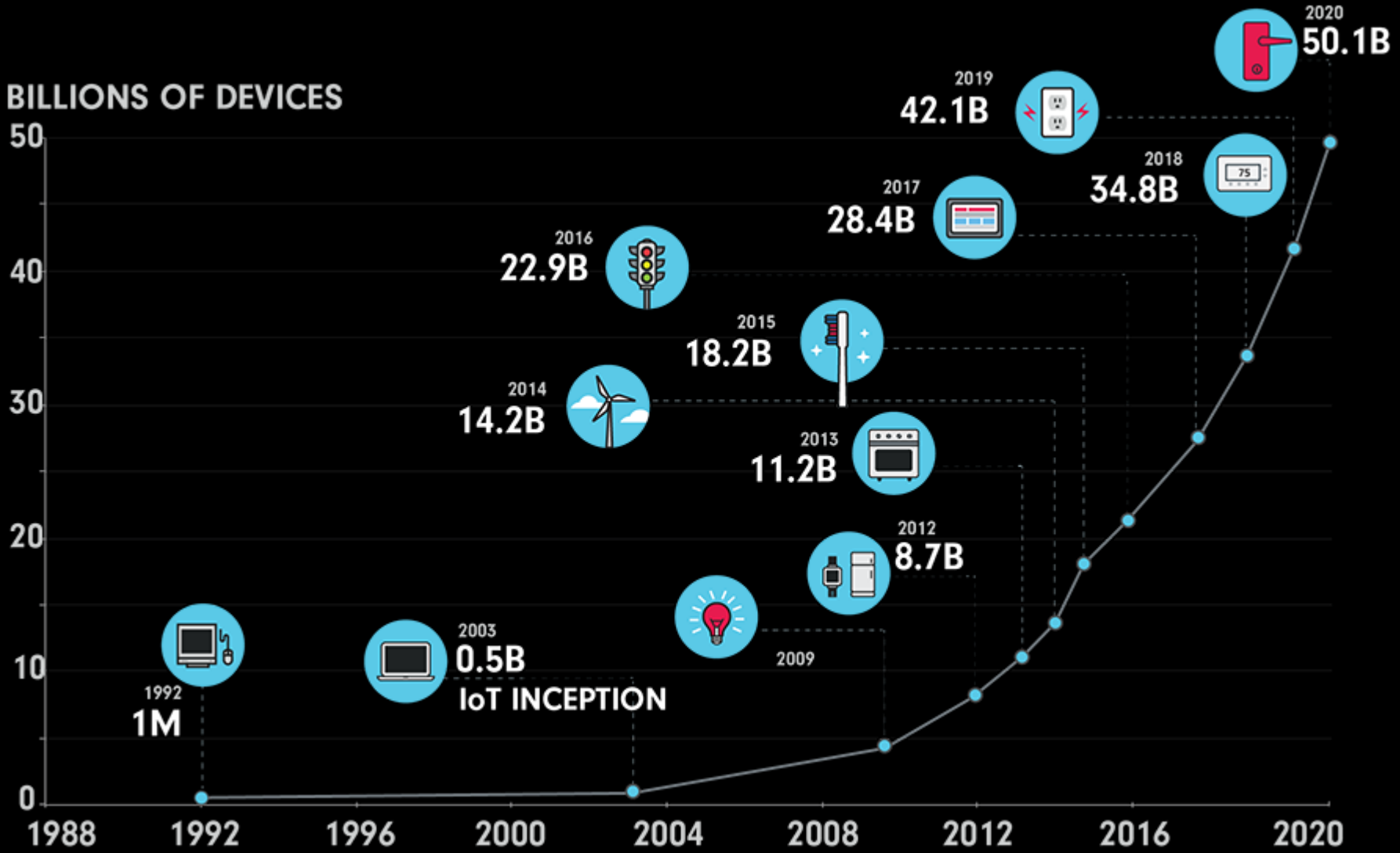# CSE610 Special Topics on Mobile Network & Mobile sensing

Lecture 1: Class Introduction
Yaxiong Xie

Wireless-connected devices are everywhere

Smart home devices

Wireless biomedical devices

Wireless wearable devices

UAVs

Wireless vehicles

Exponentially increasing number of wireless devices

3

Increasing demand for wireless connectivity

Connecting People

2005

2013

Increasing demand for wireless connectivity
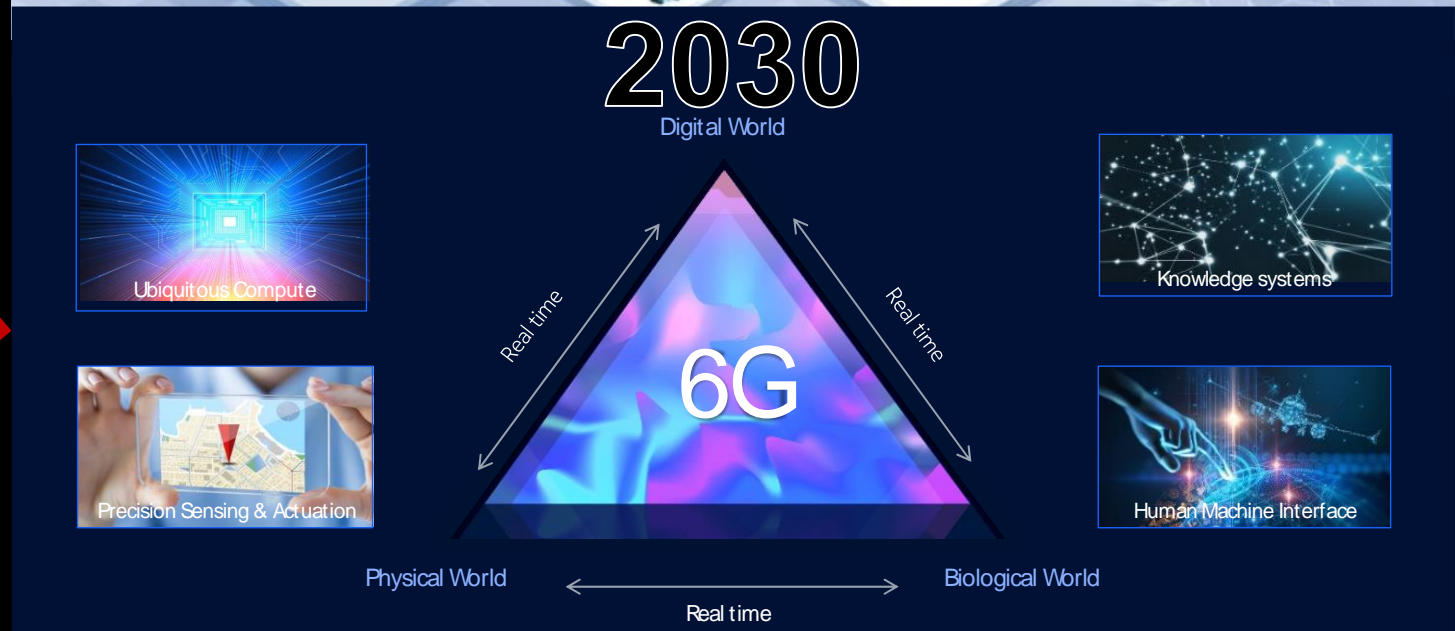
2013

2020

Connecting Everything

Increasing demand for wireless connectivity

2020

2030

Connecting

+

Sensing

Everything

Ubiquitous Compute

Precision Sensing & Actuation

Digital World

Real time

Real time

6G

Real time

Physical World

Biological World

Knowledge systems

Human Machine Interface

6G to unify the experience across physical, digital and biological worlds

NOKIA Bell Labs

CSE 610

Mobile Networks

Mobile Sensing

5G & Next Generation

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

Internet of Things

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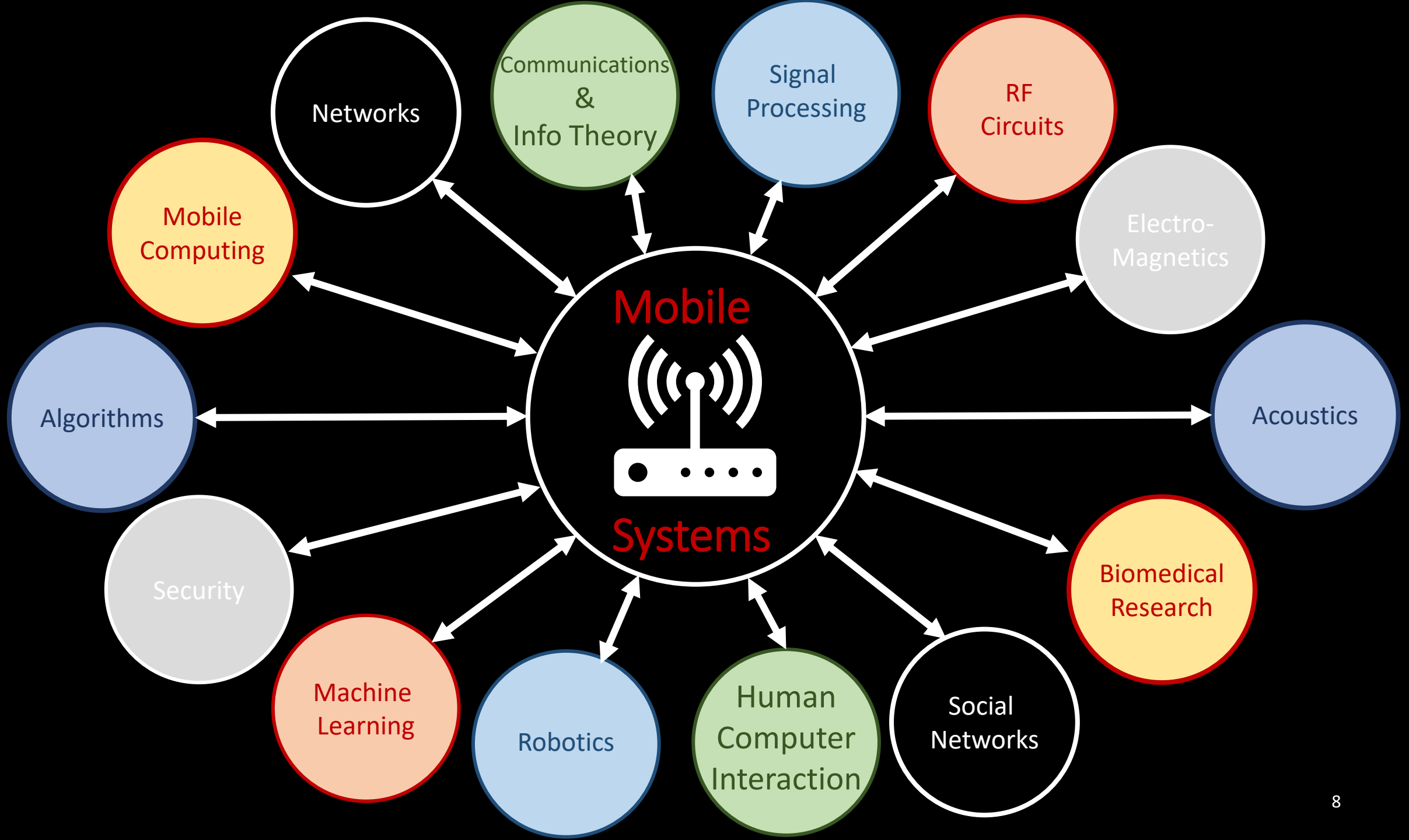- Smart Cities & Homes
- Acoustic IoT
- IoT security

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

Networks

Communications & Info Theory

Signal Processing

RF Circuits

Mobile Computing

Electro-Magnetics

Mobile Systems

Algorithms

Acoustics

Security

Biomedical Research

Machine Learning

Robotics

Human Computer Interaction

Social Networks

Course Information

- **Staff**
  - Instructor: Yaxiong Xie, 321 Davis Hall
  - Office hours: After the class, On demand via email

- **Material**
  - Lecture slides
  - Research papers
  - Slack for discussions

- **Recommended Prerequisites**
  - Any undergraduate networking, wireless, or digital communications class
  - Basic math and signal processing: probability, Fourier, …

Architecture of the course

- **Part 1: Lectures**
  - Introducing the basics of wireless communication, mobile networks, and mobile sensing
  - Mid-term test (won't be hard)

- **Part 2: Guest Lecture**
  - Invite guest lectures to introduce their state-of-the-art work

- **Part 2: Research papers**
  - Read and present research papers
  - Ask three questions before class about each paper
  - Write a summary for each paper

- **Part 3: Course projects (4 weeks)**
  - We will answer your projects related questions in class (check the course schedule)

Grading

- 10% for class participation
  - Your class participation grade will be determined based on attendance and, most importantly, your concrete contributions to the paper discussion

- 20% for the midterm

- 20% for the paper presentation

- 50% for the course project

Course Project

- **Teams:**
  - You should work in a team of 2 or 3, depending on the course enrollment
  - Please start to find your teammates ASAP (you can use Slack to talk to each other)
- **Project ideas:**
  - We strongly encourage you to propose new ideas!
    - We can turn the course projects into research papers if possible
  - We will also provide a list of suggested research topics before the proposal deadline
- **Project proposal**
  - Submit a proposal via Slack and we will get back to you with suggestions
  - More information can be found from the course website
- **Project presentation**
- **Project report**
  - State the contribution of each team member in the report

Paper Reading and Presentation

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

- **Preparing for class**
  - Please prepare **TWO** questions for each paper and post them on Slack

- 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

- Each student is required to write a short summary of the paper we discussed

Paper Reading and Presentation

Tasks for the presenters:

- **Task-1**: preparing the slides

- **Task-2**: presenting the paper and answering the questions raised by the audience
  - Audience are welcome to interrupt the presenter and raise the questions
  - Please try to ask the questions you raised on perusall during the presentation so that we could skip them later

- **Task-3**: going through the comments/questions and organize the discussion

Preparing the slides for a system paper

- Introduction and motivation
  - What's the problem the paper solves?
  - Why this problem is important?
  - What's the state-of-the-art?

- Design
  - How does the author solve the problem?

- Evaluation
  - What's the performance of the new system?

Introduction of the course content

Mobile networks
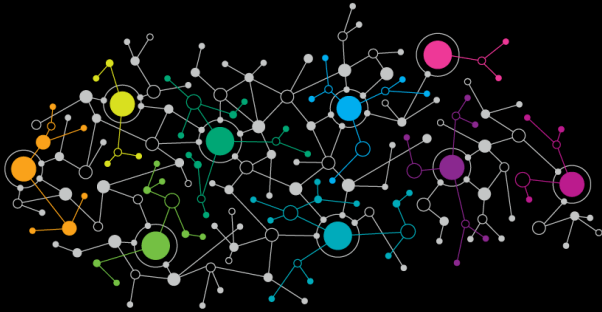
Mobile sensing
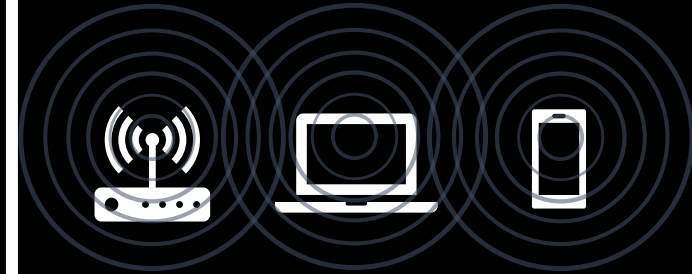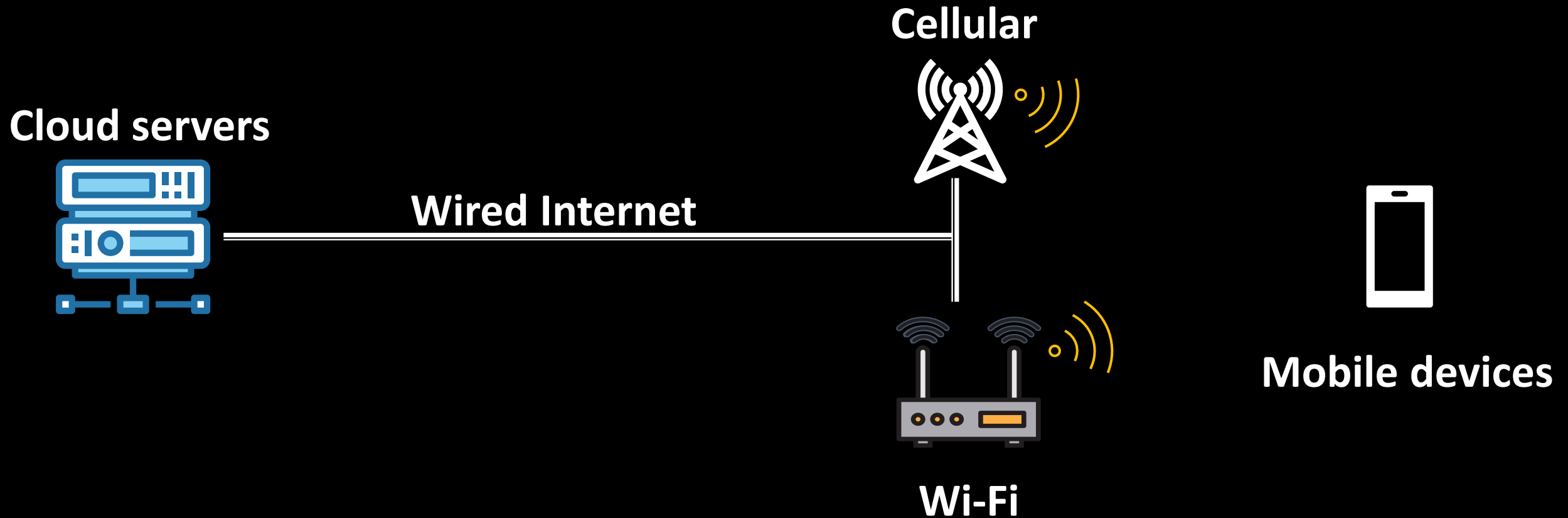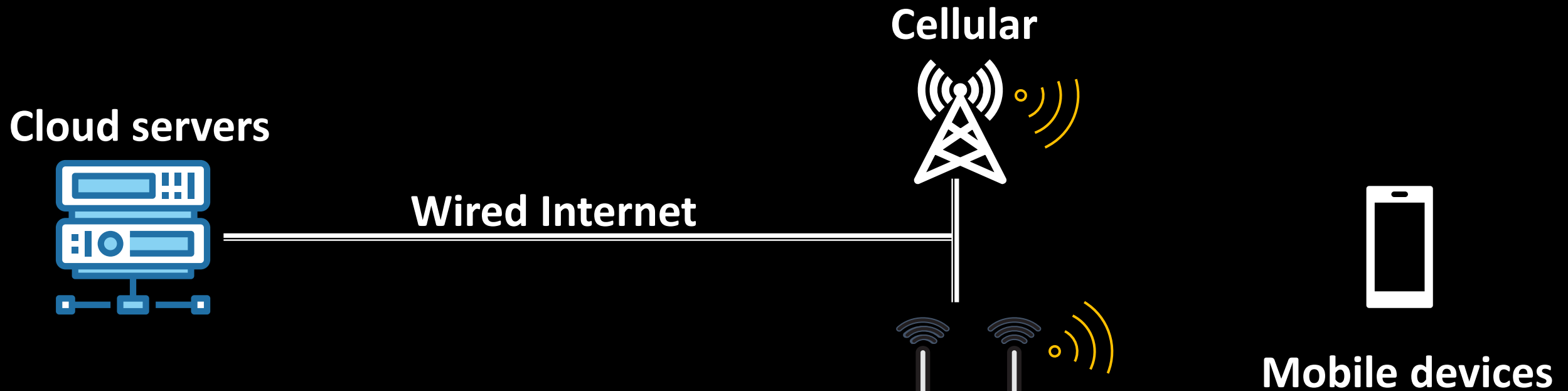
Introduction to the mobile networks

Mobile networks

Mobile networks: typical scenarios

Cellular

Cloud servers

Wired Internet

Wi-Fi

Mobile devices

Mobile networks: typical scenarios

Cellular

Cloud servers

Wired Internet
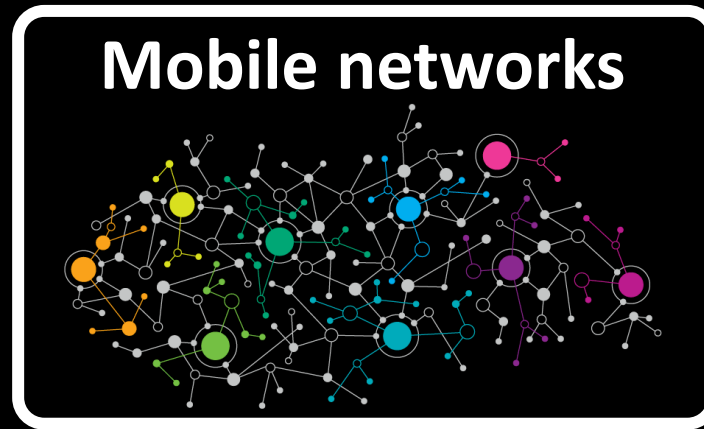
Mobile devices

Mobile network is built on top of wireless networks!

How do wireless and wired networks differ?

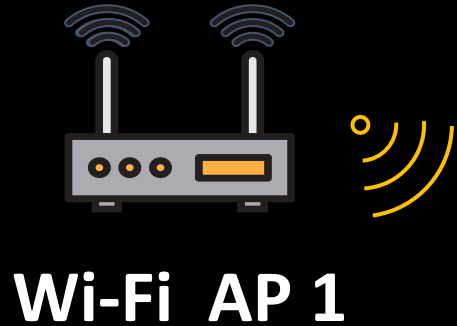- Wireless is a shared medium
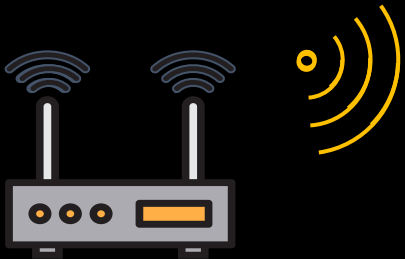
Wi-Fi

Mobile devices 1

Mobile devices 2

How do wireless and wired networks differ?

- Wireless is a shared medium
  - Interference between users using the same technology
  - Point-to-point abstraction is a wrong abstraction
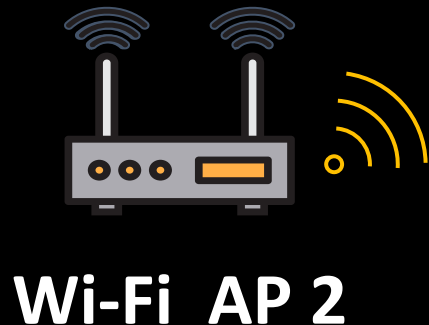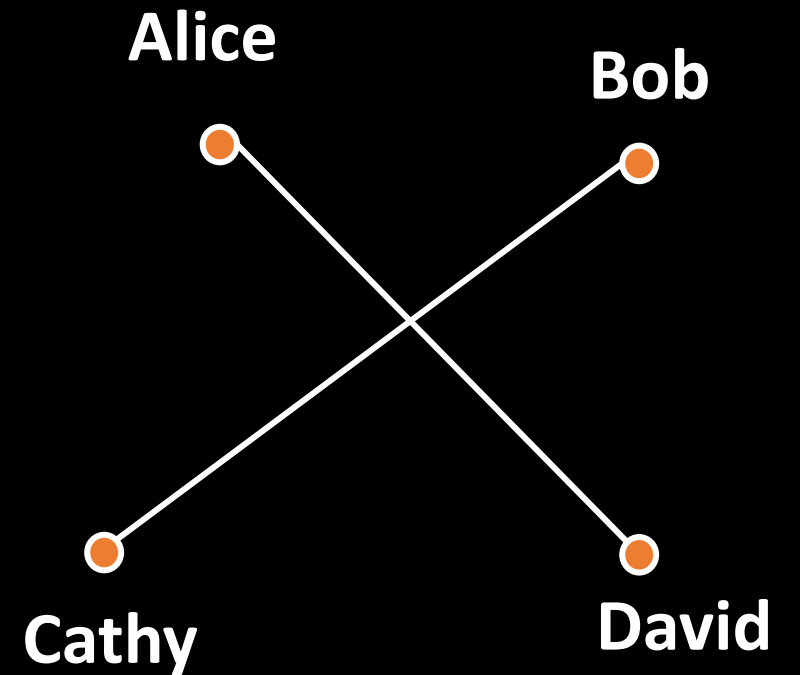
Wi-Fi AP 1

Mobile devices 2

Mobile devices 1

Wi-Fi AP 2

Alice

Bob

Cathy

David

How do wireless and wired networks differ?

- Wireless is a shared medium
- Wireless is a less reliable

  - Noise is naturally present in the system from many source
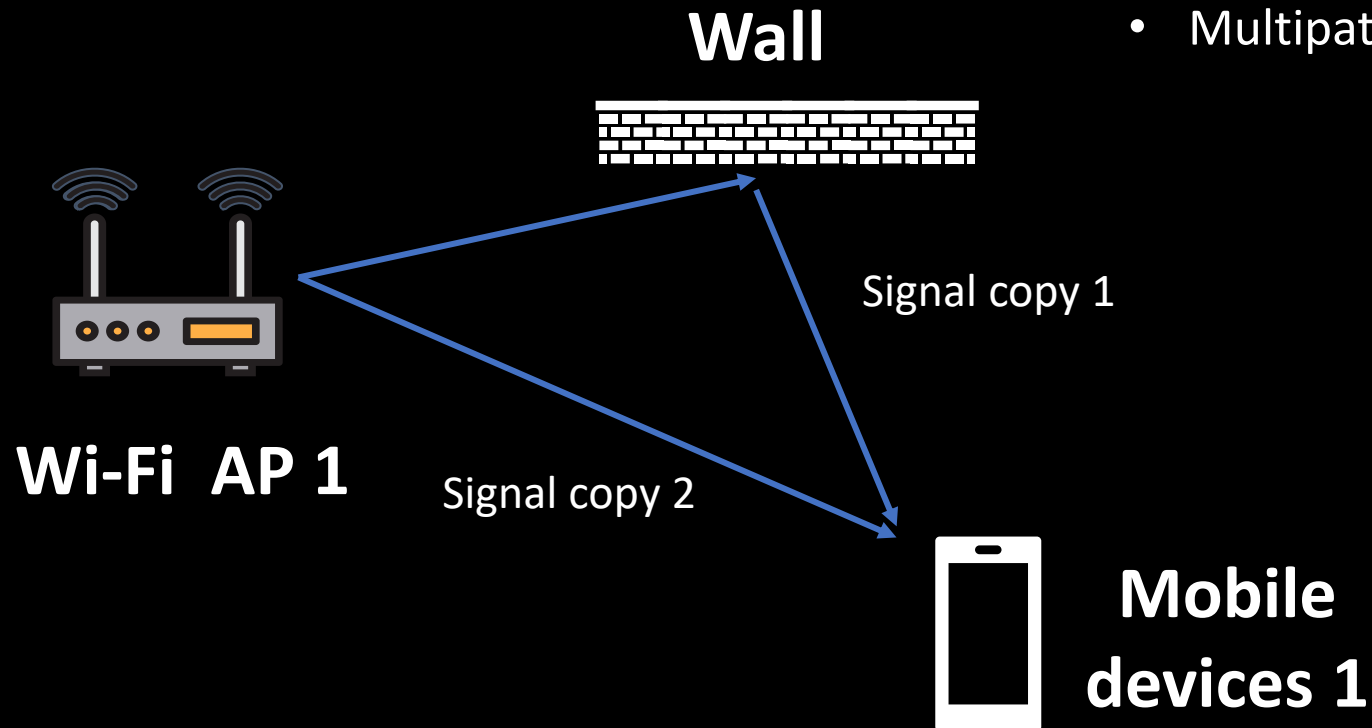 - Wireless signal attenuates during the propagation

30dBm
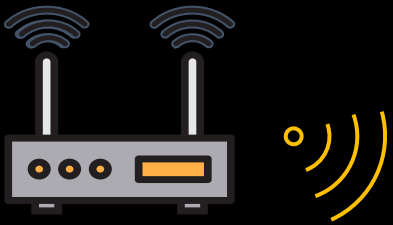
Wi-Fi AP 1

10dBm

Mobile devices 1

How do wireless and wired networks differ?

- Wireless is a shared medium
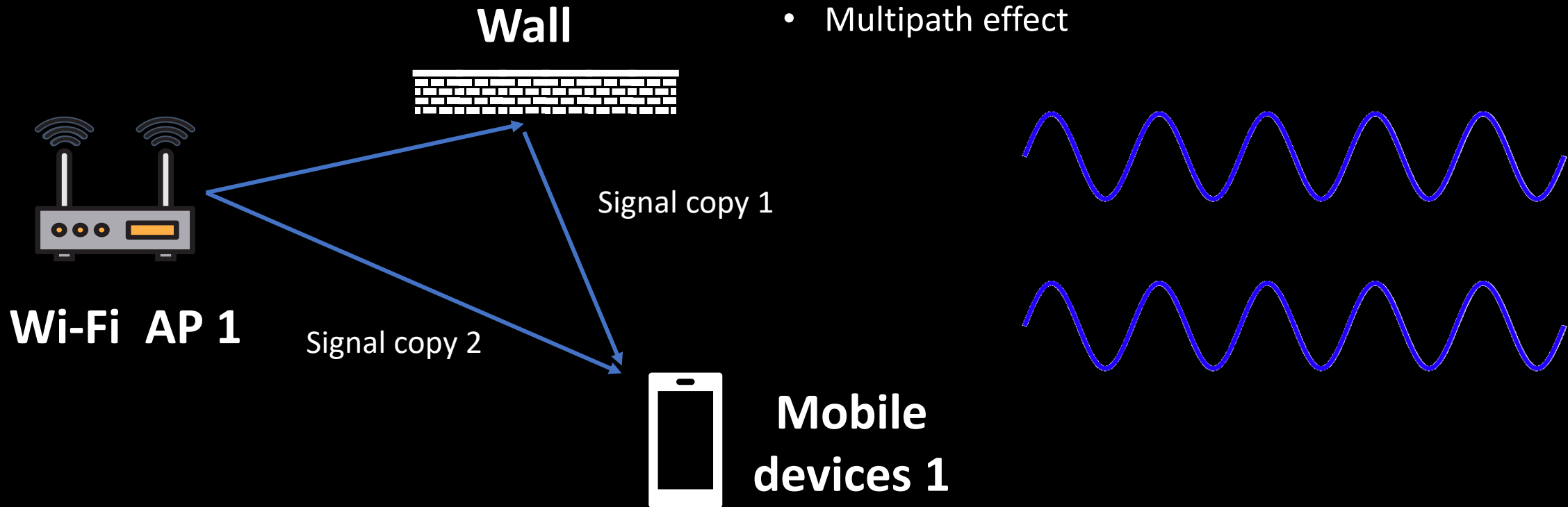- Wireless is a less reliable
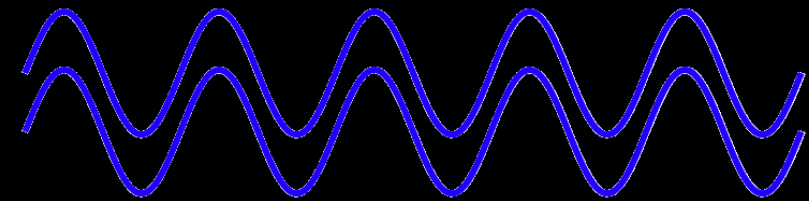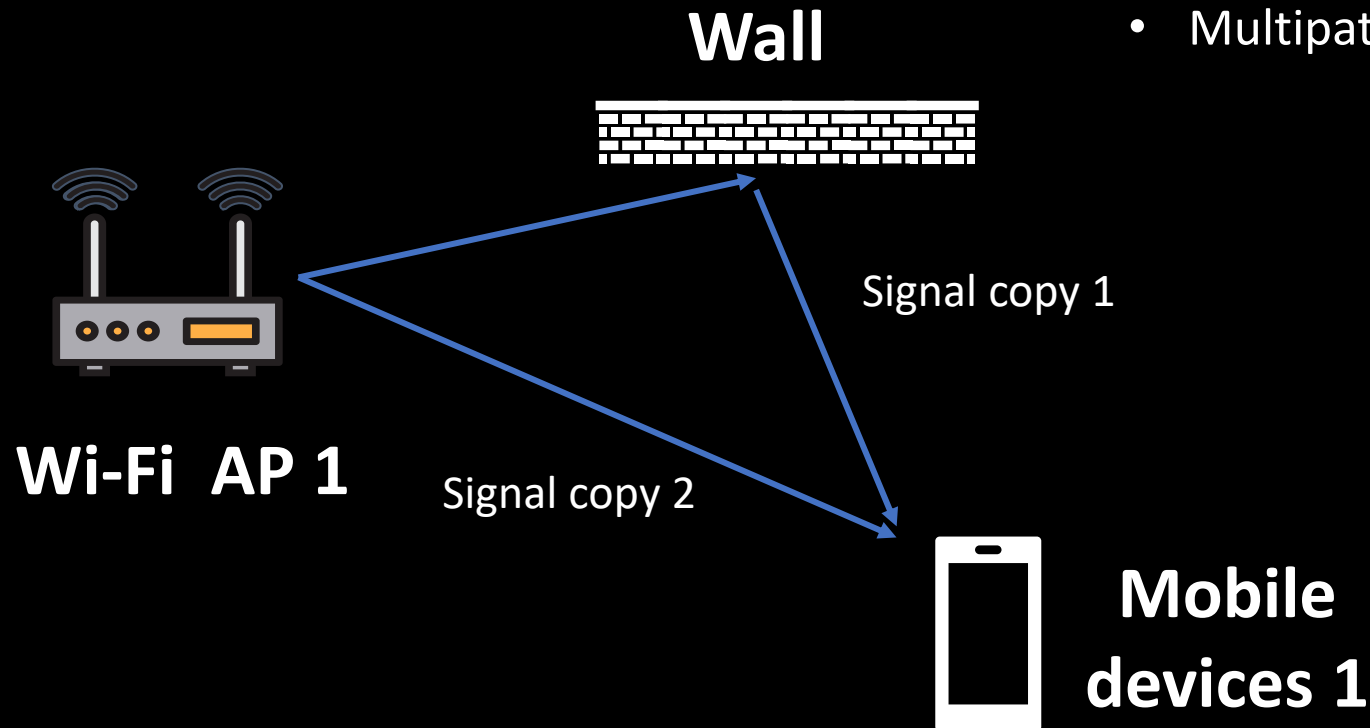
- Noise is naturally present in the system from many source
- Wireless signal attenuates during the propagation
- Multipath effect

Wall

Signal copy 1

Wi-Fi AP 1

Signal copy 2

Mobile devices 1

How do wireless and wired networks differ?

- Wireless is a shared medium
- Wireless is a less reliable

- Noise is naturally present in the system from many source
- Wireless signal attenuates during the propagation
- Multipath effect

Wall

Signal copy 1

Wi-Fi AP 1

Signal copy 2

Mobile devices 1

How do wireless and wired networks differ?

- Wireless is a shared medium
- Wireless is a less reliable

- Noise is naturally present in the system from many source
- Wireless signal attenuates during the propagation
- Multipath effect

Wall

Signal copy 1
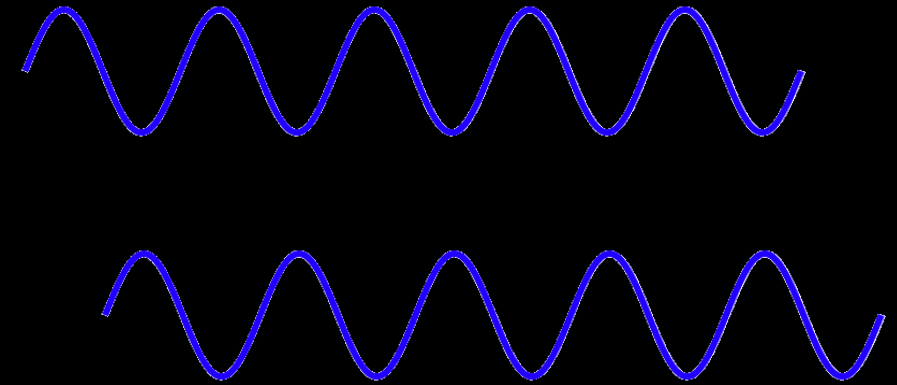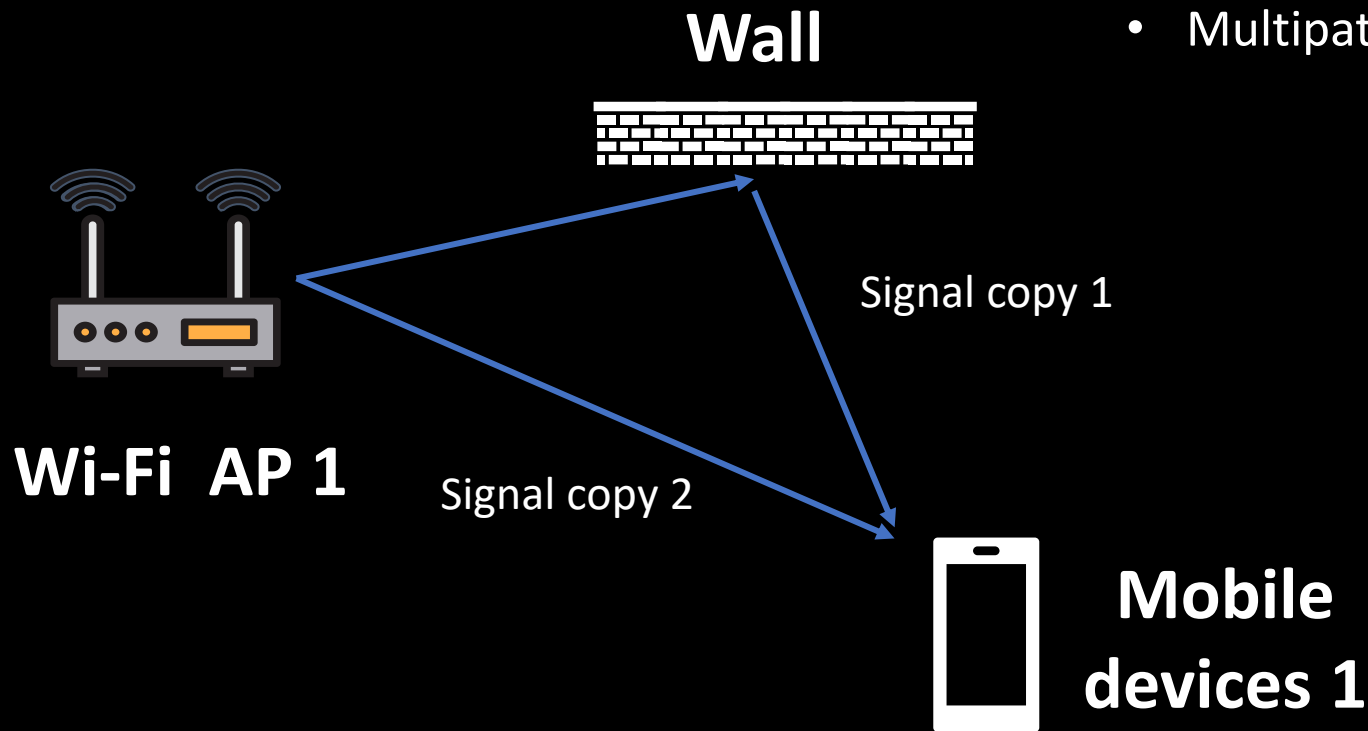
Wi-Fi AP 1

Signal copy 2

Mobile devices 1

Constructively
Signal strength is maximized!

How do wireless and wired networks differ?

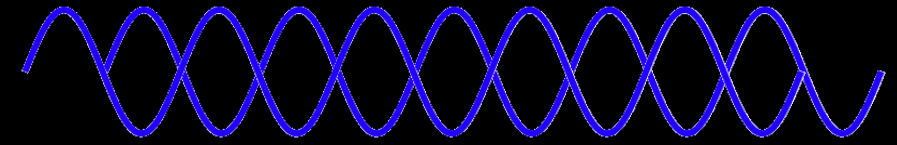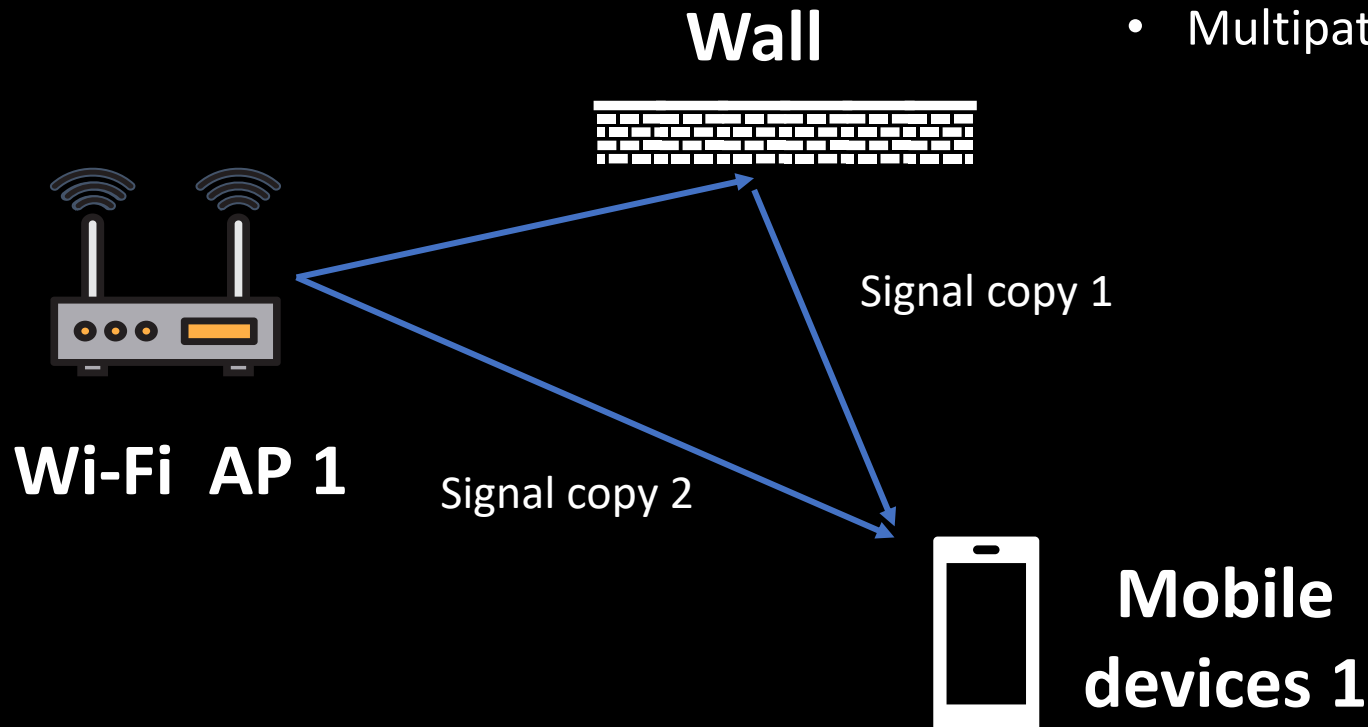- Wireless is a shared medium
- Wireless is a less reliable
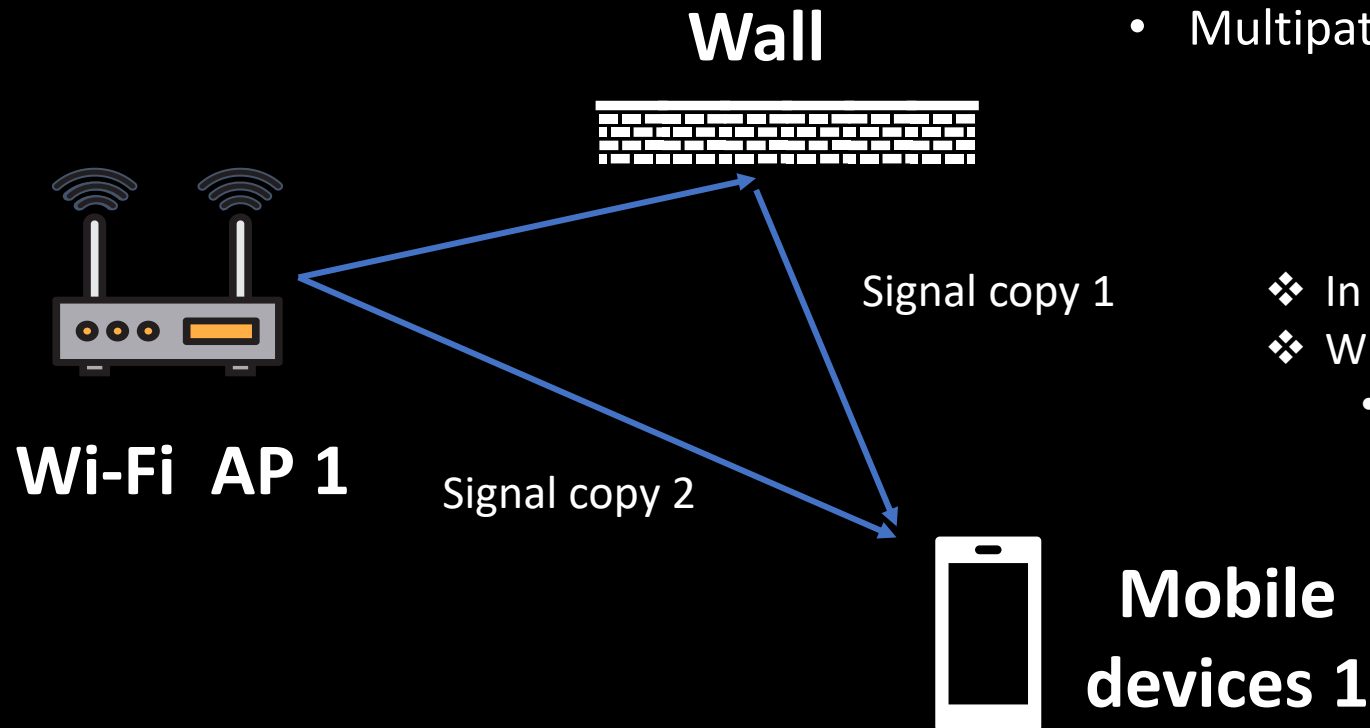
- Noise is naturally present in the system from many source
- Wireless signal attenuates during the propagation
- Multipath effect

Wall

Signal copy 1

Wi-Fi AP 1

Signal copy 2

Mobile devices 1

How do wireless and wired networks differ?

- Wireless is a shared medium
- Wireless is a less reliable

- Noise is naturally present in the system from many source
- Wireless signal attenuates during the propagation
- Multipath effect

Wall

Signal copy 1

Wi-Fi AP 1

Signal copy 2

Mobile devices 1

De-constructively
Signal strength is minimized!

How do wireless and wired networks differ?

- Wireless is a shared medium
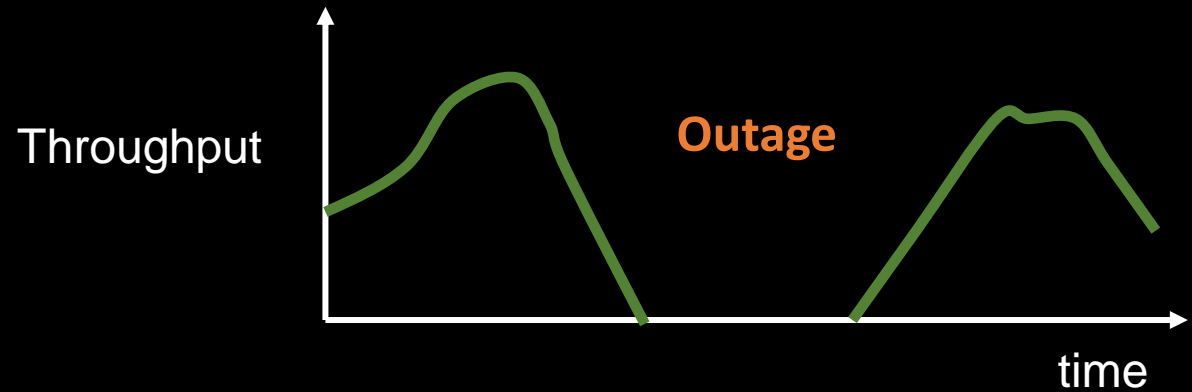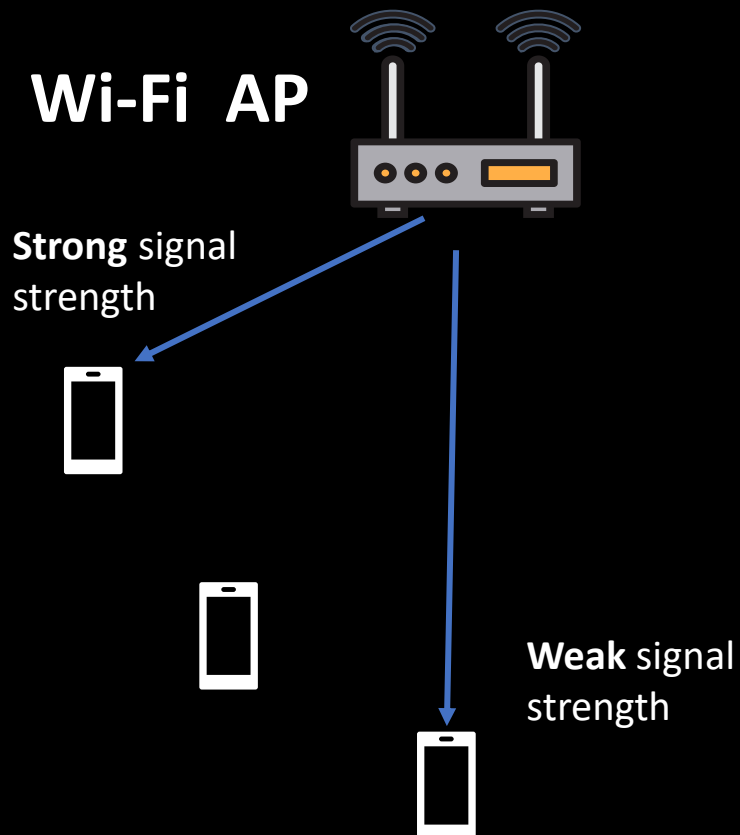- Wireless is a less reliable

- Noise is naturally present in the system from many source
- Wireless signal attenuates during the propagation
- Multipath effect

Wall

Signal copy 1

Wi-Fi AP 1

Signal copy 2

Mobile devices 1

- ❖ 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!

How do wireless and wired networks differ?

- Wireless is a shared medium
- Wireless is a less reliable
- Mobility

Wi-Fi AP

Strong signal strength

Weak signal strength

- Channel quality depends on distance, other factors
- Affects the throughput the mobile device can achieve
- Worst case: Outage, periods with no connectivity

Throughput

Outage

time

How do wireless and wired networks differ?

- Wireless is a shared medium
- Wireless is a less reliable
- Mobility

Wi-Fi AP

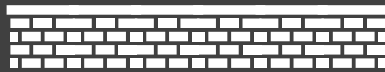- Not only the mobility of the transmitter and receiver matters!

Throughput

time
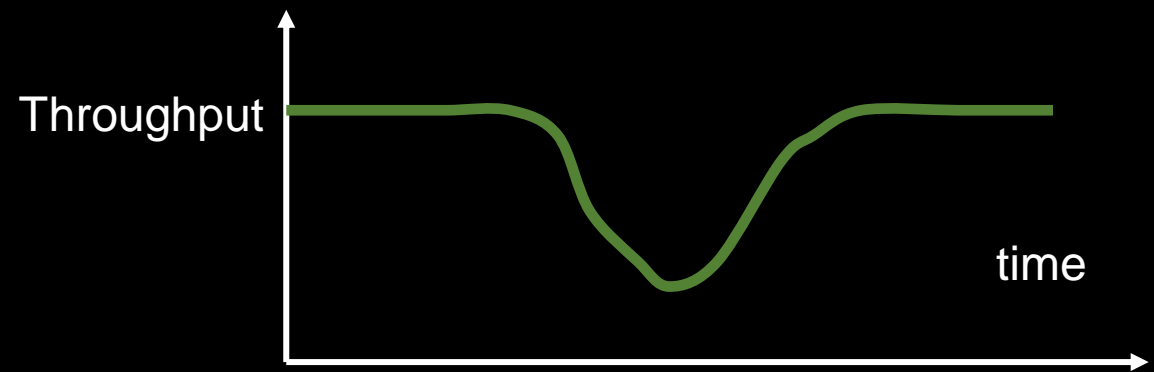
Wireless channel

Transmitter

Wireless Channel

Receiver

Wall

Multipath 2

Multipath 1

Wi-Fi AP 1

Mobile devices 1

Wireless channel changes the received signal!

Wireless channel estimation

Transmitted signal

Channel estimation describes how the transmitted signal becomes the received signal

Reconstruct the transmitted signal by reverse the channel

Wi-Fi AP 1

Received signal copy 1

Received signal copy 2

Mobile devices 1

Received signal copy 3

Wireless channel estimation

Transmitted signal

Channel estimation describes how the transmitted signal becomes the received signal

Reconstruct the transmitted signal by reverse the channel

Wi-Fi AP 1

Mobile devices 1

- How to convey information using wireless signal?
- How to guarantee reliably recovering of the information if the wireless channel cannot be fully reversed?

Mobile networks: typical scenarios
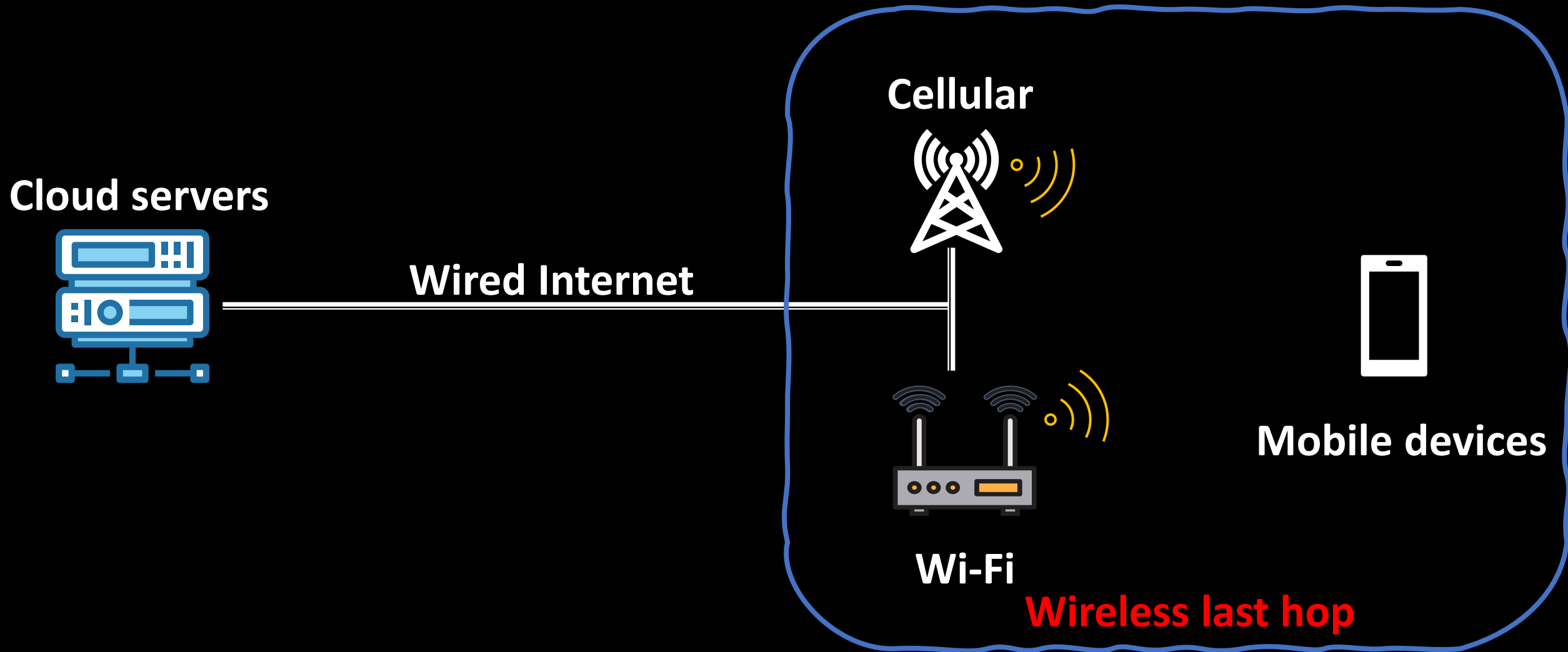
Cloud servers

Wired Internet

Cellular

Wi-Fi

Mobile devices

Wireless last hop

A wireless connection consists a wired Internet hop and a wireless last hop

Cloud servers

Wi-Fi AP / Base station

Wired Internet

A wireless connection consists a wired Internet hop and a wireless last hop

Cloud servers

Wi-Fi AP / Base station

Wired Internet

Gbps

Wireless last hop

Mbps

IoT devices

Capacity of wireless hop determines the upper bound of achievable throughput
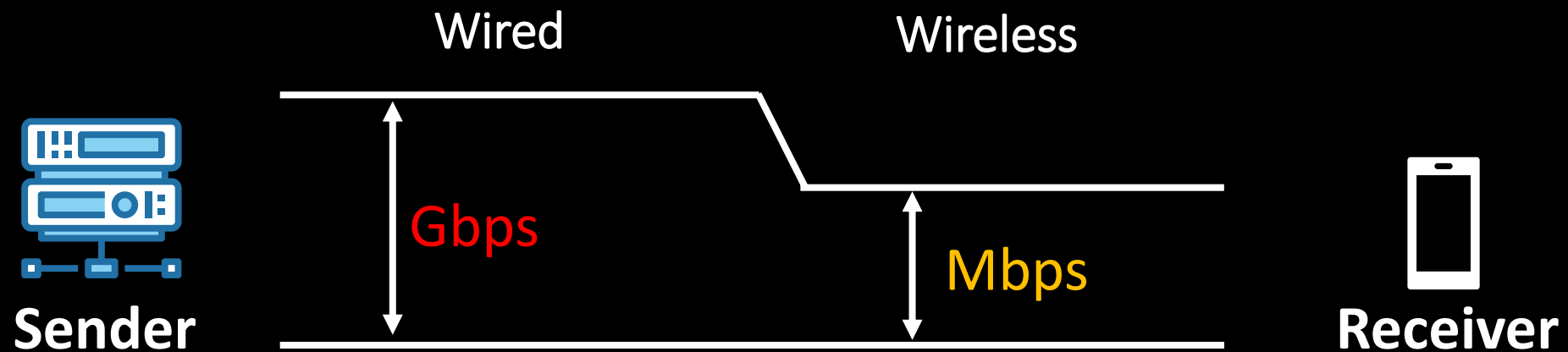
Wired

Wireless

Gbps

Mbps

Sender

Receiver

Capacity of wireless hop determines the upper bound of achievable throughput

Wired

Wireless

1 Gbps

100 Mbps

Sender

Receiver
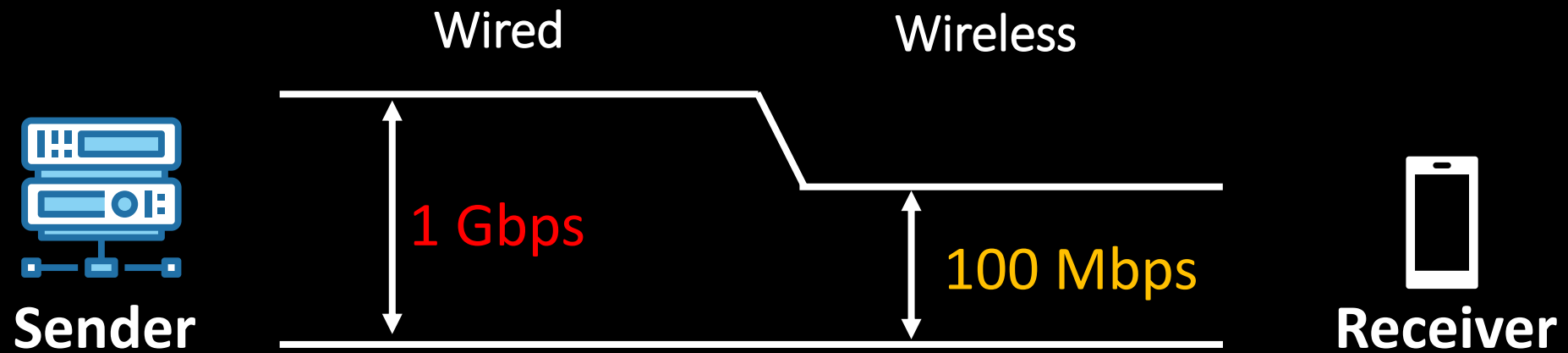
Capacity of wireless link varies!

Capacity of wireless link varies!

Wired   Wireless

Gbps   Mbps

Sender   Receiver

Capacity varies!

Wired   Wireless

Gbps   Mbps

Sender   **Receiver**

Base station

Competition between users

❖ **Wireless medium is shared across users!**
❖ **The total bandwidth is limited**
❖ **More bandwidth for one device -> less allocated bandwidth for other devices**

Mobile user 1   *Mobile user 2*

Capacity of wireless link varies!

Sender — Wired (Gbps) — Wireless (Mbps) — Receiver

Capacity varies!

Sender — Wired (Gbps) — Wireless (Mbps) — Receiver

Base station

Competition between users

Mobile user 1   *Mobile user 2*

Base station

User mobility

41

Capacity of wireless hop determines the upper bound of achievable throughput

Wired

Wireless

Gbps

Mbps

Sender

Receiver

How fast the sender should send the data?

Real-time communication applications like Zoom

Low resolution -> Smaller data size

High resolution -> Larger data size

Video encoder

Endpoint 1

Real-time communication applications like Zoom

Channel capacity

Endpoint 1

Video encoder

Video Decoder

Video Decoder

Video encoder

Endpoint 2
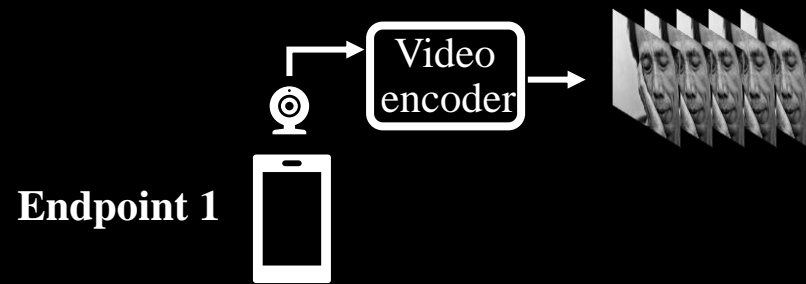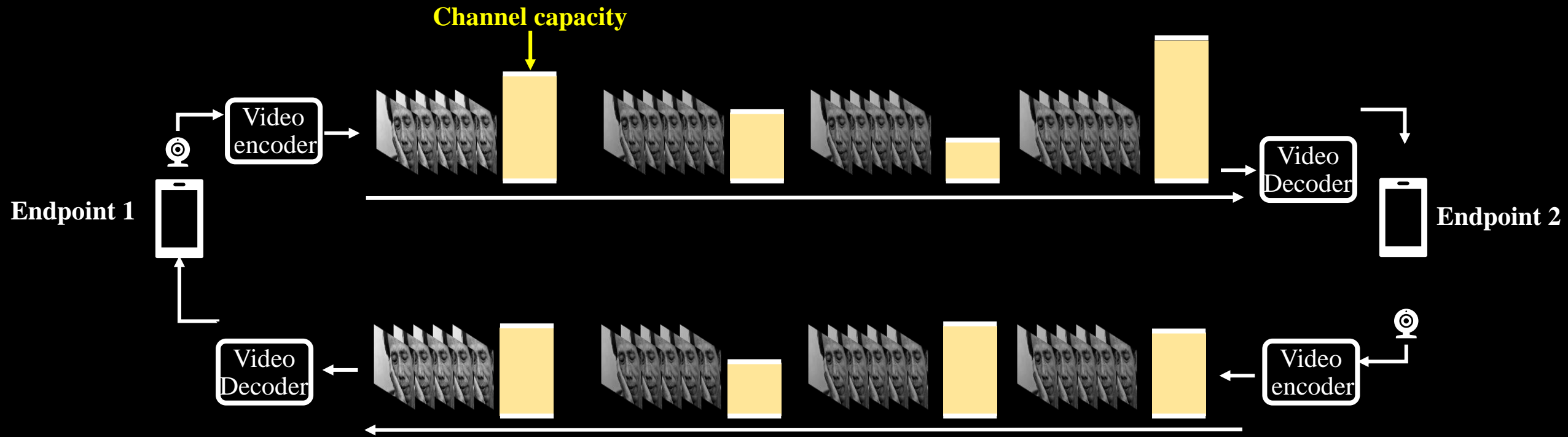
More than Wi-Fi and cellular: satellite
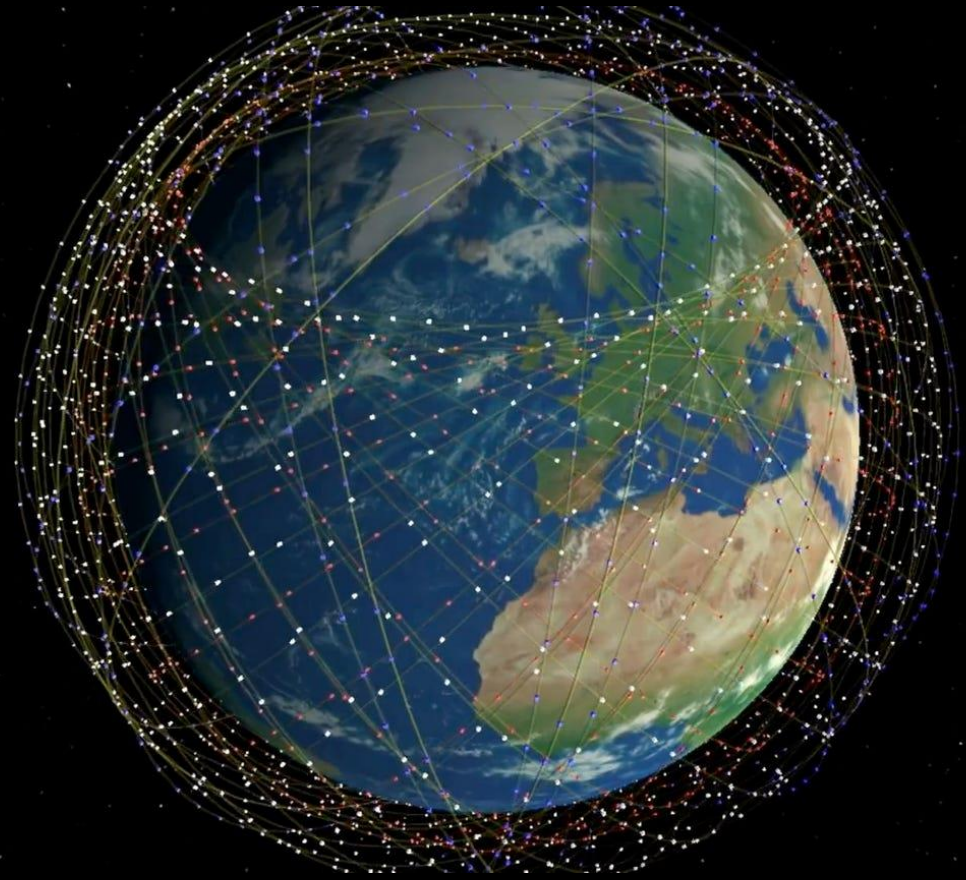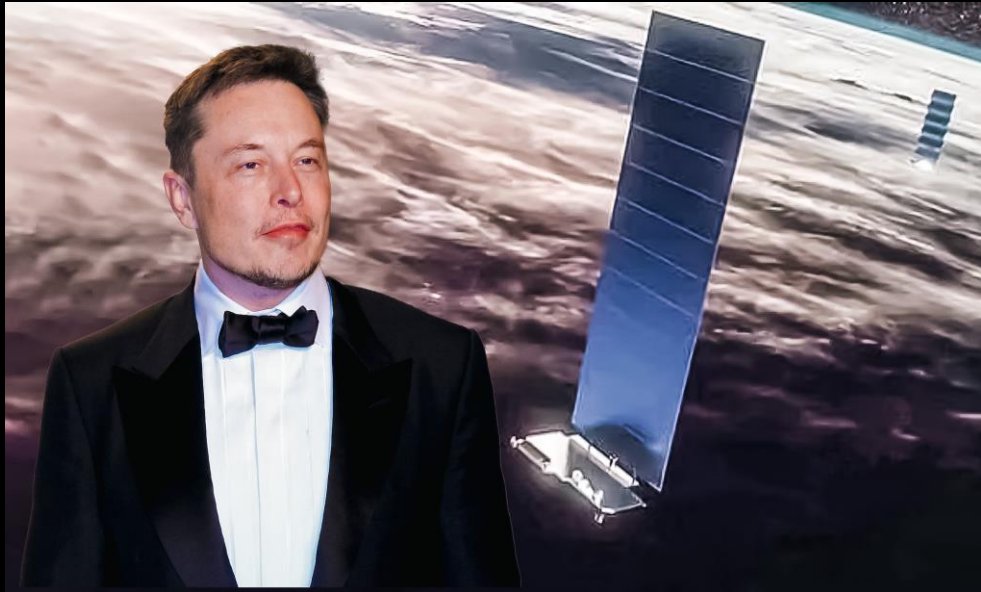
More than Wi-Fi and cellular: mm-wave

More than Wi-Fi and cellular: mm-wave

Huge bandwidth available at millimeter wave frequencies
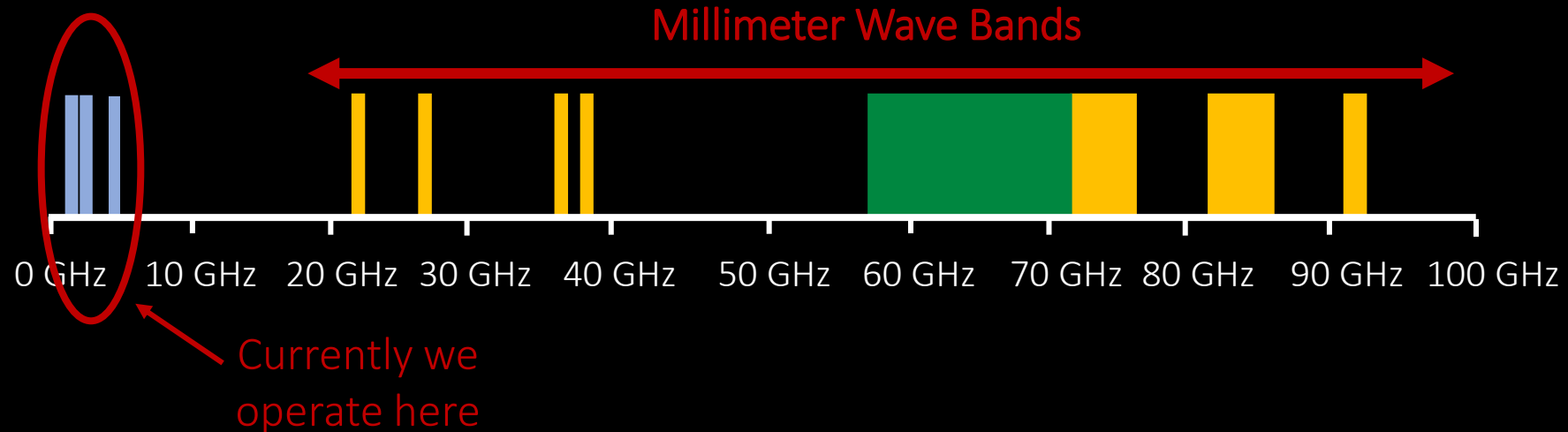
Millimeter Wave can support data rates of multi-Gbps

Millimeter Waves Suffer from Attenuation

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

Nokia & National Instruments	UCSD	UCSD	Bell Labs	Anokiwave	IBM	Fujitsu
	256 elements	64 elements	384 elements	256 elements	64 elements	64 elements
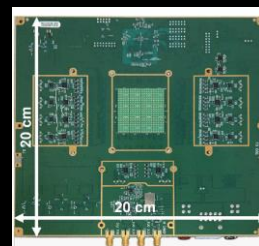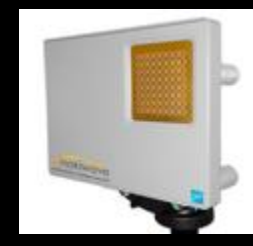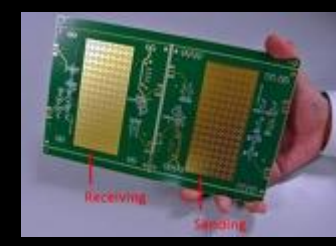
Small Wavelength enables thousands of antennas to be packed into small space → Extremely narrow beams

Today's Networks : Broadcast
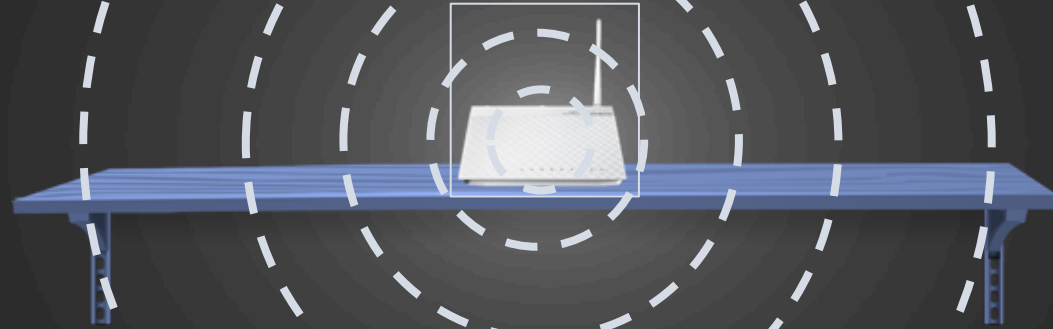
mmWave changes how wireless systems operate

mmWave changes how wireless systems operate

mmWave changes how wireless systems operate

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

Suffers in case of:
- Mobility
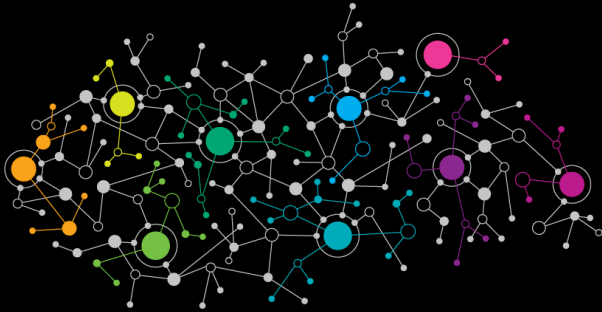- Blockage

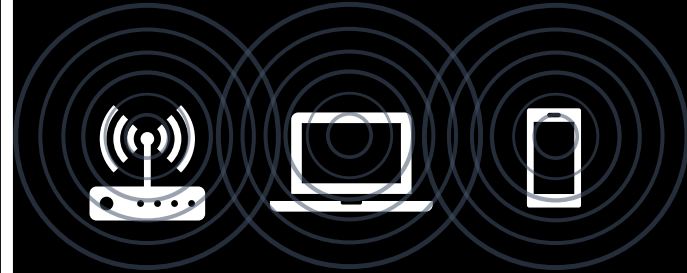# More than Wi-Fi and cellular: VLC
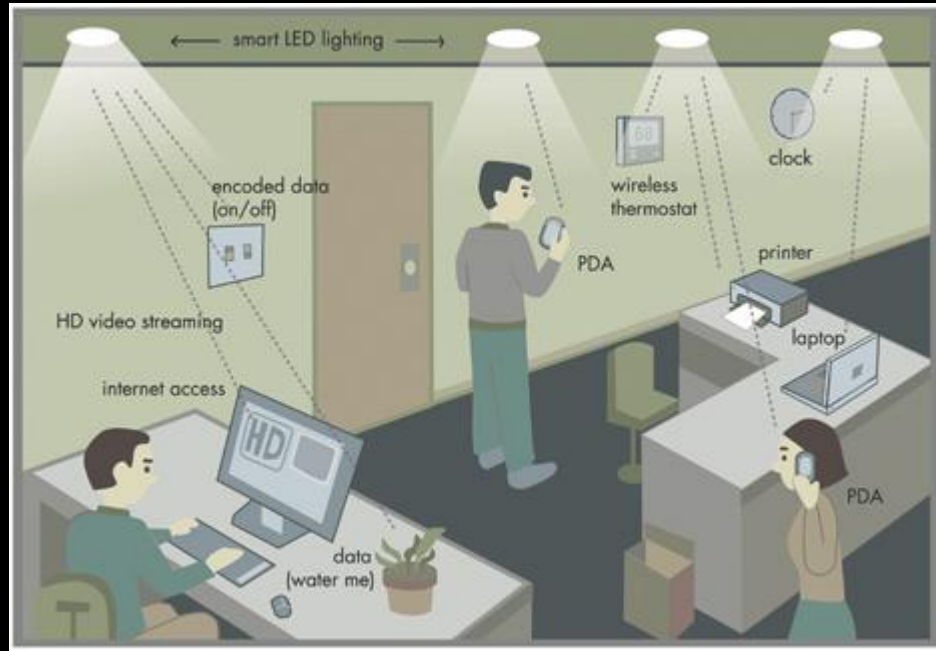
Visible light communication

The speed can be extremely fast
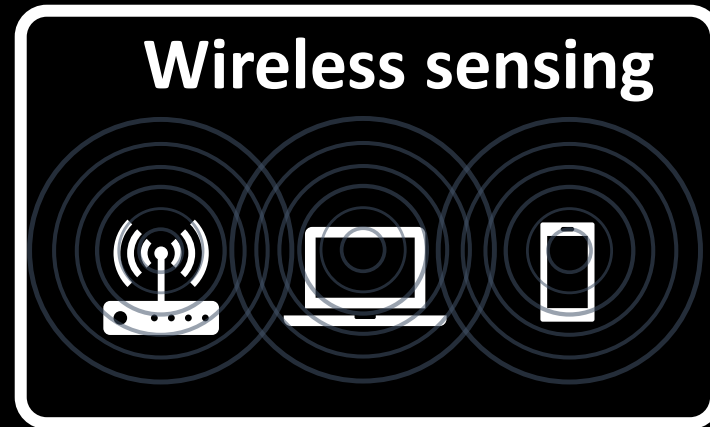**It preserves user privacy**

Introduction to the wireless networks
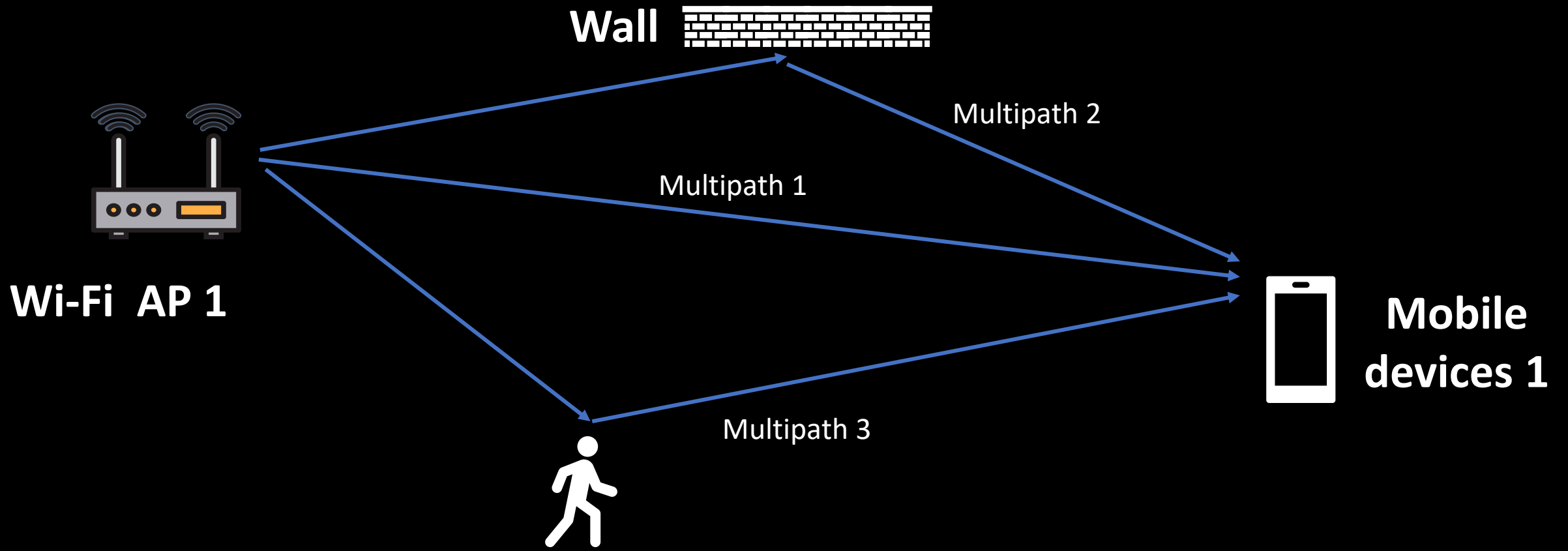
Mobile networks

Mobile sensing
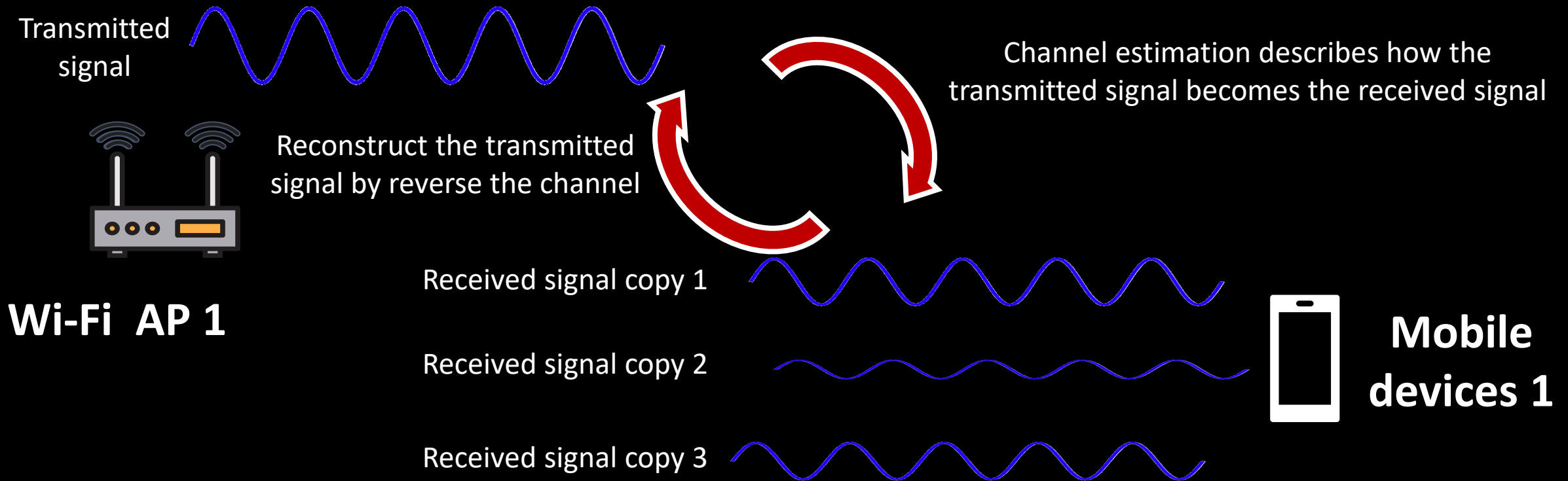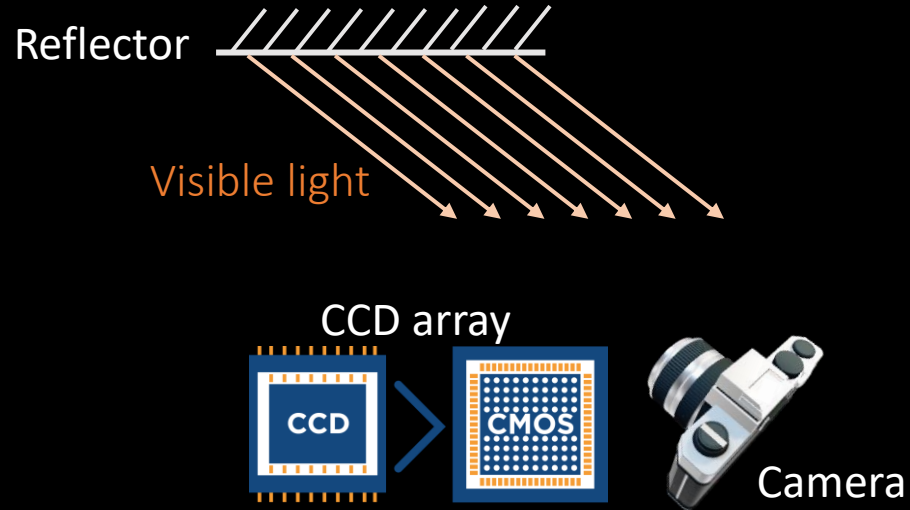
Introduction to the wireless networks

Wireless sensing

Wireless channel

Wall

Multipath 2

Multipath 1

Wi-Fi AP 1

Mobile devices 1

Multipath 3

Wireless channel estimation

Transmitted signal

Channel estimation describes how the transmitted signal becomes the received signal

Reconstruct the transmitted signal by reverse the channel

Wi-Fi AP 1

Received signal copy 1

Received signal copy 2

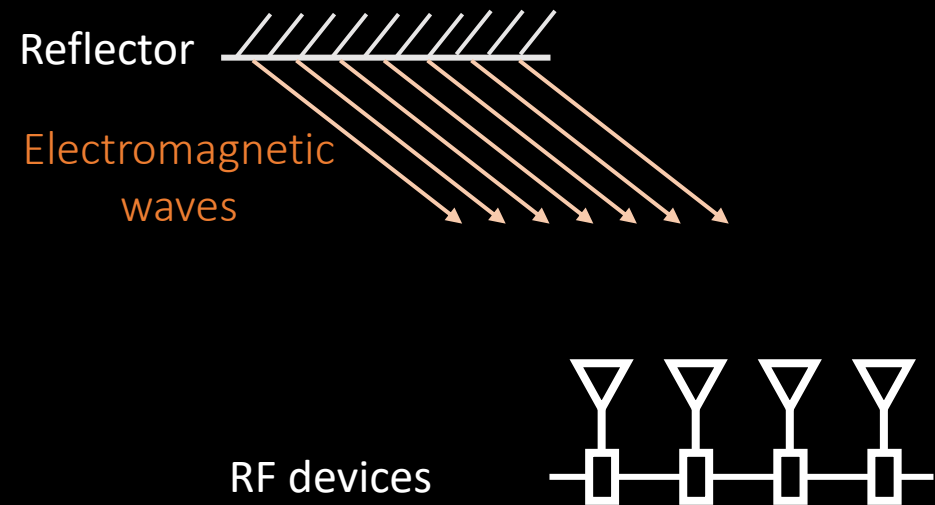Received signal copy 3

Mobile devices 1

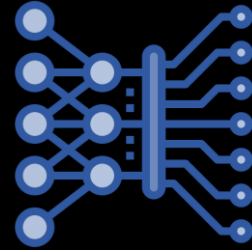# Analogy: Wireless sensing VS. Computer vision
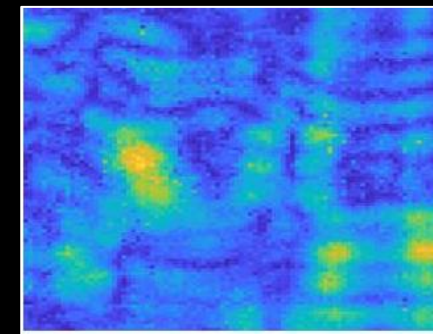
Images

Channel state information (CSI)
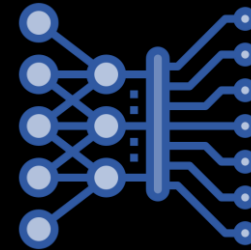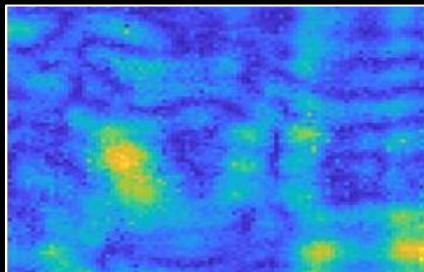
Analogy: Wireless sensing VS. Computer vision

Images

Deep Neural Network

Human skeleton

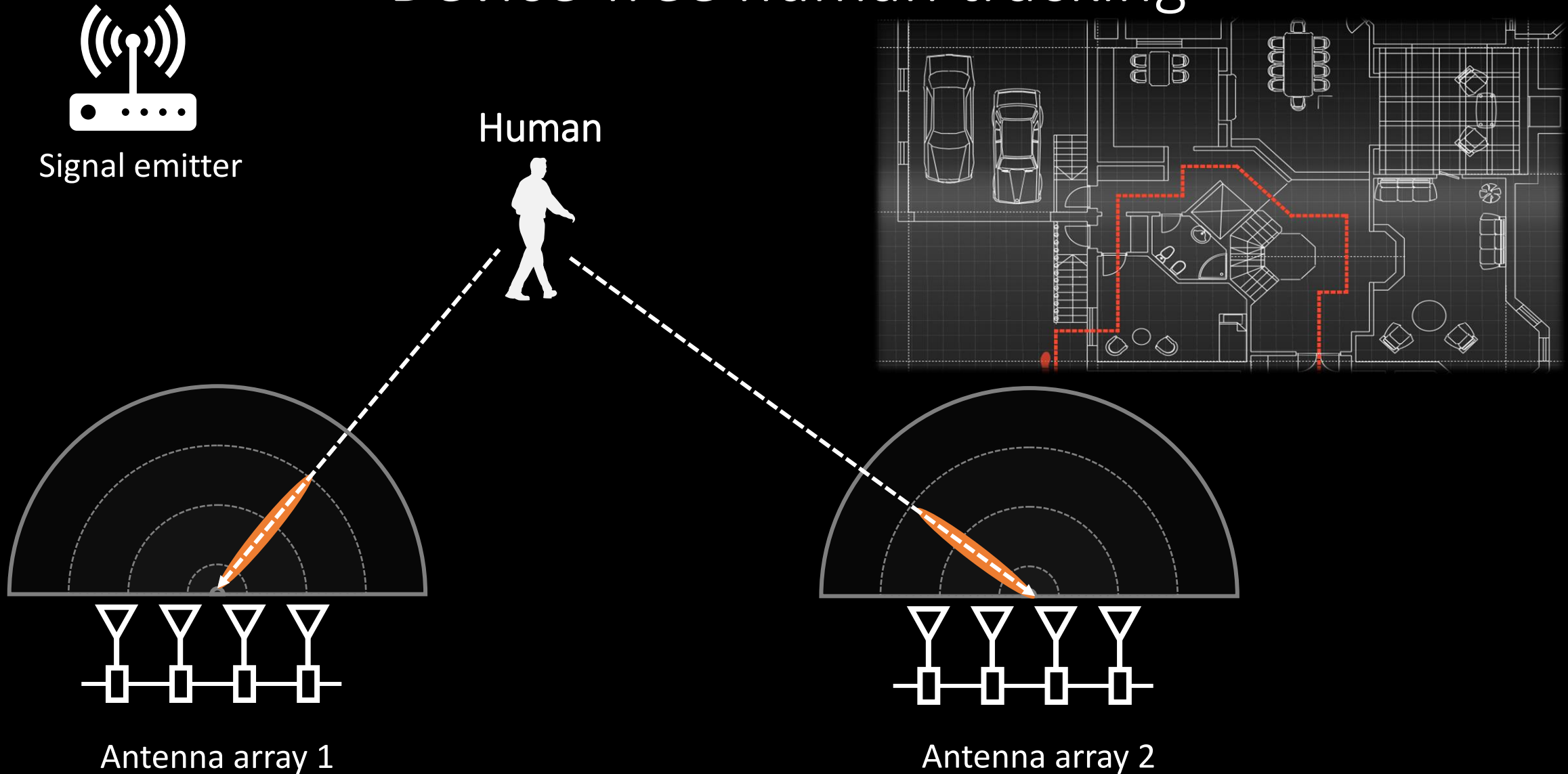**DSP** Digital Signal Processing **+**

What's the potential application?

Jiang, W., Xue, H., Miao, C., Wang, S., Lin, S., Tian, C., ... & Su, L. Towards 3D human pose construction using wifi. MobiCom 2020

Indoor localization

Mobile device

Antenna array 1

Antenna array 2
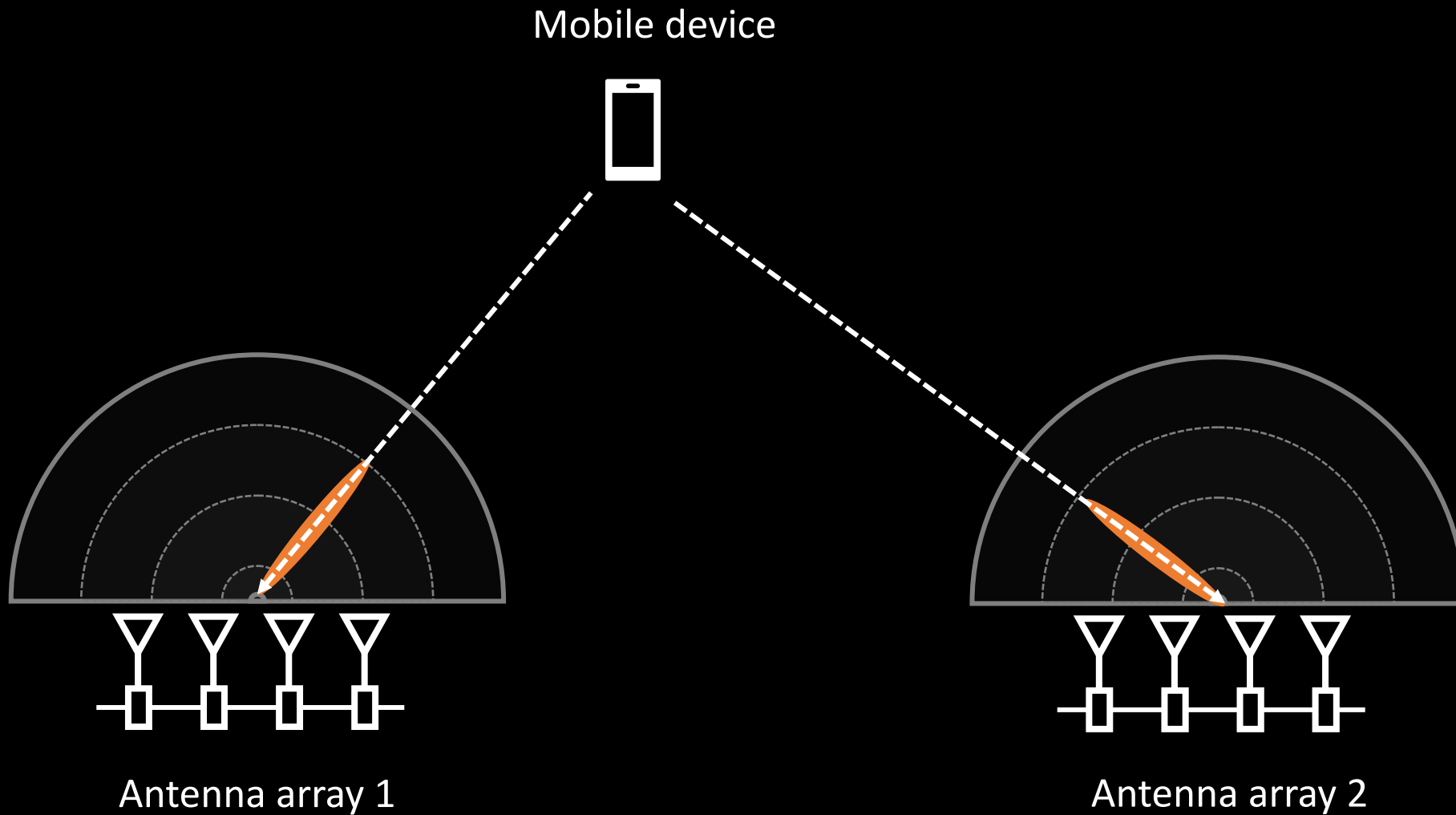
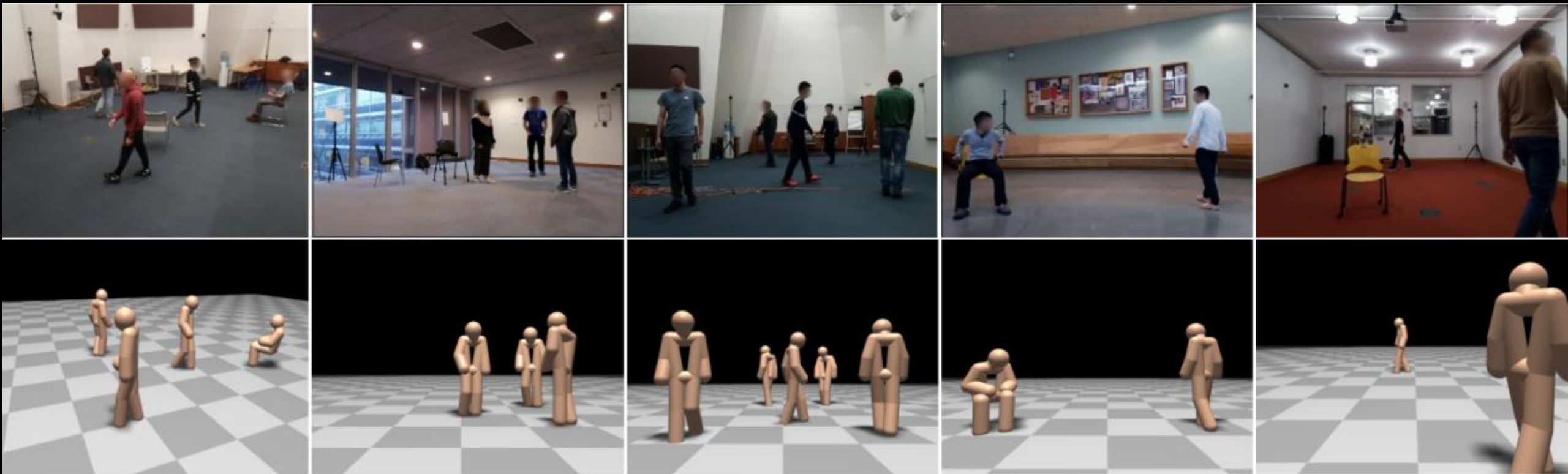# Device-free human tracking

Signal emitter

Human

Antenna array 1

Antenna array 2

3D human pose estimation

Wireless sensing + Deep learning

Thanks! Questions?