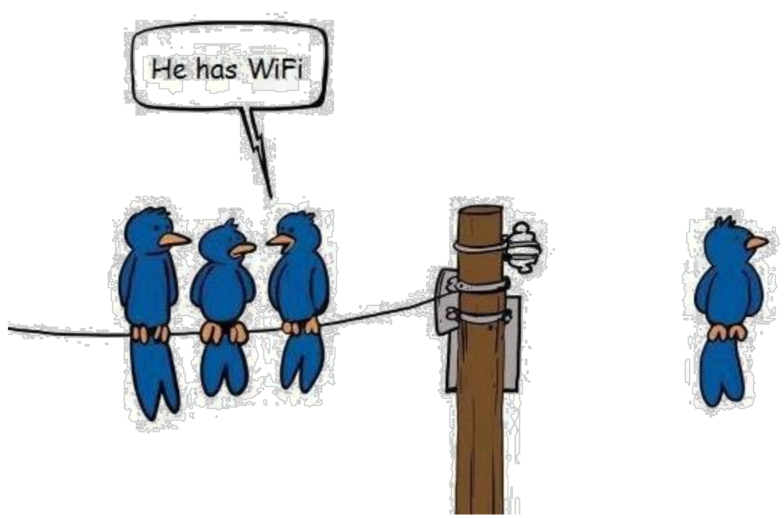
ECE 598HH: Advanced Wireless Networks and Sensing Systems

Lecture 1: Introduction to Wireless Research

Haitham Hassanieh



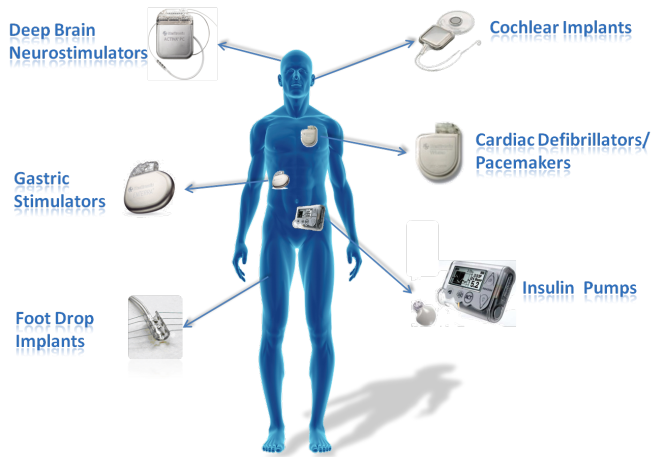
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

CSL: COORDINATED SCIENCE LAB

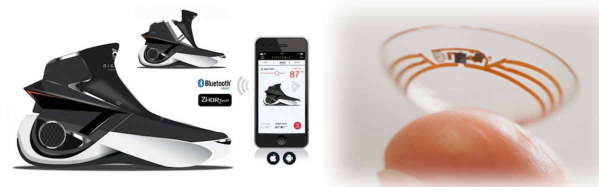
Wireless Networks Increasingly Prevalent

Wireless Homes

Wireless Biomedical Implants



Wireless Wearables



Cellular Networks

Wireless Sensors

UAVs

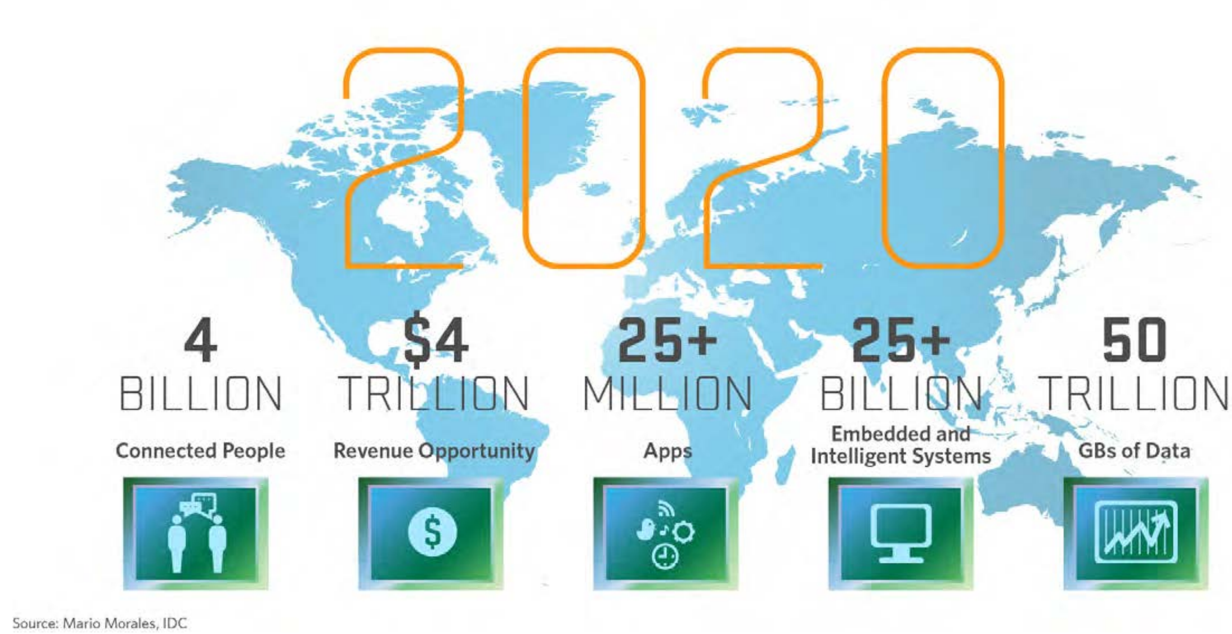
Wireless Data Centers

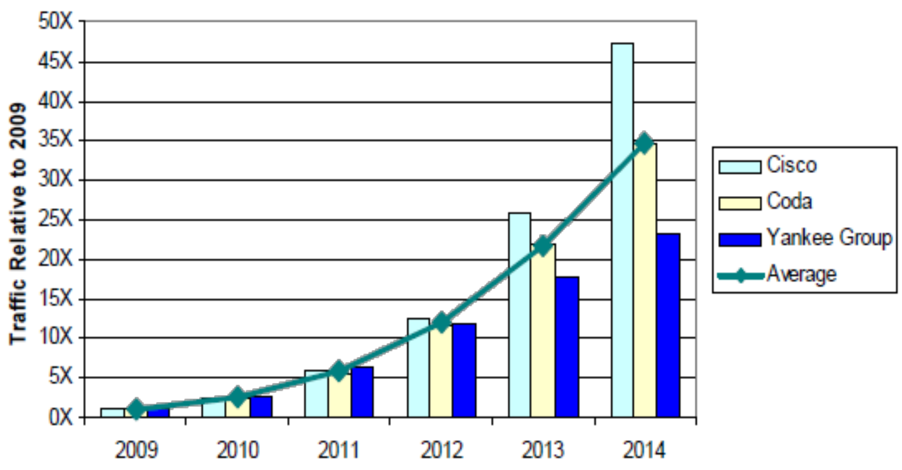
Wireless VR

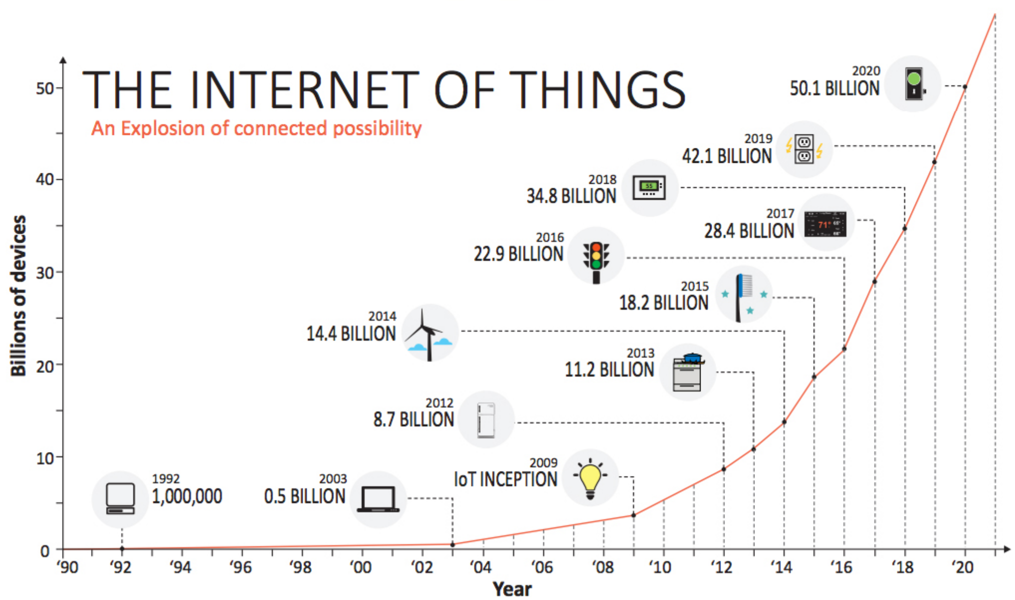
Wireless Vehicles

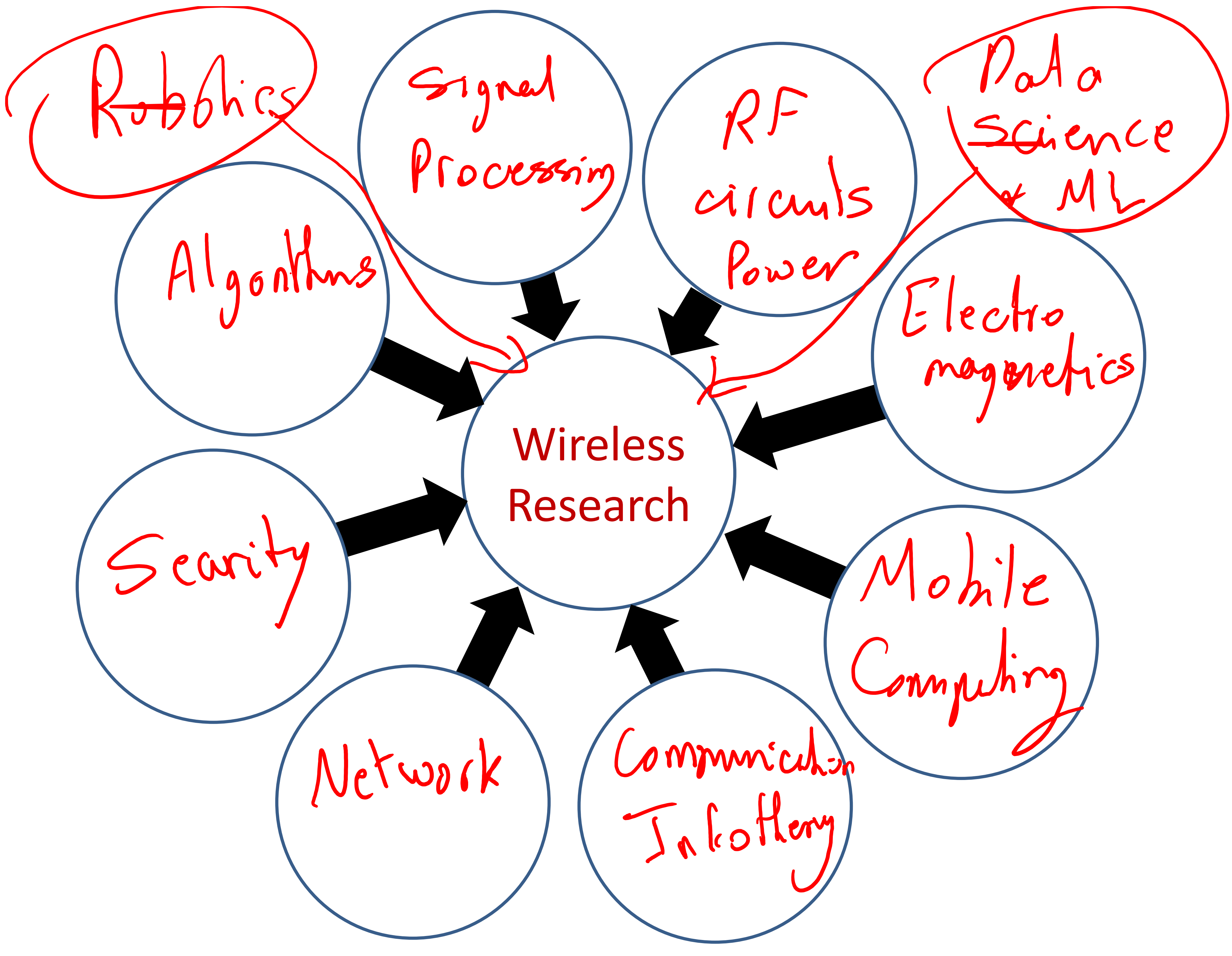
Increasing Demand for Wireless Connectivity

Increasing Demand for Wireless Connectivity








Wireless Research
Robotics
Signal Processing
RF circuits Power
Data Science & ML
Algorithms
Electromagnetics
Security
Mobile Computing
Network
Communication Info theory

Course Information

- Staff
  - Lecturer: Haitham Hassanieh, haitham@illinois.edu
  - Office hours: Monday after class or by appointment
  - TA: Suraj Jog, sjog2@illinois.edu

- Material (new class)
  - Mainly research papers
  - Lecture Slides/Notes

- Prerequisites
  - Any undergraduate networking, wireless, communications or RF class
  - Basic math and signal processing: probability, Fourier, …
  - Matlab or C programming (Important for the project).

Course Structure

- Grading
  - 50% Research Project: Proposal, Progress report, Poster, Final report
    - Research project: propose and test new ideas.
    - Negative results are OK
    - Idea can/should be related to your own research.
  - 10% Paper reviews
    - Review includes: 3 strengths, 3 weaknesses.
    - Review 10 out of the 25 assigned papers. Review due on compass before class.
    - **READ: How to read a paper?**
  - 20% Homework Assignments: 2 HWs
  - 20% Lab Assignments: 2 Labs
    - Learn how to use software defined radios in lab.
    - Run some measurements and write a Matlab code to process data. Submit your code & results
  - Bonus: Participation in class.
    - Expected to read all papers and participate in class.

Class Webpage

https://courses.engr.illinois.edu/ece598hh/sp2018/

ECE 598HH (Spring 2018): Advanced Wireless Networks and Sensing Systems

General Information | Course Schedule & Materials | Course Project

Course Description:

Wireless and mobile systems have become ubiquitous; playing a significant role in our everyday life. However, the increasing demand for wireless connectivity and the emergence of new areas such as the Internet of Things present new research challenges. This course introduces advanced research topics in wireless networks and mobile communication systems. In each lecture, we will discuss recent research papers that introduce new wireless designs, algorithms, protocols and applications. The papers are systems oriented and focus on practical challenges and solutions for building wireless and mobile systems. Students will also learn how to design and build wireless systems through a research oriented course project that focuses on the implementation aspects of practical systems.

Lecture Time & Location: Monday & Wednesday 3:00pm - 4:20pm in ECEB 4070

Instructor: Haitham Hassanieh (haitham@illinois.edu)

Office Hours: Monday 4:20pm - 5:00pm in ECEB 4070 or by appointment.

Course TA: Suraj Jog (sjog2@illinois.edu)

Office Hours: TBD

Topics:

▶ Cross Layer Networking

- Rateless Codes & Soft Information
- Interference Management
- Interference Alignment & Nulling
- Virtual MIMO
- Opportunistic Routing
- Network Coding
- Wireless Multipath TCP

▶ Internet of Things

- LoRa Networks
- Ultra-low Power Networking
- Ambient Backscatter
- Smart Cities and Environments

▶ Wireless Sensing

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

▶ Security

- Analog Cybersecurity
- Medical Devices Security
- RFIDs and Low Power Devices
- Physical Layer Security
- Wireless Vibrometry
- Acoustic IoT Security

▶ Emerging Technologies

- Millimeter Wave Systems
- Full Duplex Radios
- Software Defined Radios
- Cloud RAN
- 5G Cellular Systems
- Dynamic Spectrum Access
- Wireless Charging
- Robotics and Drones
- V2X Communications

ECE 598HH (Spring 2018): Advanced Wireless Networks and Sensing Systems

General Information | Course Schedule & Materials | Course Project

Note: This schedule is tentative and subject to change over time due to unforeseen events. Please check it regularly.

#	Date	Topics & Slides	Notes
	Jan. 15	Martin Luther King Day	
1	Jan. 17	**Lec 1:** Introduction: Overview & Logistics	**Reading:** How to Read a Paper
2	Jan. 22	**Lec 2:** Wireless Communication and Networks	
3	Jan. 24	**Lec 3:** Wireless Channel	
4	Jan. 29	**Lec 4:** OFDM	**Optional Reading:** [Thesis] (Chapter 3)
5	Jan. 31	**Lec 5:** Wireless MAC & Software Defined Radios Tutorial	**Assigned Reading:** [FICA]
6	Feb. 5	**Lec 6:** Rate Adaptation & Soft Information	**Assigned Reading:** [RRAA], [PPR] **Optional Reading:** [SoftRate], [SampleRate], [Strider]
7	Feb. 7	**Lec 7:** Interference Management	**Assigned Reading:** [ZigZag] **Optional Reading:** [SIC], [REMAP]
8	Feb. 9	**Lab 1: USRP Software Defined Radio & OFDM**	Due: Mar. 7 at 11:59pm
8	Feb. 12	**Lec 8:** MIMO 1: Multiplexing, Diversity, MU-MIMO	**Optional Reading:** [Textbook 2] (Chapter 7)
9	Feb. 14	**Lec 9:** MIMO 2: Interference Alignment and Nulling.	**Assigned Reading:** [IAC] **Optional Reading:** [Nplus]
10	Feb. 19	**Lec 10:** MIMO 3: Distributed MIMO	**Assigned Reading:** [MegaMIMO] **Optional Reading:** [AirShare], [SourceSync], [Vidyut]
11	Feb. 21	**Lec 11:** Wireless Localization 1: WiFi	**Assigned Reading:** [ArrayTrack] **Optional Reading:** [PinLoc], [PinPoint], [Chronos]
12	Feb. 26	**Lec 12:** Wireless Localization 2: RFID	▶ Homework 1 (Due: Mar. 26) **Assigned Reading:** [PinIt], [RFDraw] **Optional Reading:** [RFCompass]
13	Feb. 28	**Lec 13:** Wireless Localization 3: RFID	**Assigned Reading:** [RFind], [RFly]
14	Mar. 5	**Lec 14:** Wireless Sensing 1: Tracking	**Assigned Reading:** [WiTrack] **Optional Reading:** [WiVi], [WiTrack2]
15	Mar. 7	**Lec 15:** Wireless Sensing 2: Vital Signs & Imaging	▶ **Lab Assignment 1 Due** **Assigned Reading:** [VitalRadio] **Optional Reading:** [RFCapture]
8	Feb. 9	**Lab 2: RFID Readers & Localization**	Due: Apr. 2 at 11:59pm

Rest of Today's Lecture

Sample Class Topics

Introduction to Wireless Networks

Wireless networks provide advantages

- Mobility
- Eliminates piles of wires at home and office

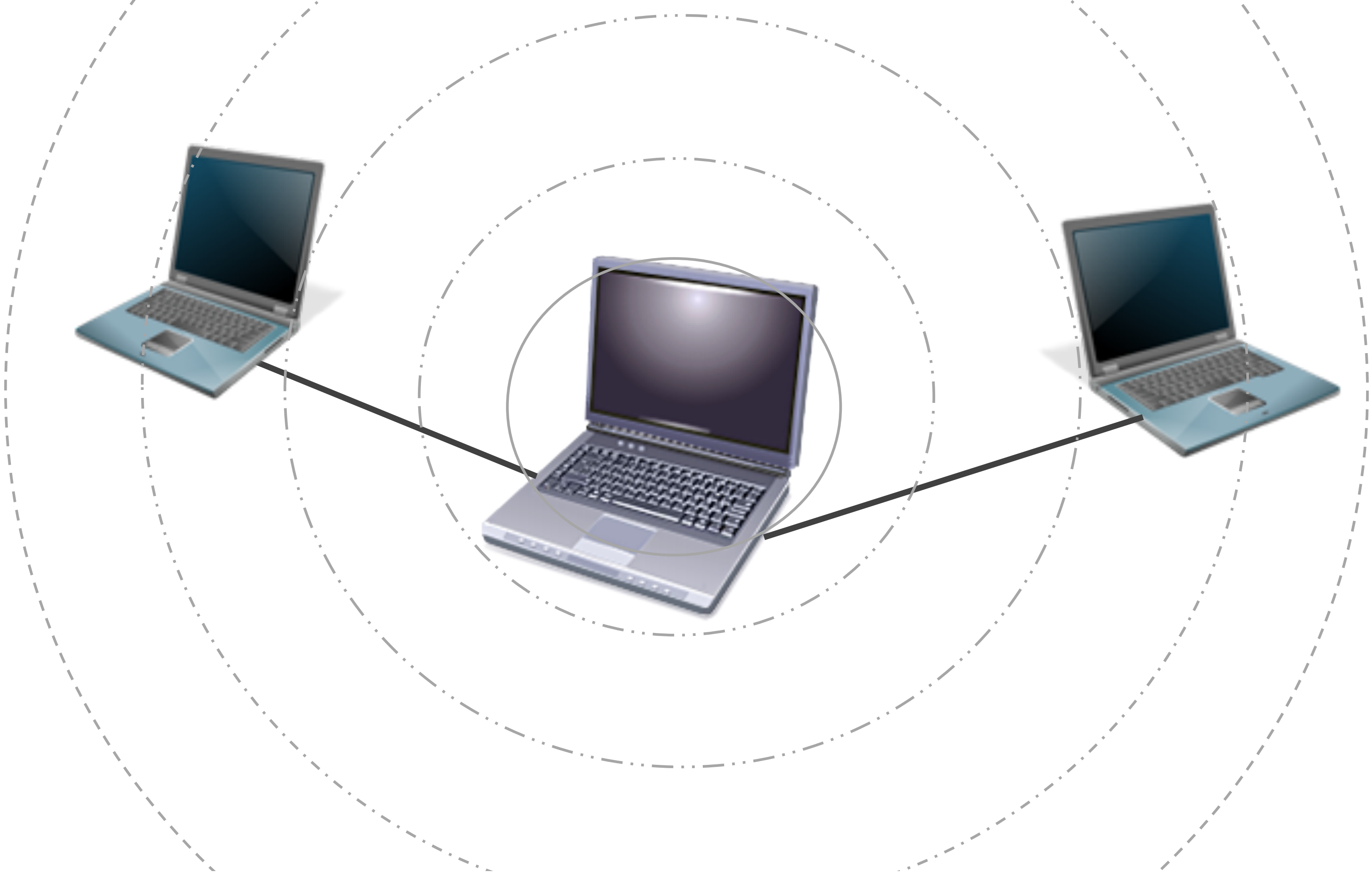
But wireless networks present different challenges

- 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

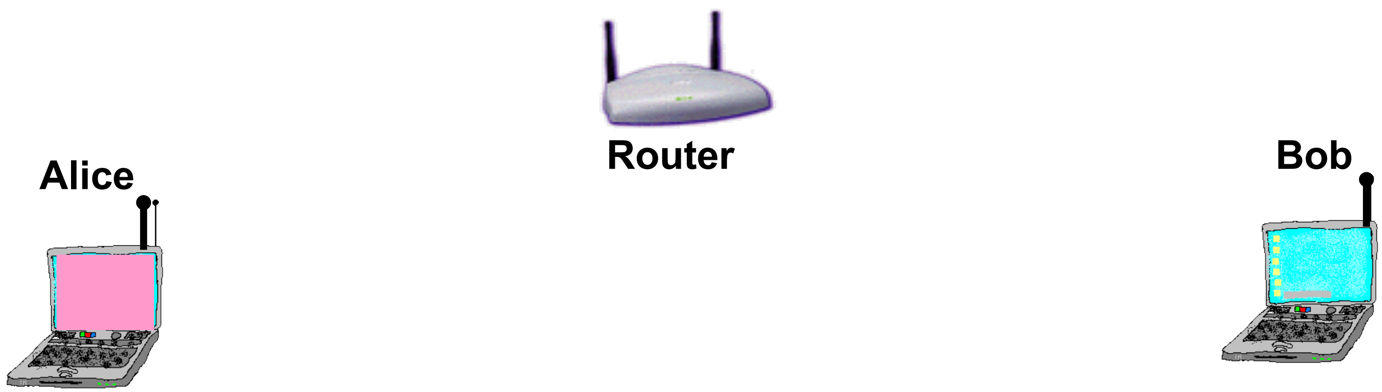
Traditional design of wireless networks mimics wired networks

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



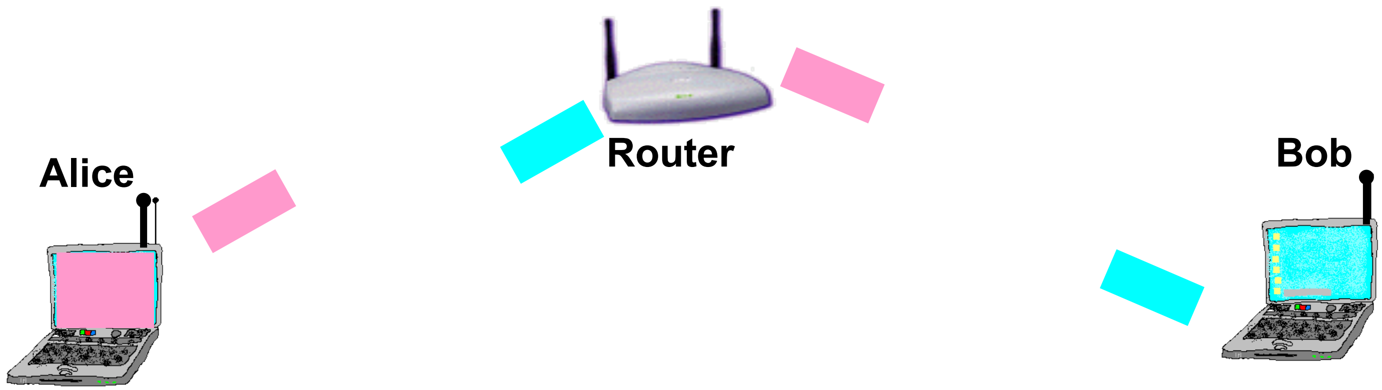
Why point-to-point is a suboptimal abstraction for wireless links?

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



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

Traditional Approach



Requires 4 transmissions

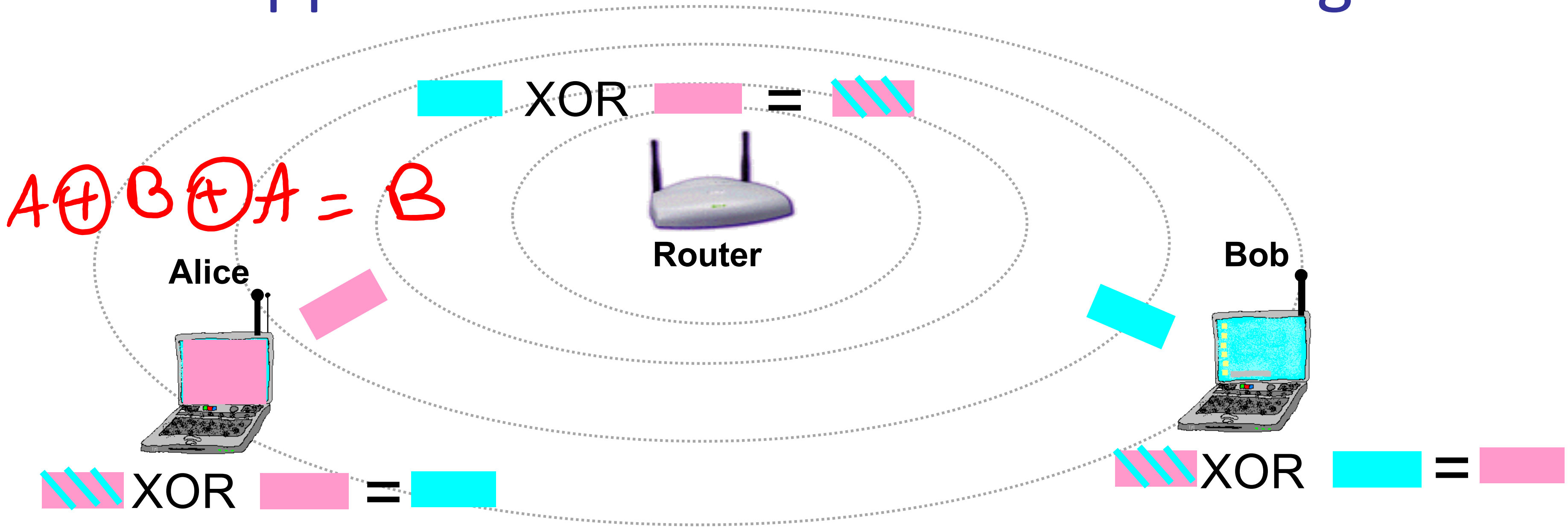
- Alice to router; Router to Bob; Bob to router; Router to Alice

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



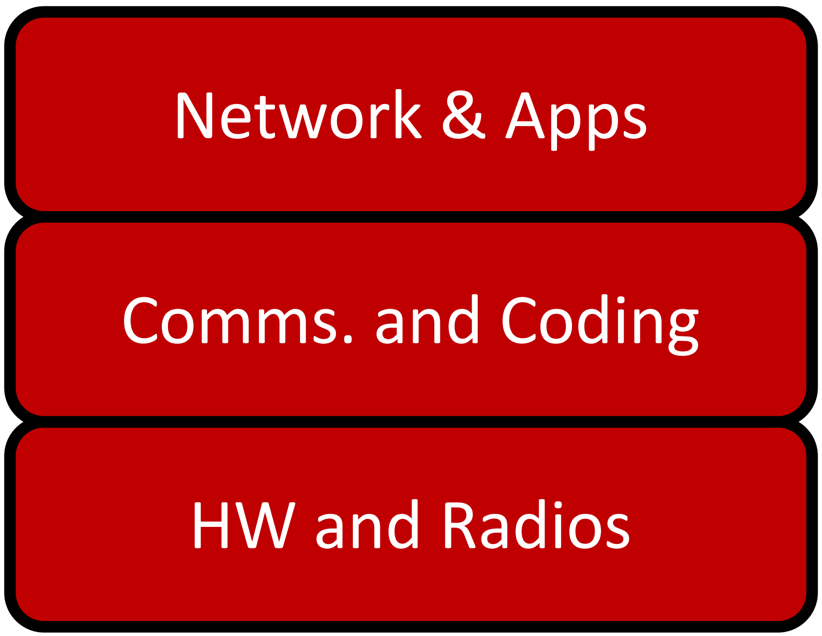
Requires 3 transmissions instead of 4

- 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

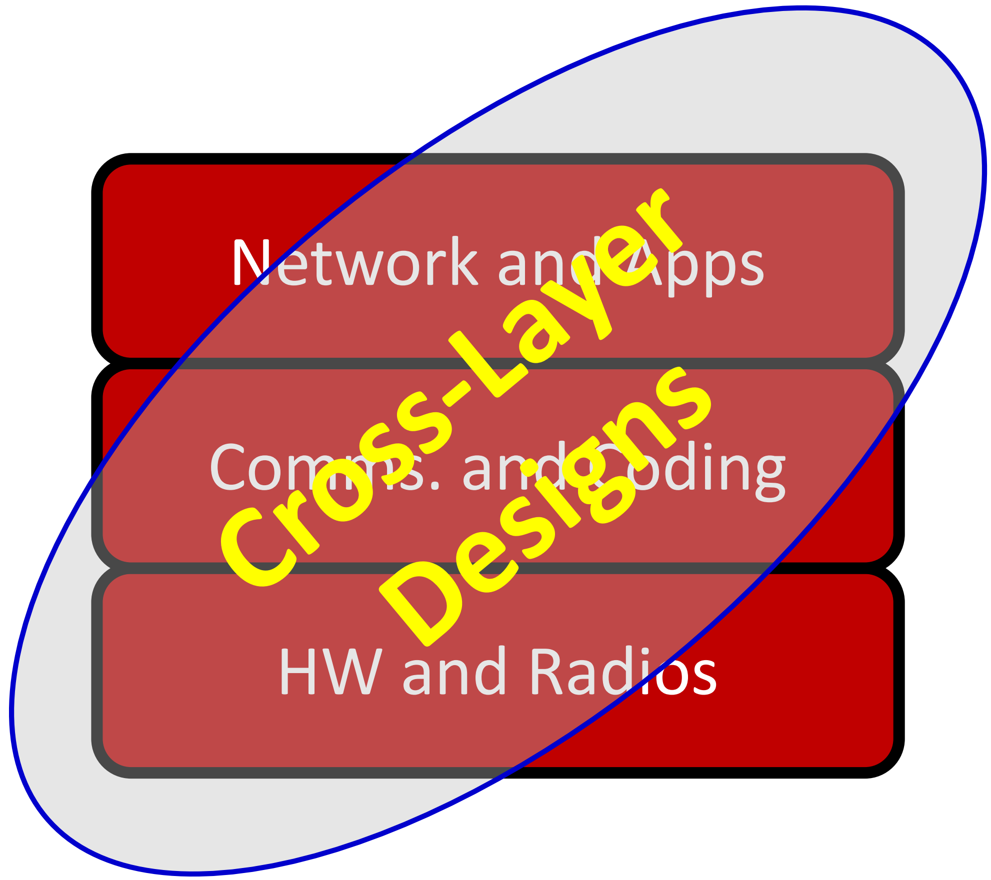
Optimize within isolated layers



Disruptive gains are unlikely

New Approach

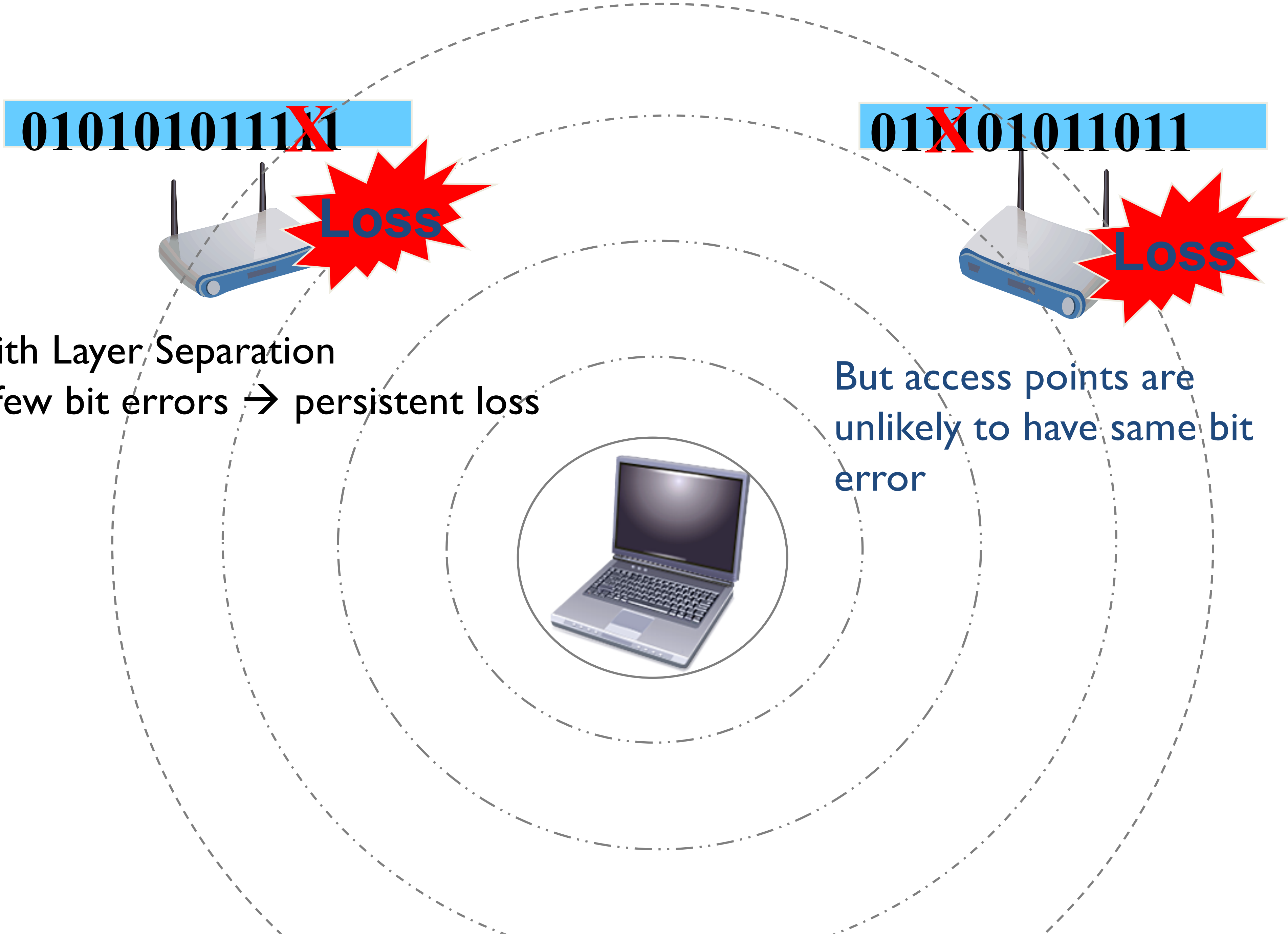
Optimize across the layers



Major opportunities!

Why layer separation is suboptimal?

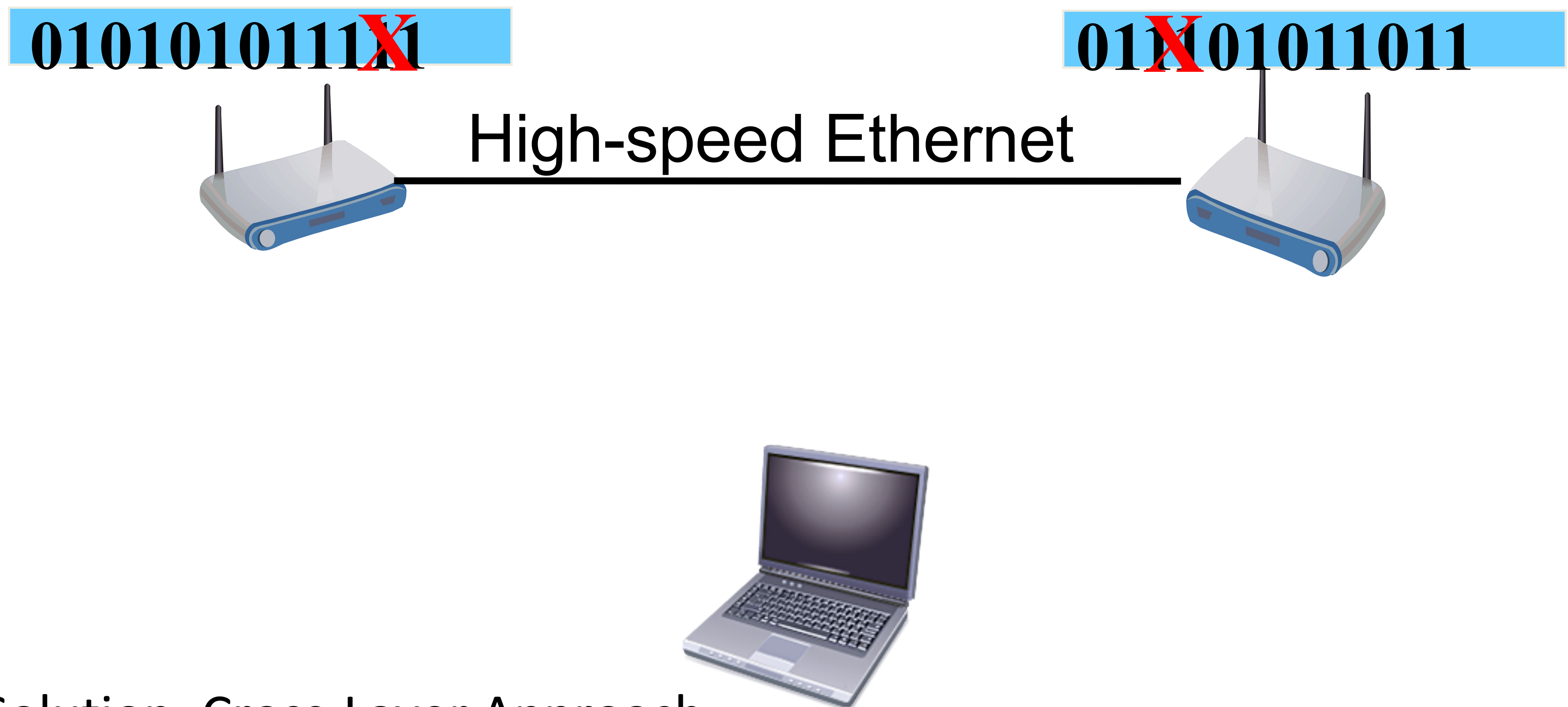
Scenario: Laptop in a Dead Spot



With Layer Separation
a few bit errors → persistent loss

But access points are unlikely to have same bit error

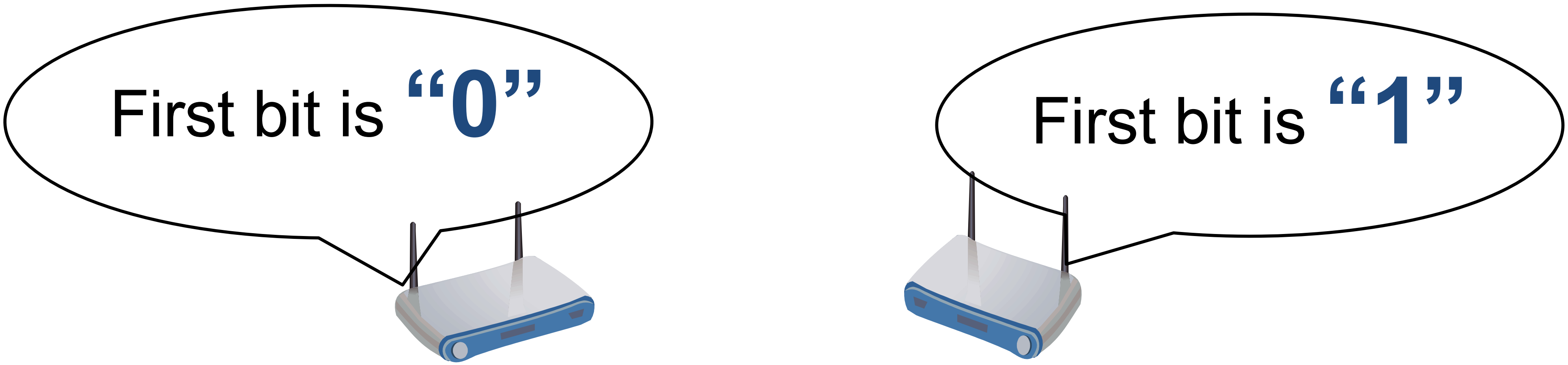
Scenario: Laptop in a Dead Spot



<u>Solution:</u> Cross-Layer Approach

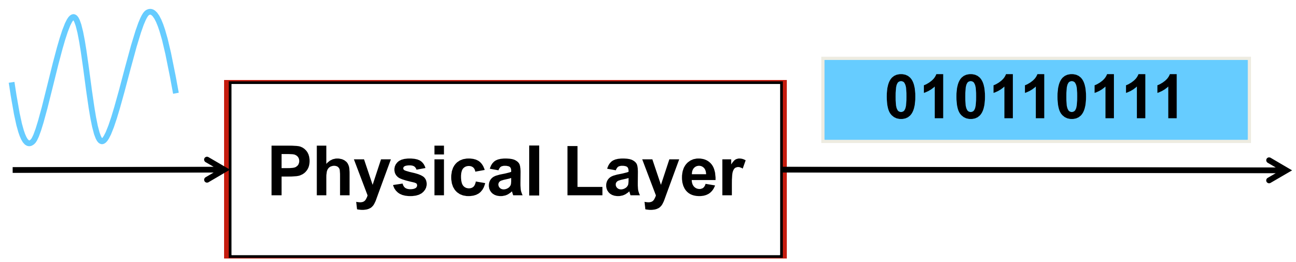
- Allow the layers to collaborate instead of acting separately
- PHY layer delivers partially correct packets
- Network layer combines correct bits across different access points to obtain correct packet

Challenge

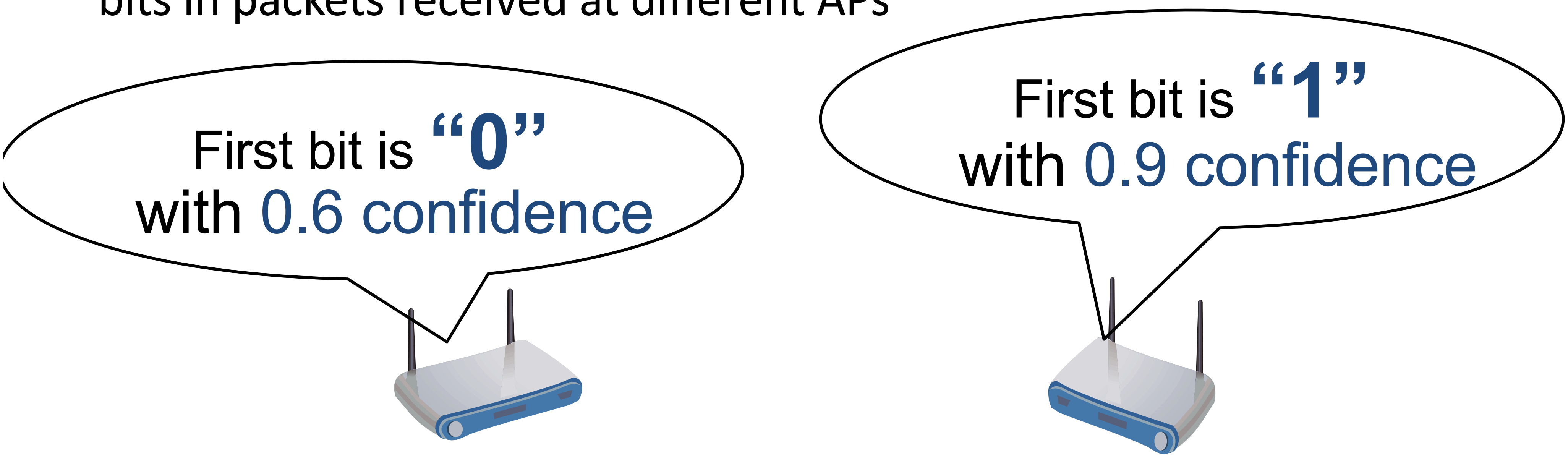


Which access point should we believe?

Solution: Network cooperates with physical layer

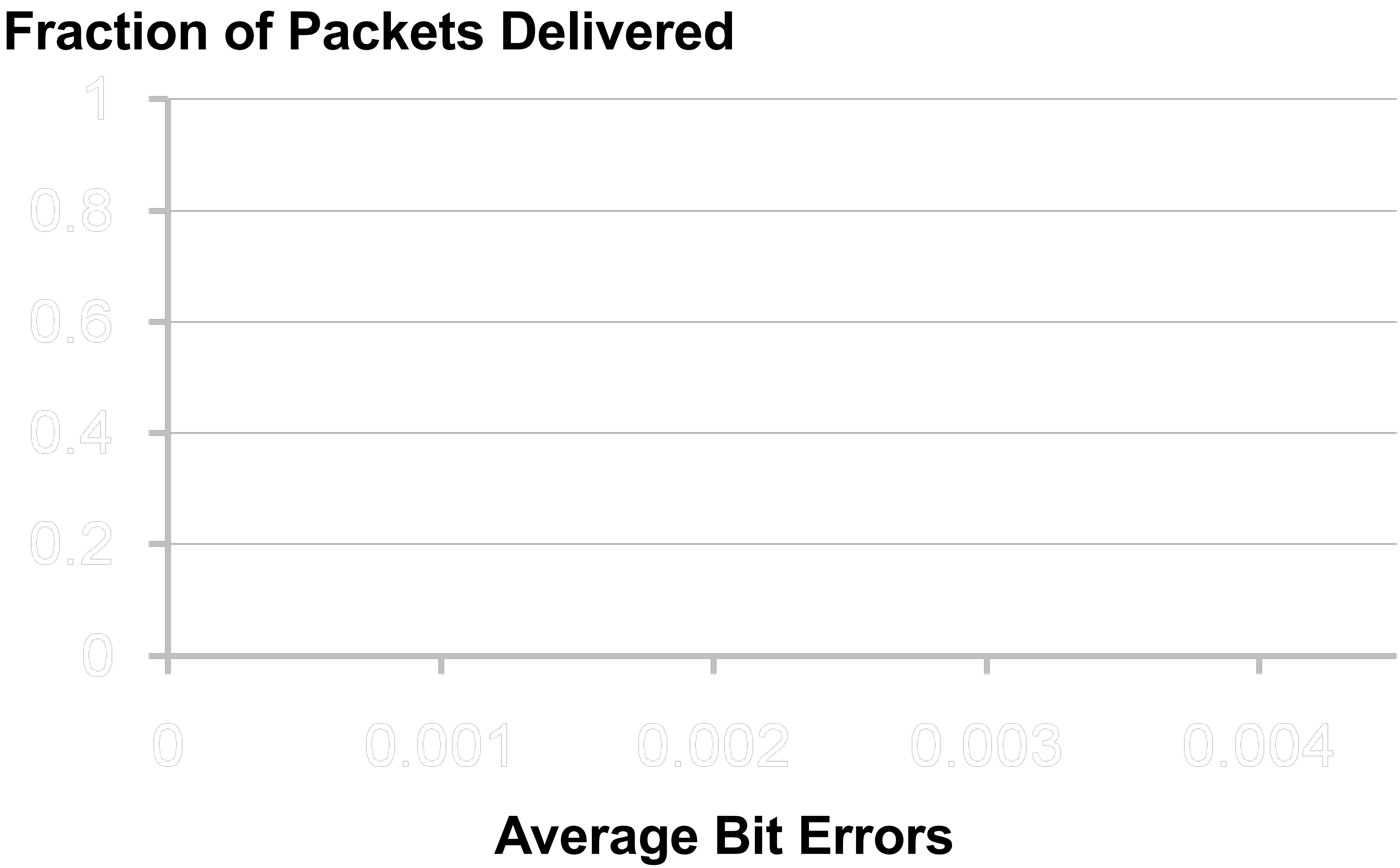


- Physical layer already estimates a confidence in its 0-1 decision
- If we expose this information to the network layer, we can compare bits in packets received at different APs

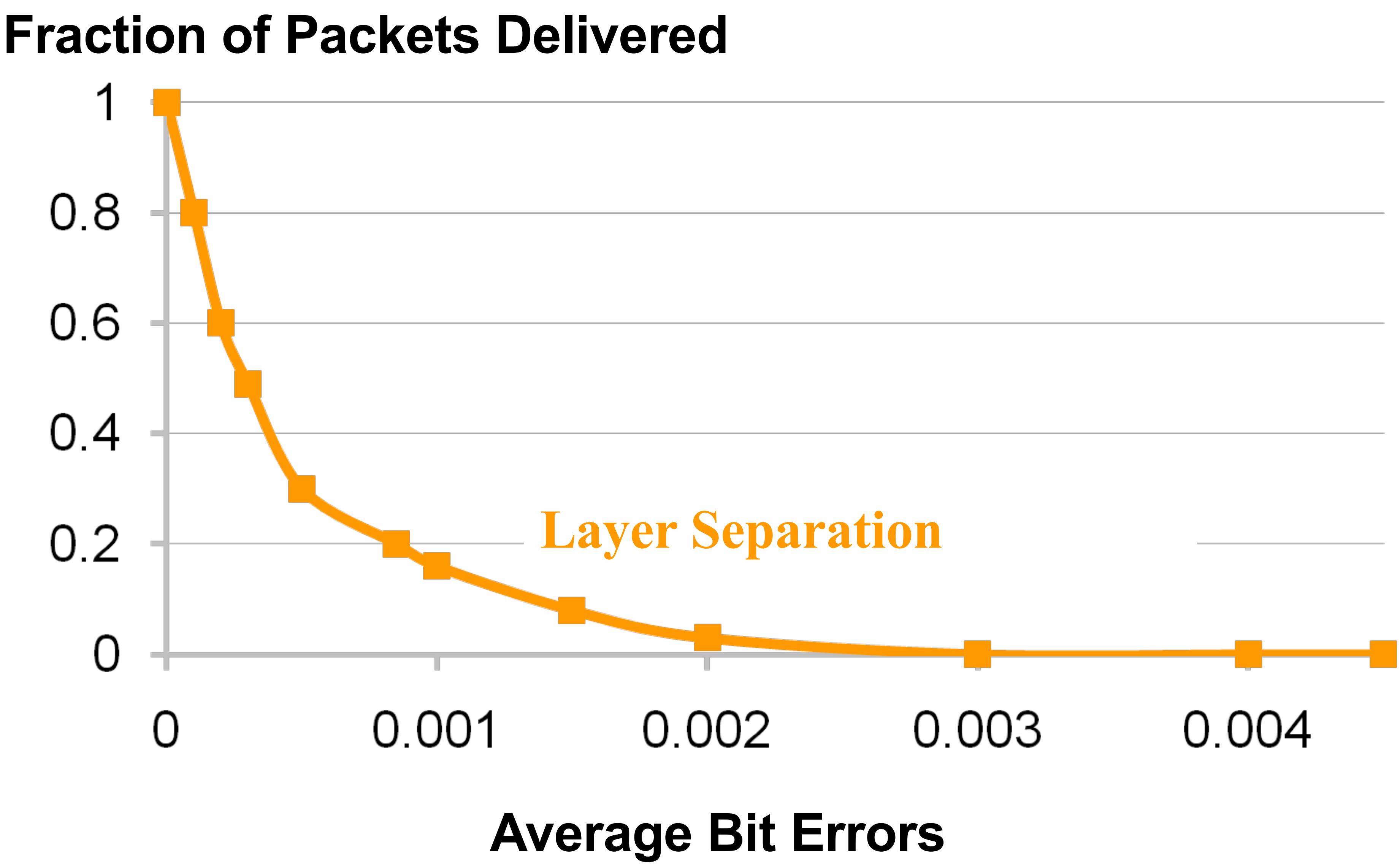


- Assign to each bit the value that corresponds to a higher confidence

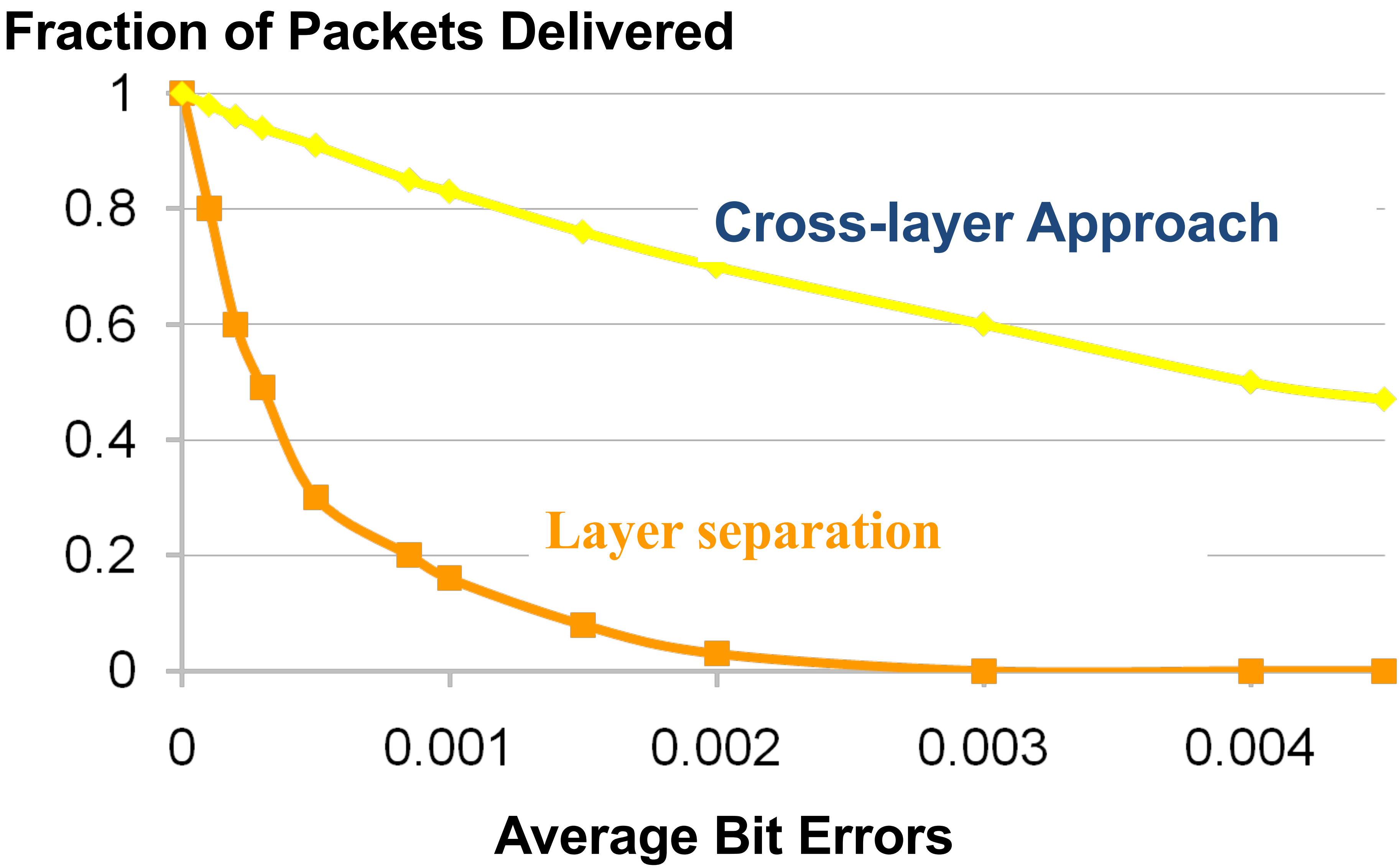
Experiment: Packet Delivery vs. Poor Coverage



Experiment: Packet Delivery vs. Poor Coverage

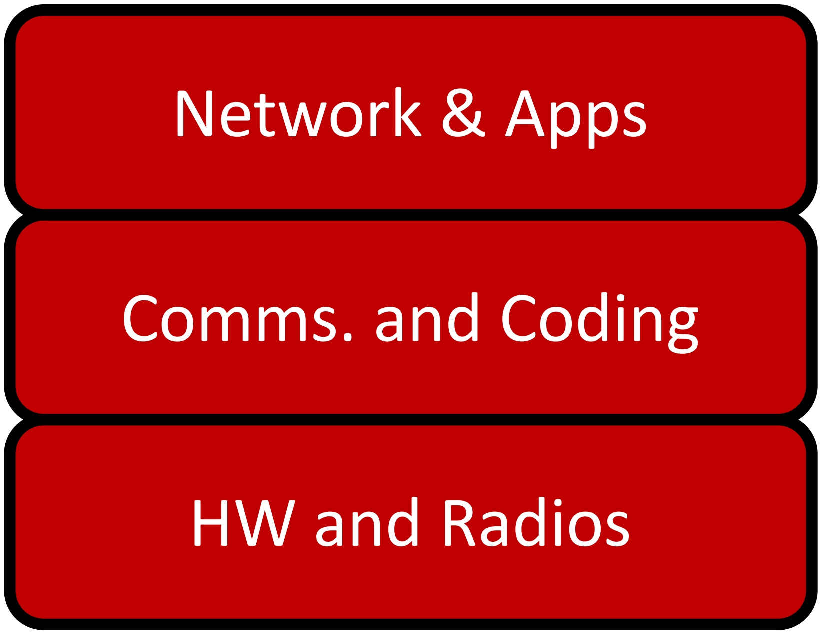


Experiment: Packet Delivery vs. Poor Coverage



Traditional Approach

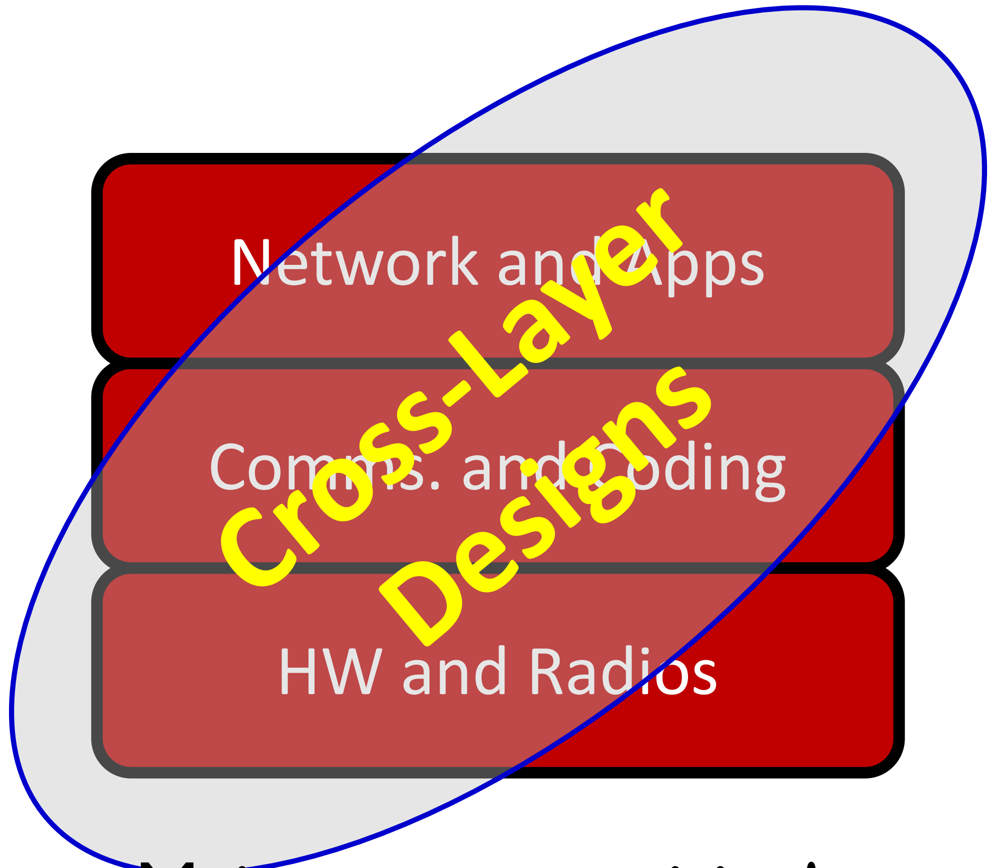
Optimize within isolated layers



Disruptive gains are unlikely

New Approach

Optimize across the layers



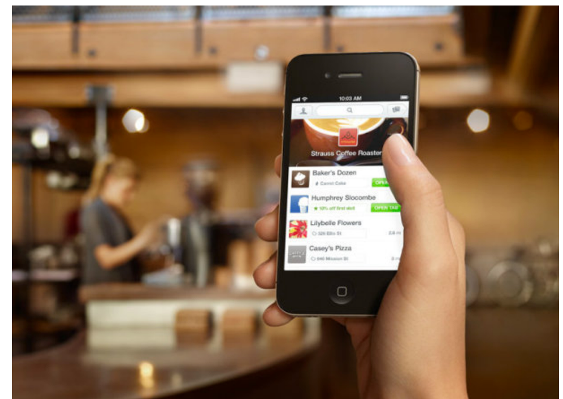
Major opportunities!

Fundamental Change in Network Architecture

New Services: Wireless Localization

GPS does not work indoor→ Use WiFi to localize.

Indoor Navigation



Business Analytics

WiFi Geofencing

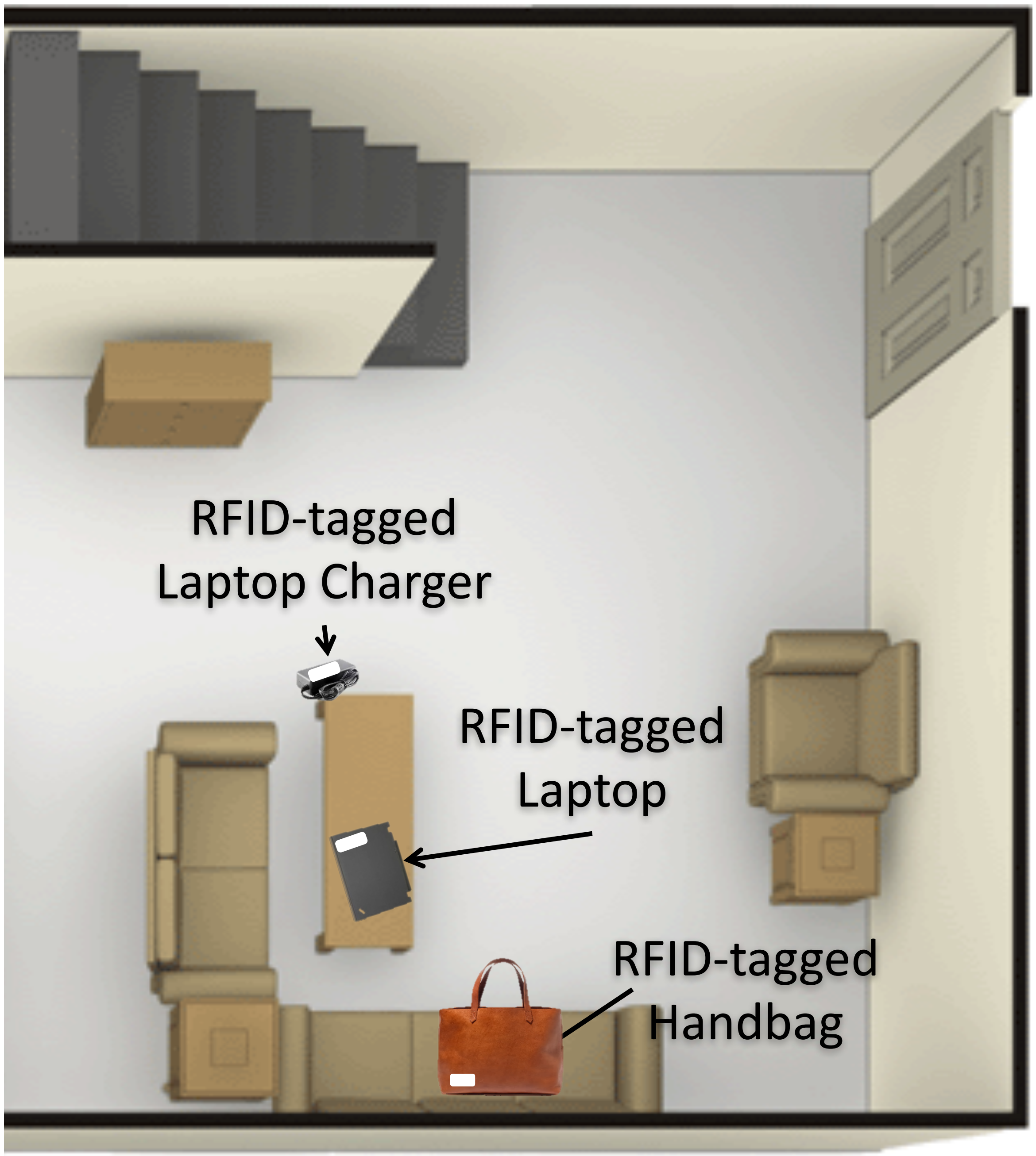
Indoor Robotic Navigation

New Services: Wireless Localization

Localize Everything and Anything!

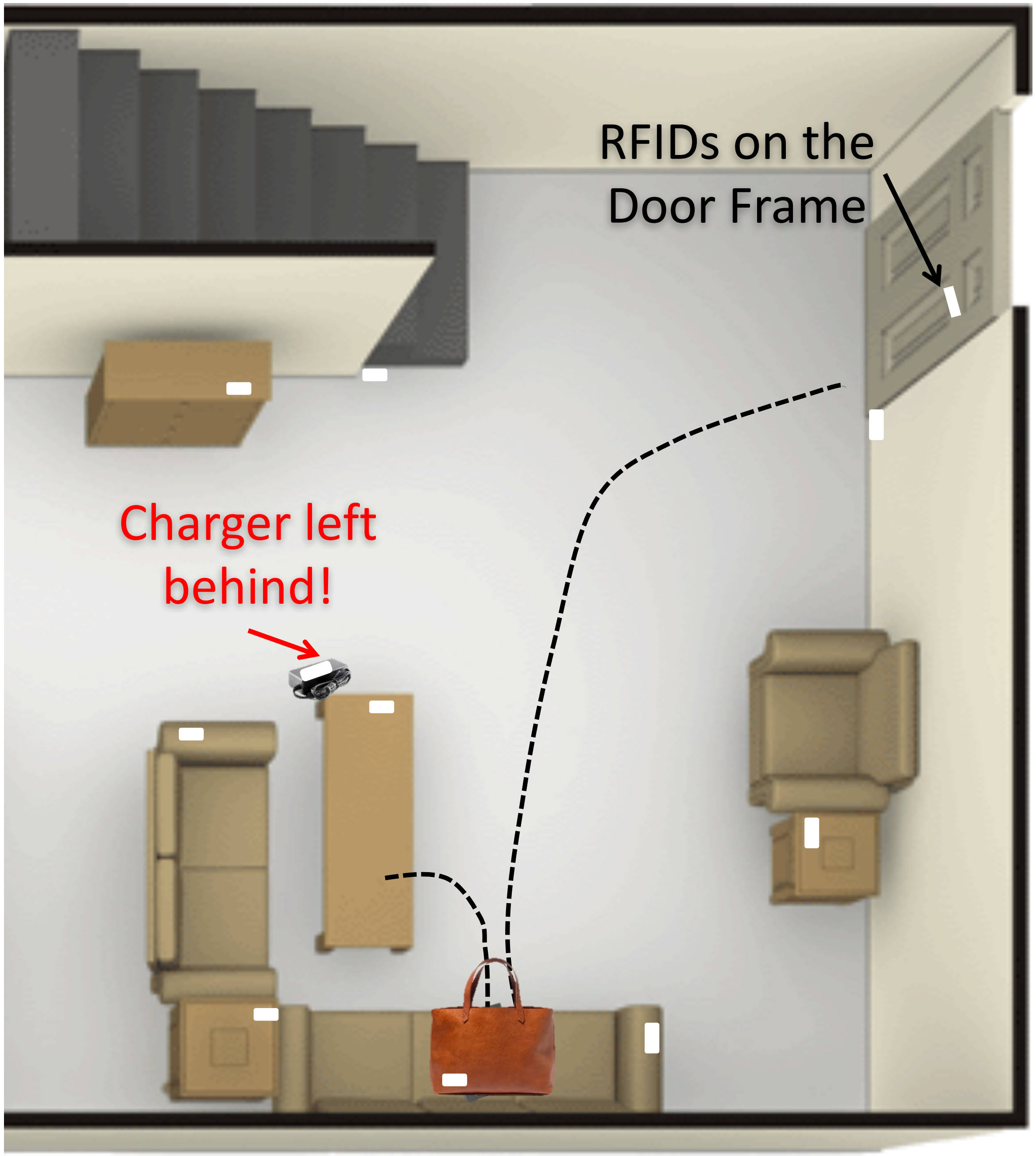
Battery-free stickers to tag any and every object

Smart Homes


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

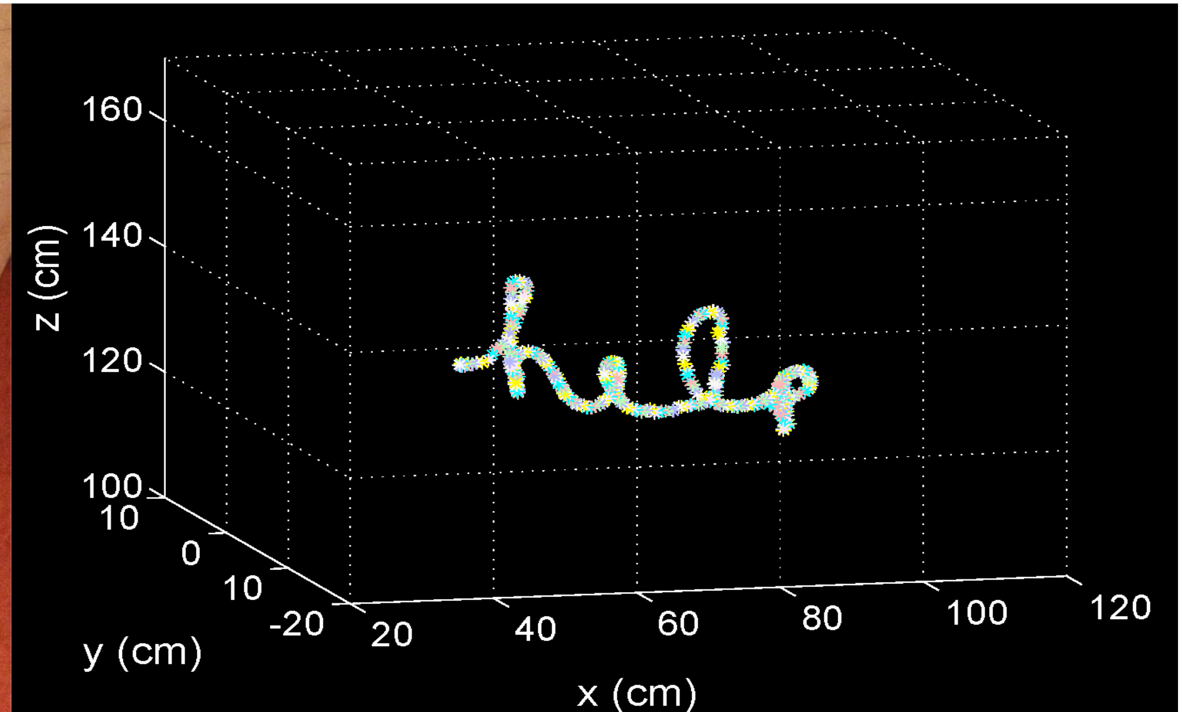
Smart Homes

Smart Homes



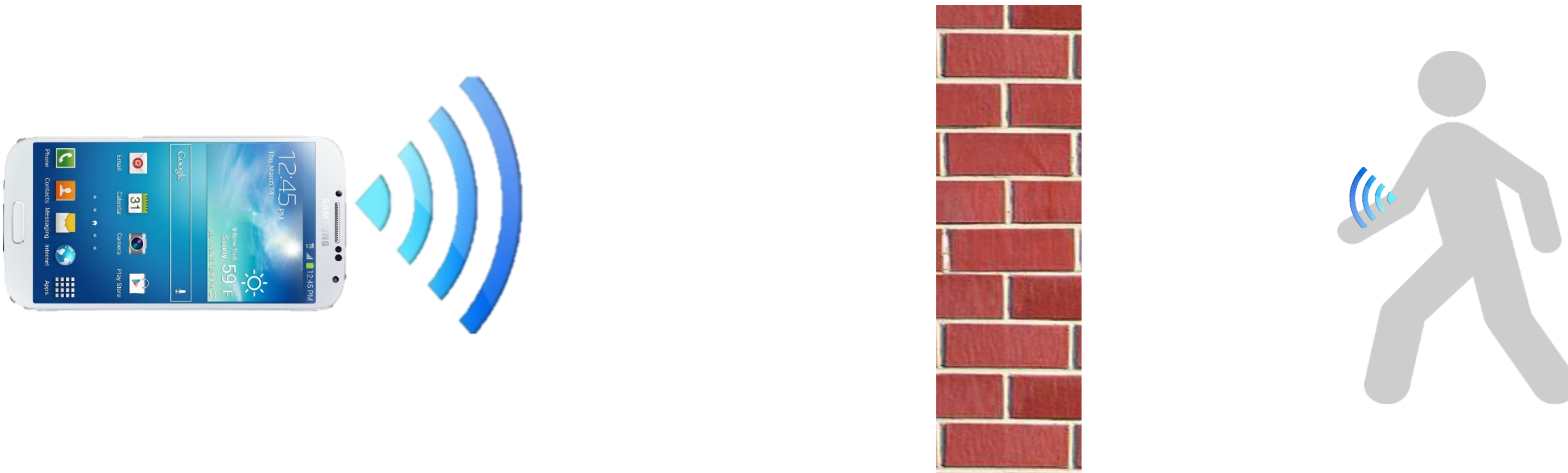
How Do We Get Virtual Touch Screens?

How Do We Get Virtual Touch Screens?

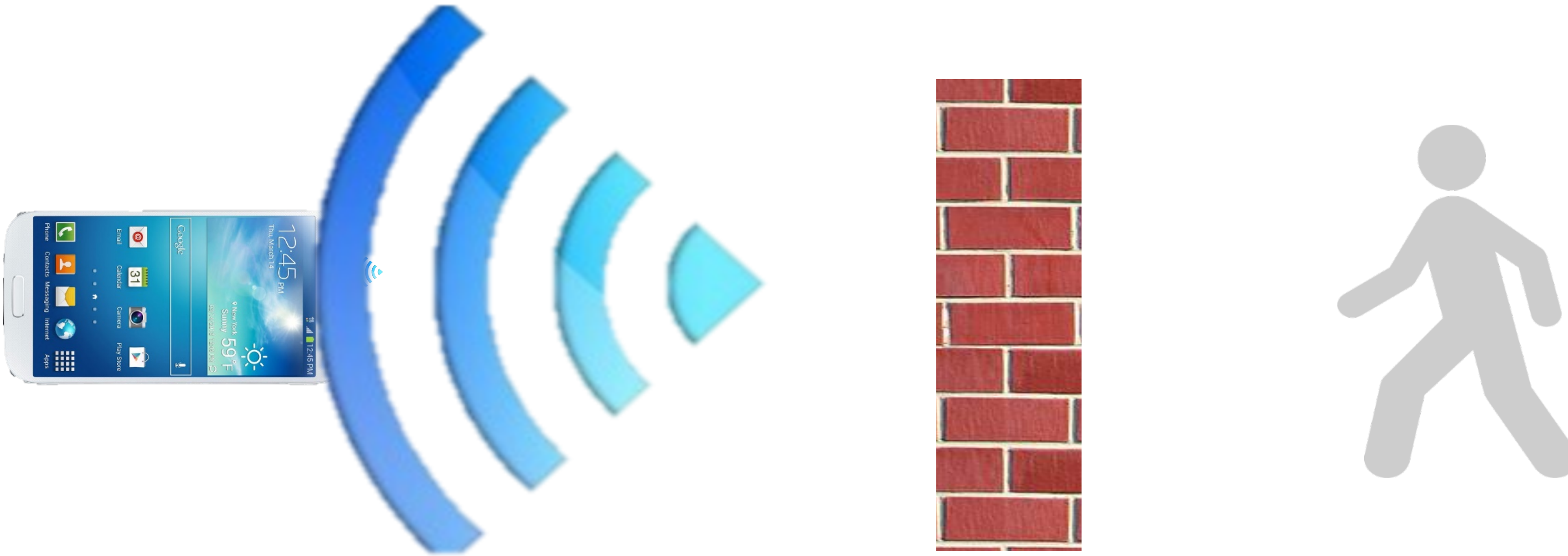


Can your cellphone give you X-ray vision?

See through-walls with WiFi

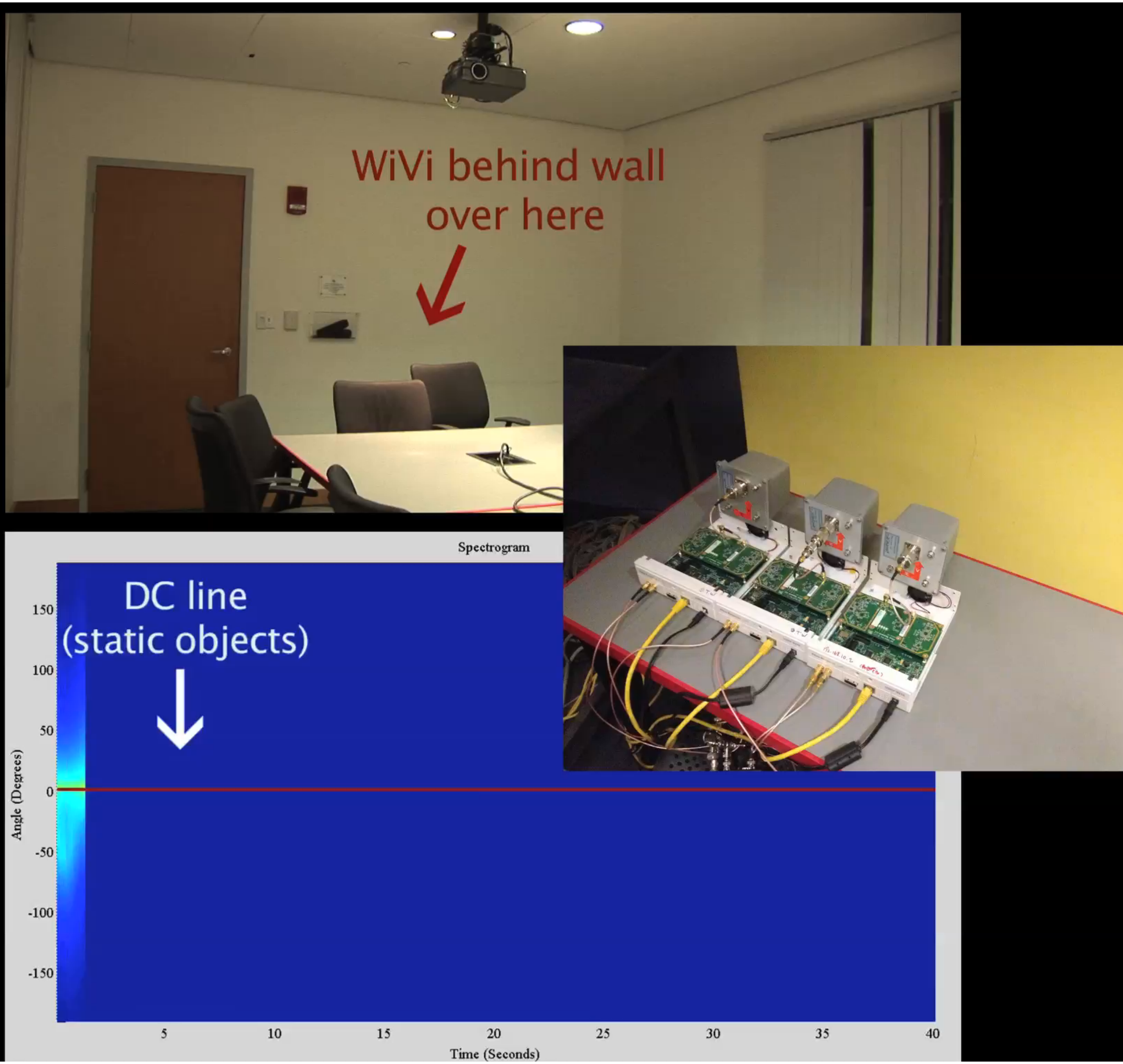


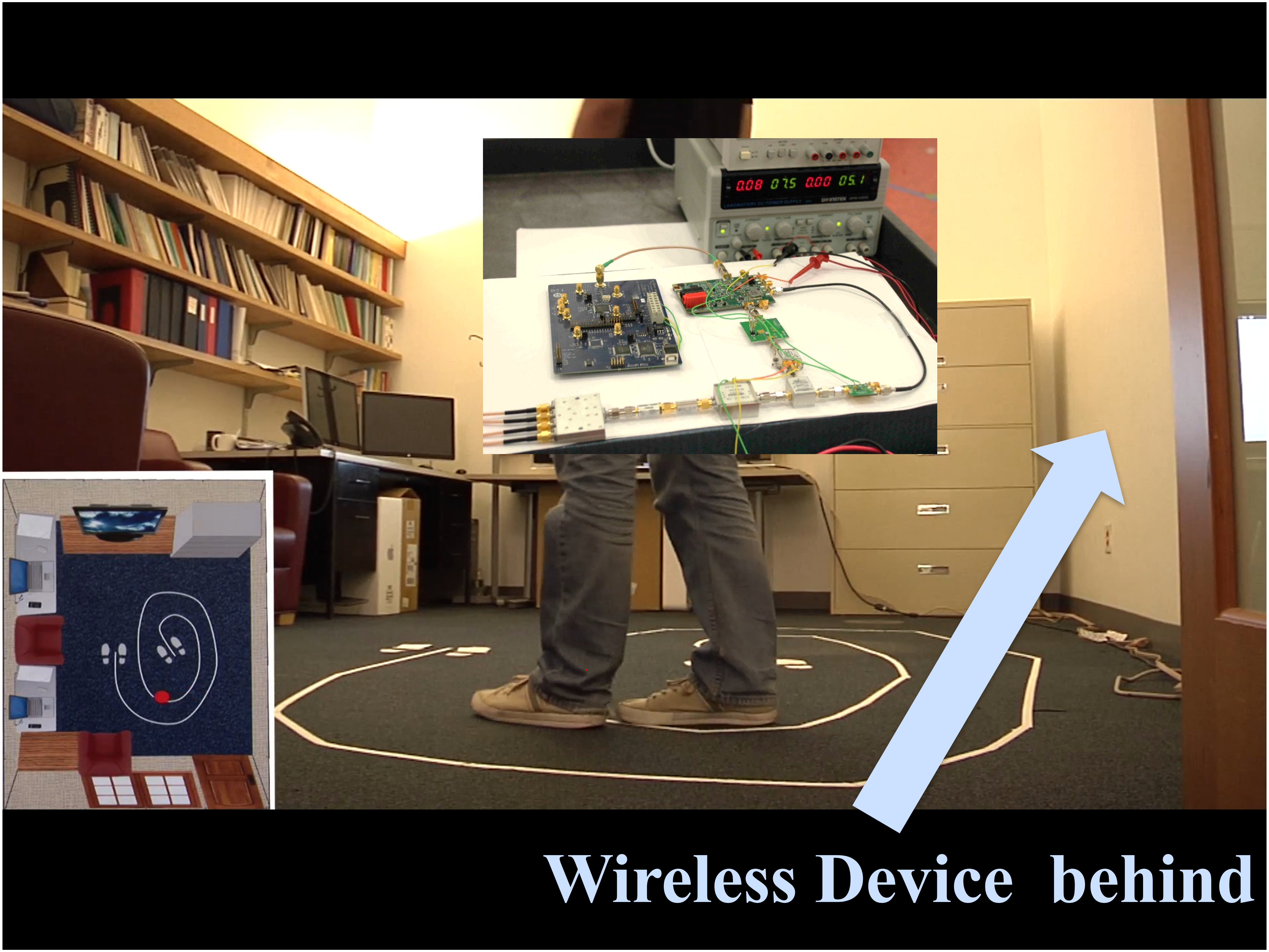
See through-walls with WiFi

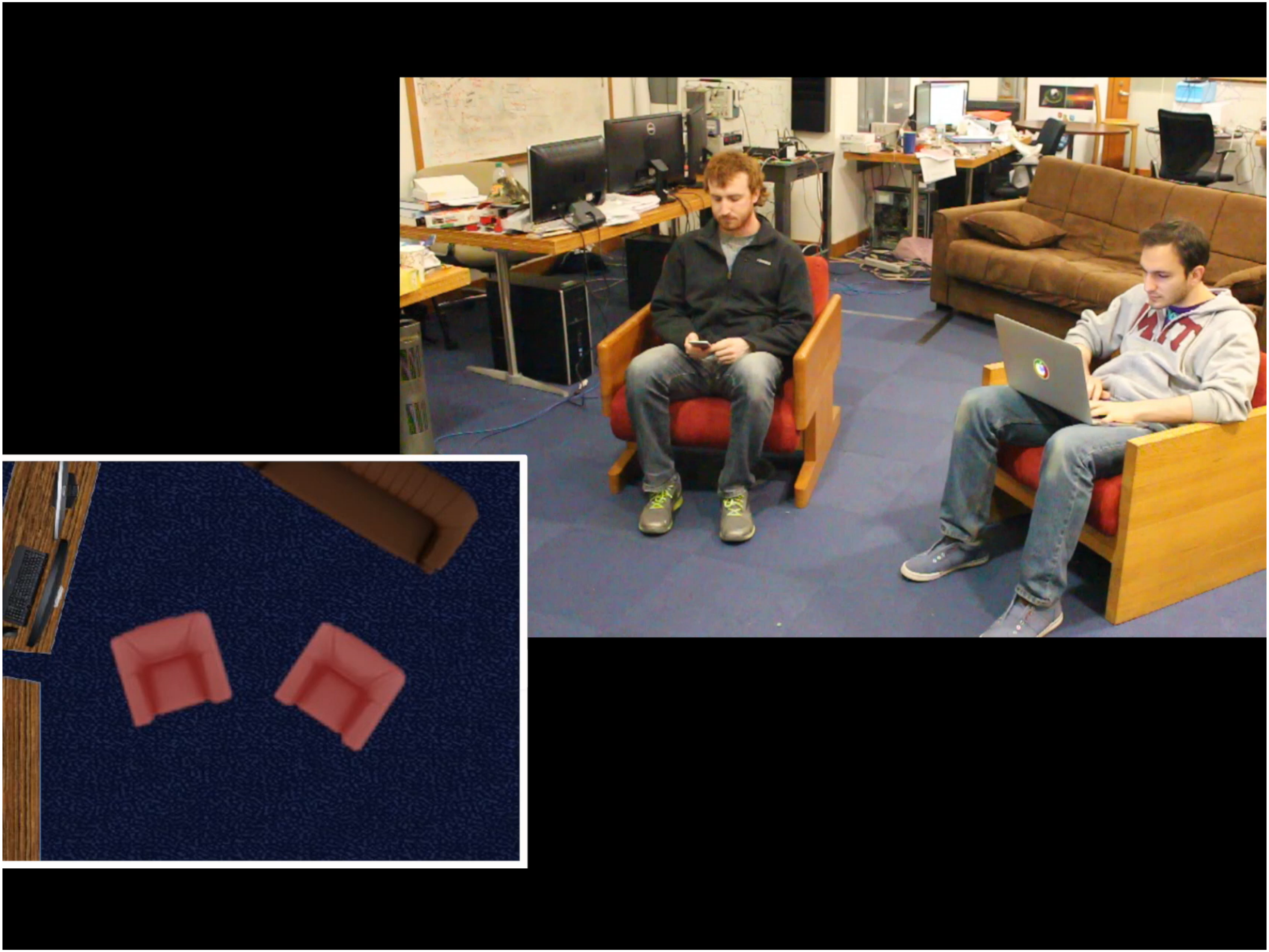


Wall refection is 10,000x stronger than reflections coming from behind the wall

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)
Angle (Degrees)
150
100
50
0
-50
-100
-150
5
10
15
20
25
30
35
40
Time (Seconds)


Wireless Device behind




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

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

Personal Health

Baby Sleep

Elderly Health

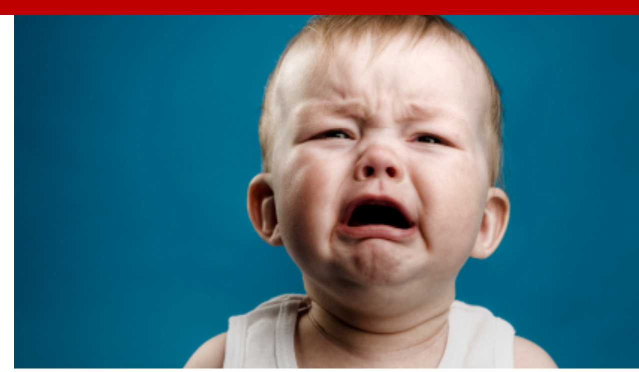
Adapt Lighting and Music to Mood

Today: technologies for monitoring vital signs are cumbersome

Breath Monitoring

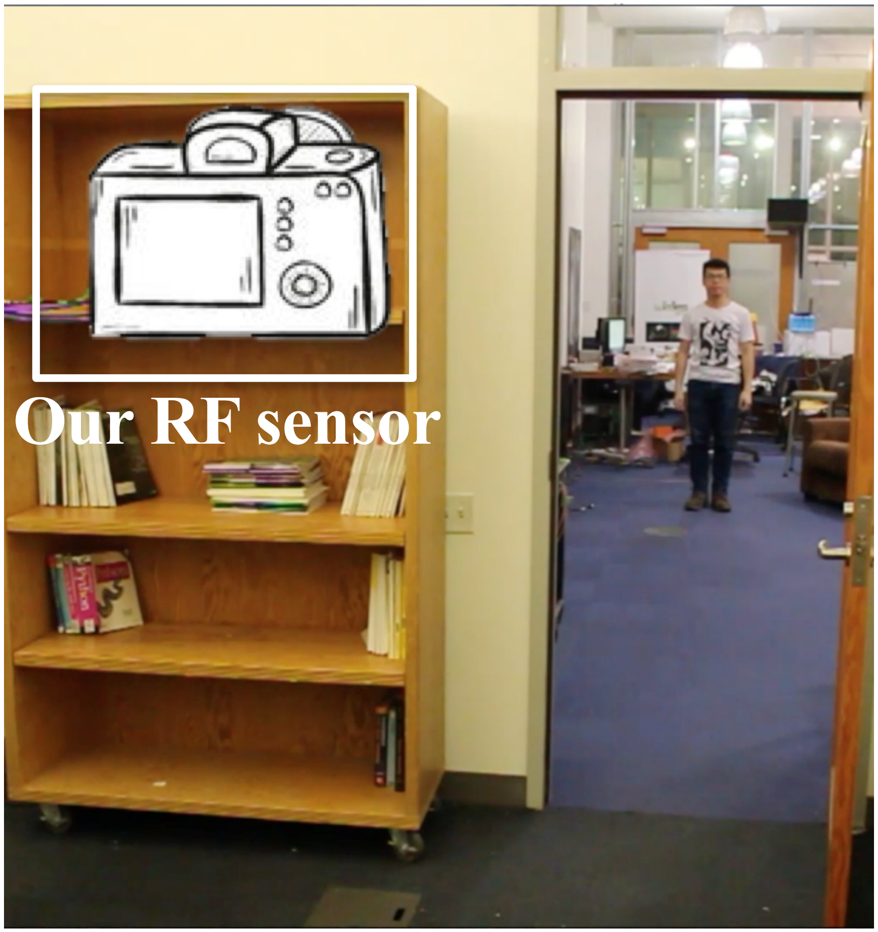
Heart Rate Monitoring

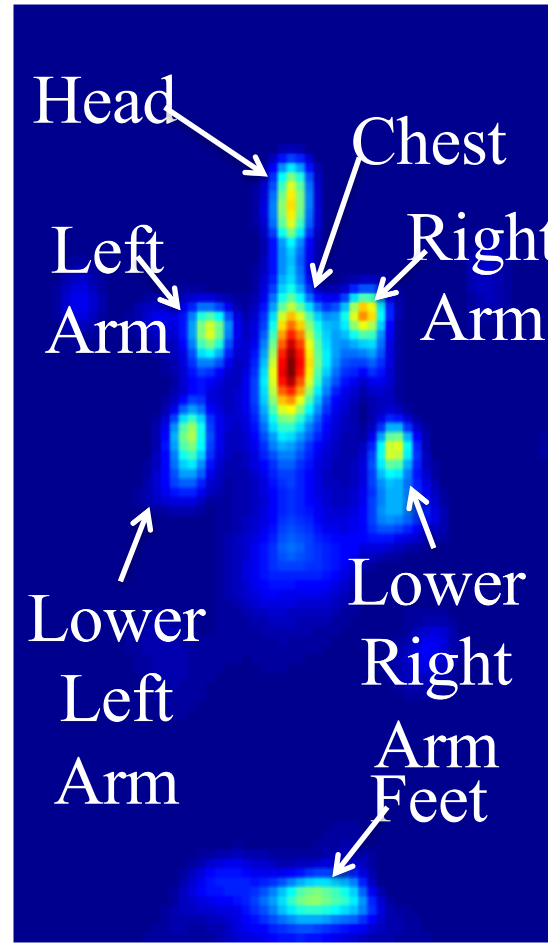
Wireless enables contactless sensing: sense humans without any sensors on their bodies



Baby Monitoring

Imaging through occlusions
using radio frequencies





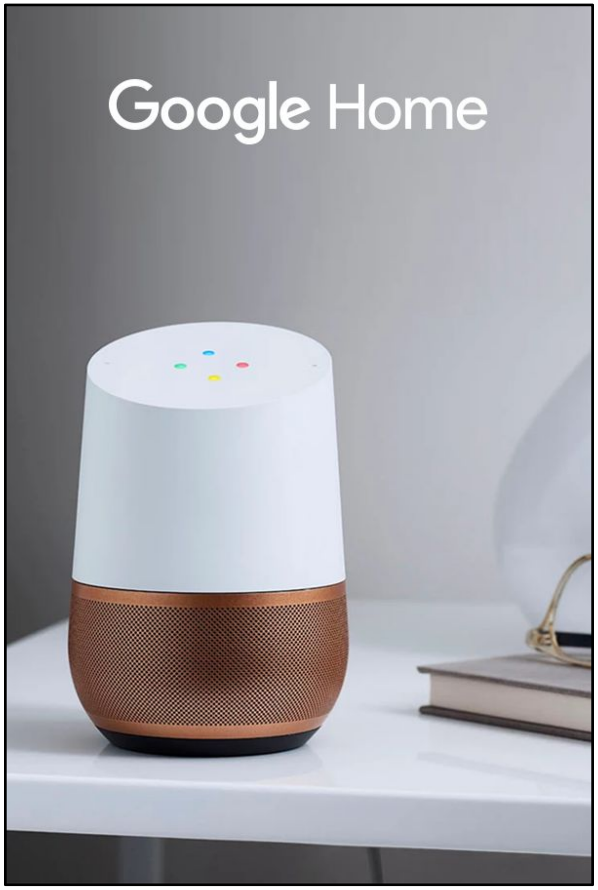
Challenge: Don't get reflections from most points in RF

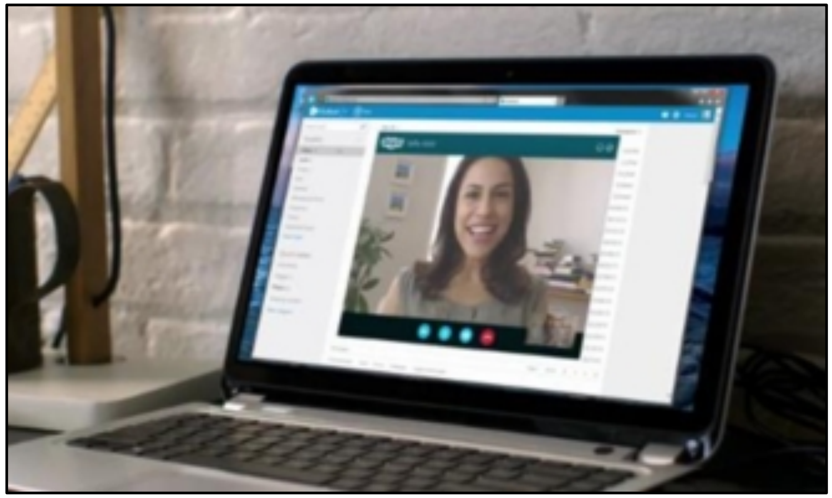
At frequencies that traverse walls, human body parts are specular **(pure mirror)**

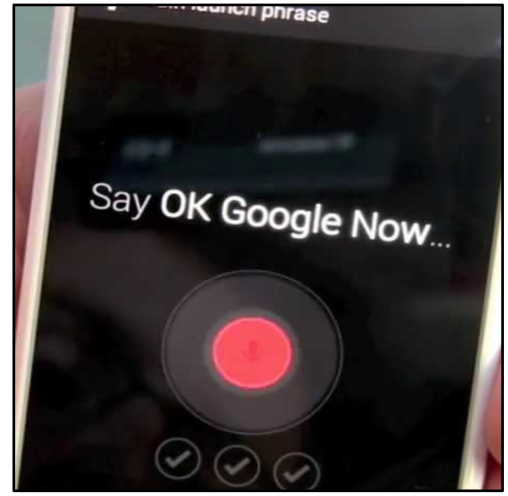
Human Walks toward Sensor

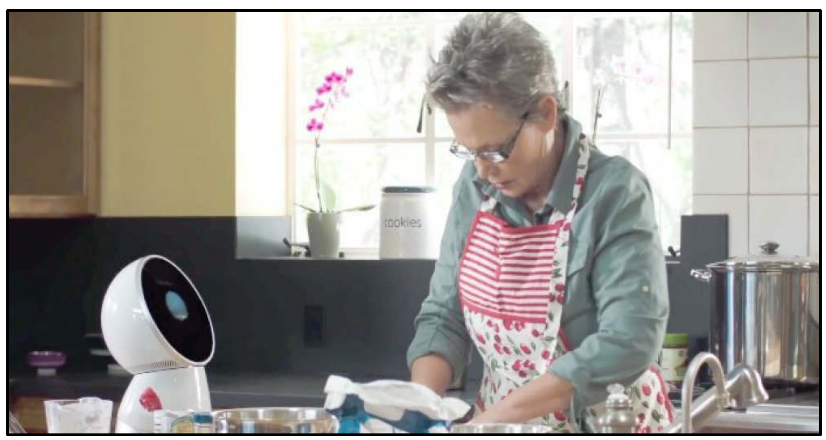
IoT Acoustic Security

Microphones are everywhere

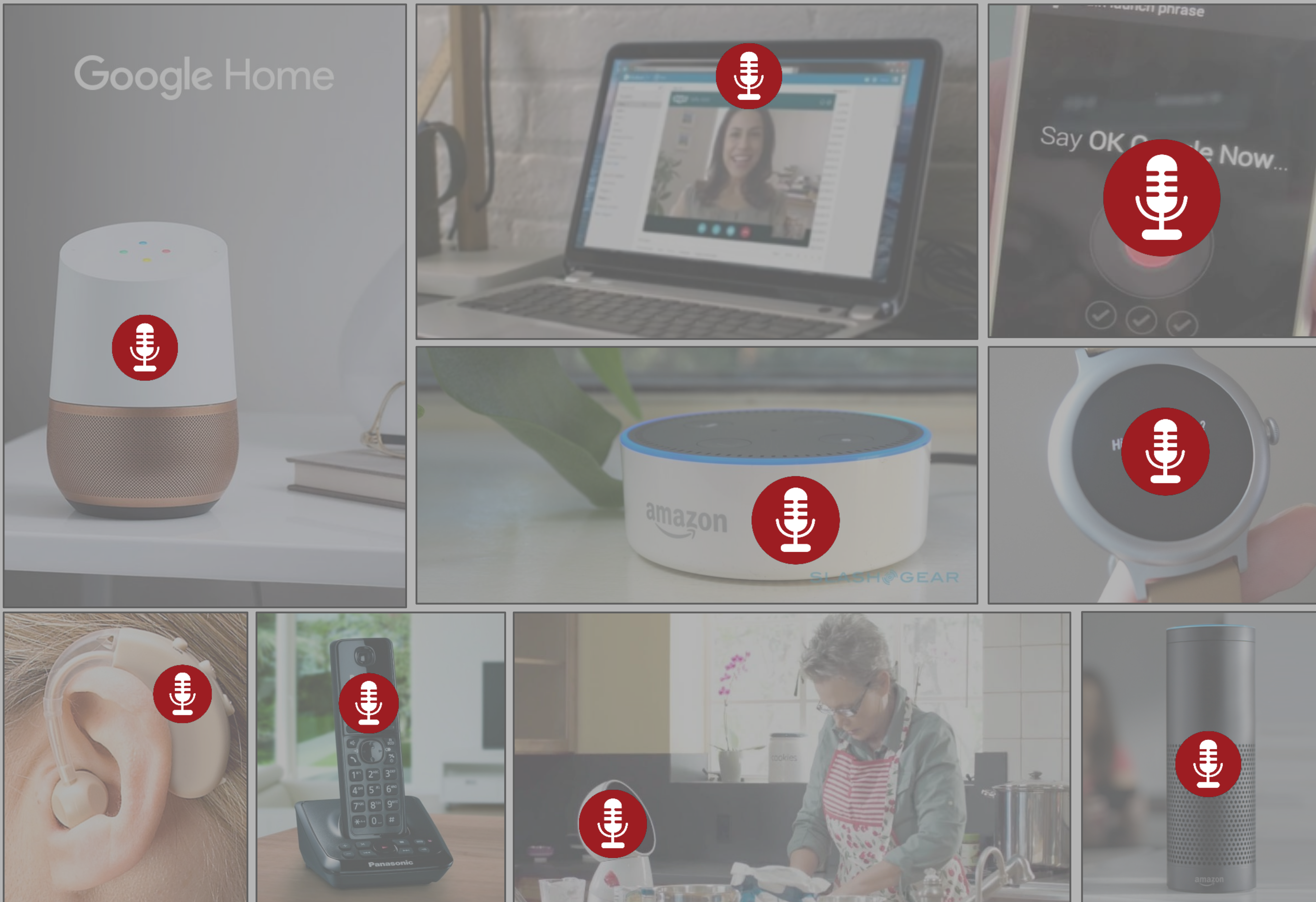




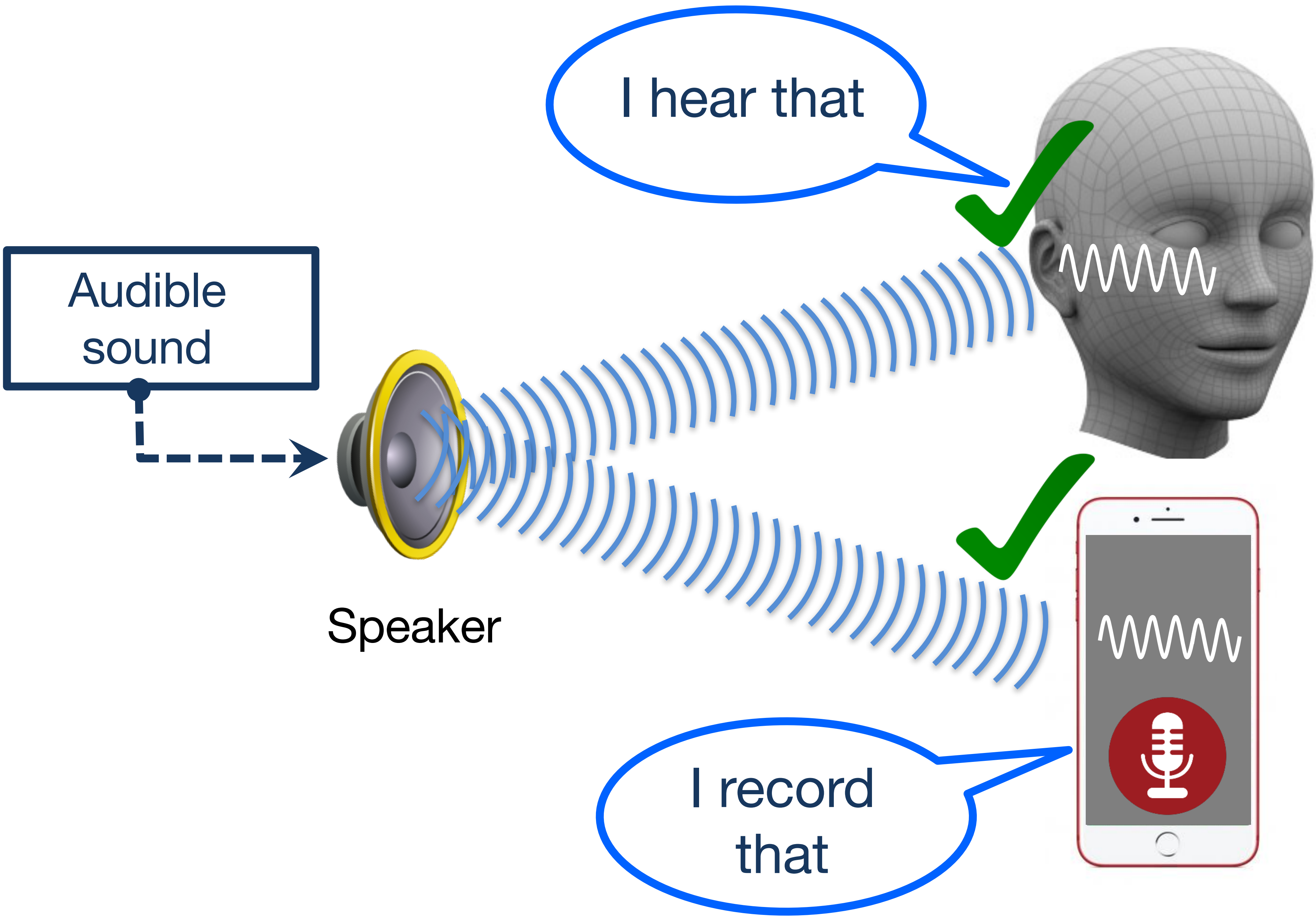




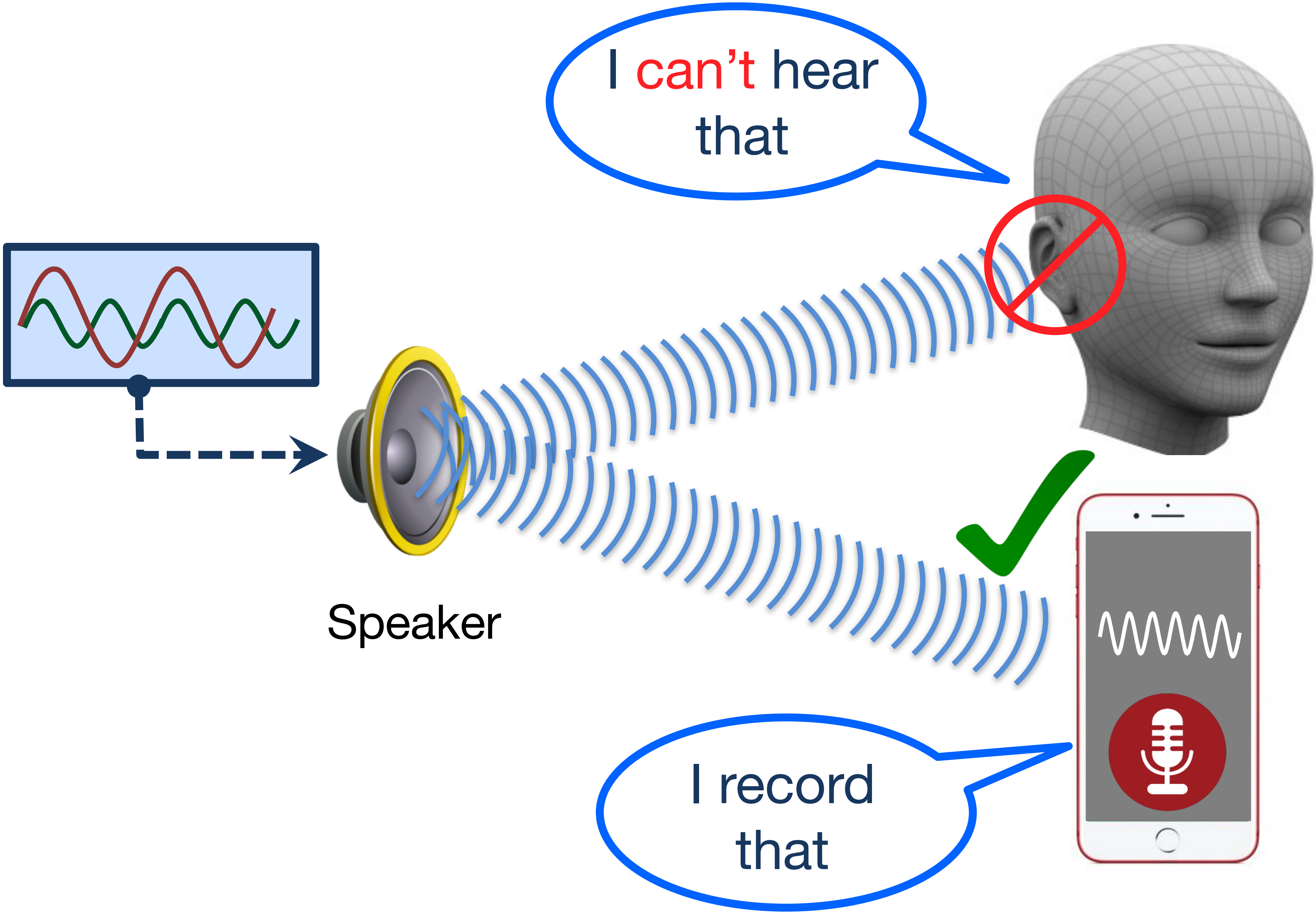
Microphones are everywhere



Microphones record audible sounds



Inaudible, but recordable !



[redacted]

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

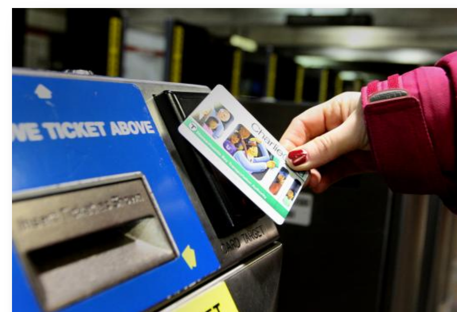
Access Control

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]

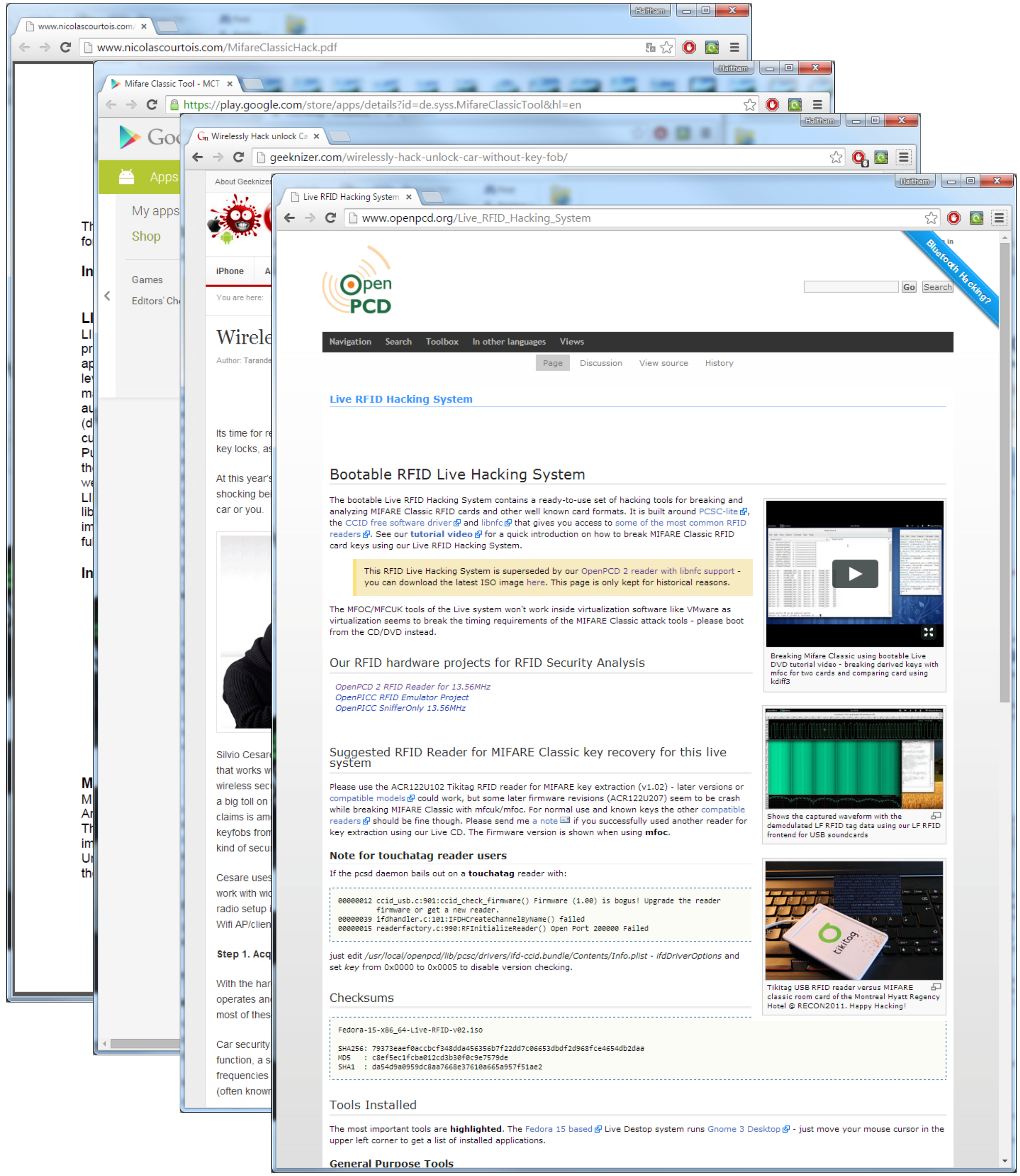
Passports
[DefCon'12, HackaDay'12,
BlackHat'06]

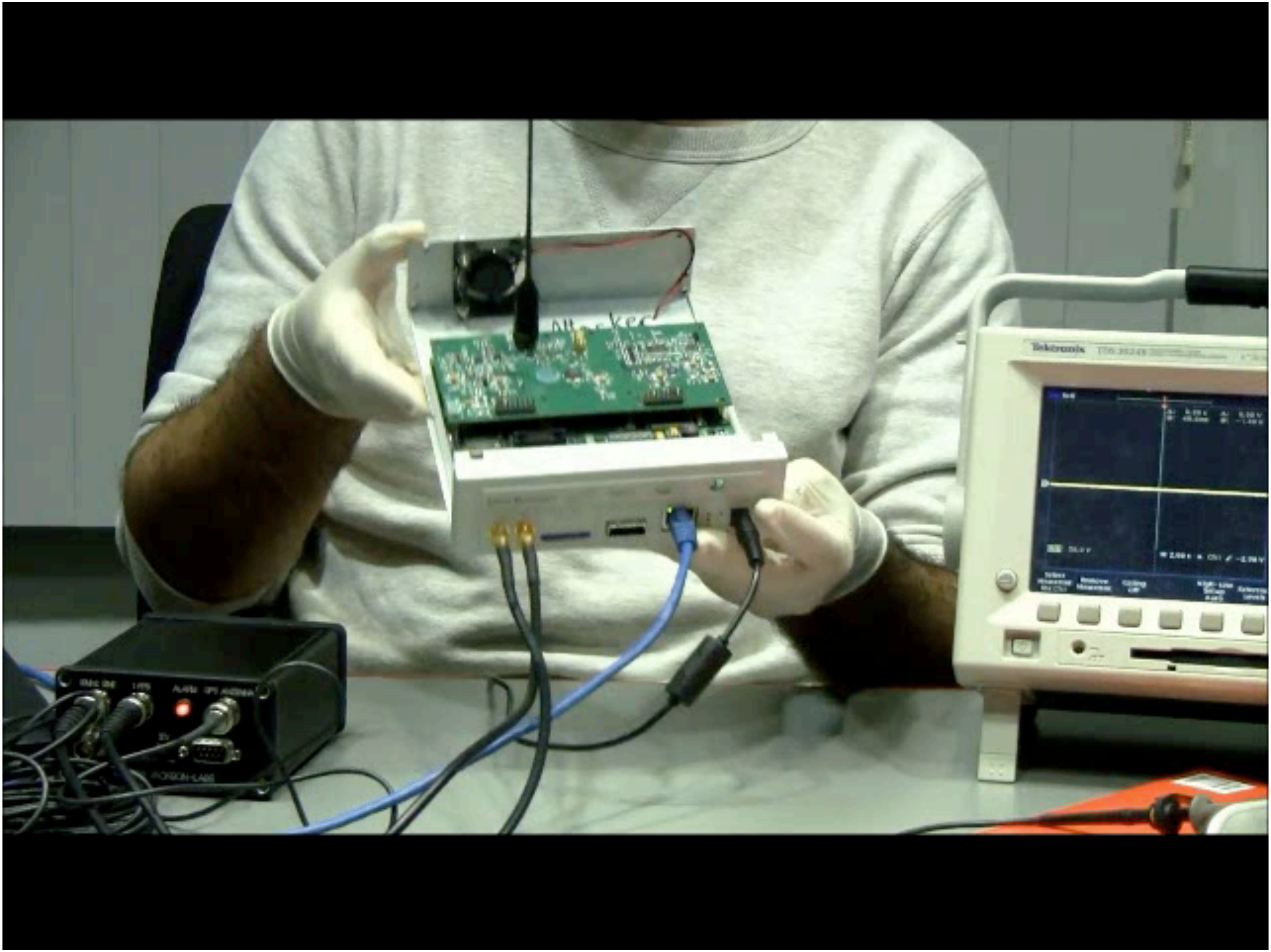
Pharmaceutical Drugs
[CCS'09, RFID'06]

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

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

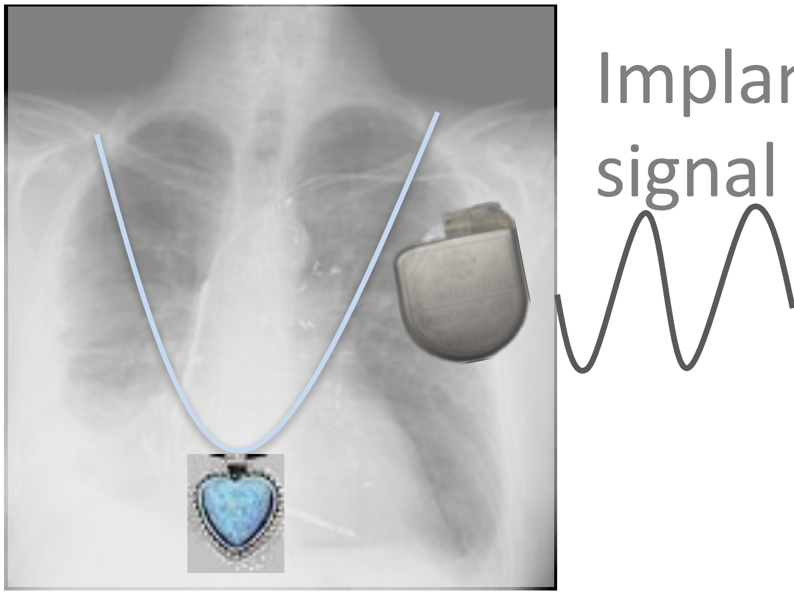
Hacking RFIDs for Dummies




Tektronix

Physical Layer Security: Encryption on the Air

Encrypt using a random signal



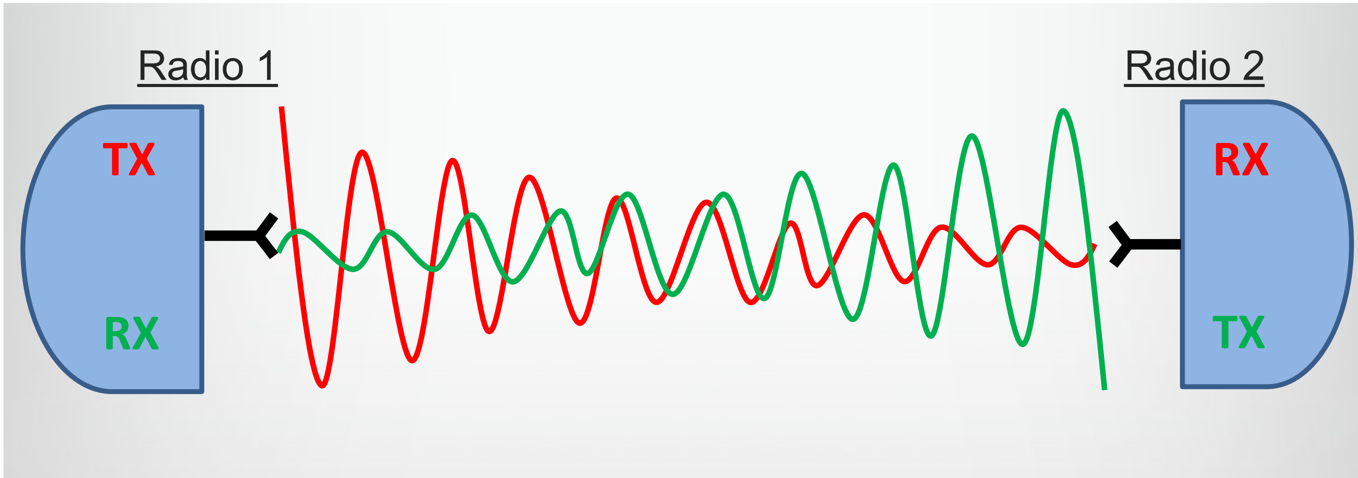
Implant's signal

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!

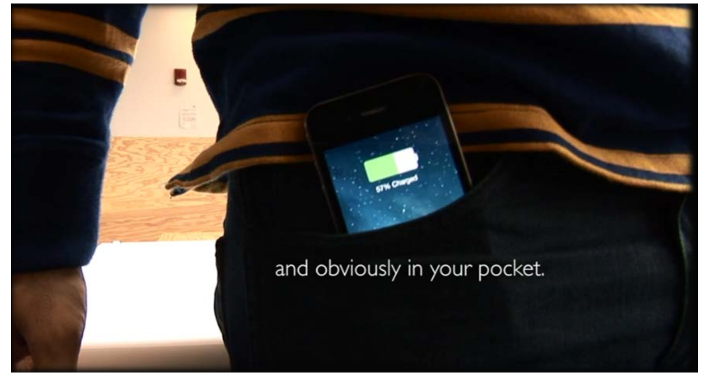
But we know the signal which we are transmitting!

→Cancel the self-interference on the hardware

→1.97x increase in throughput

Full Duplex Radios: Major change in communication protocols

Wireless Charging

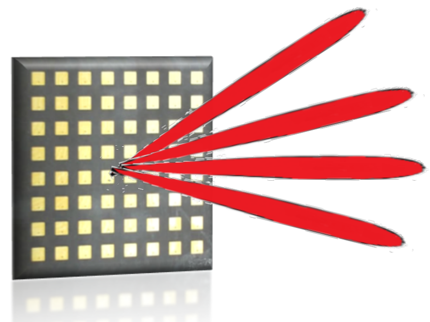


Other Topics Covered

Internet of Things

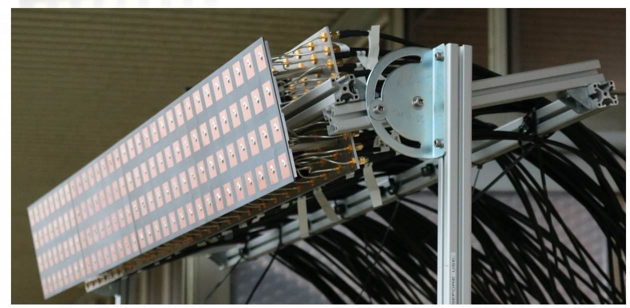
5G Networks

Acoustics



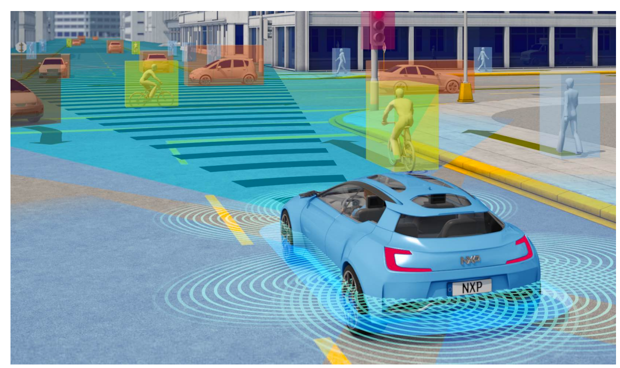
Millimeter Wave:
Wireless at Fiber
Optic Speeds

City Wide
Networks



Massive
MIMO
Base stations

Drones



Autonomous
Vehicular
Networks