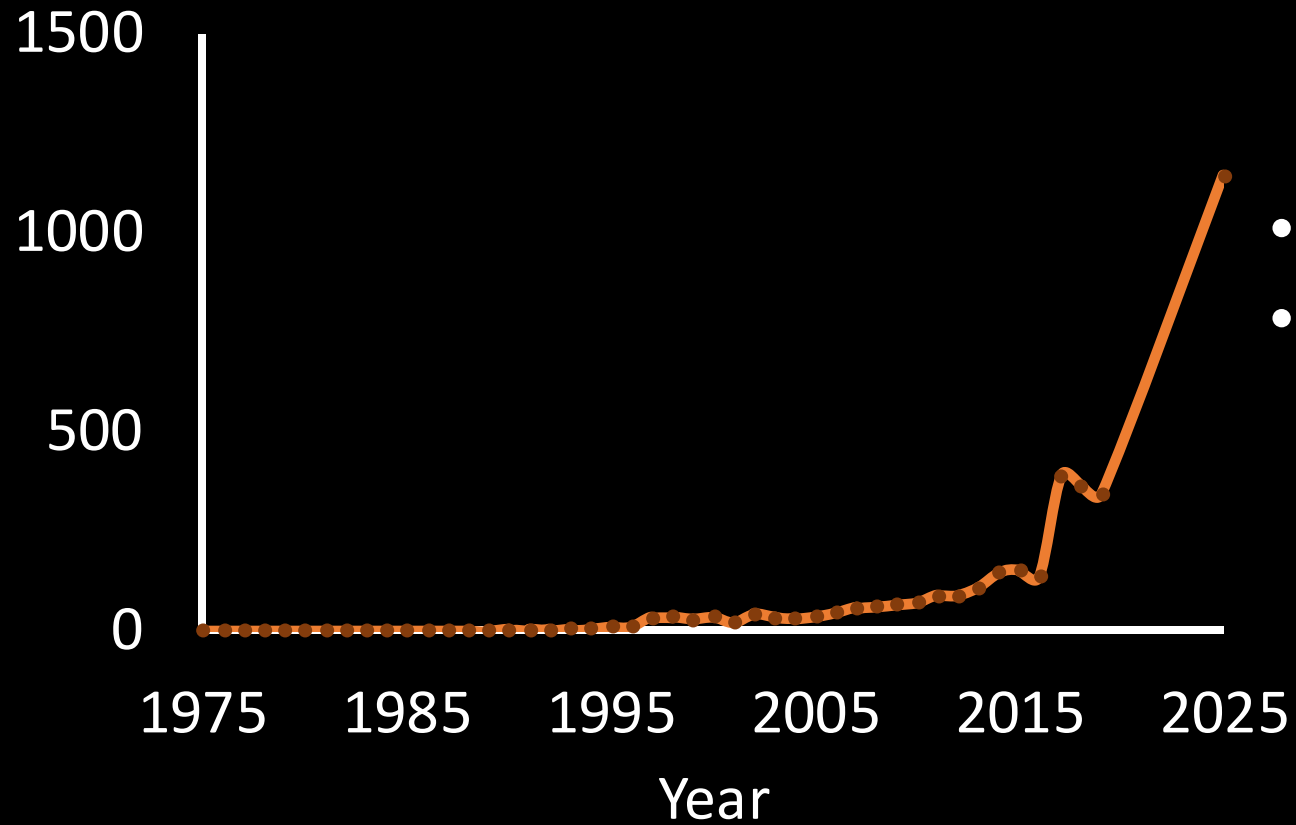


COM-405: Mobile Networks

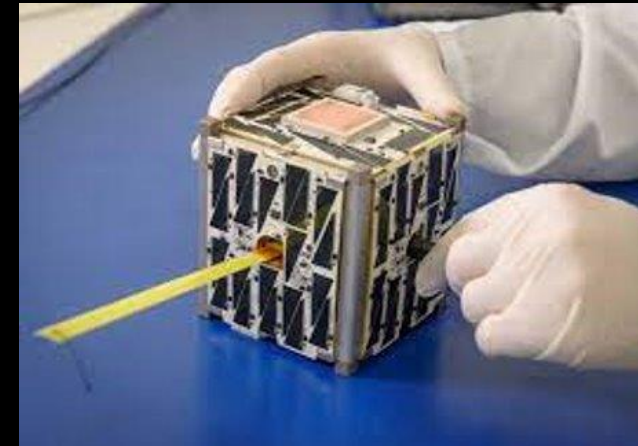
Lecture 12.2: Advanced Topics Haitham Hassanieh



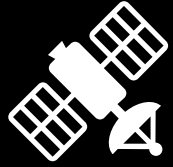
Satellites Launched Per Year



- Low-cost Cubesats
- Rideshare agreements for launch

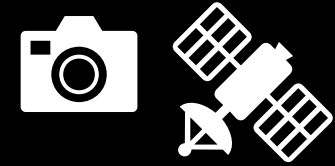
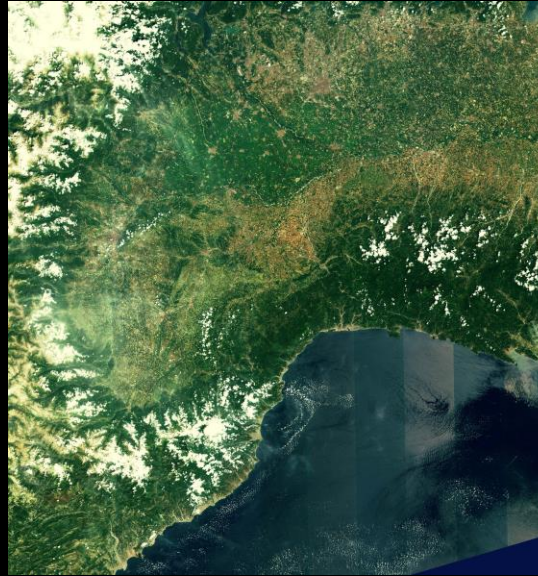


Communication



Global Internet Connectivity

Earth Observation



Sensing from Space

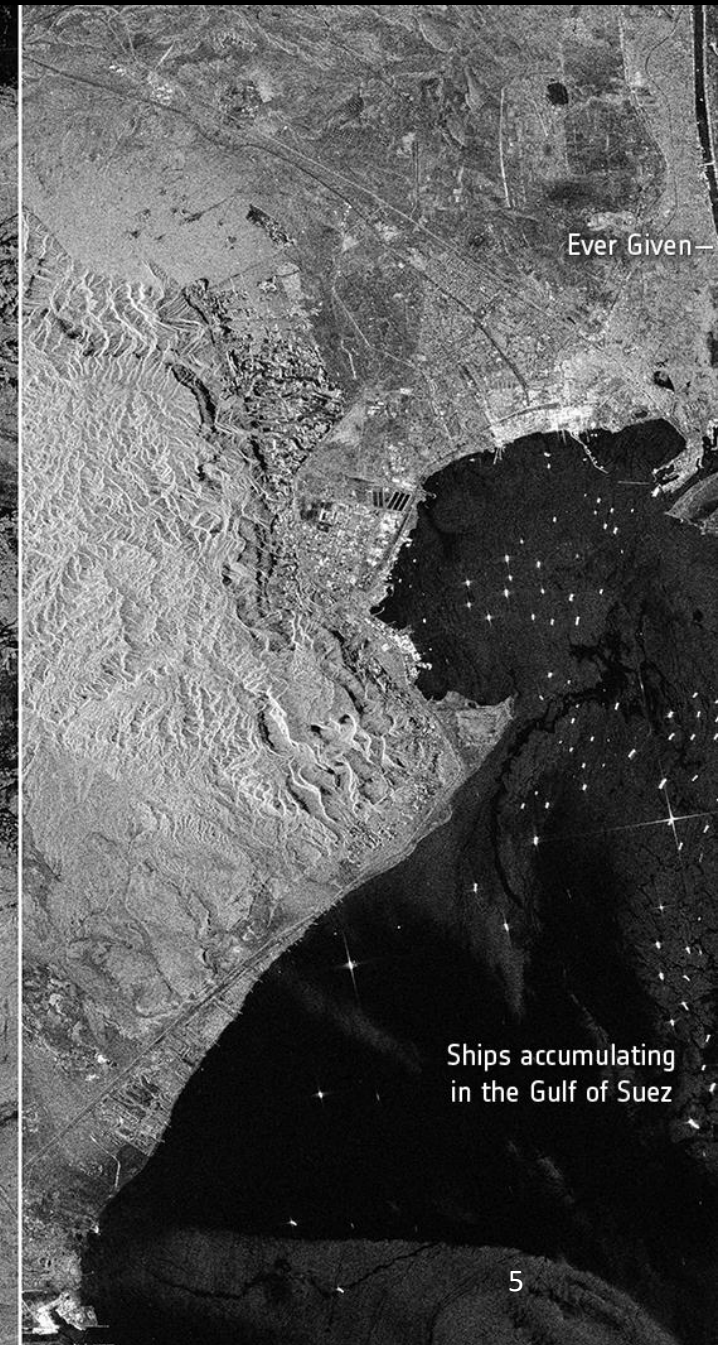
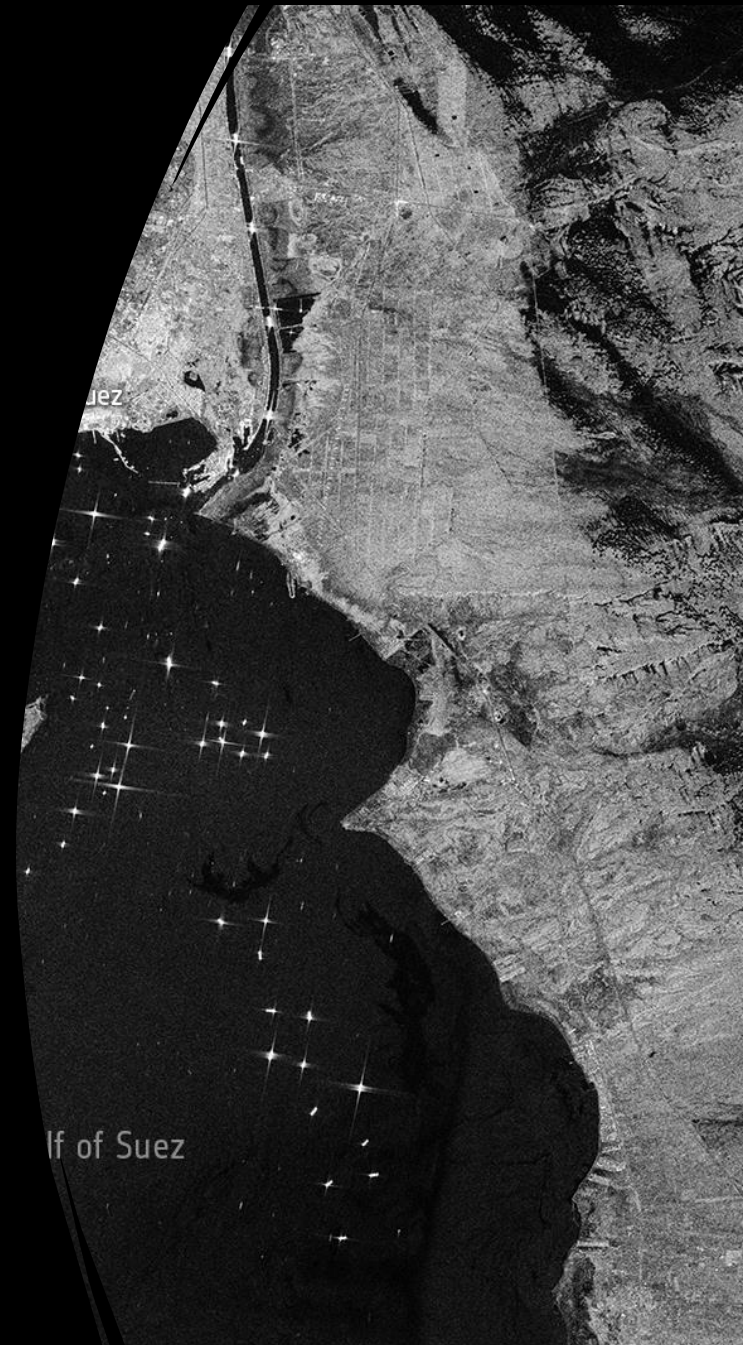
Earth Observation Applications: Agriculture

- Precision Agriculture
- Monitoring events like floods



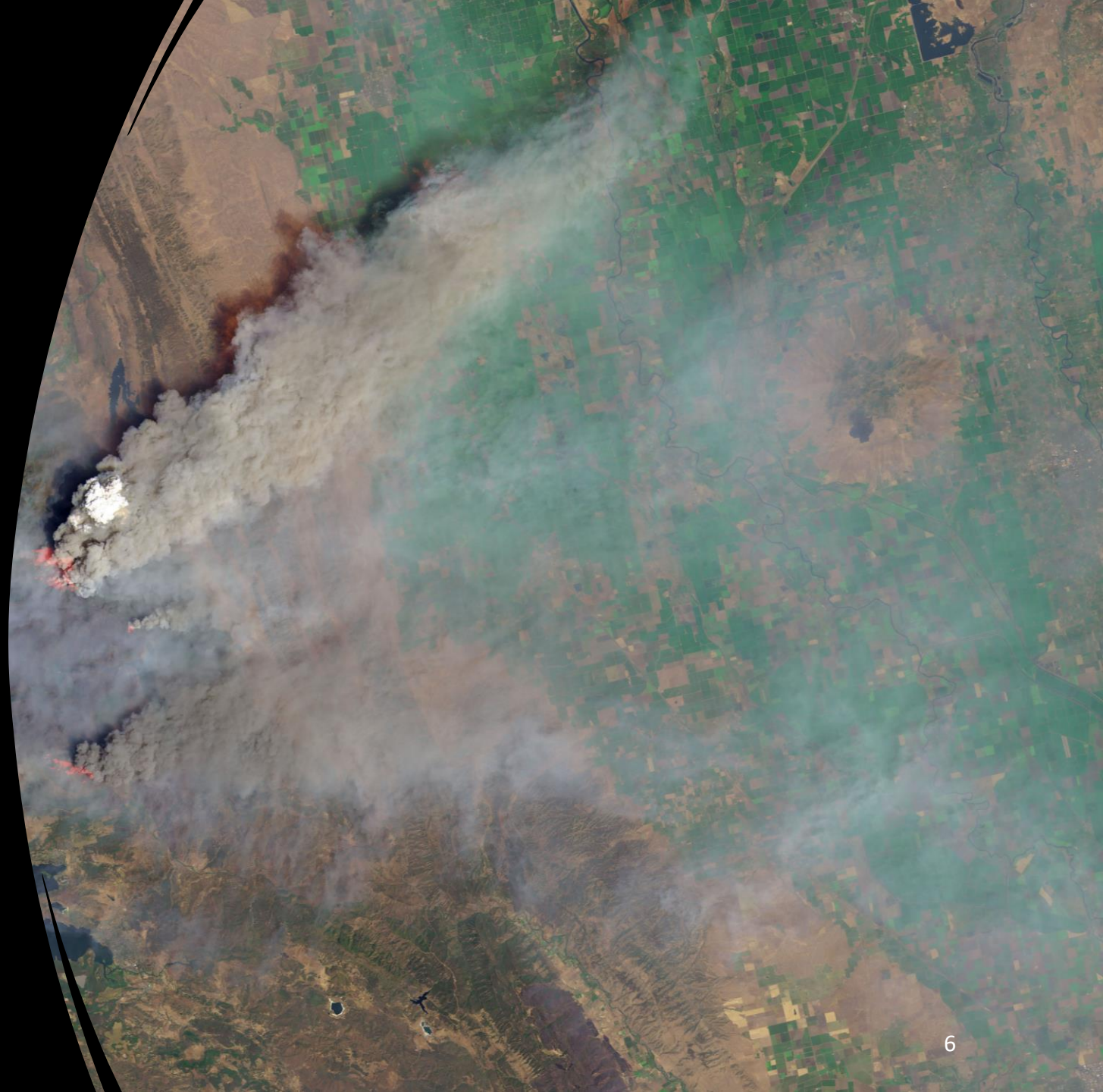
Earth Observation Applications: Maritime Tracking

- Track illegal smuggling
- Monitor ship traffic



Earth Observation Applications: Disaster Monitoring

- Early detection
- Tracking propagation



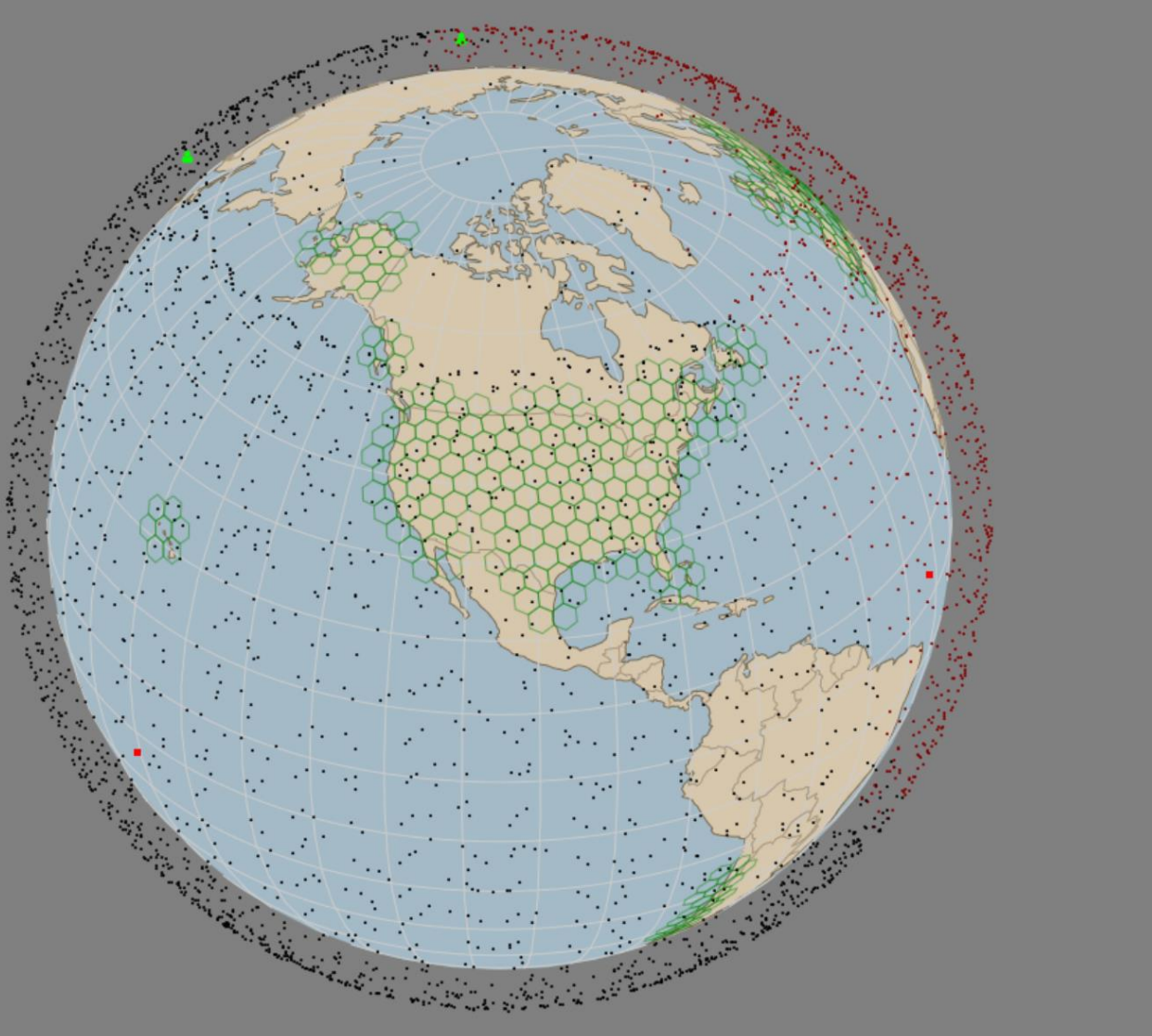


Capella Space

MAXAR

Source: NYTimes/Maxar

Communication Satellites

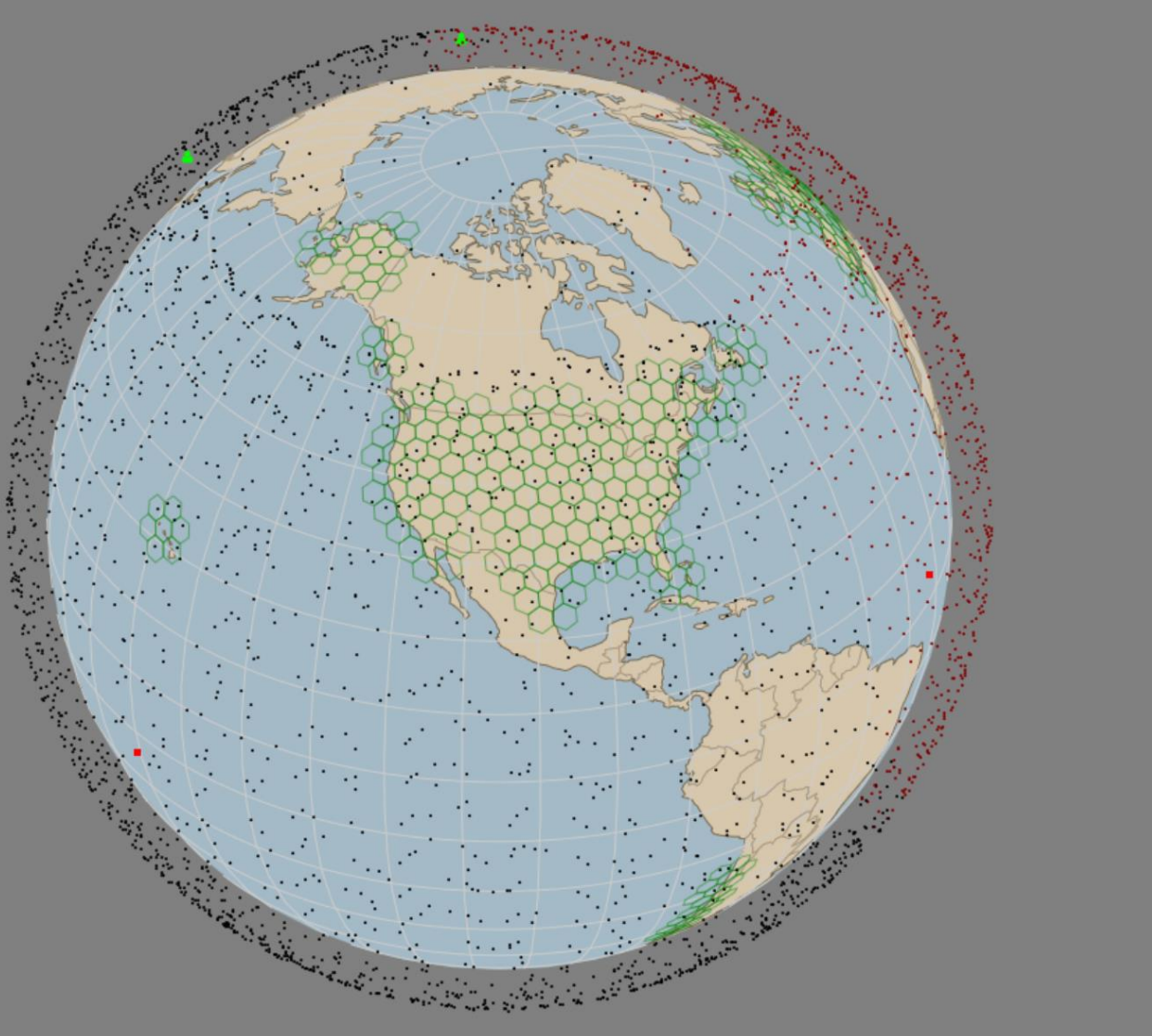


Starlink

*Nearly 5000
satellites in orbit*

42000 planned

Communication Satellites

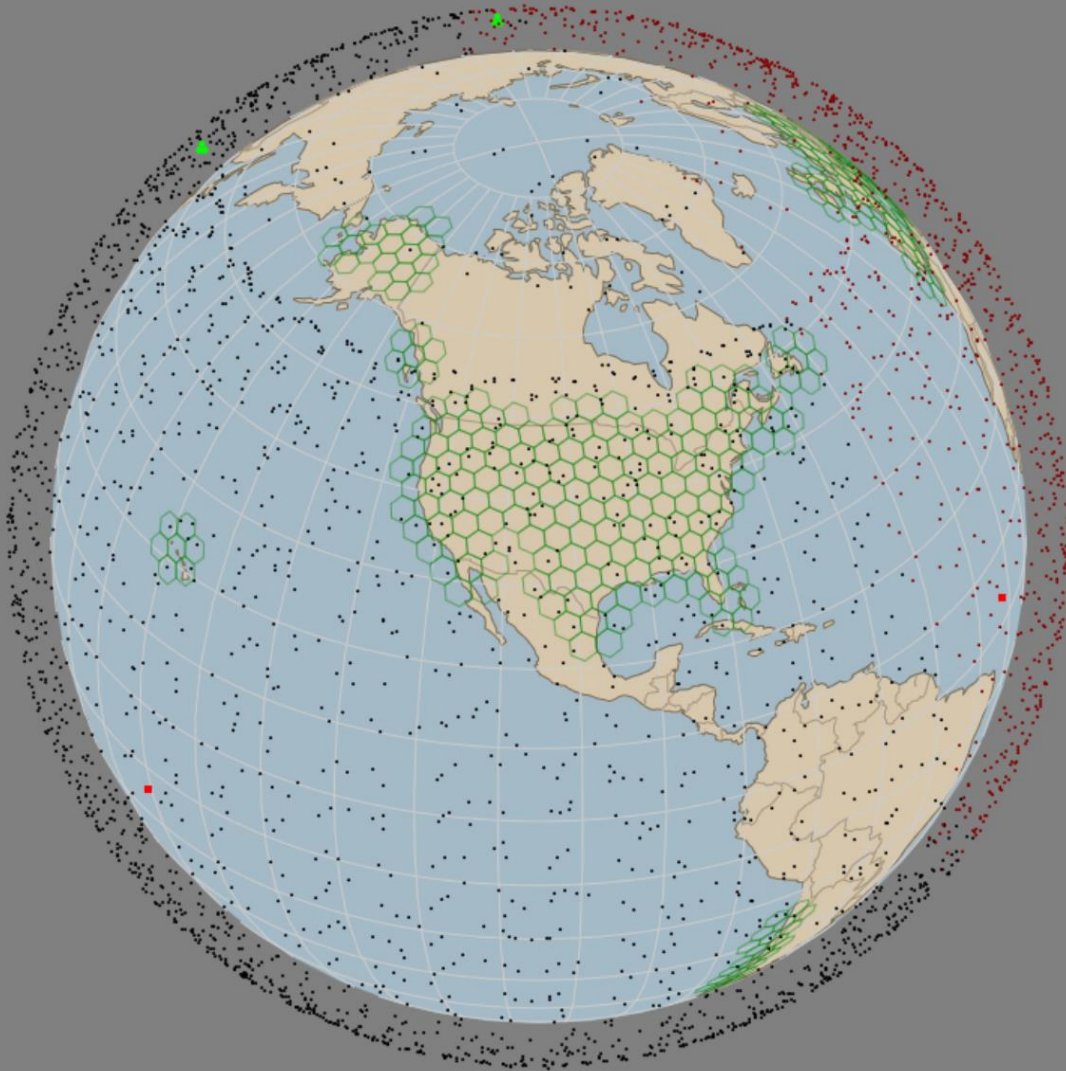


Amazon Kuiper

*Launched first set
of satellites in 2023*

3300 planned

Communication Satellites



Other Companies

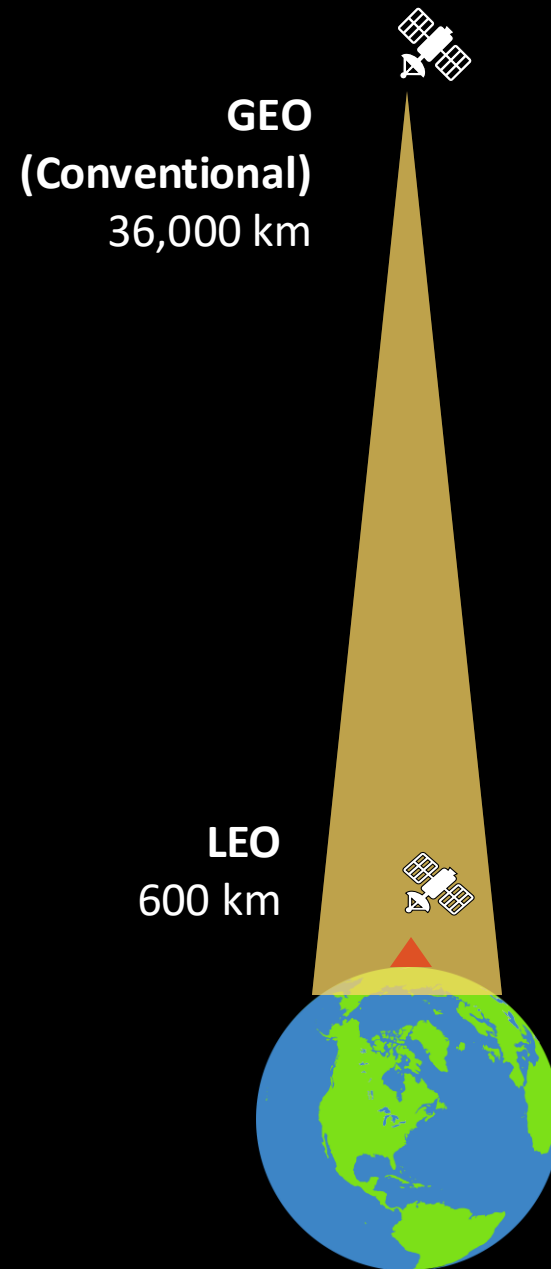
*ViaSat, HughesNet,
OneWeb, Telesat,
Echostar*

Why Satellite Internet?

- Coverage
 - Rural connectivity
 - Farms and forests
- Speed of light over air is faster than speed of light over fiber (by 50%)
 - Lower latency

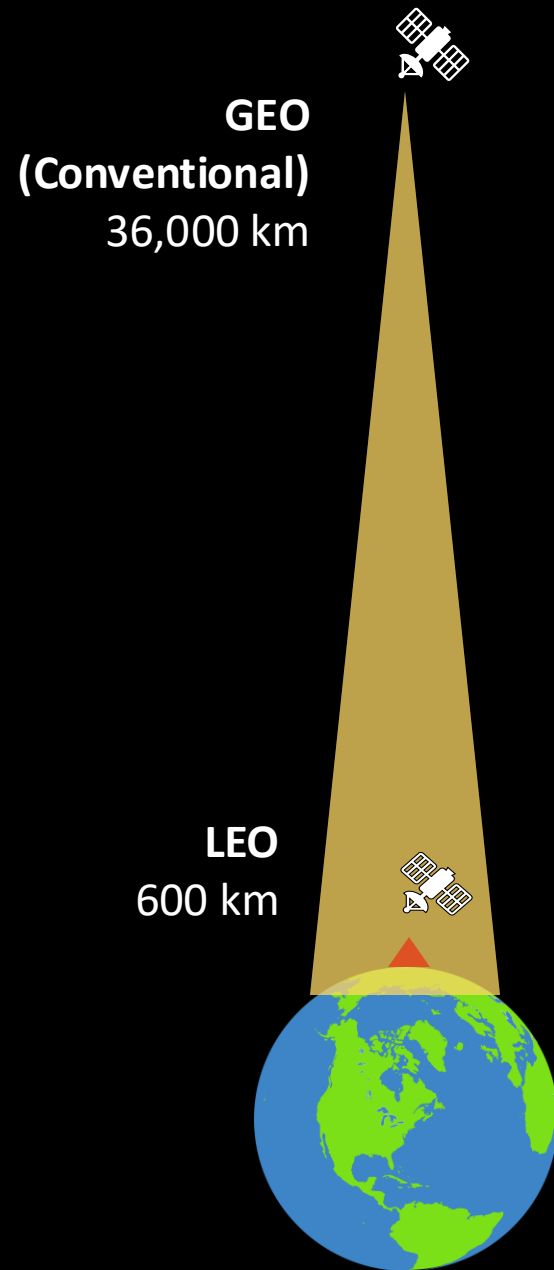


Satellite Orbits



Which orbit leads to better coverage?

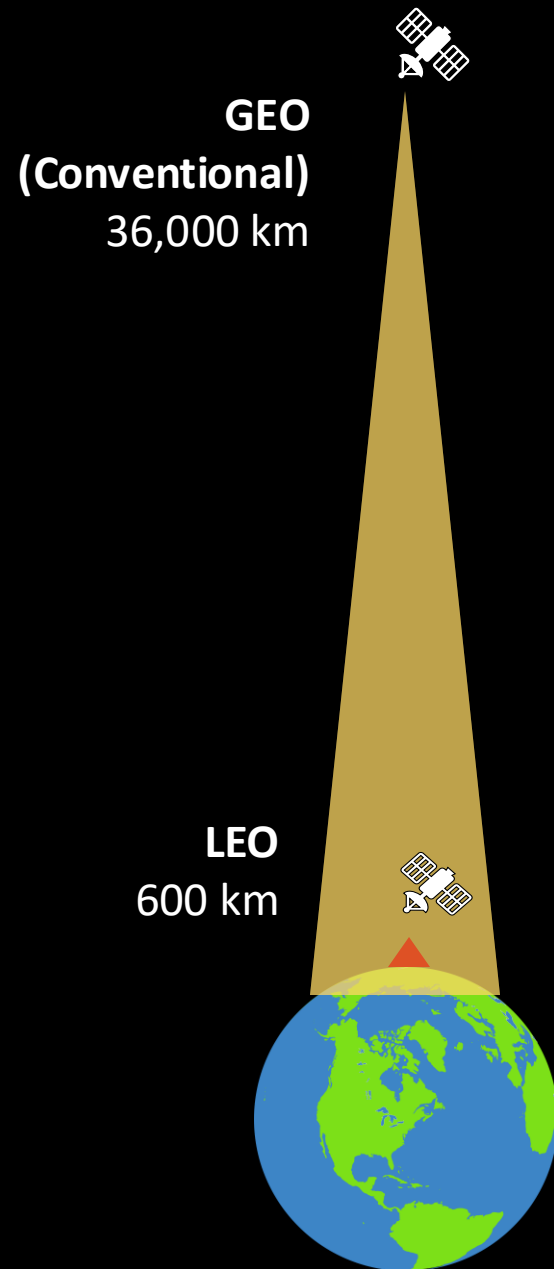
Satellite Orbits



Which satellite moves more?

Starlink satellites move few Kms per second

Satellite Orbits



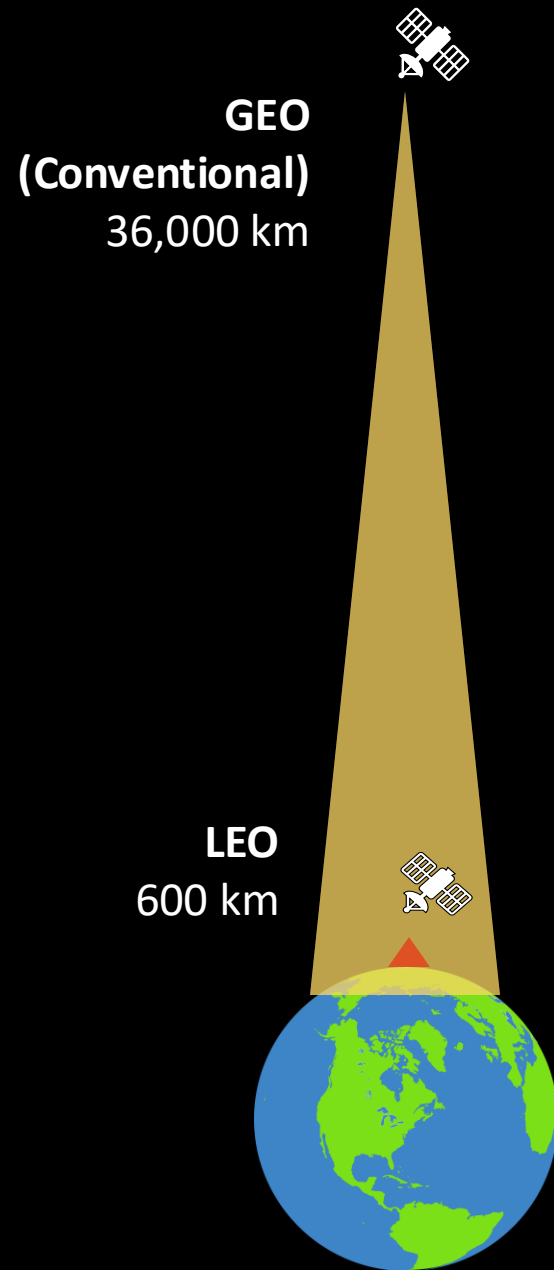
Which satellite gets stronger signals?

Power decays as d^{-2}

60X more distance

35 dB extra loss

Satellite Orbits



What about delays?

Speed of light delay:

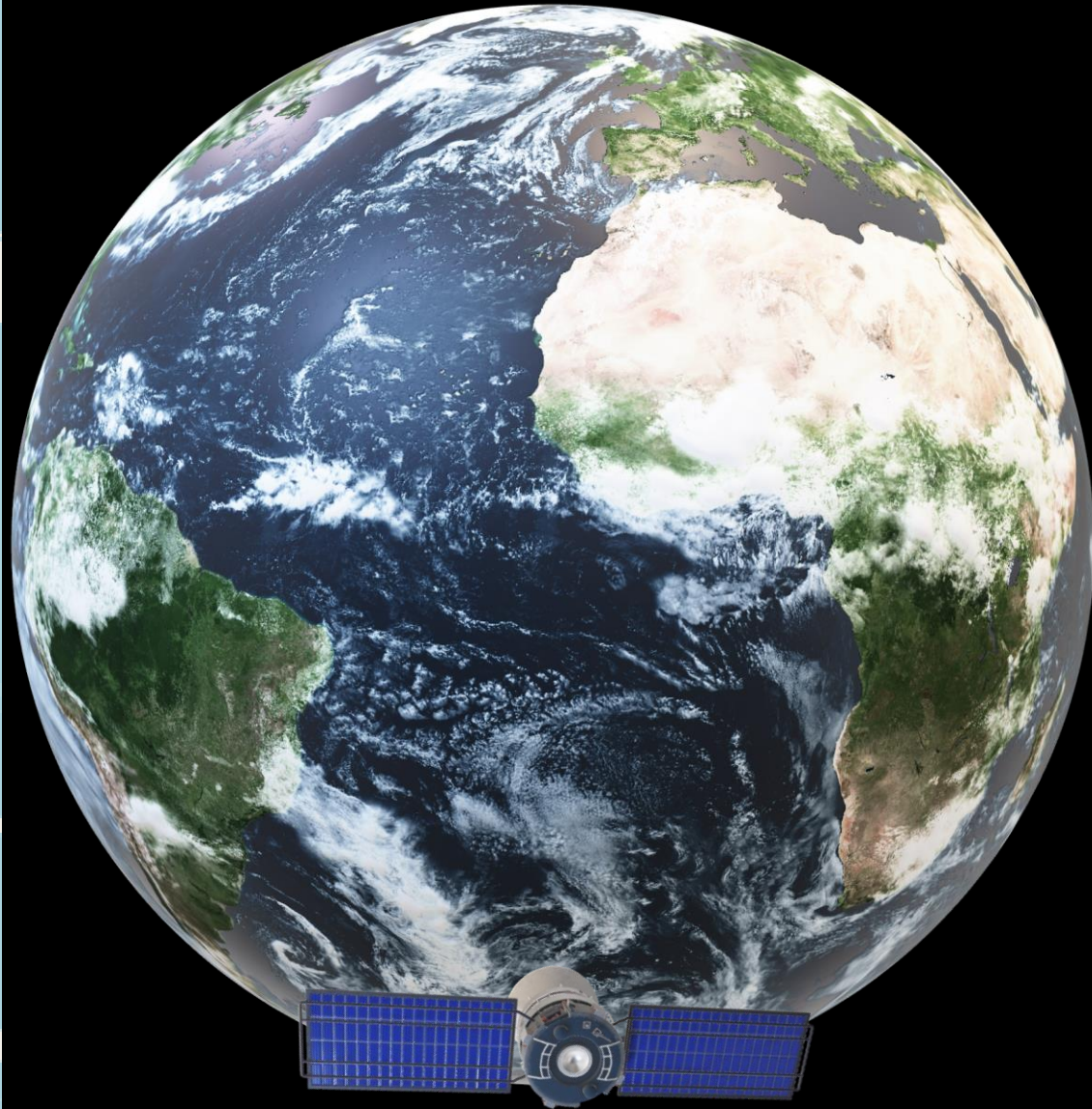
GEO: >240 ms

LEO: >4 ms

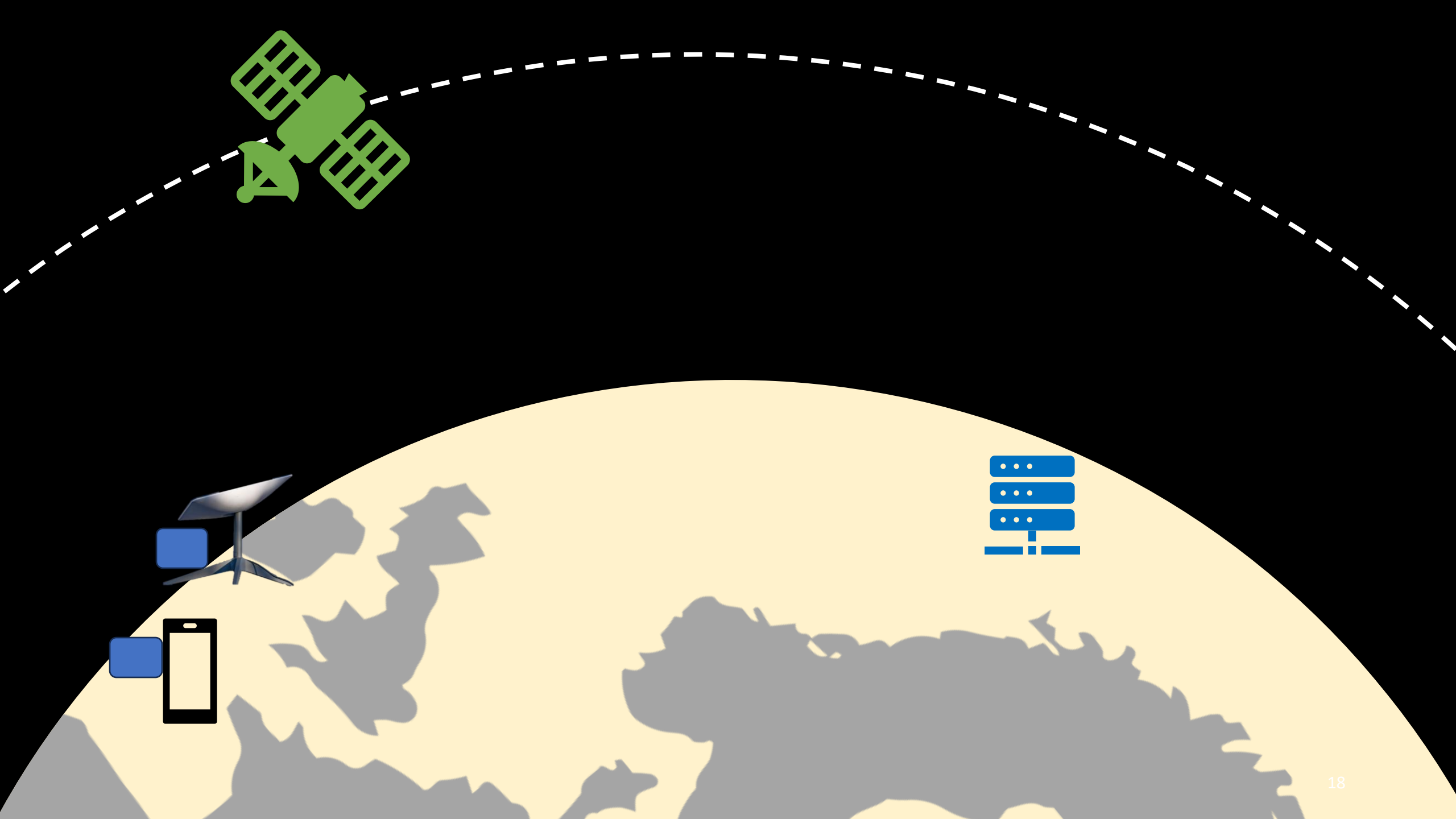
LEO Satellite Dynamics

- Low Earth Orbits
- ~90 min period

Weddell
Sea

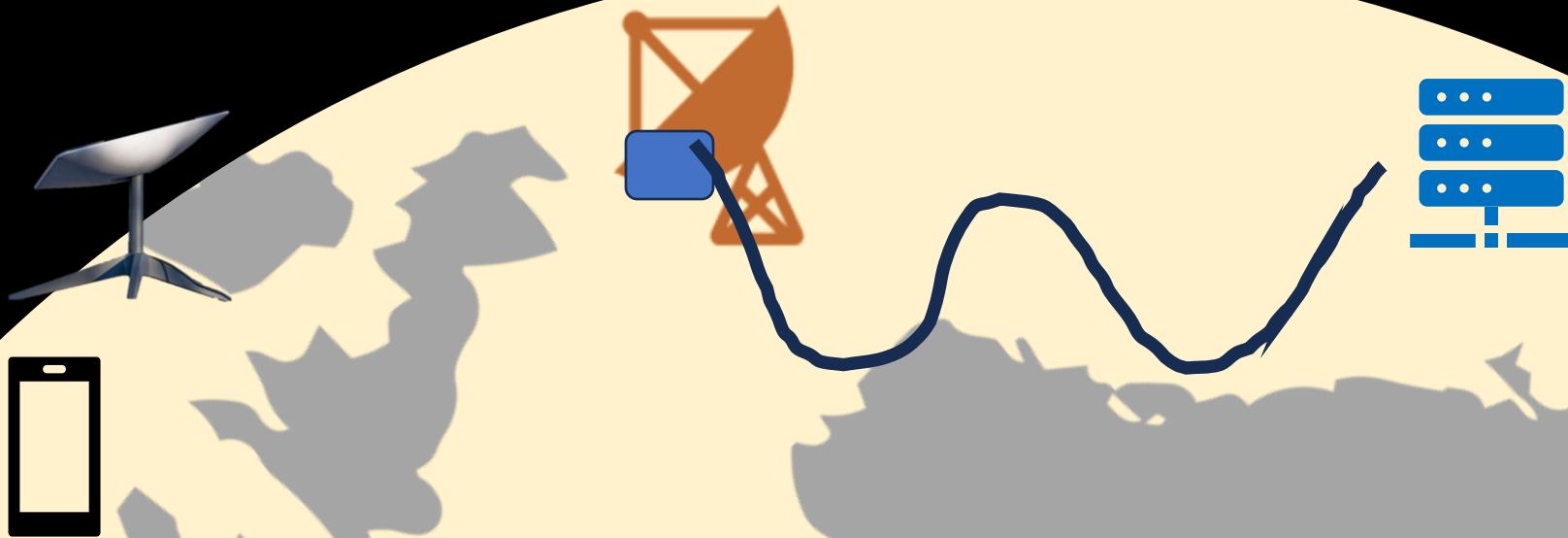


How does Satellite Internet Works?





Option 1: Bent Pipe Architecture

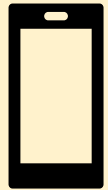
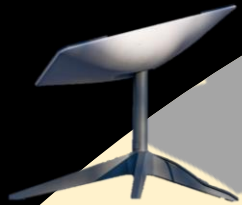


Bent-Pipe Architecture

- Needs MANY ground stations
- Starlink has nearly 100 ground stations in US



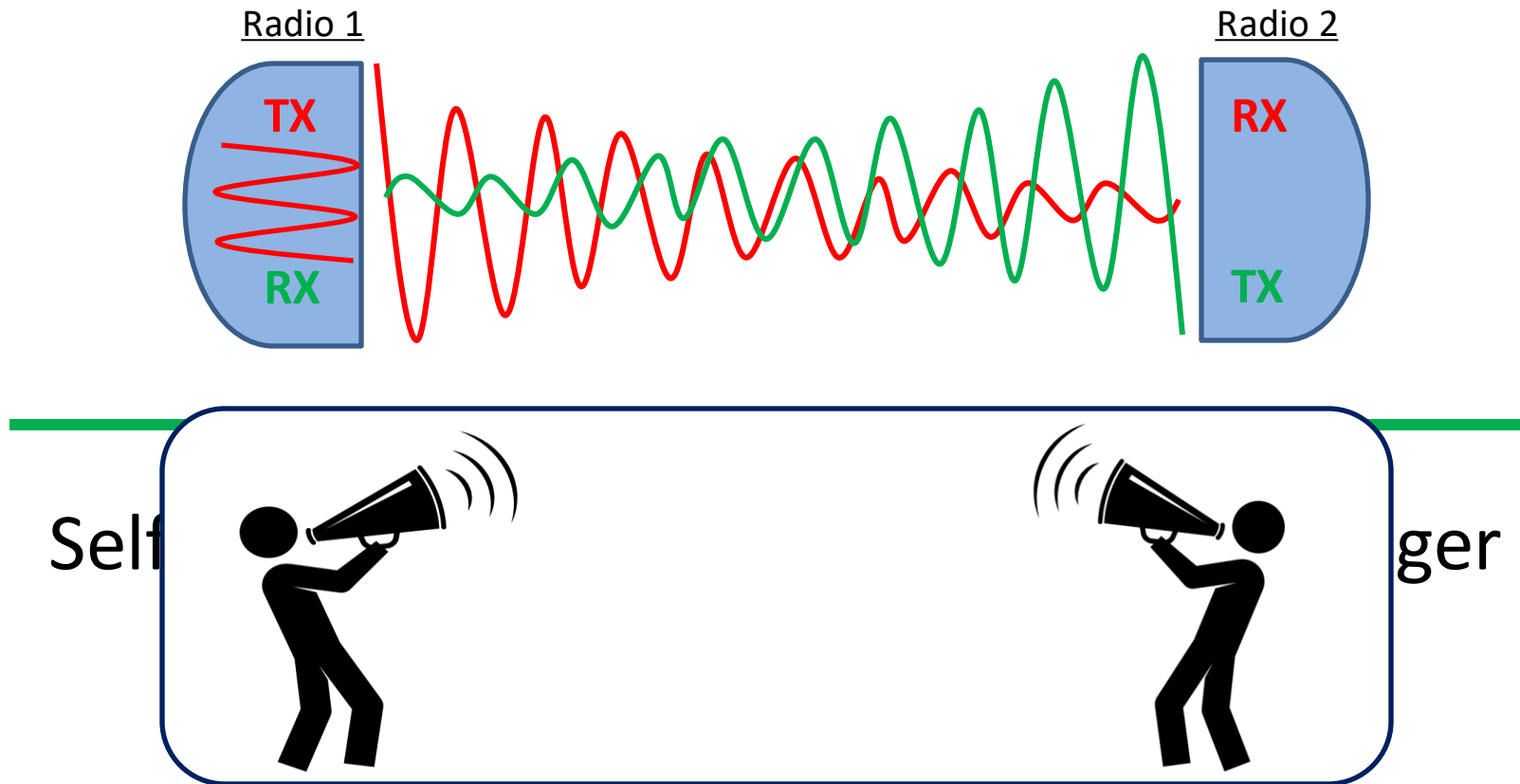
Option 2: Inter Satellite Links



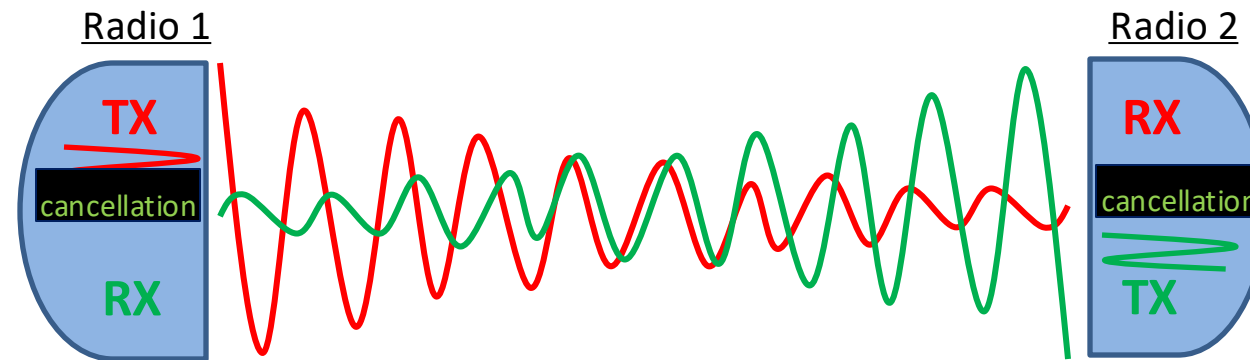
Full Duplex Radios

“It is generally **not possible** for radios to receive and transmit on the same frequency band because of the interference that results.”

Why Aren't Radios Today Full Duplex?

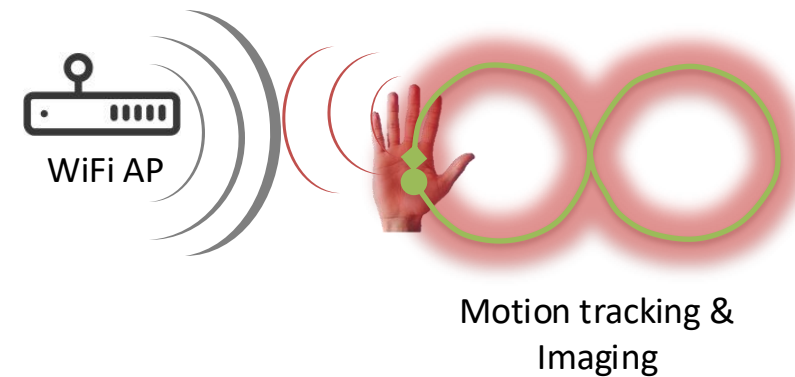
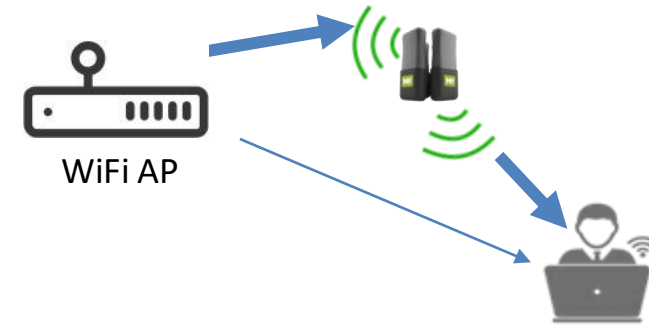


With self-interference cancellation, radios can transmit and receive on the same channel!



Applications of full duplex radios:

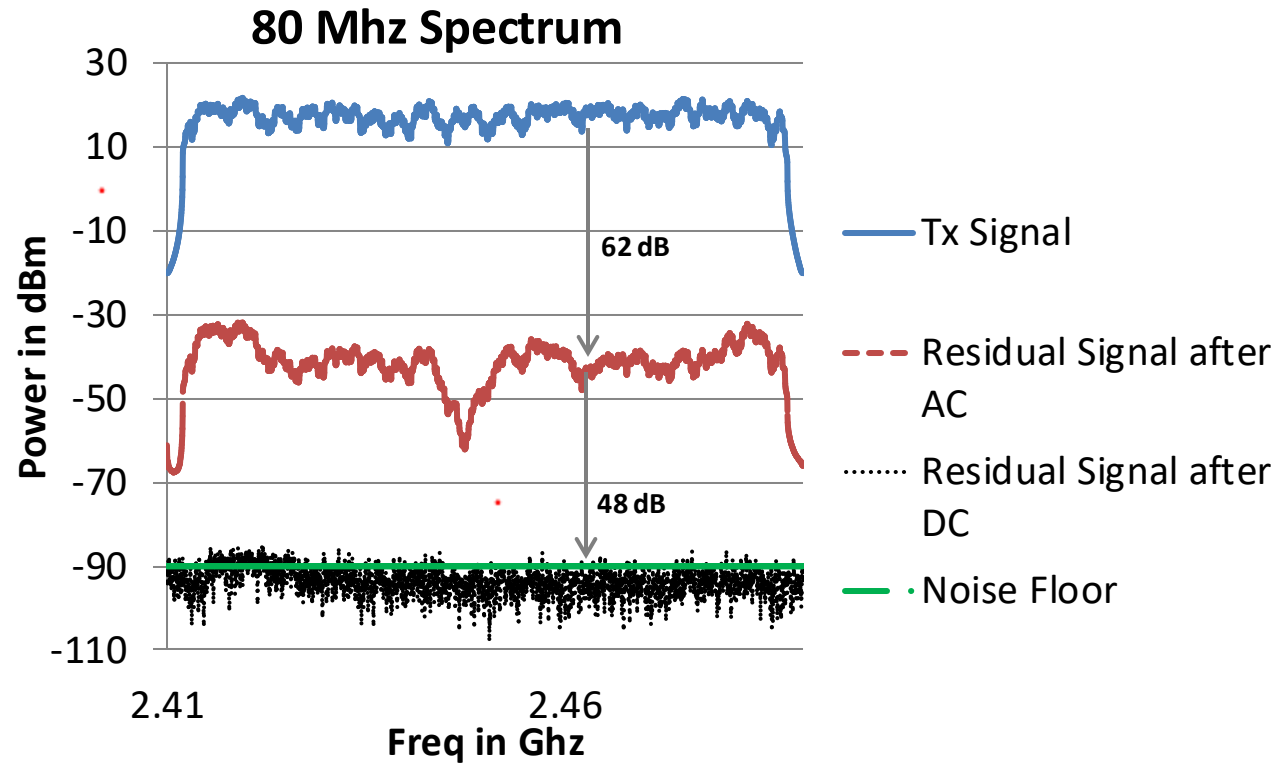
- TX/RX on same time same channel
→ Double Spectral Efficiency!
- Extend range with full duplex relays
- WiFi Backscatter
- Better MAC: CSMA/CD in wireless
- Motion tracking & imaging in WiFi
- Security: Friendly Jamming



Cancellation Performance

80 MHz Bandwidth. WiFi OFDM waveform, 20 dBm TX power at 2.45 GHz

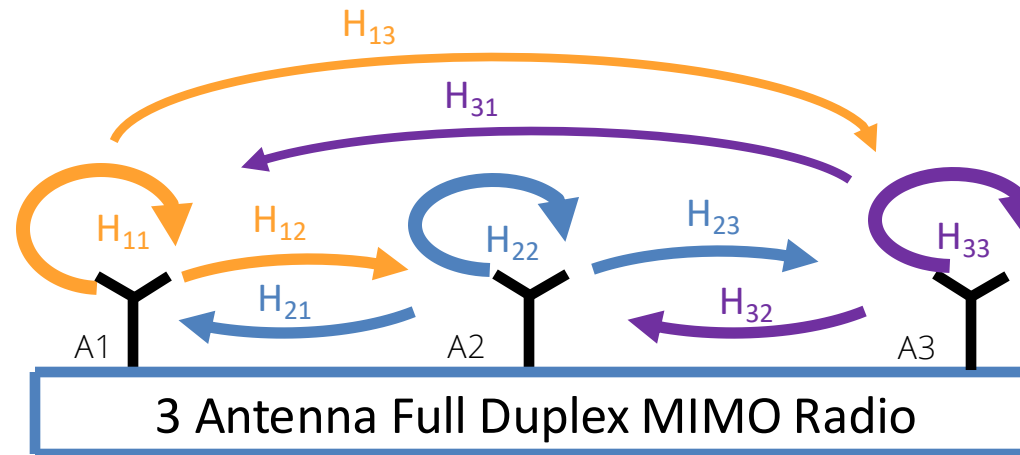
- Wideband
- Tunes to environmental changes within 8us, needs to be re-tuned every 100ms



$$\begin{array}{|c|} \hline \text{Analog} \\ \hline >60\text{dB} \\ \hline \end{array} + \begin{array}{|c|} \hline \text{Digital} \\ \hline \sim 50\text{dB} \\ \hline \end{array} = \begin{array}{|c|} \hline \text{Total} \\ \hline >110\text{dB} \\ \hline \end{array}$$

Full duplex radios: MIMO

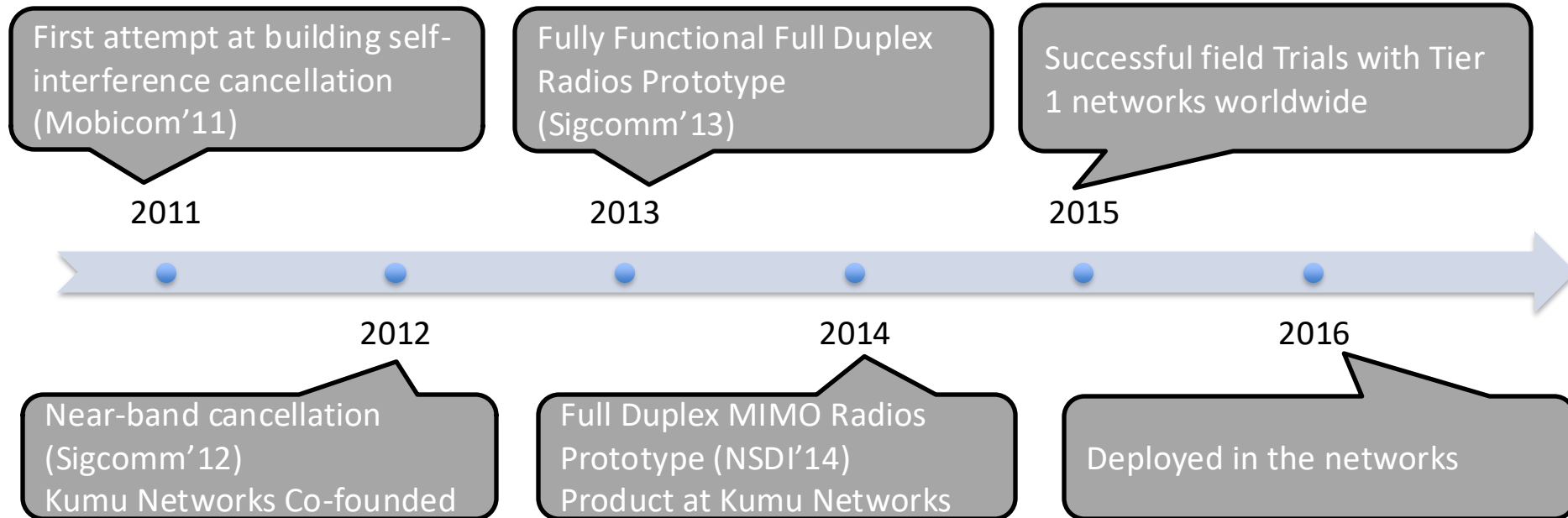
How is the MIMO full duplex problem different?



Want:

- Cancellation complexity scales linearly with M (number of antennas).
- Cancellation residue is the same as the SISO full duplex, i.e. it does not degrade with increasing number of antennas.

From Impossibility to Practice



Intelligent Reflecting Surface (IRS)

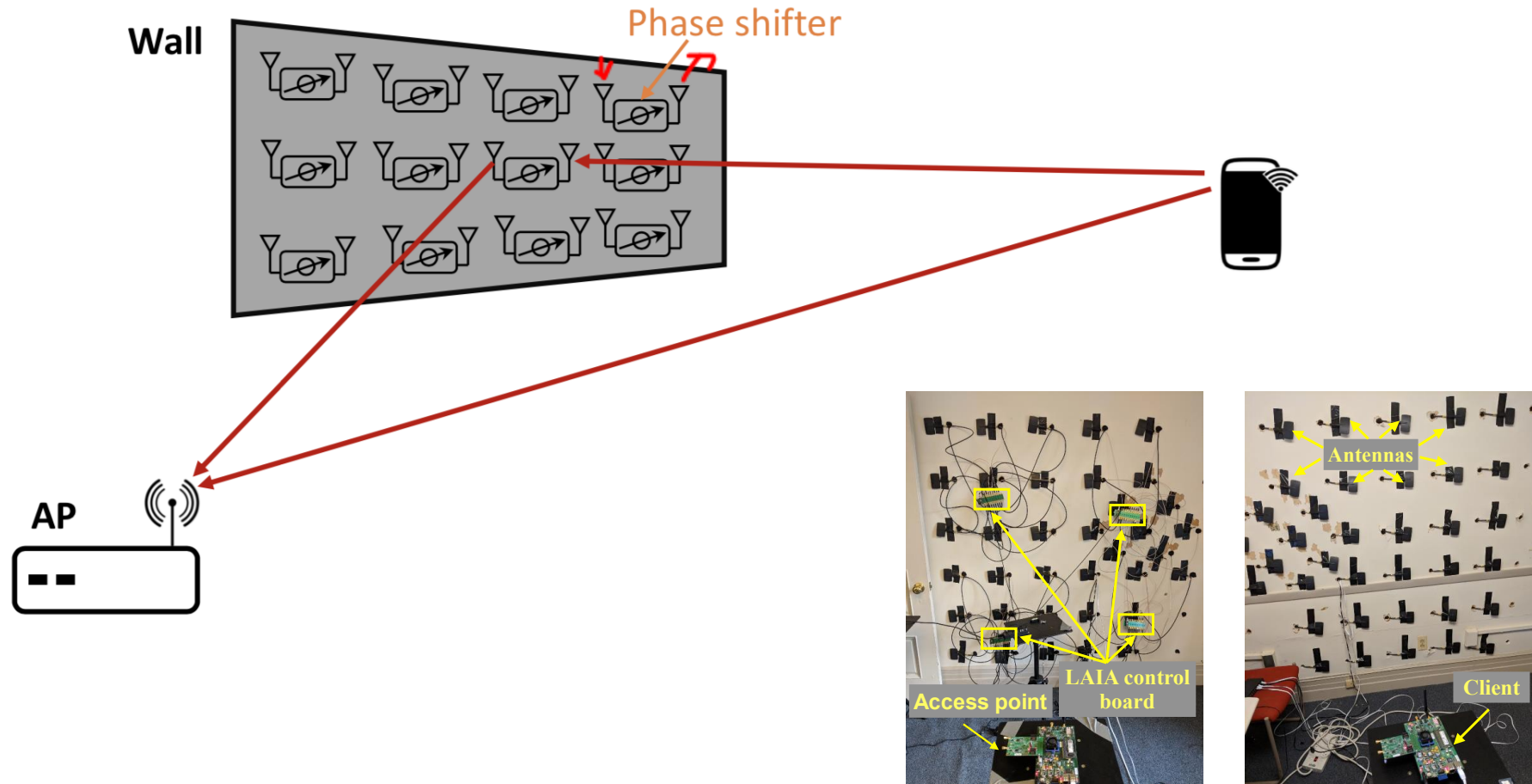
Today: Wireless Networks Adapt to Environment

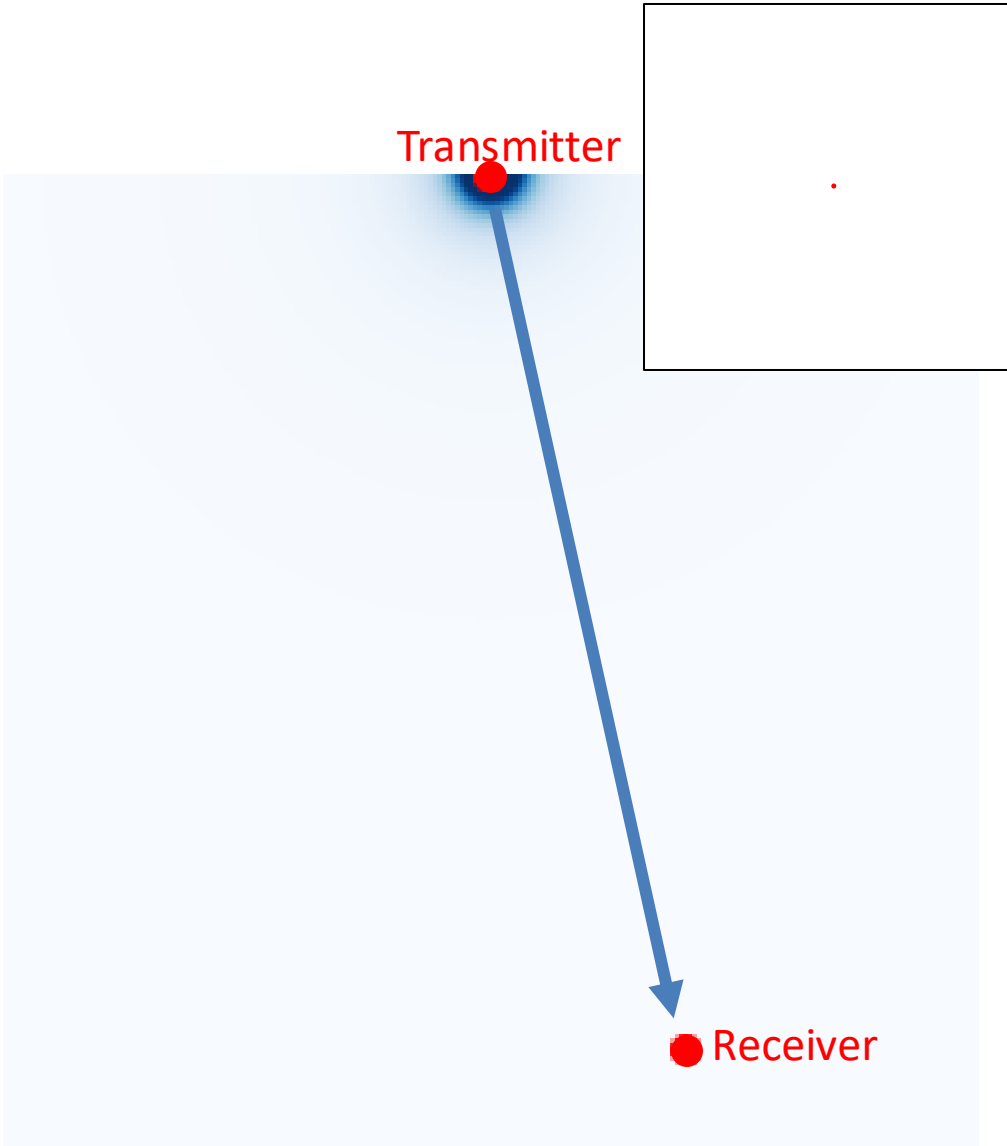
Wireless Signal Strength depends on the way the signal propagates in the environment & it changes quickly and is unpredictable.

- If Signal is Bad
 - Reduce data rate
- If Signal is Good
 - Increase data rate

New Approach: IRS (Intelligent Reconfigurable Surface)

Programmable Radio Surfaces Change the way the wireless signal propagates

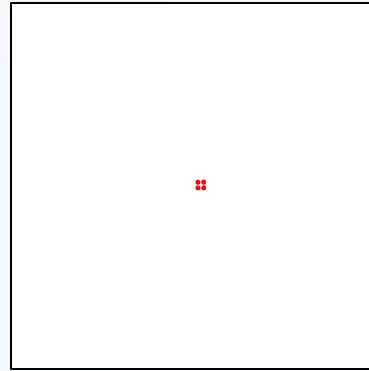




1 Antenna

Goal: Maximize signal strength at receiver

Transmitter

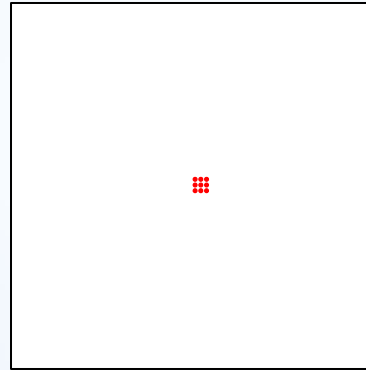


4 Antennas

Receiver



Transmitter

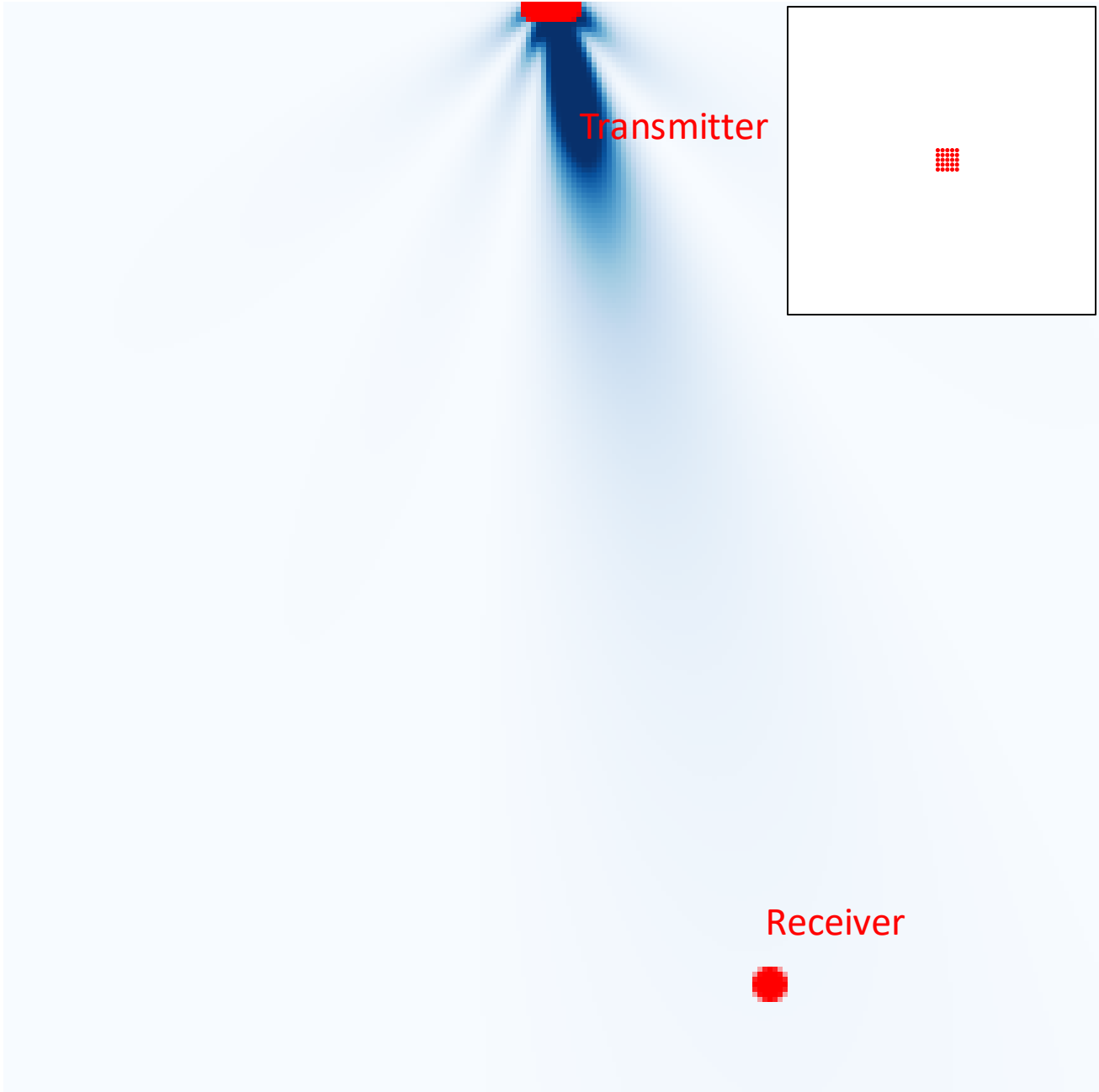


9 Antennas

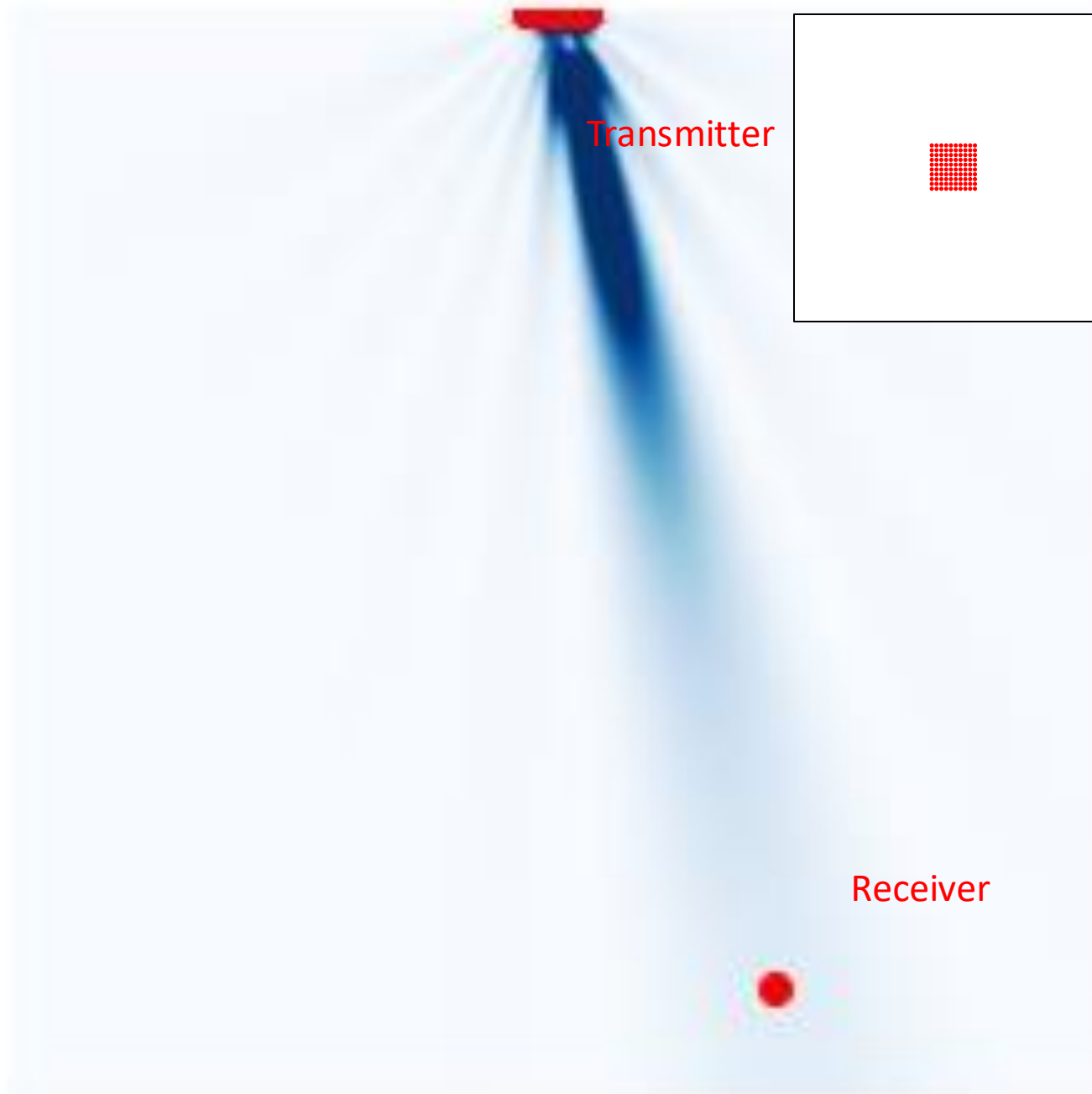


Receiver





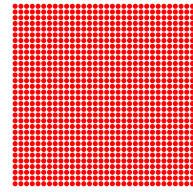
25 Antennas



100 Antennas



Transmitter

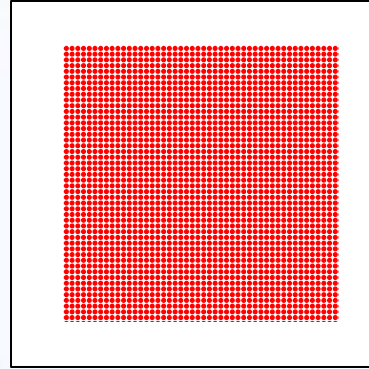


1024 Antennas

Receiver



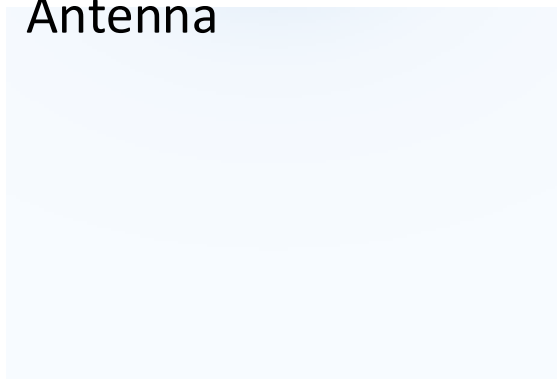
Transmitter



3136 Antennas

Receiver

1
Antenna



100 Antennas



3136 Antennas



Beamforming ability is a function of the number of wavelengths the device spans

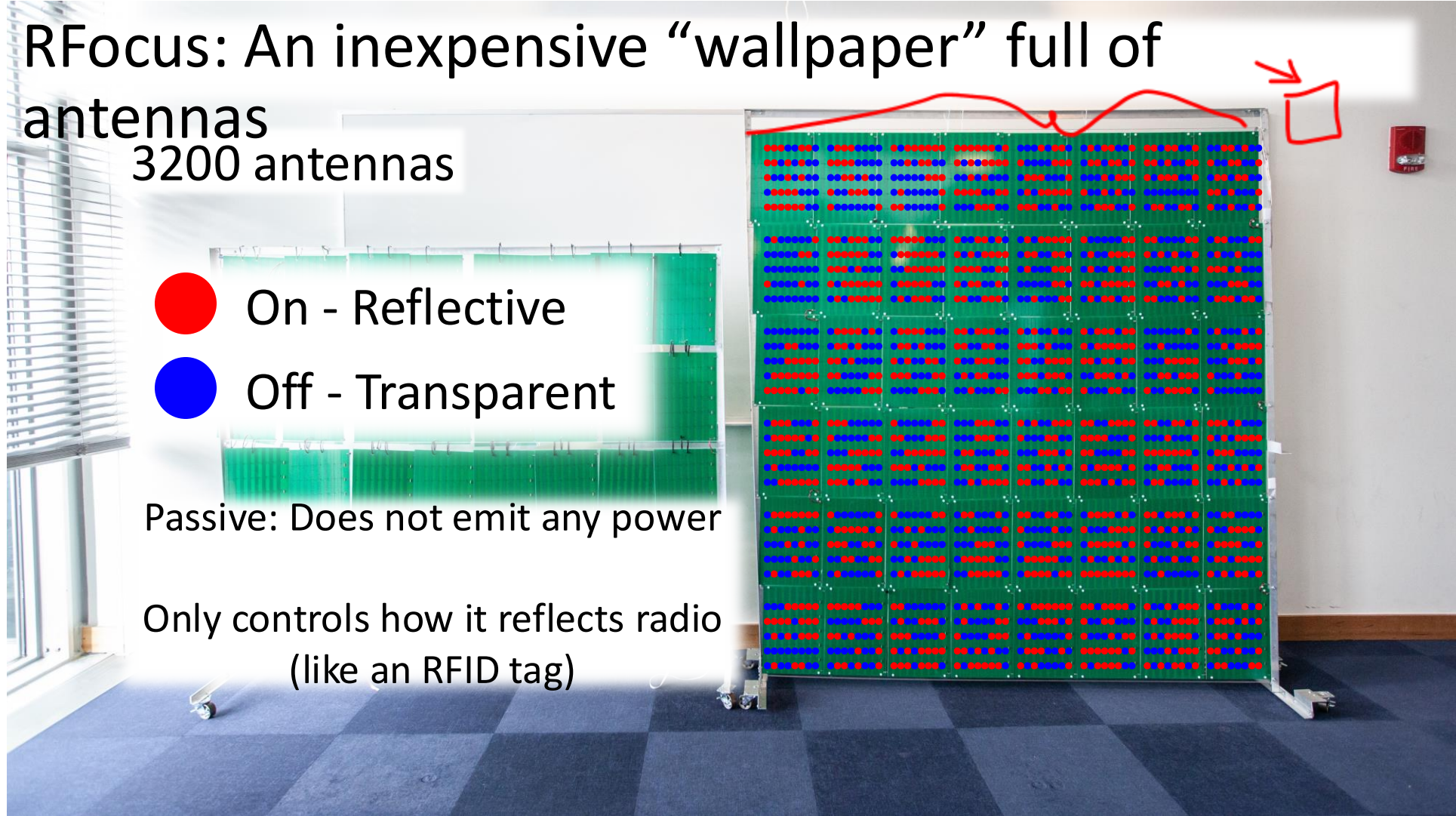
RFocus: An inexpensive “wallpaper” full of antennas

3200 antennas

- On - Reflective
- Off - Transparent

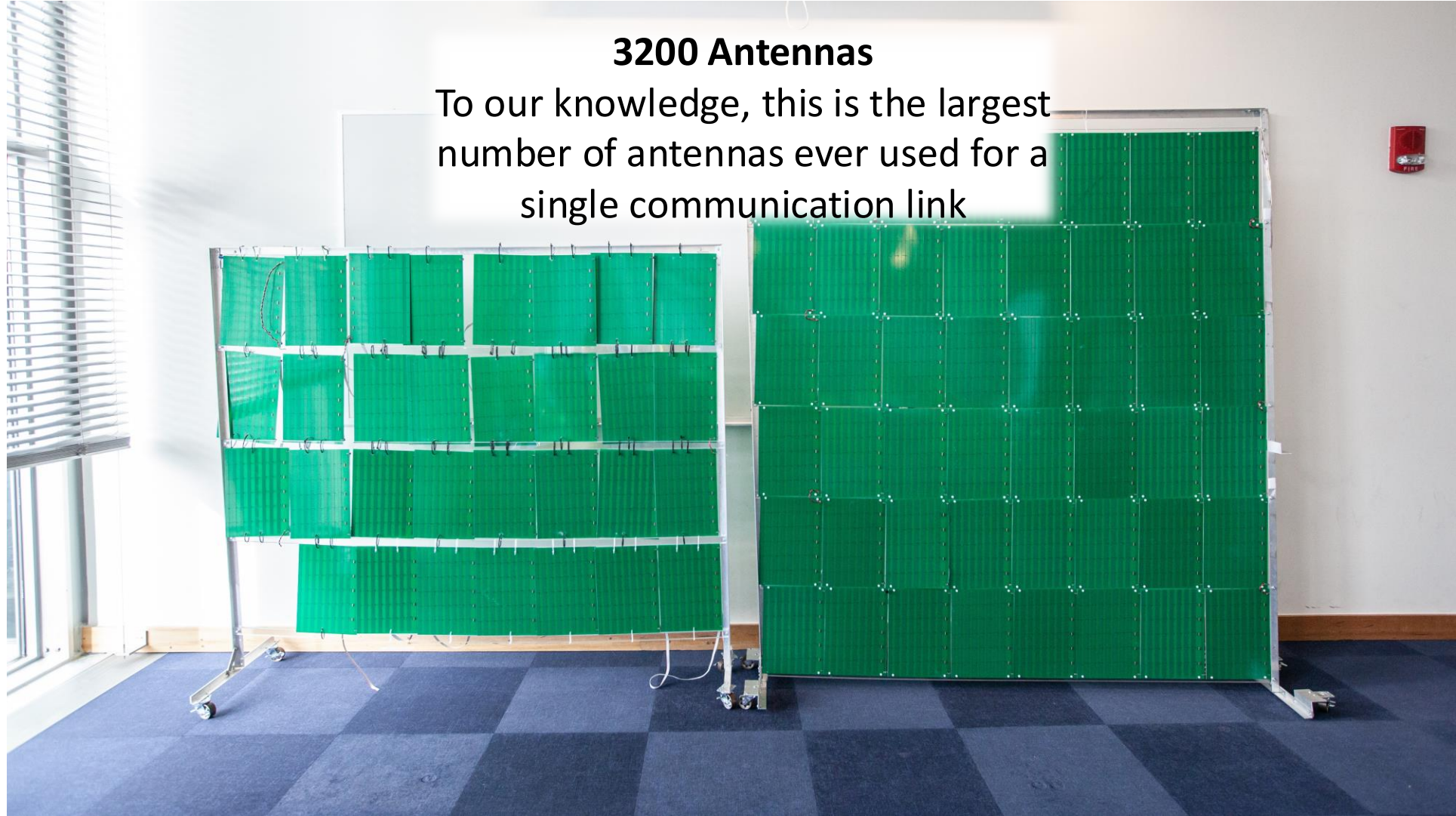
Passive: Does not emit any power

Only controls how it reflects radio
(like an RFID tag)

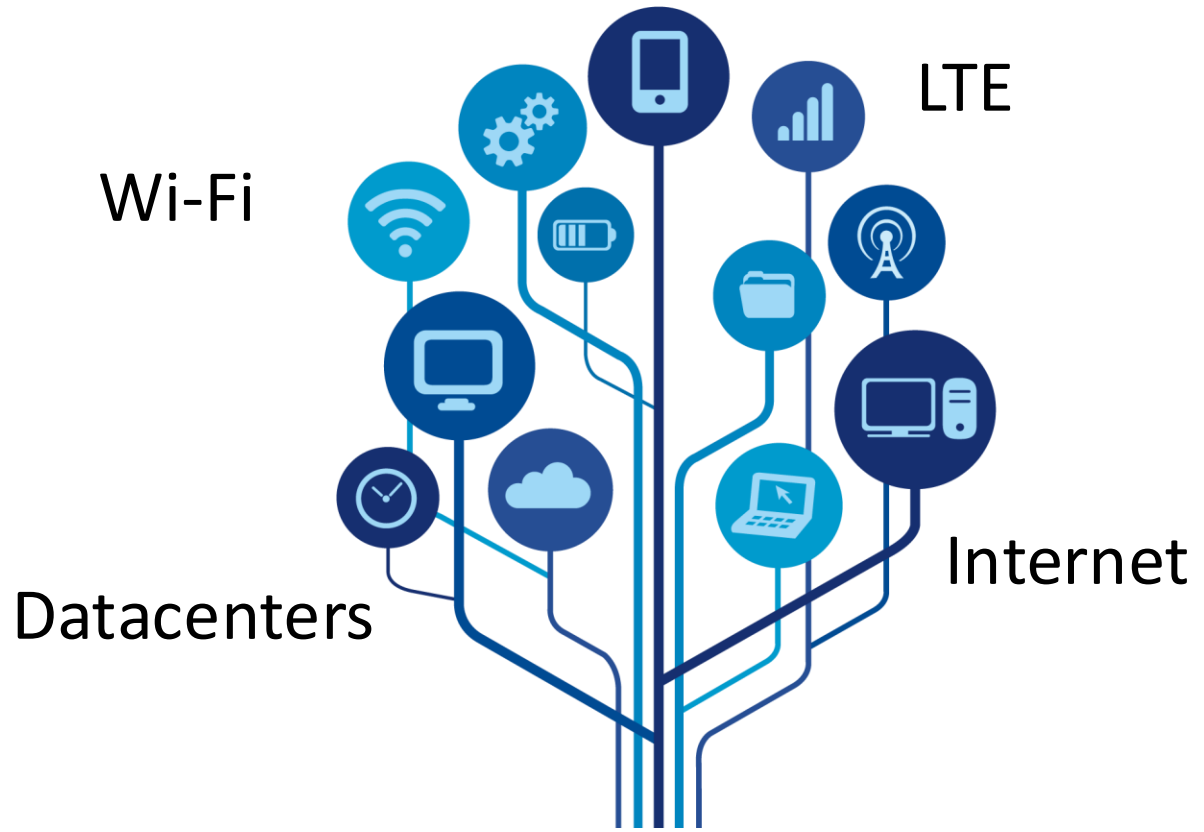


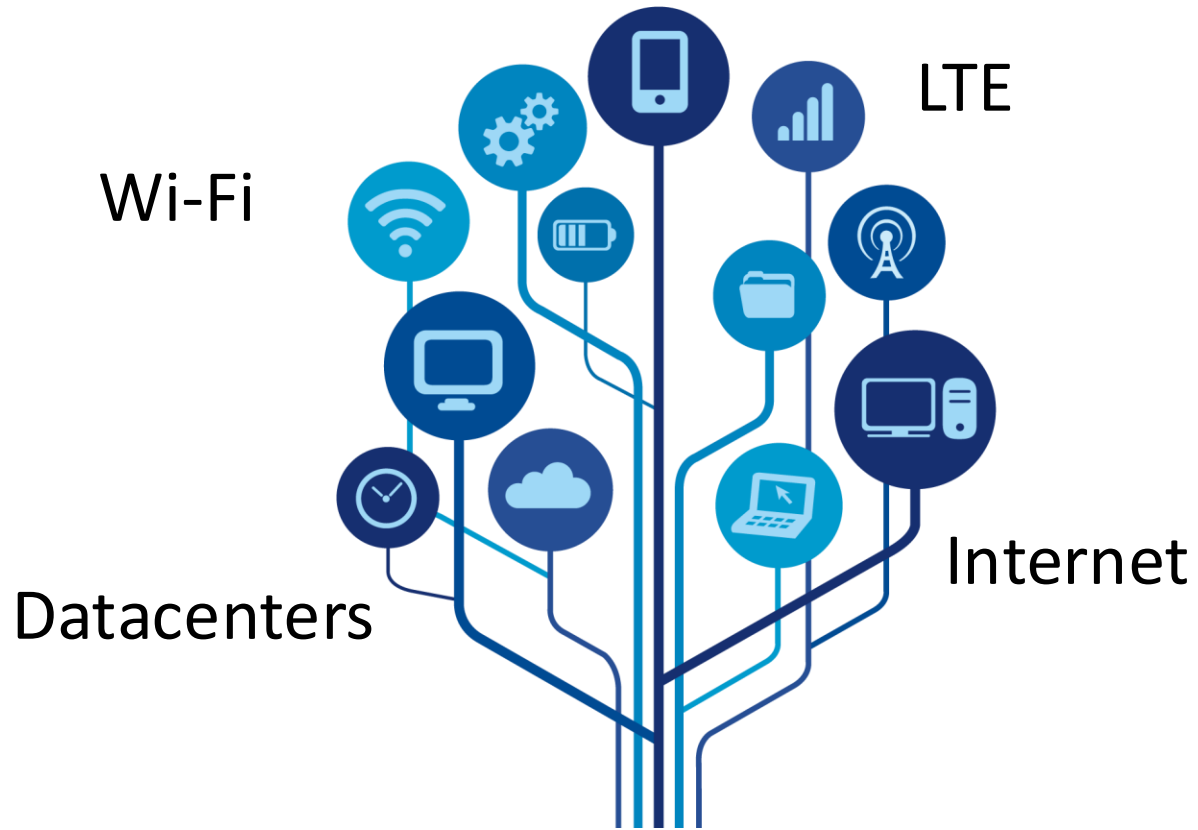
3200 Antennas

To our knowledge, this is the largest number of antennas ever used for a single communication link

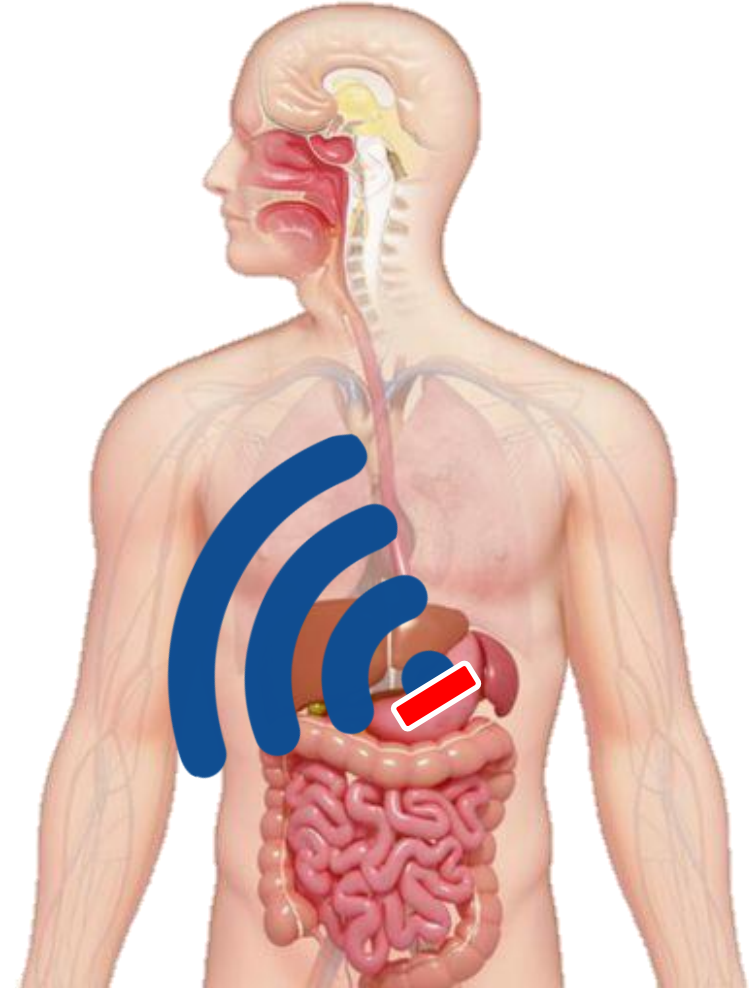


Medical Implants

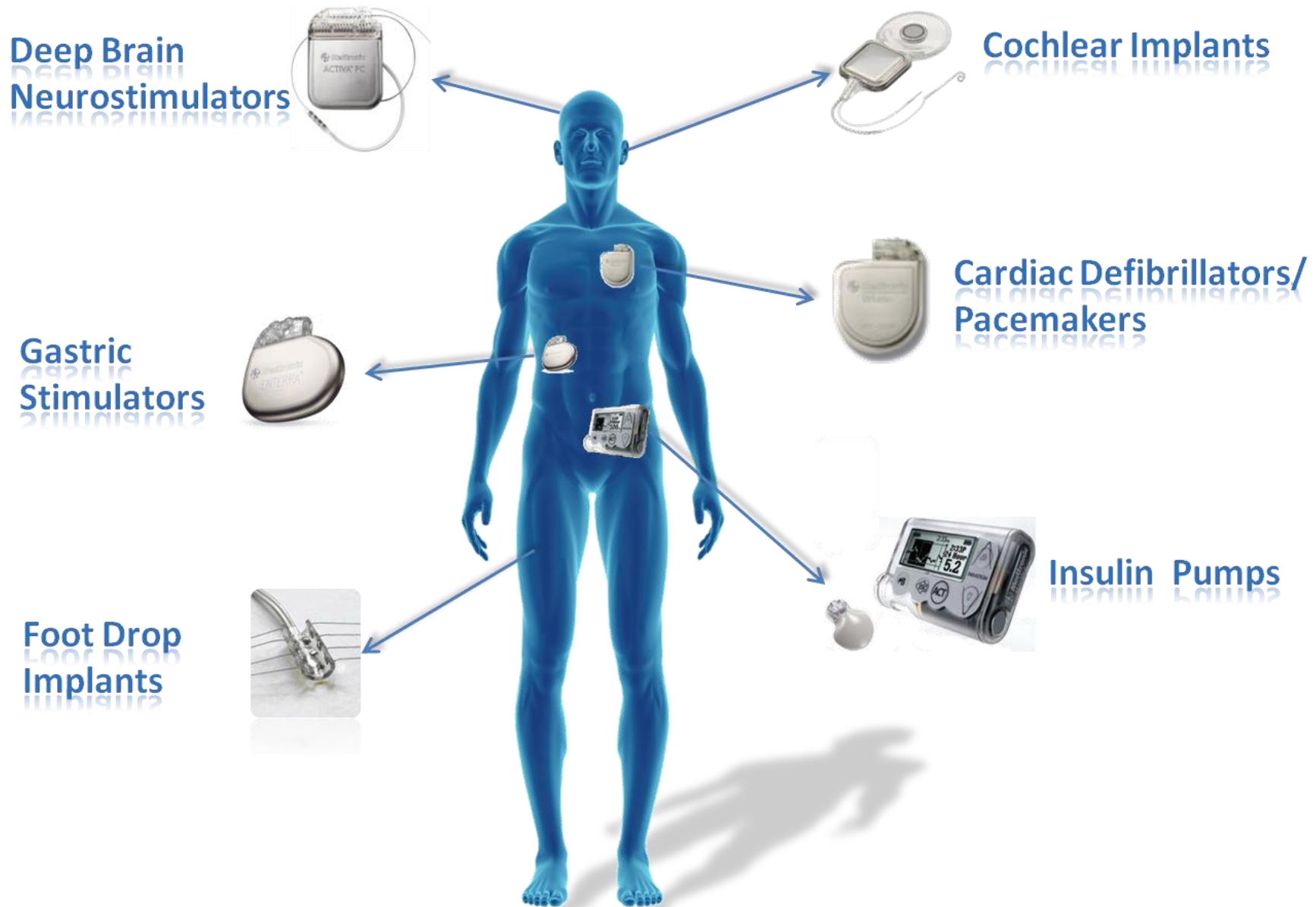




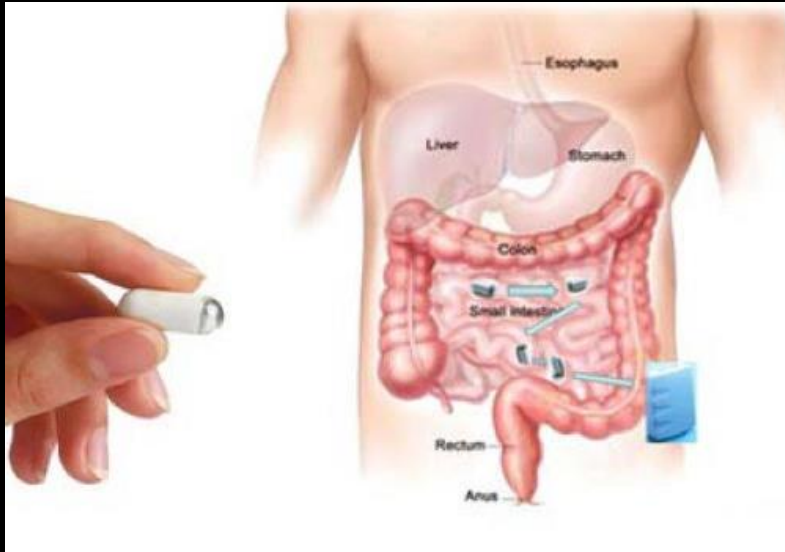
In-body Networks



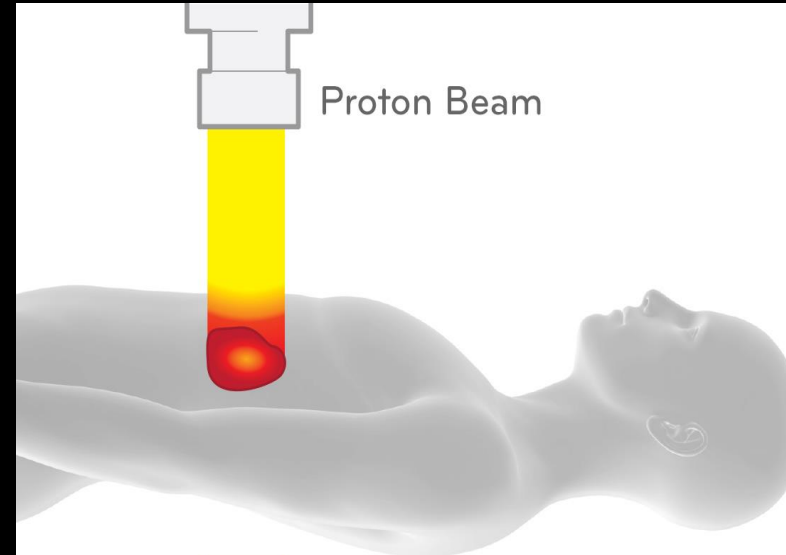
Traditional Wireless Implants



Medicine is Changing...

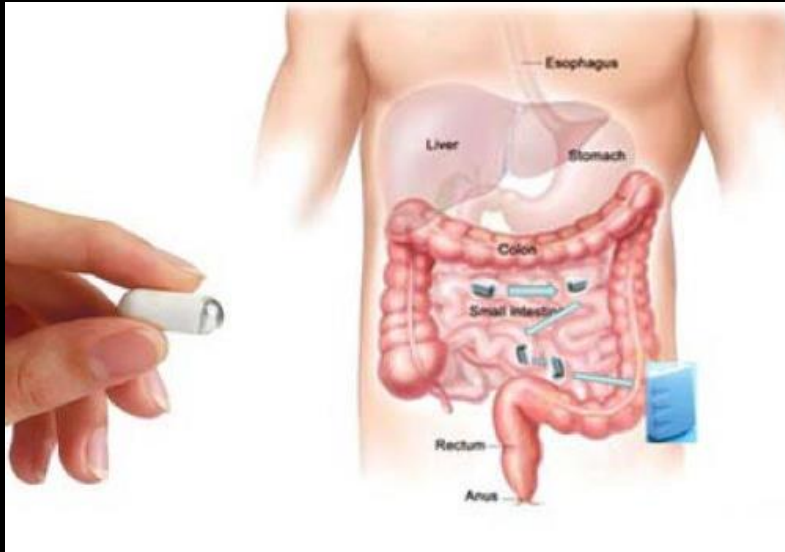


Capsule Endoscopy

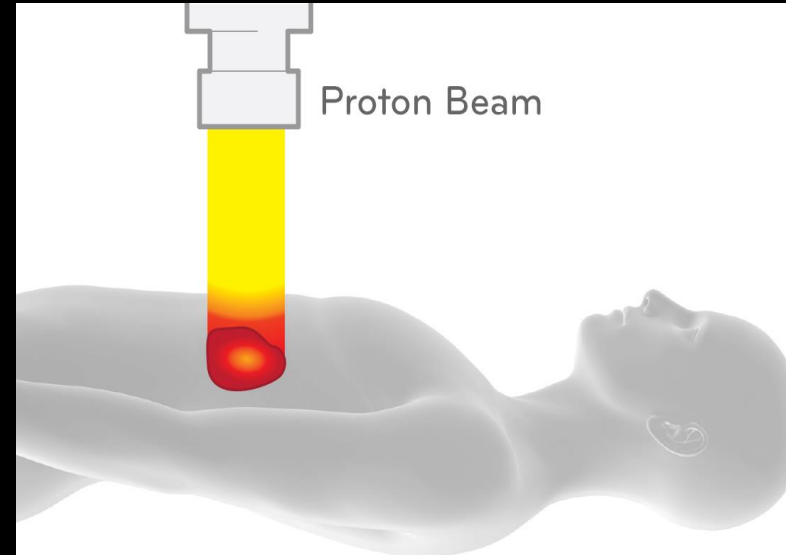


Cancer Radiation Therapy

Medicine is Changing...



Capsule Endoscopy



Cancer Radiation Therapy

In-body devices need **communication** and **localization**

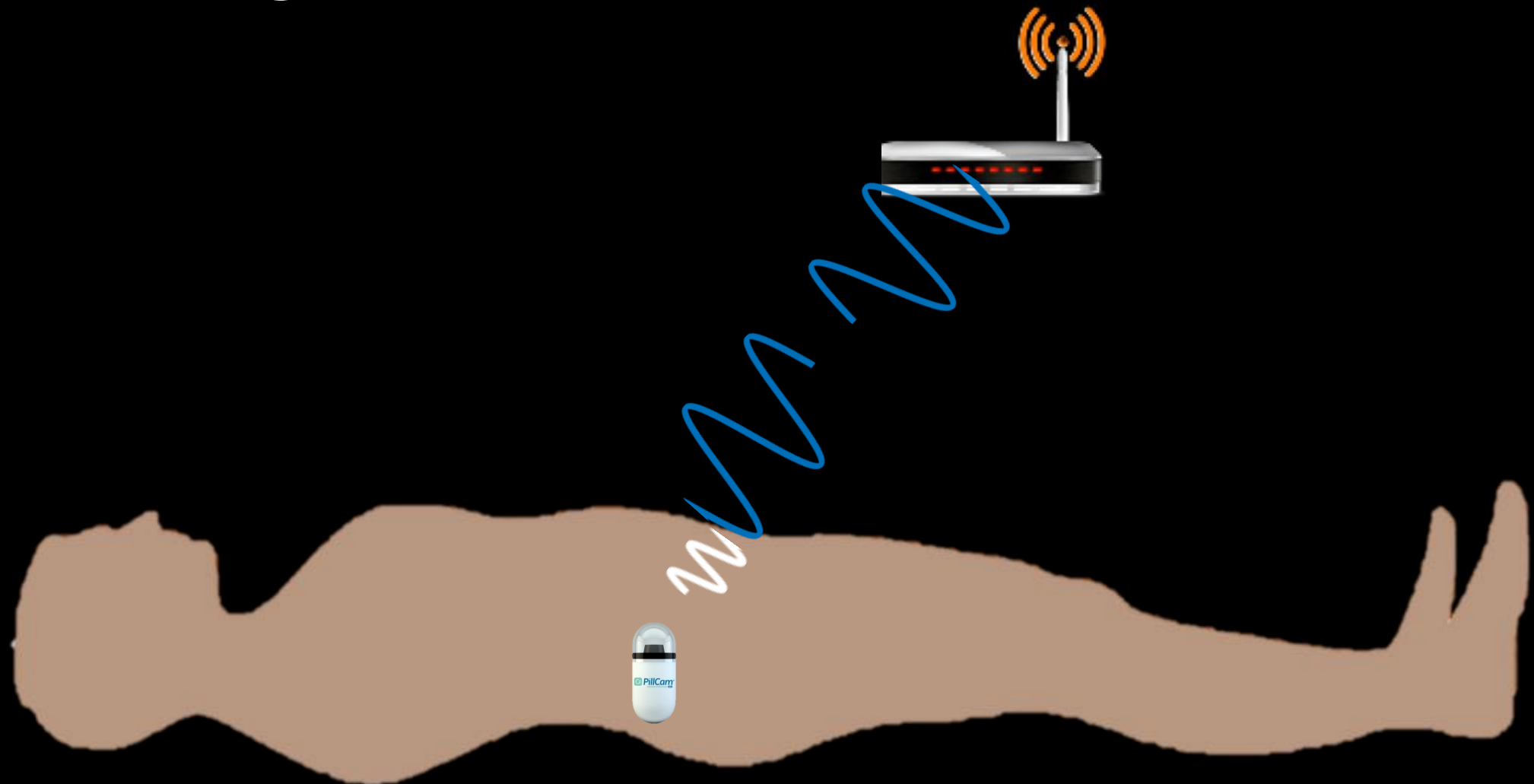
Small medical implants **cannot have batteries**

Backscatter

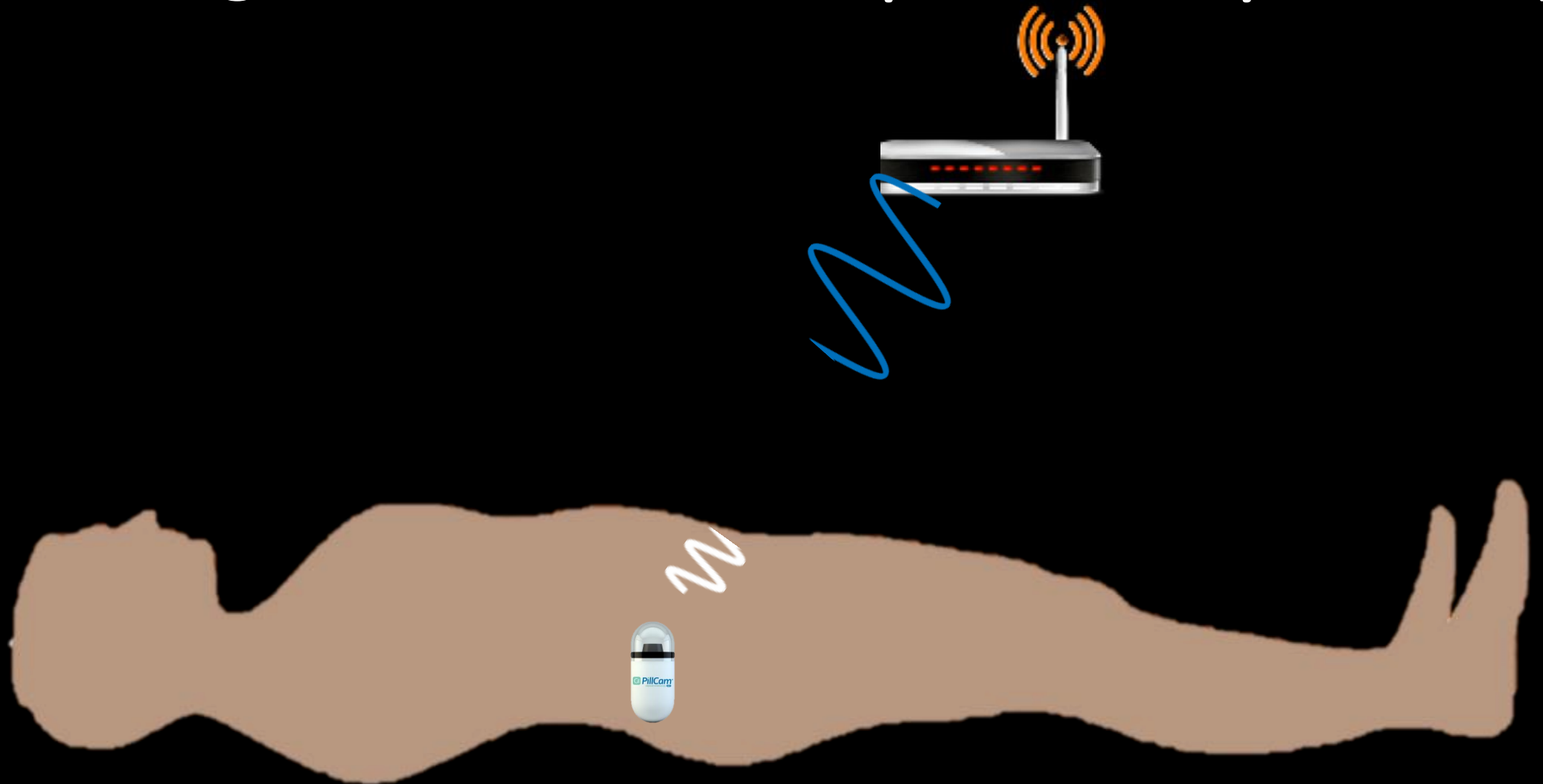


Can we use backscatter in-body?
Not as is!

Problem: Signal is Reflected off the Skin



Problem: Signal Attenuates Exponentially In-Body



Problem: Signal Attenuates Exponentially In-Body



Challenge: Reflection from the skin is 100 million to 1 billion times stronger than the target signal

Key Challenge:

Wireless signals die exponentially in the human body

The sensor will not power up unless the instantaneous energy is above a threshold

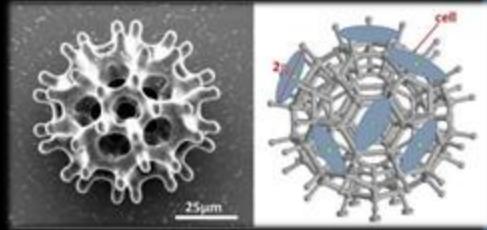
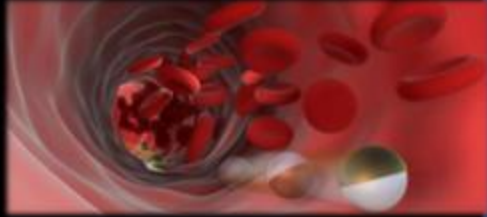




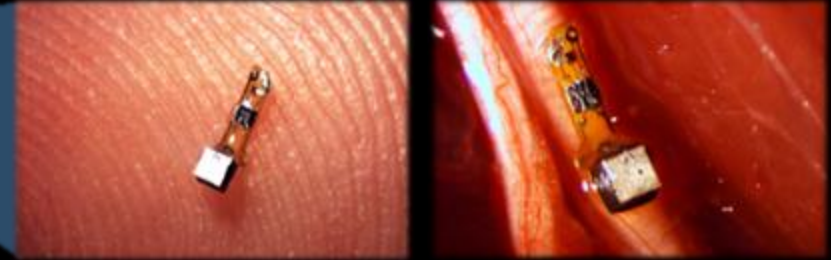
Micro and Nano Bio Implants

Microrobots for drug delivery

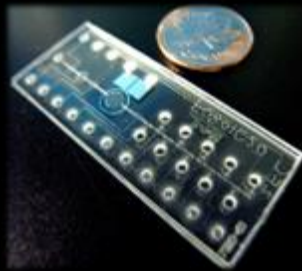
Only large beads



Micro Brain Implants



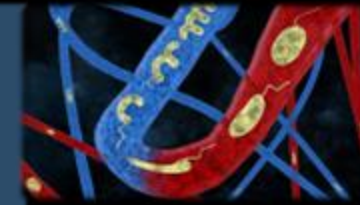
Bio-MEMS Lab-On-Chip for In body Diagnosis



Contraception Micro-Implants



Nano-Implants that can move in the blood vessels



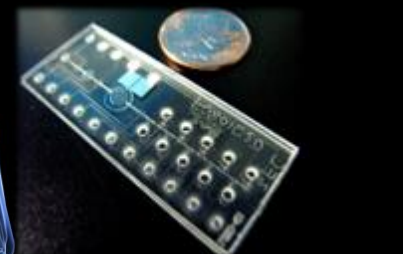
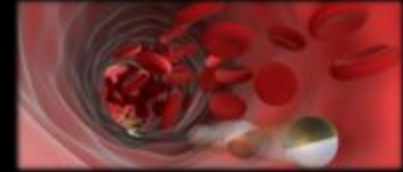
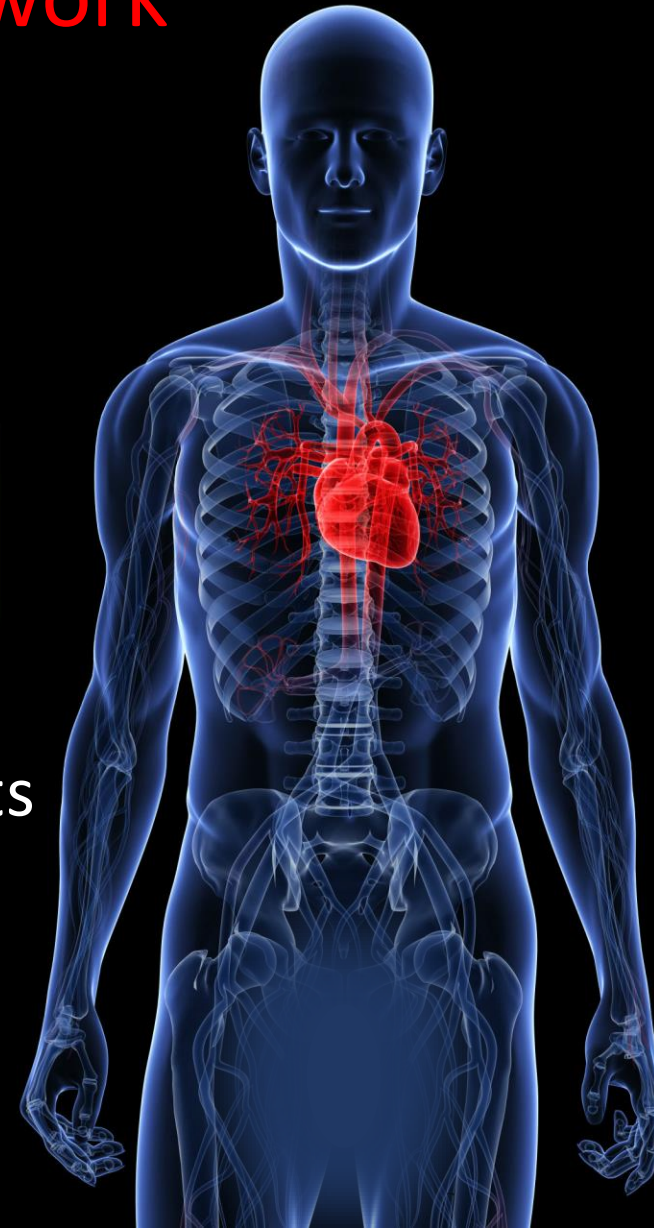
Micro and Nano Bio Implants

How to communicate with and network Nano & Micro Implants?

Traditional implants use wireless



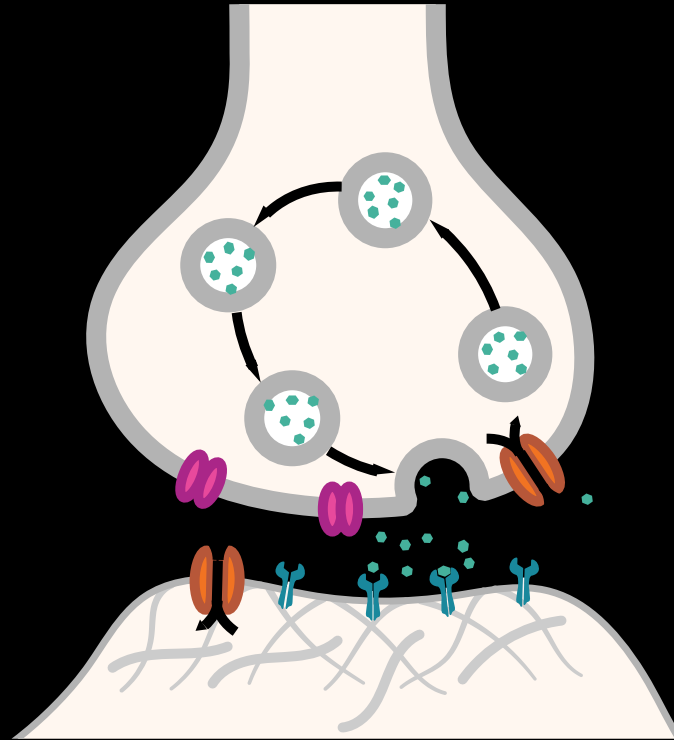
- Large form factor for nano and micro implants
- Requires powerful external device
- Cannot network implants inside the body



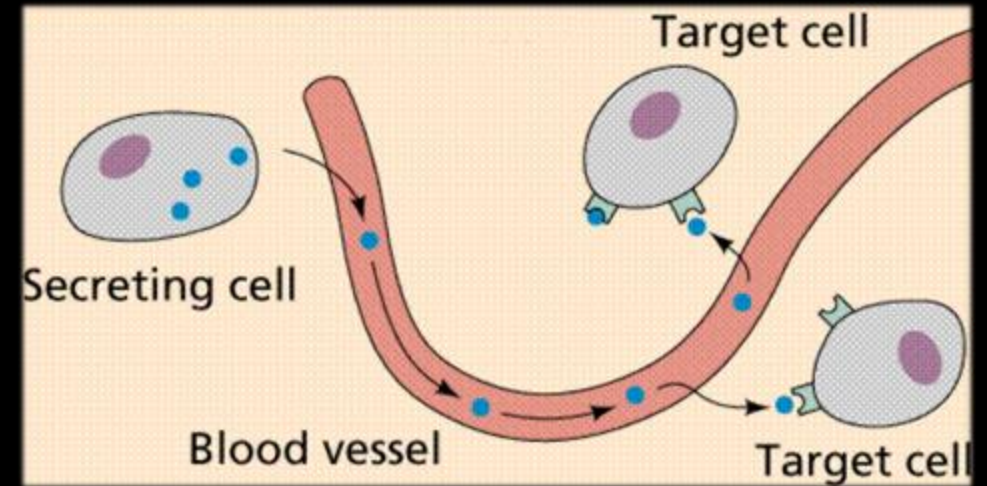
Molecular Communication

Communication paradigm inspired by chemical signaling between cells inside the body.

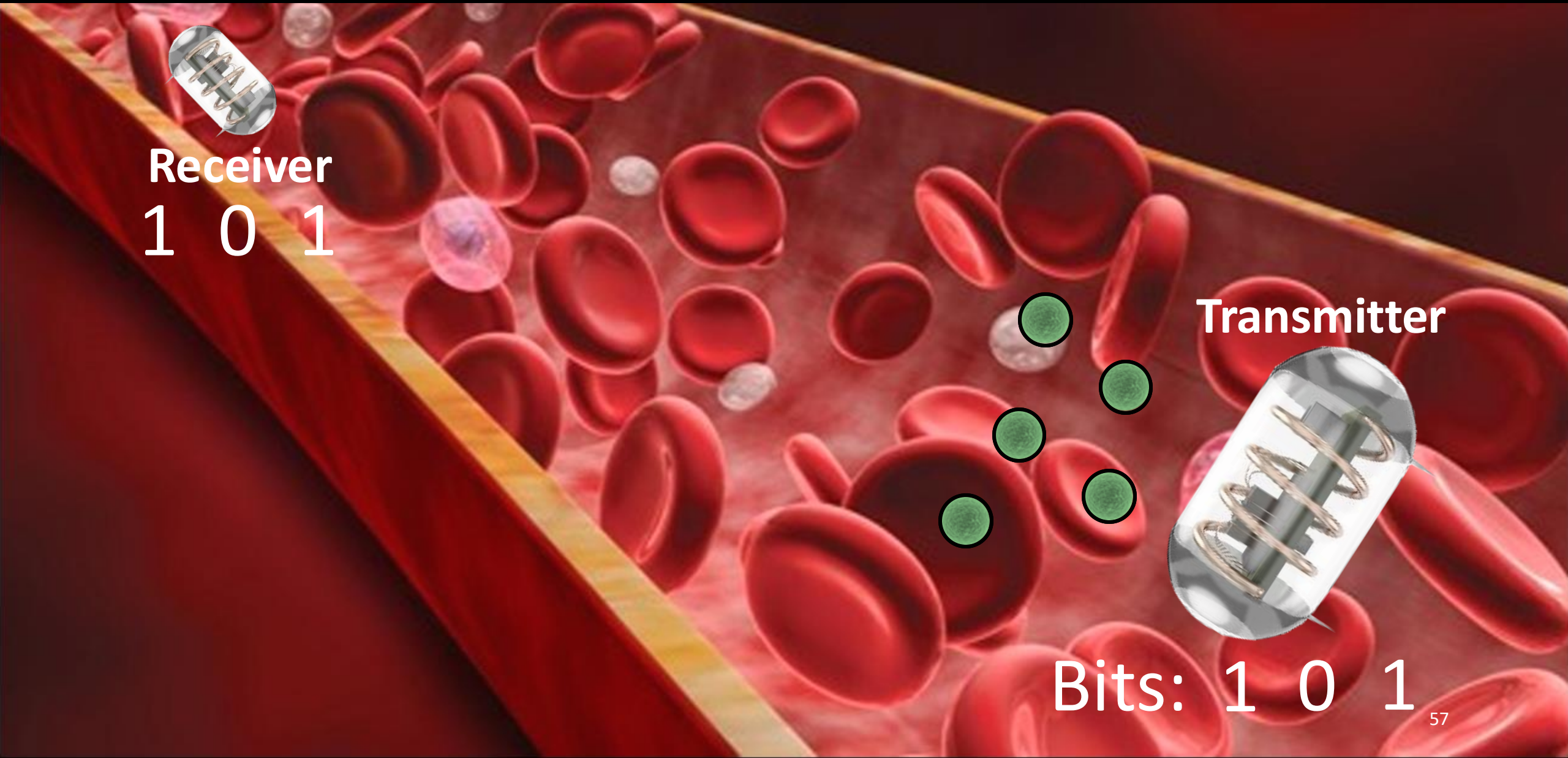
Neurons release neurotransmitters to communicate

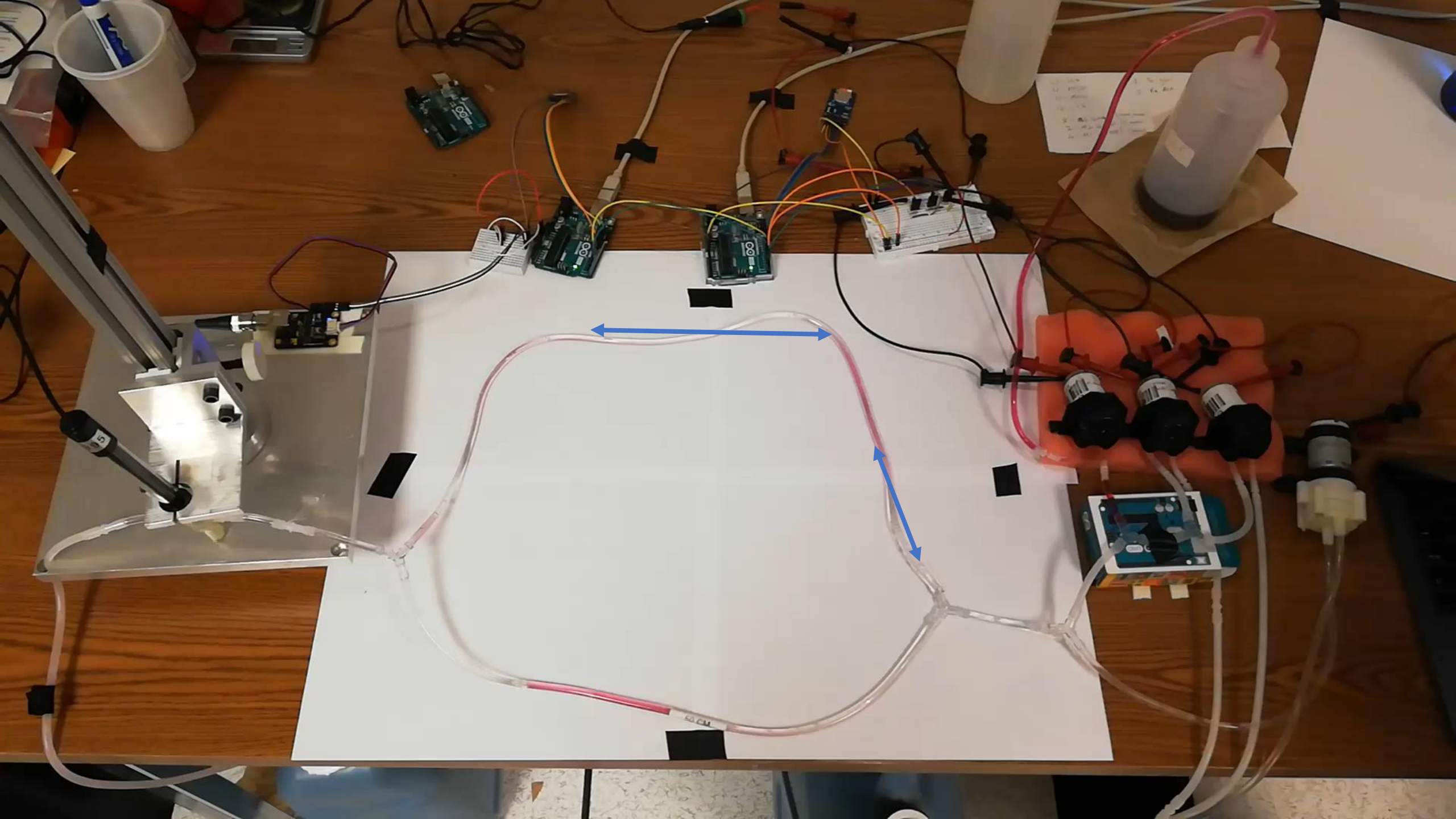


Glands release hormones into the blood stream



Encode bits by releasing molecules into the blood stream





Underwater Communication

Applications of Ocean IoT

What percentage of the ocean has never been observed or explored?

More than 80% (NOAA, 2018)

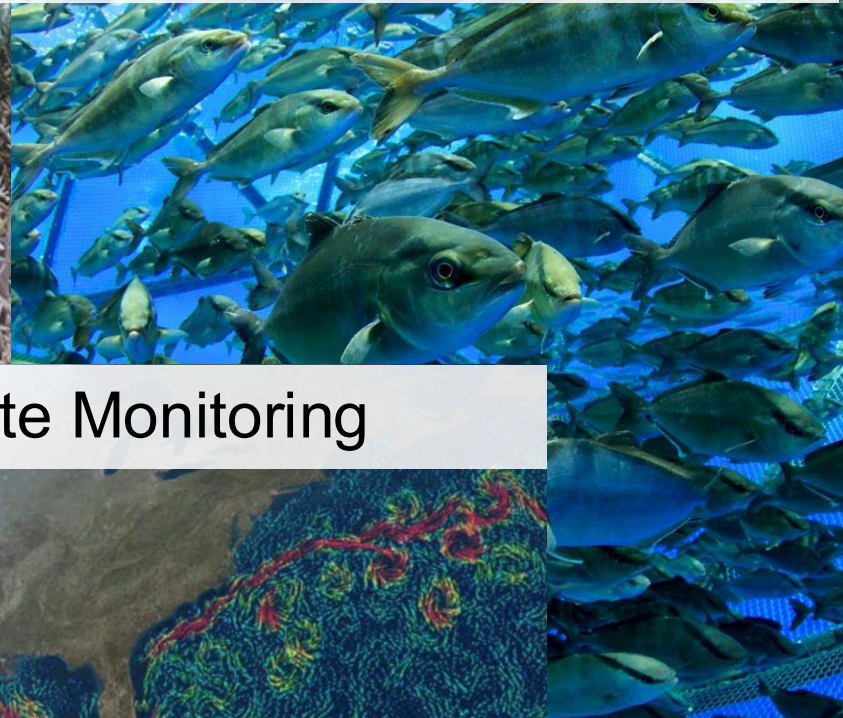
Marine Life Discovery



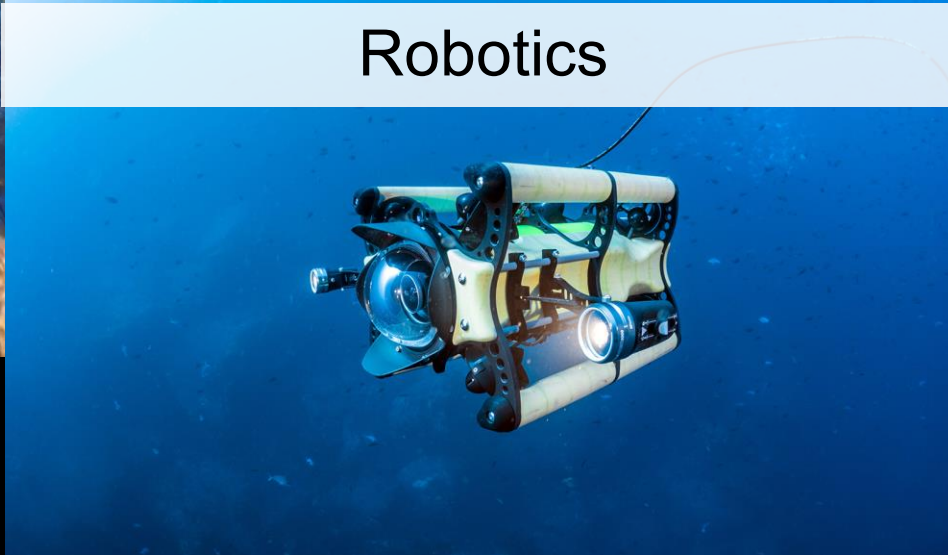
Coral Reef Imaging



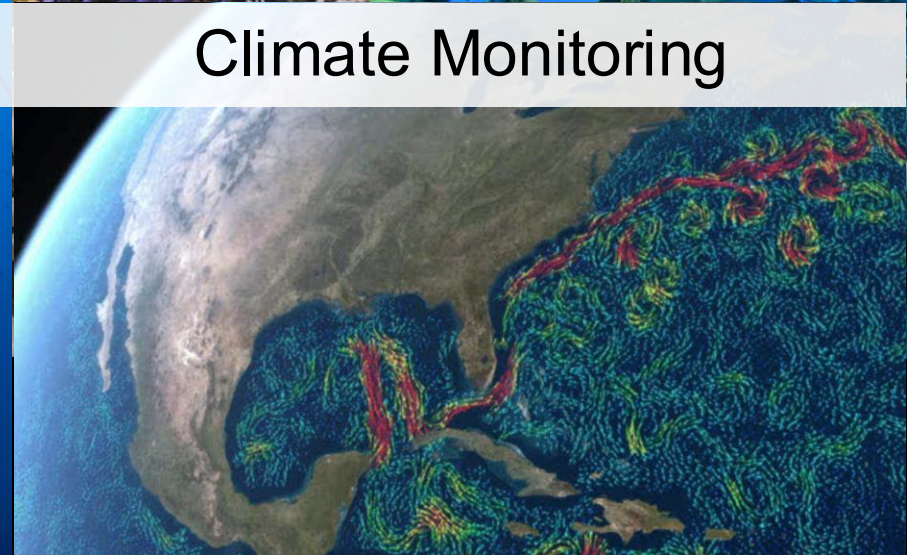
Aquaculture



Robotics



Climate Monitoring



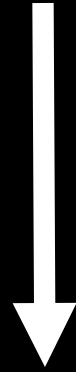
How is underwater IoT different than in-air IoT?

- Can't use radio (WiFi, bluetooth)
- Can't use GPS (radio signals)
- Power is scarce
- Direct underwater-to-air comms remains challenging



Problem: Battery life of underwater sensors is extremely limited

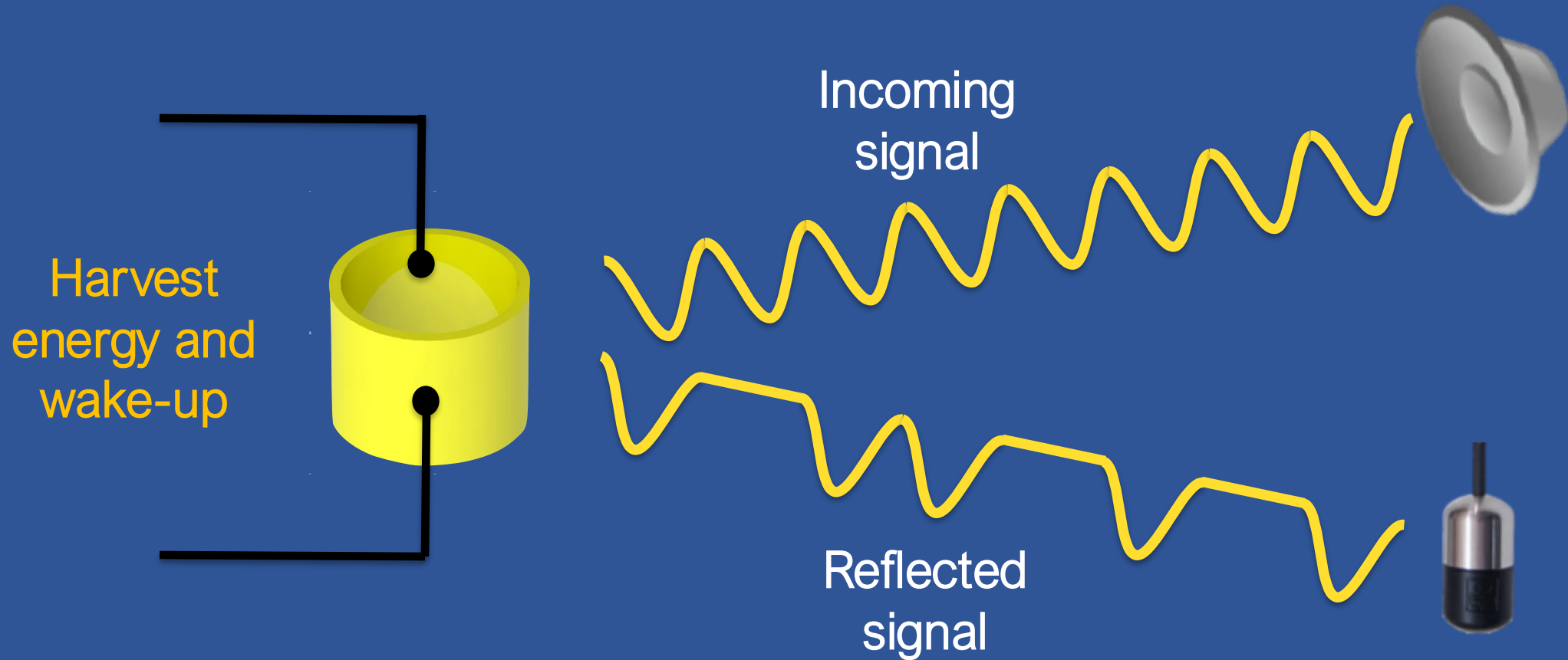
Low-power underwater transmitters consume **100s of Watts**
(e.g., WHOI low-power micro-modem 2019)



State-of-the-art sensors for tracking marine animals only last for **few hours or days**

[Animal Biotelemetry'15, Scientific Reports'17]

Key Idea: Using Acoustic backscatter



Toward Ocean-Scale Battery-free Networks & Localization

**Code + Schematics +
Tutorials:**

<https://github.com/saadafzal24/Underwater-Backscatter>



Acoustics



50 million voice assistants are sold in US




QUALCOMM

The Future of Personal Audio








Inaudible Acoustics

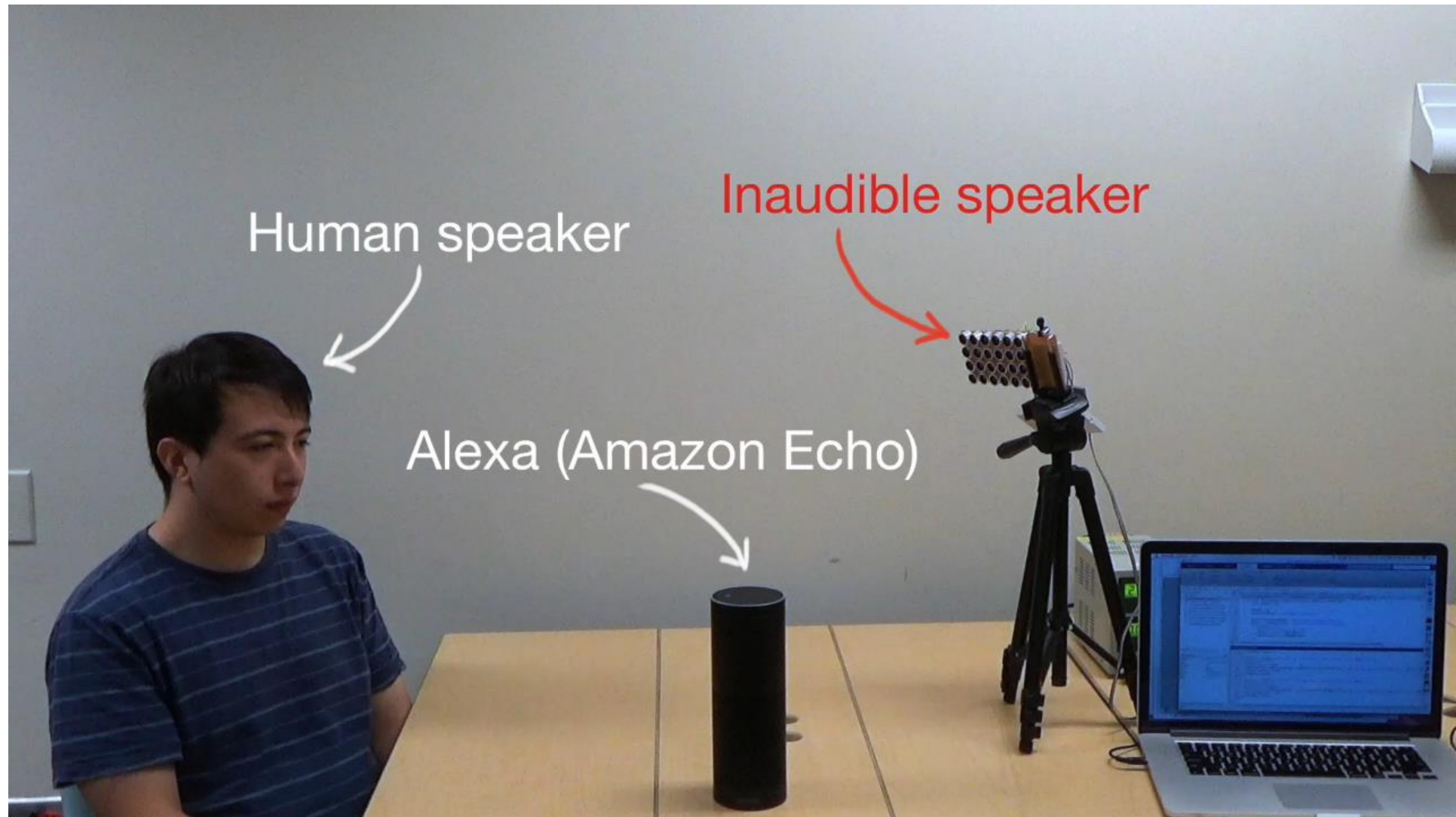
 **Normal Sound**
(< 24 kHz)    

 **Ultrasound**
(> 25 kHz)    

 **This project**
(> 25 kHz)    

 **“Alexa, open the garage door!”**    

Inaudible Acoustics





Wireless network of smart IoT devices in homes & workplaces for noise cancellation

A wireless IoT network for noise cancellation



A wireless IoT network of microphones for multi-source noise cancellation



Wireless Charging

Wireless Charging

Today: zero distance &
highly sensitive to orientation

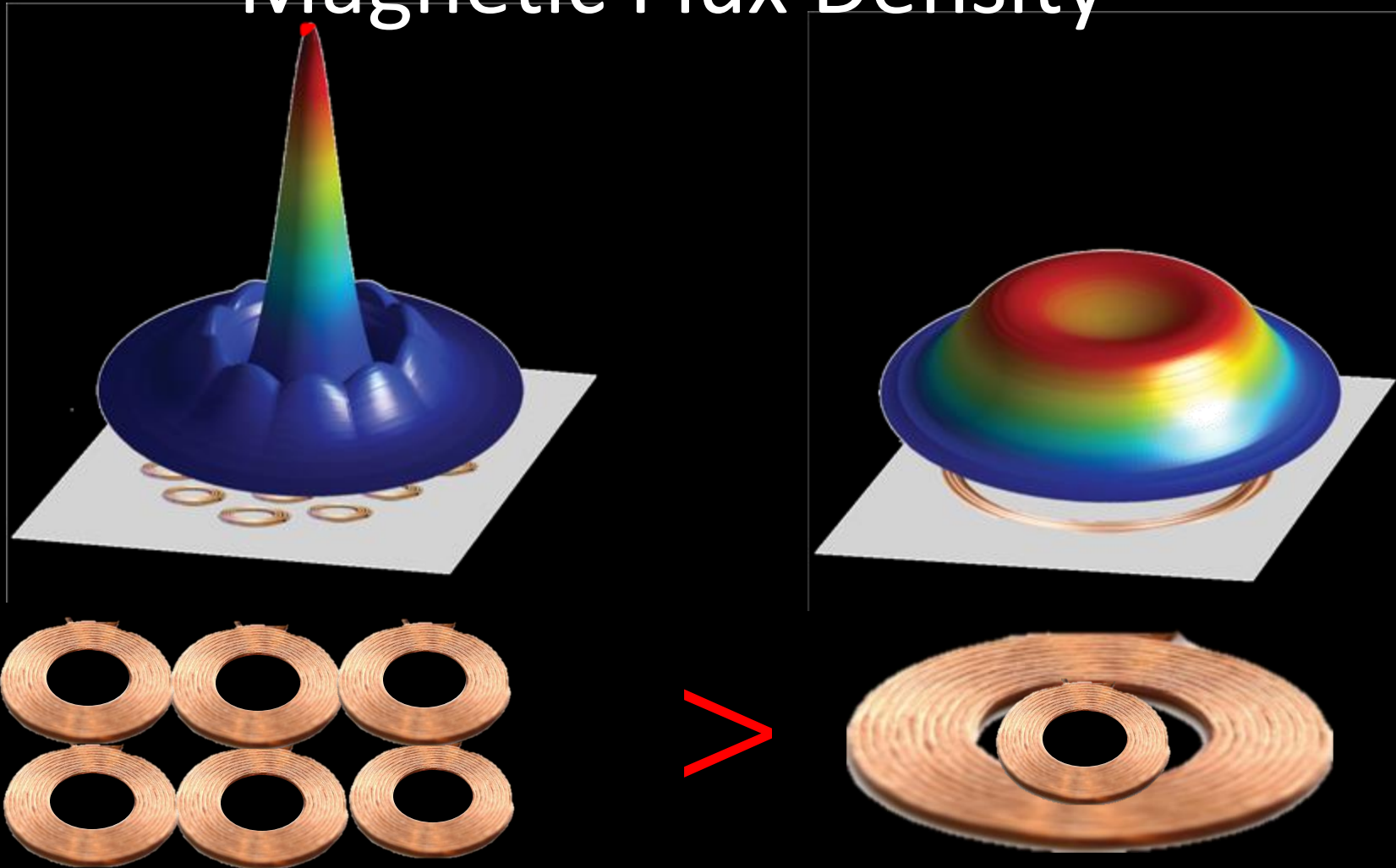


MagMIMO



Why not increase the transmit coil size?

Magnetic Flux Density











Wireless Food & Material Sensing

Can we sense food and liquids in closed containers?



Is it safe?
Is it authentic?
Has it expired?

Applications

ASIA PACIFIC

China's Top Food Quality Official Resigns

By DAVID BARBOZA SEPT. 22, 2008



A baby suffering from kidney stones after drinking tainted formula was treated Monday at a hospital in Chengdu, China. China Photos, via Getty Images

SHANGHAI — The chief of China's food and product quality agency was forced to resign Monday in a growing scandal over the country's tainted milk supply, which has already sickened more than 50,000 infants and killed at least three children, according to the state-run Xinhua news agency.

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The Observer Wine

The great wine fraud

Rudy Kurniawan amassed a vast fortune trading in rare wines. Trouble is, he was bottling them himself. Ed Cumming reports on a vintage swindle

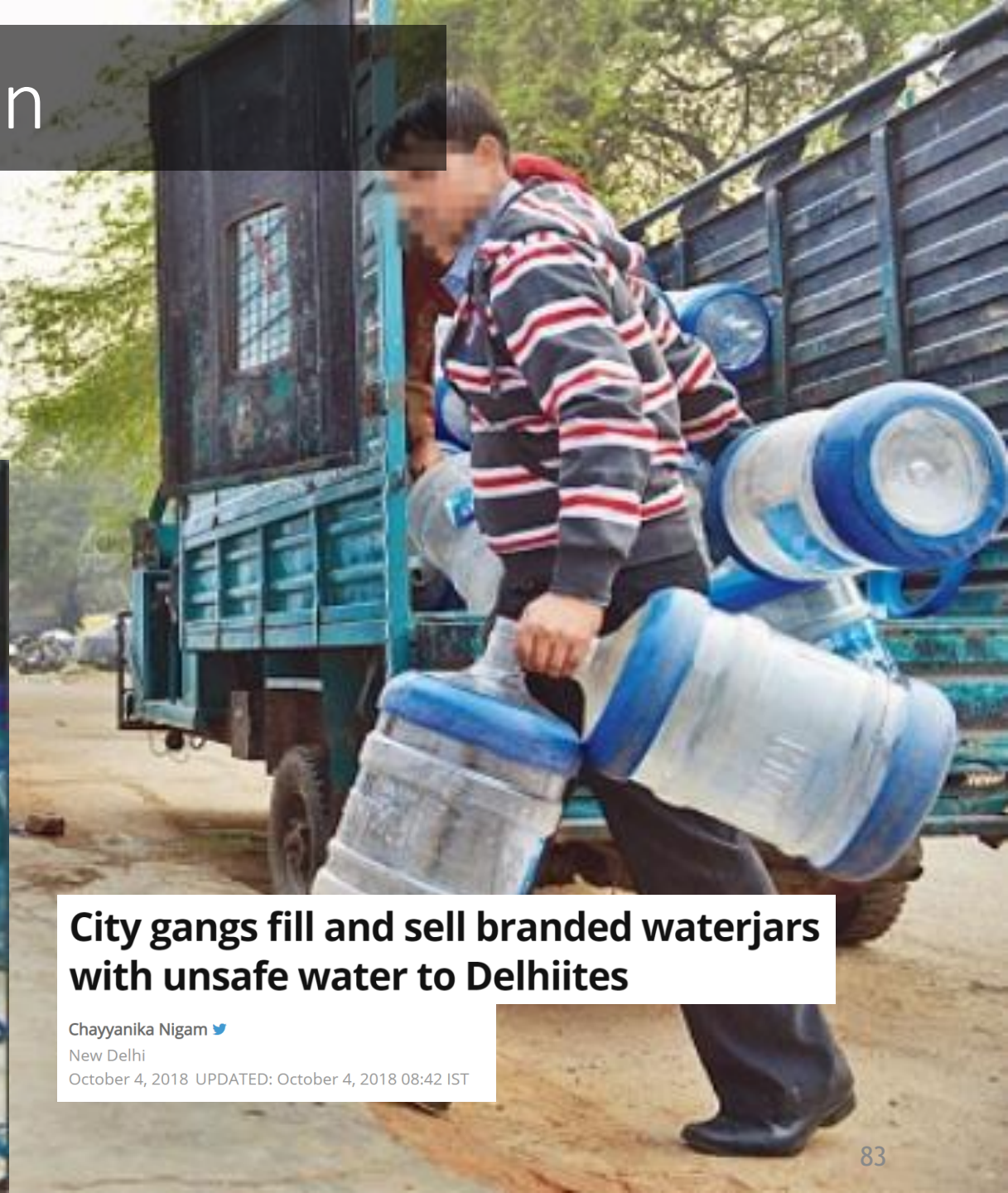
Ed Cumming

Sat 10 Sep 2016 19.05 EDT


World

Fake drugs kill people and fund terror. African leaders hope to do something about it.

Water Contamination



City gangs fill and sell branded waterjars with unsafe water to Delhiites

Chayyanika Nigam 

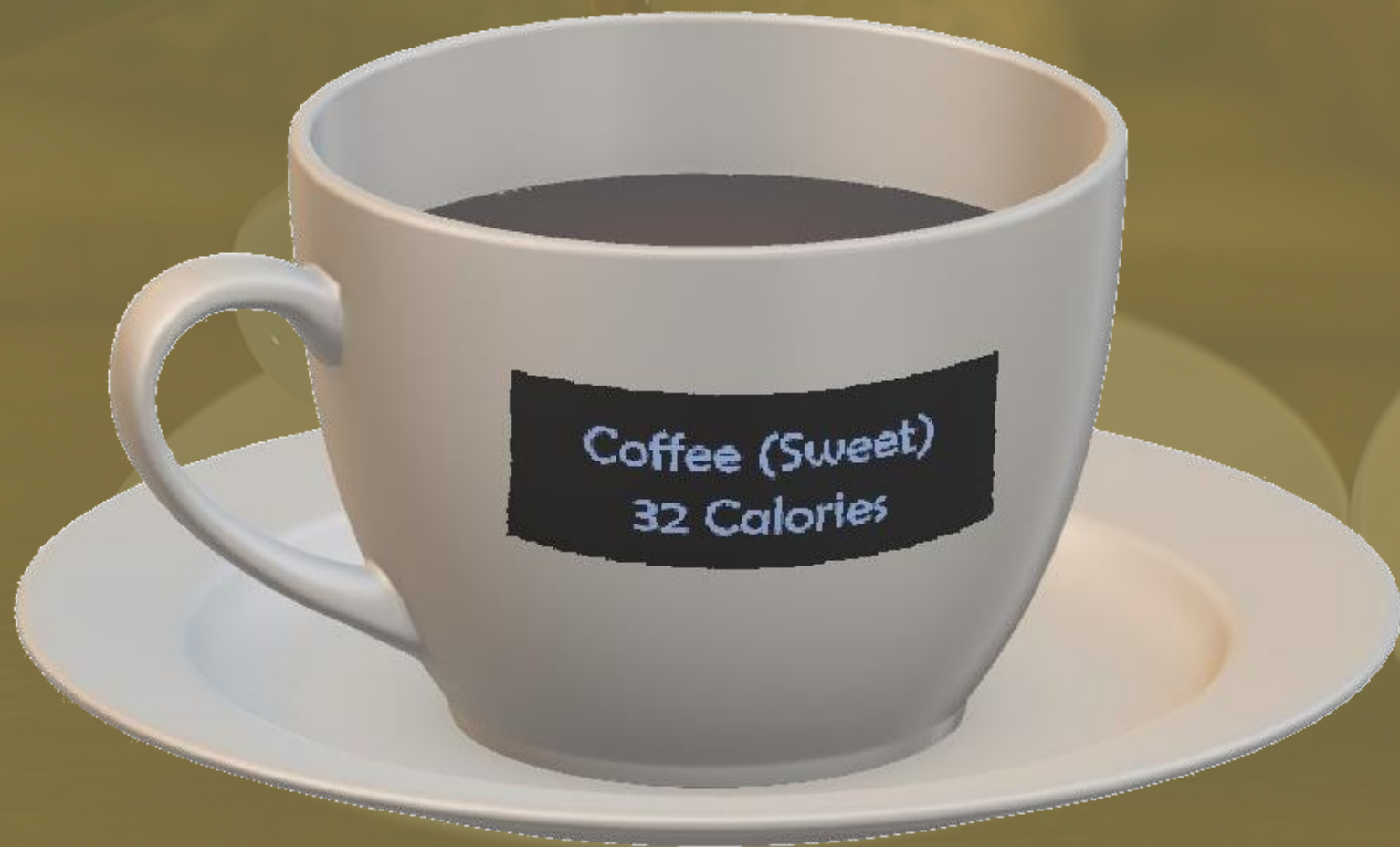
New Delhi

October 4, 2018 UPDATED: October 4, 2018 08:42 IST

Airport Security



Calorie Cup



Wireless Sensing Liquids



Wireless Sensing Liquids



Wireless Sensing Liquids



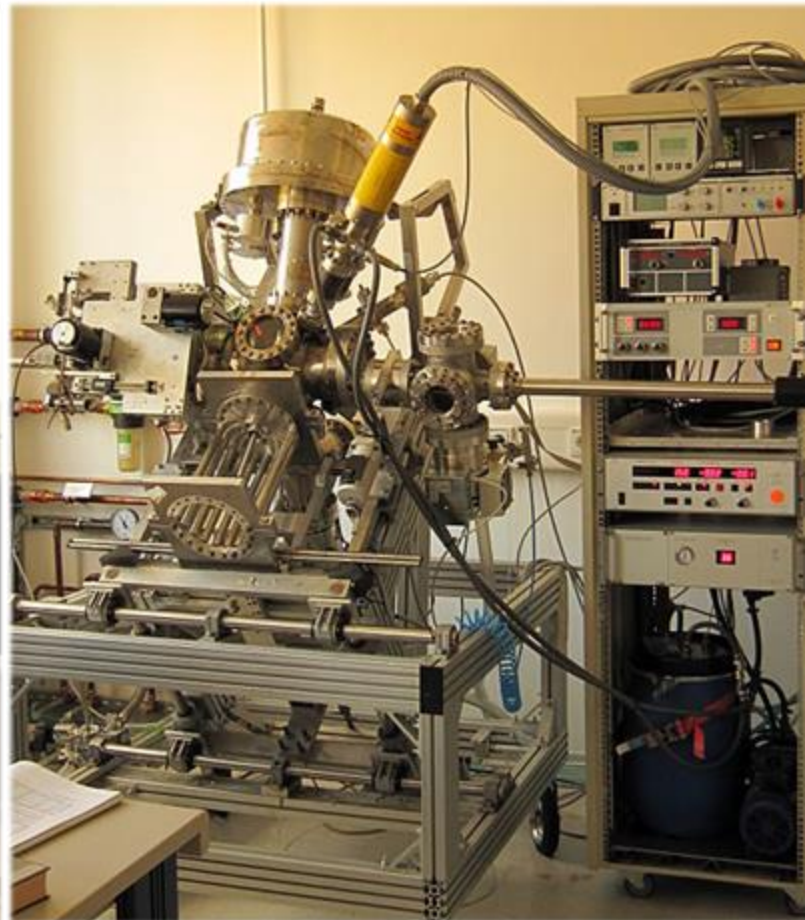
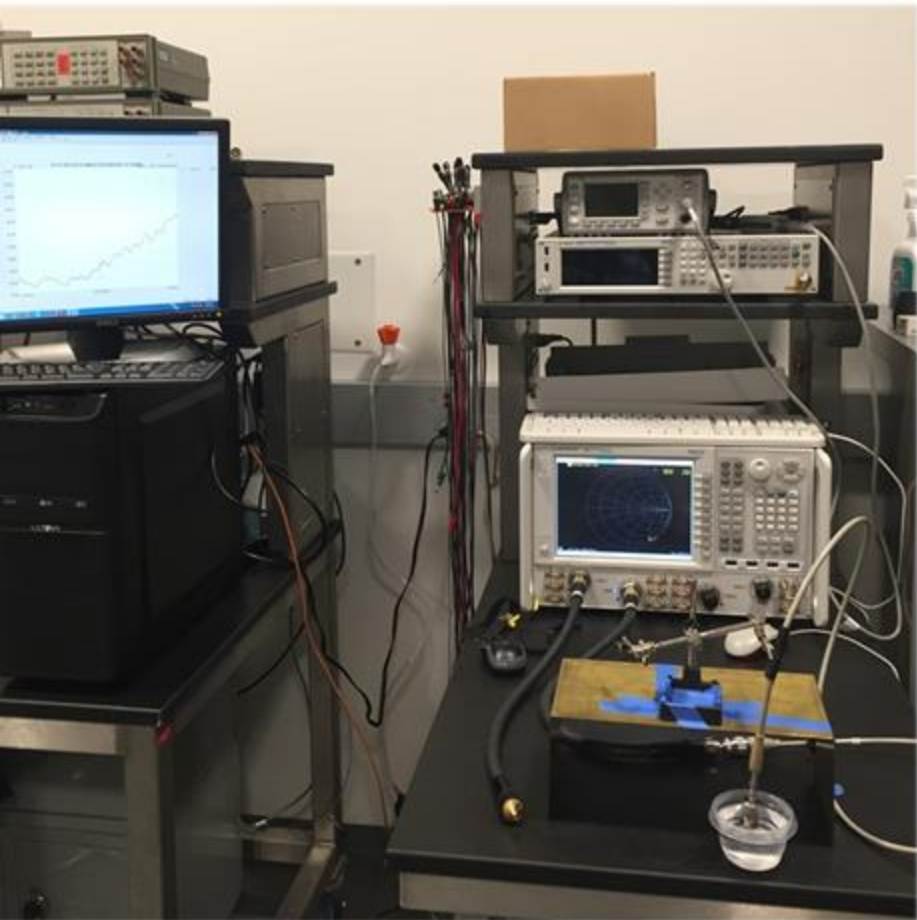
LiquiD: Wireless Sensing Liquids



Wireless Sensing Liquids



Existing Solutions

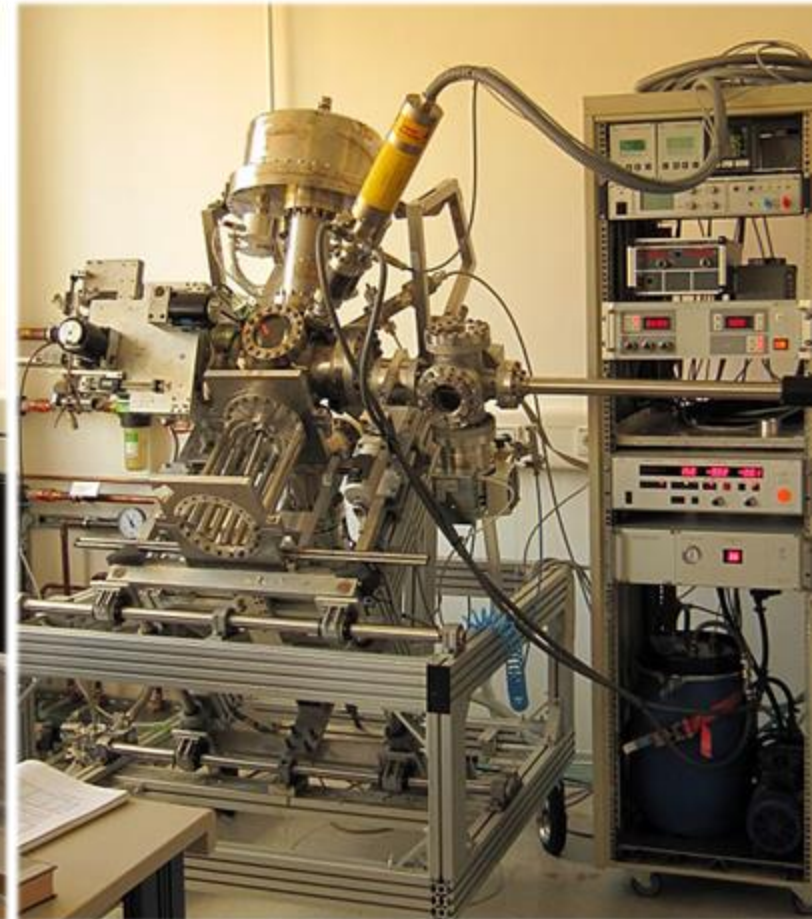
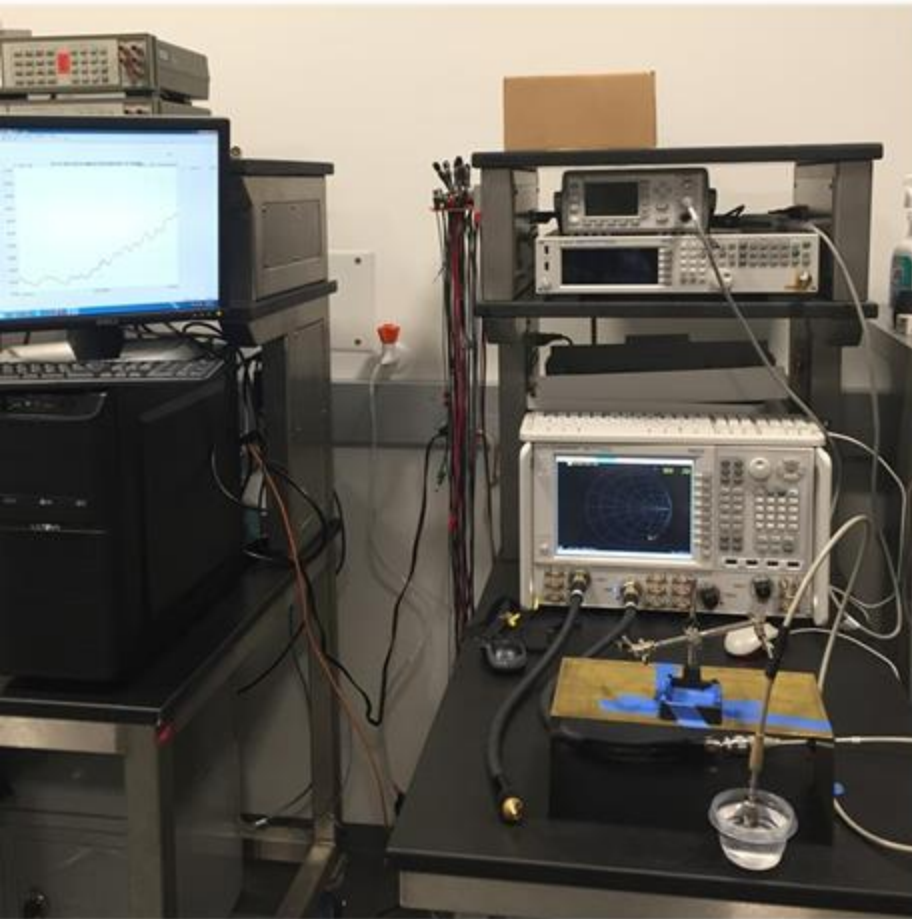


Existing Solutions

✗ Dipping a Probe: Invasive

✗ Chemical Analysis: Destructive

✗ Expensive (\$50k +) and Bulky: Inconvenient



- ✓ Identify liquids without touching it: Non-invasive
- ✓ Using low power, wireless signals: Non-destructive
- ✓ Small and cheap: IoT



Material sensing opens up many applications!

Robotic Grasping



Quality Control



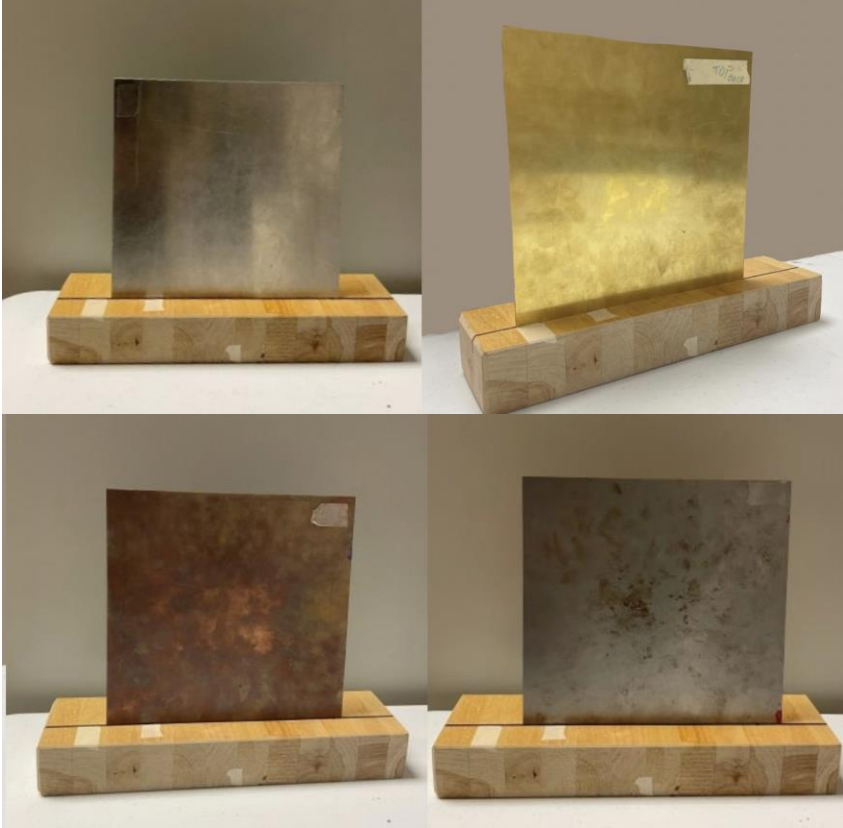
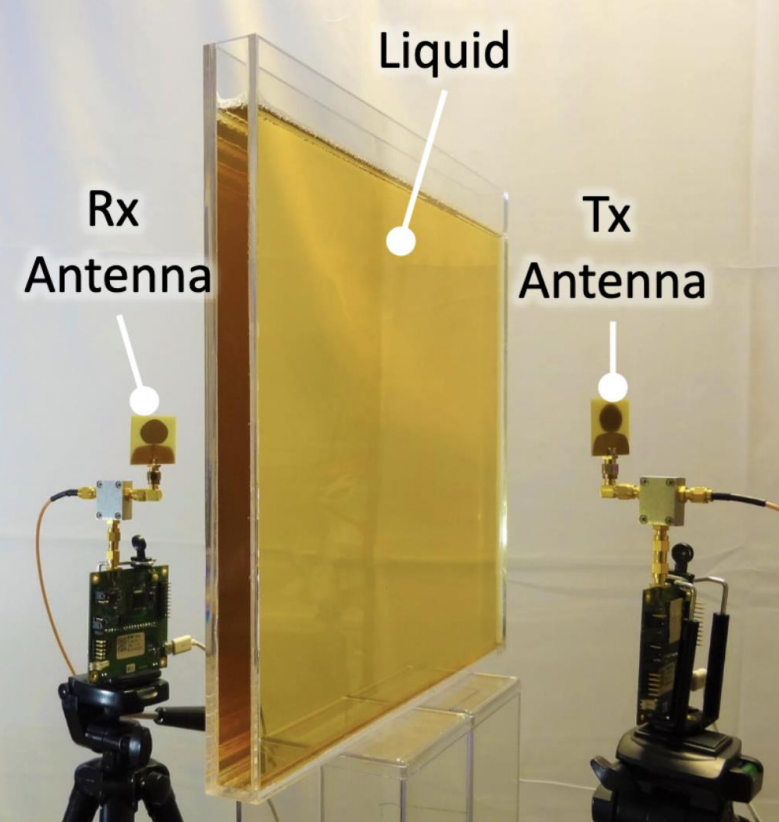
Waste Sorting



Liquid & Food Control



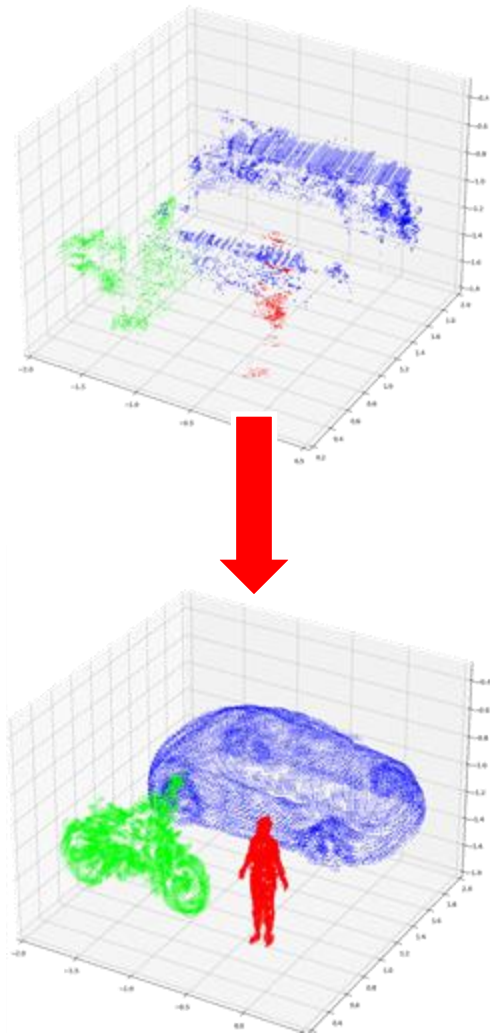
Material sensing with wireless signals



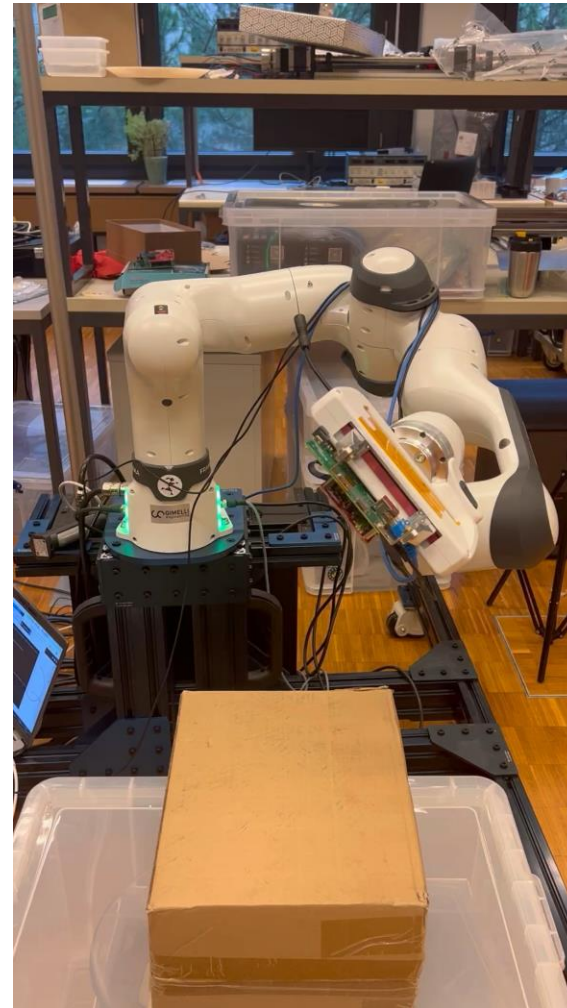
Wireless Imaging

Wireless Imaging

3D Radar Shape Reconstruction

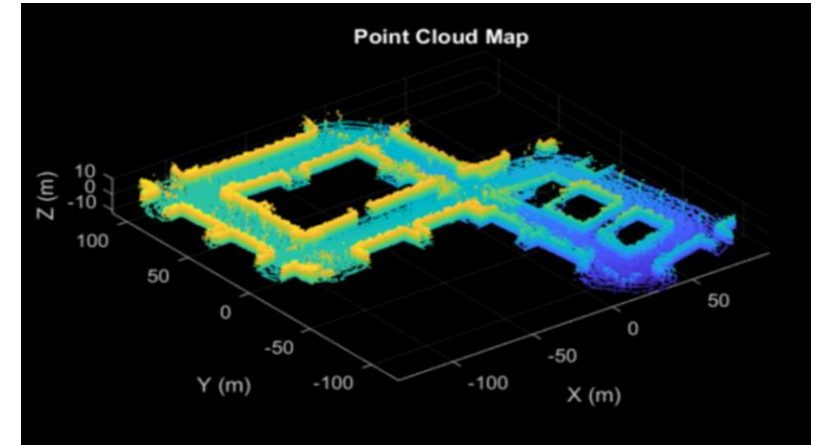


Imaging Inside Boxes



Wireless Imaging

Radar SLAM



Around the Corner Imaging

