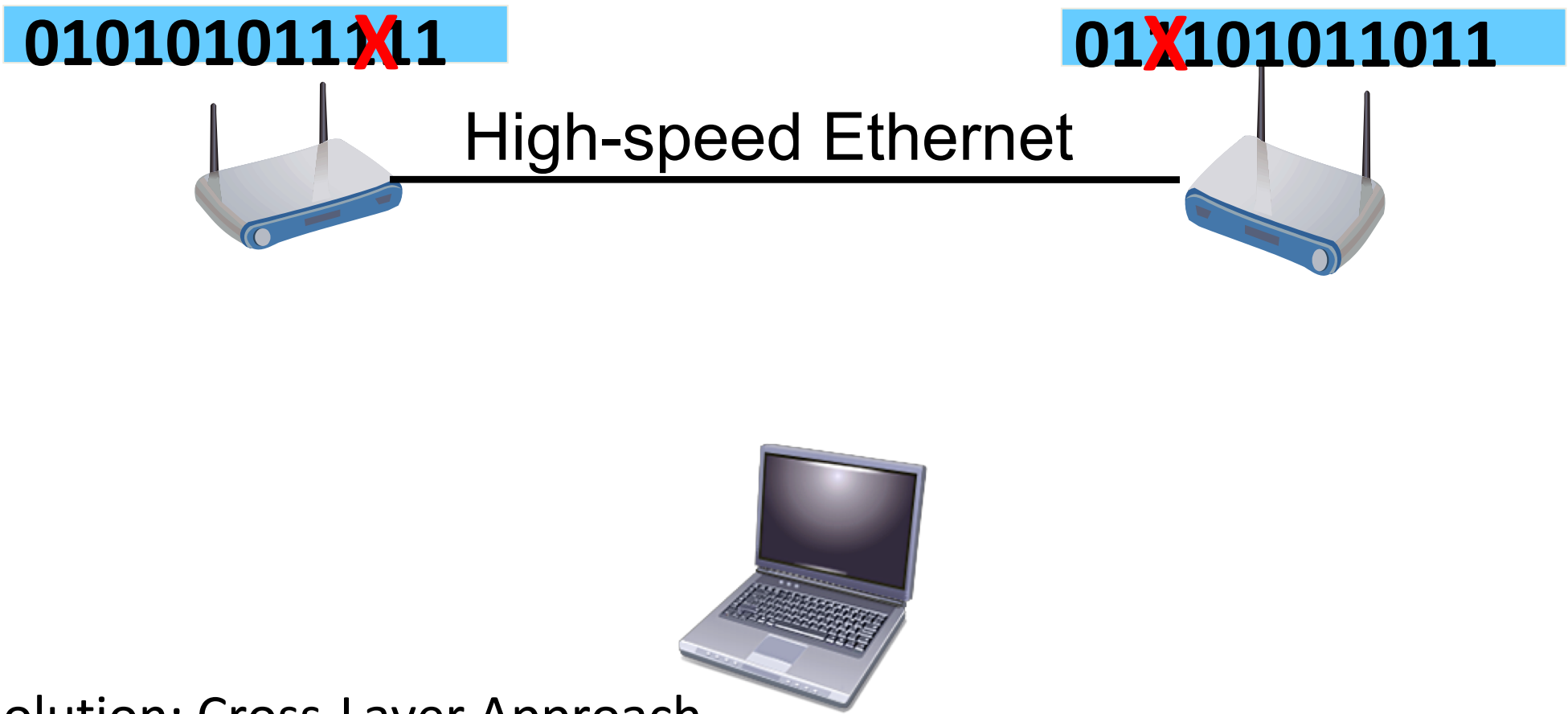


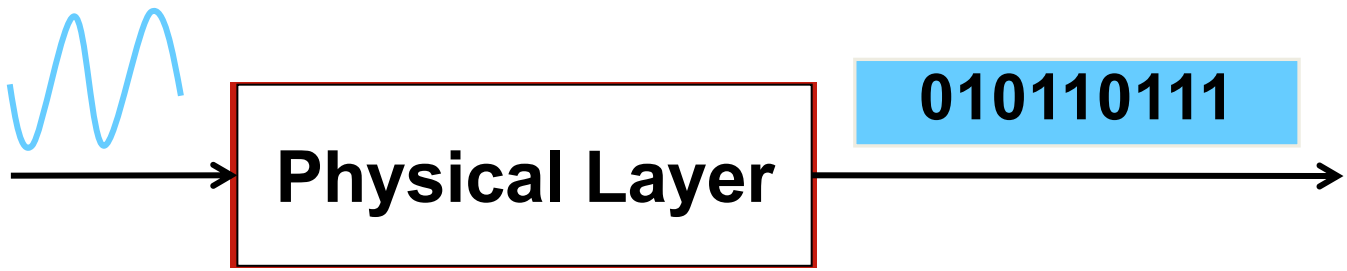
Solution: Cross-Layer Approach

- Allow the layers to collaborate instead of acting separately
- PHY layer delivers partially correct packets
- Network layer combines correct bits across different access points to obtain correct packet

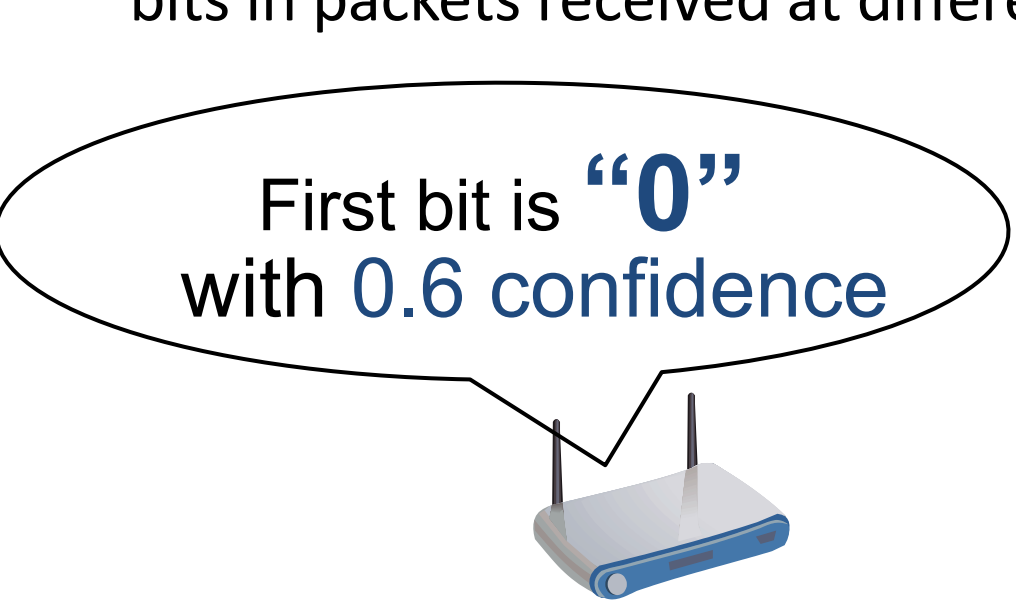
Challenge

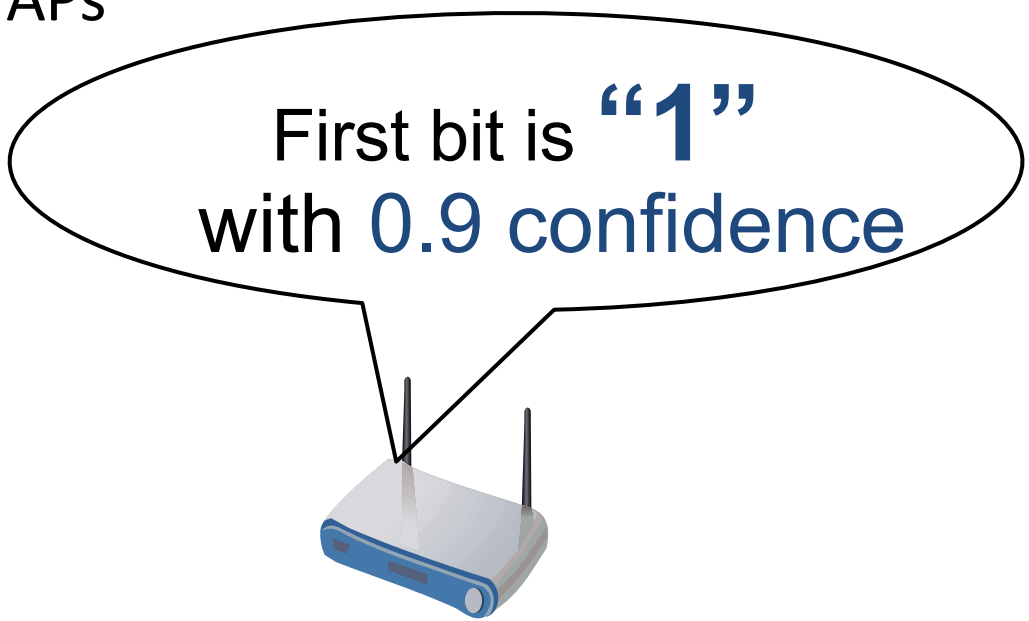
Which access point should we believe?

Solution: Network cooperates with physical layer



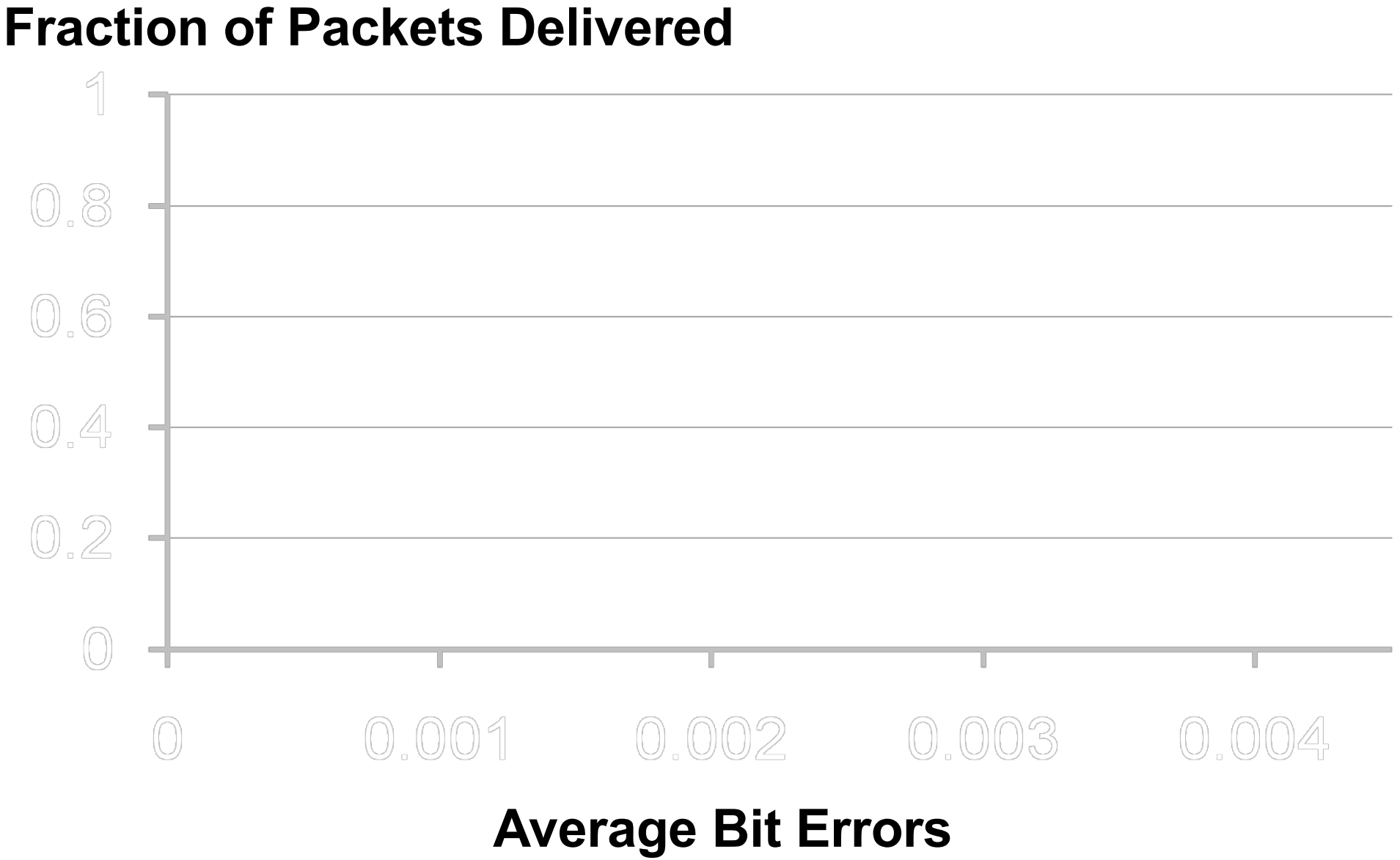
- Physical layer already estimates a confidence in its 0-1 decision
- If we expose this information to the network layer, we can compare bits in packets received at different APs





- Assign to each bit the value that corresponds to a higher confidence

Experiment: Packet Delivery vs. Poor Coverage



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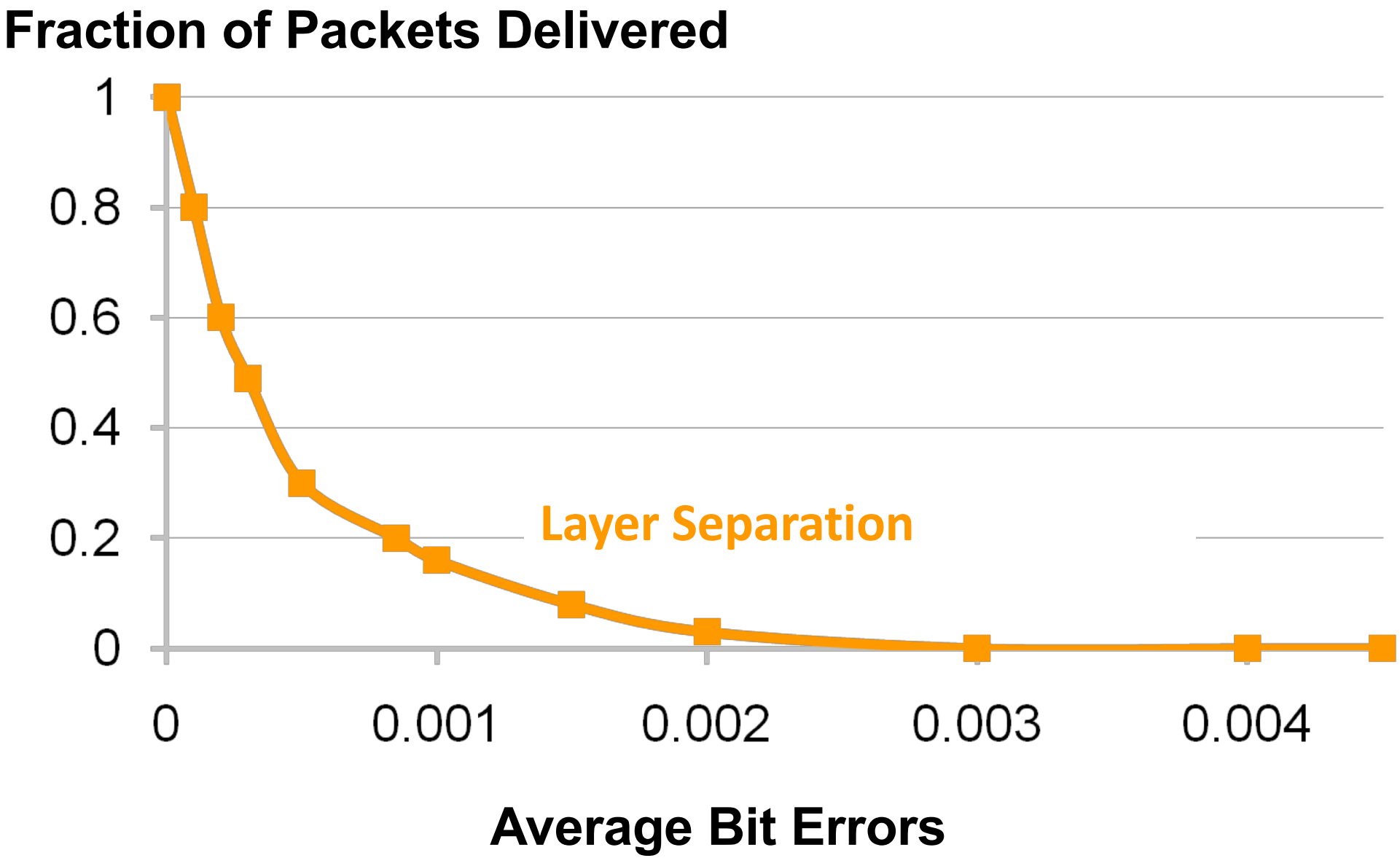

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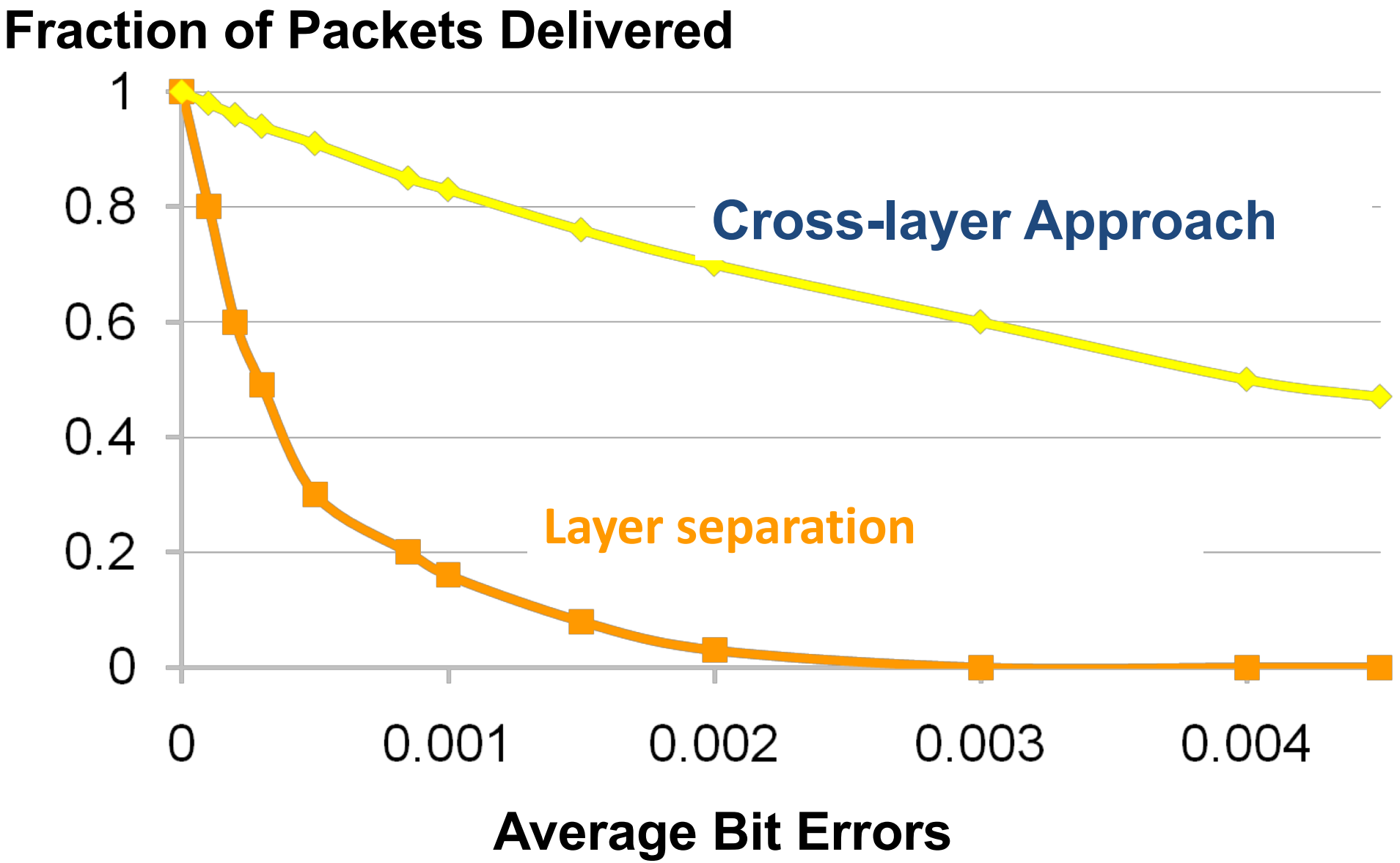
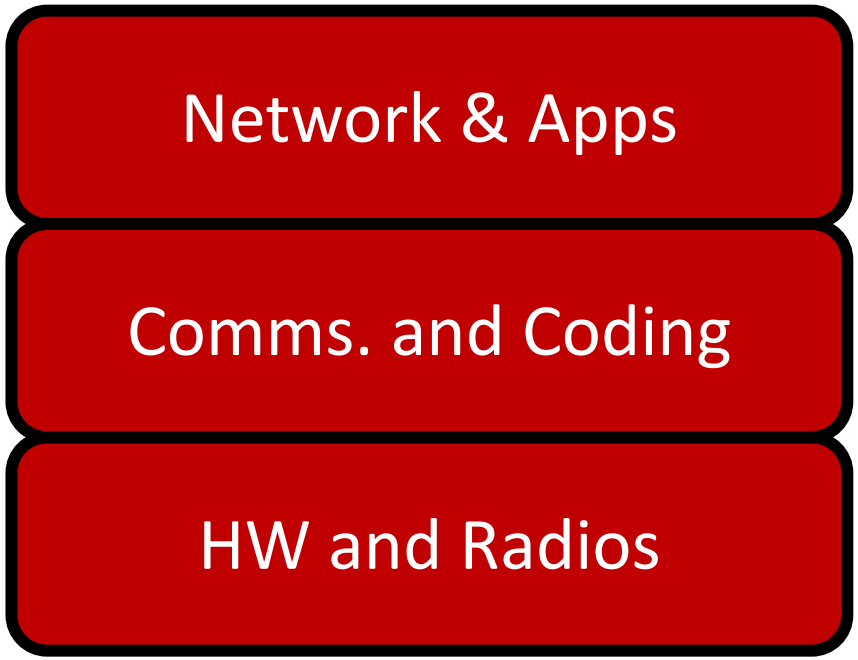


Traditional Approach

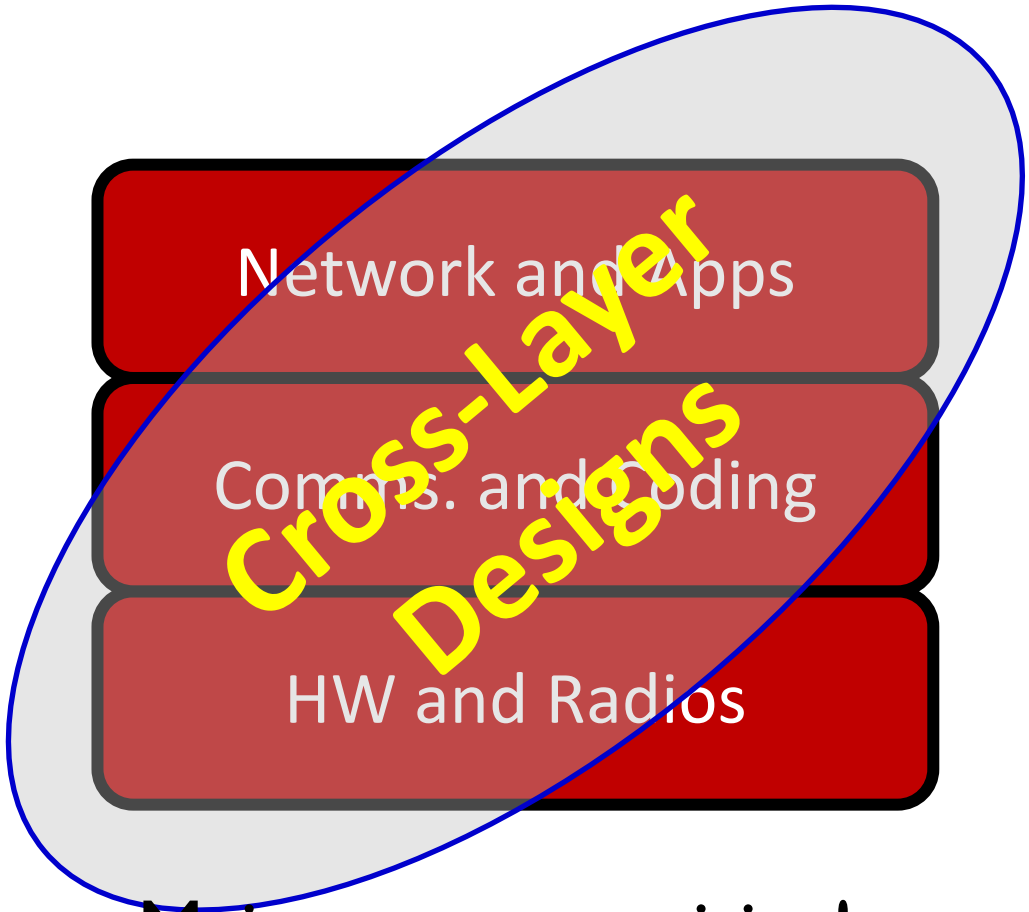
Optimize within isolated layers



Disruptive gains are unlikely

New Approach

Optimize across the layers

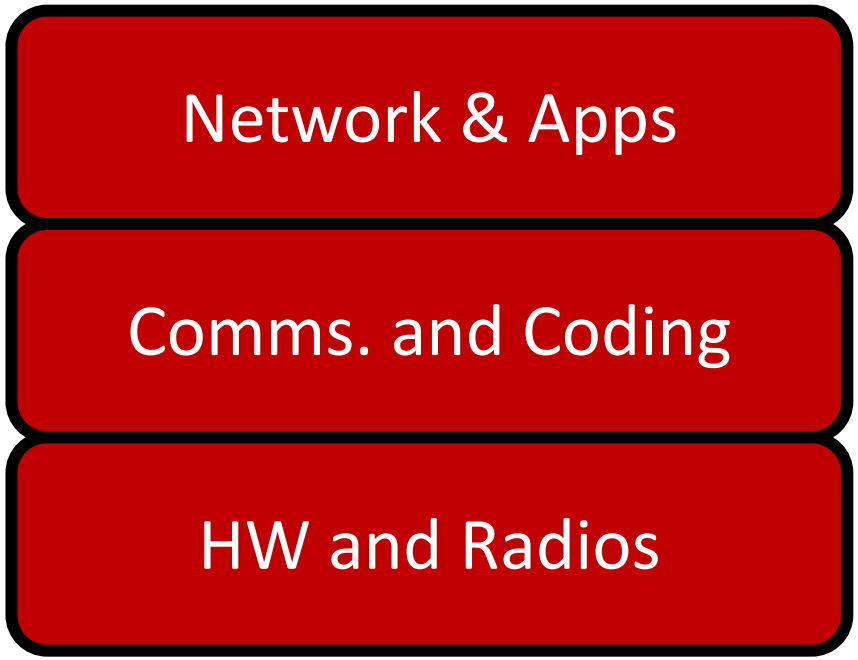


Major opportunities!

Fundamental Change in Network Architecture

Traditional Approach

Optimize within isolated layers



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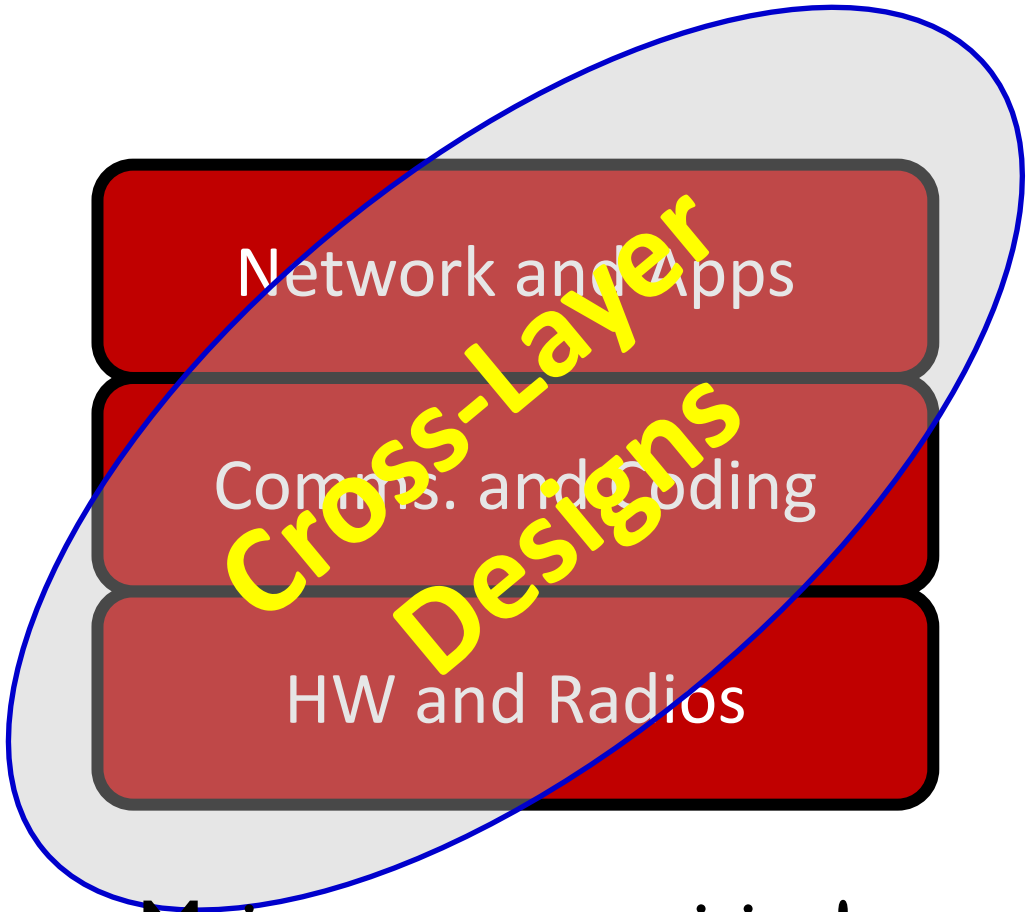


Major opportunities!

Can we design machine learning based architecture?

New Services: Wireless Localization

GPS does not work indoor→ Use WiFi to localize.

Indoor Navigation

Business Analytics

WiFi Geofencing

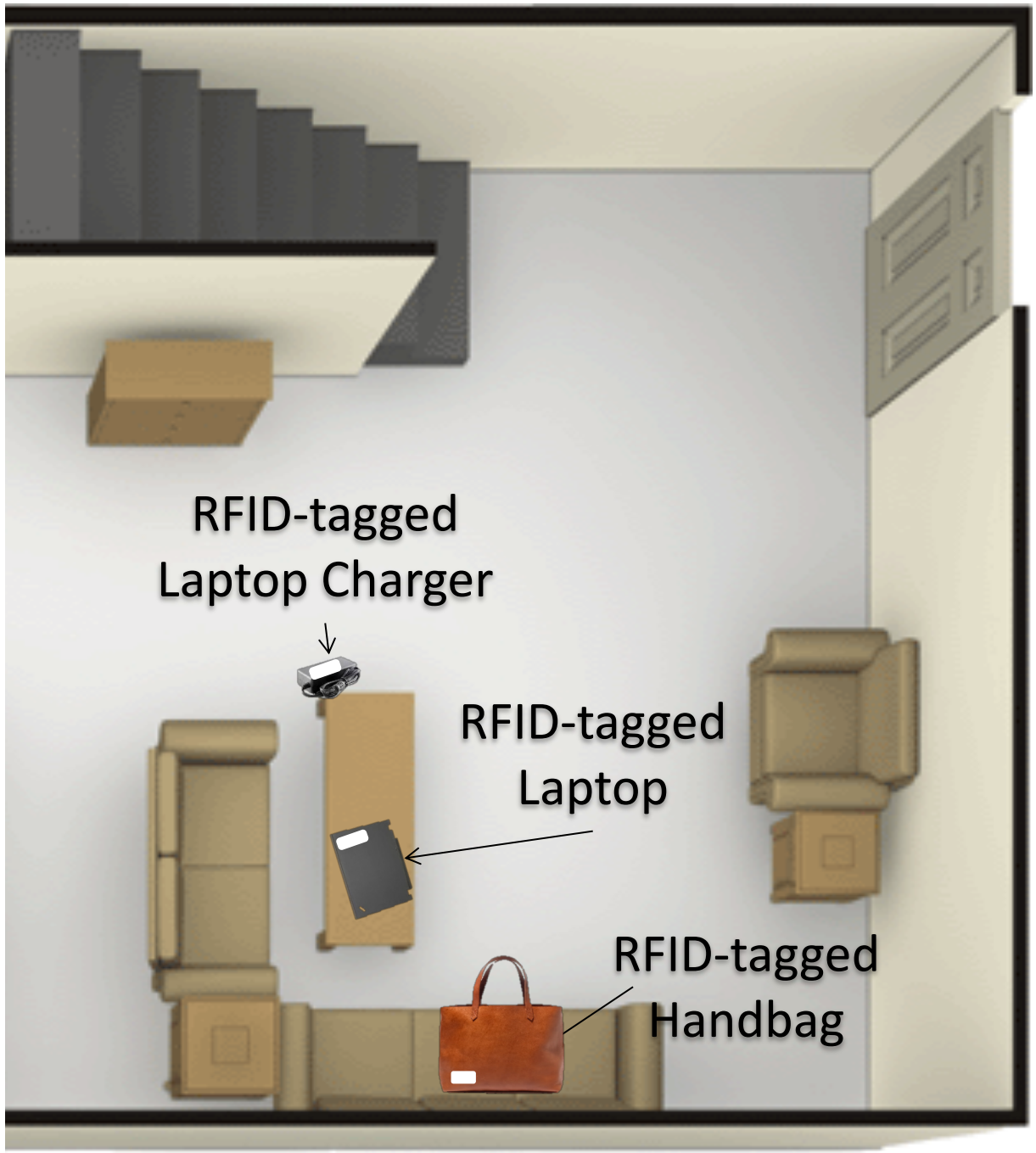
Indoor Robotic Navigation

New Services: Wireless Localization

Localize Everything and Anything!

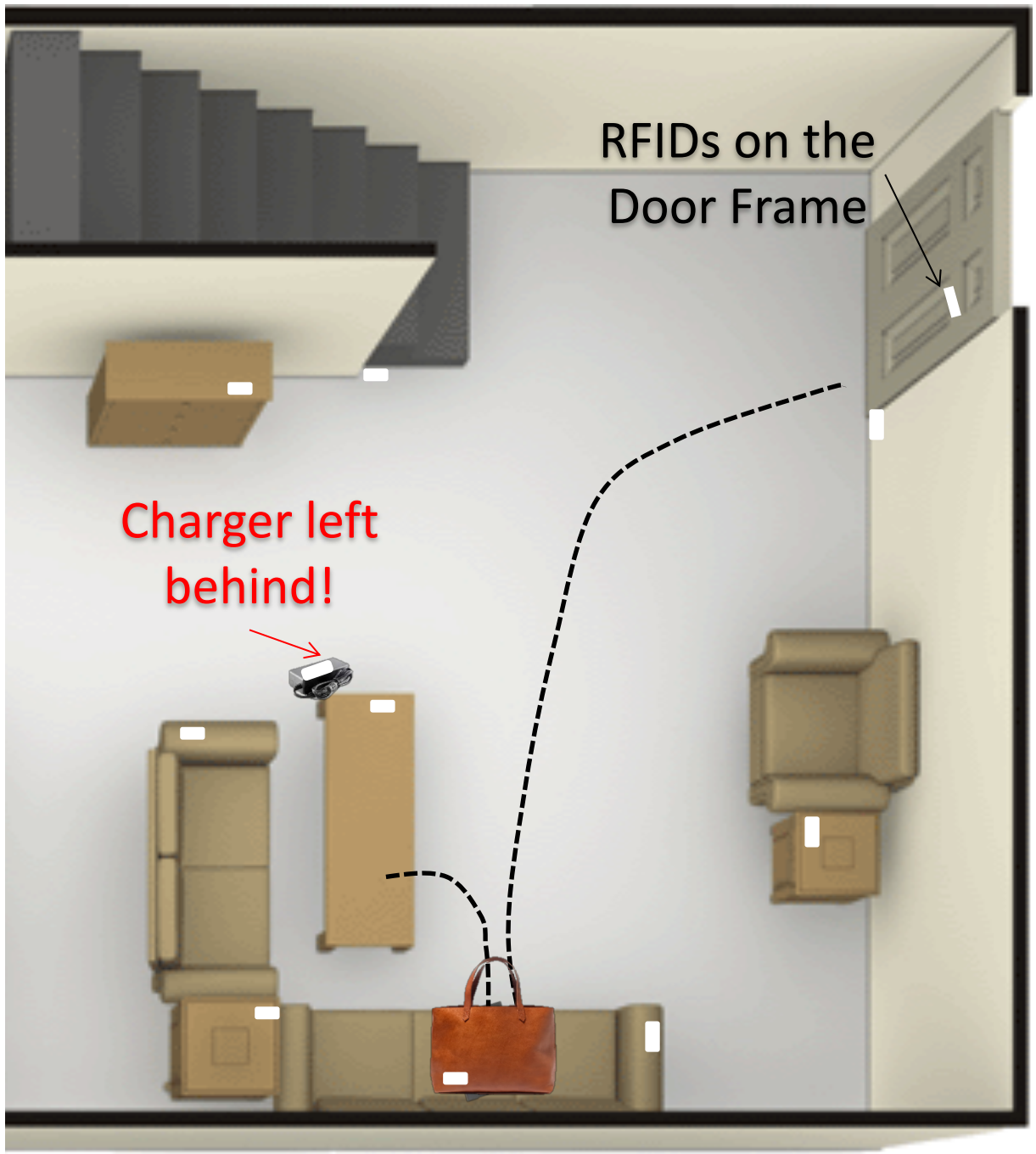
Battery-free stickers to tag any and every object

Smart Homes


RFID-tagged
Laptop Charger
RFID-tagged
Laptop
RFID-tagged
Handbag

Smart Homes

Smart Homes



How Do We Get Virtual Touch Screens?

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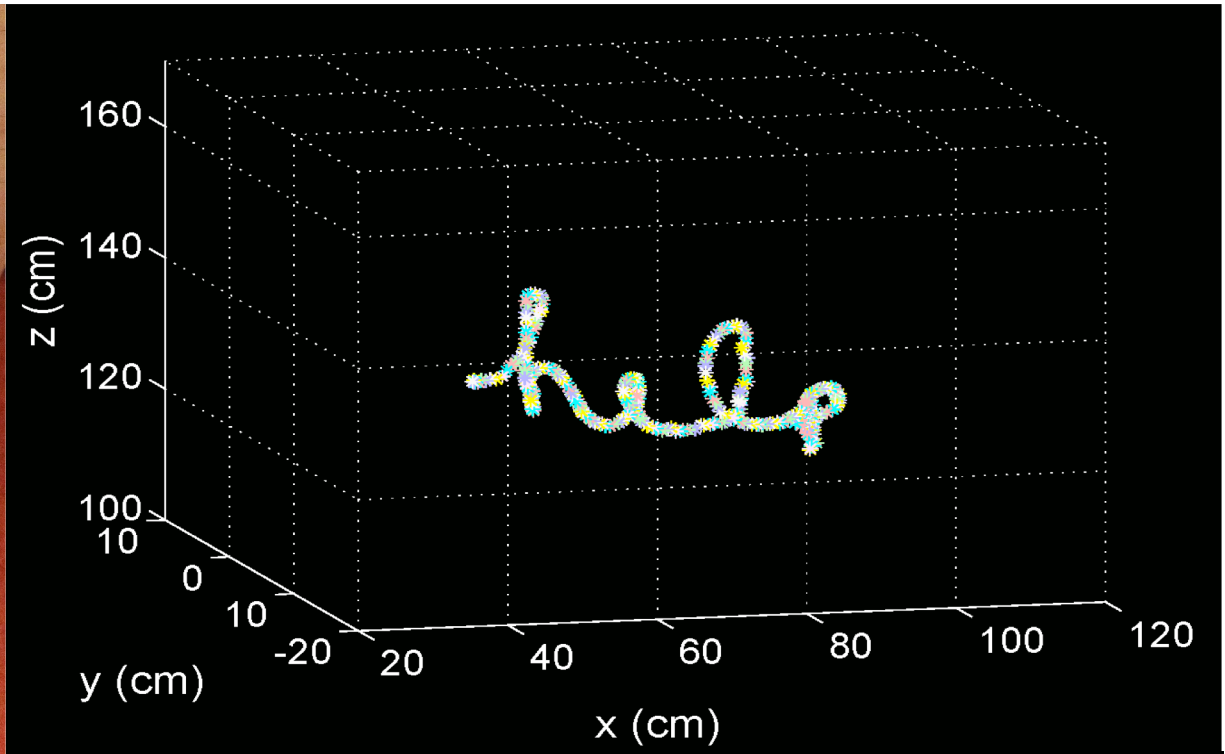
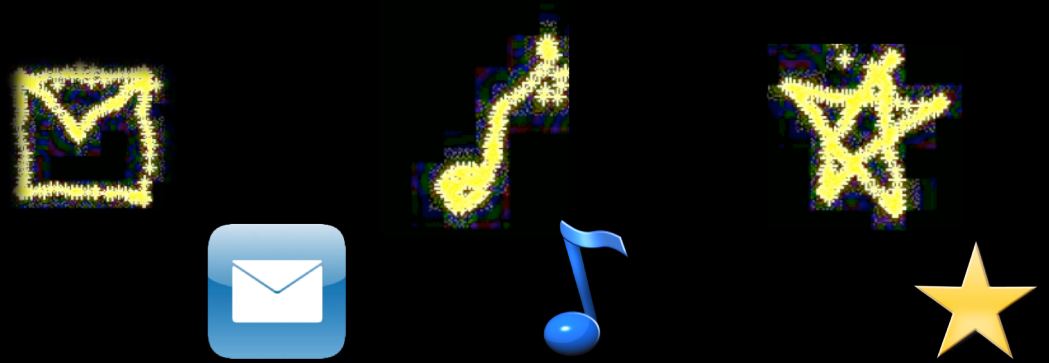
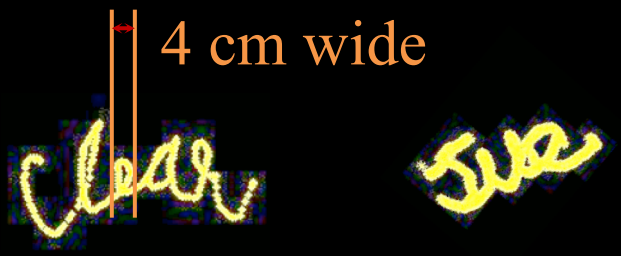




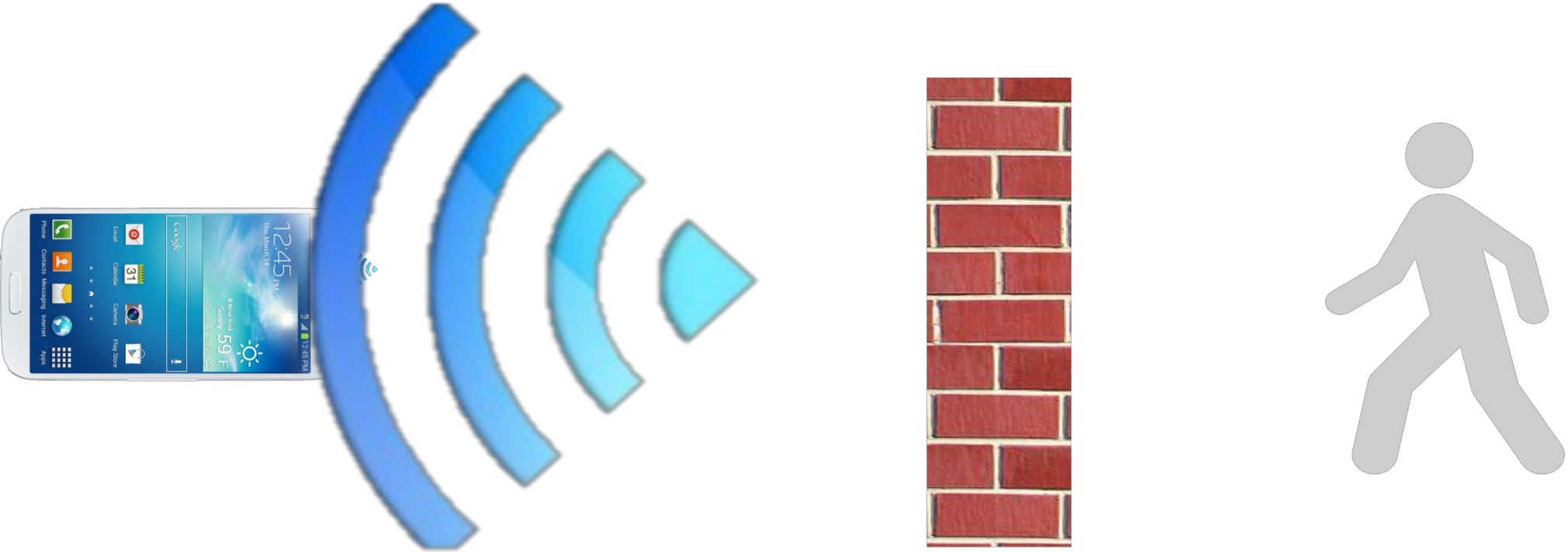


“Clear” “Jue”

Can your cellphone give you X-ray vision?

See through-walls with WiFi

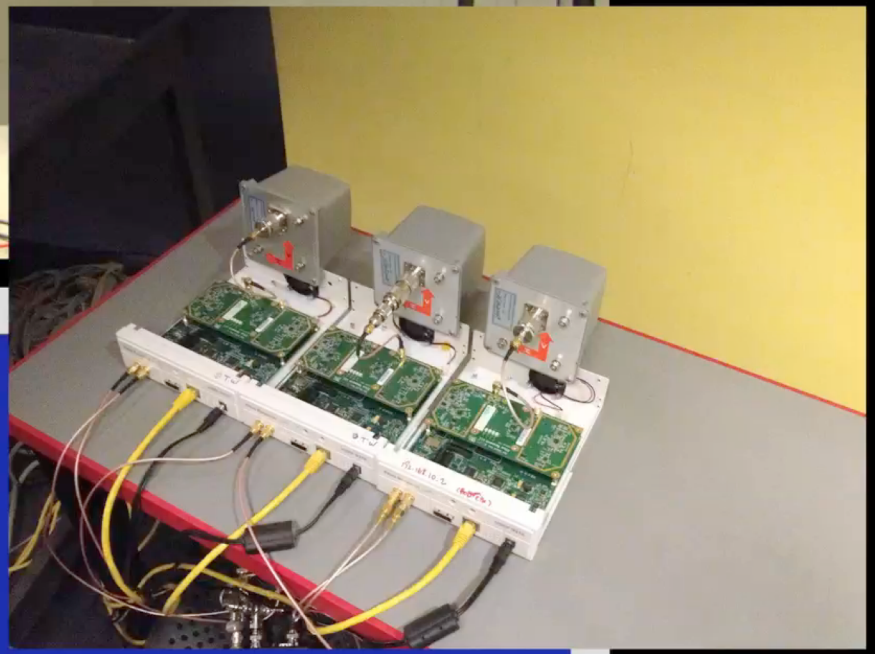
See through-walls with WiFi

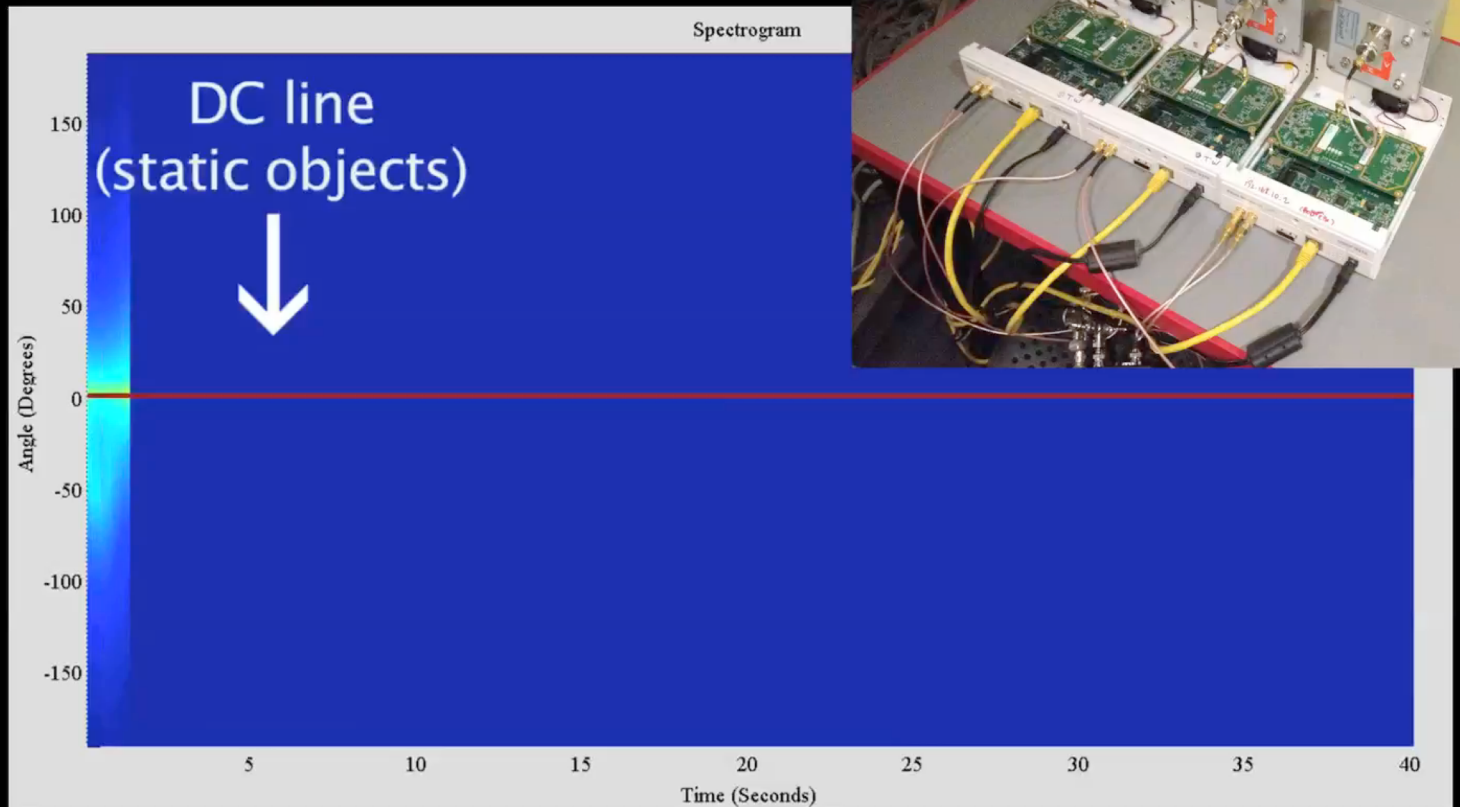


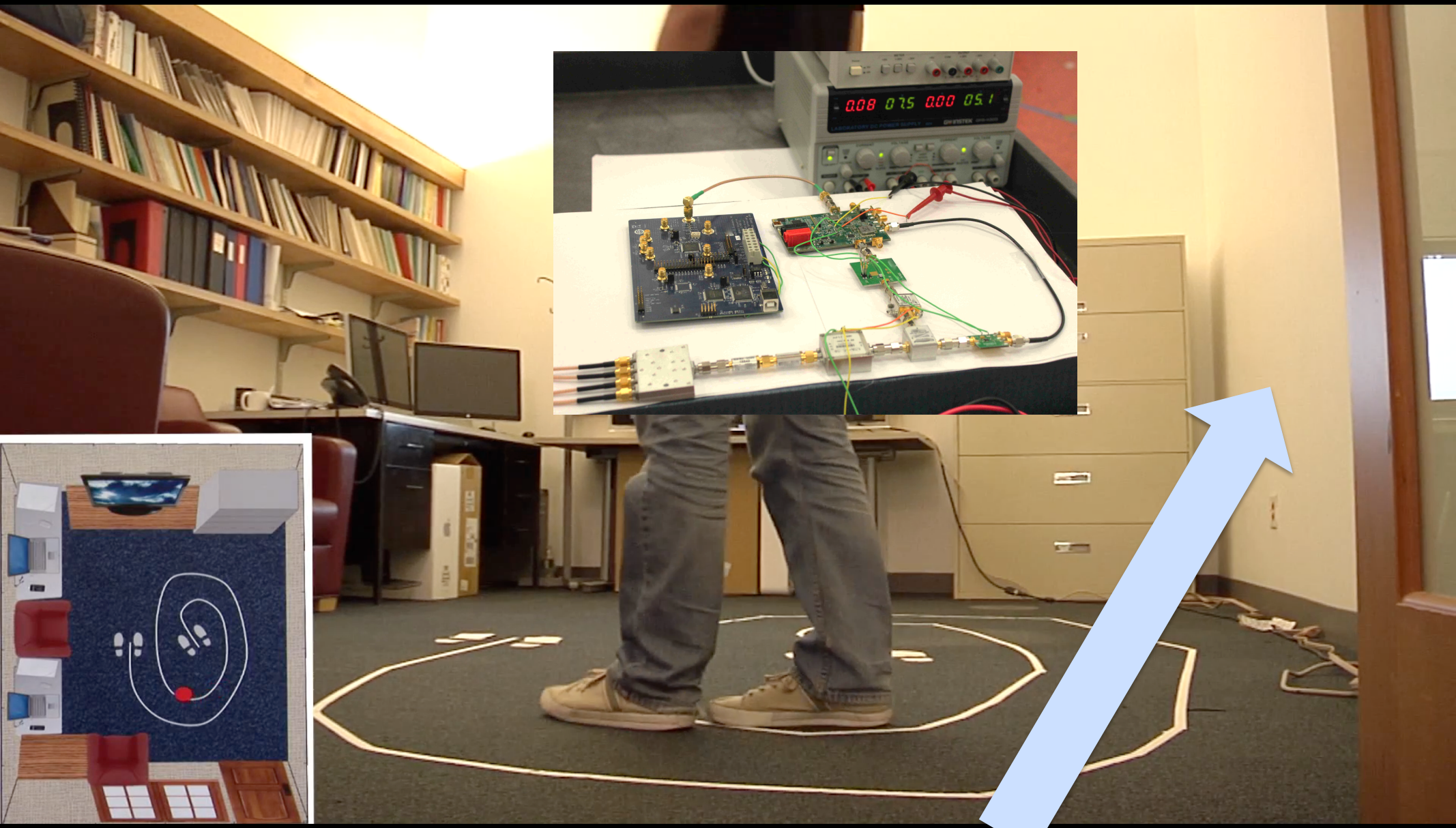
Wall refection is 10,000x stronger than reflections coming from behind the wall

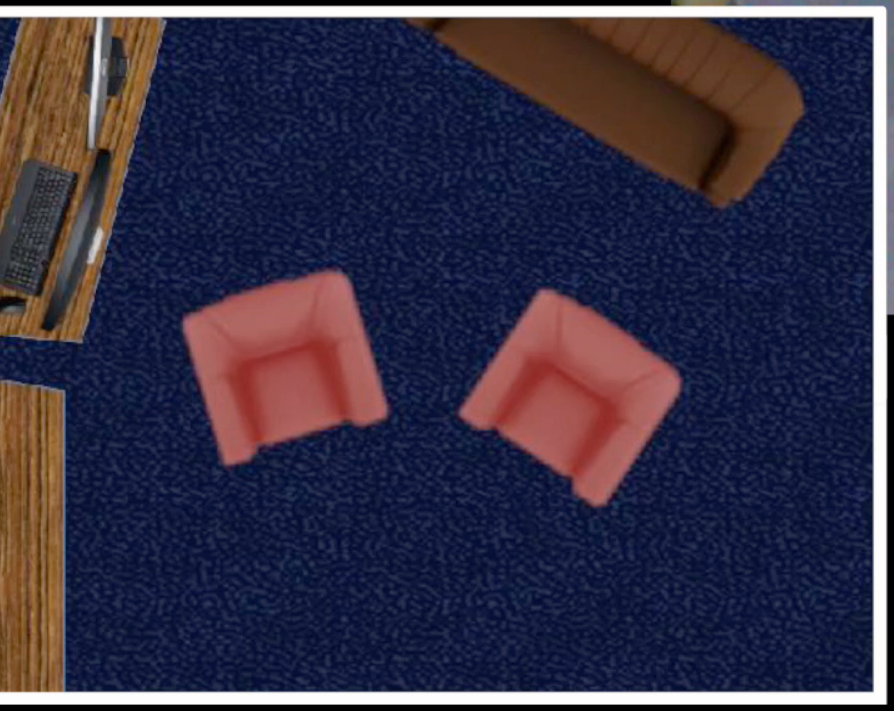
Solution: Use two transmit antennas and one receive antenna; the two transmitted waves cancel each other for static objects but not animated objects

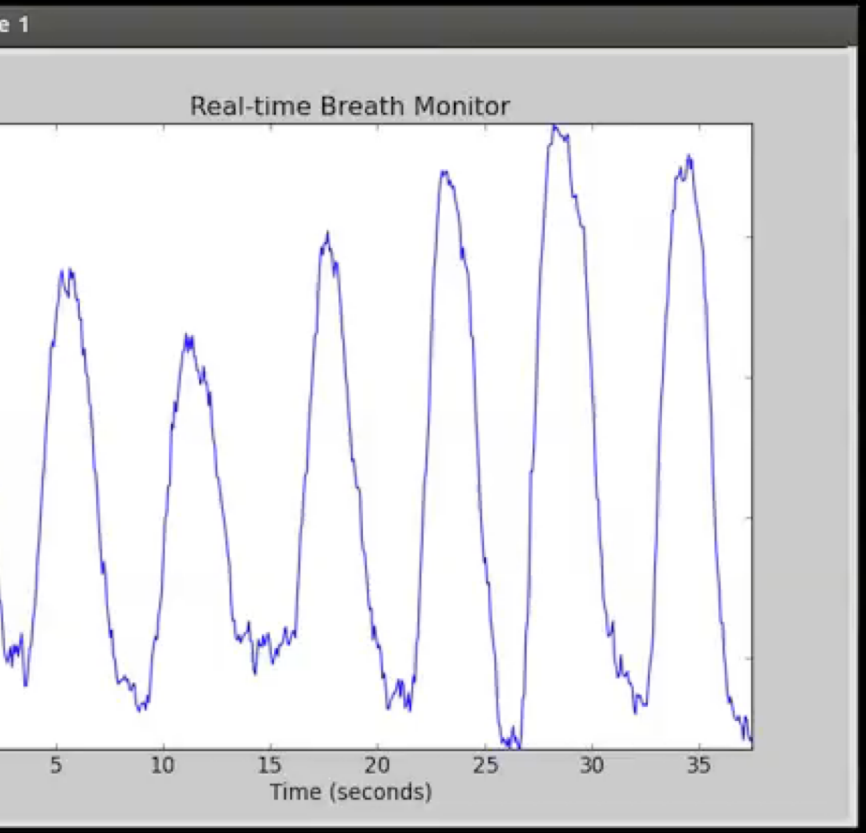

WiVi behind wall
over here




Spectrogram
DC line
(static objects)
150
100
50
0
-50
-100
-150
Angle (Degrees)
5
10
15
20
25
30
35
40
Time (Seconds)


Wireless Device behind




e 1
Real-time Breath Monitor
5
10
15
20
25
30
35
Time (seconds)

Baby Monitoring

Smart homes that monitor and adapt to our breathing and heart rates?

Personal Health

Baby Sleep

Elderly Health

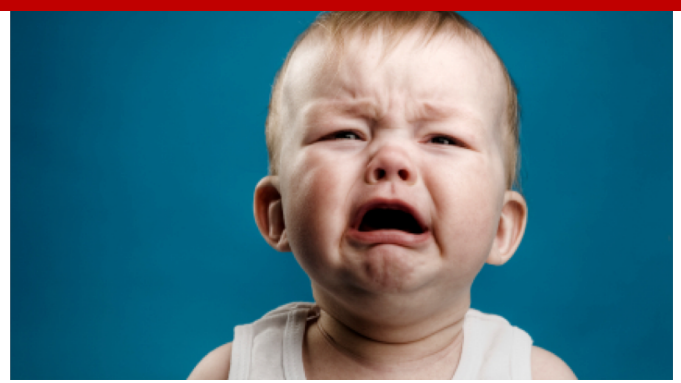
Adapt Lighting and Music to Mood

Today: technologies for monitoring vital signs are cumbersome

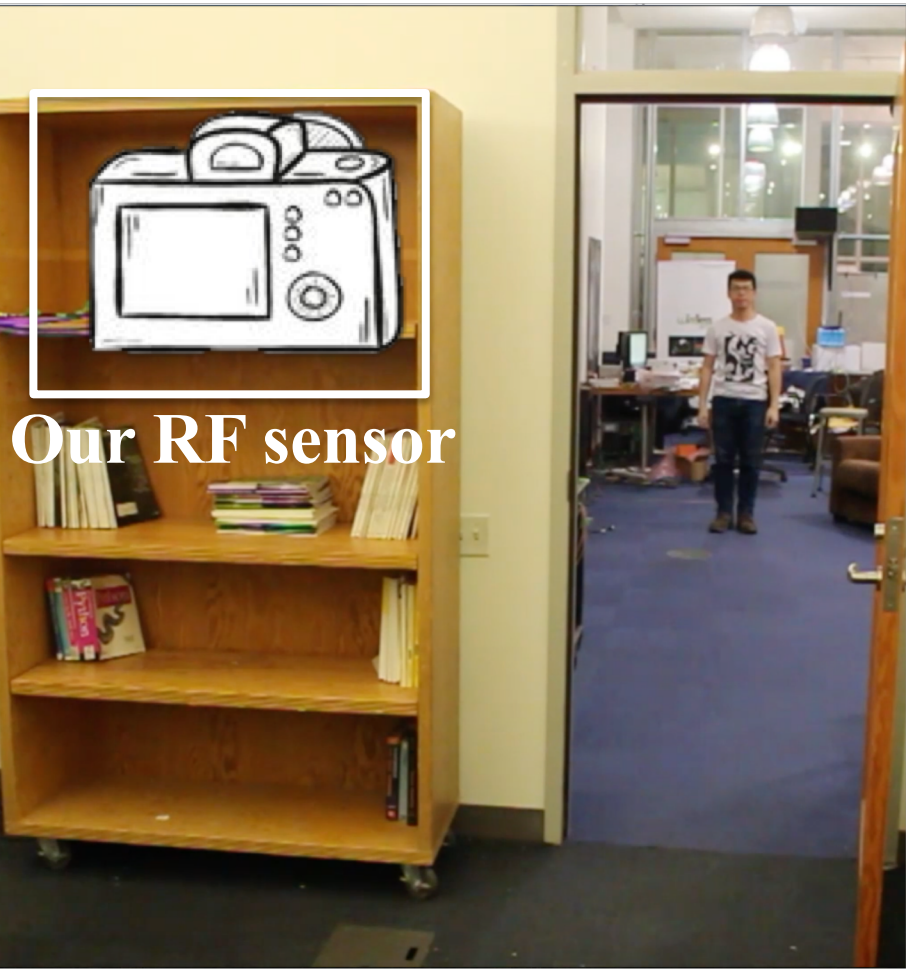
Breath Monitoring

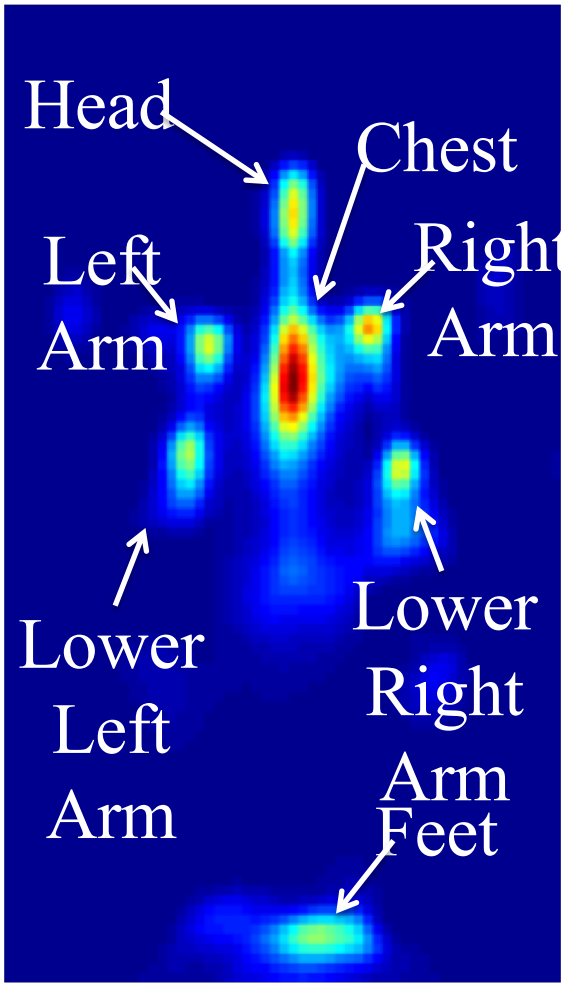
Heart Rate Monitoring

Wireless enables contactless sensing: sense humans without any sensors on their bodies



Imaging through occlusions
using radio frequencies





Challenge: Don't get reflections from most points in RF

At frequencies that traverse walls, human body parts are specular **(pure mirror)**

Human Walks toward Sensor

Wireless Security

Medical implants and sensors are power limited

➔ Can’t have strong cryptography

➔ Easy to eavesdrop on the signal, capture confidential data and hack devices.

RFIDs Are Used in Sensitive Applications

Access Control

Credit Cards

Passports

Pharmaceutical Drugs

Anti-Theft Car Immobilizers

Public Transportation

RFIDs Are Used in Sensitive Applications

Access Control
[SECRYPT'09, S&P'09
ESORICS'08, Usenix'08]

Credit Cards
[DefCon'13, ShmooCon'12,
DefCon'11 , Usenix'05]

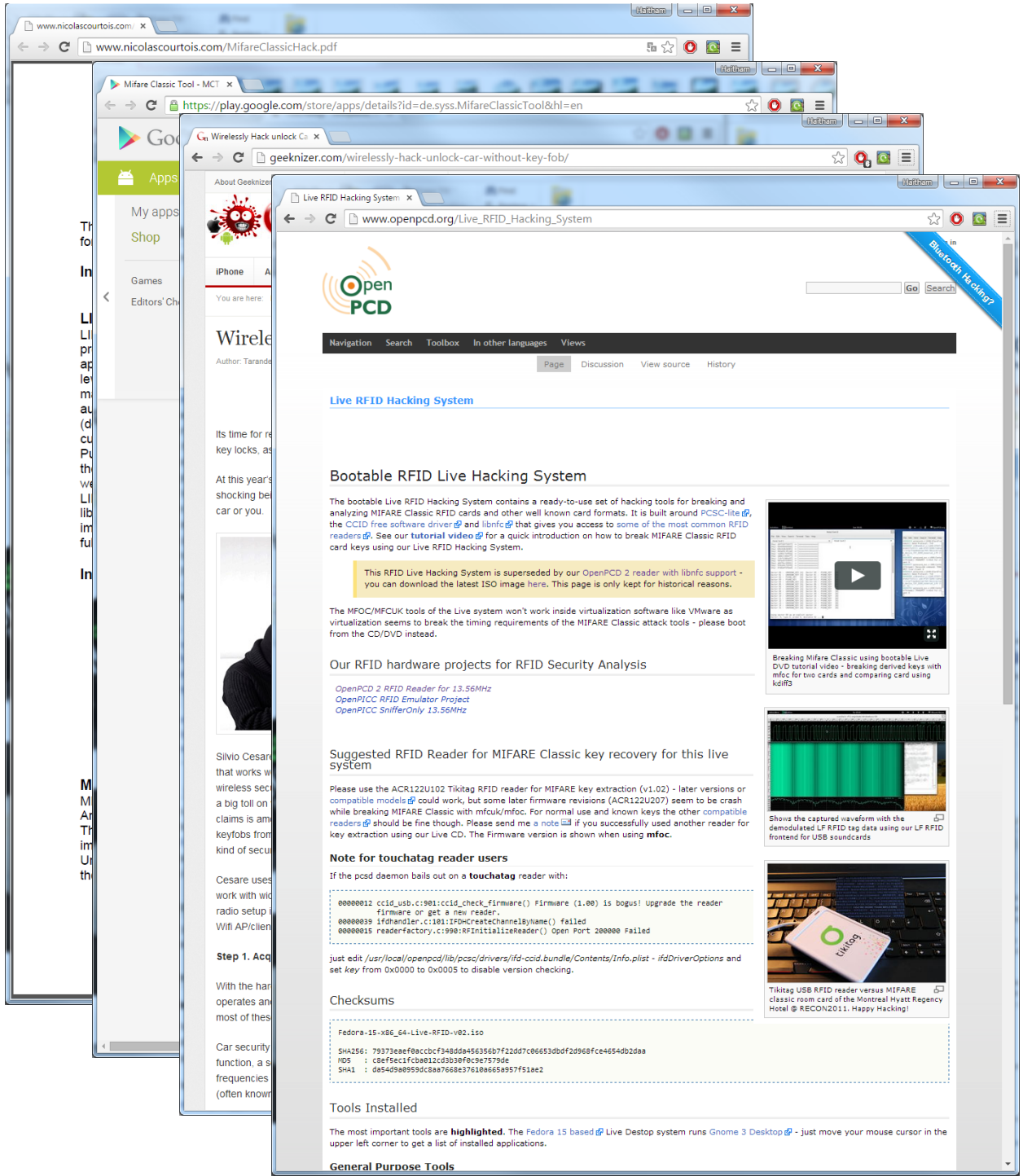
Passports
[DefCon'12, HackaDay'12,
BlackHat'06]

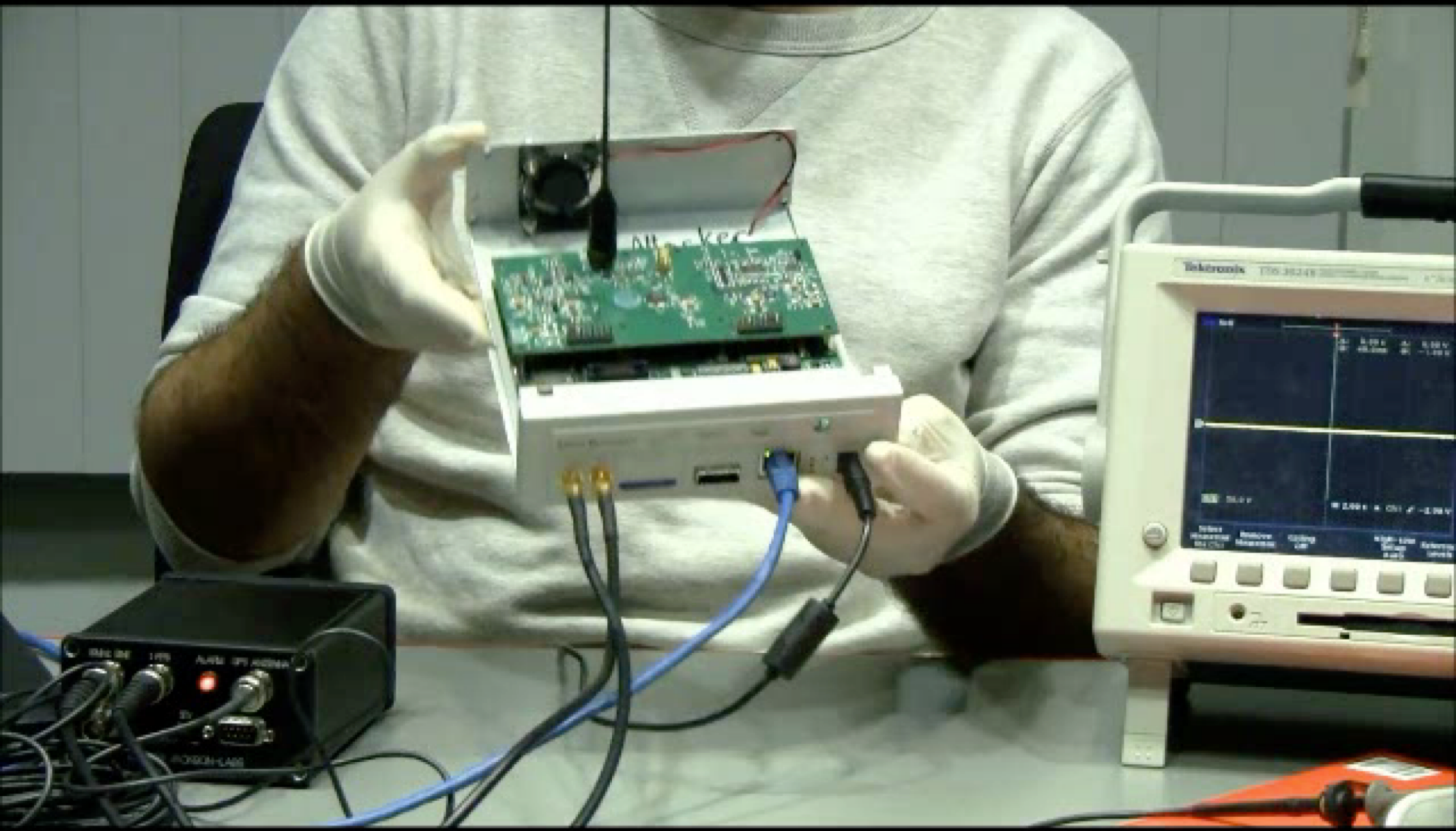
Pharmaceutical Drugs
[CCS'09, RFID'06]

Anti-Theft Car Immobilizers
[Usenix'12, Usenix'05]

Public Transportation
[Defcon'08, MIT'08, S&P'09]

Hacking RFIDs for Dummies




Tektronix

Physical Layer Security: Encryption on the Air

Encrypt using a random signal

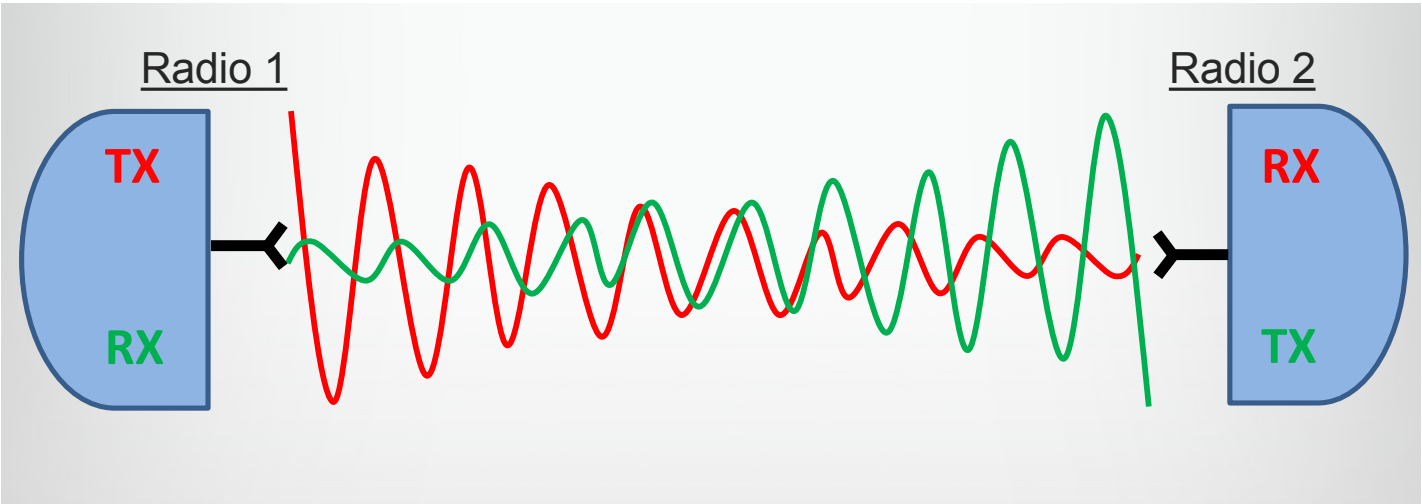
Implant's signal

Random Sum

Doesn't know jamming signal

Can secure medical devices even if they have no encryption of weak encryption

Today's Radios Are Half Duplex



Self Interference is hundred billion times 110dB+ stronger than the received signal!

But we know the signal which we are transmitting!

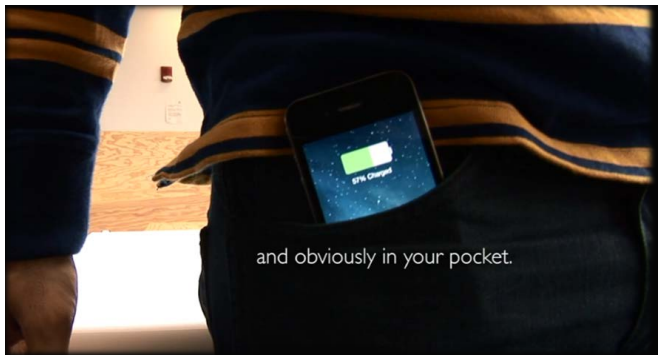
→Cancel the self-interference on the hardware

→1.97x increase in throughput

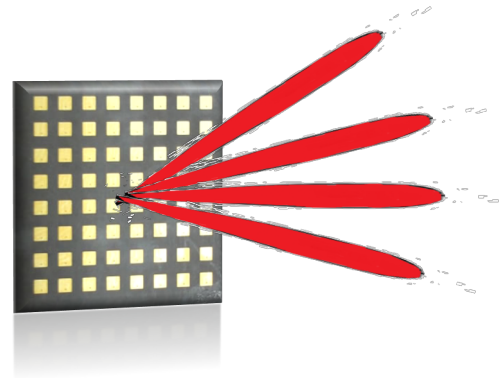
Full Duplex Radios: Major change in communication protocols

Other Topics Covered

Wireless Charging



Millimeter Wave Communication



Wireless at Fiber Optic Speed using massive antenna arrays

Visible Light Communication