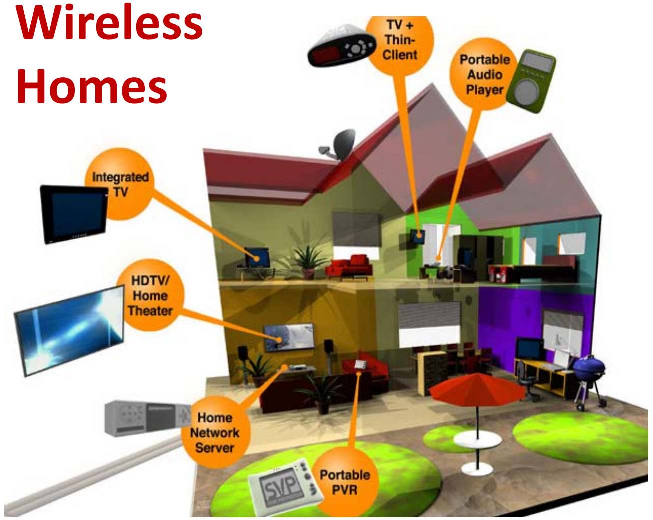
COS 563: Wireless Networks (G)

Lecture 1: Class Introduction
Kyle Jamieson

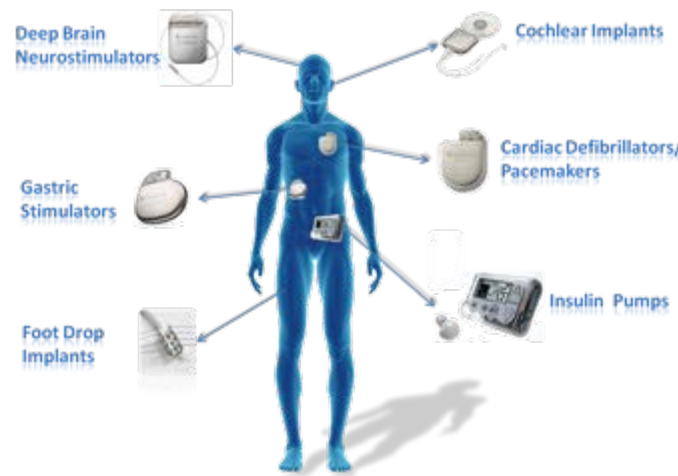
Slides credit: Adapted from Haitham Hassanieh

Wireless Networks Are Every Where

Wireless Homes



Wireless Biomedical Implants



Wireless Wearables

Cellular Networks

Wireless Sensors

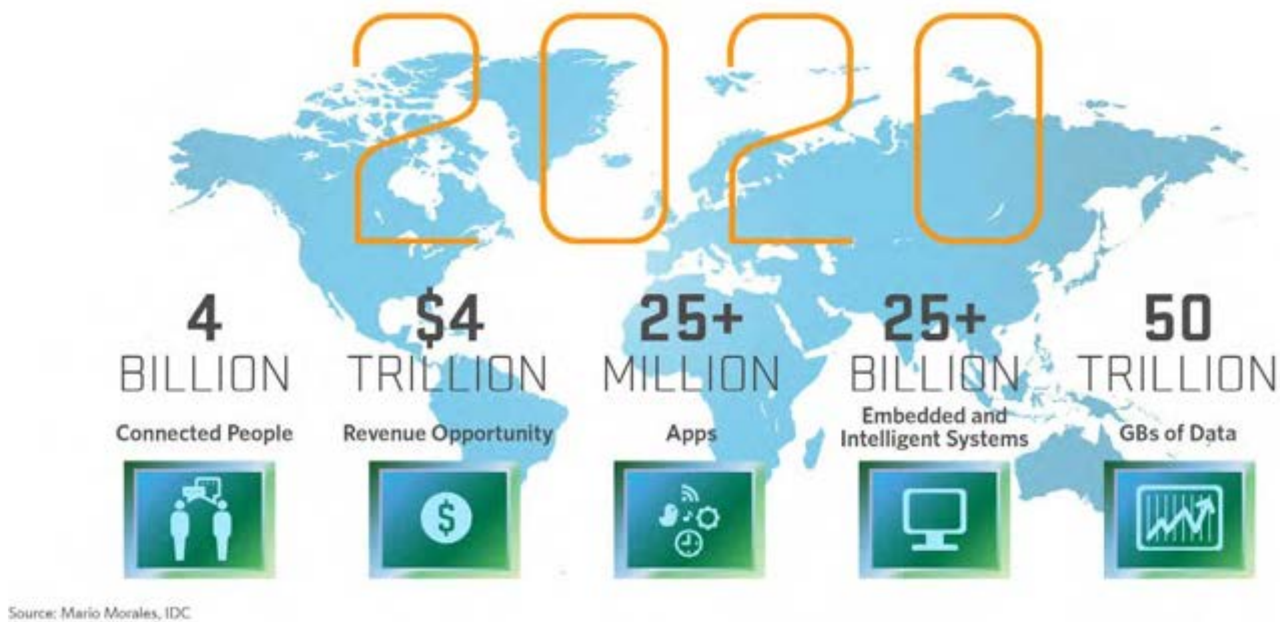
UAVs

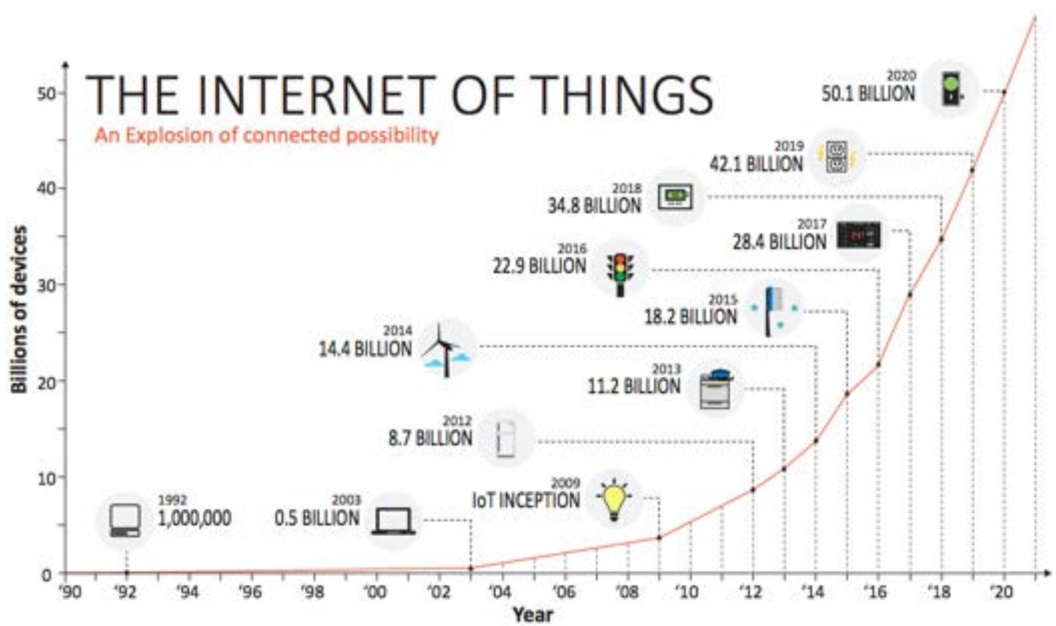
Wireless Data Centers

Wireless VR

Wireless Vehicles

Increasing Demand for Wireless Connectivity





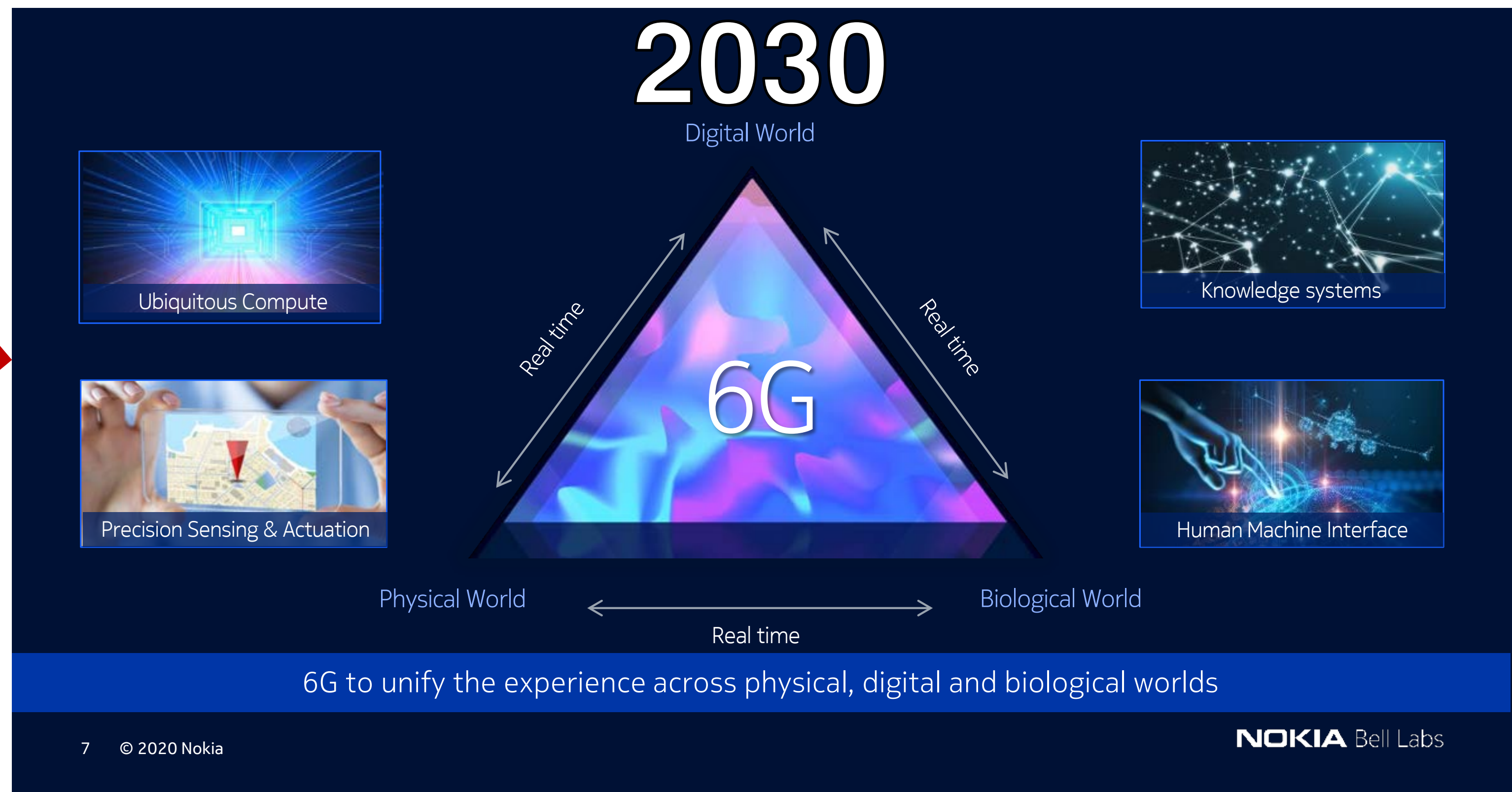
Increasing Demand for Wireless Connectivity

Connecting People

Increasing Demand for Wireless Connectivity

Connecting Everything

Increasing Demand for Wireless Connectivity



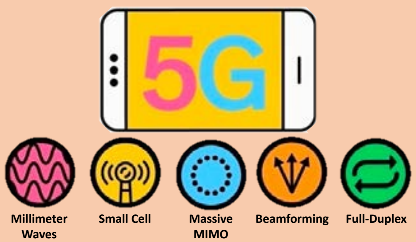
Connecting
+
Sensing
Everything

COS 563

Wireless Networks

Wireless Sensing

5G & Next Generation

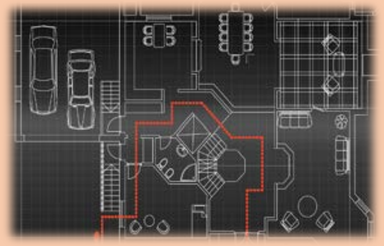


- Millimeter Wave Networks
- Massive MIMO
- Full Duplex Radios
- Dynamic Spectrum Access
- Programmable Surfaces

Internet of Things

- LoRa Networks
- Backscatter Networks
- Smart Cities & Homes
- Acoustic IoT
- IoT security

Wireless Localization



- WiFi Localization
- Battery Free Localization
- Antenna Arrays
- Time of Flight
- Tracking

Wireless Imaging

- Radar Imaging
- Self Driving Cars
- Through wall Imaging
- Human Imaging
- 3D Mesh Recovery

Cross Layer Wireless

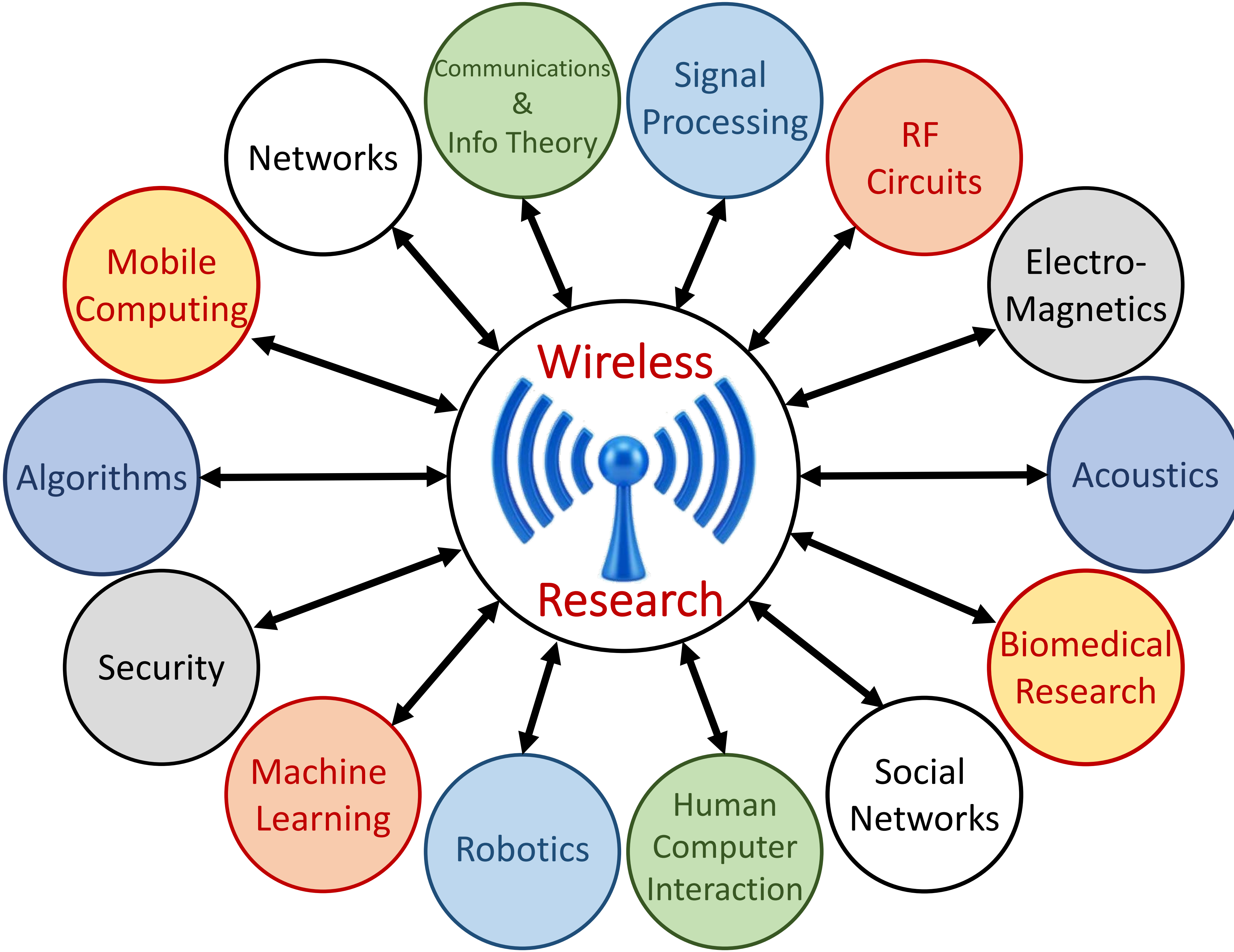
- Rateless Code & Soft PHY
- Interference Alignment
- Virtual MIMO
- Opportunistic Routing
- Network Coding

Emerging Areas

- Self-driving Cars
- Medical Micro-Implants
- Robotics & Drones
- Underwater Networks
- Noise Cancellation

Wireless Sensing

- Gesture Sensing
- Vital Sign Monitoring
- Behavioral Sensing
- Human Sensing
- Food Sensing



Networks
Communications & Info Theory
Signal Processing
RF Circuits
Electro-Magnetics
Mobile Computing
Wireless Research
Algorithms
Acoustics
Security
Biomedical Research
Machine Learning
Robotics
Human Computer Interaction
Social Networks

Course Information

- Staff
  - Instructors: Kyle Jamieson, Yaxiong Xie
  - Office hours: Tuesday after class
- Material
  - Mainly research papers
  - Lecture Slides
  - **Perusal** for discussions & questions
- Recommended Prerequisites
  - Any undergraduate networking, wireless, or digital communications class
  - Basic math and signal processing: probability, Fourier, …
  - Programming maturity (important for the project)

Class Participation

- Papers will be discussed in a very involved manner. All students are expected to have thoroughly read and considered each assigned paper, and to be prepared to pose and answer questions about each reading.

- **Preparing for class.** Please prepare at least **five** comments or questions for each paper and post those comments or questions on Perusall

- Class participation grade will be determined based on attendance and, most importantly, your concrete contributions to the paper discussion both on Perusall and in class

Term Project

- Open-ended systems research project
  - topics reached after discussion with the class instructor
  - Projects should be done in groups of one or two
  - All software code/firmware, hardware designs, etc shared privately with instructor

- All group students expected to share equally in implementation
  - At end of semester, each student working in a group asked to describe contributions of teammate

Grading

- Class participation: 30%

- Precept lead: 20%
  - Organize discussion, may answer questions
  - Submit a 500-1000-word report that summarizes both discussion and paper

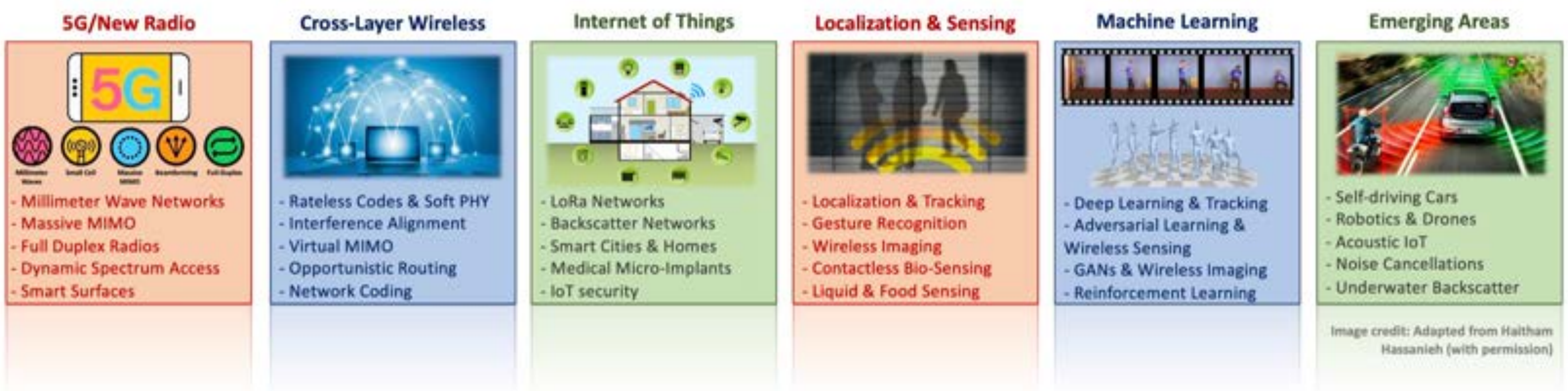
- Project: 50%, comprised of:
  - Checkpoint #1 - project proposal - 10%
  - Checkpoint #2 - preliminary demo - 10%
  - Checkpoint #3 - project presentation - 10%
  - Checkpoint #4 - final report (5 pages + biblio) - 20%

Class Webpage

www.cs.princeton.edu/courses/archive/spring21/cos563

COS 563 Wireless Networks (Spring 2021)

Home Syllabus Reading List Announcements Canvas Perusall



Overview

COS-563 is a graduate-level class that explores recent developments in wireless networks and sensing systems. Topics include an overview of general wireless network architecture, including the abstraction of underlying and overlying hardware and layers in the networking stack, integration with overlying applications, and concurrency, performance, and resource allocation in wireless networks. Further topics include millimeter-wave communication, multi-hop networks, underwater and water-air communications, low power backscatter and long range networks, Wi-Fi based localization, and wireless radar and sensing.

The course will include two precept based discussion meetings per week, in which students will read and discuss papers on the foregoing topics, and a semester-long project.

Class Participation

Papers will be discussed in a very involved manner. All students are expected to have thoroughly read and considered each assigned paper, and to be prepared to pose and answer questions about each reading.

Preparing for class. Please prepare at least **five** comments or questions for each paper and post those comments or questions on Perusall one day prior to class. General instructions on how to read and review a paper can be found here.

Your class participation grade will be determined based on attendance and, most importantly, your concrete contributions to the paper discussion both on Perusall and in class.

During the paper discussion in class, we will divide the students into groups and select one student in each group as the paper discussion leader (leaders will be selected in a round-robin manner). The leader should organize the disscussion and may answer questions from the group members. The leader is also required to submit a 500 to 1000-word report that summarizes both the discussion and the paper. The deadline for report submission is 48 hours after the class.

Note: Class attendance is required. With that being said, we understand that students sometimes can be in unexpected situations. Do let the instructors know if you have to miss a class, and we can make arrangements to accommodate the absence.

Syllabus

COS 563 Wireless Networks: Syllabus

Home Syllabus Reading List Announcements Canvas Perusall

Textbooks

The following optional texts are for your reference:

- **Wireless Communication Networks and Systems**, by Cory Beard and William Stallings (ISBN: 0133594173, available online).
- **Fundamentals of Wireless Communication [T & V]**, by David Tse and Pramod Viswanath (available online).
- **Computer Networks: A Systems Approach**, third edition, by Larry Peterson and Bruce Davie.

Schedule

Also available as an ical file that you can subscribe to. This schedule is preliminary and subject to change.

Date	Topics	Readings	Notes
Tue 02/02	Class Introduction; How to Read a Paper	**Pre-Reading:** HowToRead	
	Part 1: Wireless from the Transport Layer Downwards		
Thu 02/04	Stochastic Forecasts for Wireless Cellular Networks	**Pre-Reading:** Sprout	
Tue 02/09	Transport Protocol Design using Machine Learning	**Pre-Reading:** Remy	
Thu 02/11	Introduction to 5G Cellular Networks	**Pre-Reading:** 5G overview	Student lead: AKS
Tue 02/16	Understanding Operational 5G Networks	**Pre-Reading:** 5GMeasure	
Thu 02/18	Fine-grained PHY-layer Information for Congestion Control	**Pre-Reading:** PBECC	
	Part 2: Multi-hop and Mesh Wireless Networks		
Tue 02/23	Packet Radio Medium Access Control	**Pre-Reading:** Maca	
Thu 02/25	Medium Access in Wireless Local Area Networks	**Pre-Reading:** Macaw	
Mon 03/01			Project team must be formed by 1 March.
Tue 03/02	Mesh Networking	**Pre-Reading:** Roofnet05	
	Part 3: Bit Rate Adaptation and Rateless Codes		
Thu 03/04	Bit Rate Aadaptation in 802.11	**Pre-Reading** RRAA	
Tue 03/09	Rateless Codes	**Pre-Reading:** Spinal	
	Part 4: New Physical Media		
Thu 03/04	Communication via Physical Vibrations	**Pre-Reading:** Ripple2	
Tue 03/09	Visible Light Communication	**Pre-Reading:** DarkLight	
Thu 03/11			*No class*
Tue 03/16			*Spring recess week*
Wed 03/17			Project proposal due.

Sample Topics in this Class

- Network Coding
- Cross Layer Networking
- 5G Millimeter Wave
- Full Duplex
- Programmable surfaces

- Localization: Smart homes
- Human Sensing & Imaging
- Self Driving Cars
- Medical Implants
- Food Sensing

Introduction to Wireless Networks

Wireless networks provide advantages

- Mobility
- Eliminates piles of wires at home and office

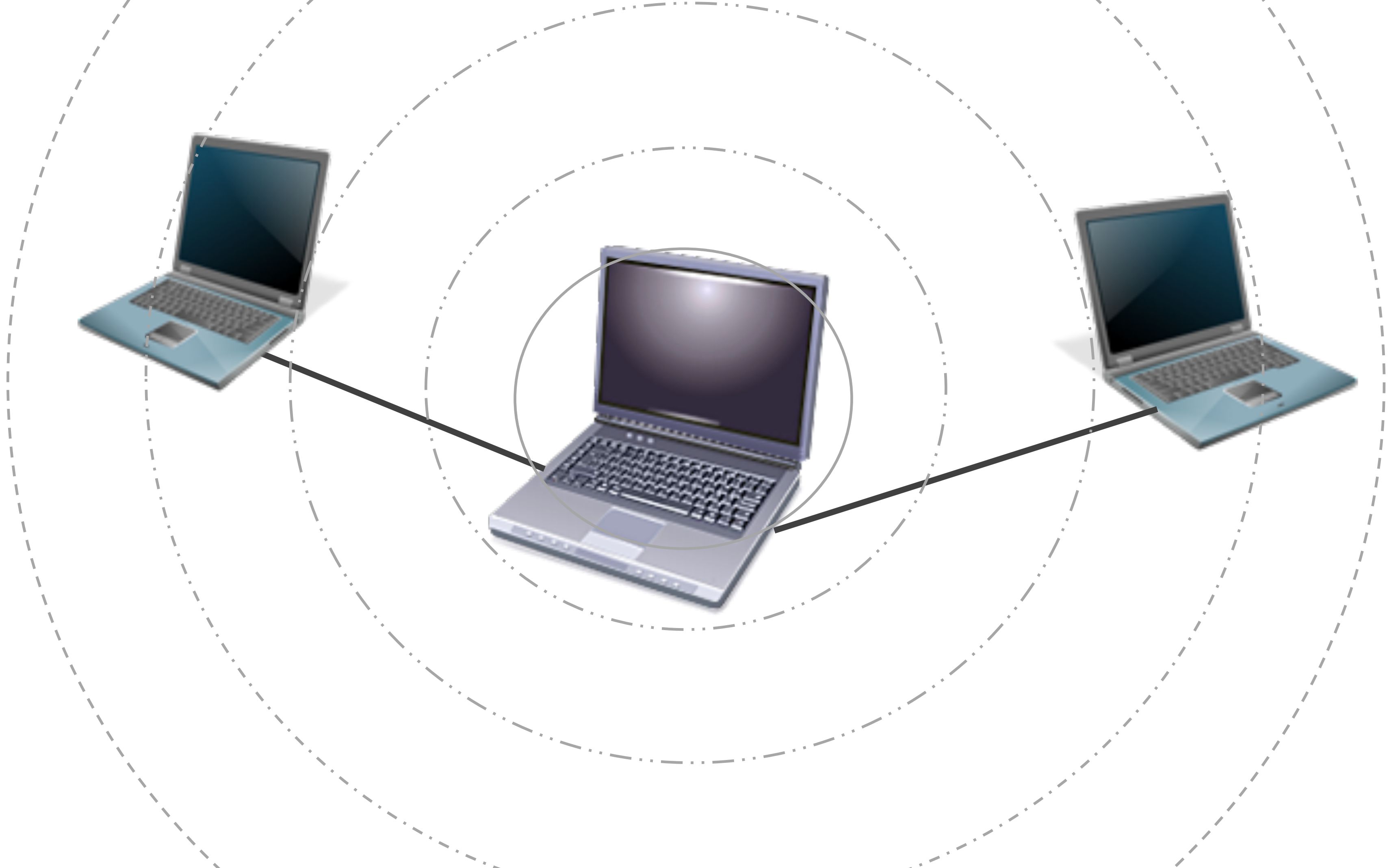
But wireless networks present different challenges

- Medium is shared → Interference
- Medium is shared → Throughput ↘ as Devices ↗
- Channel can bad & unstable → Losses + 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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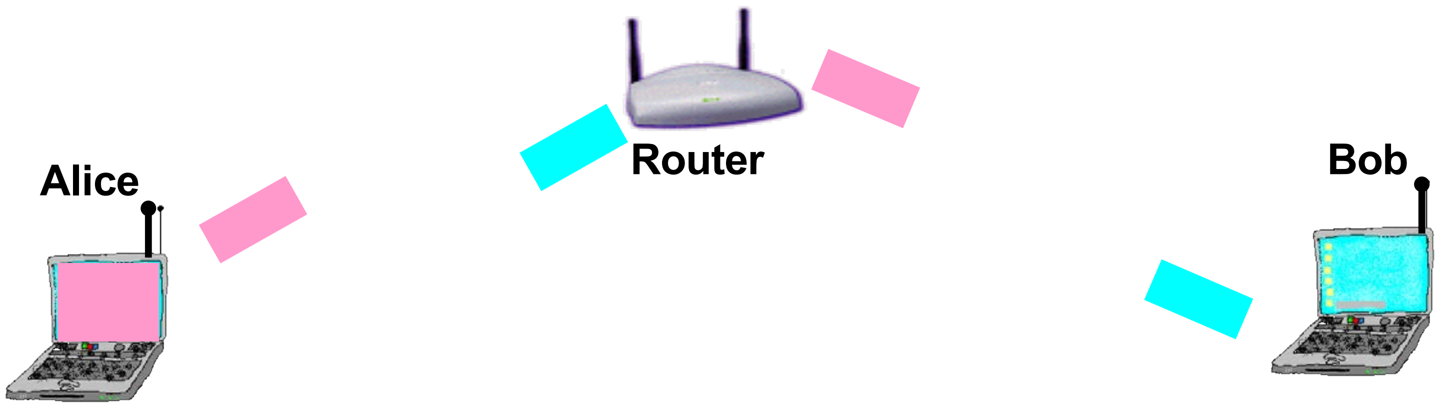
Traditional Approach



Requires 4 transmissions

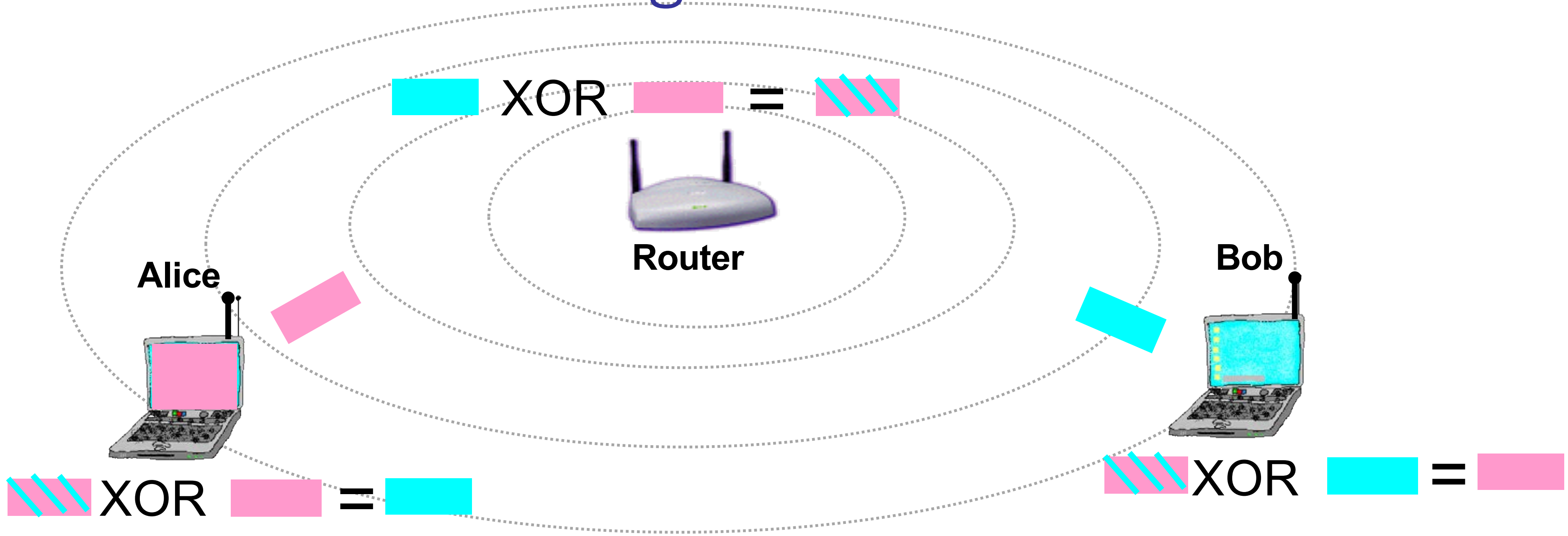
- Alice to router; Router to Bob; Bob to router; Router to Alice

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.

Approach: Network Coding



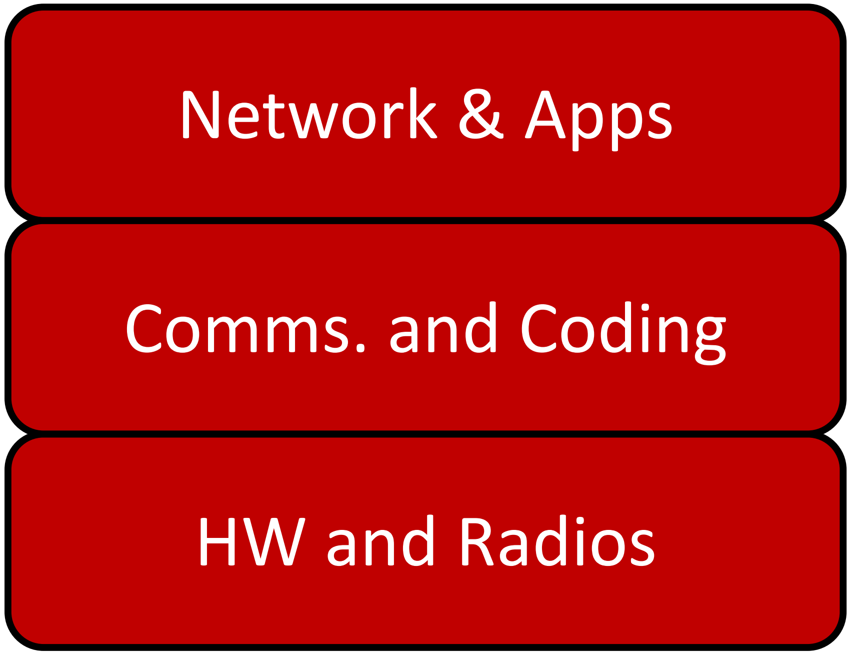
Requires 3 transmissions instead of 4

- 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

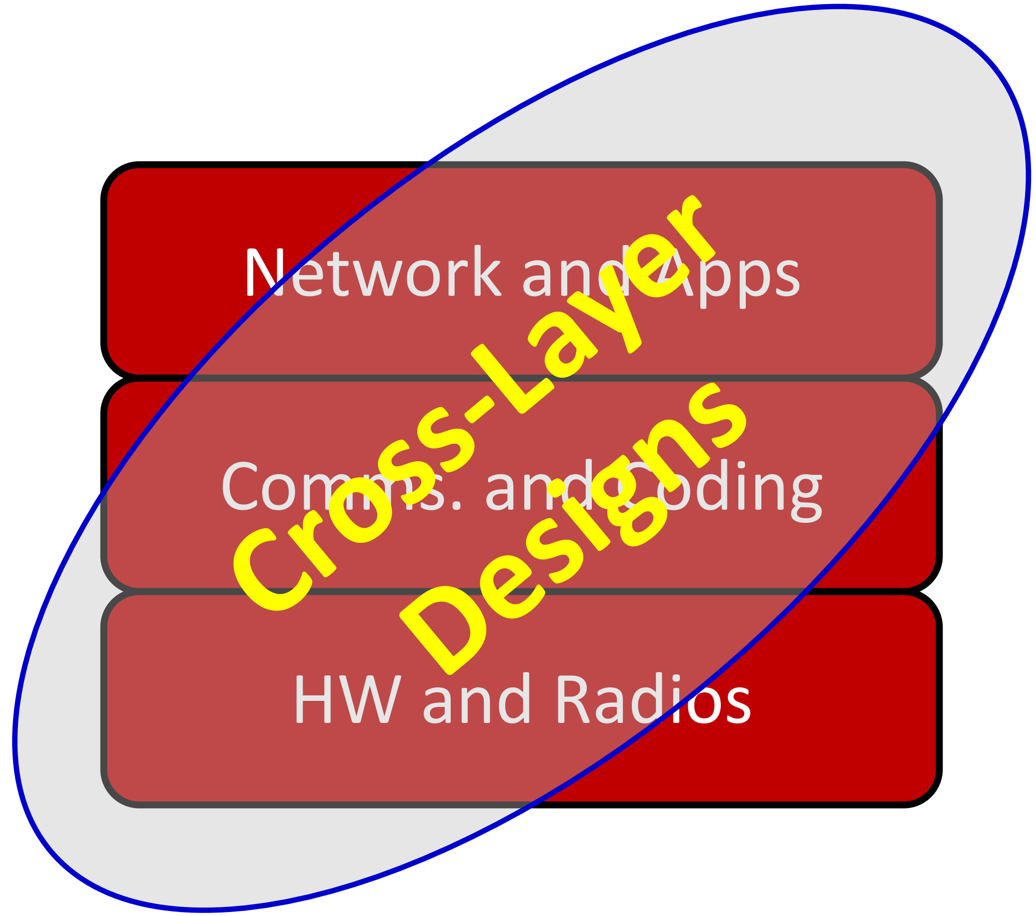
Optimize within isolated layers



Disruptive gains are unlikely

New Approach

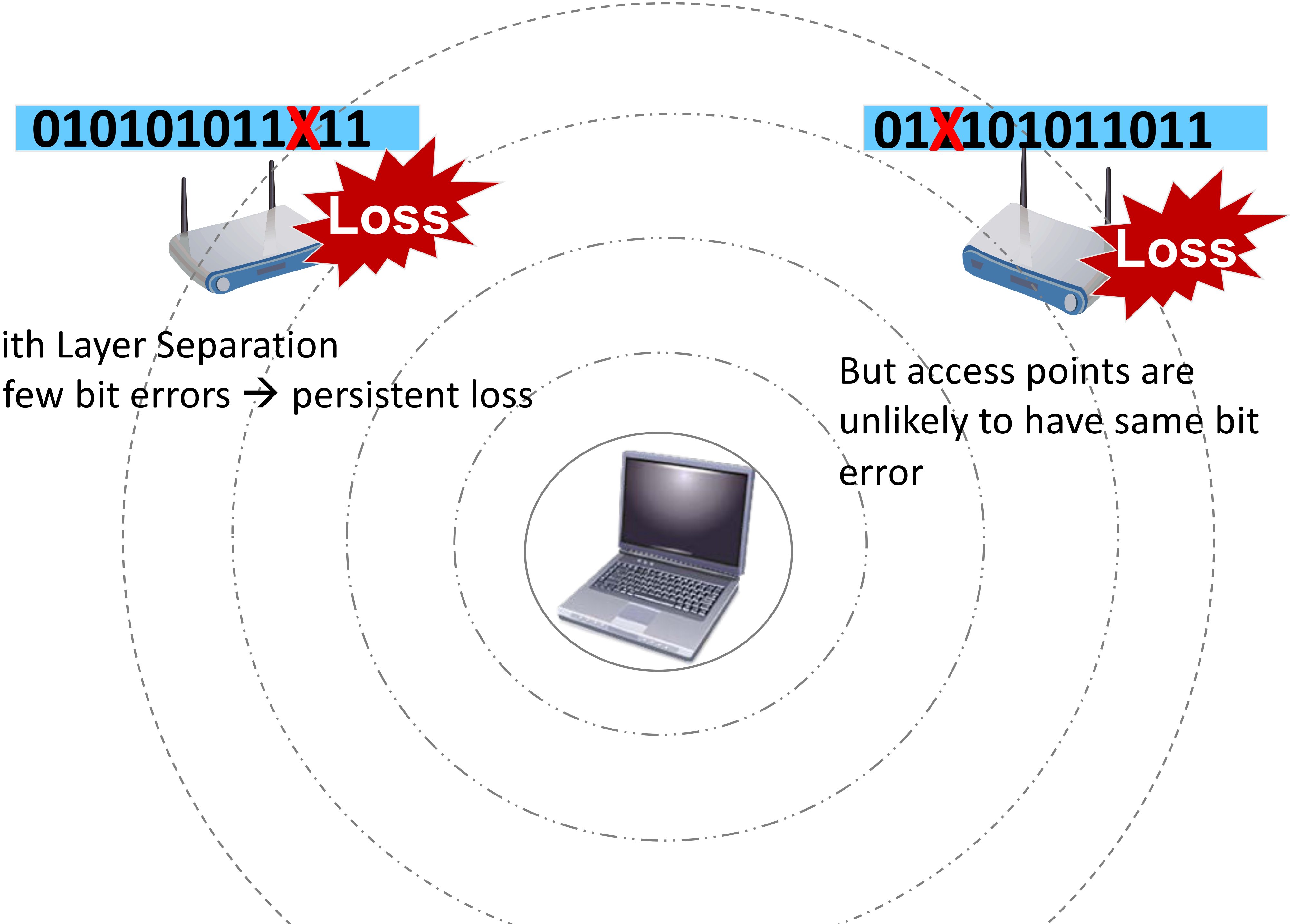
Optimize across the layers



Major opportunities!

Why is layer separation suboptimal in wireless networks?

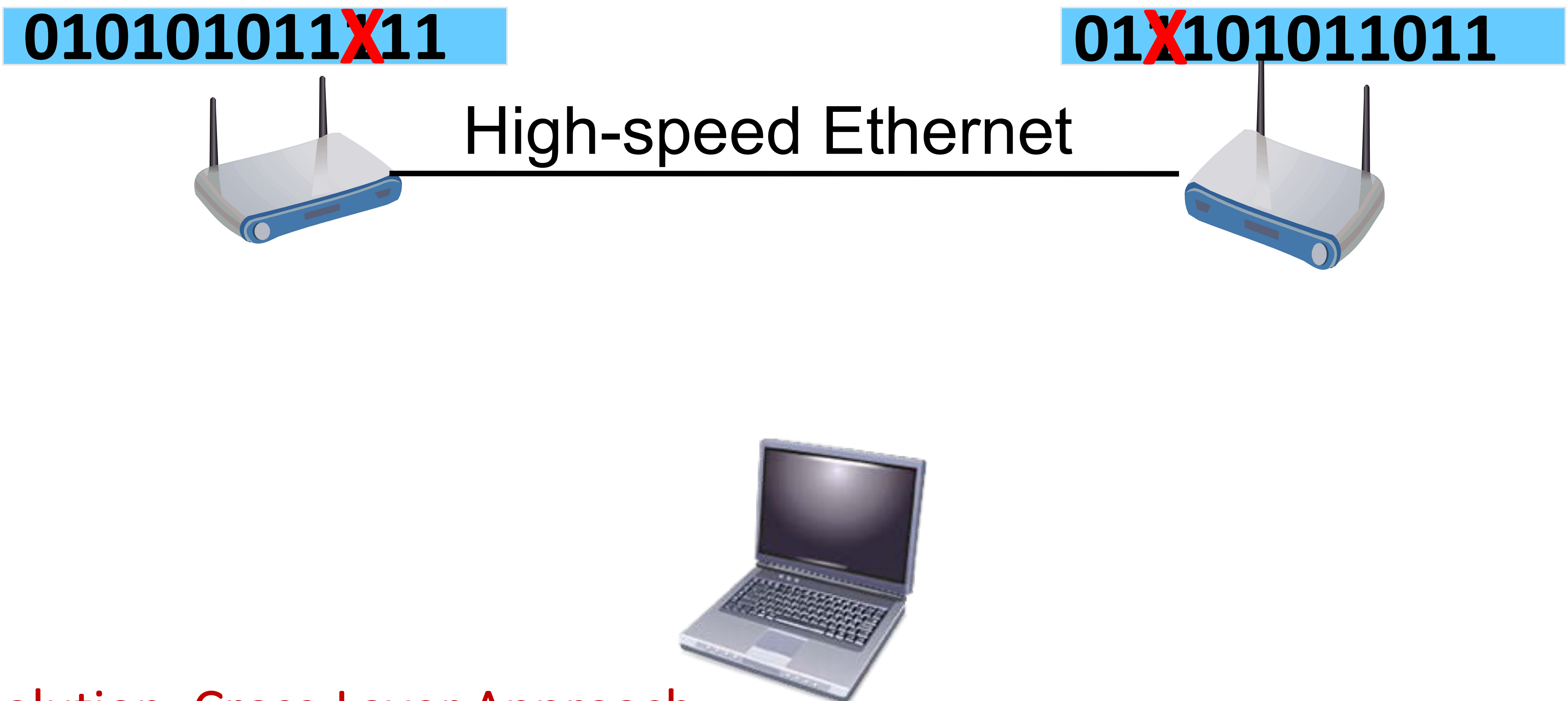
Scenario: Laptop in a Dead Spot



With Layer Separation
a few bit errors → persistent loss

But access points are unlikely to have same bit error

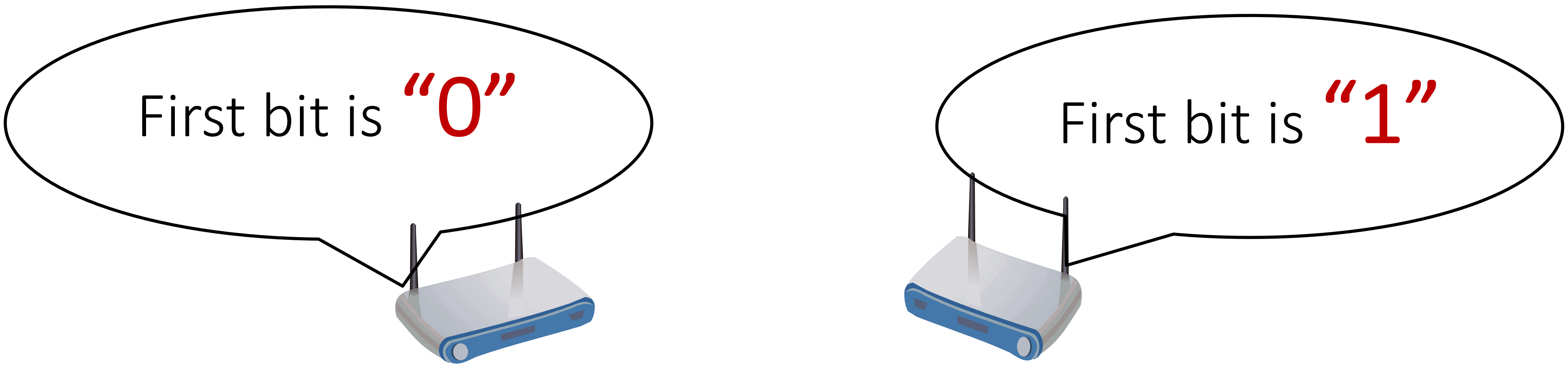
Scenario: Laptop in a Dead Spot



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

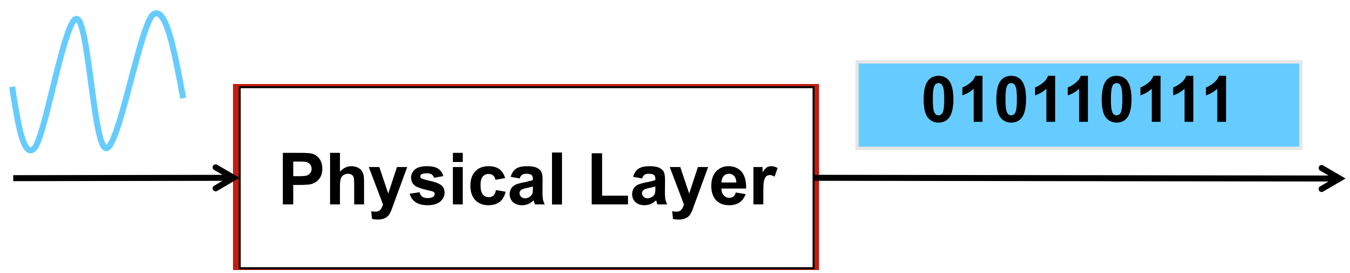
- Allow the layers to collaborate instead of acting separately
- PHY layer delivers partially correct packets
- Network layer combines correct bits across different access points to obtain correct packet

Challenge

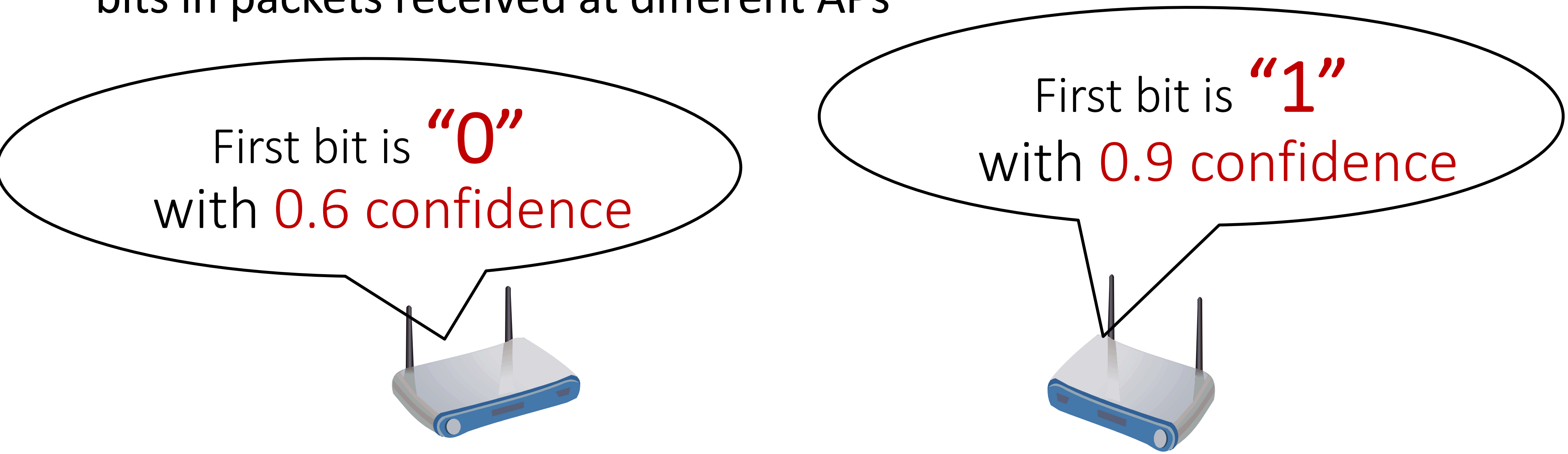


Which access point should we believe?

Solution: Network cooperates with physical layer

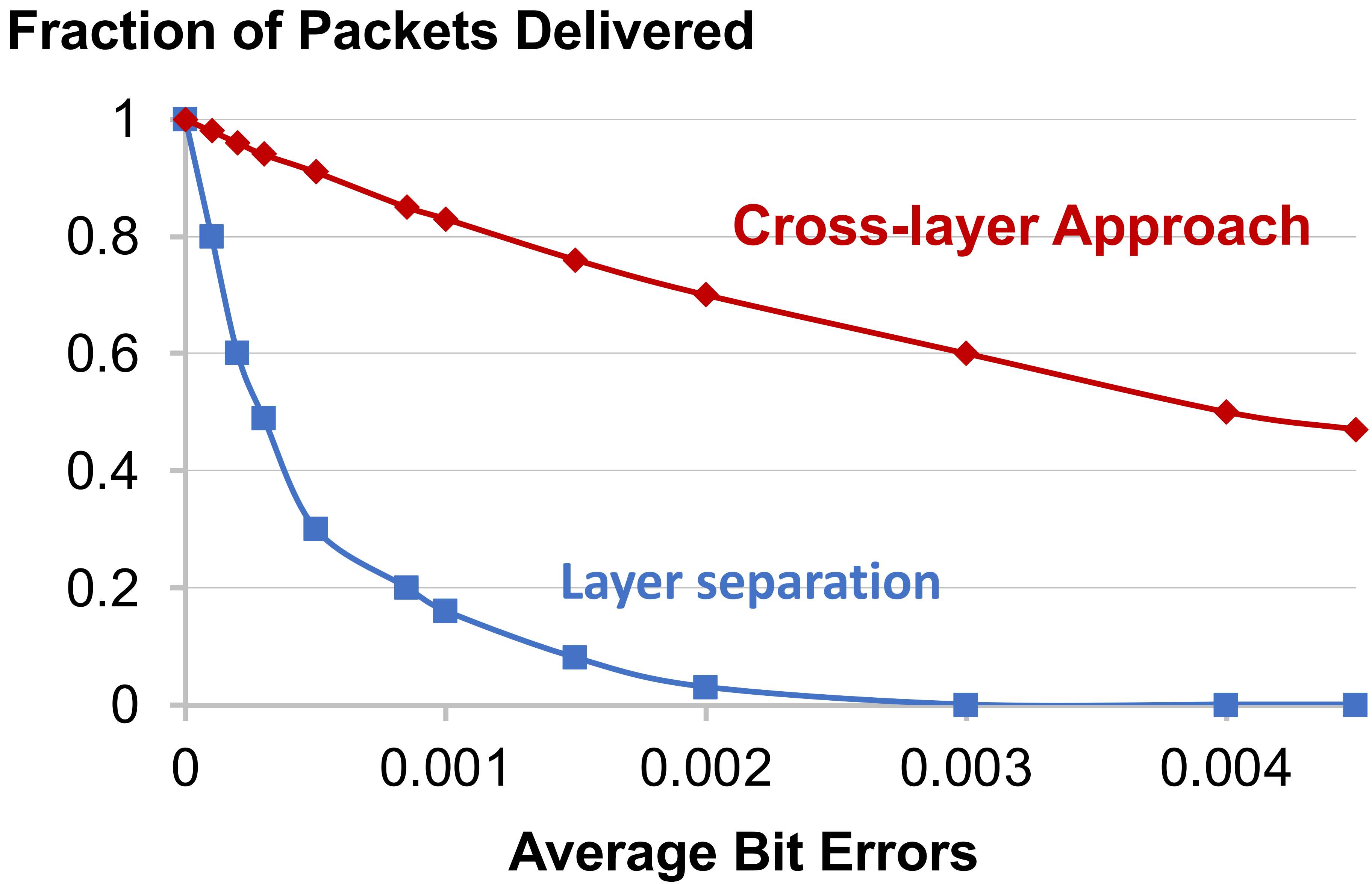


- Physical layer already estimates a confidence in its 0-1 decision
- If we expose this information to the network layer, we can compare bits in packets received at different APs

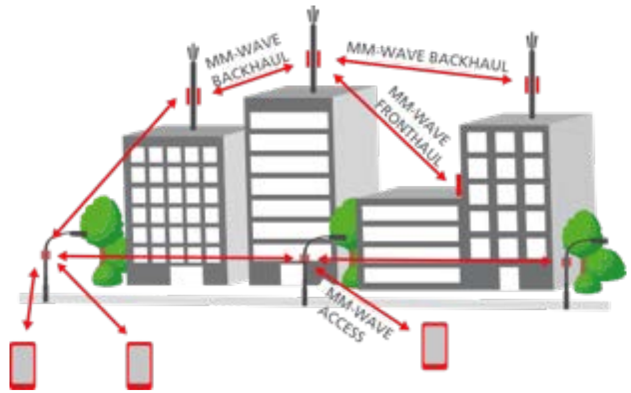


- Assign to each bit the value that corresponds to a higher confidence

Experiment: Packet Delivery vs. Poor Coverage



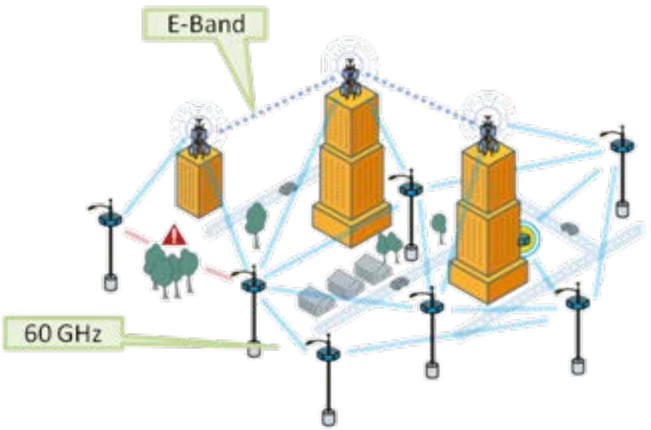
High Data Rate Applications



5G Wireless Backhaul & Access

Virtual Reality

Connected Vehicles



mmWave Mesh Networks

Robotic Networks

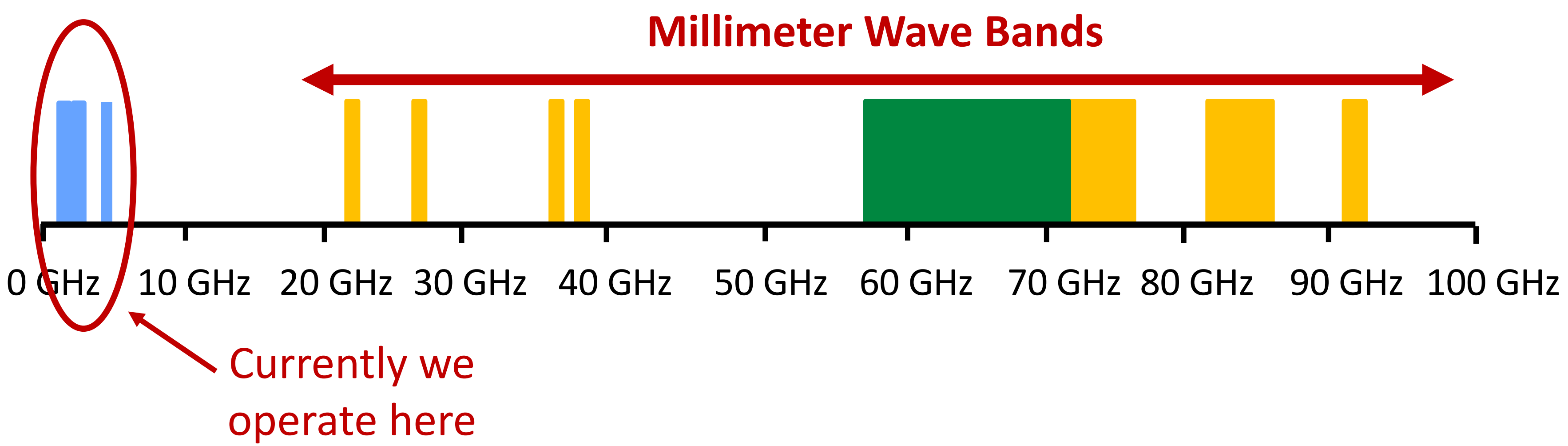
Wireless Data Centers

VR requires a cable connection to a PC

Significantly limits mobility & experience

Millimeter Wave Technology

Huge bandwidth available at millimeter wave frequencies



Millimeter Wave can support data rates of multi-Gbps

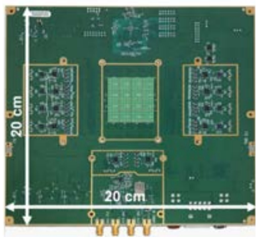
Millimeter Waves Suffer from Attenuation

mmWave radios use phased antenna arrays to focus the power along one direction

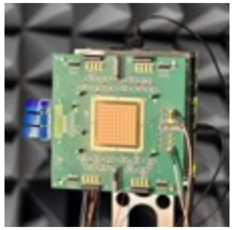

Nokia & National Instruments


UCSD
256 elements

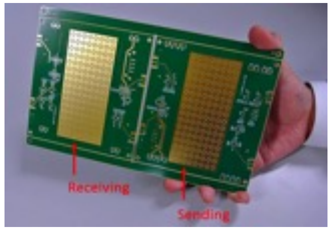

UCSD
64 elements



Bell Labs
384 elements


Anokiwave
256 elements

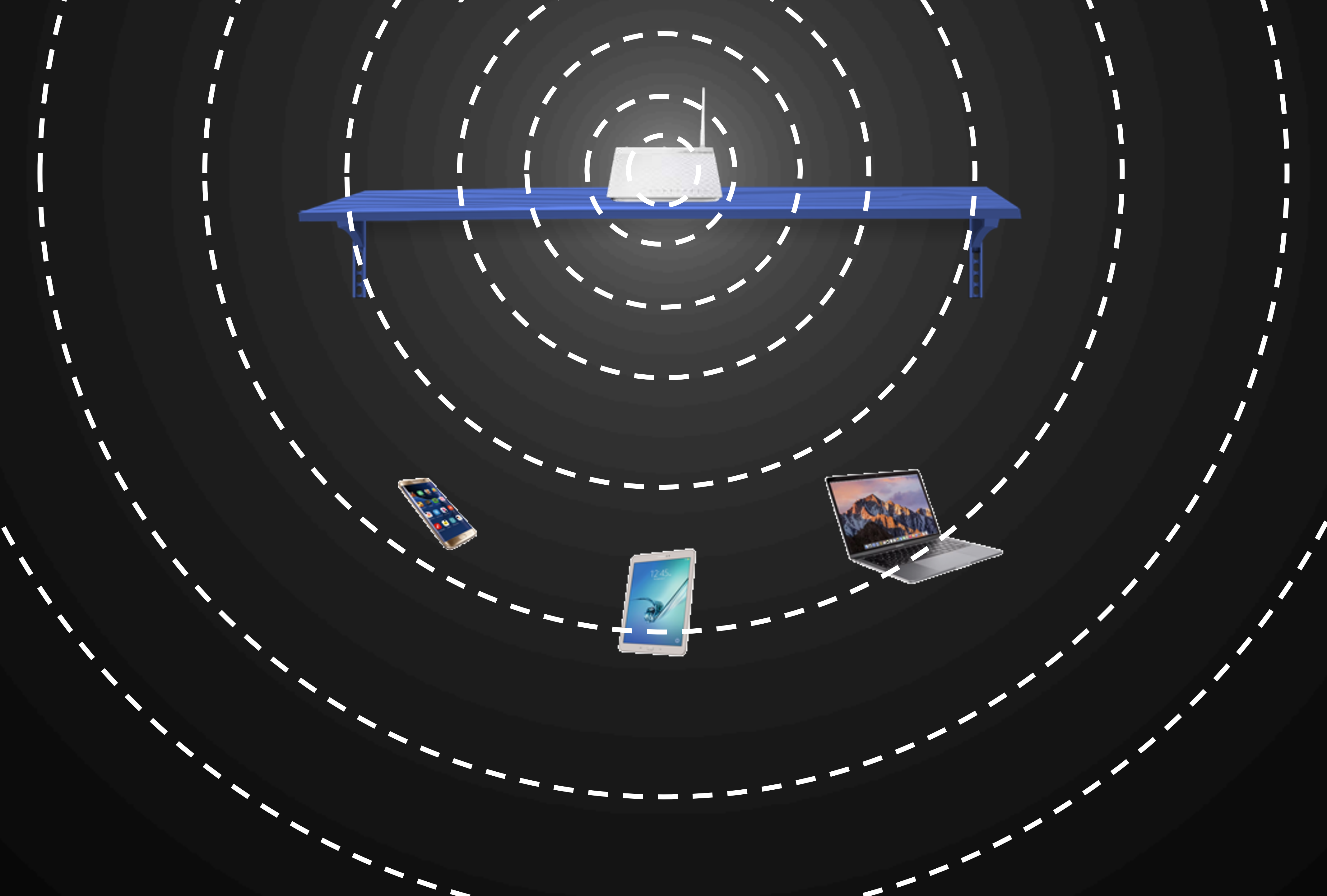

IBM
64 elements



Fujitsu
64 elements

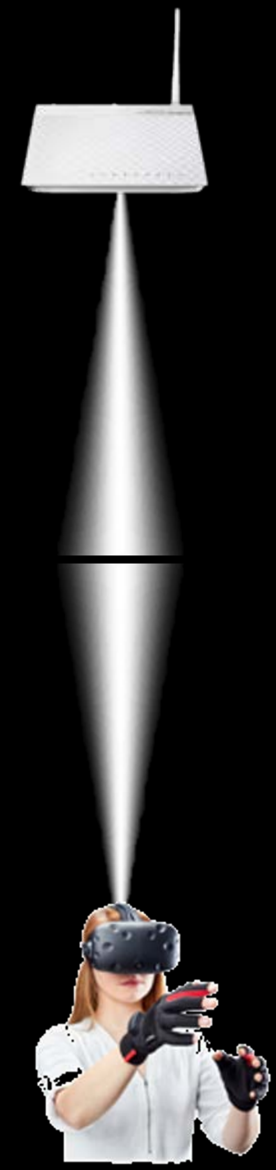
Small Wavelength enables thousands of antennas to be packed into small space → Extremely narrow beams

Today's Networks : Broadcast

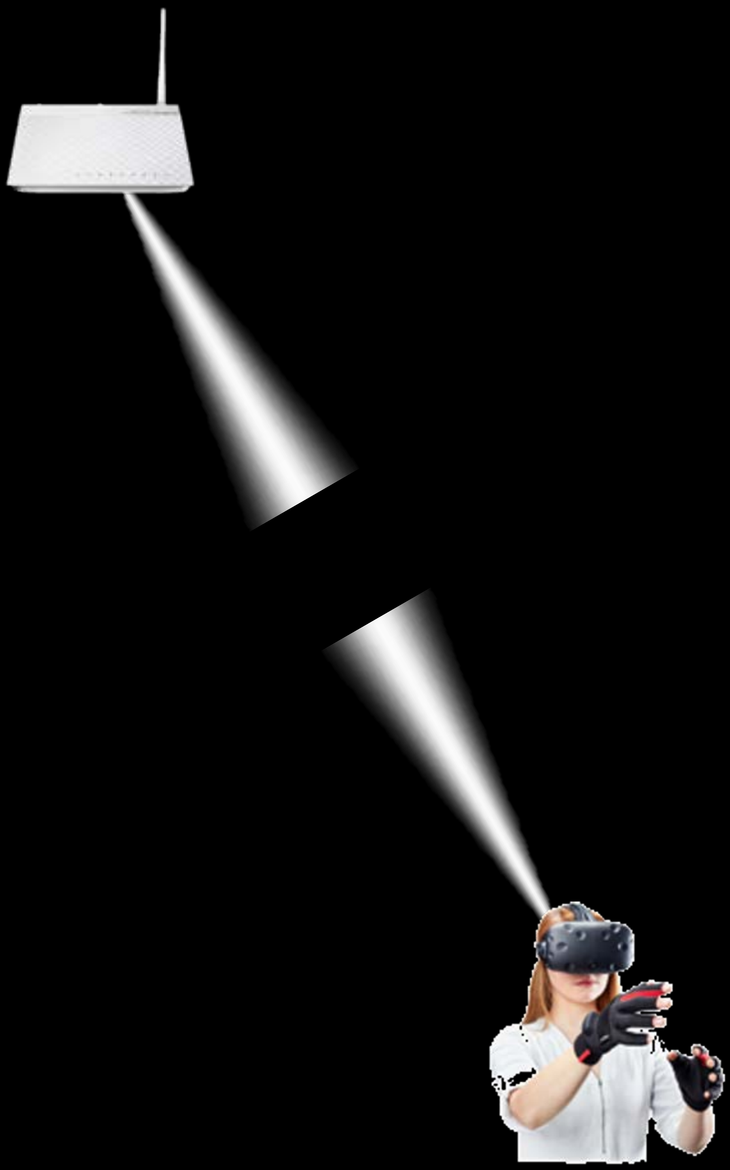


mmWave changes how wireless systems operate

mmWave: Narrow-beam Antennas



Need to quickly find the right beam alignment and track the user.

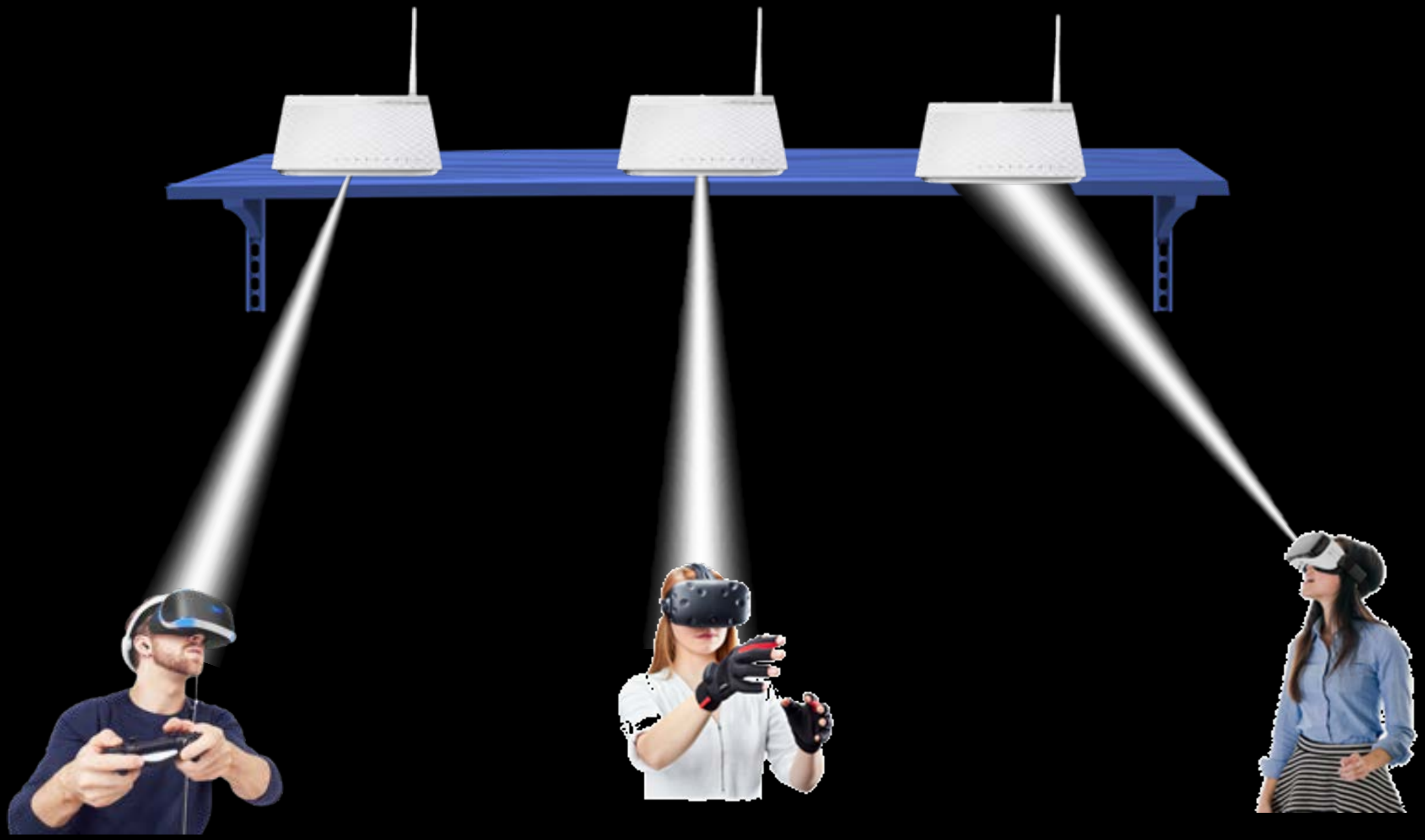


Suffers in case of:

- Mobility
- Blockage
- Multi-users

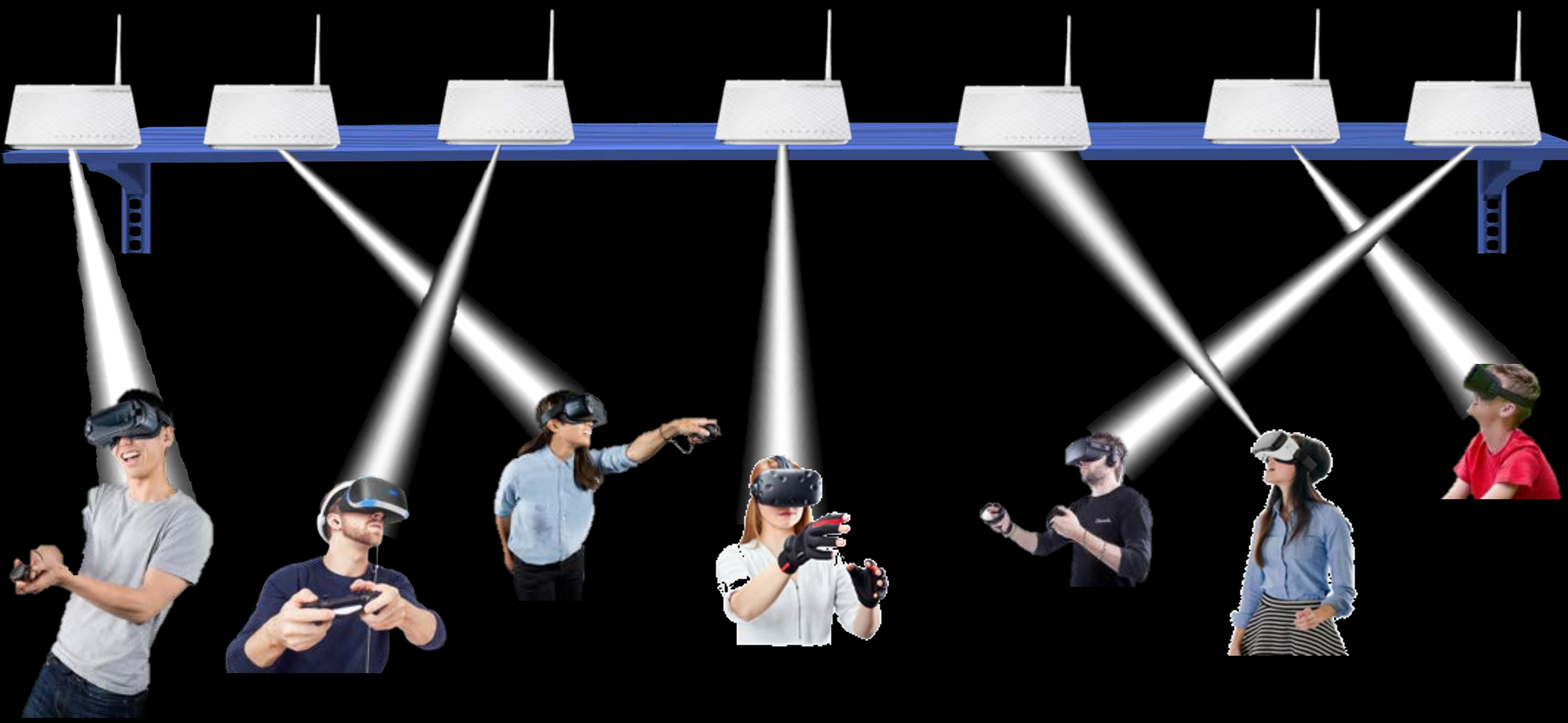
mmWave changes how wireless systems operate

mmWave: Narrow-beam Antennas

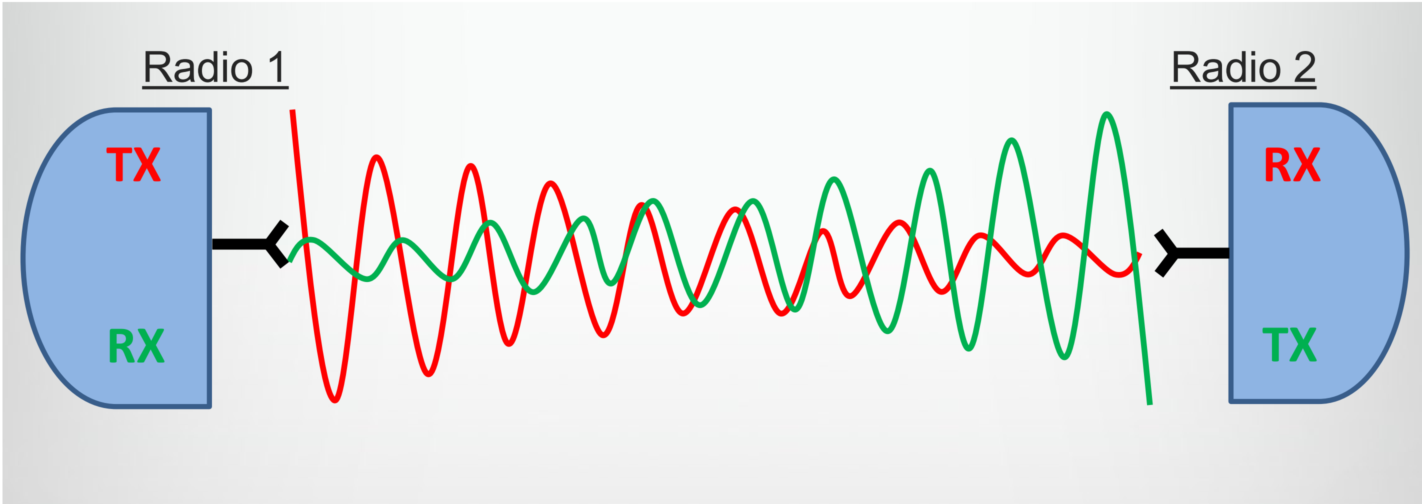


mmWave changes how wireless systems operate

mmWave: Narrow-beam Antennas



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

Today: Wireless Communication Adapt to Channel Conditions

- Wireless Channel changes quickly and is unpredictable.

- If Channel is Bad

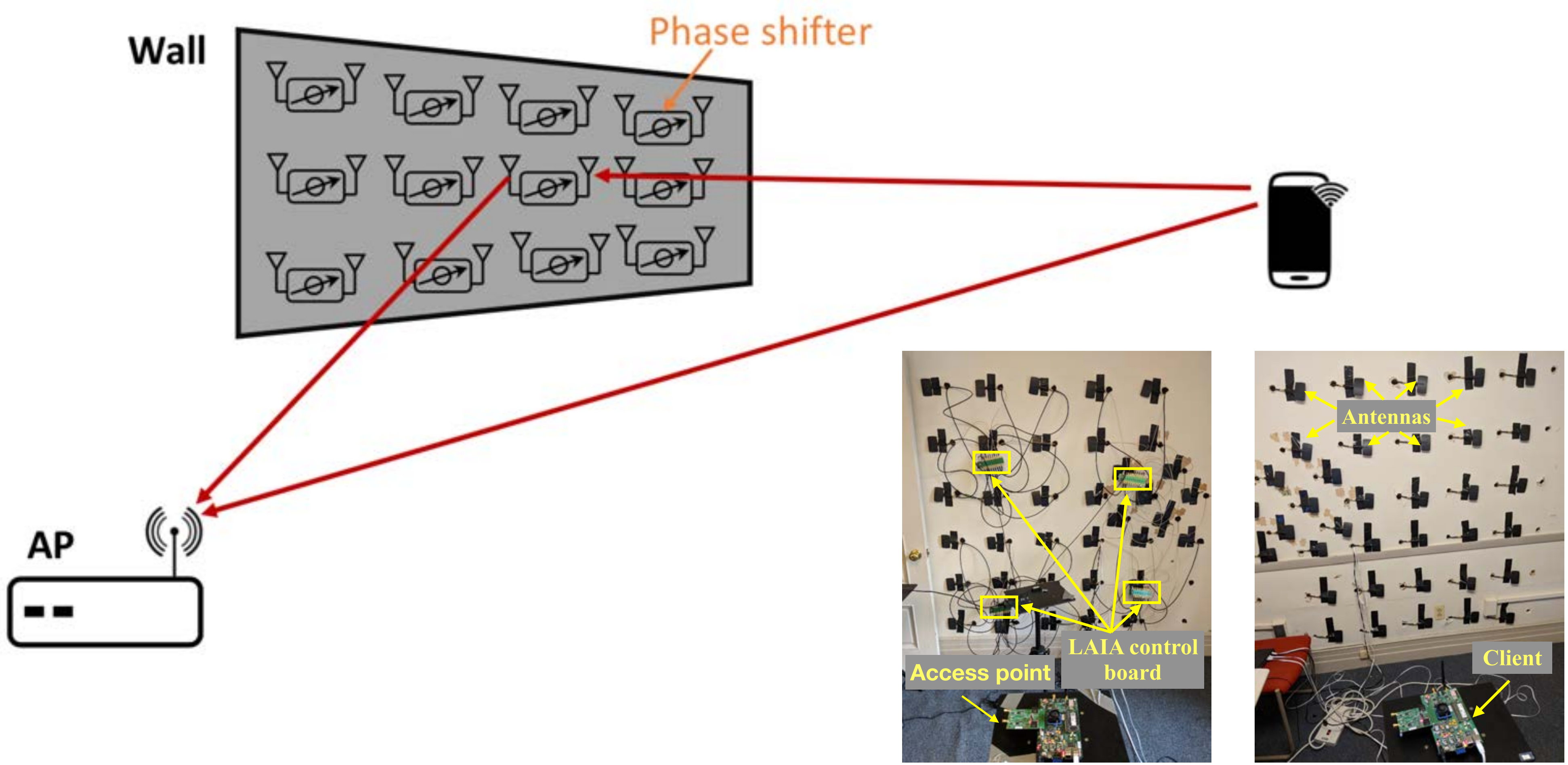
  → Reduce data Rate, more coding

- If Channel is Good

  → Increase data rate, less coding

Today: Wireless Communication Adapt to Channel Conditions

New Approach: Programmable Radio Surfaces Change the wireless channel itself



How to Read a Paper

S. Keshav

Next class meeting: Sprout