Emerging Wireless Technologies: Millimeter Wave, Untethered VR, Smart Cities, Health IoT

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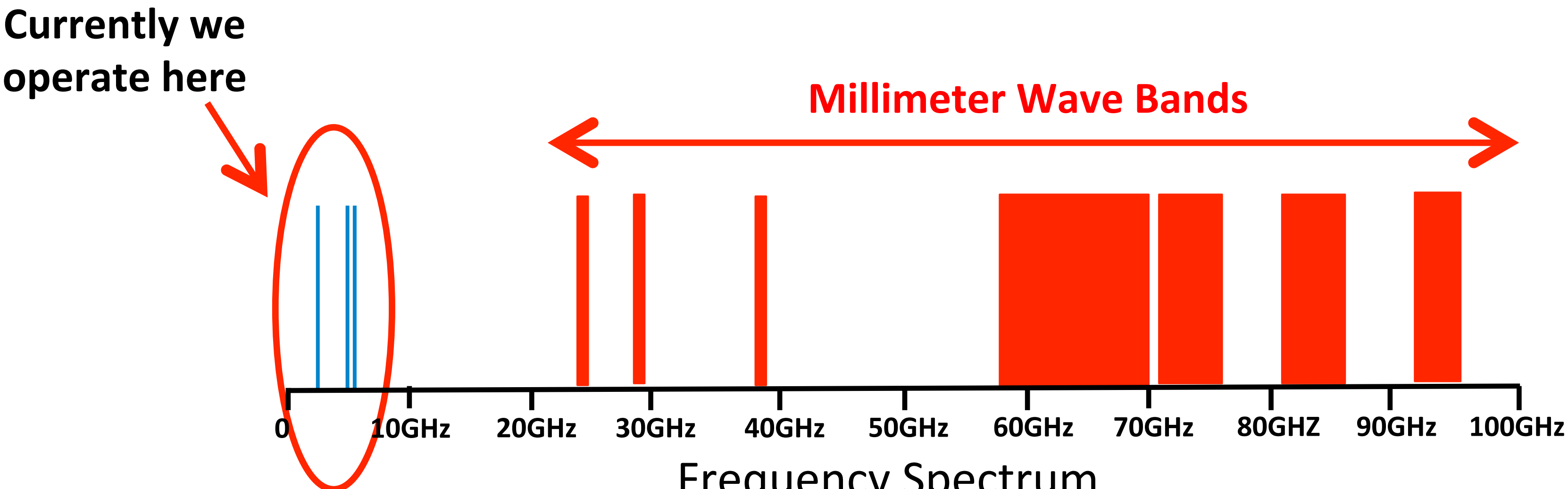
Emerging Applications

High-Throughput Millimeter Wave (mmWave) Systems

Spectrum Scarsity



Millimeter Wave Technology enables high-throughput wireless links

Millimeter wave changes how wireless systems operate

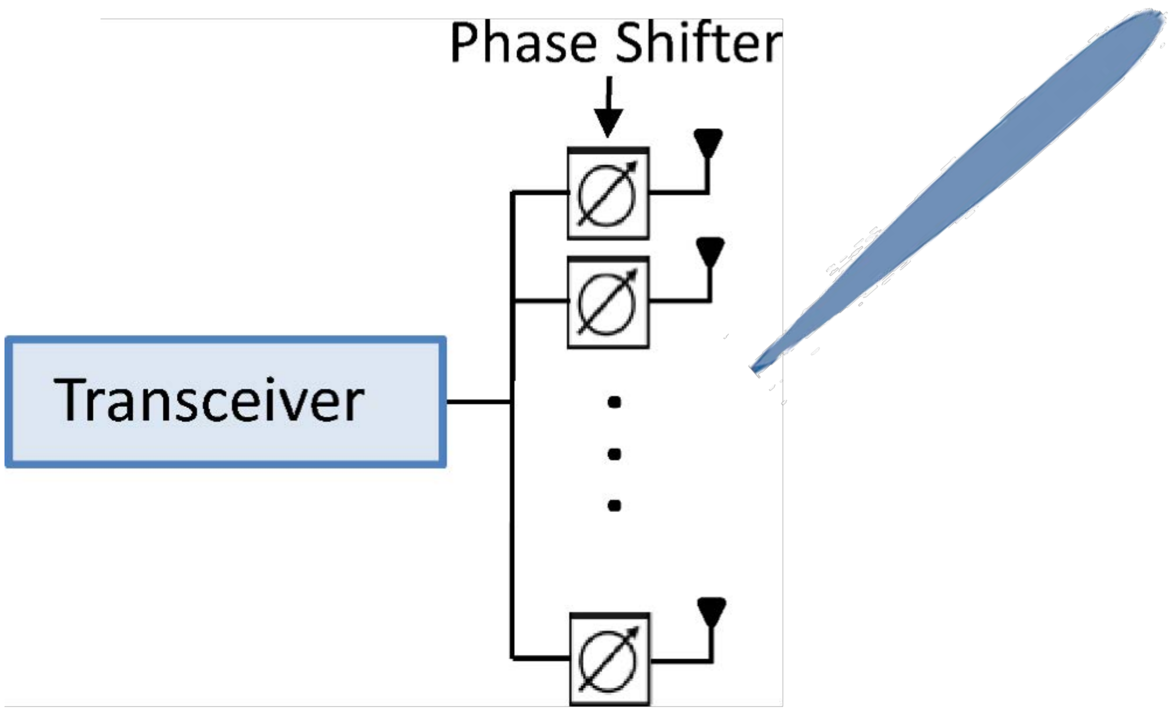
Today: Broadcast

Millimeter wave changes how wireless systems operate

Millimeter Wave: Pencil-beam Antennas

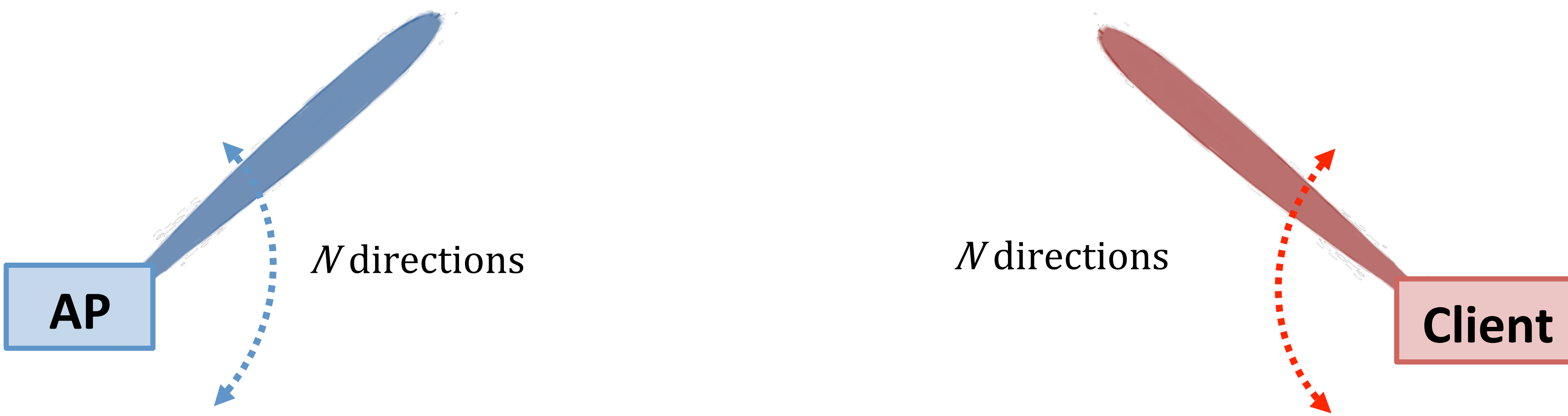
Communication is possible only when the beams are aligned

Millimeter wave radios use phased arrays to create a beam



Naïve Approach: Exhaustive Scan

N : number of possible directions



$O(N^2)$ measurements → Too slow

802.11ad Scan

Stage 1: Client uses omni-directional; AP scans directions

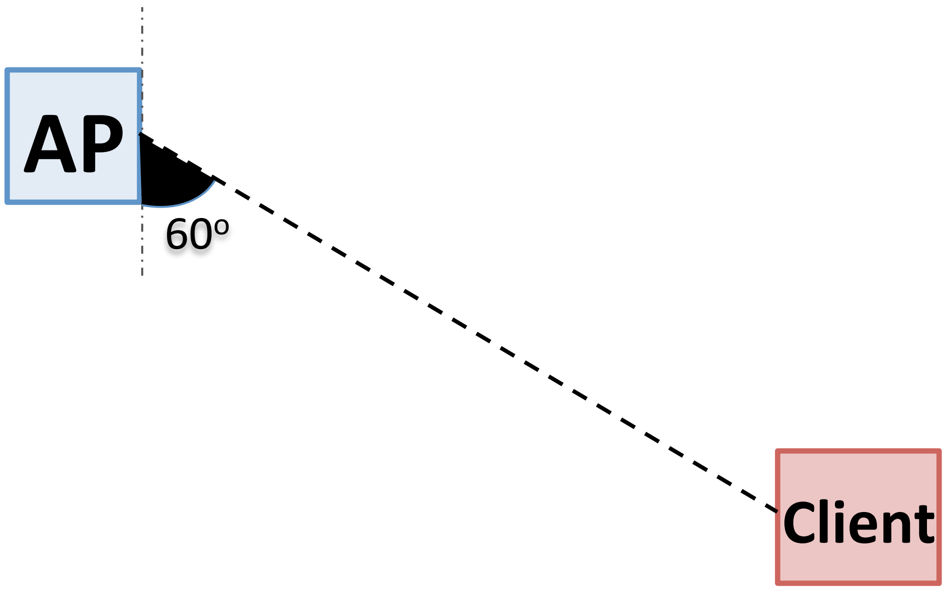
802.11ad Scan

Stage 2: AP uses omni-directional; client scans directions

$O(N)$ measurements →Still Too Slow

Can we find the best beam alignment without scanning the space?

Solution Idea

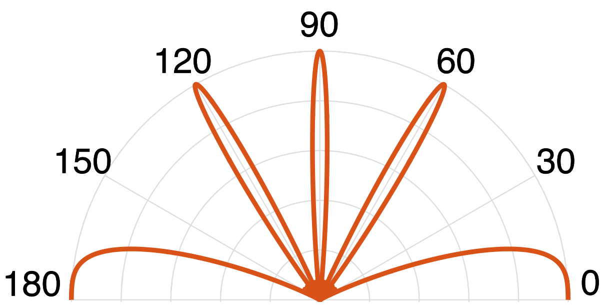


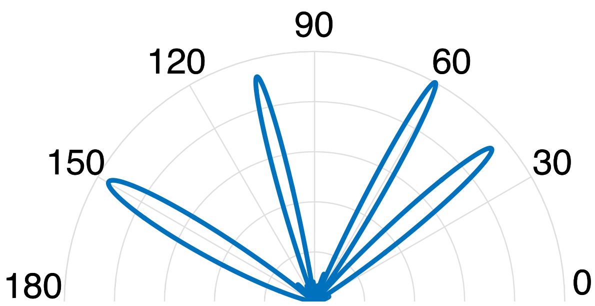
Potential Direction of the Client:
0º, 60º, 90º or 120º
40º, 60º, 100º or 150º

60º is direction of client

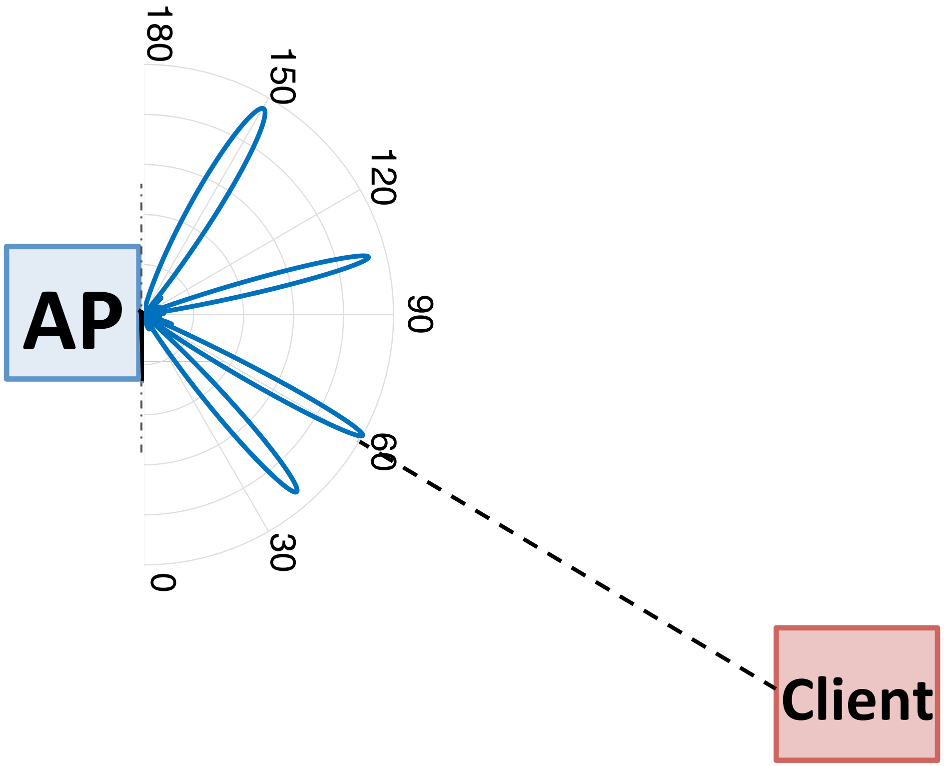
Construct a Multi-Armed Beam:

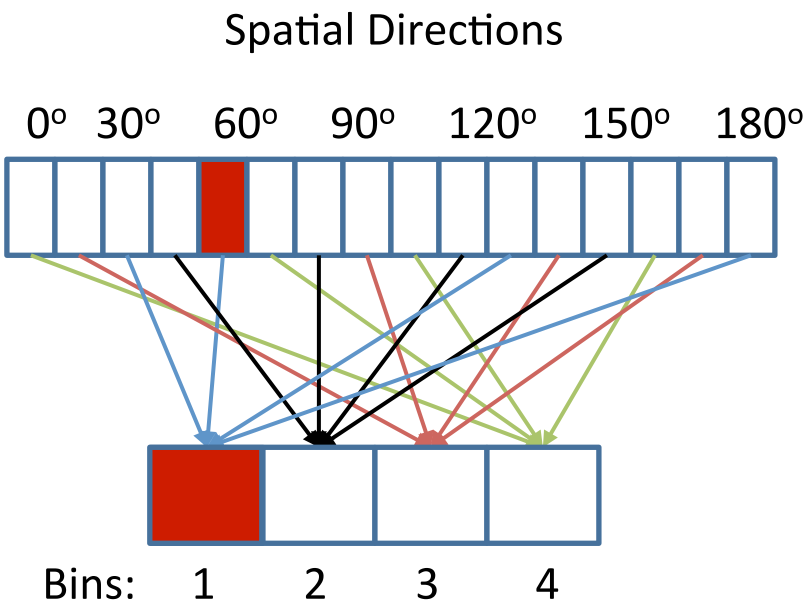
Simultaneously collects signals from multiple directions.





Multi-Armed Beams = Hashing





Hashing

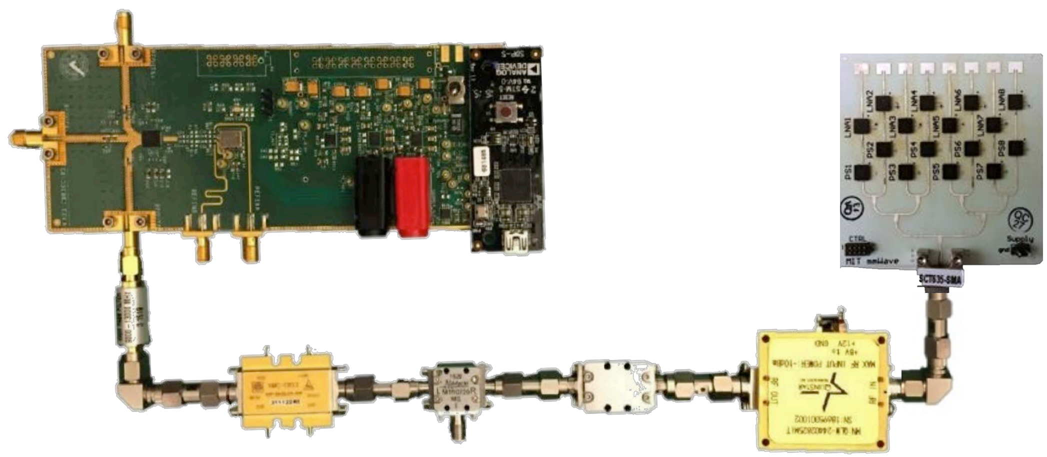
- Pick multi-armed beams to create random hash functions

Voting

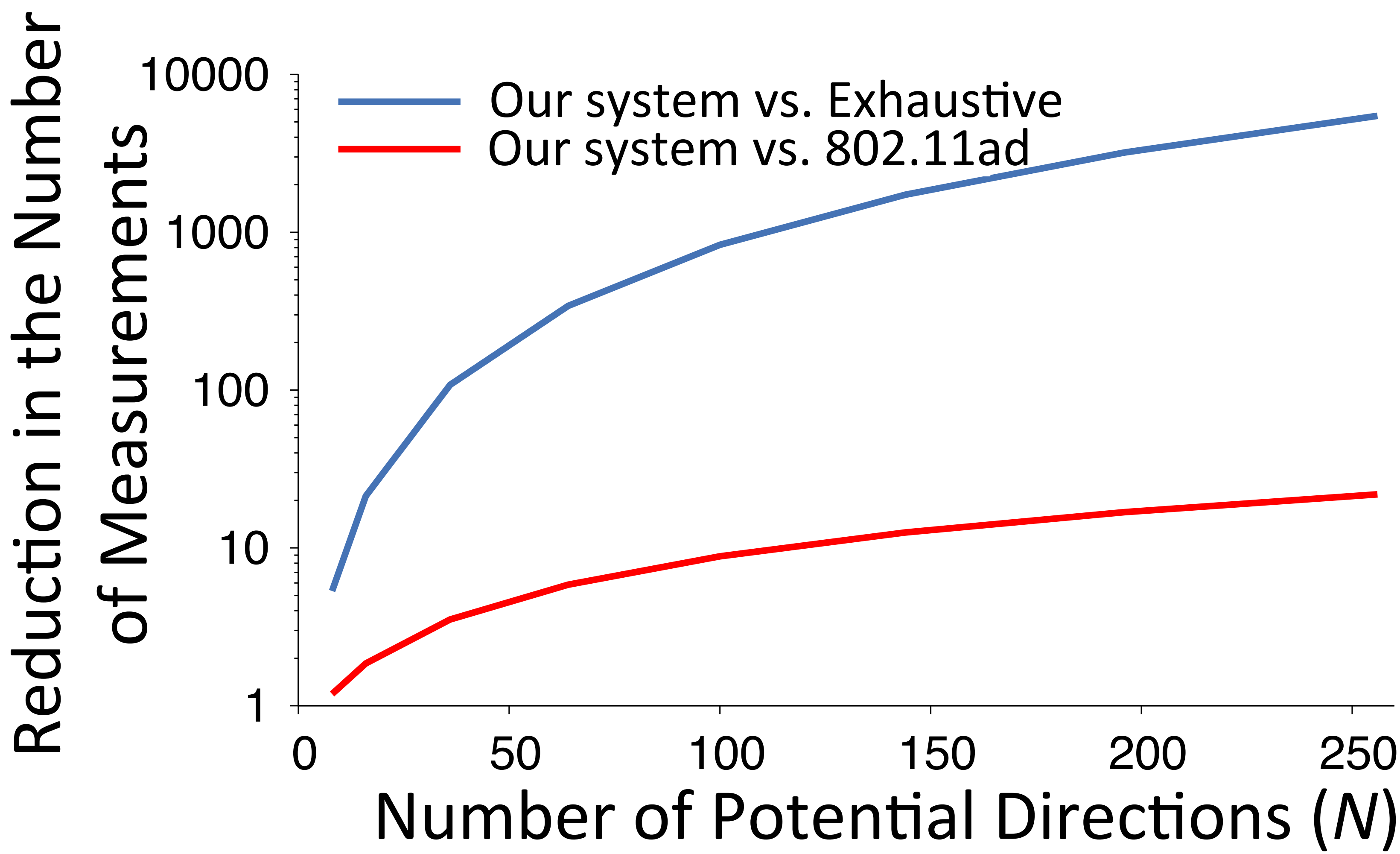
- Estimate the true direction using voting

Implementation and Evaluation

Built a Millimeter Wave Radio with a Phased Array.



Number of Measurements



Our system uses orders of magnitude fewer measurements

Beam Alignment Latency

Number of Directions	802.11ad	Our algorithm
16	1ms	0.5ms
64	4ms	0.8ms
128	106ms	0.9ms
256	310ms	1.0ms

High-Speed Millimeter Wave Links with Low Delay

Untethered Virtual Reality

VR headsets require a cable connection to a PC

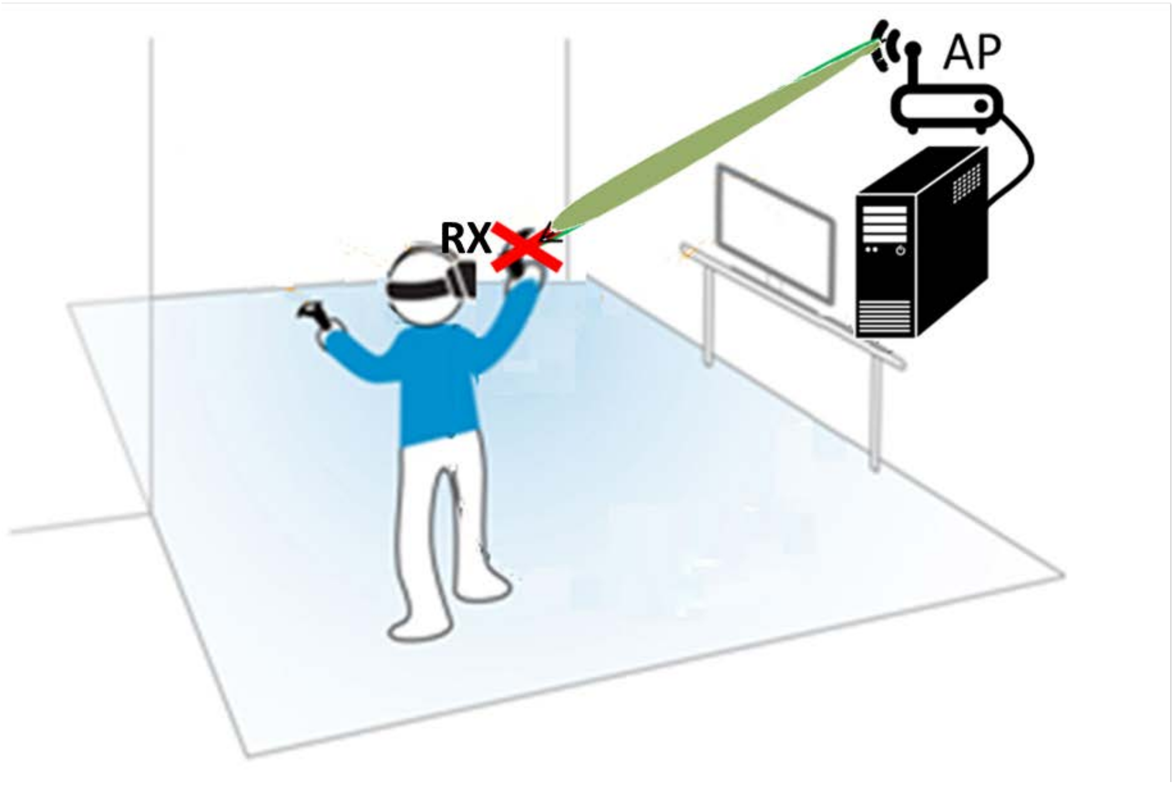
Stream 6.4 Gbps of data from PC to headset

Untethered Virtual Reality

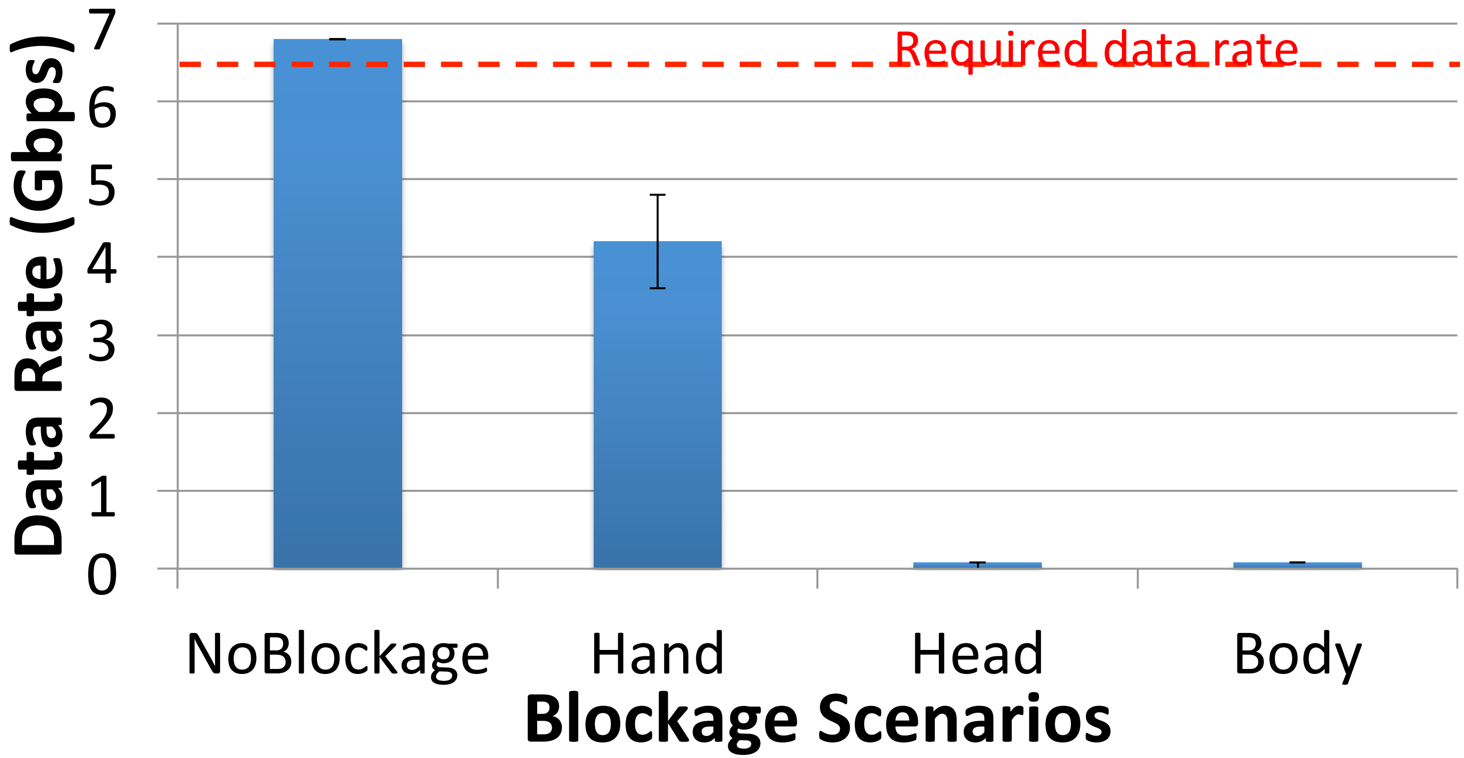
~~Typical wireless systems: WiFi, cellular, etc.~~

mmWave Technology

Can we enable untethered VR?



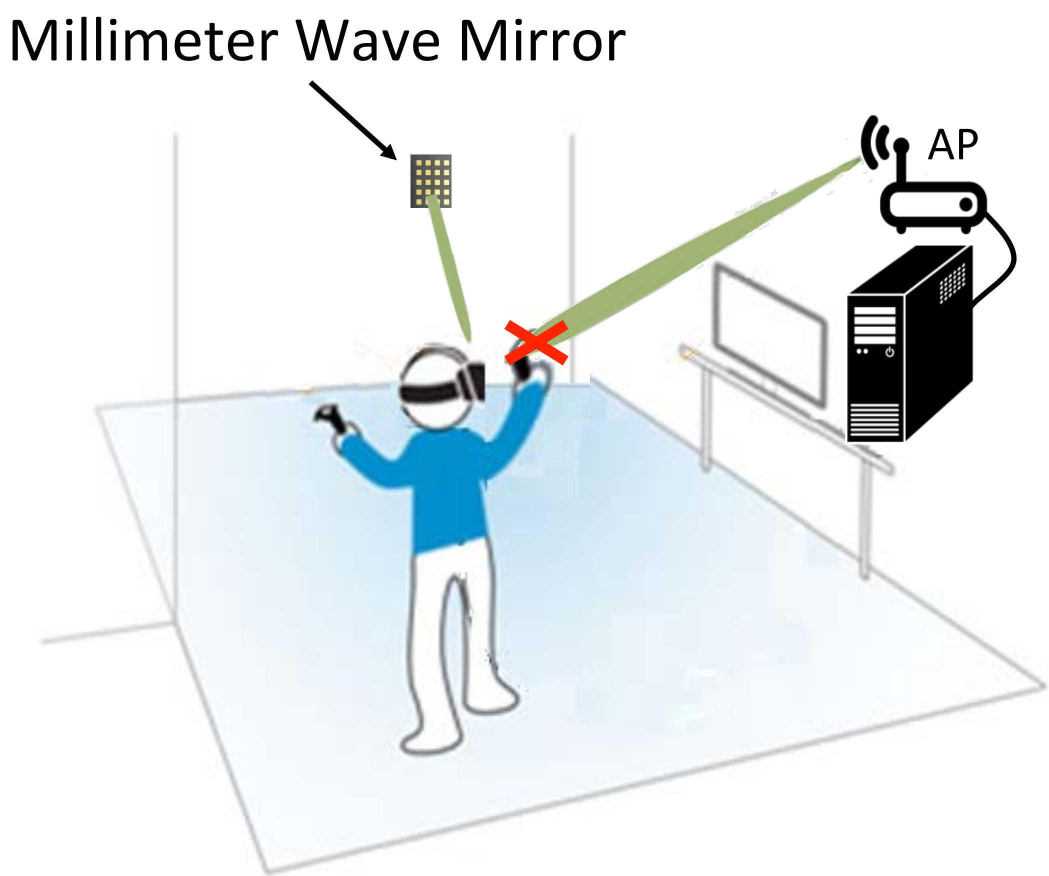
Impact of Signal Blockage



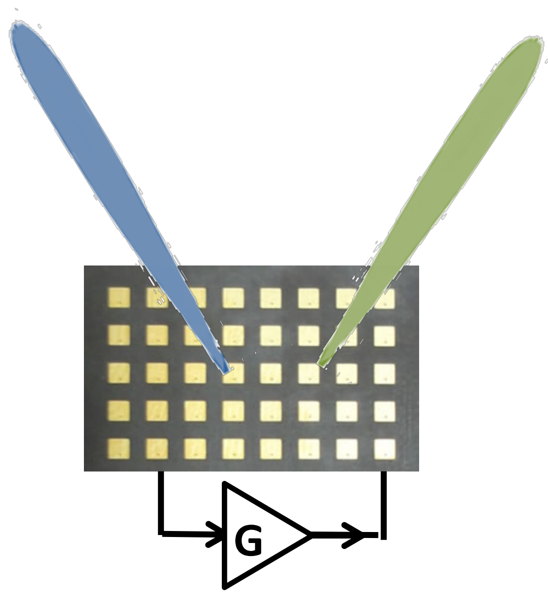
Blocking millimeter wave signals results in a significant drop in data rate

How can we solve the blockage problem?

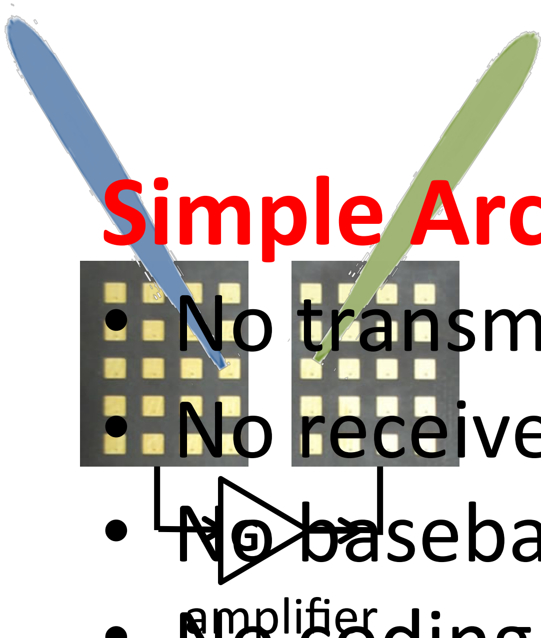
Idea



Mirror Architecture



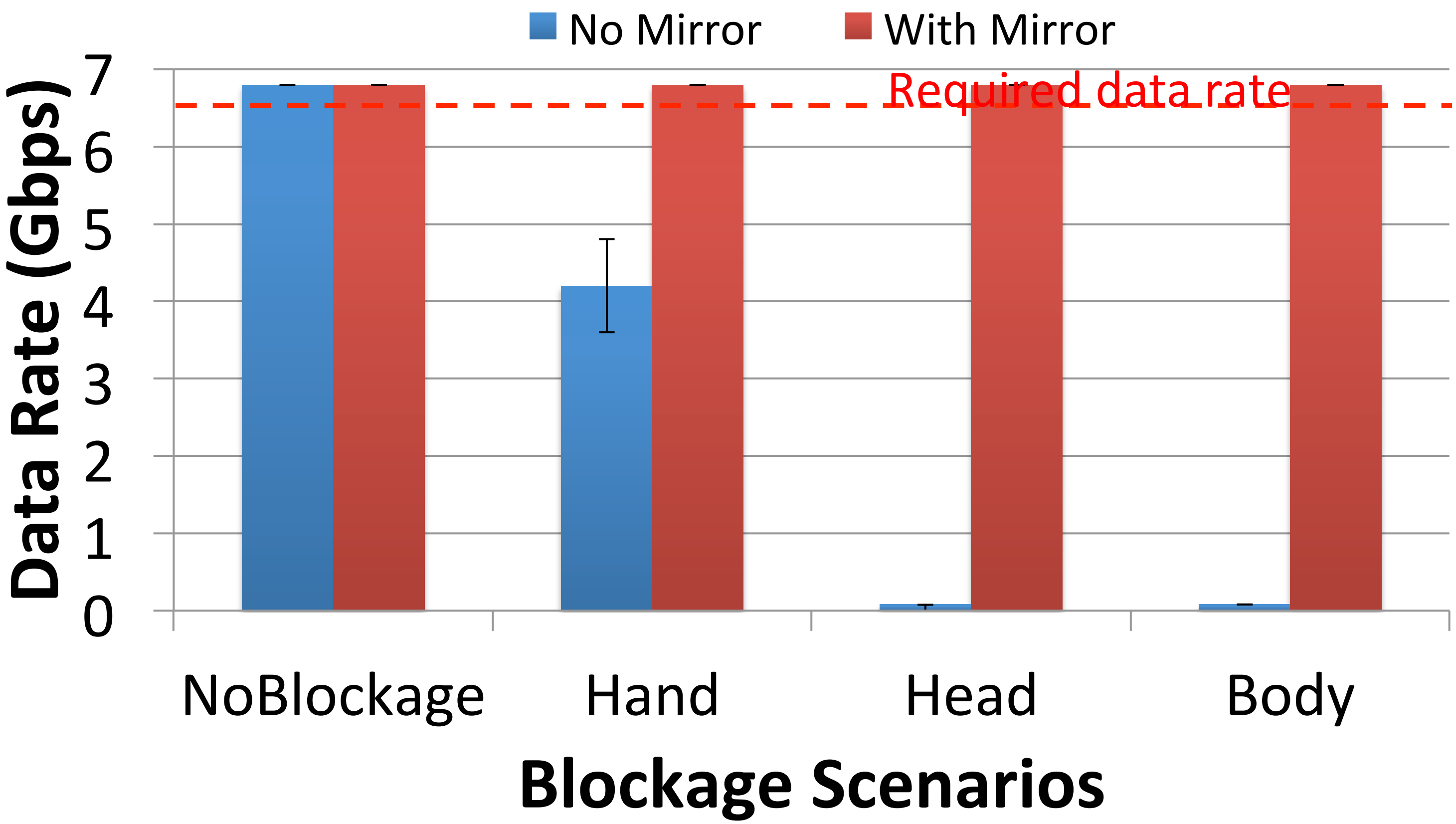
Mirror Architecture



Simple Architecture:

- No transmitter chain
- No receiver chain
- No baseband processor
- No coding/decoding

Data Rate Performance



Solved the blockage problem

Smart Cities

Smart City Services

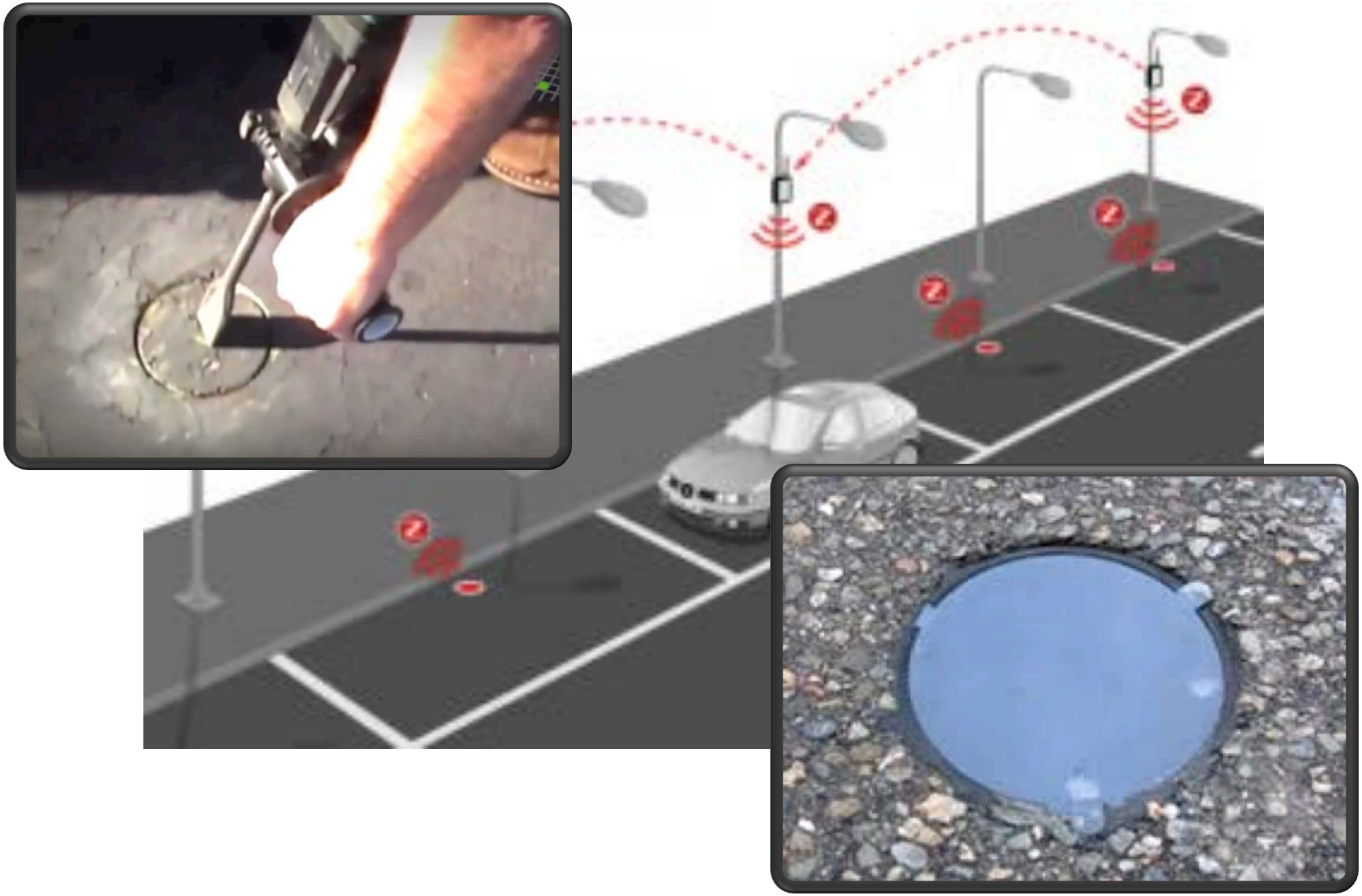
Traffic Management

Detect Red-Light Runner

Smart Parking

Key Problem: each service needs a new infrastructure

Smart Parking



Traffic Management

Ideally…

1) ONE Infrastructure

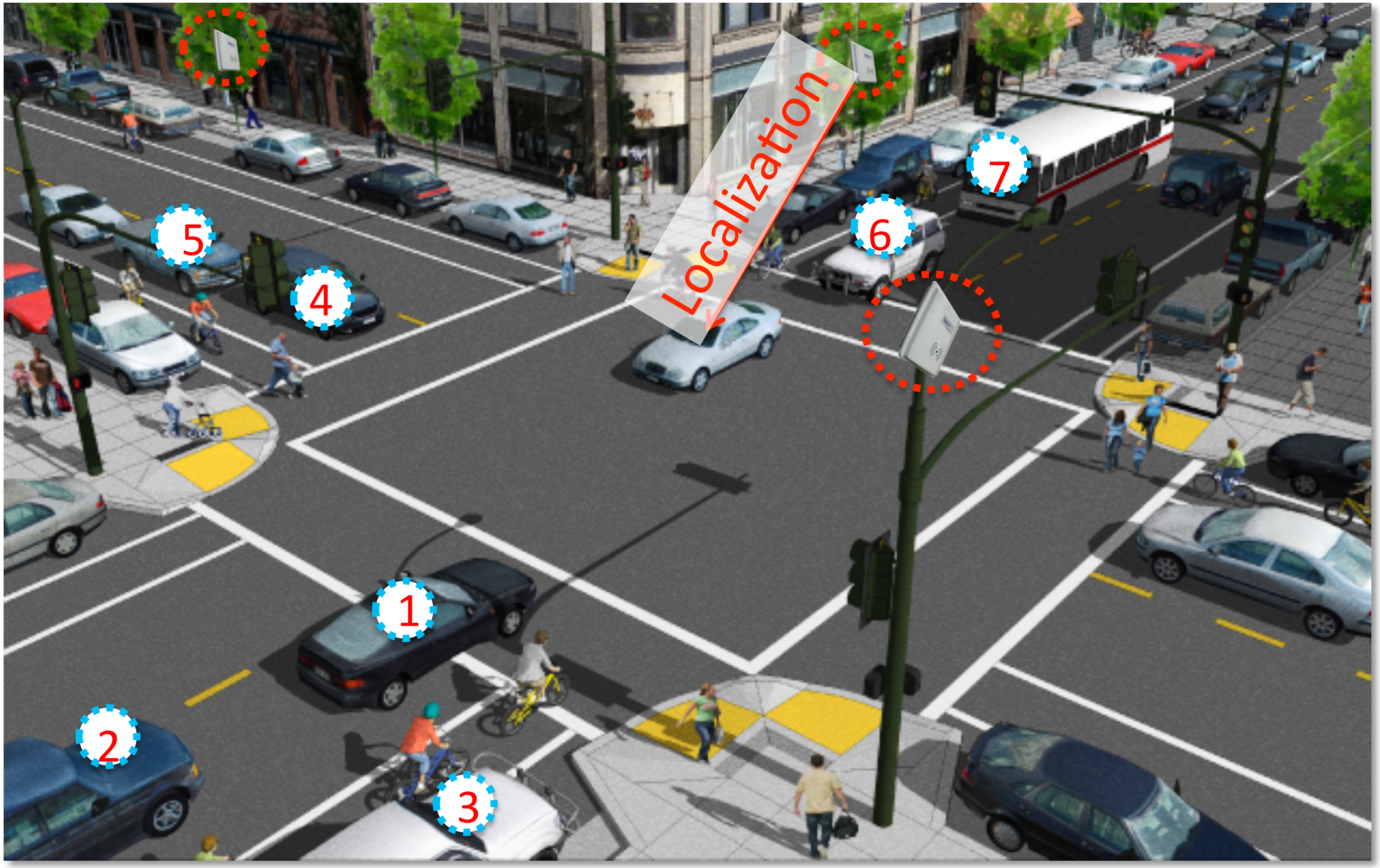
2) Ease of Maintenance

3) We don’t want to add new devices to cars

Electronic Toll Transponders

Some states are making it mandatory

Opportunities



One infrastructure for many smart services

Challenge: Interference

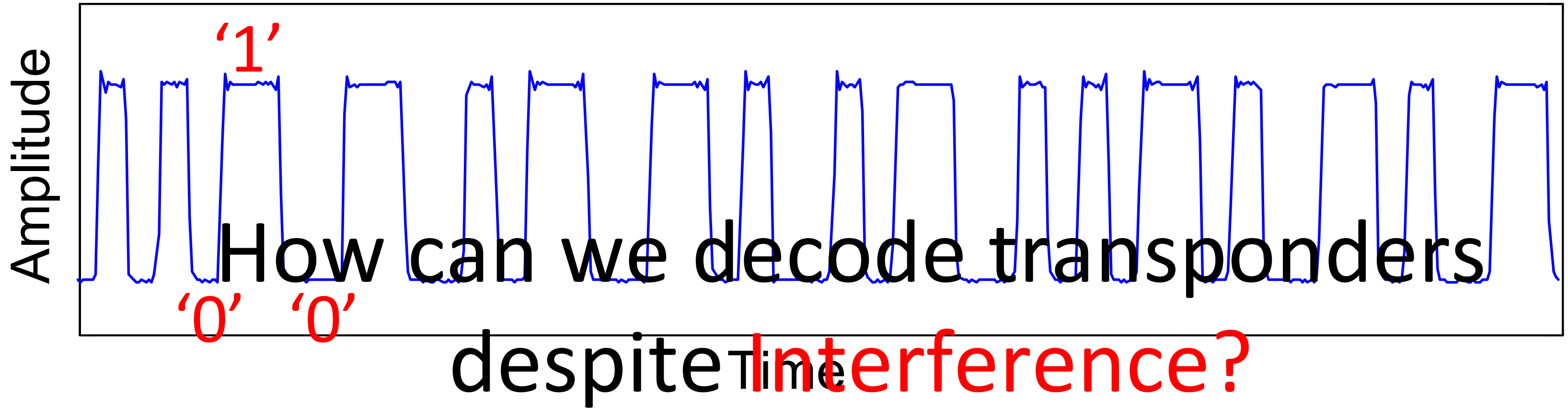
Wireless query

One car responds

Wireless query

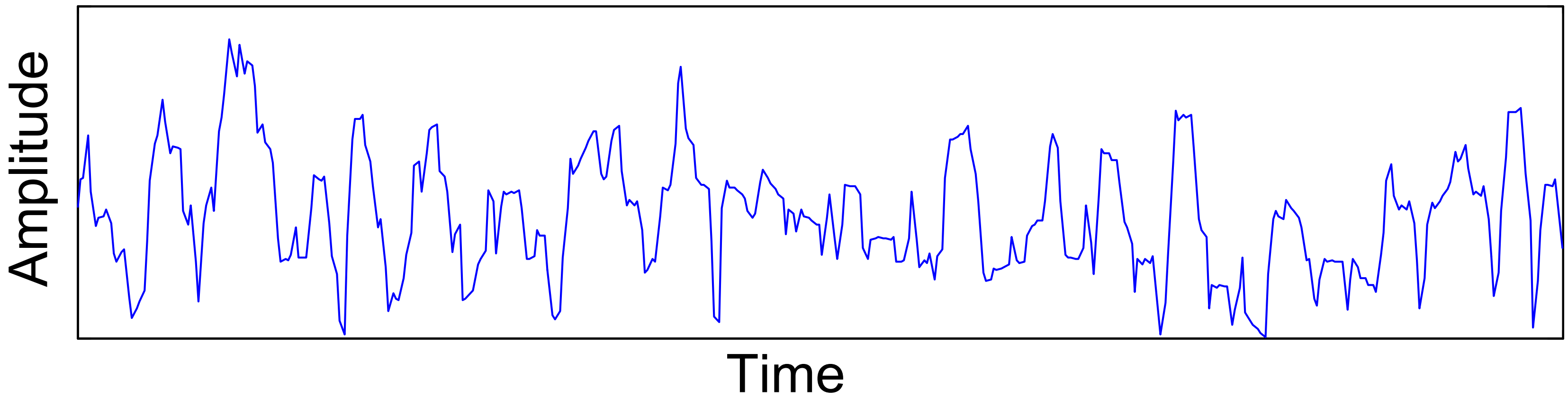
All cars respond

One Transponder Responds → Decodable



How can we decode transponders despite Interference?

Multiple Transponders Respond



Structure of the Signal

Time-Domain

$\cdot e^{j2\pi f_c t}$

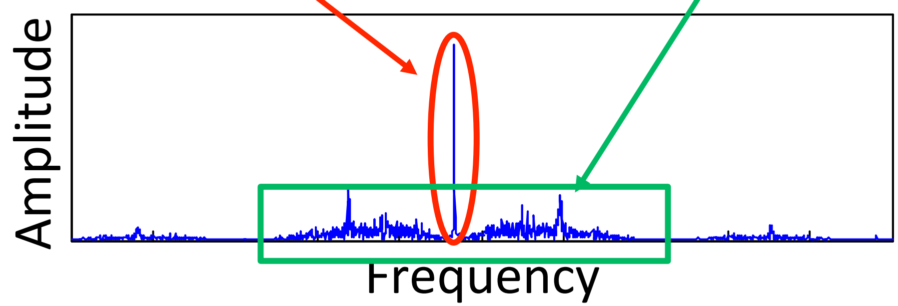
Carrier

Freq-Domain

$\delta(f-f_c)+S(f-f_c)$

Spike

Data



Structure of the Signal

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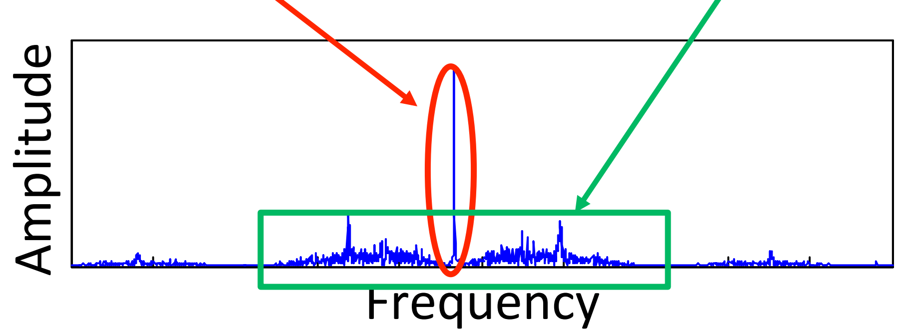
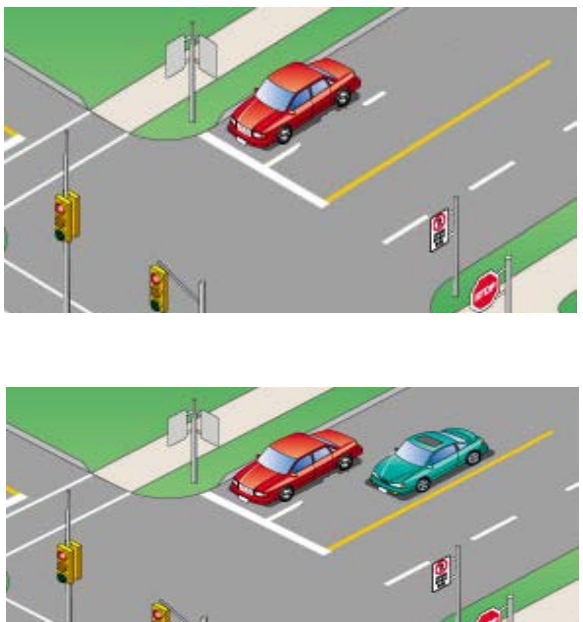
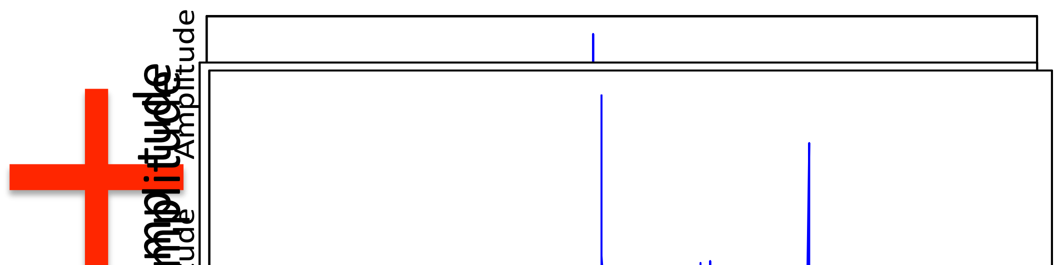
Spike

Data

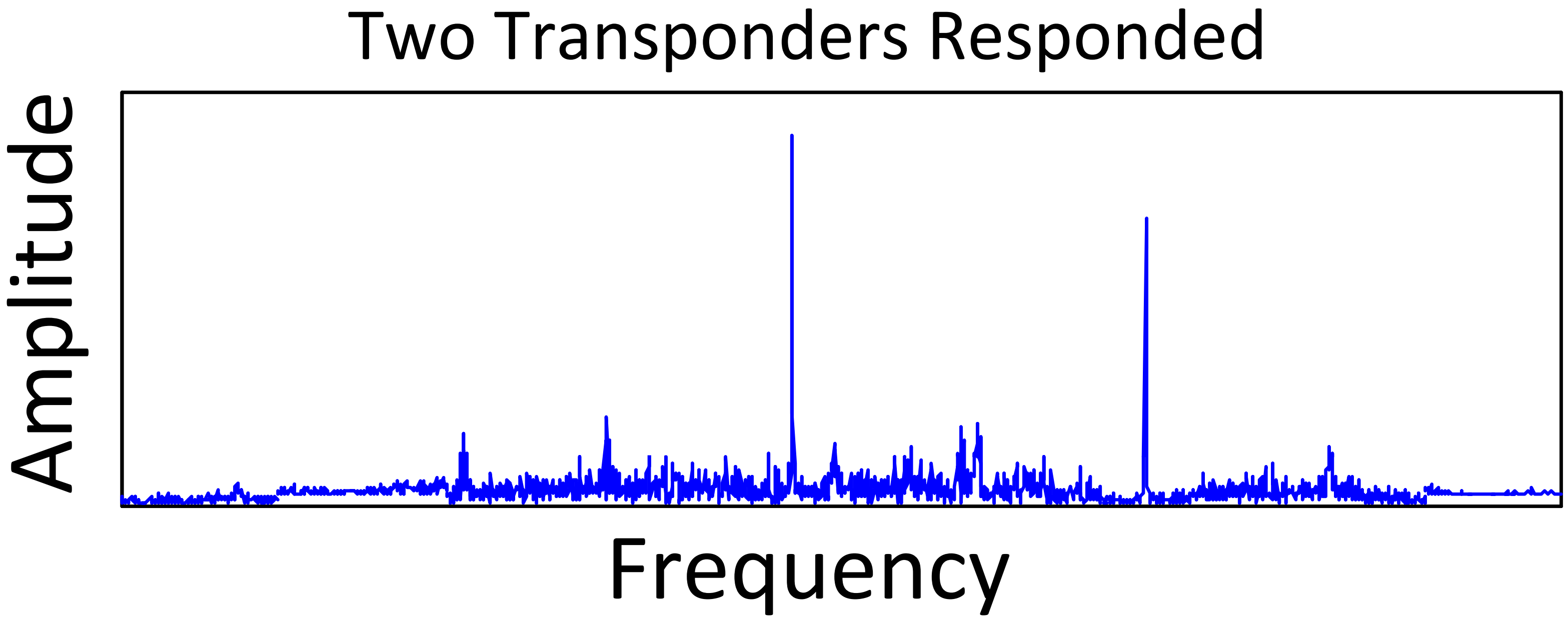




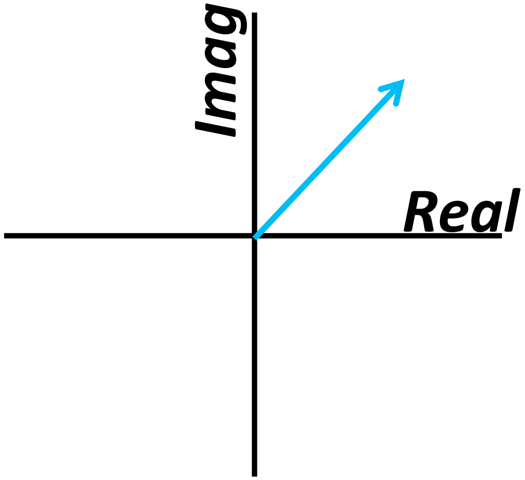


We are able to count despite interference

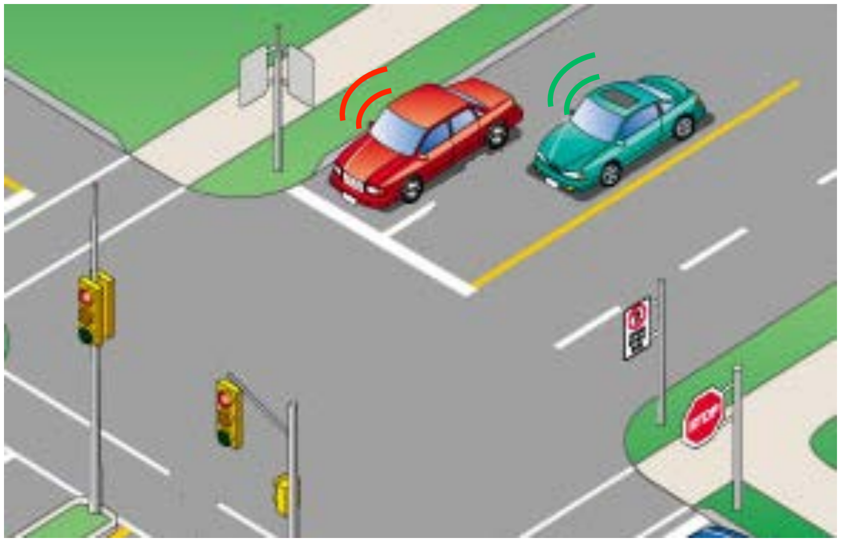
How can we decode transponders despite Interference?

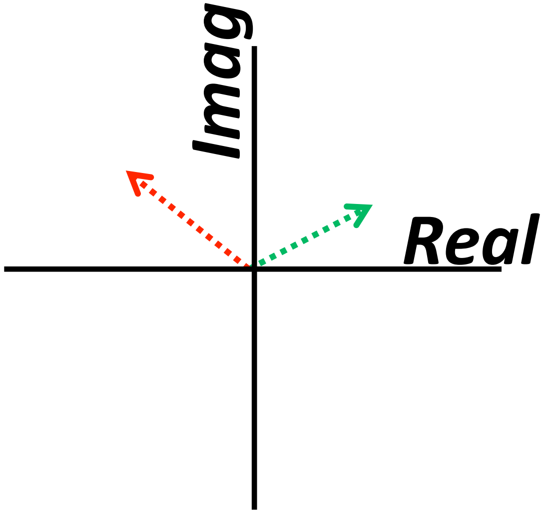


Decoding Transponders

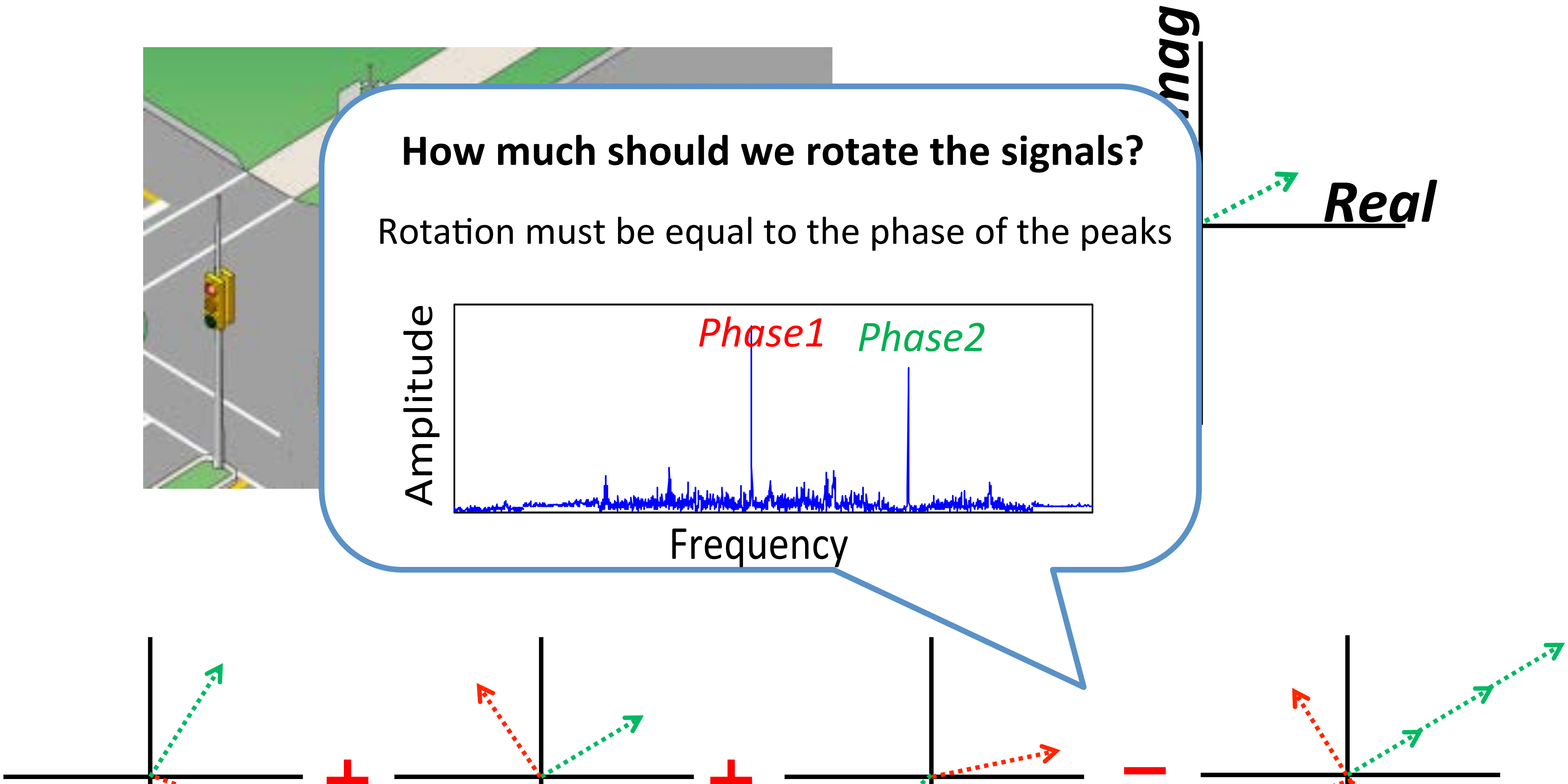


Decoding Transponders



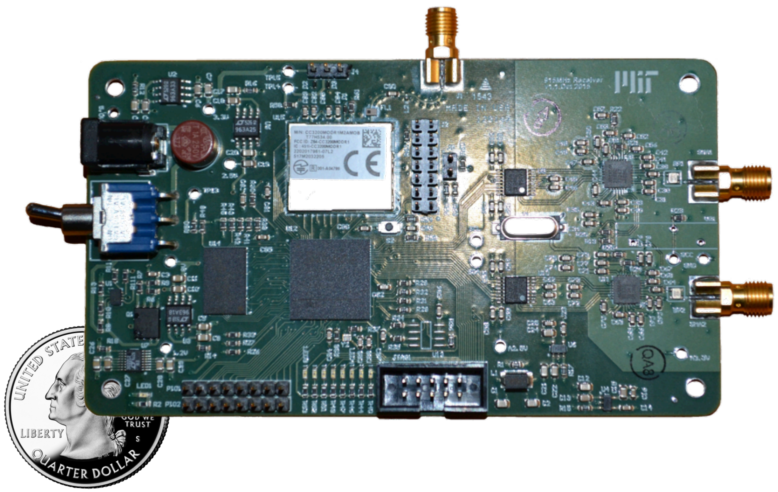


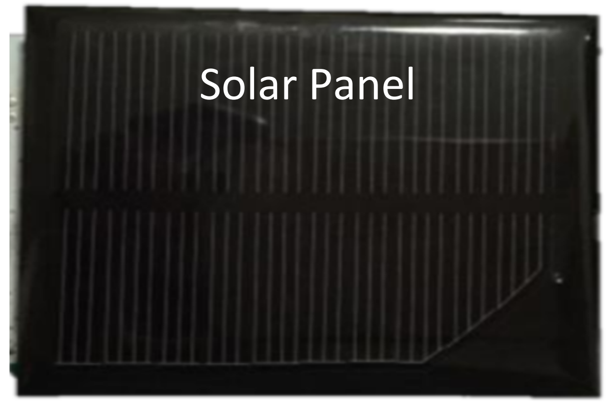
Decode by Combining Multiple Responses

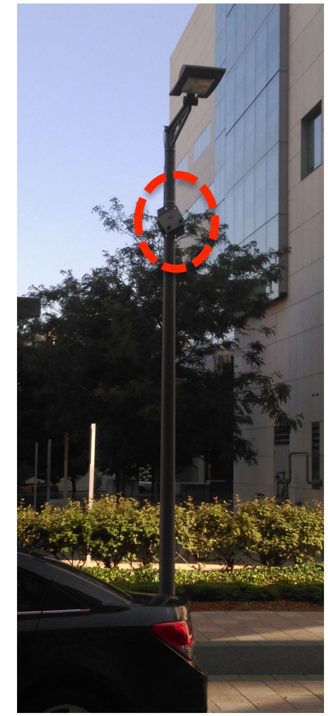


We are able to decode despite interference

Implementation and Evaluation

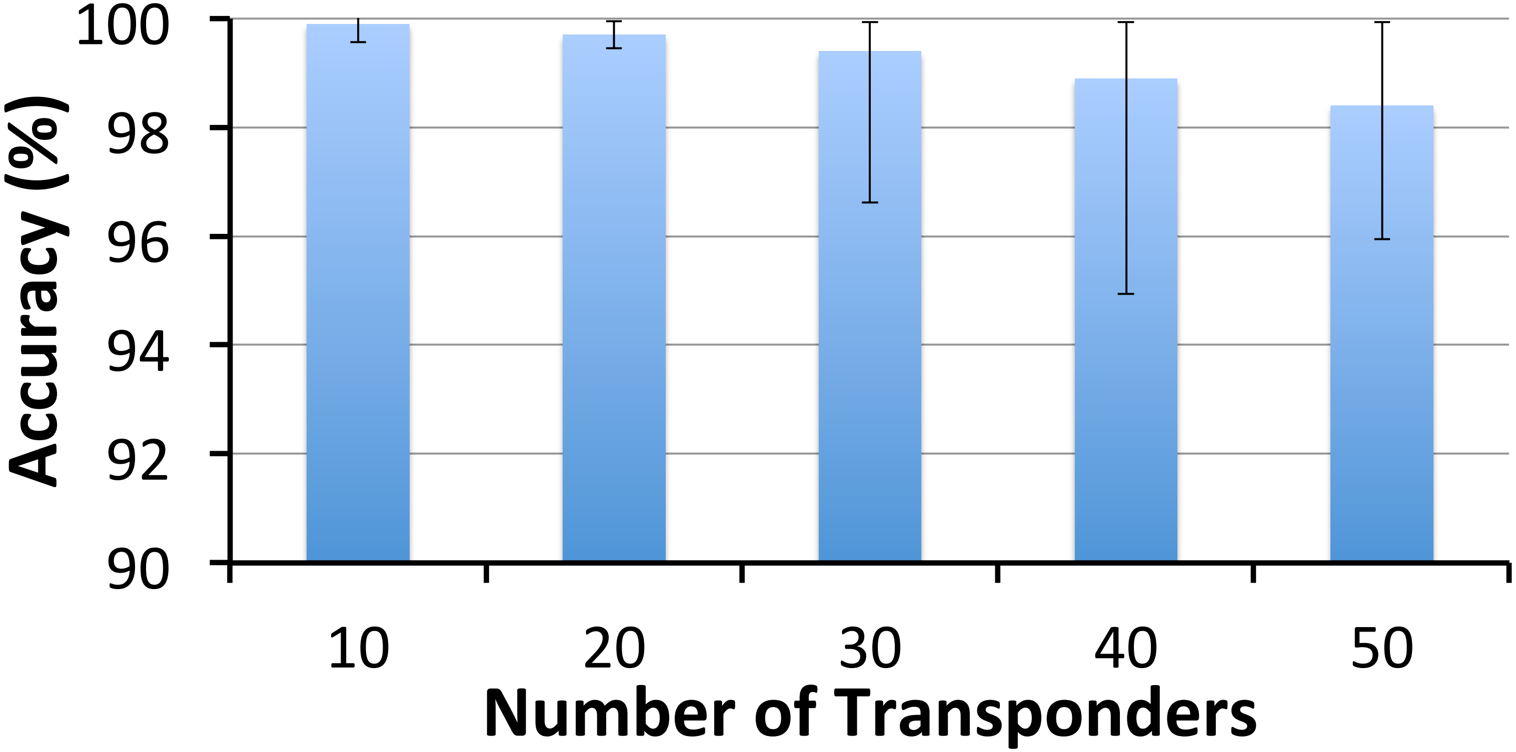




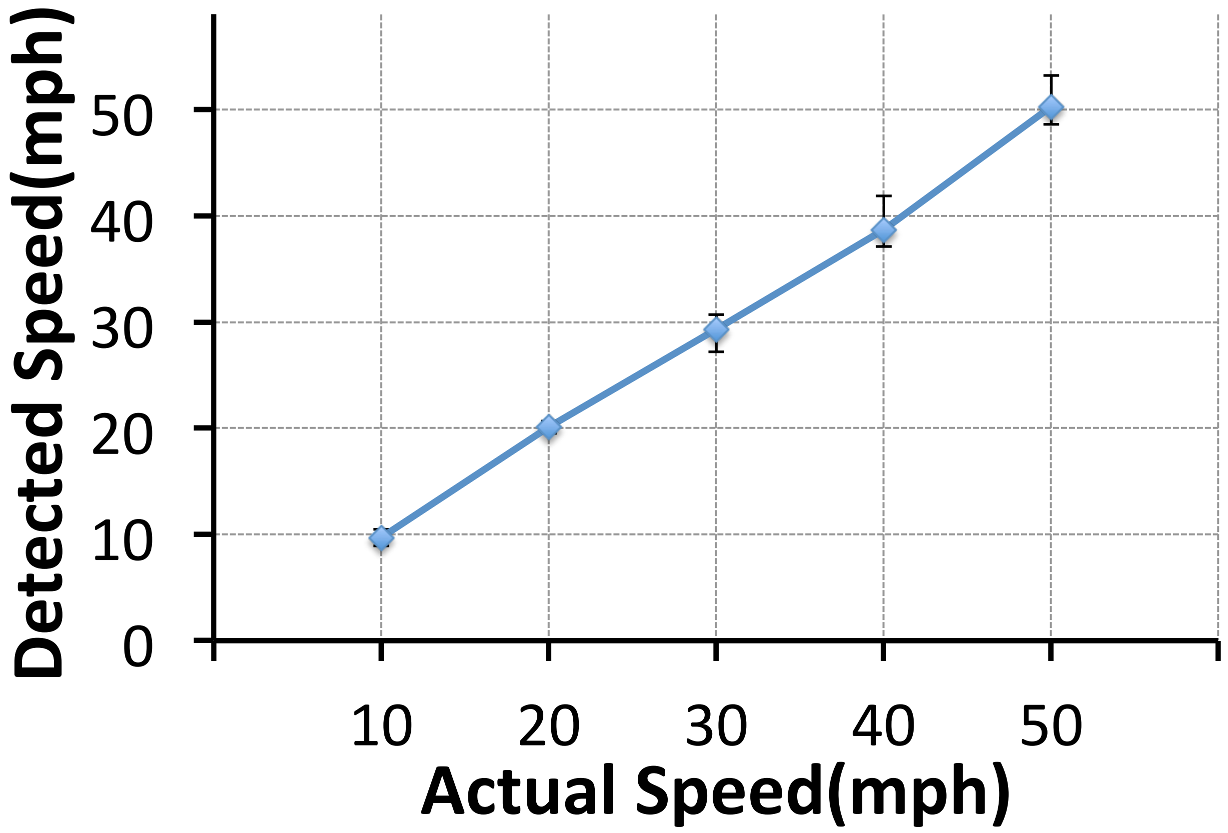


- Built a prototype of our sensors
- Evaluated in four streets
- Standard E-ZPass transponders on the cars

Accuracy of Counting Transponders

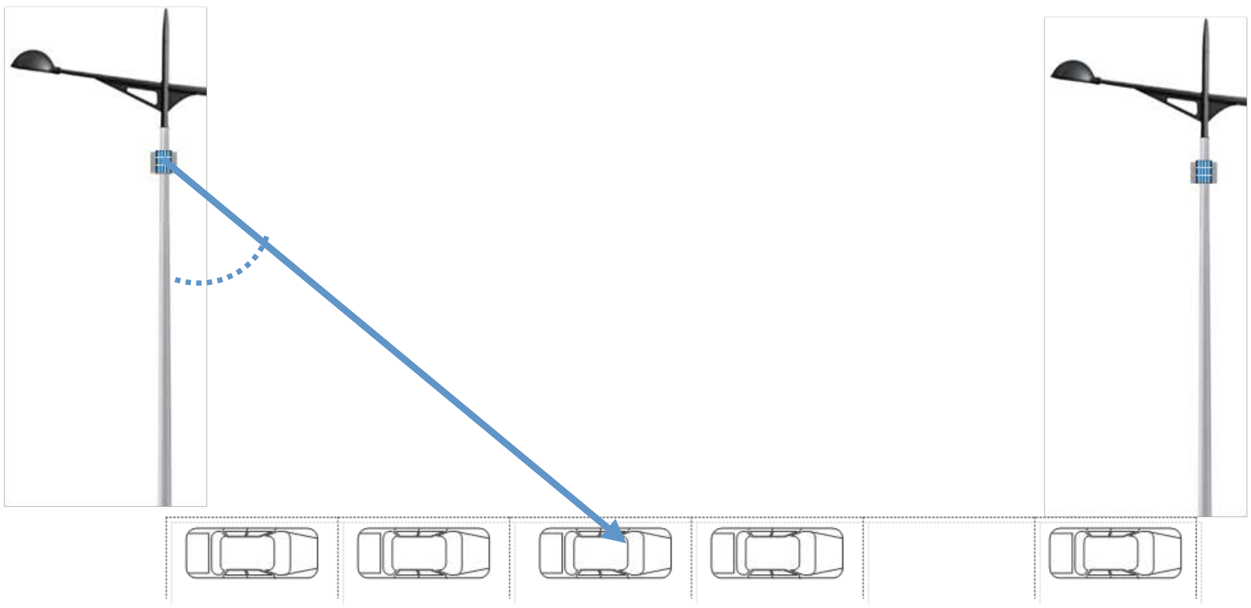


Speed Detection Accuracy

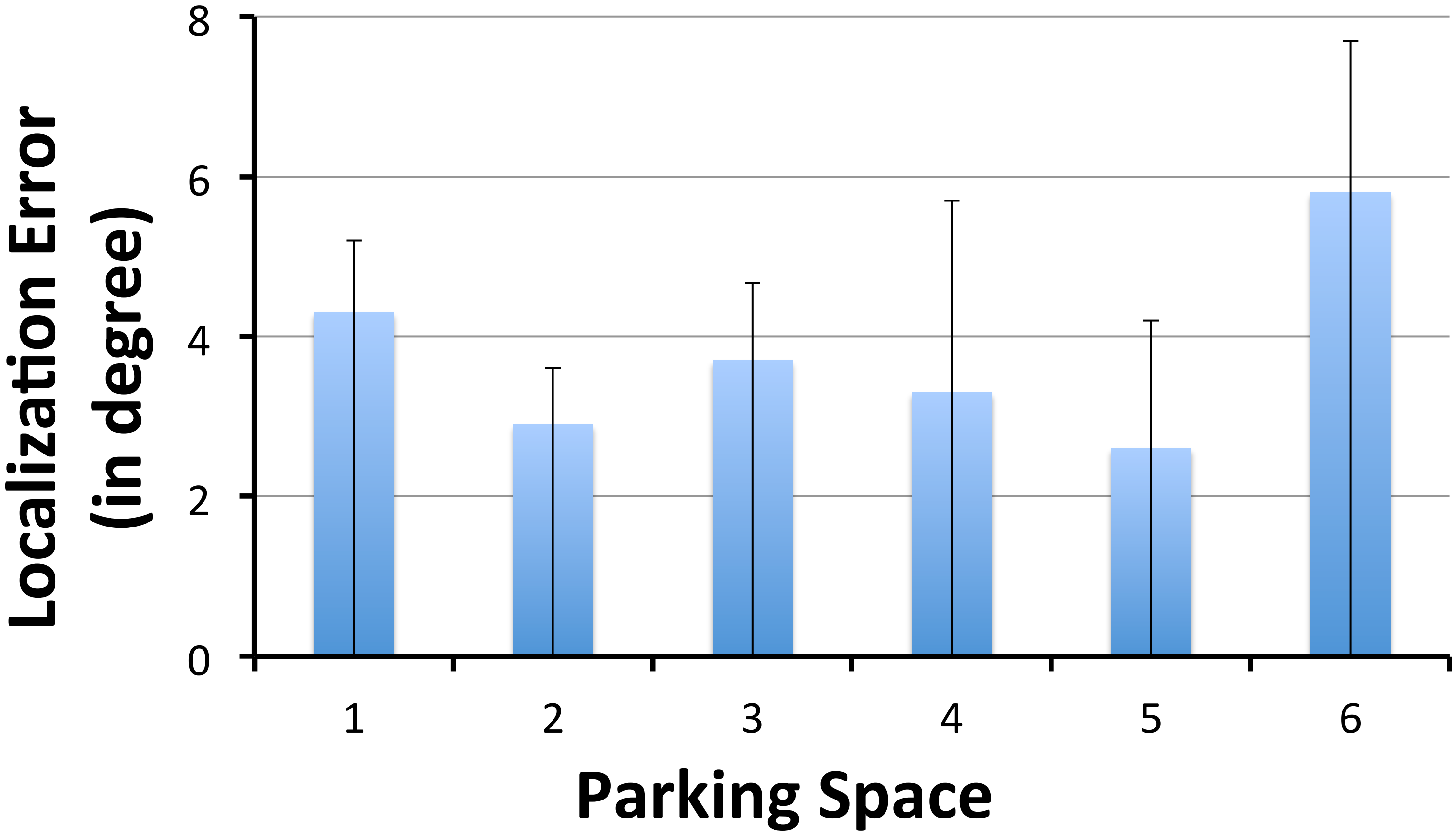


Our system detects the speed to within 8%

Accuracy of Localizing Transponders



Accuracy of Localizing Transponders



Enough accuracy to detect occupied versus available parking spots

Power Consumption

E-toll transponder

Leveraging existing low-power E-toll transponders

ensor

Average power consumption	Solar panel (10x10cm)

Low-power and self-sustaining

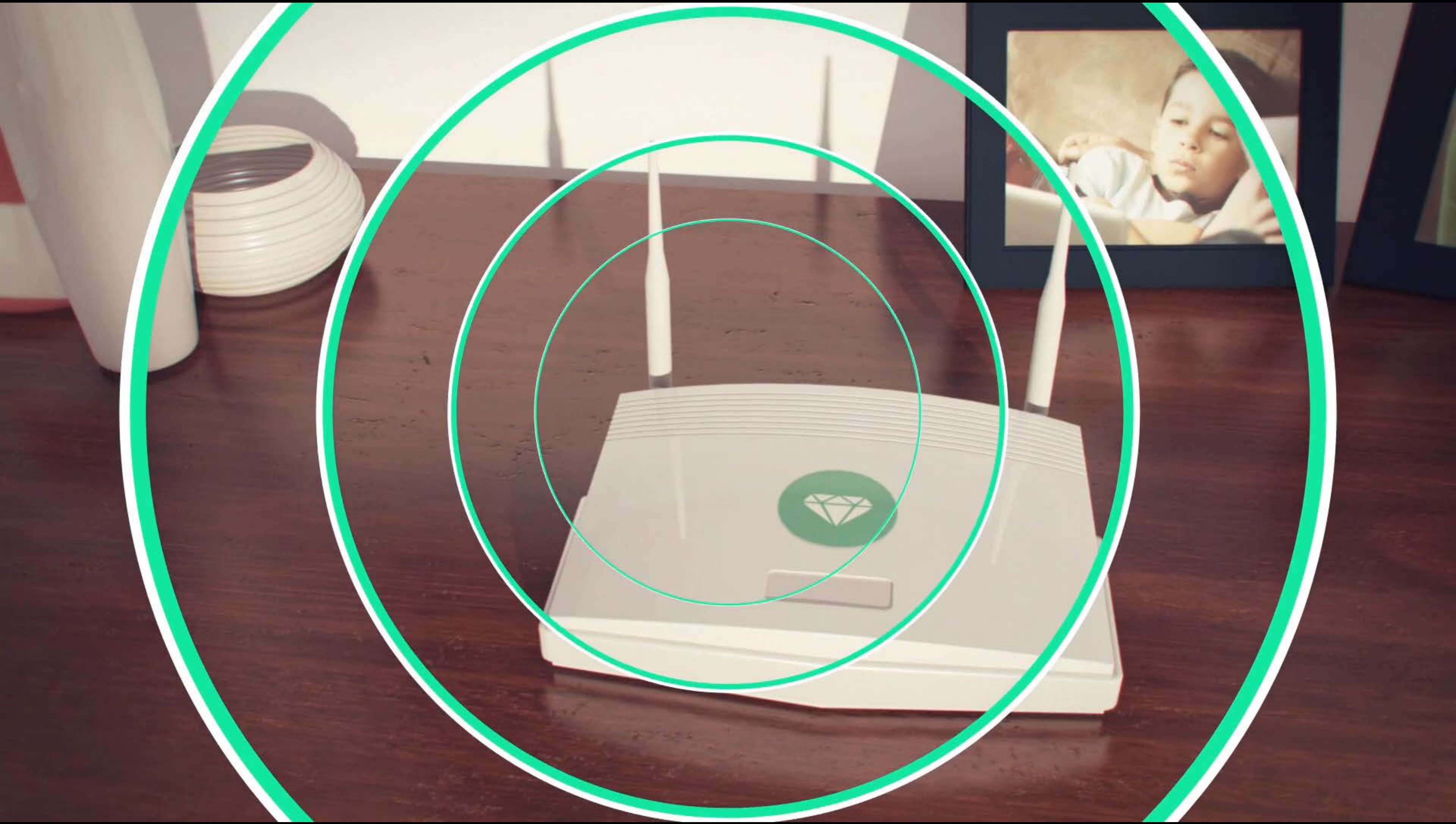
Make Homes Health-Aware

Make the Home Health-Aware

A WiFi-like device that sits at home and monitors health

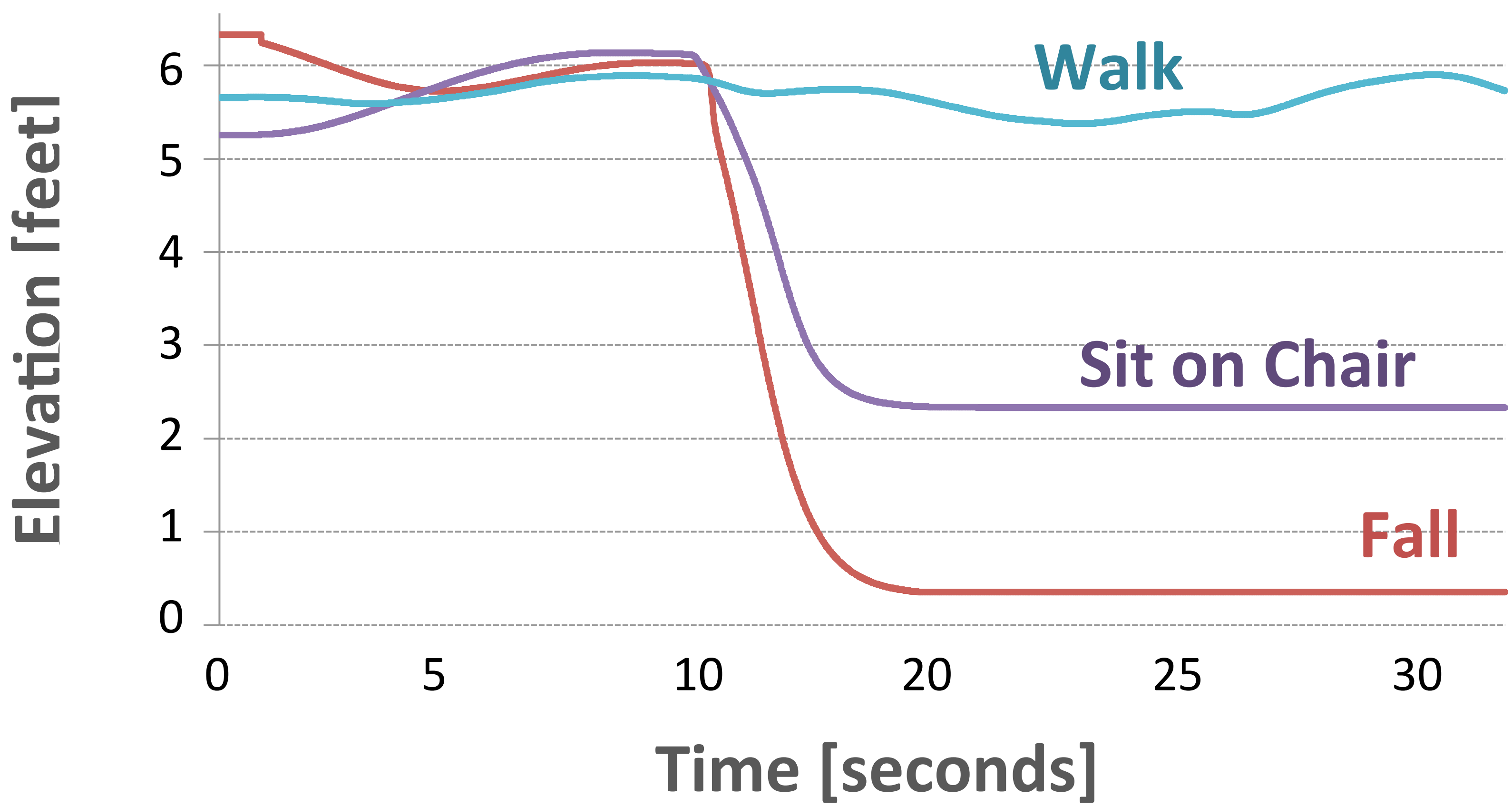
- Gait and mobility
- Elderly Falls
- Breathing and Heart Rate
- Sleep

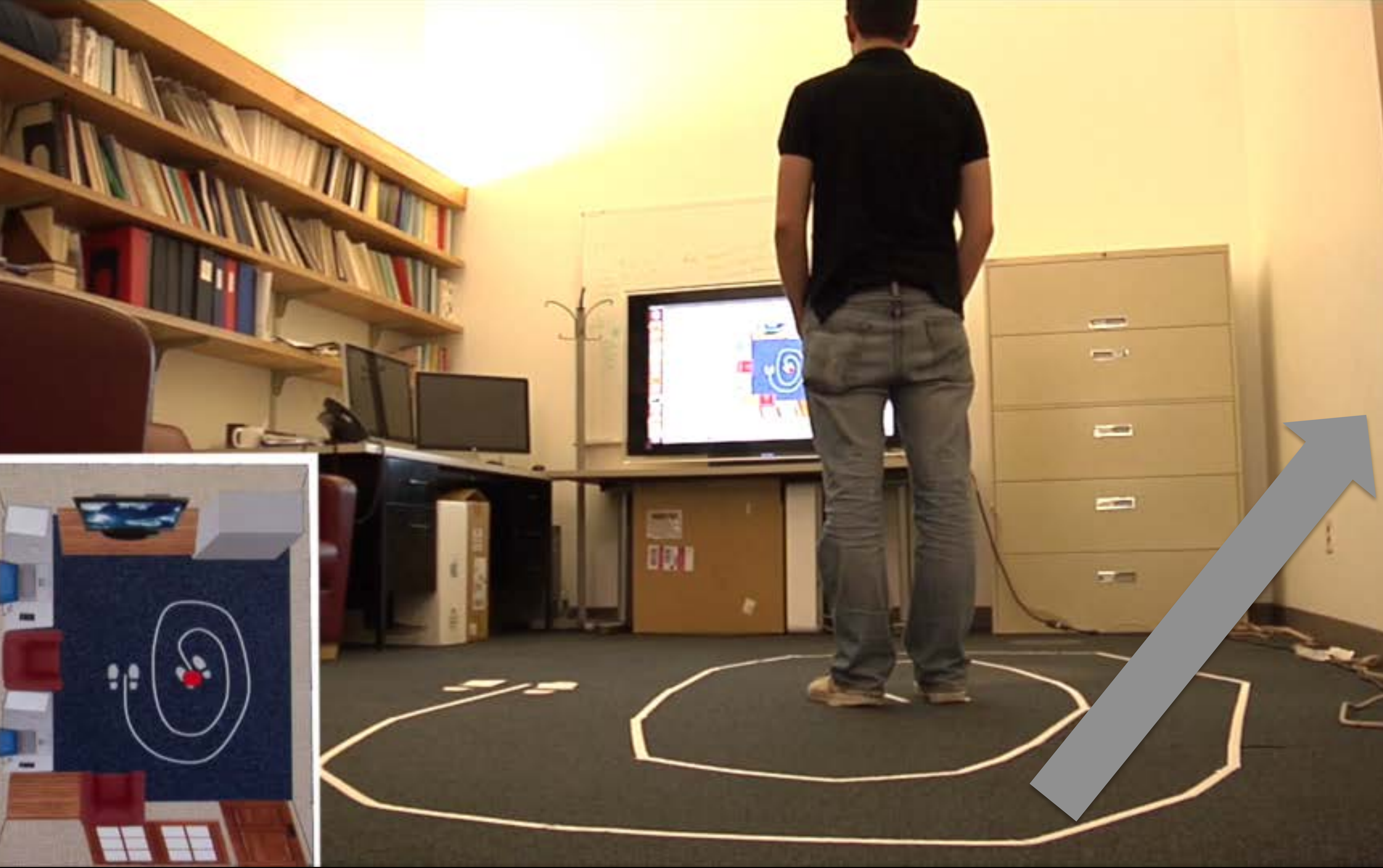
Emerald



Emerald monitors health with radio signals

Fall Detection





Emerald is behind the wall

Activities

1. Sleep

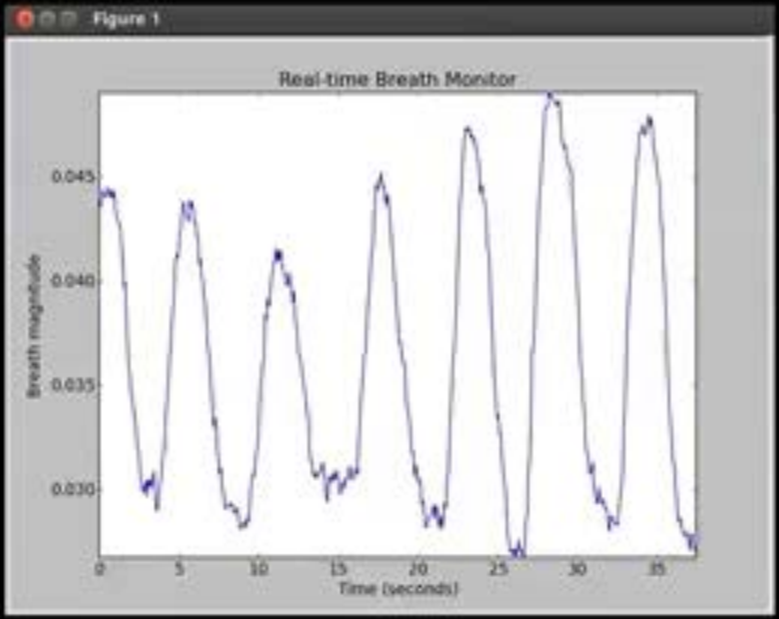
Activities

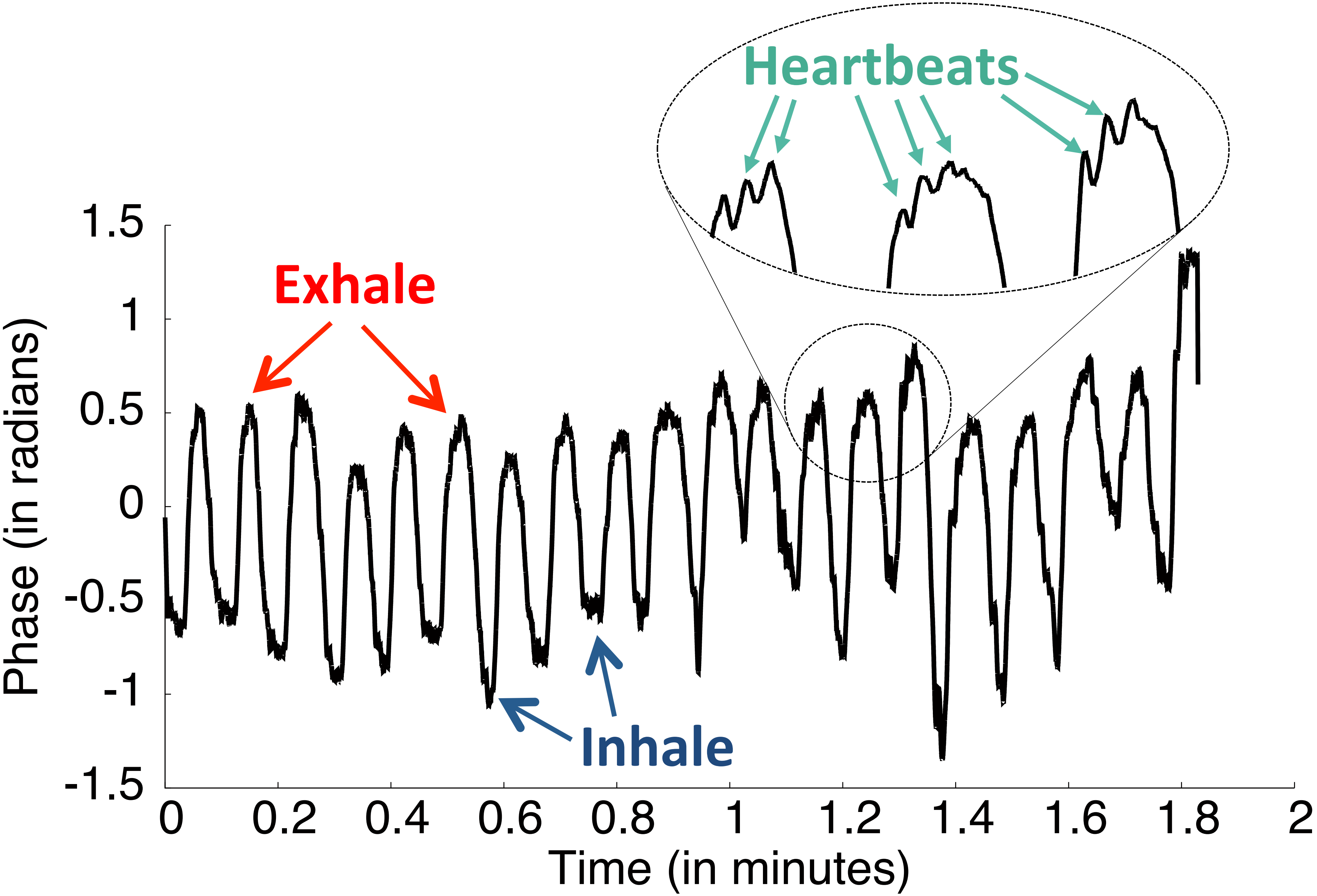
2. Kitchen Activities

Activities

3. Socialization vs. withdrawal

BREATH MONITORING





Heartbeats
Exhale
Inhale
1.5
1
0.5
0
-0.5
-1
-1.5
Phase (in radians)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (in minutes)

For more information, contact dk@mit.edu

Summary

Exciting wireless technologies:

- Millimeter Wave High-Speed Networks
- Untethered Virtual Reality
- Smart Cities
- Smart Homes that are Health Aware

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