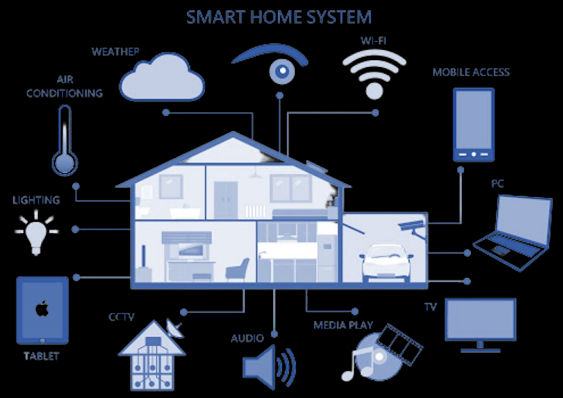
CSE610 Special Topics on Mobile Network & Mobile sensing

Lecture 1: Class Introduction

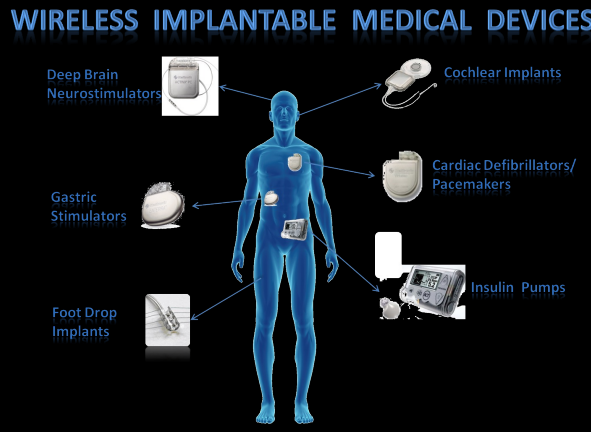
Yaxiong Xie

Wireless-connected devices are everywhere

Smart home devices



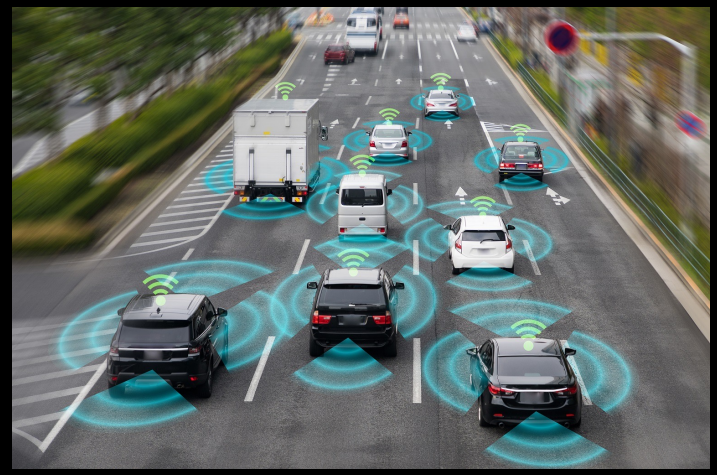
Wireless biomedical devices



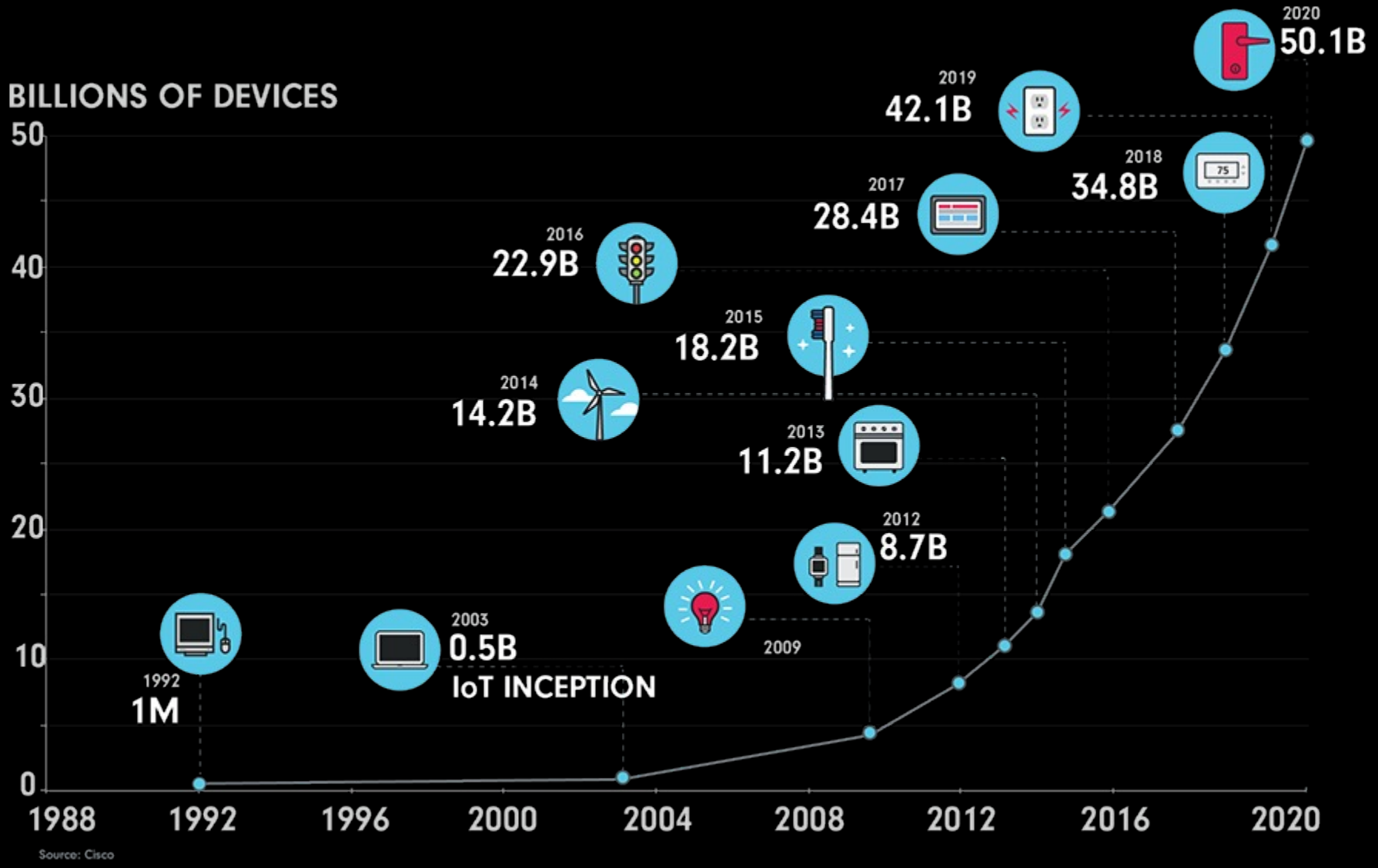
Wireless wearable devices

UAVs

Wireless vehicles



Exponentially increasing number of wireless devices



Increasing demand for wireless connectivity

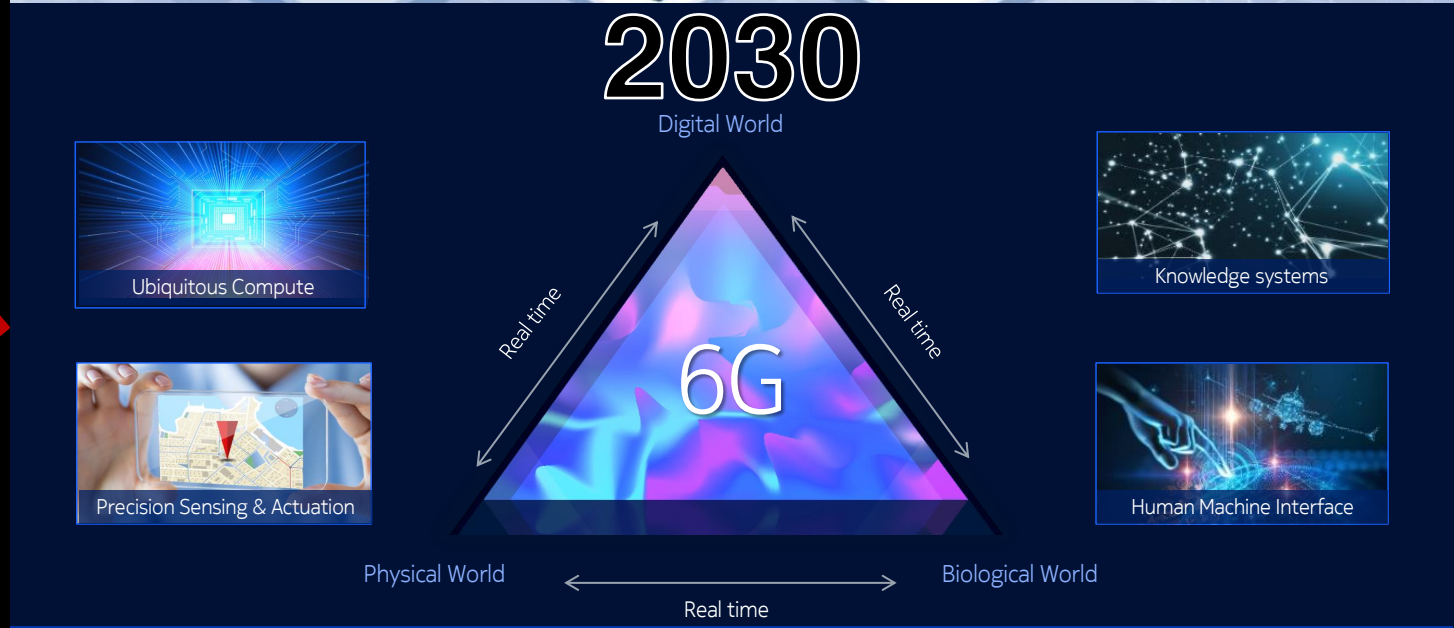
Connecting People

Increasing demand for wireless connectivity

Connecting Everything

Increasing demand for wireless connectivity

Connecting
+
Sensing
Everything



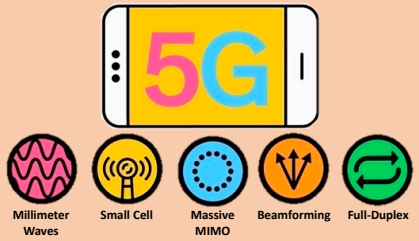
6G to unify the experience across physical, digital and biological worlds

NOKIA Bell Labs

CSE 610

Mobile Networks

5G & Next Generation



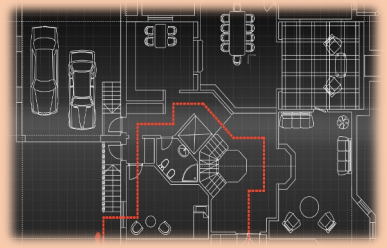
- Millimeter Wave Networks
- Massive MIMO
- Full Duplex Radios
- Dynamic Spectrum Access
- Programmable Surfaces

Internet of Things

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

Mobile Sensing

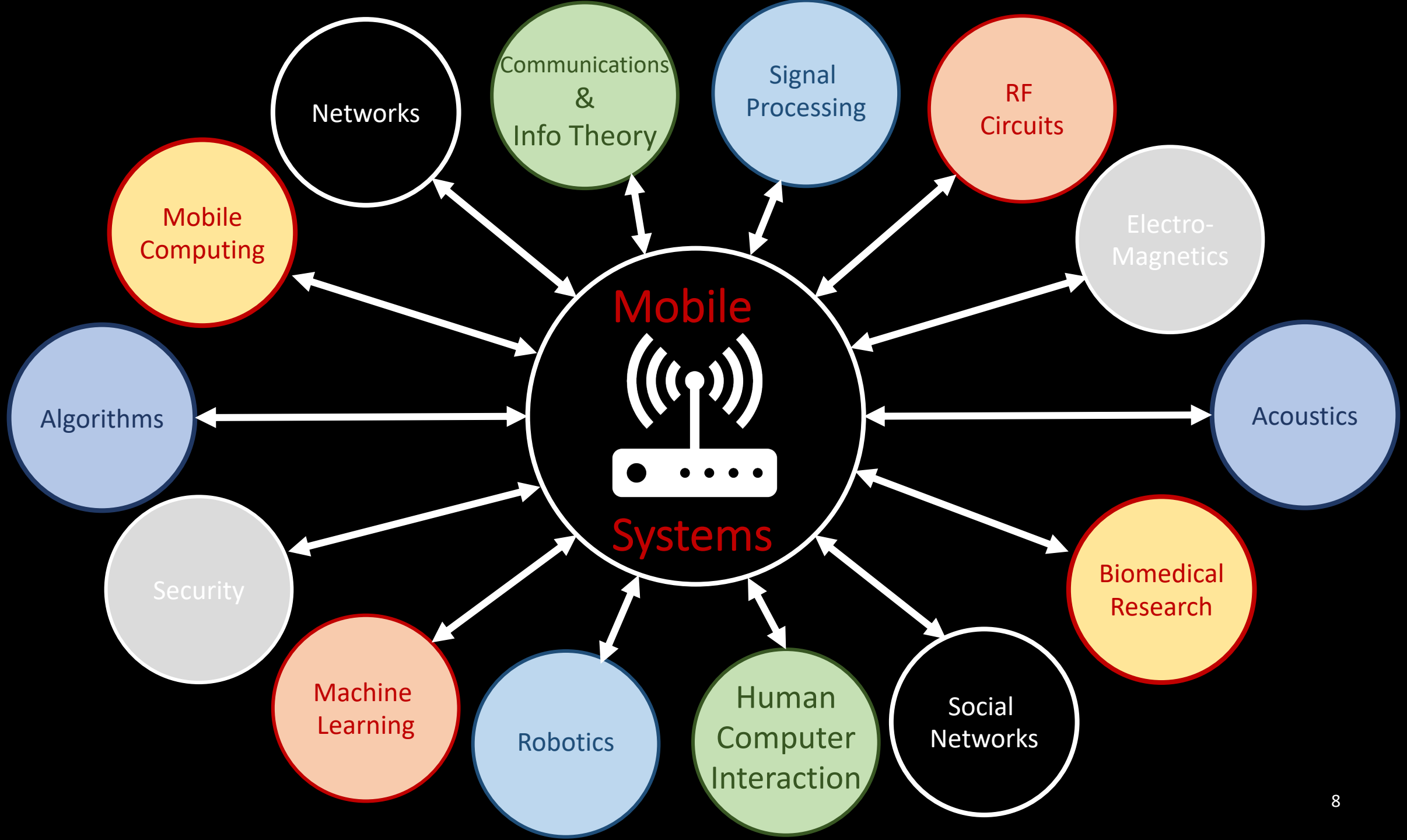
Wireless Localization



- 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 (6 weeks)**
  - Introducing the basics of wireless communication, mobile networks, and mobile sensing
  - Mid-term test (won't be hard)
- **Part 2: Research papers (4 weeks)**
  - 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:

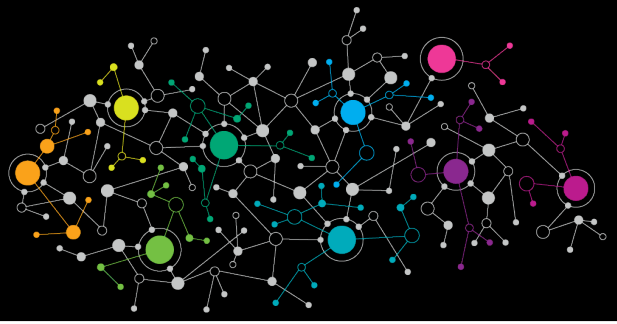
- **Task-1**: preparing the slides
- **Task-2**: presenting the paper and answering the questions raised by the audience
  - Audience are welcome to interrupt the presenter and raise the questions
  - Please try to ask the questions you raised on perusall during the presentation so that we could skip them later
- **Task-3**: going through the comments/questions and organize the discussion

Preparing the slides for a system paper

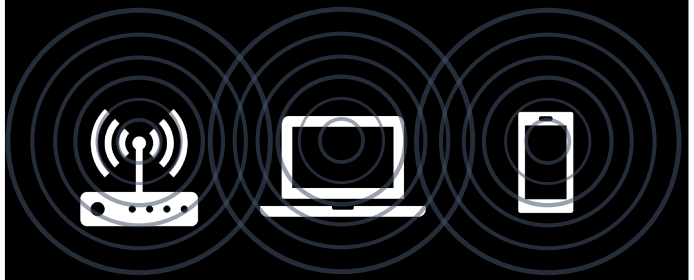
- Introduction and motivation
  - What's the problem the paper solves?
  - Why this problem is important?
  - What's the state-of-the-art?
- Design
  - How does the author solve the problem?
- Evaluation
  - What's the performance of the new system?

Introduction of the course content

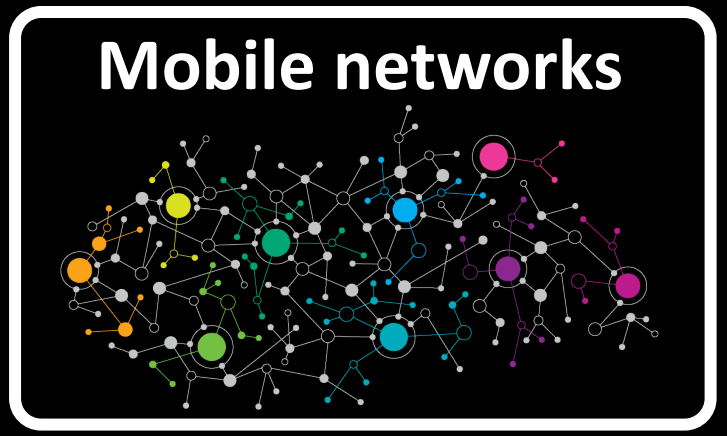
Mobile networks



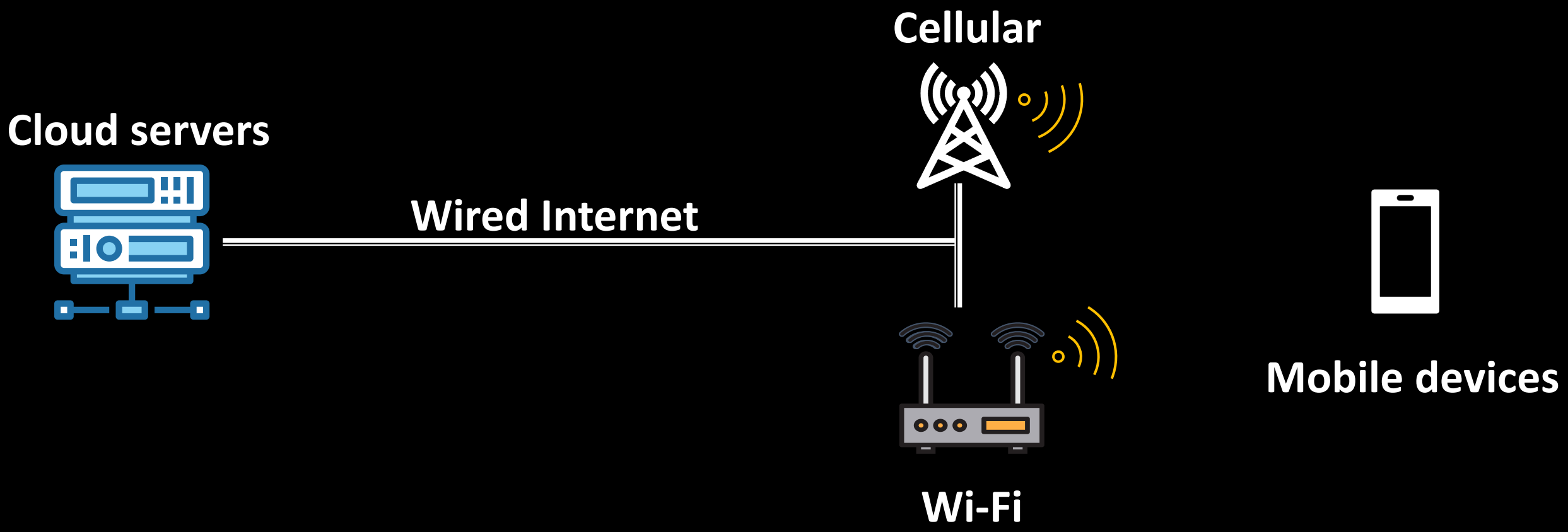
Mobile sensing



Introduction to the mobile networks



Mobile networks: typical scenarios



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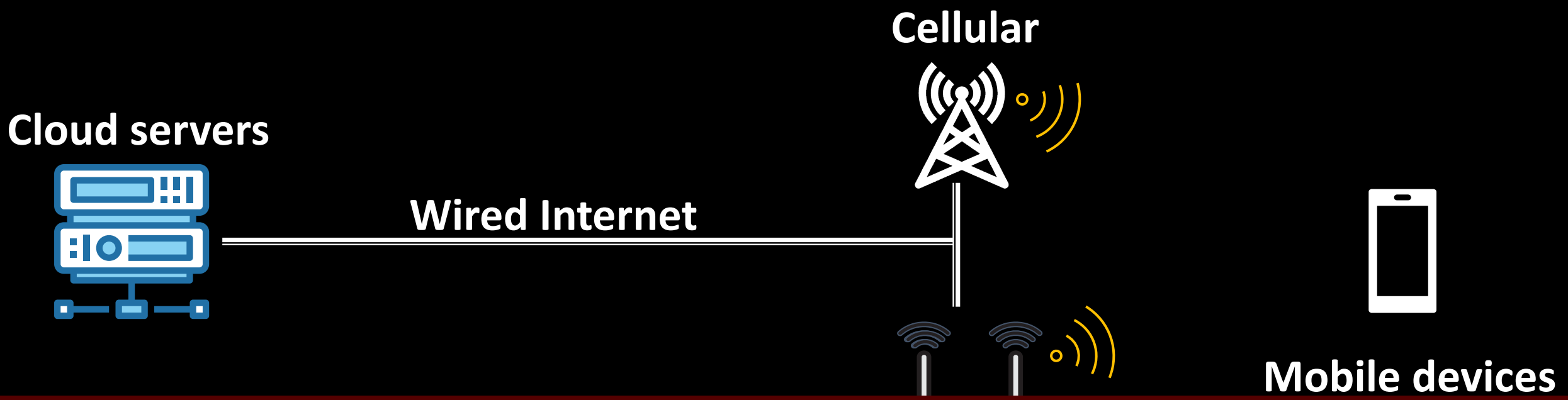
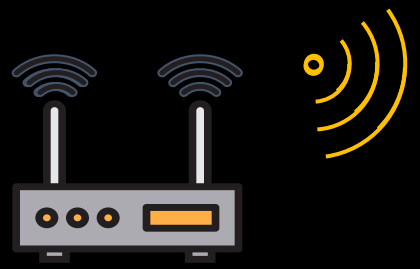


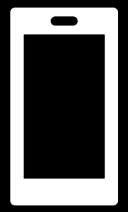
Mobile network is built on top of wireless networks!

How do wireless and wired networks differ?

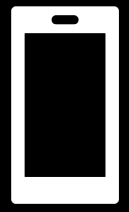
- Wireless is a shared medium



Wi-Fi



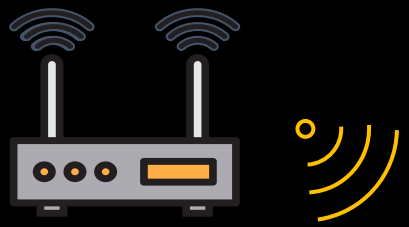
Mobile devices 1



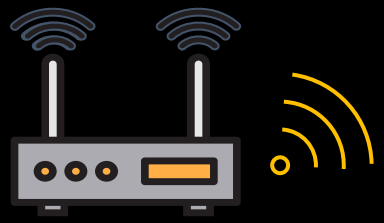
Mobile devices 2

How do wireless and wired networks differ?

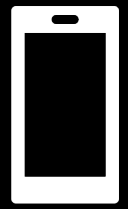
- Wireless is a shared medium
  - Interference between users using the same technology
  - Point-to-point abstraction is a wrong abstraction



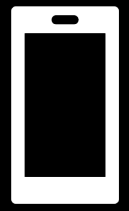
Wi-Fi AP 1



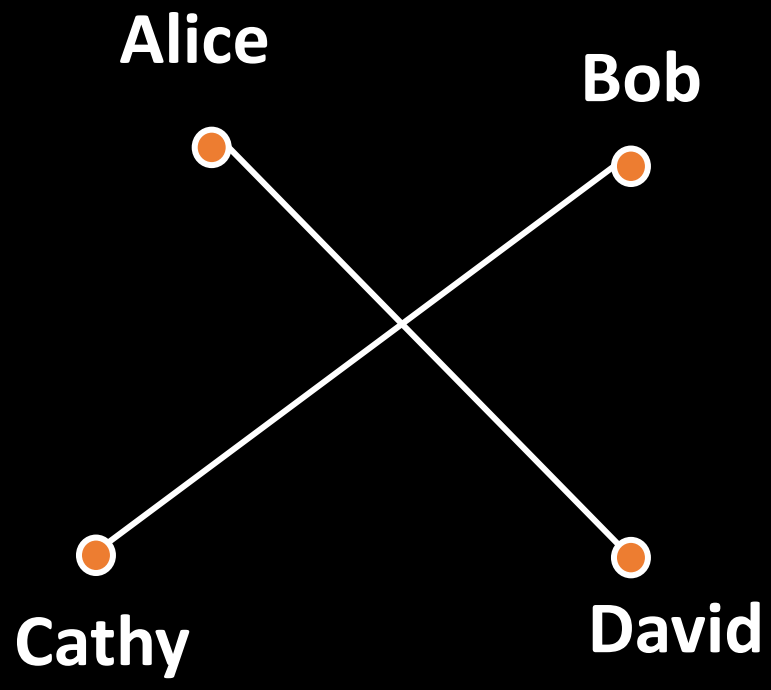
Wi-Fi AP 2



Mobile devices 2



Mobile devices 1



How do wireless and wired networks differ?

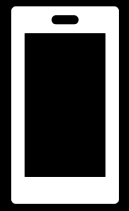
- Wireless is a shared medium
- Wireless is a less reliable

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

30dBm

Wi-Fi AP 1

10dBm



Mobile devices 1

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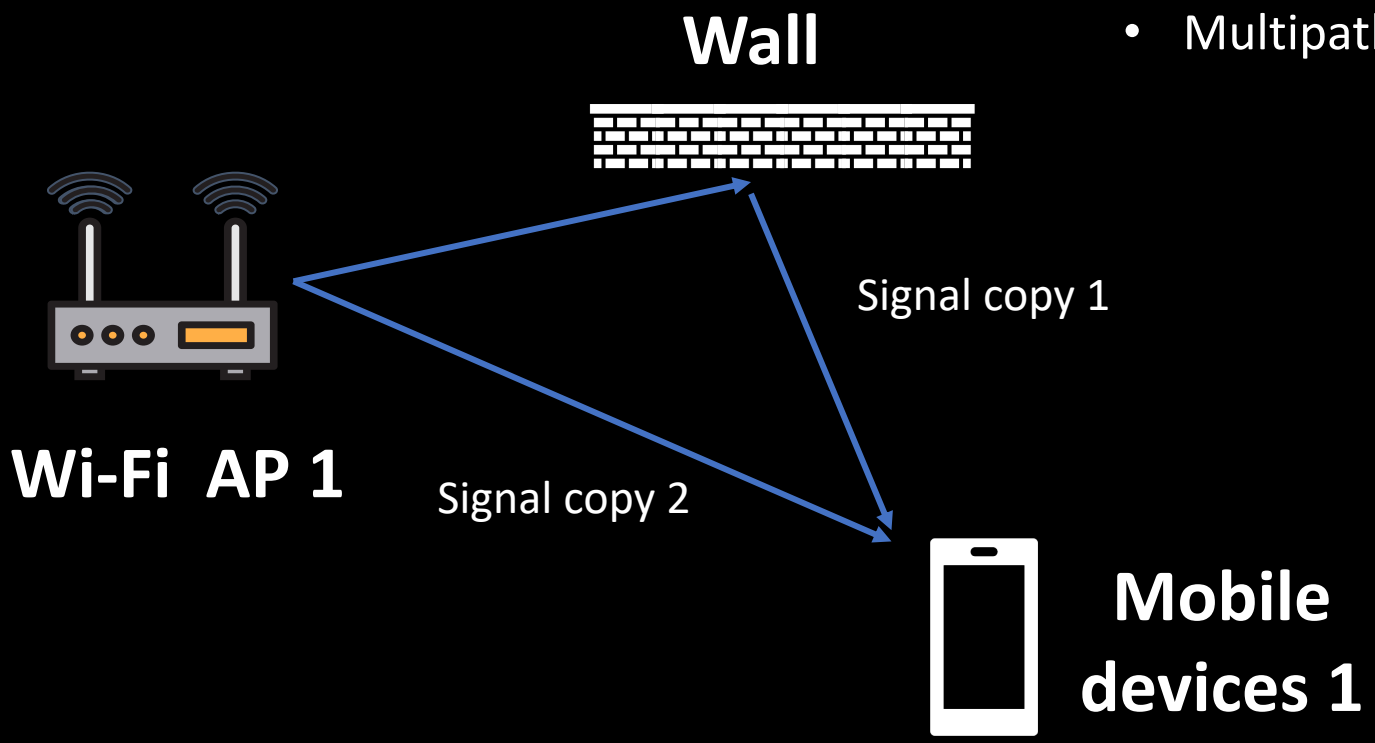
- Multipath effect



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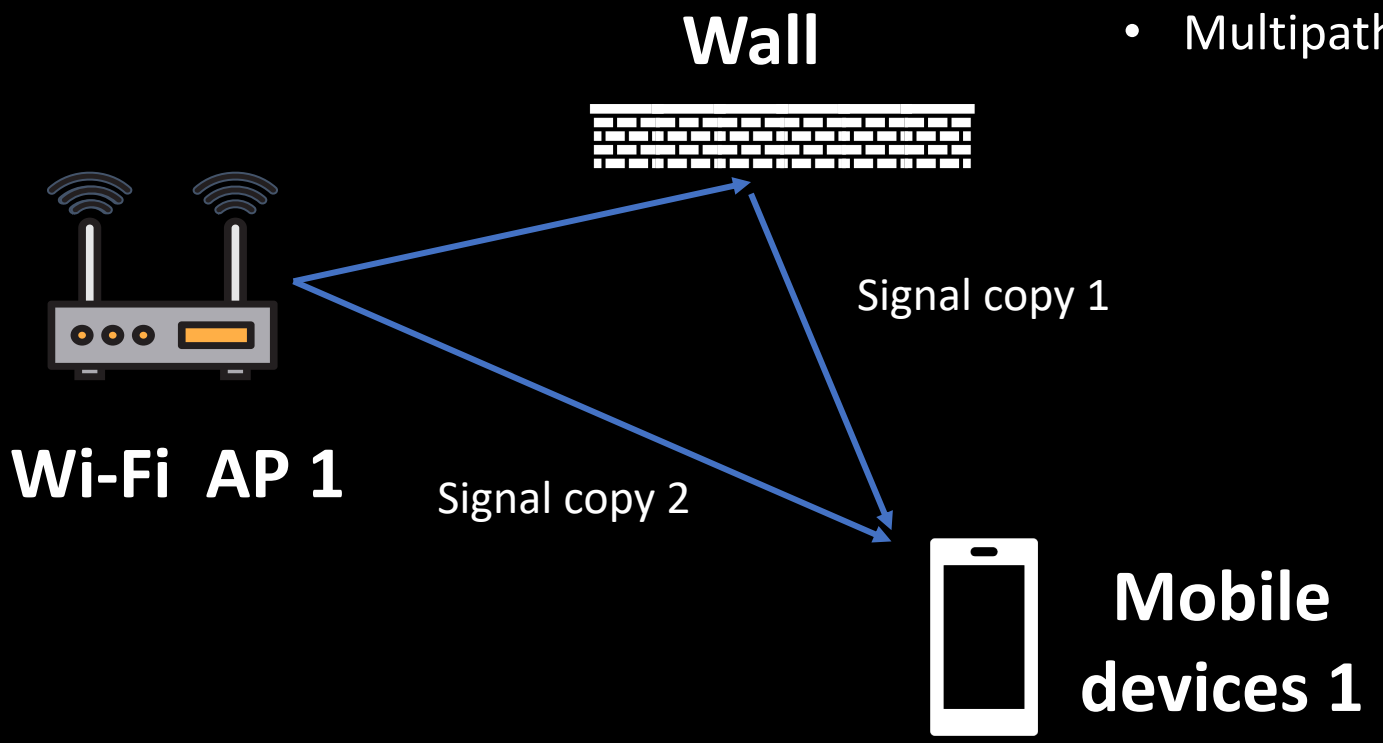

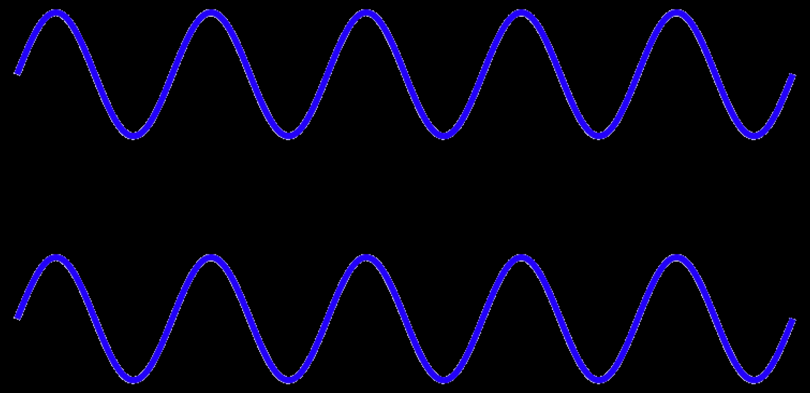

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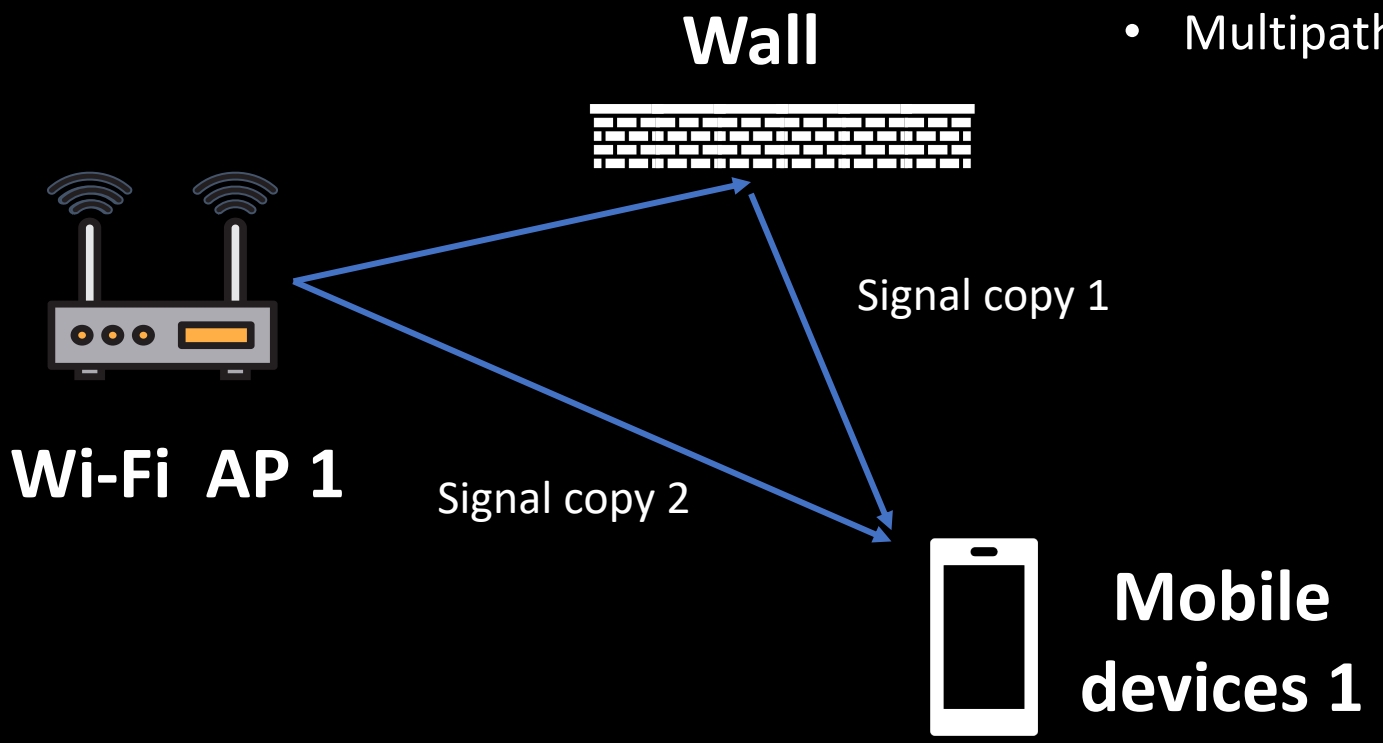

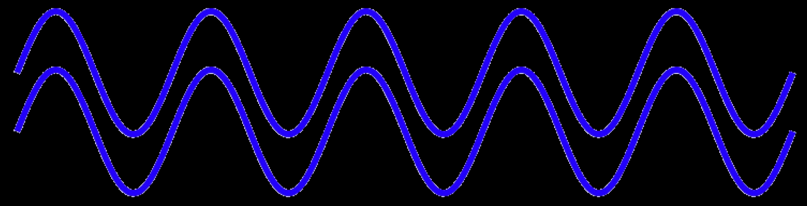

Constructively
Signal strength is maximized!

How do wireless and wired networks differ?

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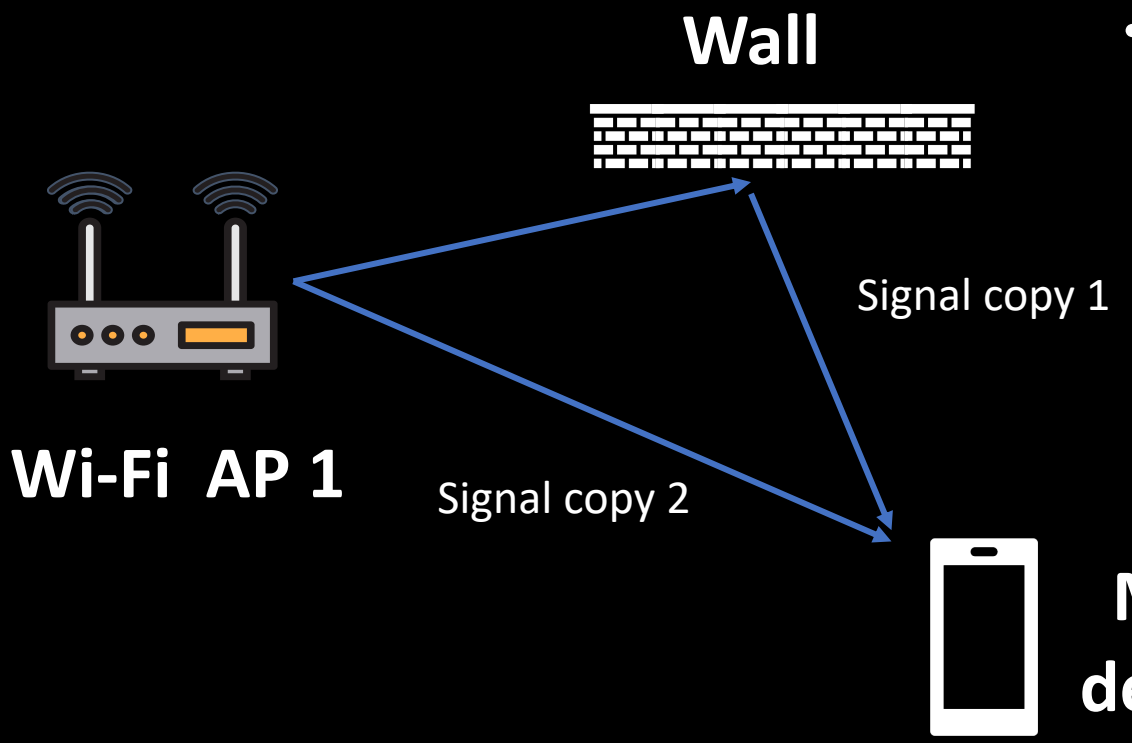

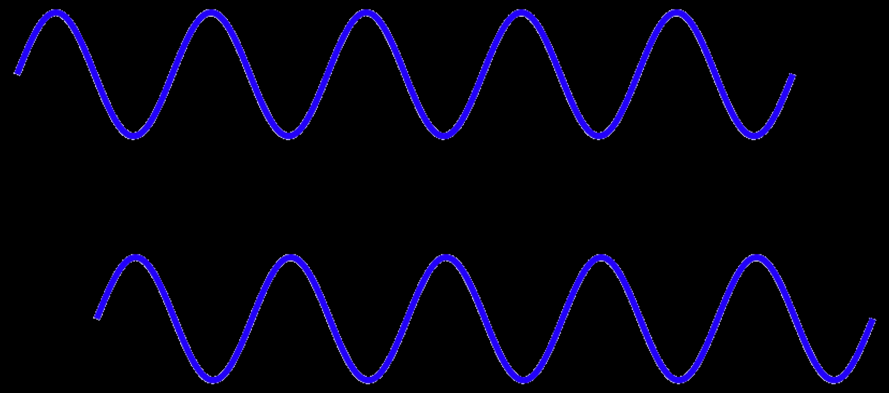

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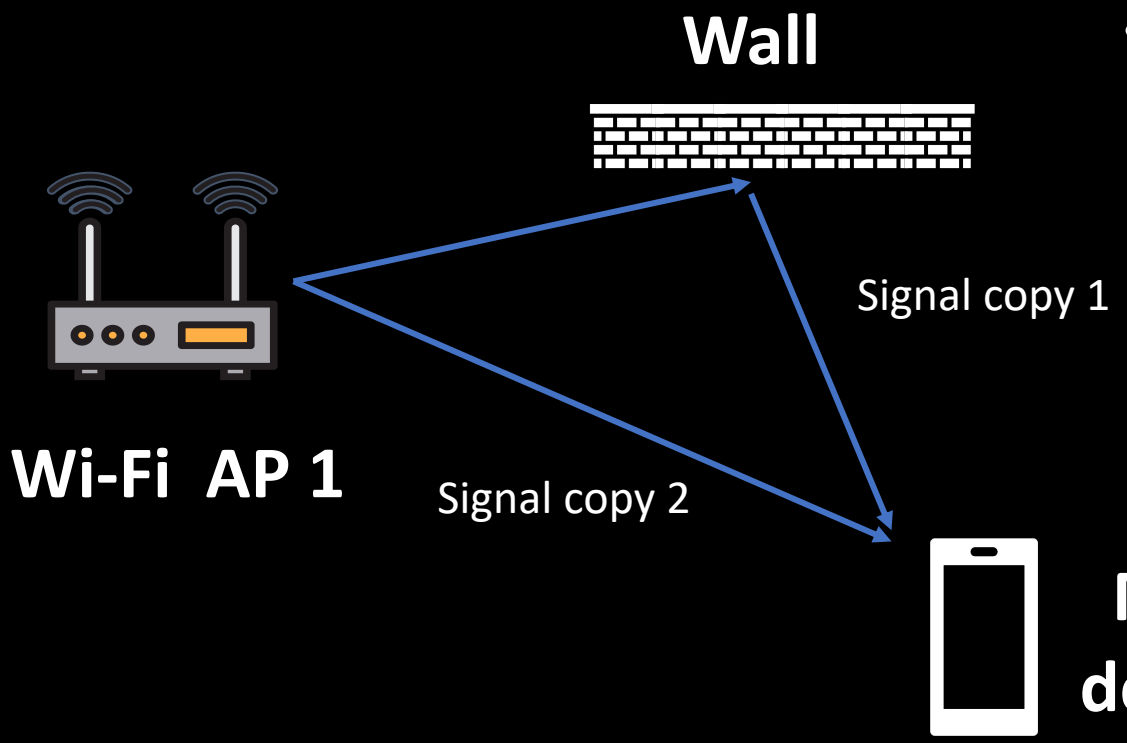

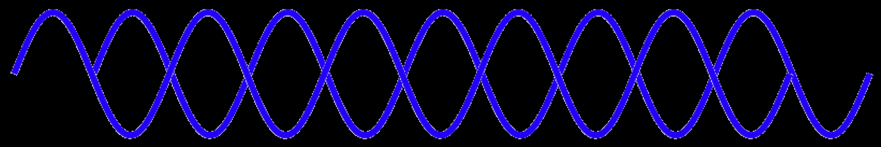

De-constructively
Signal strength is minimized!

How do wireless and wired networks differ?

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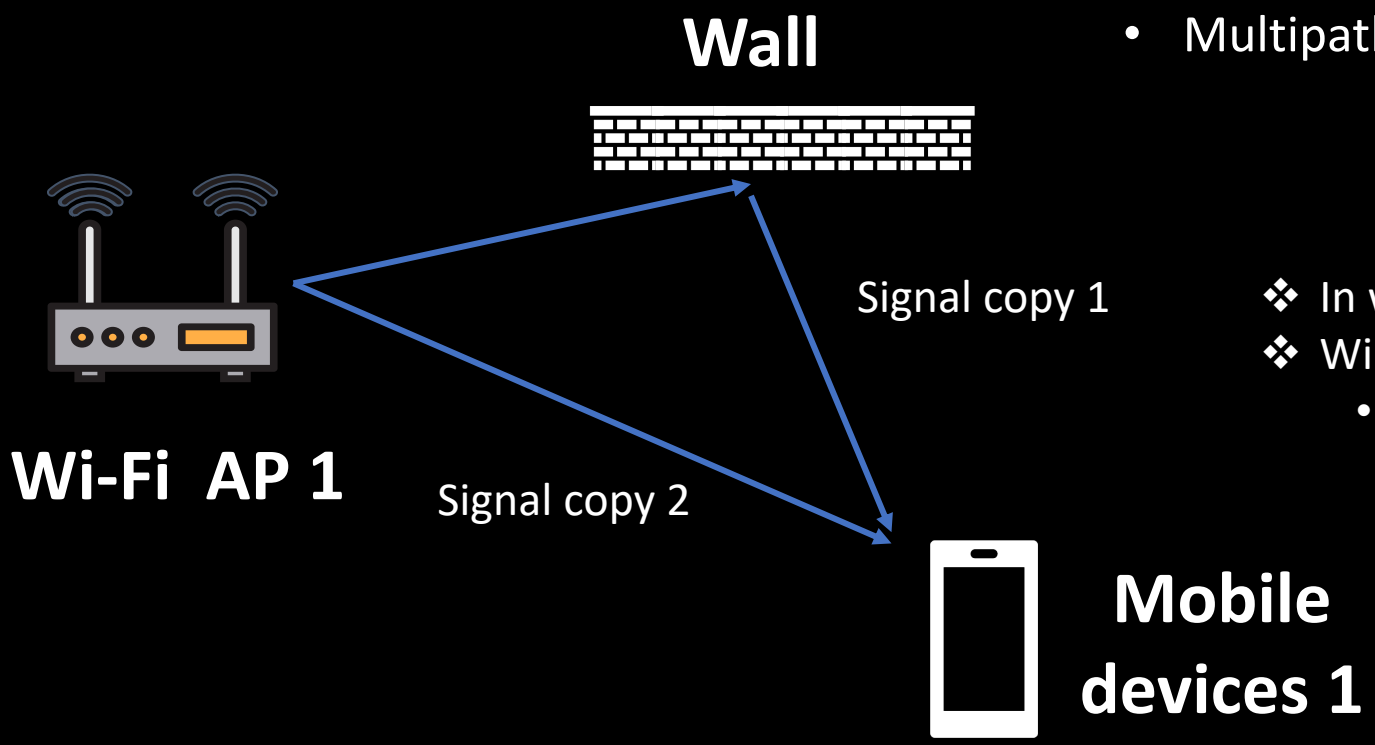
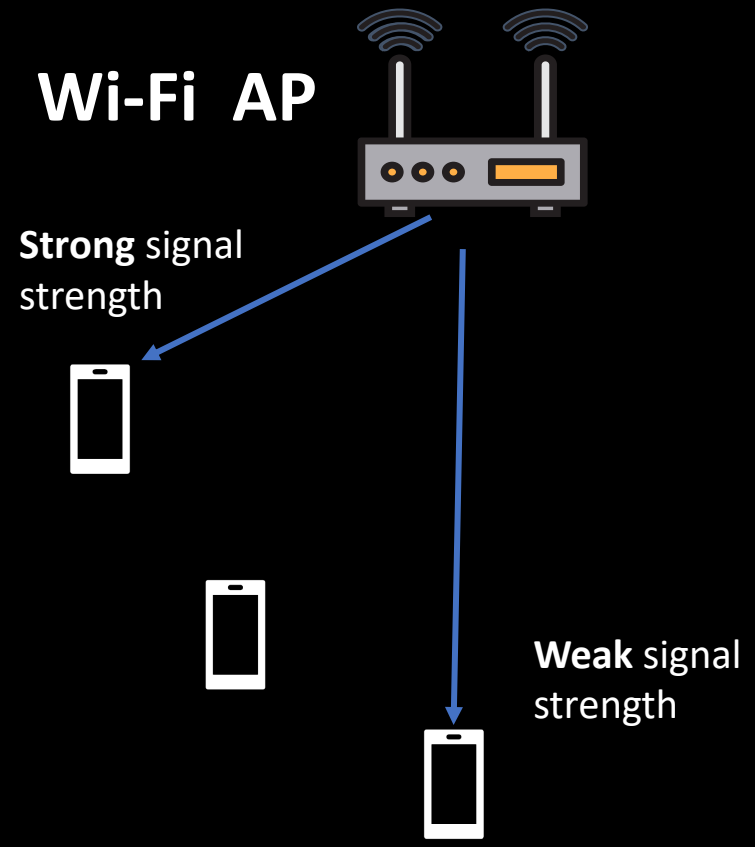
- Multipath effect



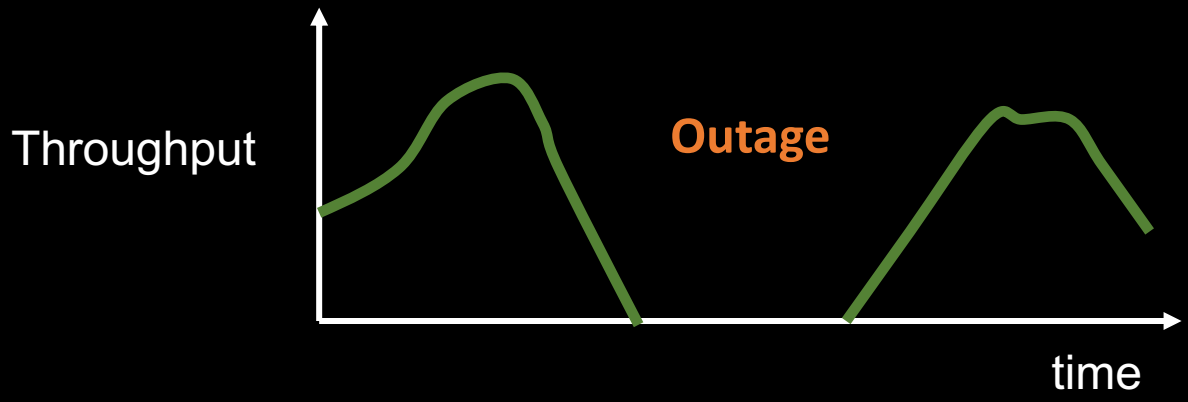
- In wired networks, link **bit error rate** is **10^{-12} and less**
- Wireless networks are **far from that target**
  - Bit error rates of **10^{-6} and above** are common!

How do wireless and wired networks differ?

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



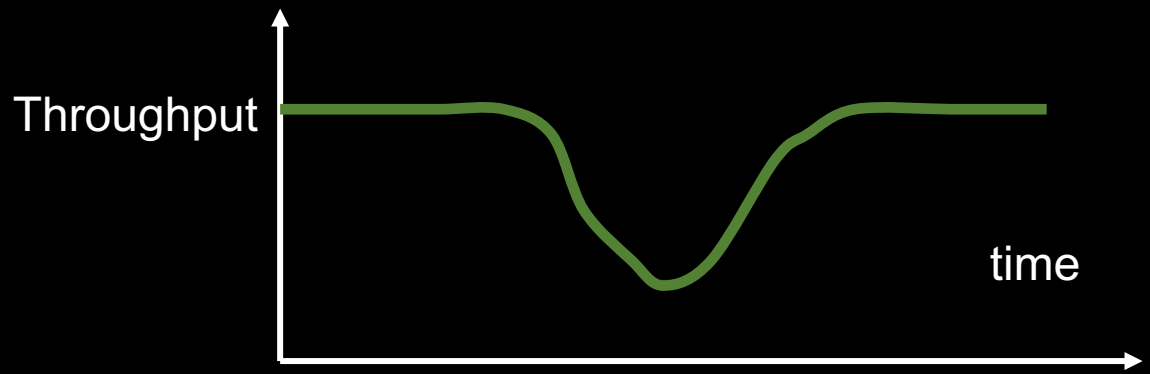
- Channel quality depends on distance, other factors
- Affects the throughput the mobile device can achieve
- Worst case: Outage, periods with no connectivity



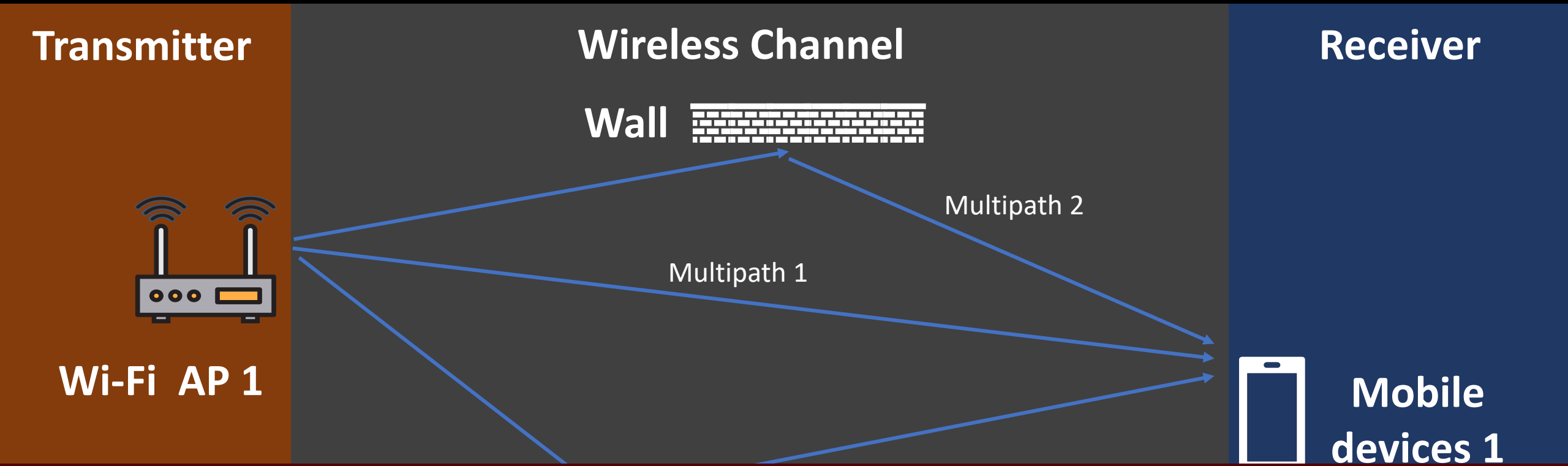
How do wireless and wired networks differ?

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

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



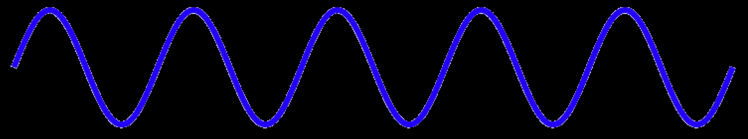
Wireless channel



Wireless channel changes the received signal!

Wireless channel estimation

Transmitted signal

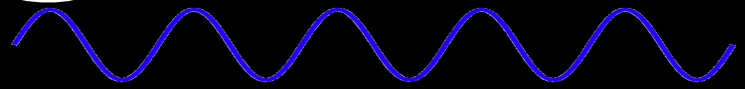


Wi-Fi AP 1

Reconstruct the transmitted signal by reverse the channel

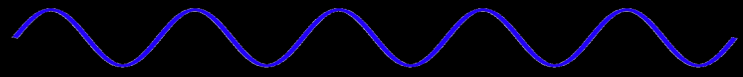
Channel estimation describes how the transmitted signal becomes the received signal

Received signal copy 1



Received signal copy 2

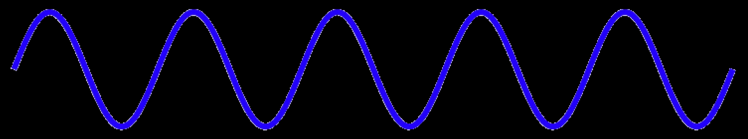
Received signal copy 3



Mobile devices 1

Wireless channel estimation

Transmitted signal



Wi-Fi AP 1

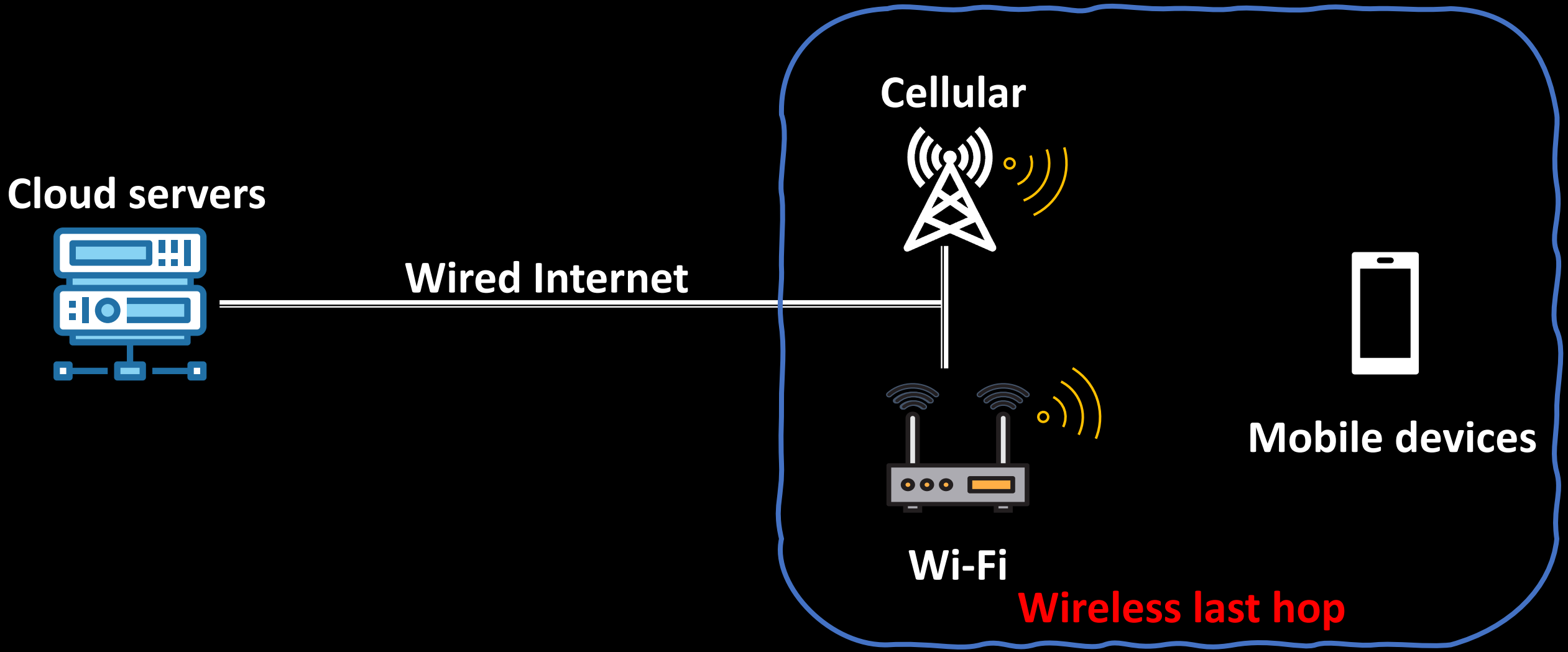
Reconstruct the transmitted signal by reverse the channel

Channel estimation describes how the transmitted signal becomes the received signal

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



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

Cloud servers

Wi-Fi AP / Base station

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

Cloud servers

Wired Internet

Gbps

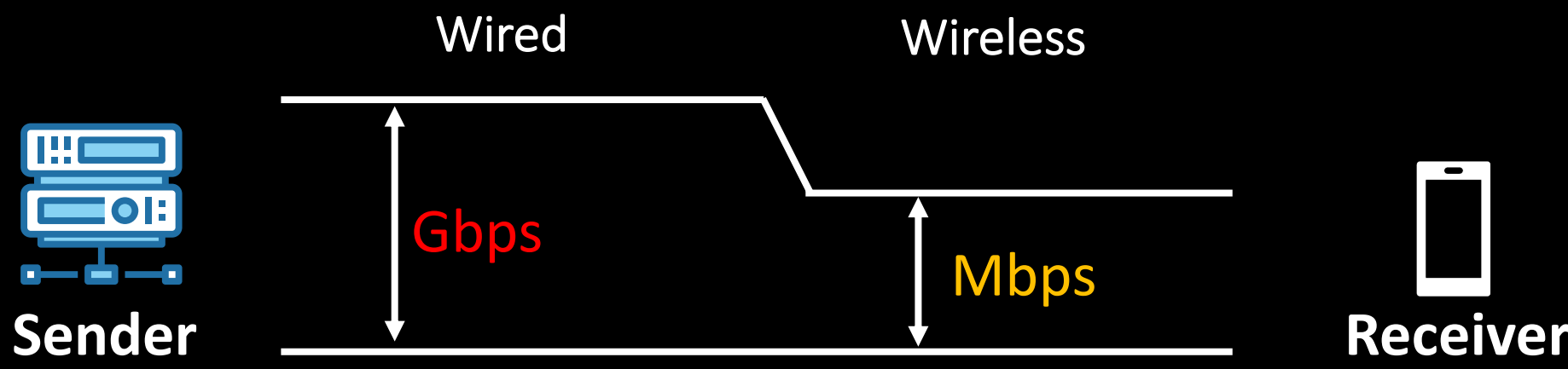
Wi-Fi AP / Base station

Wireless last hop

Mbps

IoT devices

Capacity of wireless hop determines the upper bound of achievable throughput



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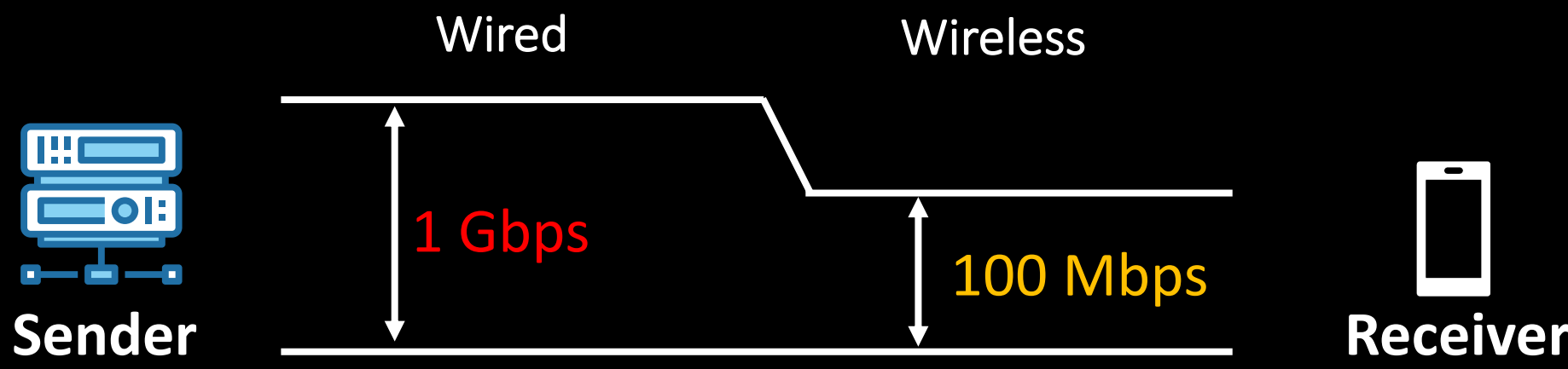
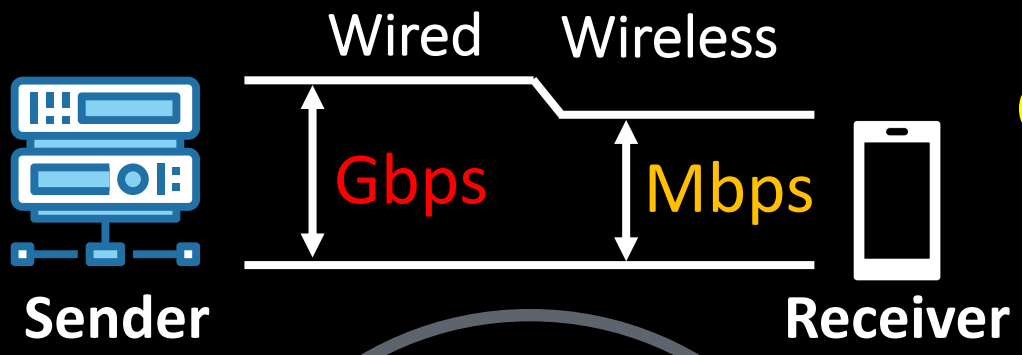
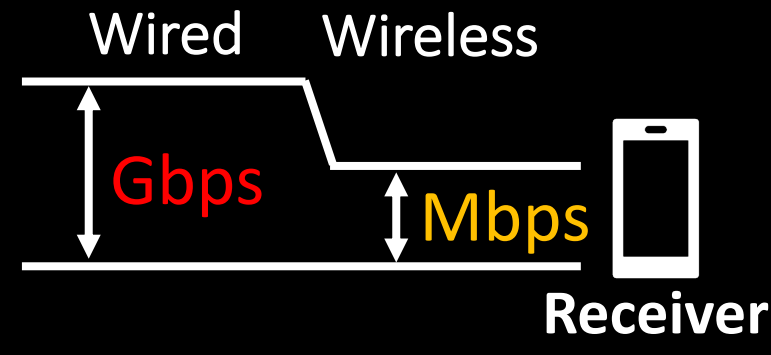


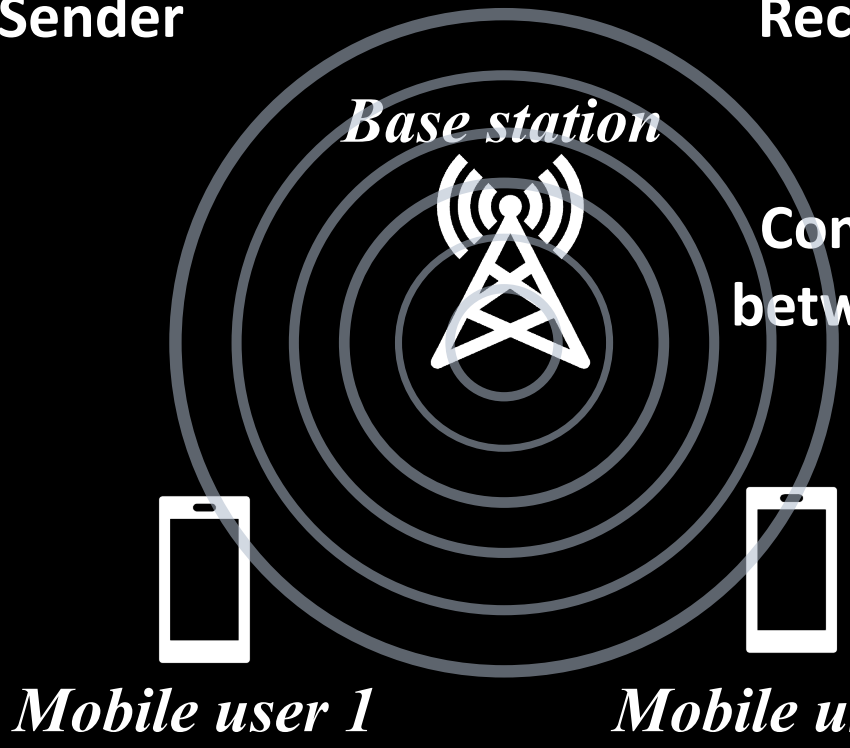
Capacity of wireless link varies!

Capacity of wireless link varies!



Capacity varies!

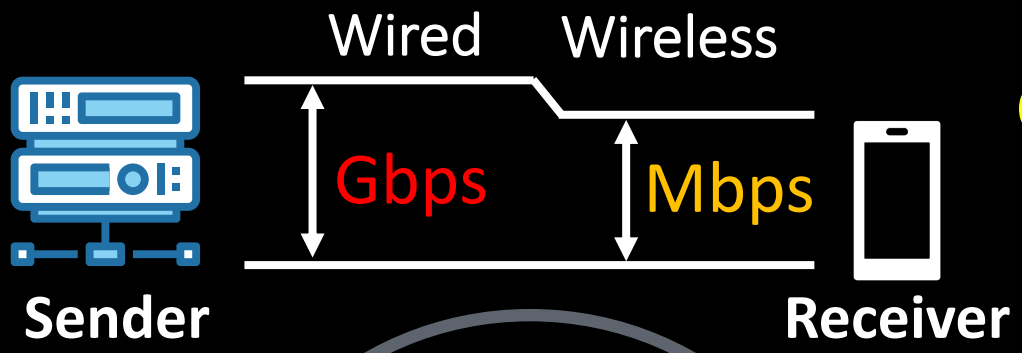




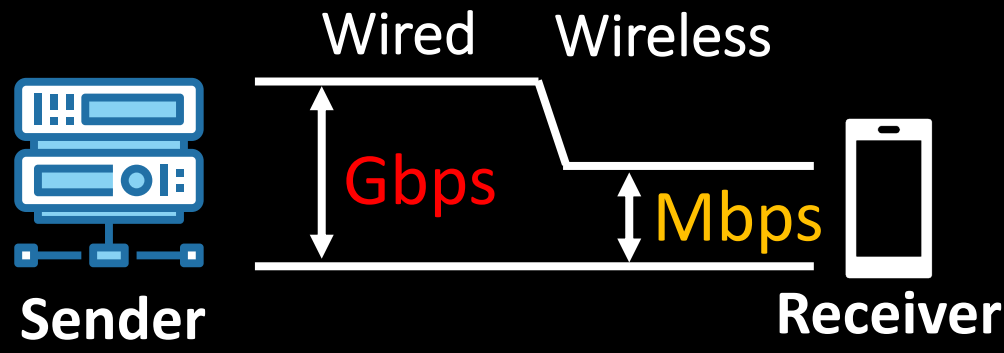
Competition between users

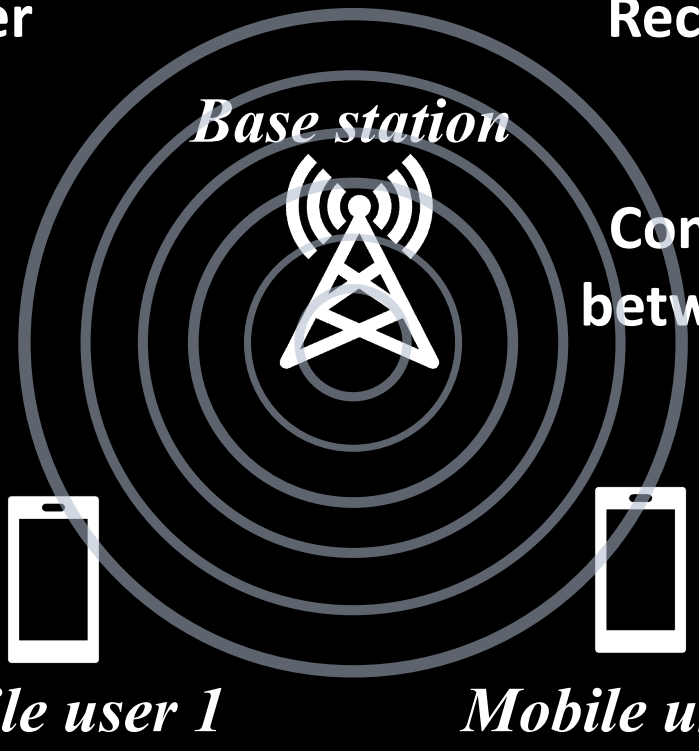
- **Wireless medium is shared across users!**
- **The total bandwidth is limited**
- **More bandwidth for one device -> less allocated bandwidth for other devices**

Capacity of wireless link varies!



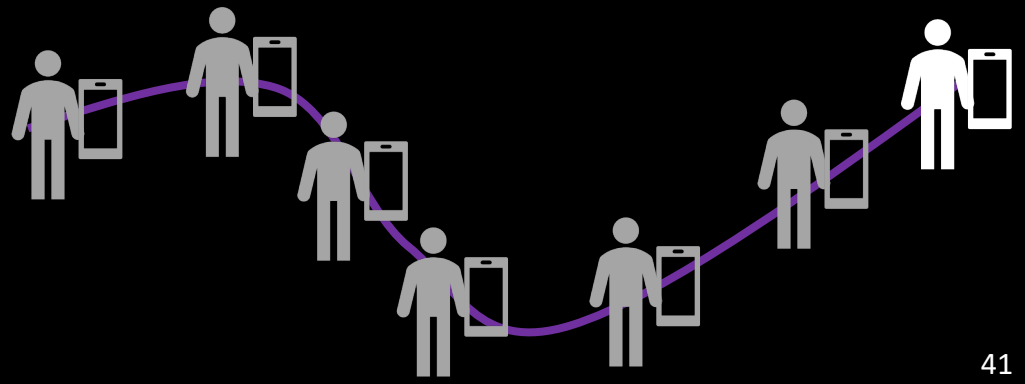
Capacity varies!



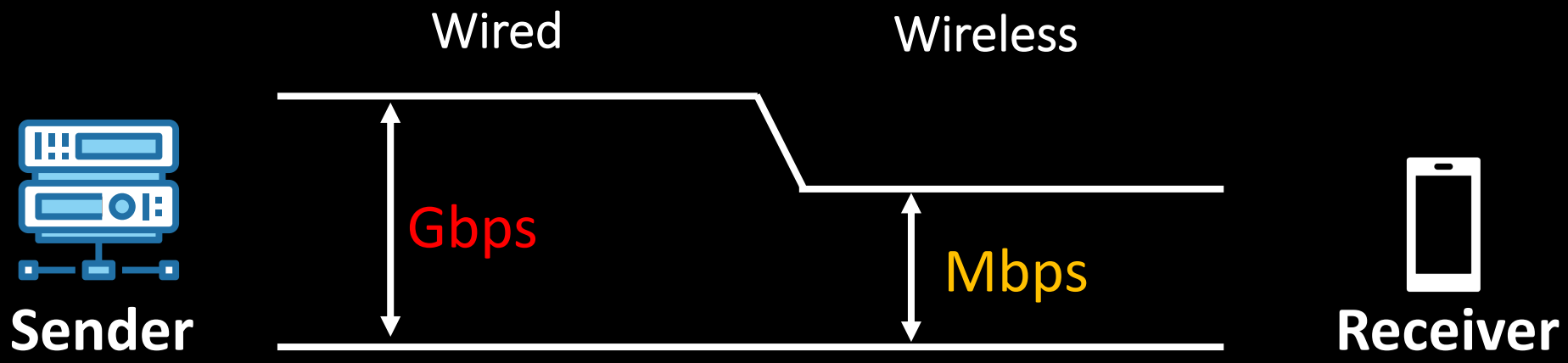


Competition between users

User mobility

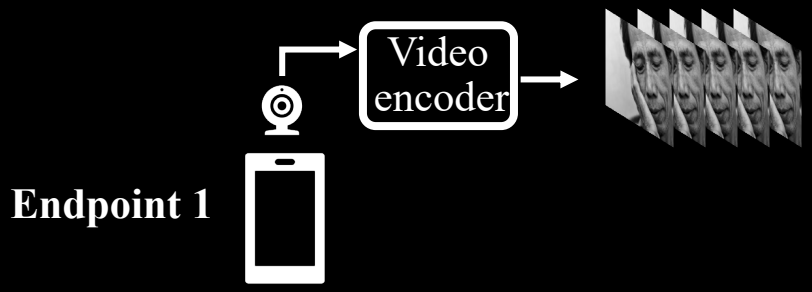


Capacity of wireless hop determines the upper bound of achievable throughput



How fast the sender should send the data?

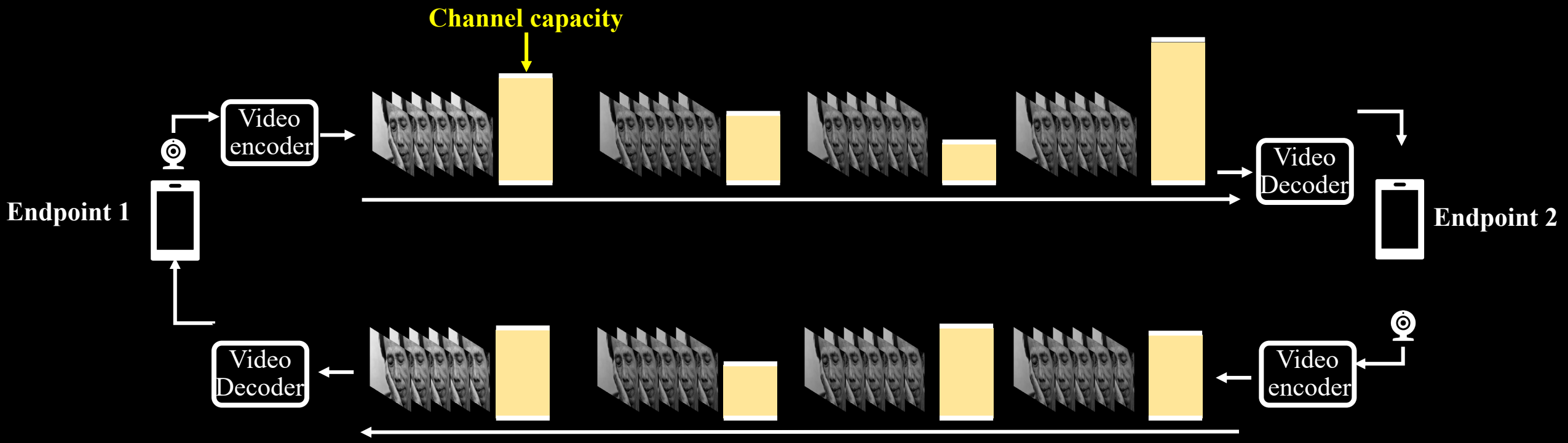
Real-time communication applications like Zoom



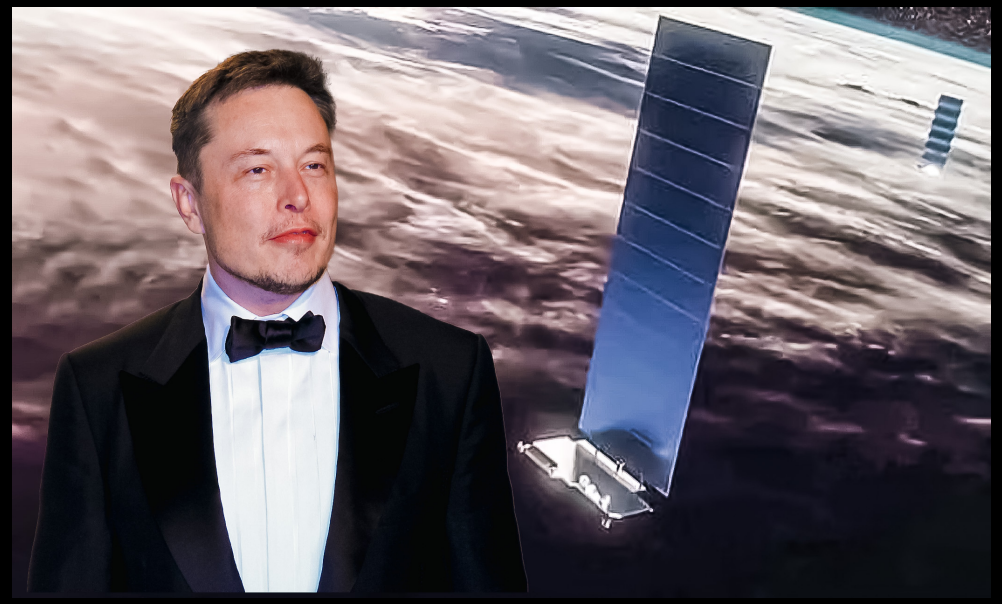
Low resolution -> Smaller data size

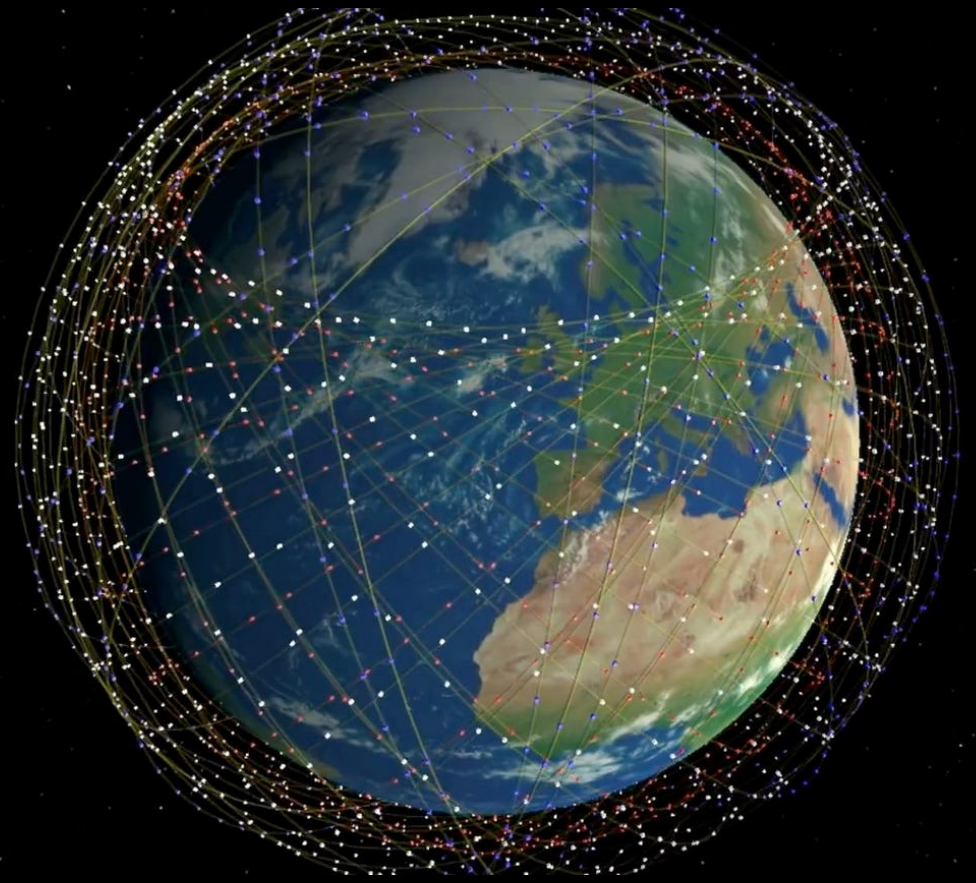
High resolution -> Larger data size

Real-time communication applications like Zoom



More than Wi-Fi and cellular: satellite

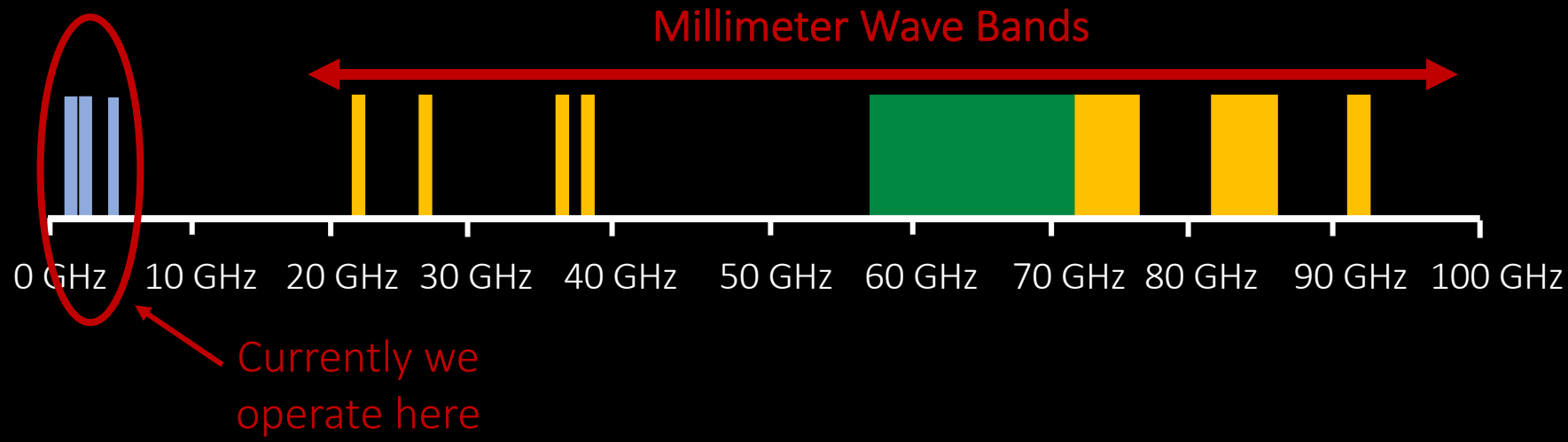




More than Wi-Fi and cellular: mm-wave

More than Wi-Fi and cellular: mm-wave

Huge bandwidth available at millimeter wave frequencies



Millimeter Wave can support data rates of multi-Gbps

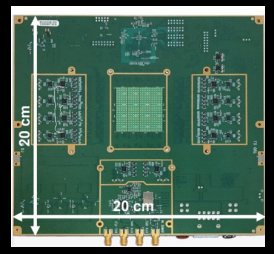
Millimeter Waves Suffer from Attenuation

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

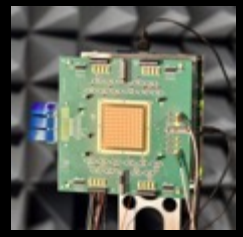
Nokia & National Instruments

UCSD
256 elements

UCSD
64 elements

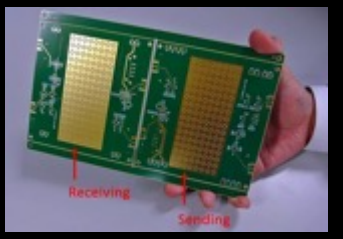


Bell Labs
384 elements



Anokiwave
256 elements

IBM
64 elements



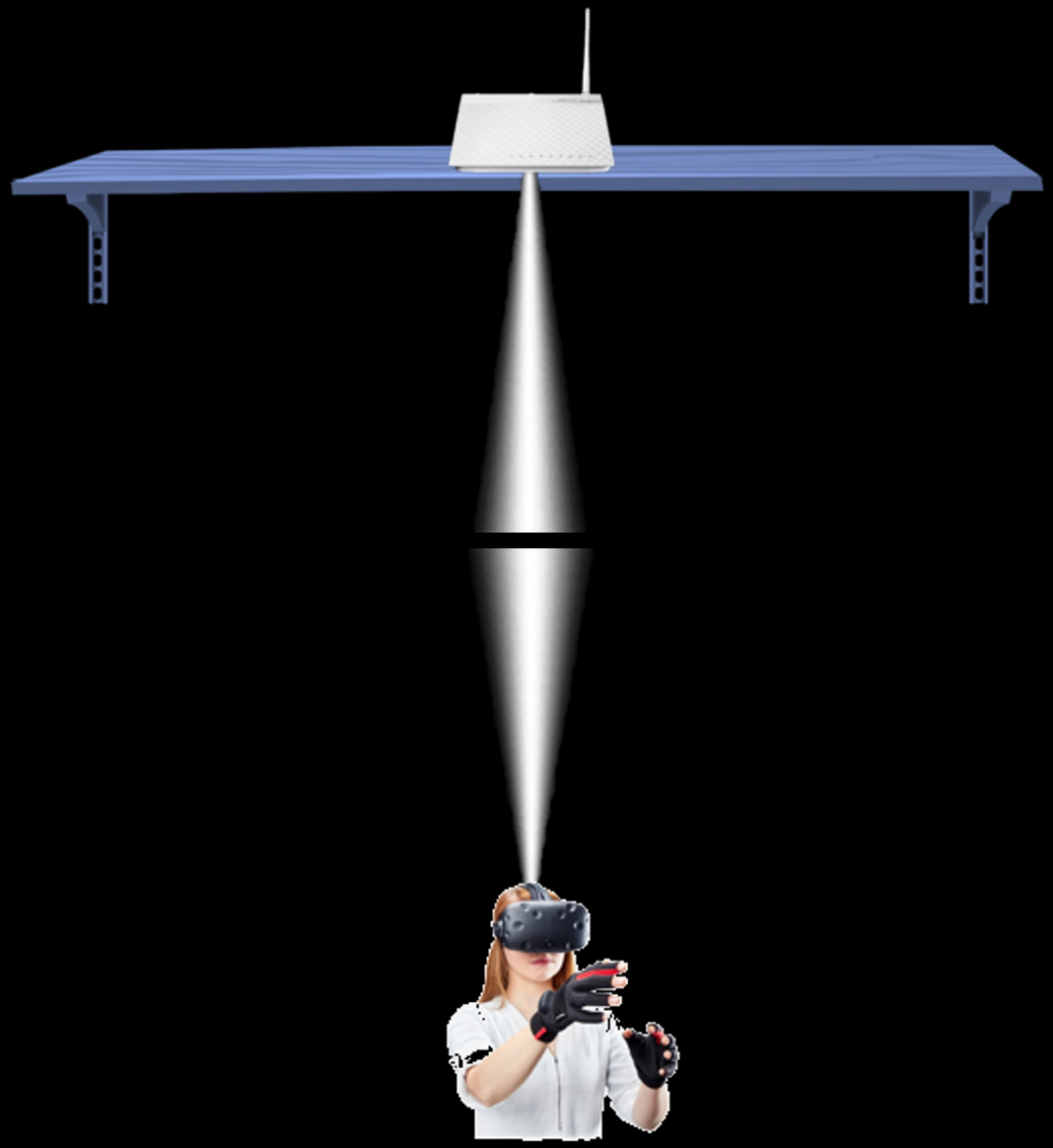
Fujitsu
64 elements

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

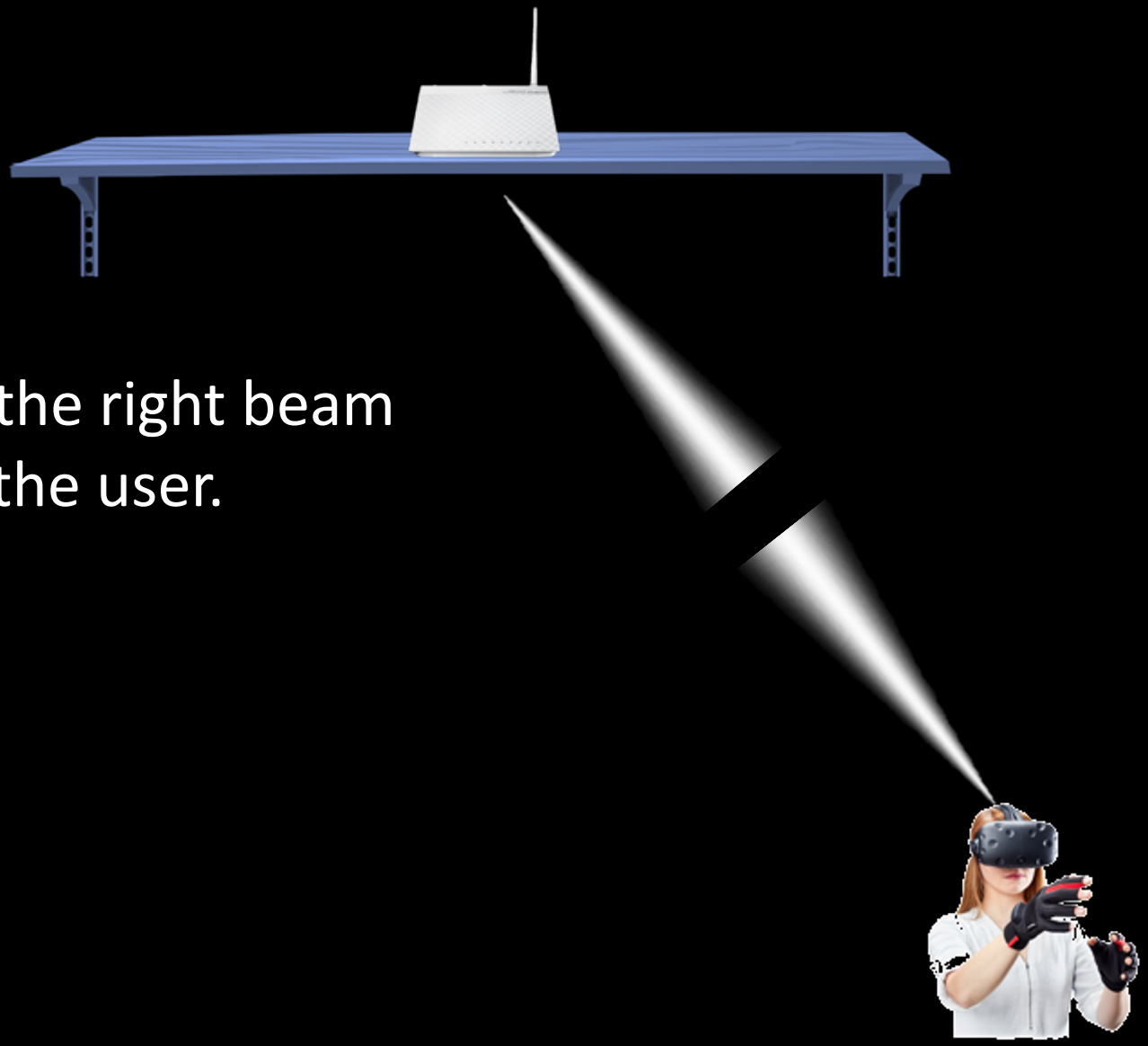
Today’s Networks : Broadcast

mmWave changes how wireless systems operate

mmWave changes how wireless systems operate



mmWave changes how wireless systems operate

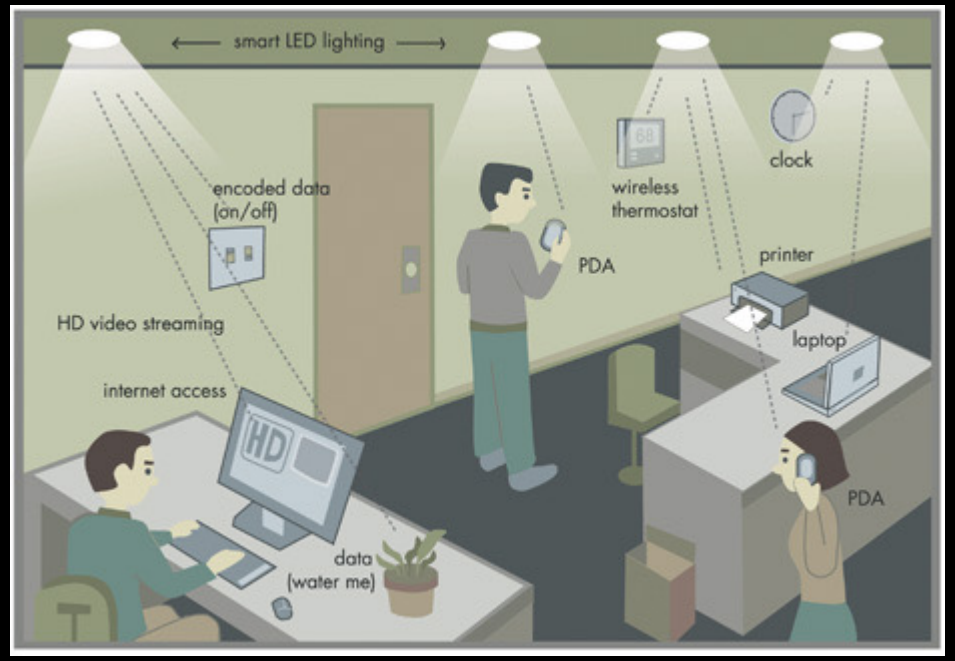


Need to quickly find the right beam alignment and track the user.

Suffers in case of:

- Mobility
- Blockage

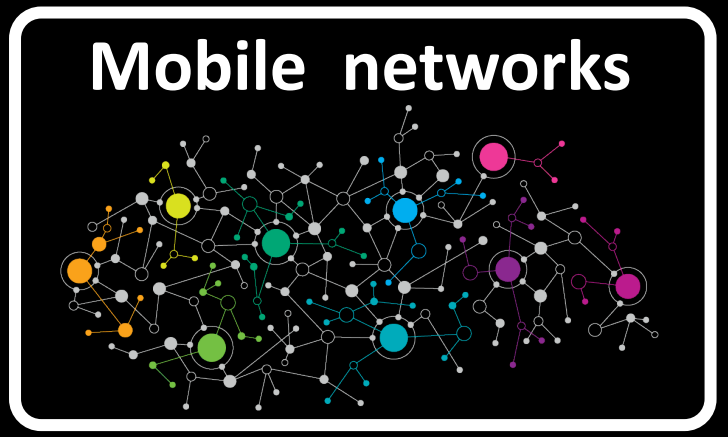
More than Wi-Fi and cellular: VLC

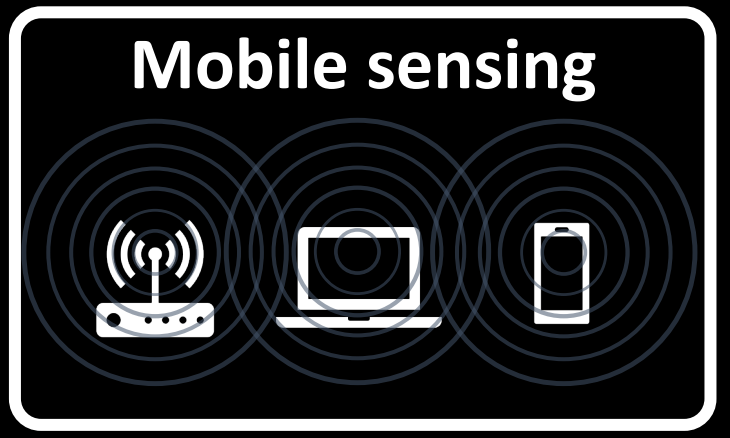


Visible light communication

The speed can be extremely fast
It preserves user privacy

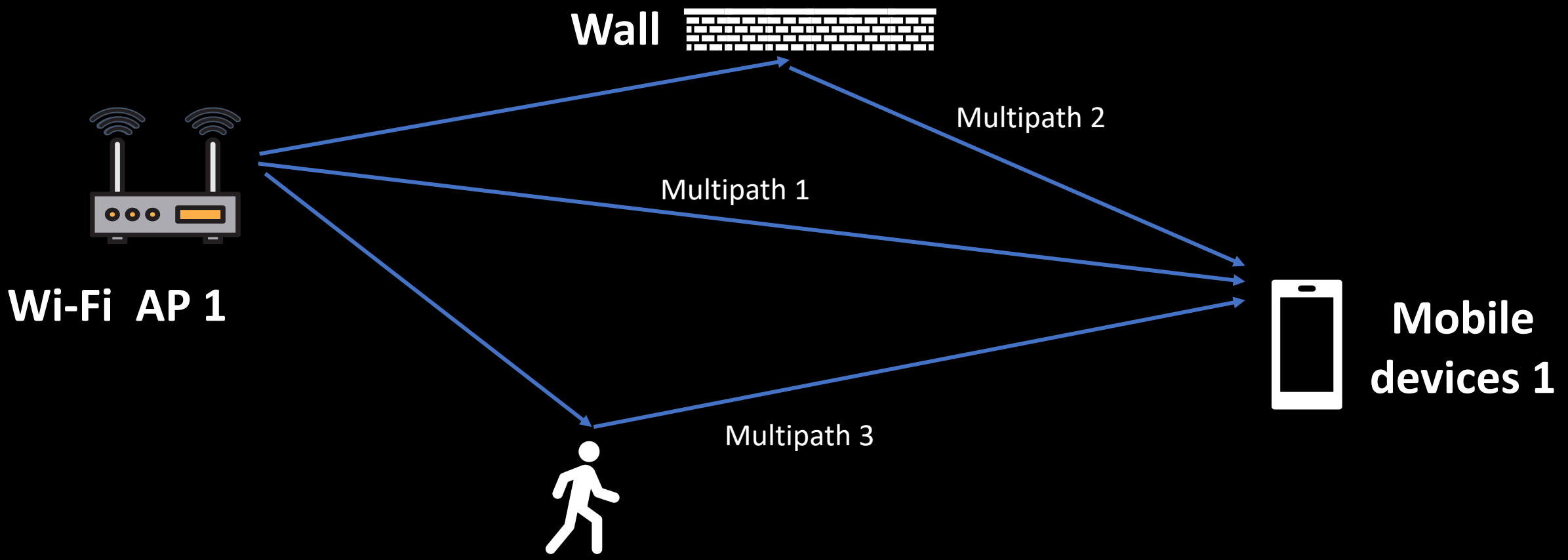
Introduction to the wireless networks





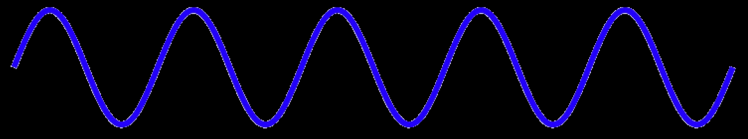
Introduction to the wireless networks

Wireless channel



Wireless channel estimation

Transmitted signal

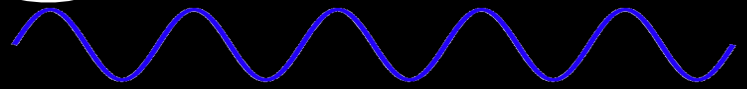


Wi-Fi AP 1

Reconstruct the transmitted signal by reverse the channel

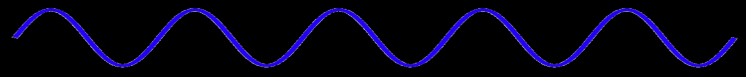
Channel estimation describes how the transmitted signal becomes the received signal

Received signal copy 1



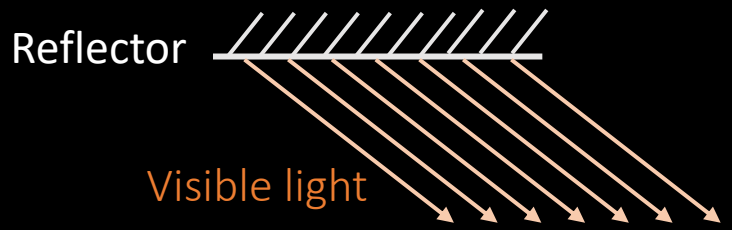
Received signal copy 2

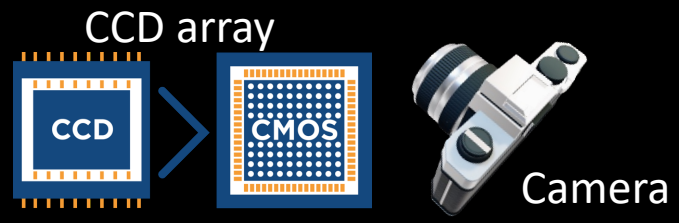
Received signal copy 3



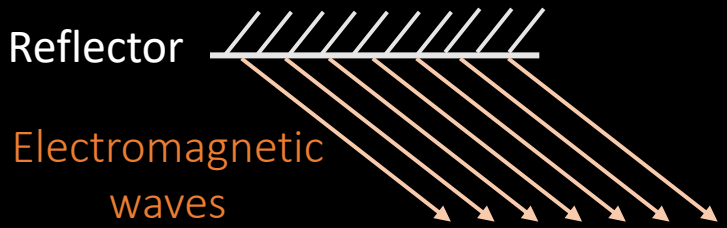
Mobile devices 1

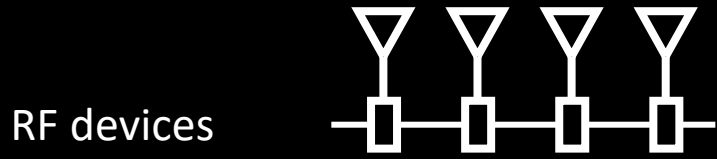
Analogy: Wireless sensing VS. Computer vision

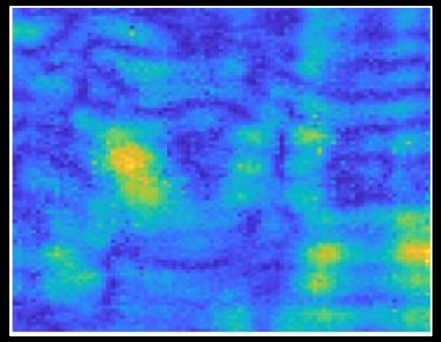




Images



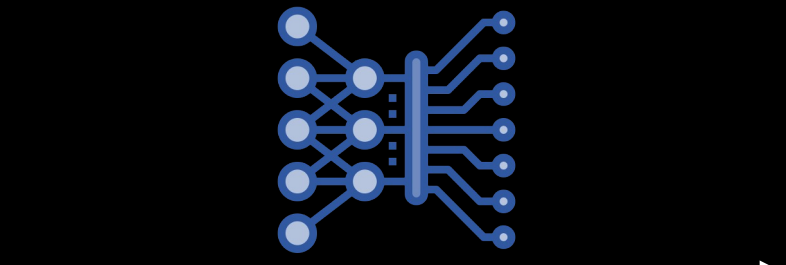




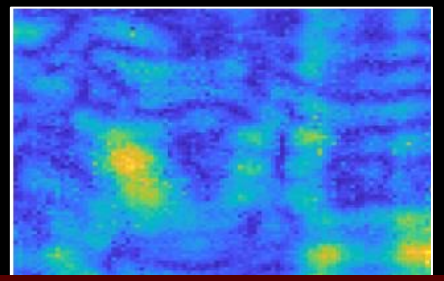
Channel state information (CSI)

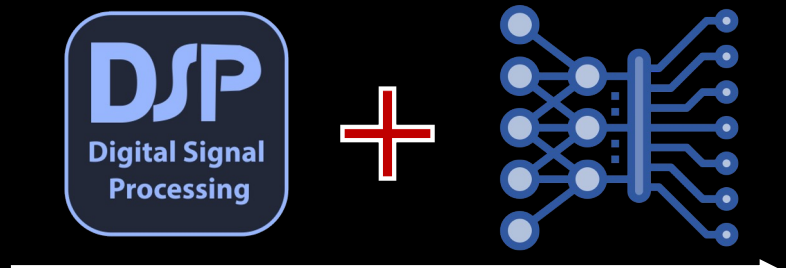
Analogy: Wireless sensing VS. Computer vision

Images



Human skeleton



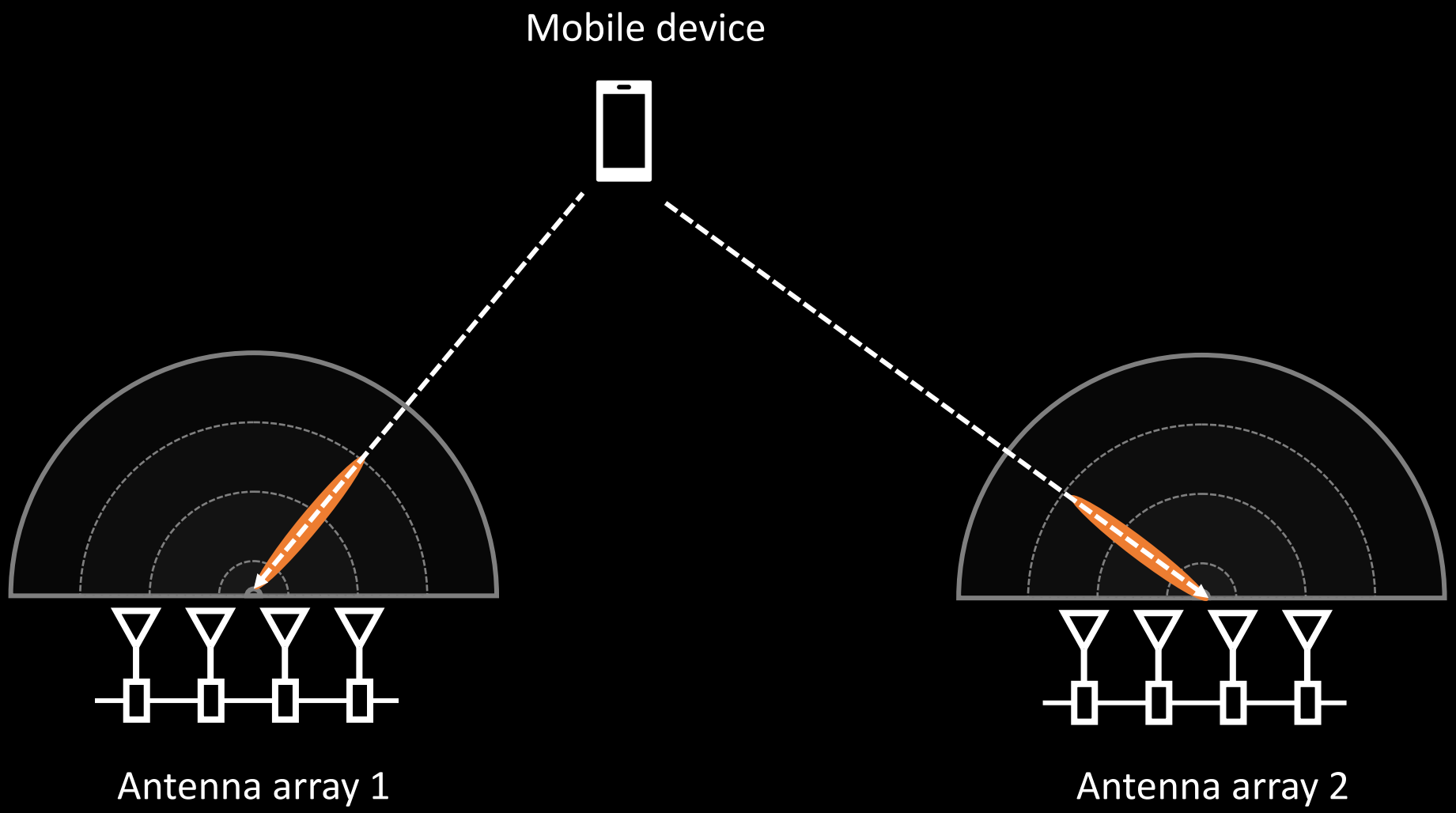


What's the potential application?

Image source: https://pixabay.com/photos/asleep-sleepy-man-asian-guy-tired-5500058/

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

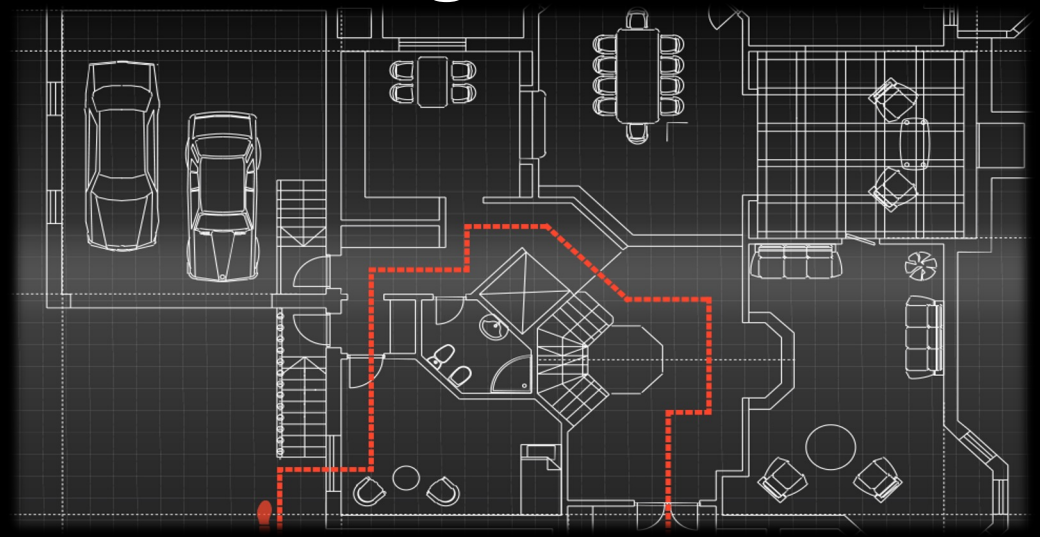
Indoor localization

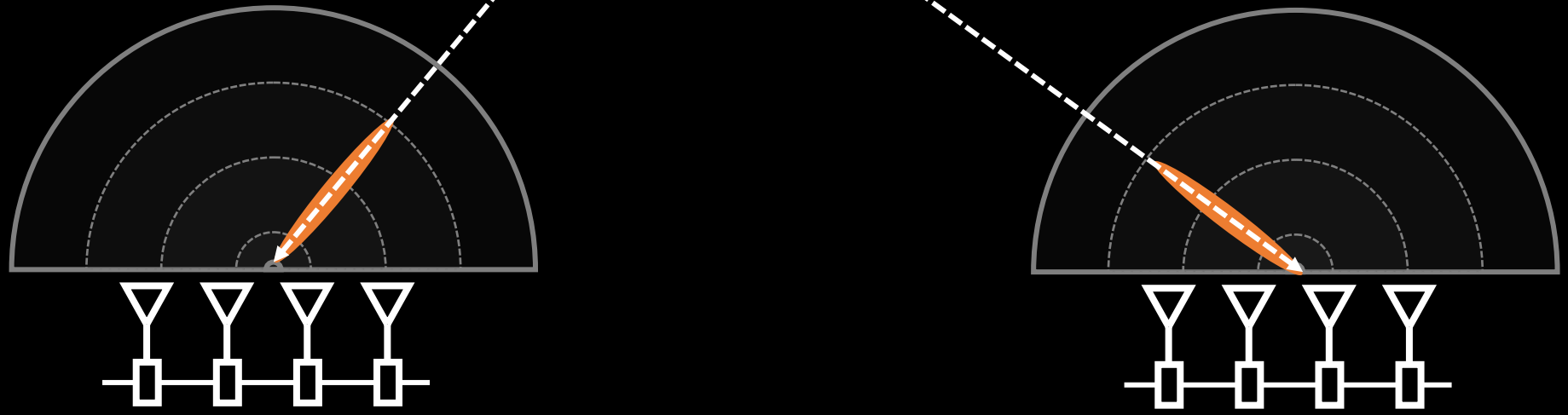


Device-free human tracking

Signal emitter

Human





Antenna array 1

Antenna array 2

3D human pose estimation

Wireless sensing + Deep learning

Thanks! Questions?