Wireless Technologies for Indoor Localization, Smart Homes, and Smart Health

Dina Katabi

Andrew & Erna Viterbi Professor, MIT

Computer Science and Artificial Intelligence Laboratory (CSAIL)
Massachusetts Institute of Technology

INDOOR LOCALIZATION

GPS HAS CHANGED HOW WE NAVIGATE OUTDOOR SPACE

GPS does not work indoors…

APPLICATIONS OF INDOOR LOCALIZATION

Navigation

Business Analytics

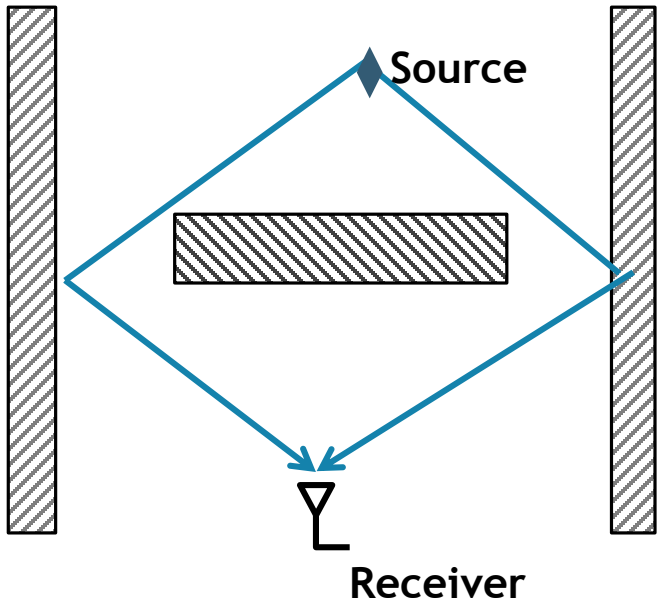
Inventory

Want to use RF signals for indoor localization

THE CHALLENGE: MULTIPATH EFFECT

Localization uses **Power** or **Angle-of-Arrival (AoA)**

But, signal bounces off objects in the environment



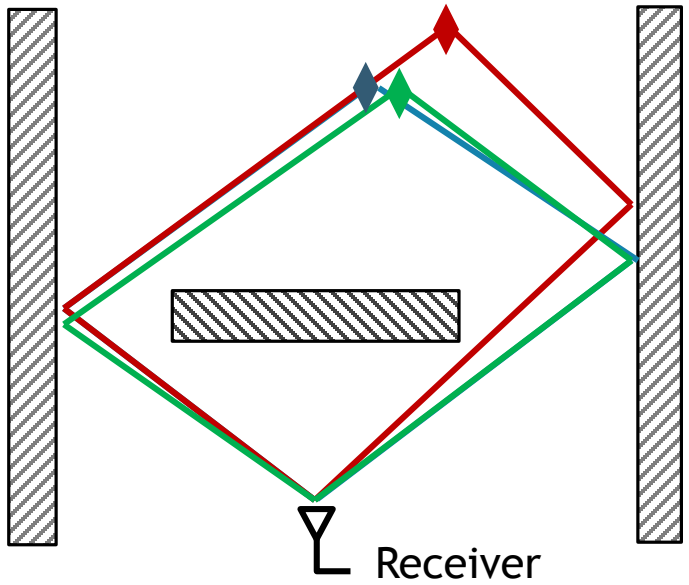
- Angle of signal is not the direction of the source
- Received power depends on how reflections combine and not the distance to the source

OUR APPROACH

Exploit multipath to increase accuracy

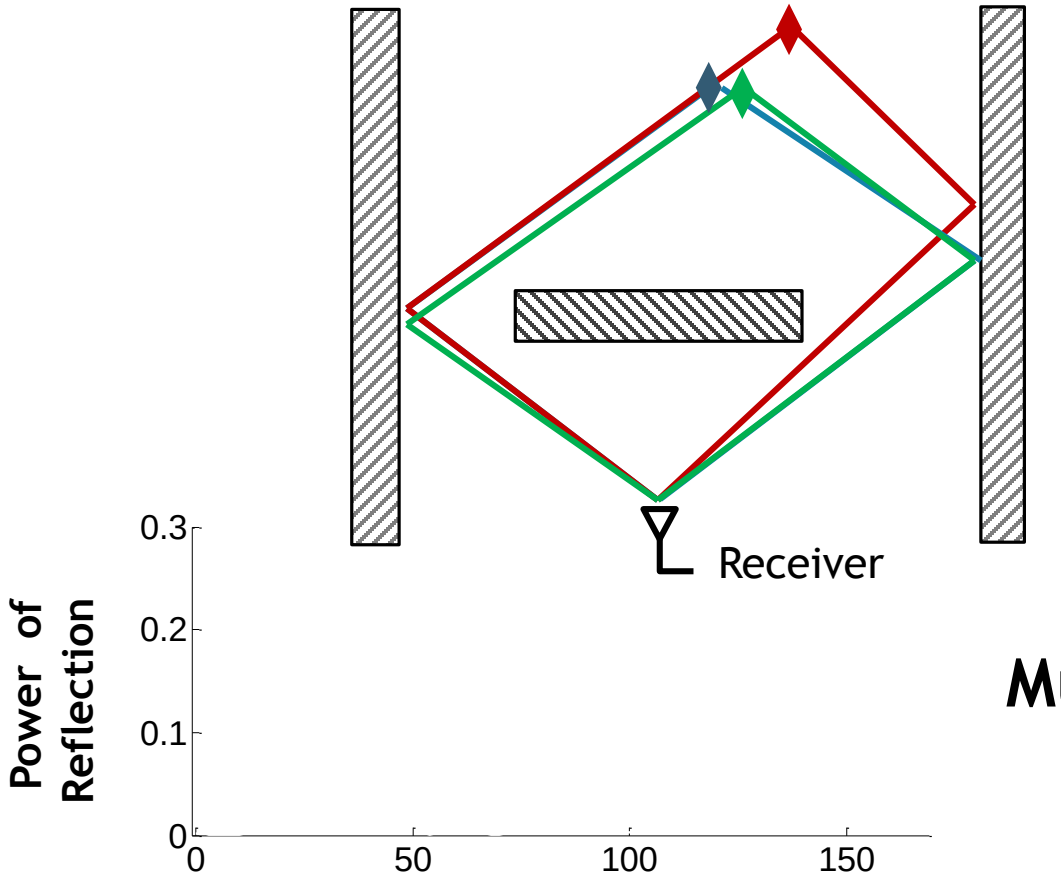
EXPLOIT MULTIPATH

Signals from nearby sources propagate along closer paths and experience similar reflections



EXPLOIT MULTIPATH

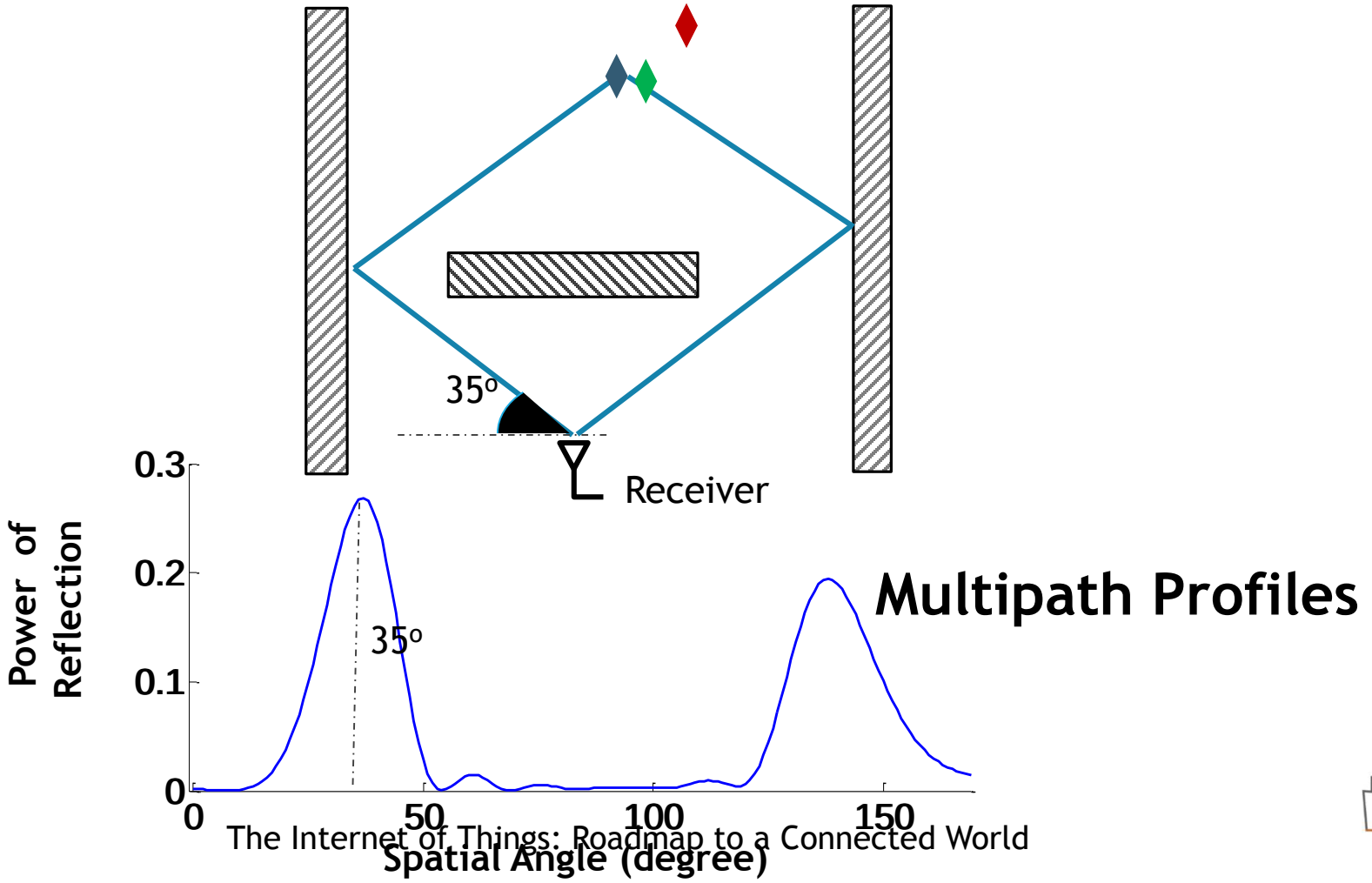
Signals from nearby sources propagate along closer paths and experience similar reflections



Multipath Profiles

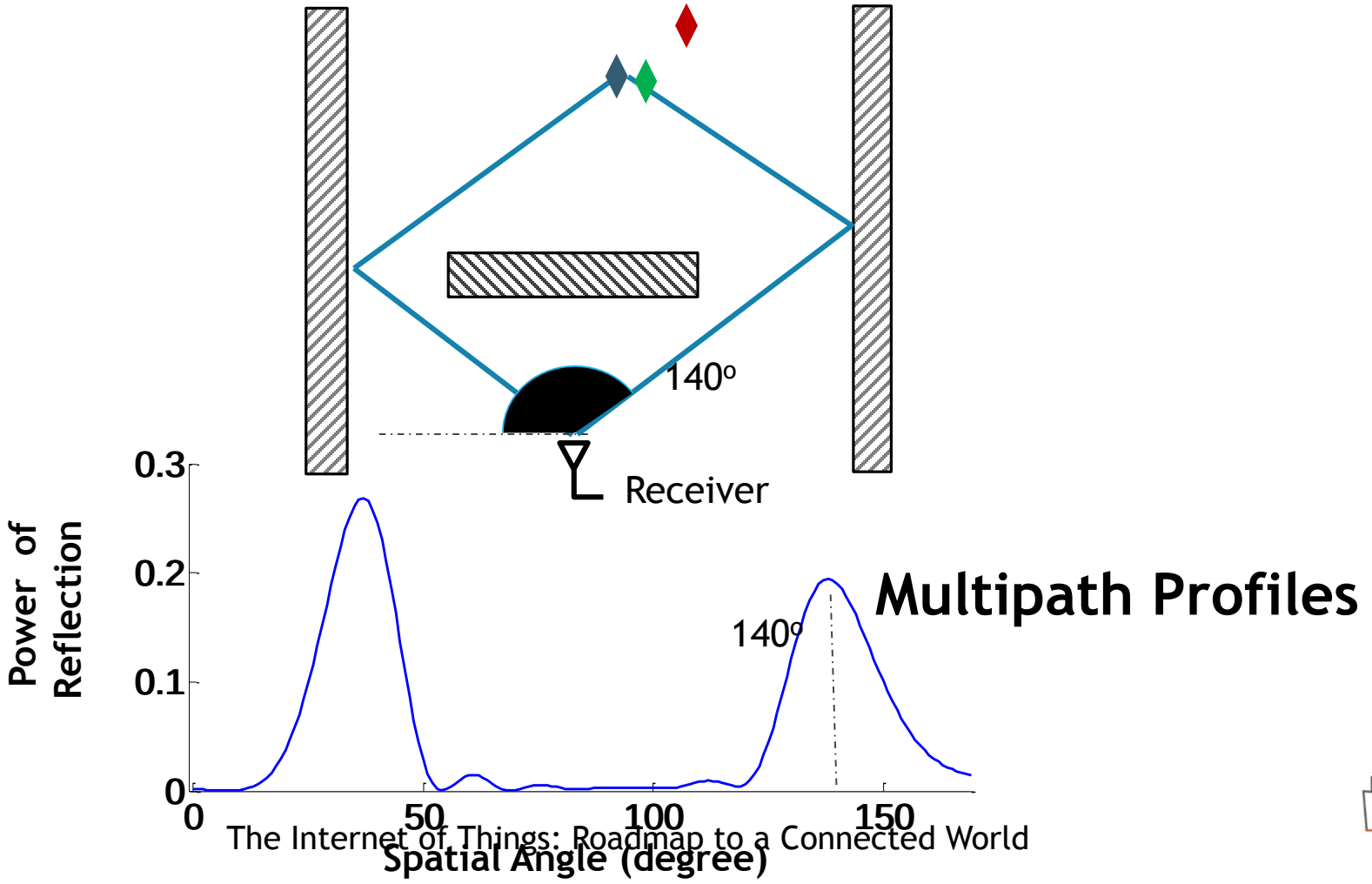
EXPLOIT MULTIPATH

Signals from nearby sources propagate along closer paths and experience similar reflections



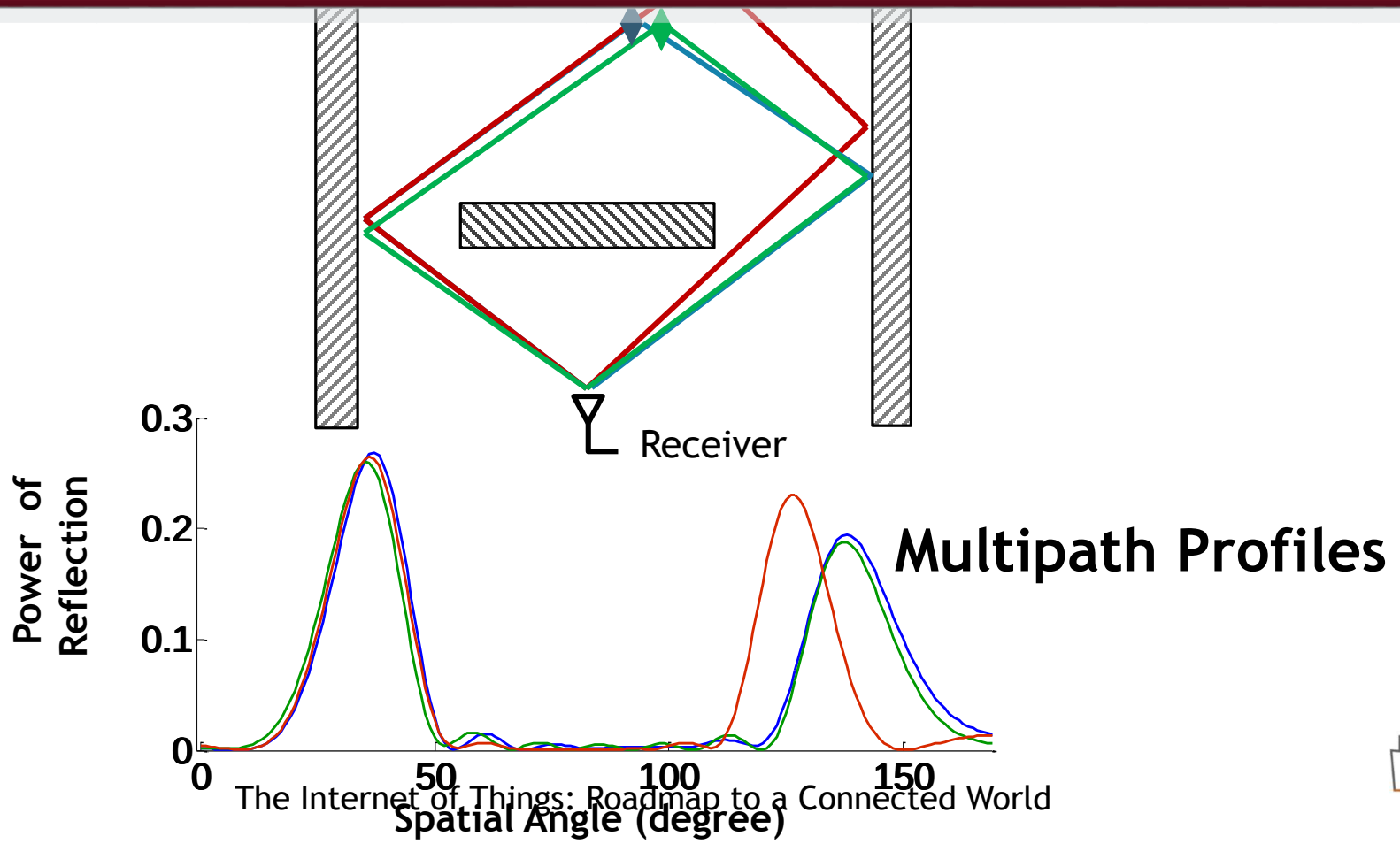
EXPLOIT MULTIPATH

Signals from nearby sources propagate along closer paths and experience similar reflections

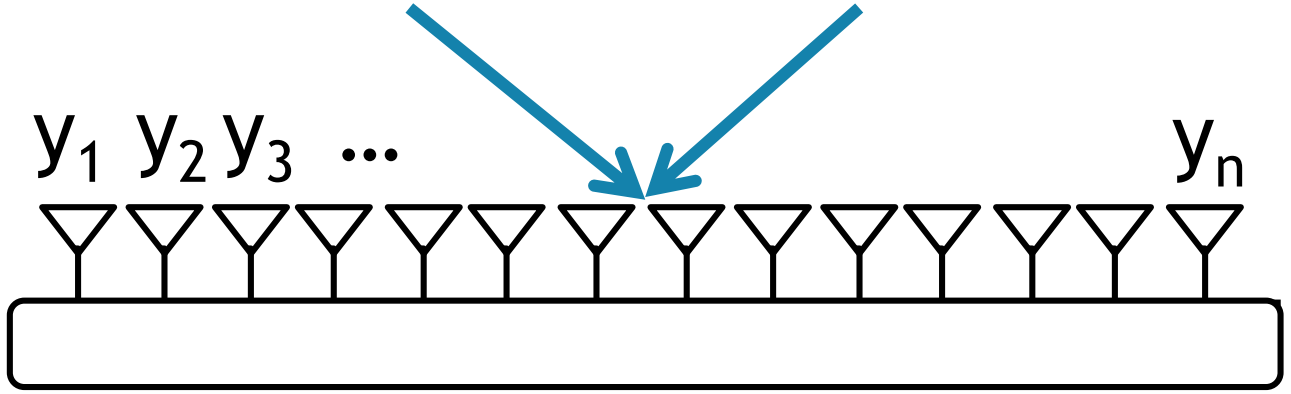


EXPLOIT MULTIPATH

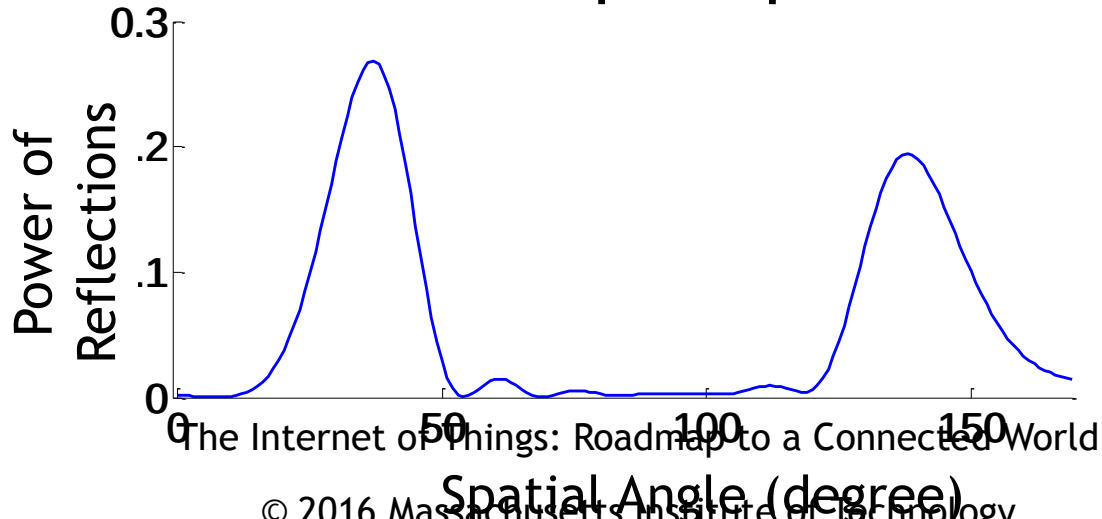
Multipath reflections tell us about distance from a reference source



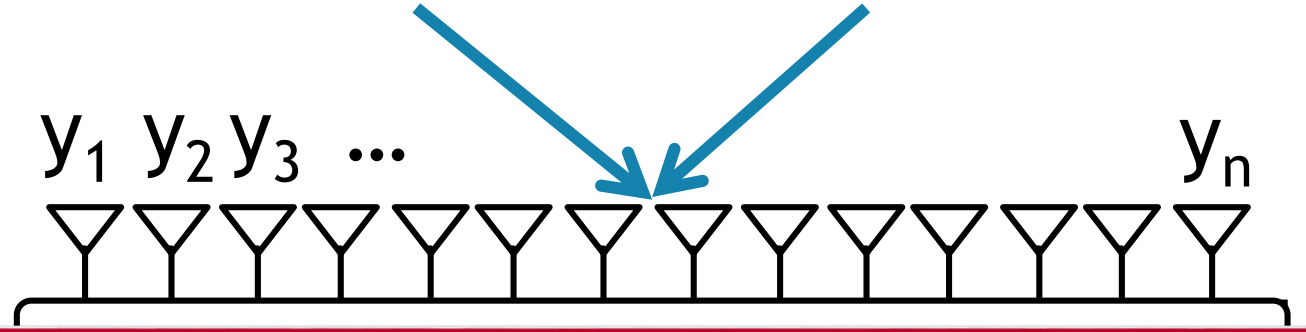
CAPTURING MULTIPATH PROFILES WITH AN ANTENNA ARRAY



Use textbook equations to process y_1, …, y_n and obtain the multipath profile



CAPTURING MULTIPATH PROFILES WITH AN ANTENNA ARRAY



Use t

obtain

Accurate multipath profiles require many antennas in the array

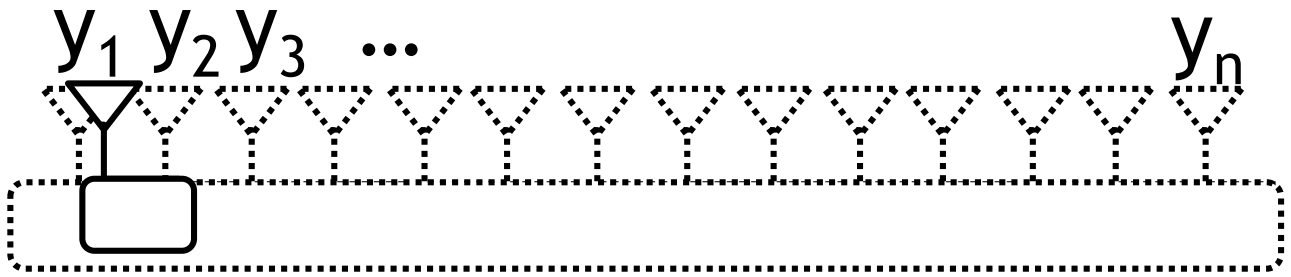
➔ Array is bulky and expensive

Po

Refl

Spatial Angle (degree)

CAPTURING MULTIPATH WITH A MOVING ANTENNA



Can capture very accurate multipath profiles with a single antenna

WORKS EVEN WITH RFIDS

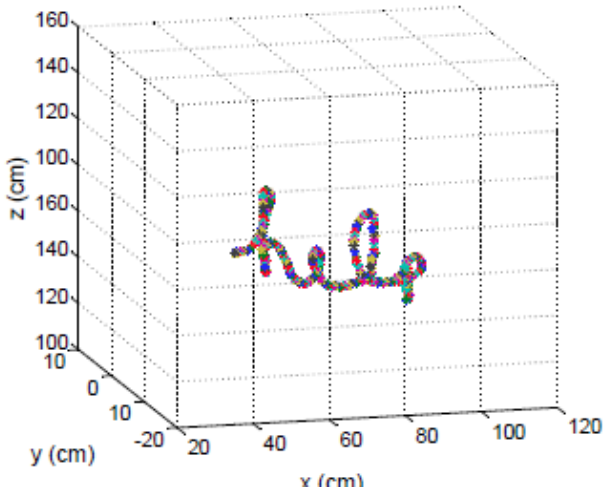
Battery-free stickers to tag any and every object

Say we can accurately localize RFIDs

No more customer checkout lines

No more customer checkout lines

VIRTUAL TOUCH SCREENS IN THE AIR [SIGCOMM'14]



Work with occlusions and obstructions

"RF-IDraw: Virtual Touch Screen in the Air Using RF Signals", Jue Wang, Deepak Vasisht, and Dina Katabi, ACM SIGCOMM, Chicago, Illinois, August 2014.

SMART HOMES

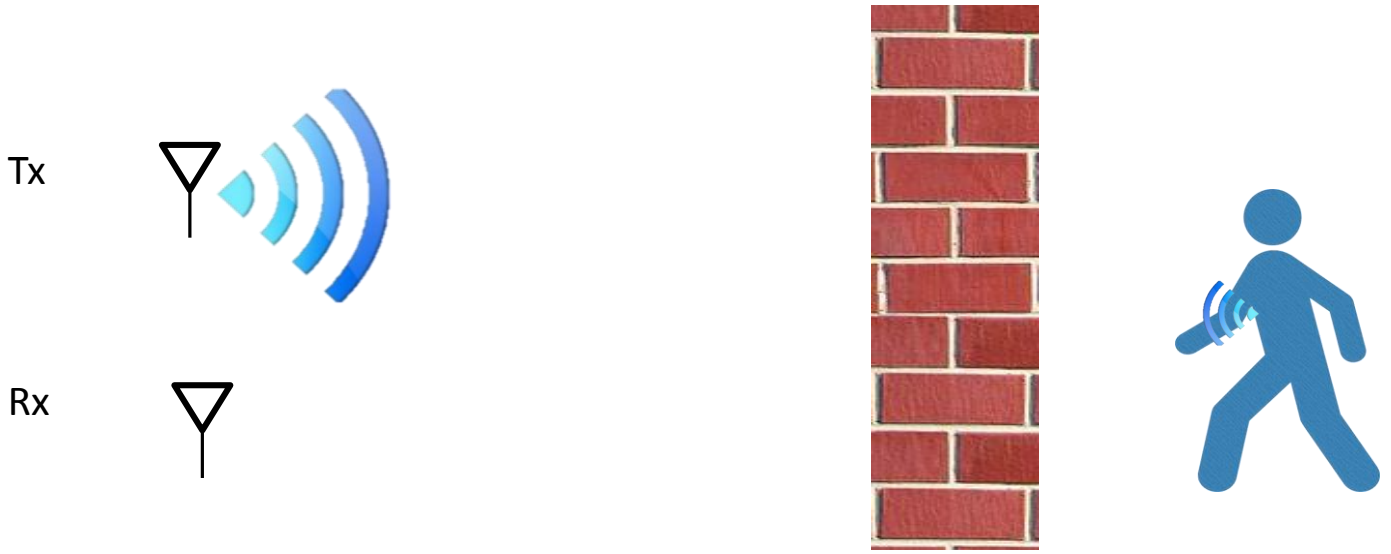
SMART HOMES THAT TRACK OUR ACTIVITIES

What if our home can detect when we wake up and open the shades; or turn the lights on as we walk toward a room

SMART HOMES THAT TRACK OUR ACTIVITIES

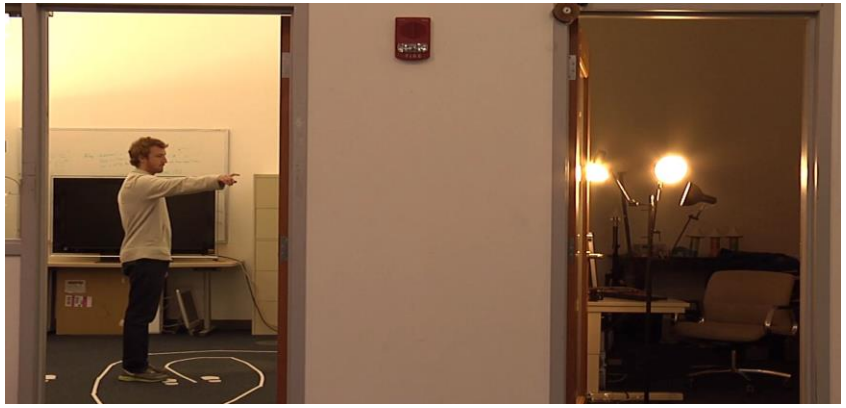
What if our home can detect when we wake up and open the shades; or turn the lights on as we walk toward a room

Device-Free Localization: Tracks a person using signal reflections off his/her body. No need for any on-body sensor



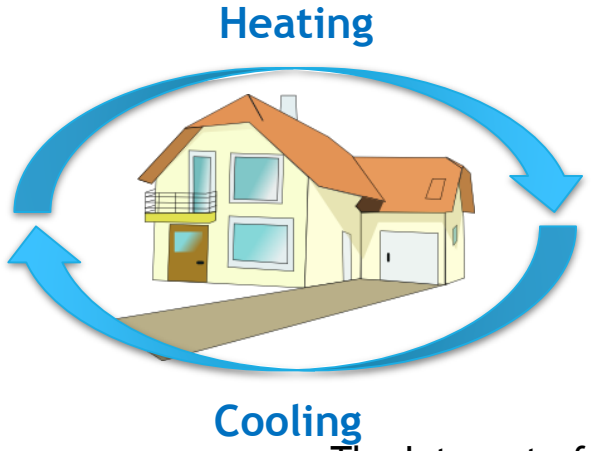
APPLICATIONS

Gesture Control



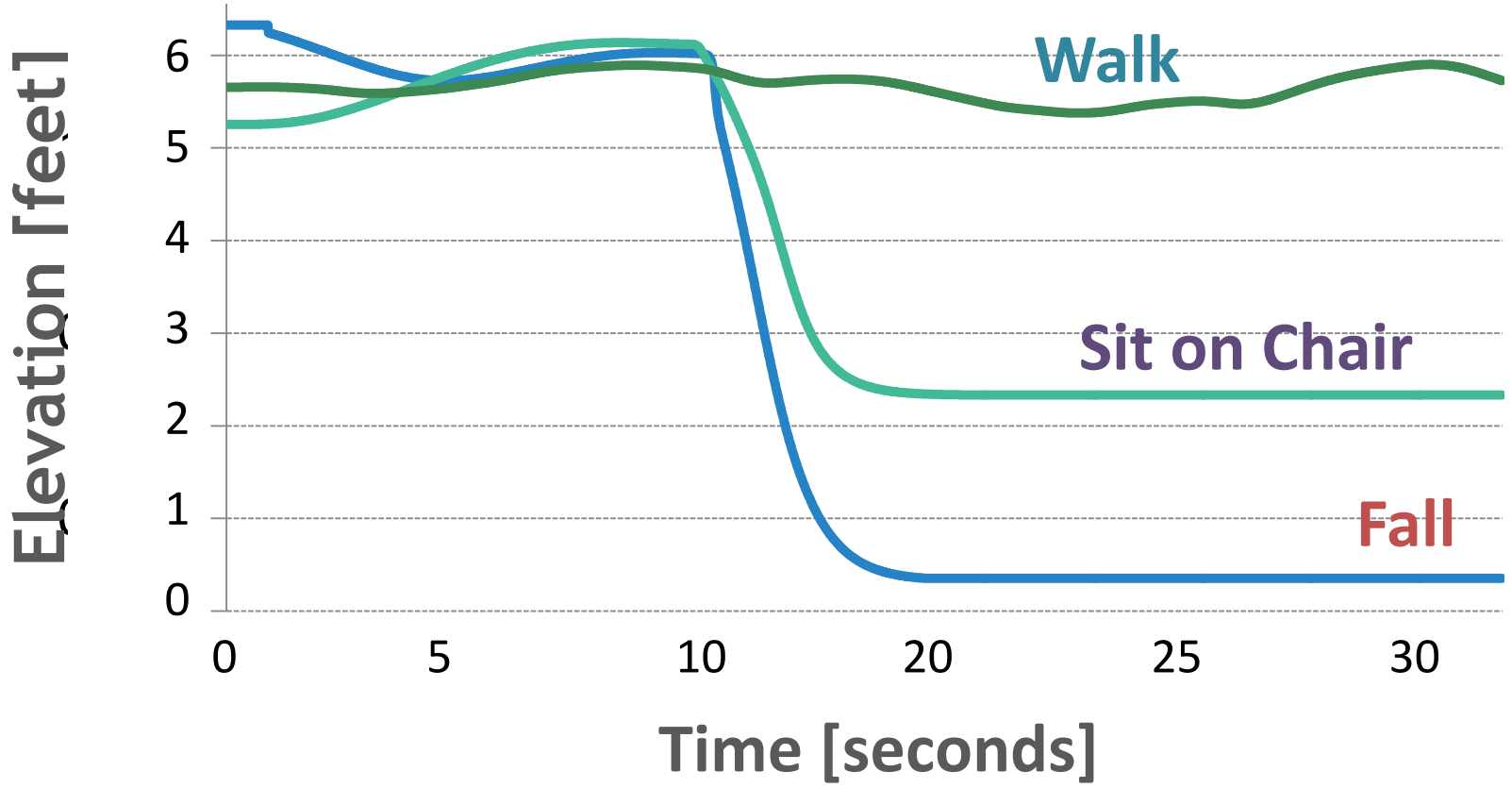
Gaming

Smart Heating & Cooling

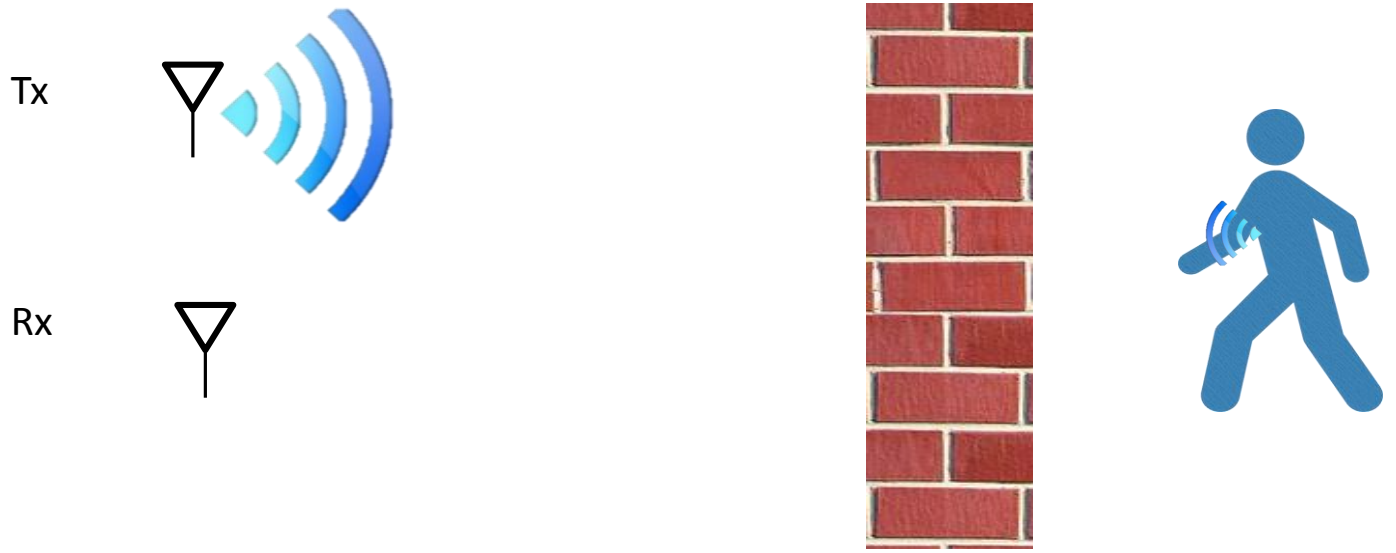


Elderly Fall Detection

FALL DETECTION



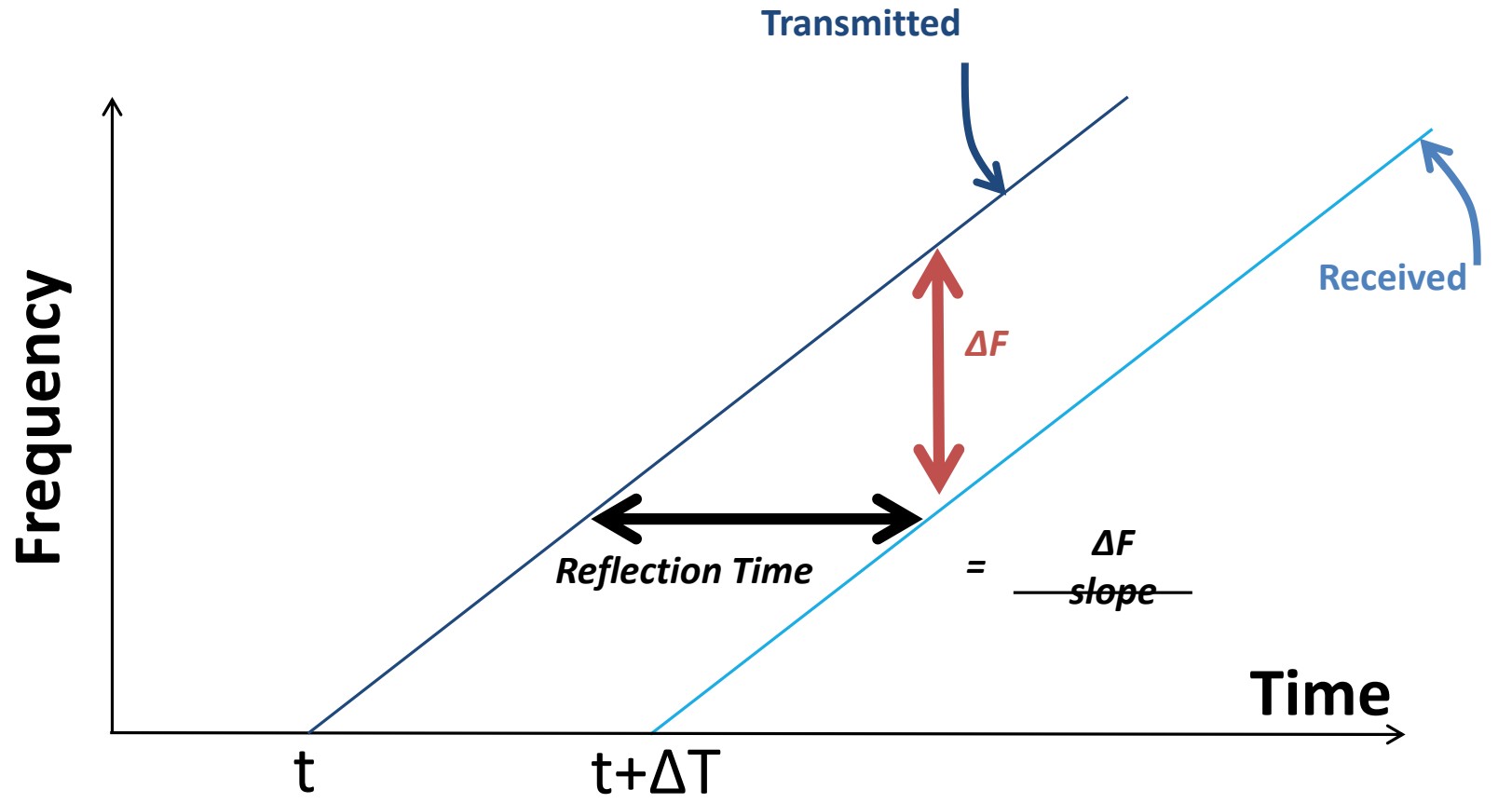
HOW DOES IT WORK?



Distance = Reflection time x speed of light

How do we measure reflection time?

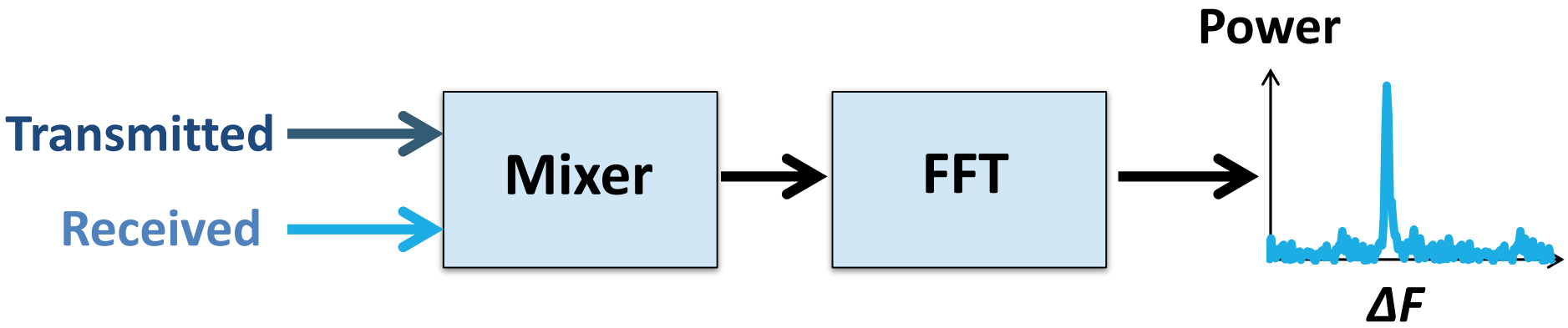
FREQUENCY MODULATED CARRIER WAVE (FMCW)



How do we measure ΔF?

MEASURING ΔF

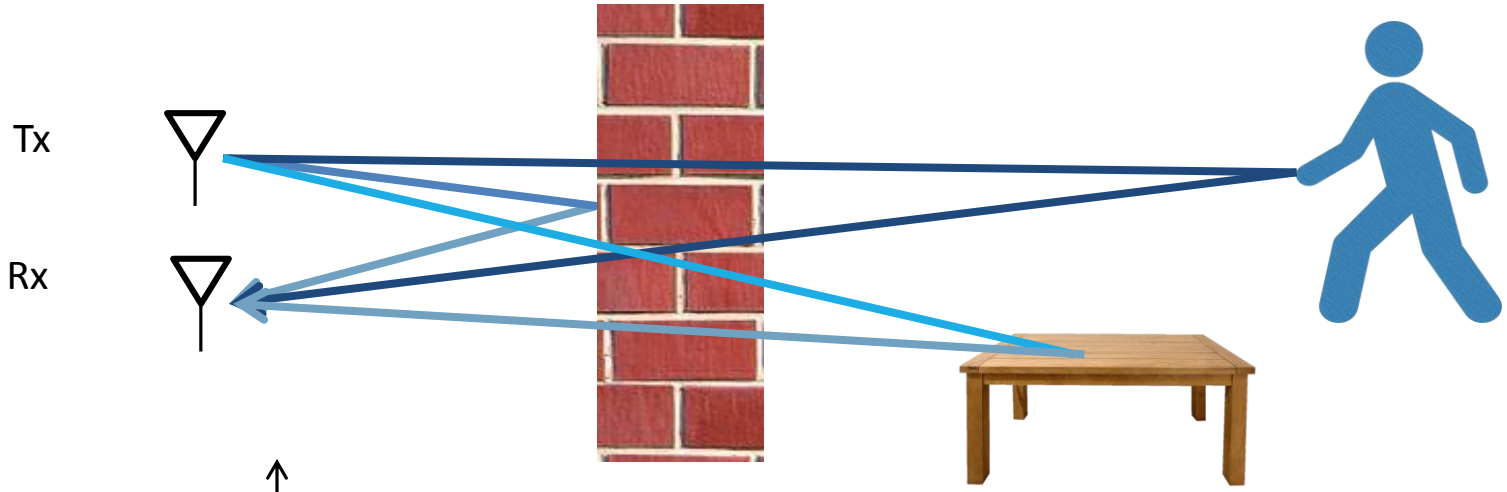
- **Subtracting frequencies is easy (e.g., removing carrier in WiFi)**
- **Done using a mixer**

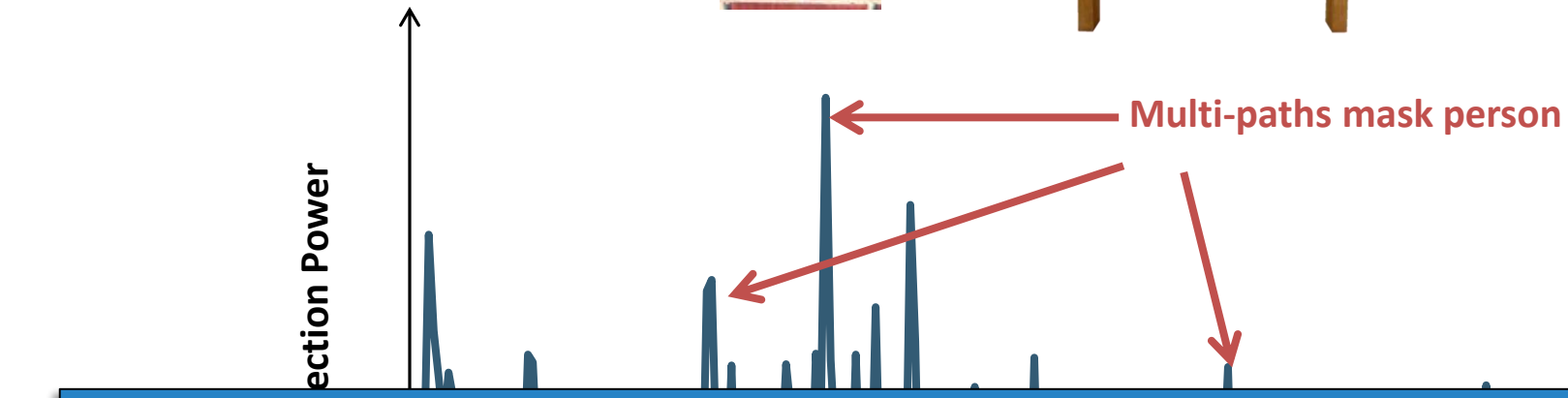


Signal whose frequency is *ΔF*

ΔF → Reflection Time → Distance

CHALLENGE: MULTIPATH➔ MANY REFLECTIONS



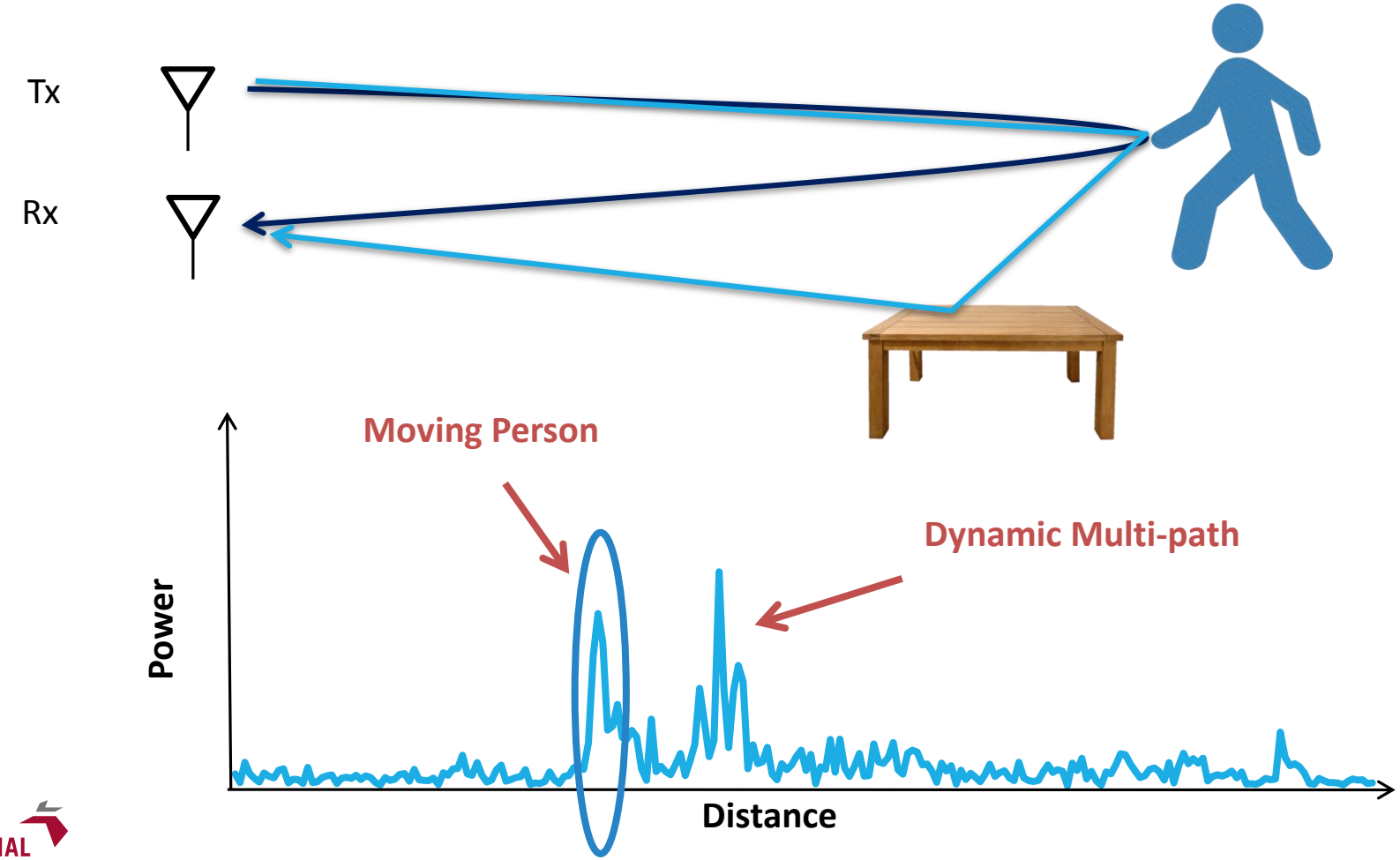


Smart algorithms that disentangle a person's reflections from the multipath

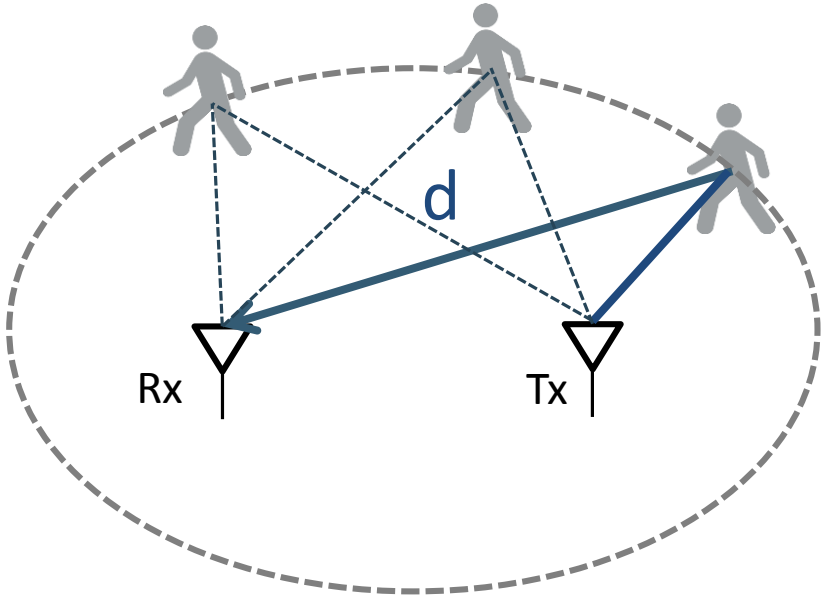
STATIC OBJECTS DON'T MOVE ➔ ELIMINATE BY SUBTRACTING CONSECUTIVE MEASUREMENTS

DYNA

The direct reflection arrives before dynamic multipath!



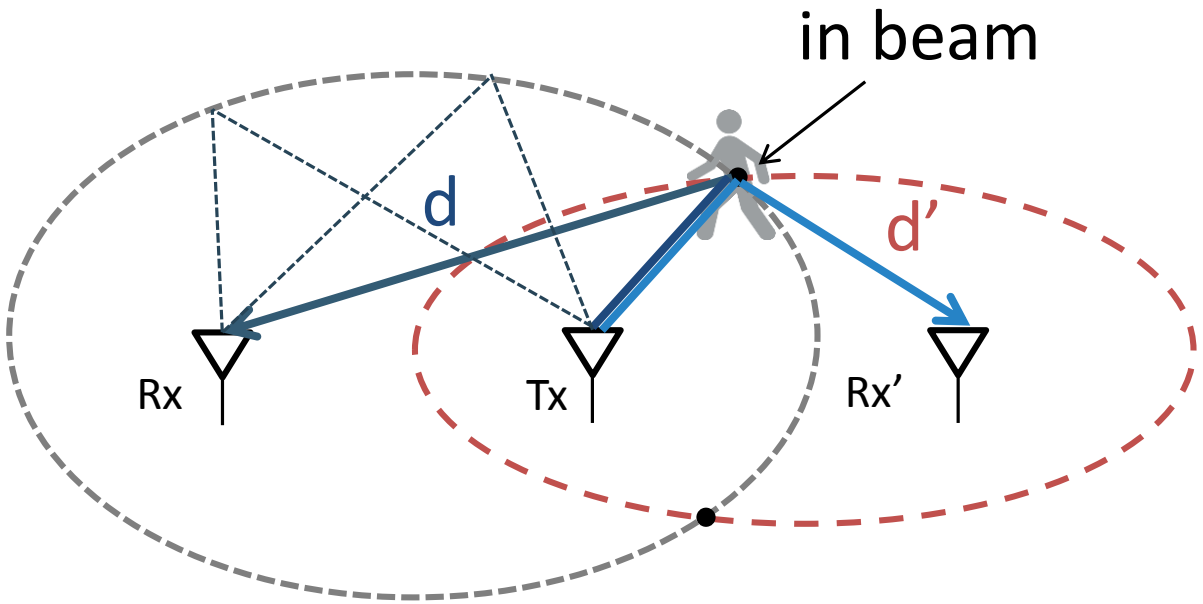
From Distances to Localization



Person can be anywhere on an ellipse whose foci are (Tx,Rx)

One ellipse is not enough to localize!

From Distances to Localization



WiTrack uses directional antennas so only one point is in-beam

Extend to 3D by using 3 Rx antennas and taking the intersection of ellipsoids

SMART HEALTH

UBIQUITOUS HEALTH & COMFORT MONITORING

Can smart homes monitor and adapt to our breathing and heart rates?

Can smart homes monitor and adapt to our breathing and heart rates?

Can smart homes monitor and adapt to our breathing and heart rates?

Personal Health

Baby Sleep

Elderly Health

Apnea test @home

Adapt Lighting and Music to Mood

BUT: TODAY'S TECHNOLOGIES FOR MONITORING VITAL SIGNS ARE CUMBERSOME

Breath Monitoring

Heart Rate Monitoring

Not suitable for elderly & babies

CAN WE MONITOR BREATHING AND HEART RATE FROM A DISTANCE?

VITAL-RADIO

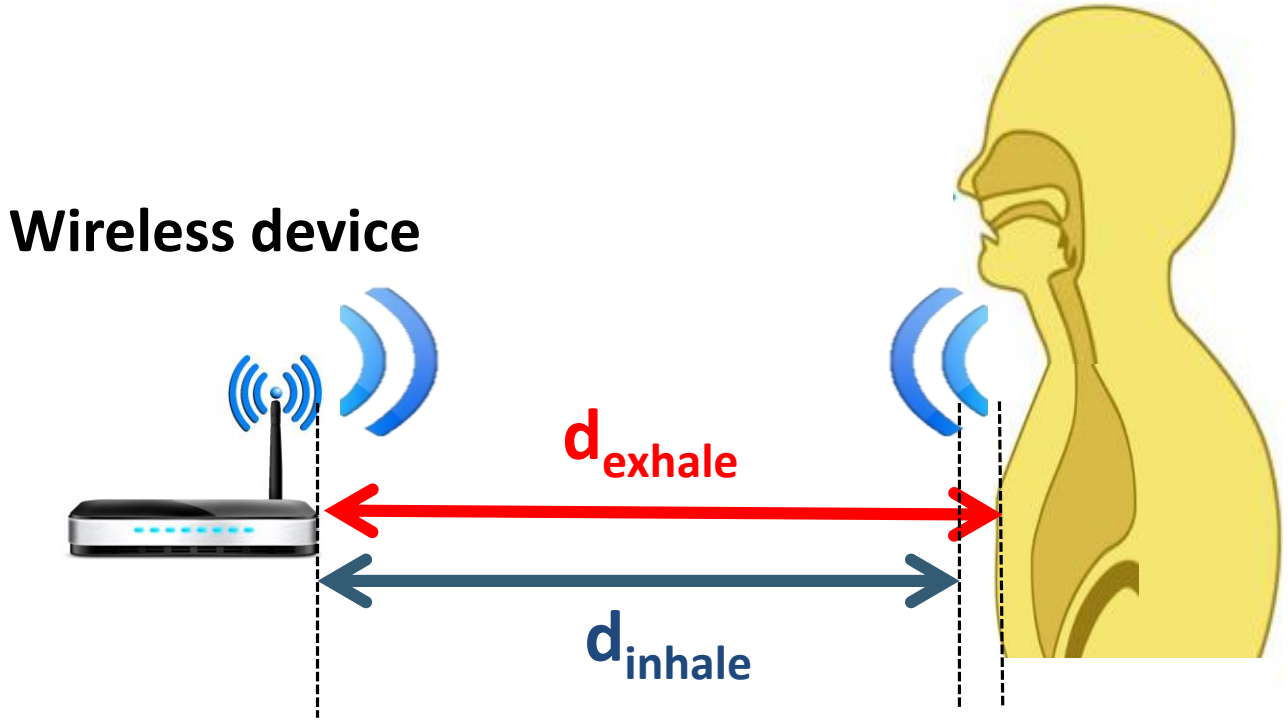
Technology that monitors breathing and heart rate remotely with accuracy comparable to FDA approved devices

Can monitor multiple users simultaneously

Operates through walls and can cover multiple rooms

IDEA: USE WIRELESS REFLECTIONS OFF THE HUMAN BODY

IDEA: USE WIRELESS REFLECTIONS OFF THE HUMAN BODY

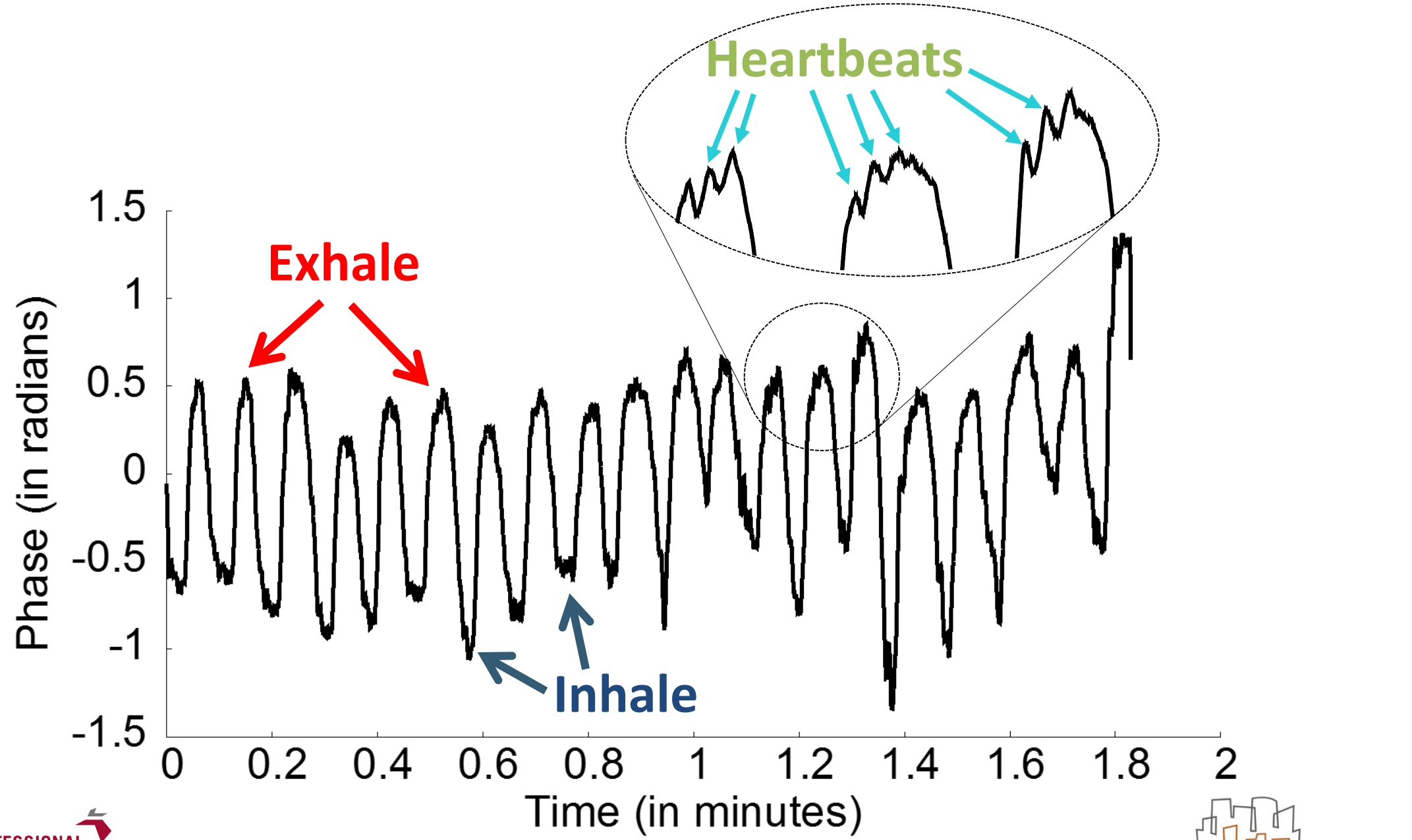


Wireless wave has a phase:

$$\phi = 2\pi \frac{\text{distance}}{\text{wavelength}}$$

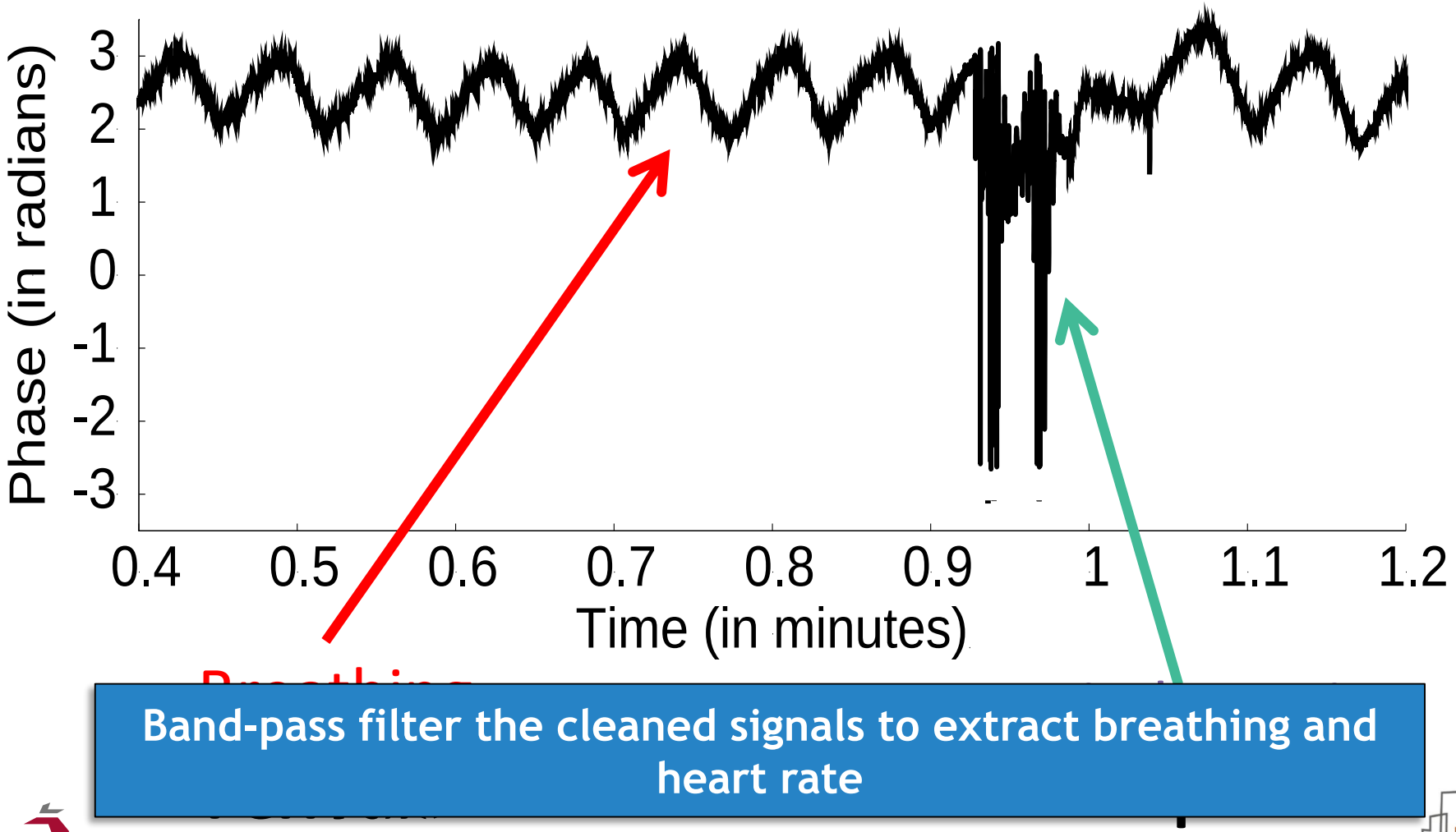
- Chest Motion changes distance
- Heartbeats also change distance

LET'S ZOOM IN ON THESE SIGNALS



What happens when a person moves his limb?

What happens when a person moves his limb?

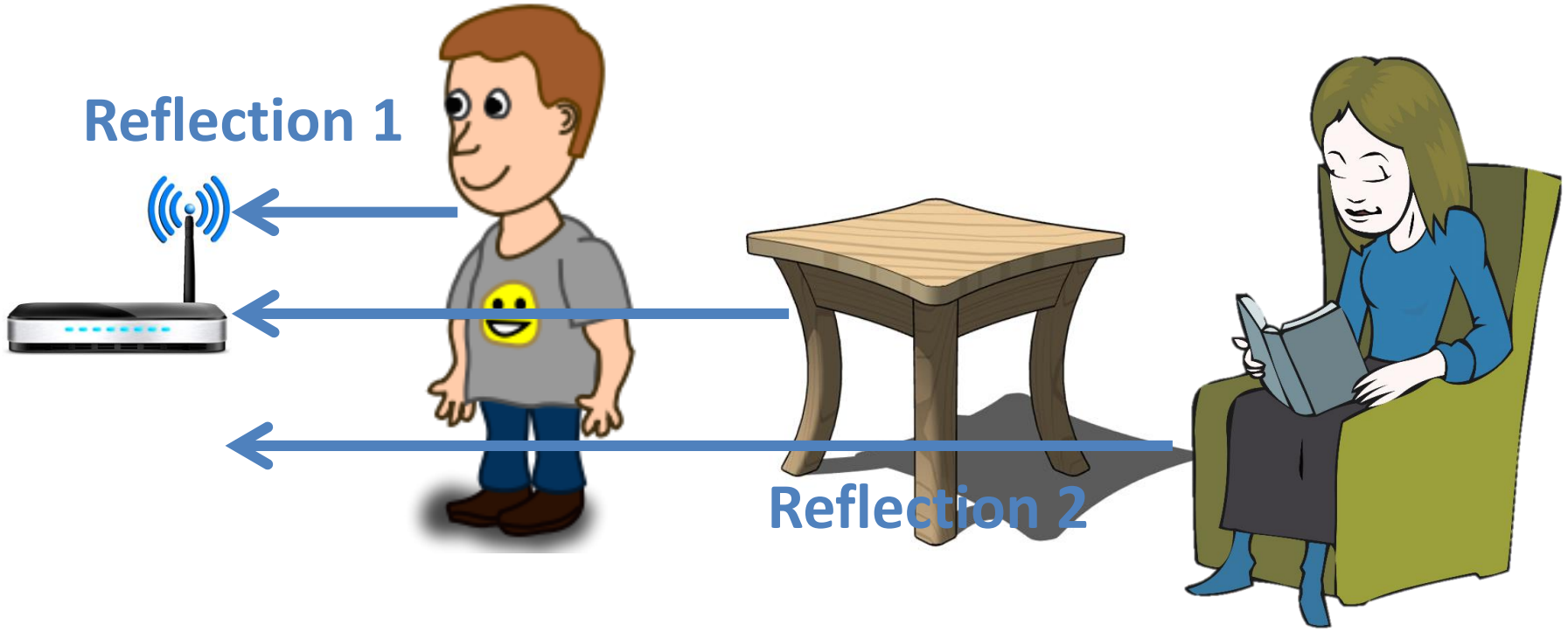


Band-pass filter the cleaned signals to extract breathing and heart rate

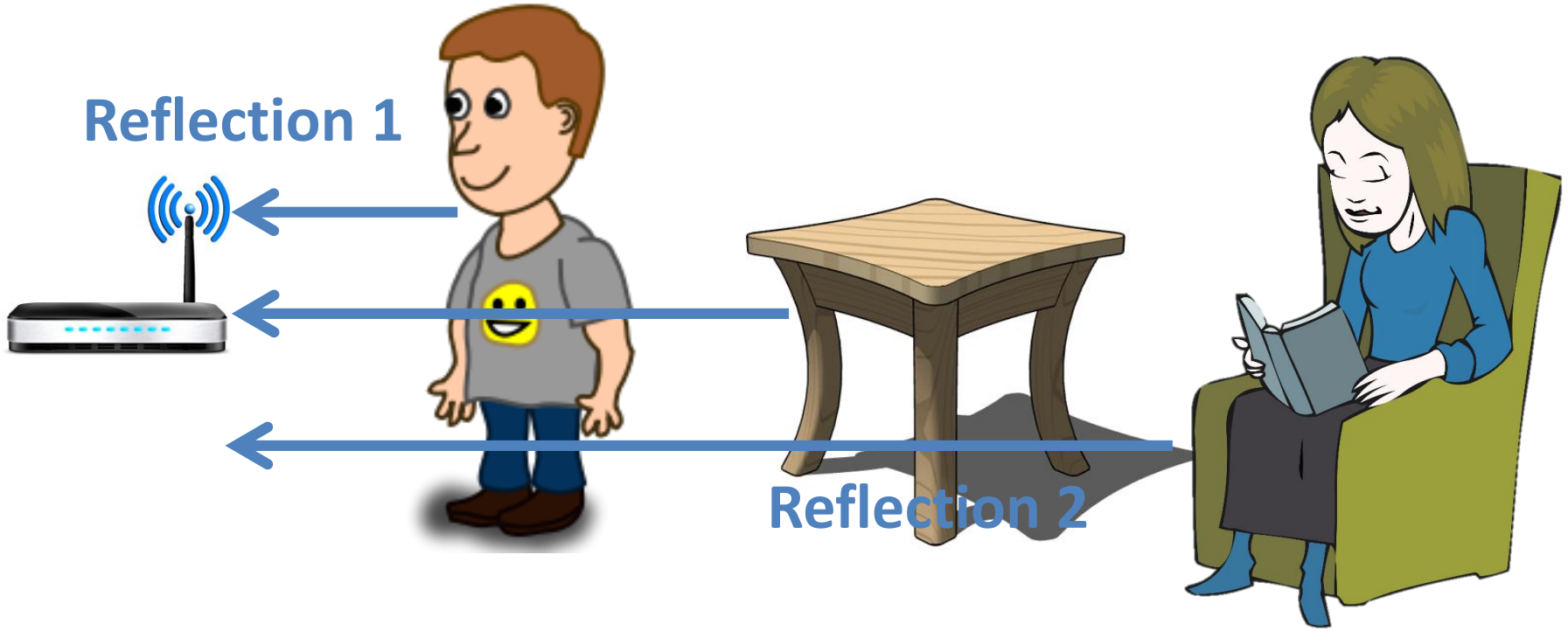
WHAT HAPPENS WITH MULTIPLE USERS IN THE ENVIRONMENT?

REFLECTIONS FROM DIFFERENT OBJECTS COLLIDE

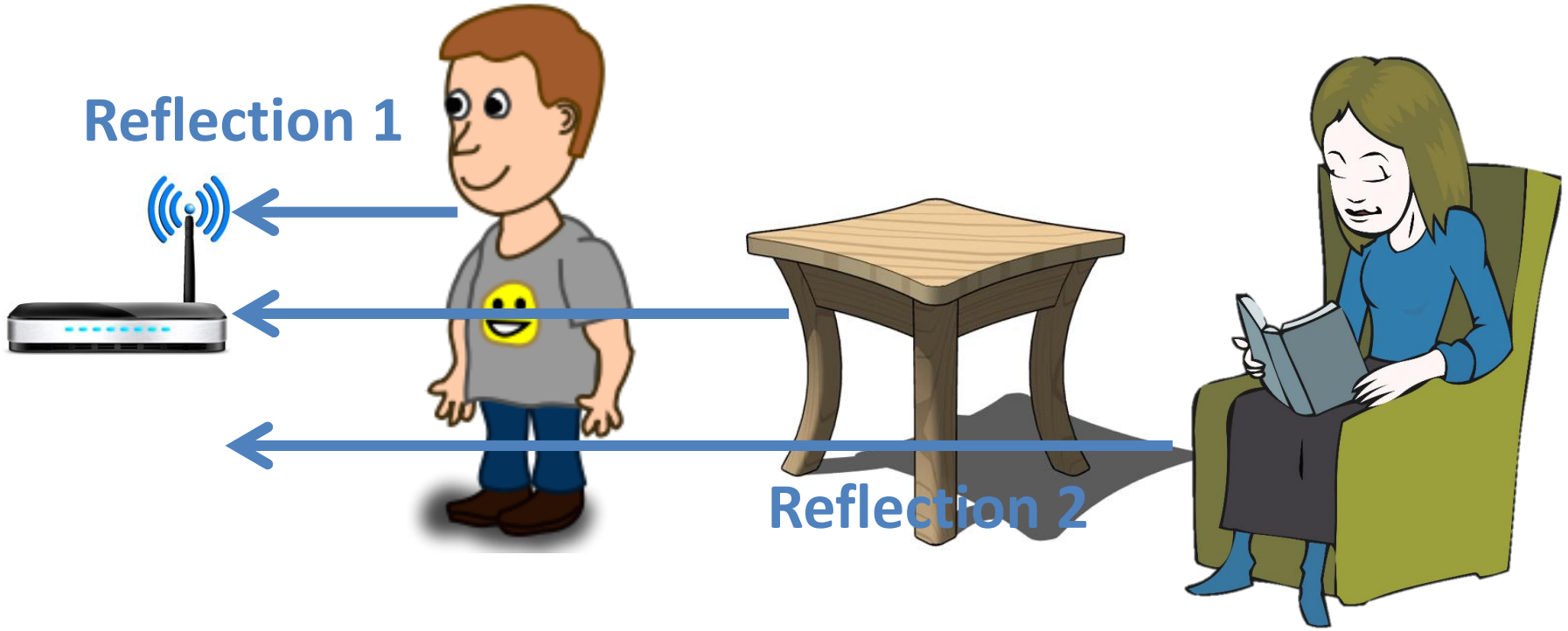
Problem: Phase becomes meaningless!



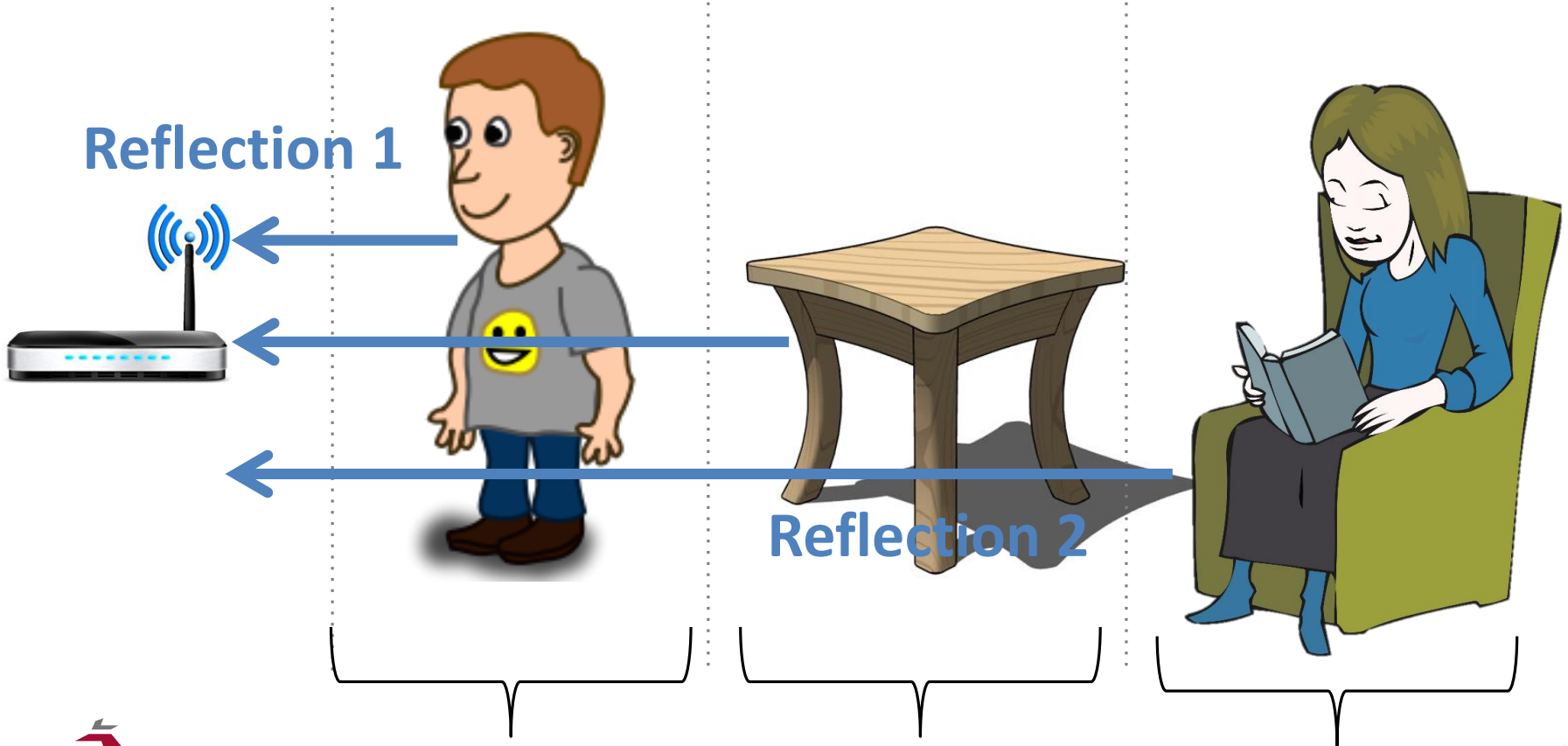
Idea: Wireless positioning can be used to locate various devices



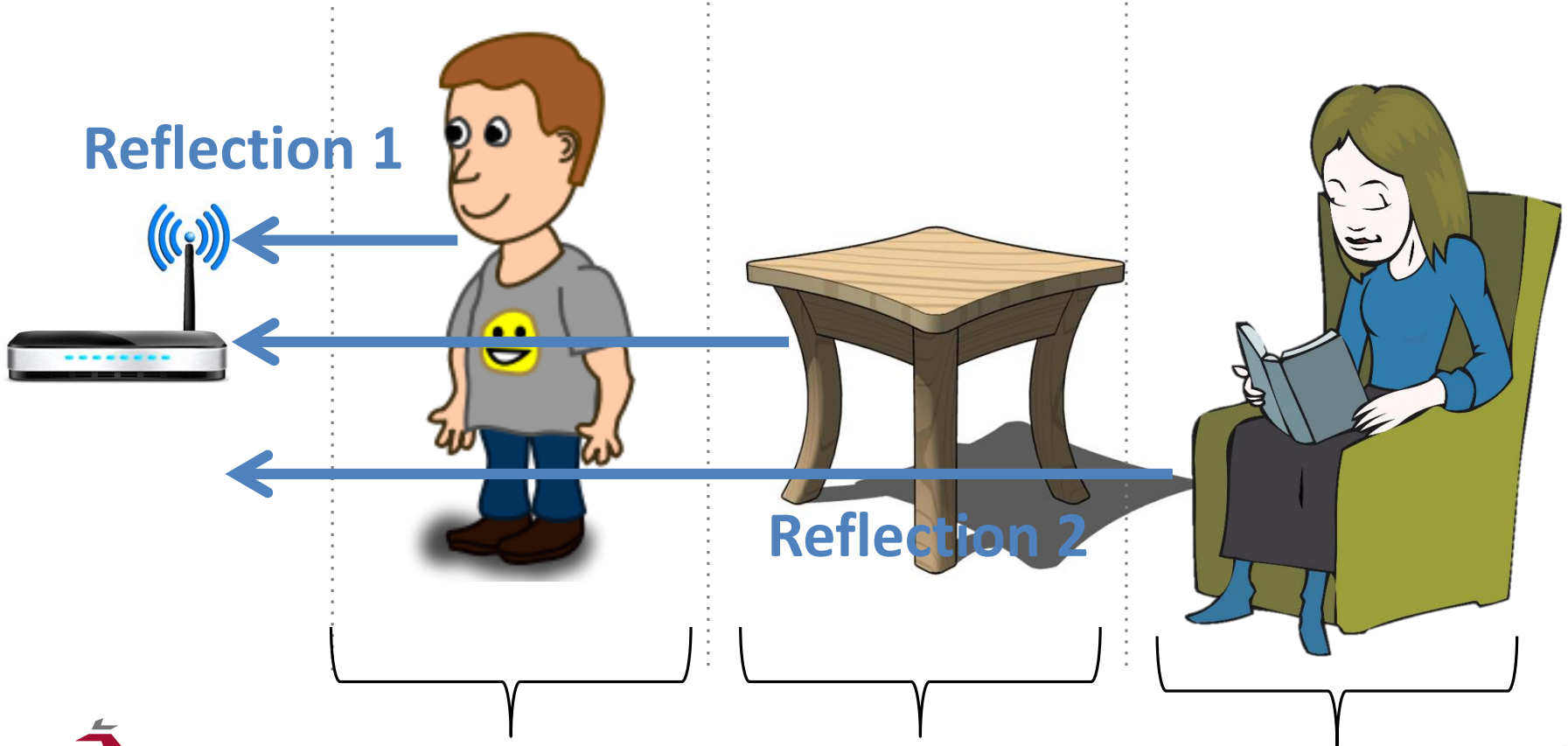
Solution: Use wireless positioning as a filter to isolate reflections from different positions



Solution: Use wireless positioning as a filter to isolate reflections from different positions



Solution: Use wireless positioning as a filter to isolate reflections from different positions



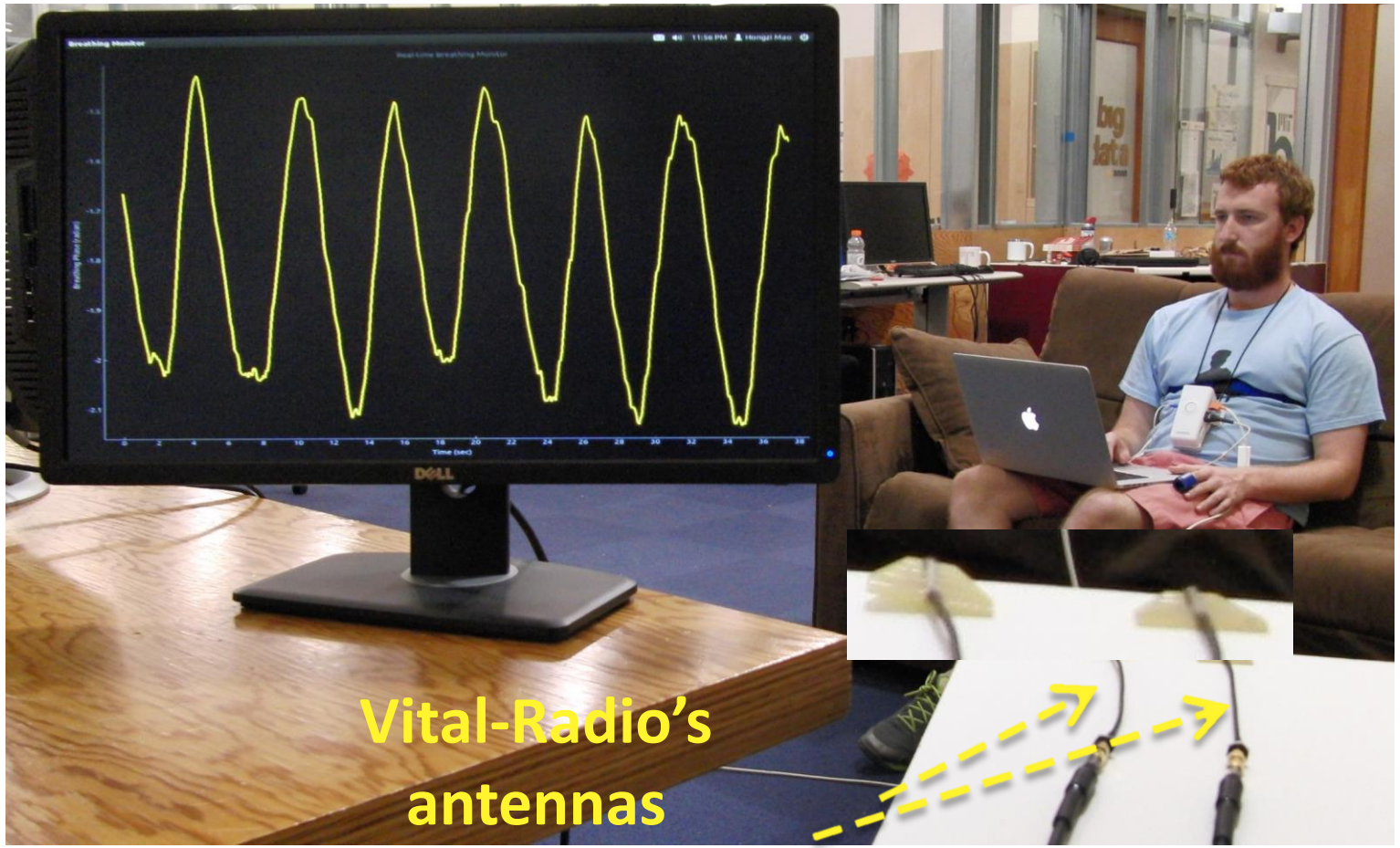
PUTTING IT TOGETHER

Step 1: Transmit a wireless signal and capture its reflections

Step 2: Isolate reflections from different objects based on their positions

Step 3: Zoom in on each object's reflection to obtain phase variations due to vital signs

VITAL-RADIO EVALUATION



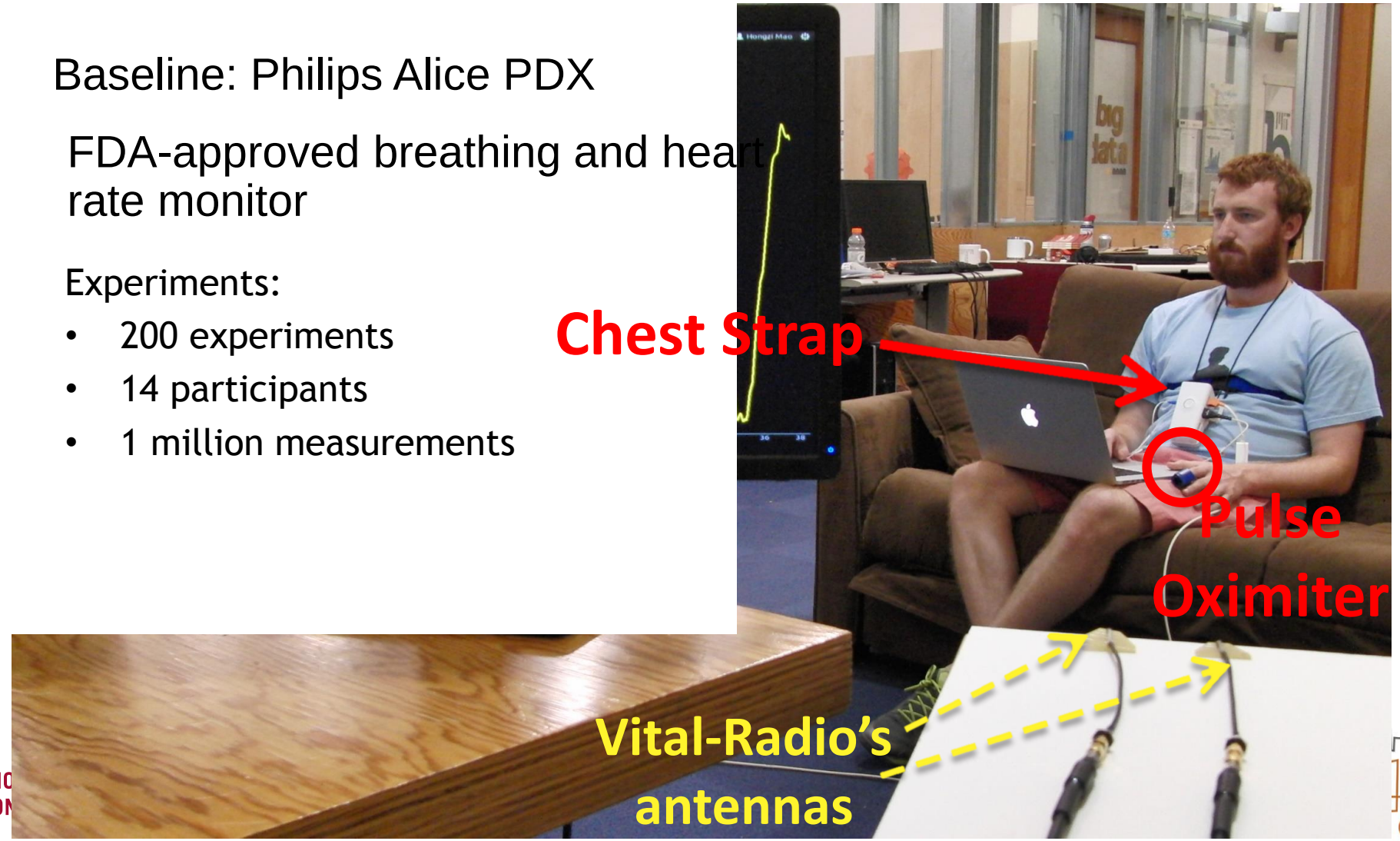
VITAL-RADIO EVALUATION

Baseline: Philips Alice PDX

FDA-approved breathing and heart rate monitor

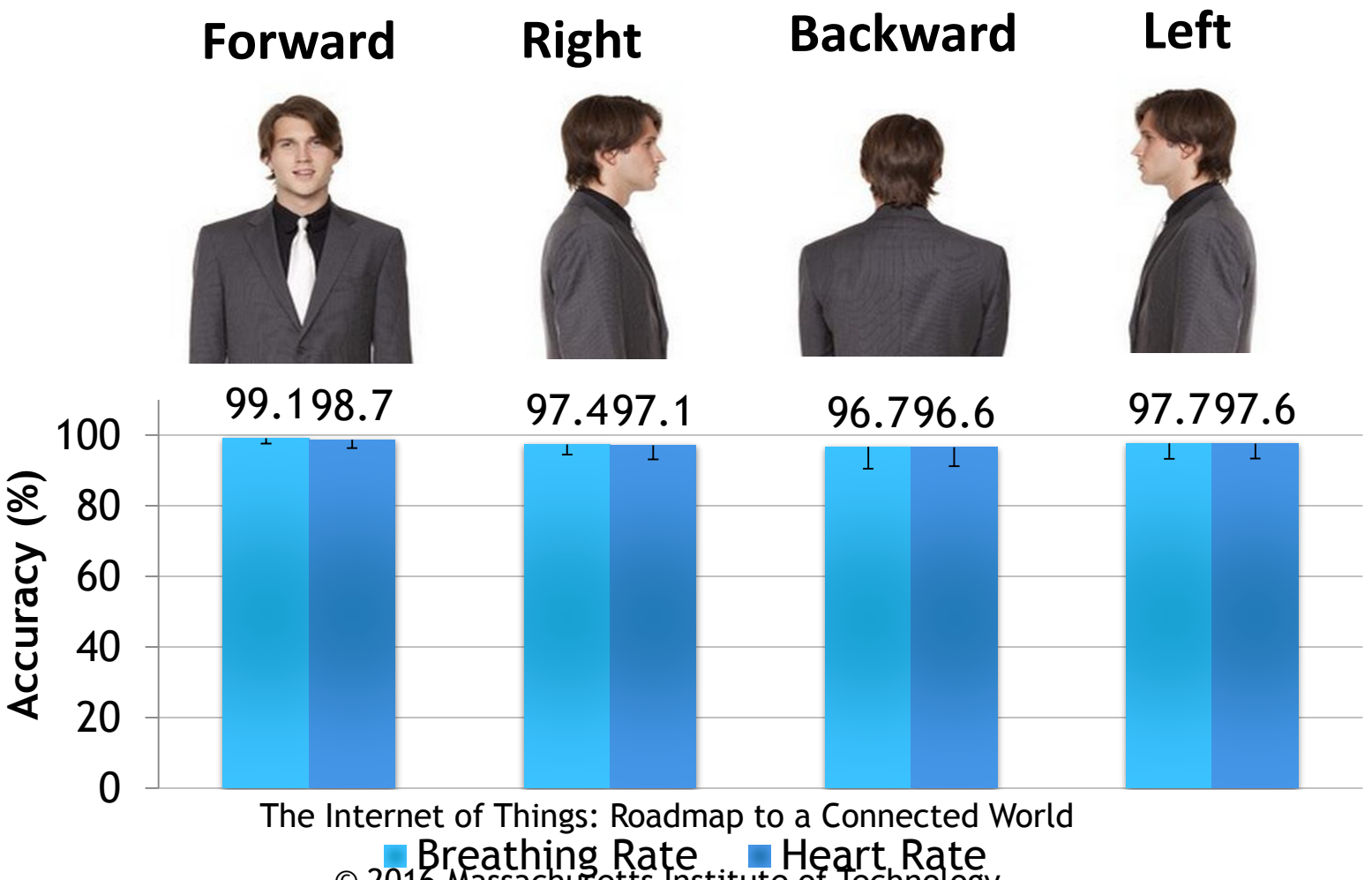
Experiments:

- 200 experiments
- 14 participants
- 1 million measurements



ACCURACY VS. ORIENTATION

User is 4m from device, with different orientations



REFERENCES

Capturing the Human Figure Through a Wall, Fadel Adib, Chen-Yu Hsu, Hongzi Mao, Dina Katabi, Fredo Durand, ACM SIGGRAPH Asia'15, Kobe, Japan, November 2015.

Multi-Person Localization via RF Body Reflections, Fadel Adib, Zach Kabelac, Dina Katabi, Usenix NSDI'15, Oakland, California, May 2015.

Smart Homes That Monitor Breathing and Heart Rate, Fadel Adib, Hongzi Mao, Zach Kabelac, Dina Katabi, Robert C. Miller, CHI'15, Seoul, South Korea, April 2015.

Caraoke: An E-Toll Transponder Network for Smart Cities, O. Abari, D. Vasisht, D. Katabi and A. Chandrakasan, ACM Special Interest Group on Data Communication (SIGCOMM), London UK, August 2015.

AirShare: Distributed Coherent Transmission Made Seamless, O. Abari, H. Rahul, D. Katabi and M. Pant,IEEE International Conference on Computer Communications (INFOCOM), Hong Kong, April 2015.

REFERENCES

Securing RFIDs by Randomizing the Modulation and Channel, Haitham Hassanieh, Jue Wang, Dina Katabi, and Tadayoshi Kohno, NSDI'15, USENIX Symposium on Networked Systems Design and Implementation, May 2015.

Accurate Indoor Localization with Zero Startup Cost, Swarun Kumar, Stephanie Gil, Dina Katabi and Daniela Rus, ACM MobiCom'14, Maui HI, 2014.

RF-IDraw: Virtual Touch Screen in the Air Using RF Signals, Jue Wang, Deepak Vasisht, and Dina Katabi, ACM SIGCOMM, Chicago, Illinois, August 2014.

- RF-Compass: Robot Object Manipulation using RFIDs. Jue Wang, Fadel Adib, Ross Knepper, Dina Katabi, and Daniela Rus. ACM MobiCom'13, Miami, Florida, October 2013.
- Dude, Where's My Card? RFID Positioning That Works with Multipath and Non-Line of Sight. Jue Wang and Dina Katabi, ACM SIGCOMM'13, Hong Kong, August 2013.

THANK YOU!

Dina Katabi
Andrew & Erna Viterbi Professor, MIT

Computer Science and Artificial Intelligence Laboratory (CSAIL)
Massachusetts Institute of Technology